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Tini a Tangaroa

Settlement indices for 2017/18 fishing year for the red rock lobster (*Jasus edwardsii*)

New Zealand Fisheries Assessment Report 2019/54

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Table of Contents

EXECUTIVE SUMMARY

Forman, J.S.; McKenzie, A.; Stotter, D.R. (2019). Settlement indices for 2017/18 fishing year for the red rock lobster (*Jasus edwardsii*).

***New Zealand Fisheries Assessment Report 2019*/54. 41 p.**

This report addresses objective one of the Ministry for Primary Industries project CRA201802 (Estimating settlement).

We update the information on annual patterns of settlement for the red rock lobster (*Jasus edwardsii*) on crevice collectors at key sites in CRA 3 (Gisborne), CRA 4 (Napier and Castlepoint), CRA 5 (Kaikoura), CRA 7 (Moeraki), and CRA 8 (Halfmoon Bay and Jackson Bay).

In the 2017/18 fishing year, two groups of collectors in Gisborne, Napier, Castlepoint, and Moeraki, four groups in Kaikoura, and one group in Halfmoon Bay and Jackson Bay were monitored. Each group has at least three collectors that are checked monthly when possible and a monthly mean catch per group of collectors is calculated. A raw and standardised index based on the rock lobster fishing year, April to March, is produced from the groups of collectors at each site.

The 2017/18 settlement year was notable for the very high settlement at Moeraki and the record low settlement at Gisborne. At Moeraki, the group of collectors under the old pier (MOE007) had to be removed for safety reasons on 29 June 2017 and replaced by a new group (MOE008) that had been set up in March 2017 under the main service wharf close-by. A three month (April–June) overlap of checks between these two groups was made, but there was insufficient data, under the usual criteria, for standardised indices to be produced for the 2017/18 year. However, since the settlement at Moeraki was of interest and particularly high, the criteria for data selection were loosened, so that a preliminary standardised index could be calculated for 2017/18 (see methodology for more details). It was found that settlement at Moeraki in 2017/18 was a record high. Above average settlement was also recorded at the adjacent site at Halfmoon Bay (CRA 8). At Kaikoura, settlement was below its long-term mean and Napier, Castlepoint, and Jackson Bay all recorded settlement very close to their long-term means.

1. INTRODUCTION

Rock lobsters are one of New Zealand's most valuable fisheries. Understanding larval recruitment processes will greatly assist the management of this fishery because it may explain changes in levels of recruitment to the fishery and enable the prediction of trends in catch levels at least four years in advance, allowing management and commercial strategies to be implemented. This report updates the patterns of spatial and temporal settlement of *Jasus edwardsii* on crevice collectors in New Zealand.

Rock lobsters spend several months as phyllosoma larvae in waters tens to hundreds of kilometres offshore. They return to the shore as postlarvae (pueruli) after metamorphosing near the shelf break. The puerulus is the settling stage: it resembles the juvenile in shape and is 9–13 mm in carapace length, but it is transparent. Pueruli settle when they cease extensive forward swimming and take up residence on the substrate. Some older pueruli and young juveniles, however, move after first settling elsewhere. Post-settlement migration (secondary dispersal) such as this is not uncommon among invertebrates (e.g., Reyns & Eggleston 2004), the young redistributing from high-density settlement habitats is thought to be a strategy to reduce density-dependent mortality. The puerulus moults into the first juvenile instar (sometimes referred to as the first-moult postpuerulus) a few days to three weeks after settlement. Higher water temperatures reduce the time taken to moult. Depending on sex and locality, the rock lobster then takes about 4–11 years to reach minimum legal size.

The development of sampling programmes to estimate levels of postlarval settlement that can be used to predict fishery performance is a goal for both palinurids (e.g., Phillips et al. 2000, Gardner et al. 2001) and homarids (e.g., Wahle et al. 2004), with encouraging or well-demonstrated success for some projects. In New Zealand there are significant correlations between the level of settlement and the fishery catch per unit effort (CPUE) for most fishery areas. The best correlations occur in fisheries with shorter intervals between settlement and recruitment, and in those with large contrasts in the settlement record (Booth & McKenzie 2008).

Monthly occurrence of pueruli and young juveniles on crevice collectors (Booth & Tarring 1986) has been followed at up to nine key sites within the main New Zealand rock lobster fishery since the early 1980s. The indices of settlement are now reported annually. It has become clear from this and other monitoring, that settlement is not uniform in time or space. Settlement occurs mainly at night and at any lunar phase, is seasonal, and levels of settlement can vary by an order of magnitude or more from year to year (Booth & Stewart 1993, Forman et al. 2014).

For further information on the puerulus sampling program in New Zealand see Booth et al. (2004, 2006).

OBJECTIVES

1. To determine trends in puerulus settlement at selected key sites around New Zealand.

Specific Objectives

To estimate monthly and annual indices of puerulus settlement at key sites in CRA 3, CRA 4, CRA 5, CRA 7 and CRA 8 (Gisborne, Napier, Castlepoint, Kaikoura, Moeraki, Halfmoon Bay, and Jackson Bay).

2. METHODS

2.1 Recording settlement on collectors

Levels of puerulus settlement are monitored using ‘crevice’ collectors (Booth & Tarring 1986, Booth et al. 1991) at seven key sites that encompass much of the main rock lobster fishing coast of New Zealand. The collector was developed in New Zealand to catch *J. edwardsii* pueruli and is now used throughout much of the range of *J. edwardsii*. They are inexpensive, easily set and checked, and provide (unlike many other types of collector) a standard settlement surface for between-month and between-site comparisons.

Each key site is separated from its neighbour by 150–400 km, and most sites were chosen after trying many locations (Figure 1). Criteria for the establishment of key sites included the distance from the neighbouring site, proximity to the open ocean, accessibility, tractability, and the level of puerulus catch.

At each key site, collectors are set in groups of between 3 and 20, with at least 2–3 m between individual collectors. It is unclear whether or not there is interference in the catch between collectors at these spacings, but because the distances remain unaltered, any interference is likely to have a minimal impact on the overall monthly and annual index. At each site there is a core group of at least three (although usually five) collectors. At most sites there have been up to three additional groups of three or more collectors, set in both directions along the coast as conditions allow. Since 2002, however, fewer of these additional groups of collectors have been monitored; the focus is now on the core group (usually the one first established, and therefore with the longest record of settlement). Where feasible, one other group of collectors is also monitored. See Table 1 for a summary of the collector sites, the number of collectors by site, and the method of collector deployment. Methods of deployment include shore based collectors which are attached to concrete weights in sheltered subtidal locations, suspended collectors which are hung from wharf piles with the collectors suspended just off the bottom, and closing collectors which have a closing mechanism that surrounds the collector as it is hauled up by boat.

Collectors are generally checked monthly as weather and tides allow and are cleaned of heavy growth so that the condition of collectors is consistent. Repairs required are noted at each collector check and these are made in the field where possible. Spare (and conditioned) collectors are maintained at each site or nearby as replacements. If possible, collector replacement is made outside the main settlement season.

At most sites, local people are employed to check the collectors, under NIWA’s direction. Quality control of checks and equipment is maintained with direct contact once or twice per year. A standard result form is completed and sent to NIWA after each check. At Castlepoint and Moeraki, NIWA staff check the collectors. Monthly checks, especially during the main winter settlement season, are not always possible for all groups of collectors because of logistical issues. Two groups of collectors in Kaikoura (KAI005 and KAI006) are fully managed by CRAMAC 5 and one other group of collectors in Kaikoura (KAI003) is funded by CRAMAC 5 but is maintained by NIWA.

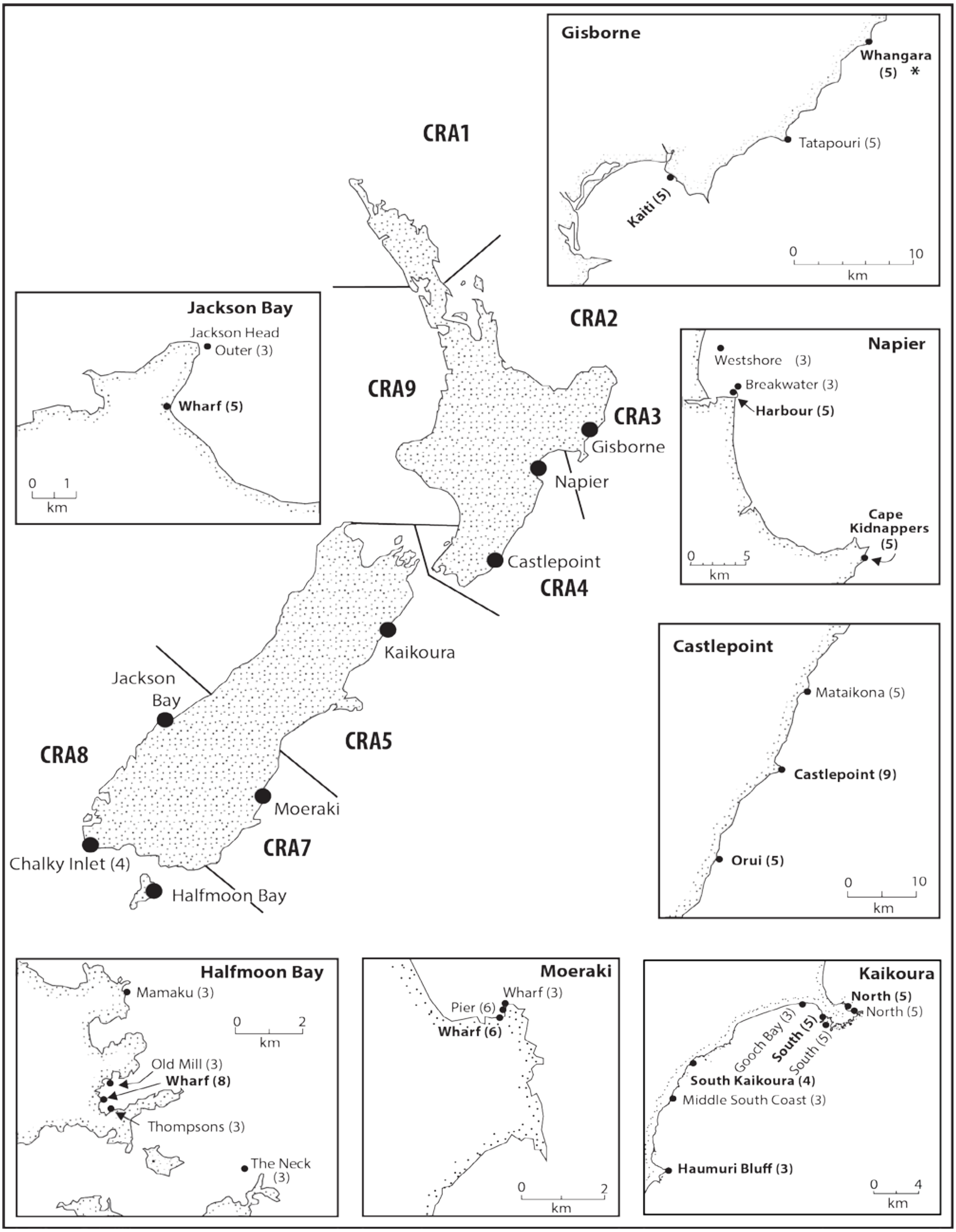

Figure 1: Map of New Zealand showing the location of collectors at the key monitoring sites (although not all groups are now checked). The sites that are checked are in bold and the number of collectors in that set is in brackets. Also shown are the CRA areas; CRA 6 is the Chatham Islands and CRA 10 is the Kermadec Islands (to the northeast of the North Island).

Table 1: Number of collectors, method of collector deployment, and years of operation of all collectors used in the settlement index. For definitions of collector type see Section 2.1, Booth & Tarring (1986), and Phillips & Booth (1994).

Site	Number of collectors	Location	Method of deployment	Years of operation
Gisborne	5	Harbour (GIS001)	Shore	1987–2003
	5	Whangara (GIS002)	Shore	1991–Present
	5	Tatapouri (GIS003)	Shore	1994–2006
	5	Kaiti (GIS004)	Shore	1994–Present
Napier	5	Harbour (NAP001)	Suspended	1979–Present
	3	Westshore (NAP002)	Closing	1991–1999
	5	Cape Kidnappers (NAP003)	Shore	1994–Present
	3	Breakwater (NAP004)	Shore	1991–2002
Castlepoint	9	Castlepoint (CPT001)	Shore	1983–Present
	5	Orui (CPT002)	Shore	1991–Present
	5	Mataikona (CPT003)	Shore	1991–2006
Kaikoura	5	South peninsula (KAI001)	Shore	1981–Present
	3	South peninsula (KAI002)	Shore	1988–2003
	5	North peninsula (KAI003)	Shore	1980–Present
	3	North peninsula (KAI004)	Shore	1992–2003
	4	South Kaikoura KAI005)	Shore	2008–Present
	3	Haumuri Bluff (KAI006)	Shore	2008–Present
	3	Gooch Bay (KAI008)	Shore	1980–1983
	3	Middle South Coast (KAI009)	Shore	1981–1988
Moeraki	3	Wharf (MOE002)	Closing	1990–2006
	6	Pier (MOE007)	Suspended	1998–2017
	6	Wharf (MOE008)	Suspended	2017–Present
Halfmoon Bay	8	Wharf (HMB001)	Suspended	1980–Present
	3	Thompsons (HMB002)	Closing	1988–2002
	3	Old Mill (HMB003)	Closing	1990–2002
	3	The Neck (HMB004)	Closing	1992–2002
	3	Mamaku Point (HMB005)	Closing	1992–2002
Jackson Bay	5	Jackson wharf (JAC001)	Suspended	1999–Present
	3	Jackson Head (JAC002)	Closing	1999–2006
Chalky Inlet	4	Chalky Inlet (CHI001)	Closing	1986–2012

2.2 Calculating indices of settlement

All standardisations before 2014 used settlement data based on the Calendar year. In contrast all standardisations presented here use the fishing year from 1 April to 31 March, with the year label being that which April is in. For example, 20 April 2004 is in the 2004 fishing year, while 11 Feb 2004 is in the 2003 fishing year. An alternative labelling also used is to call the 2004 fishing year the 2004/05 fishing year. The change from a calendar to a fishing year was requested by the Rock Lobster Working Group (RLWG), and aligns with the year used in stock assessments, for which the standardised puerulus indices are offered as data inputs.

The standardised index of annual settlement used here incorporates all settlement for the year for each site, irrespective of month. This approach to the standardisation was based on Bentley et al. (2004), but with the adjustments noted below: assignment of the month for settlement, and the groups of collectors used. The term 'settlement' refers to the presence of pueruli and juveniles up to 14.5 mm carapace length (CL, the maximum size for a first-instar juvenile observed in laboratory studies).

Following Bentley et al. (2004) the standardisation used collectors that were sampled at least 36 times (equivalent to three years of monthly sampling). No outliers were removed from any of the data sets after fitting. In Bentley et al. (2004) outliers were removed, but the effect on the standardised indices was minor.

Because a collector check on any one day is thought to be a snapshot of what has been going on for about the last 14 days, the appropriate month to label as settlement may not be the nominal month. In standardisations prior to 2014, if the check took place up to the seventh of the month its catch was attributed to the previous month. This also avoids the situation where if a collector is checked on the first and last day of a month, there are two records for that month, but none for the previous or subsequent months. Nonetheless, it was decided by the RLWG that the nominal month should be used for standardisations.

At three sites (Gisborne, Jackson Bay, and Moeraki) some pilot groups of collectors were dropped because of logistical reasons or because they did not capture pueruli very well. For Jackson Bay and Moeraki even the best groups of collectors, after dropping of pilot groups, recorded very low pueruli count numbers. For example, for the JKB001 group of collectors zero counts are recorded about 60% of the time, and for the MOE002 and MOE007 group of collectors about 80% of the time (Forman et al. 2014, Appendix 1). To reduce the proportion of zero samples at some sites, the months used for the standardisation are restricted to those months where the proportion of non-zero counts are highest (Table 2). In some fishing years for a site, the total number of samples is low (less than 10), and that year is dropped from the standardisation.

The annual index takes into account changes in collector location and sampling to date. A generalised linear model framework was used, in which the response (dependent) variable is the log of numbers of settlers per collector sample and a negative binomial distribution is used. For Kaikoura and Moeraki alternative distributions were investigated (quasi-Poisson, zero-inflated Poisson, zero-inflated negative binomial) and the negative binomial was chosen as the best (Forman et al. 2016). In a previous standardisation for Gisborne alternative distributions were investigated and the negative binomial was chosen as the best (Forman et al. 2015). For the other sites the RLWG decided that the negative binomial distribution should be used.

The predictor variables available to the standardisations were year, group, and month. The year variable was included in all models; the other independent variables group and month were added to the model in a stepwise process. At each step the variable that most improved the fit of the model measured by the Akaike Information Criterion (AIC) was included (Akaike 1974).

In summary, the standardisation method common to all sites (but modified for Moeraki) was to:

1. use the fishing year from 1st April to 31st March
2. use the actual month in which a sample was taken (instead of samples taken up to the 7th of the month being assigned to the previous month)
3. drop collectors with fewer than 36 samples
4. restrict where necessary the months used (to reduce the proportion of zero counts in the data)
5. drop fishing years with fewer than 10 samples
6. use a negative binomial model for the data

7. use year, month, and group (collector is not offered as an alternative to group) as the predictor variables in the standardisation.

However, since the settlement at Moeraki was of interest and particularly high, collectors from MOE008 were also used even if they had fewer than 36 samples, so that a preliminary standardised index could be calculated for the 2017/18 fishing year.

Each set of annual indices is presented as the annual value divided by the geometric mean of the annual values, or where the annual values are close to zero (Moeraki and Halfmoon Bay) by dividing by the arithmetic mean of the annual values. In either case, a value for the index above 1 represents above average settlement for that year, and a value below 1 indicates below average settlement. For comparison, a raw form of these indices is also given (arithmetic mean for each year), which is also scaled to have an average value of 1 over all years.

The data set used for all sites is an extract from the *rocklob* database and is complete for the 2017/18 fishing year (i.e. data is complete up to 31 March 2018).

3. RESULTS

3.1 Standardised indices

Standardised indices were produced for the sites Gisborne (CRA 3), Napier (CRA 4), Castlepoint (CRA 4), Kaikoura (CRA 5), Moeraki (CRA 7), Halfmoon Bay (CRA 8), and Jackson Bay (CRA 8). There were no new data for Chalky Inlet (CRA 8). To reduce the number of zeros a subset of months was used for many of the standardisations (Table 2).

For each site, plots are given in the following sections for puerulus data characteristics, standardised index, and standardisation diagnostics. Diagnostics look reasonable for all sites (Appendix 1). The standardised indices for all sites are summarised in Table 3.

Table 2: Months for which data were used in standardisation.

Site	Months	For further detail on months used
Gisborne	May–September	Forman et al. 2015
Napier	All	Forman et al. 2017
Castlepoint	All	Forman et al. 2017
Kaikoura	January–September	Forman et al. 2016
Moeraki	May–October	Forman et al. 2014
Halfmoon Bay	May–December	Forman et al. 2014
Jackson Bay	All	Forman et al. 2014

Table 3: Standardised annual indices for each site. Year is fishing year 1 April–31 March. '–': no usable sampling was done; 0.00: no observed settlement.

Fishing year	Gisborne CRA 3	Napier CRA 4	Castlepoint CRA 4	Kaikoura CRA 5	Moeraki CRA 7	Halfmoon Bay CRA 8	Chalky Inlet CRA 8	Jackson Bay CRA 8
1979	–	0.78	–	–	–	–	–	–
1980	–	1.26	–	–	–	–	–	–
1981	–	2.07	–	0.55	–	7.87	–	–
1982	–	1.15	2.42	0.74	–	0.38	–	–
1983	–	1.34	1.17	0.16	–	3.83	–	–
1984	–	0.41	0.71	0.37	–	0.3	–	–
1985	–	0.22	0.57	0.24	–	0	0.36	–
1986	–	–	0.82	0.09	–	0.11	0.21	–
1987	3.43	–	1.62	1.04	–	1.54	1.42	–
1988	2.93	1.38	0.92	0.40	–	0.22	1.31	–
1989	1.03	1.19	1.14	0.80	–	0.58	1.64	–
1990	0.46	1.05	1.08	1.57	–	0.42	1.84	–
1991	1.11	2.46	2.11	6.63	0.00	0.91	1.03	–
1992	2.97	2.10	2.12	5.25	0.07	0.53	0.52	–
1993	1.85	2.21	1.05	2.03	0.00	0.00	0.14	–
1994	3.18	1.54	0.87	1.07	0.00	1.16	1.64	–
1995	1.14	1.06	0.92	0.60	0.05	0.39	0.40	–
1996	1.74	1.54	1.27	0.64	0.44	0.32	1.76	–
1997	1.04	1.07	1.69	1.96	0.19	0.55	1.41	–
1998	1.88	0.97	1.06	1.93	0.25	0.29	0.50	–
1999	0.29	0.43	0.34	1.27	0.05	0.23	1.70	0.24
2000	0.95	0.73	0.52	1.29	1.96	1.18	1.26	0.50
2001	1.18	1.23	0.71	0.53	0.82	1.70	0.60	0.20
2002	0.99	1.44	0.77	3.25	0.42	1.43	1.42	1.27
2003	2.87	1.31	0.92	3.31	3.55	3.88	1.56	0.49
2004	0.75	1.05	0.49	1.02	0.18	0.15	0.30	0.37
2005	2.61	1.27	1.26	2.24	0.04	0.00	–	1.15
2006	0.29	0.64	0.47	1.09	0.03	0.13	–	0.24
2007	0.38	0.92	1.03	1.65	0.03	0.47	–	0.20
2008	0.67	0.64	1.04	1.57	0.05	0.09	–	0.07
2009	1.79	0.88	1.06	0.51	0.32	0.99	–	0.13
2010	0.64	0.93	1.17	1.24	0.69	1.62	7.03	1.84
2011	0.19	0.48	0.89	0.55	0.51	0.14	1.44	2.00
2012	0.70	0.70	0.58	1.10	0.61	0.18	4.37	6.60
2013	0.97	0.95	1.69	0.71	0.88	0.74	–	12.06
2014	0.41	1.02	0.69	1.23	0.27	0.84	–	18.97
2015	1.57	1.04	1.65	0.85	5.88	0.54	–	4.95
2016	1.22	0.68	1.85	2.72	2.05	1.35	–	11.86
2017	0.17	1.00	1.05	0.78	7.68	1.98	–	1.02

4. SUMMARY AND DISCUSSION

In this section trends over time for each site are discussed, and monthly puerulus settlement for currently operating collectors is plotted.

Gisborne

Settlement at Gisborne in 2017/18 was the lowest on record (Figure 2). Although settlement was above the long-term mean in the previous two years, five of the last eight years have been well below the long-term mean. Whangara recorded higher settlement than Kaiti for all months except March. Two peaks were detected at Whangara; the usual winter peak, occurring in June, and another more unusual summer peak, occurring in December. Kaiti was relatively flat throughout the year and without any major peaks. Both sites recorded settlement throughout the year except for March, which is usually a time when settlement increases (Figure 3).

Napier

Settlement at Napier increased slightly from last year but only to its long-term mean (Figure 4). Over the last 12 years, settlement has been close to or below the long-term mean, and no significantly high settlement has occurred since the 1990s. The settlement patterns over winter between the Port of Napier and Cape Kidnappers were similar, however, in summer, Cape Kidnappers recorded, like Whangara in Gisborne, a significant December peak, that was not recorded at the Port of Napier (Figure 5).

Castlepoint

Settlement at Castlepoint decreased from last year to a level close to its long-term mean (Figure 6). The Castlepoint group recorded a winter peak in June and a summer peak in February. Orui recorded relatively low settlement over winter but peaked, like Castlepoint, in February (Figure 7). Three of the last five years have been above the long-term mean.

Kaikoura

Settlement at Kaikoura fell below its long-term mean (Figure 8). Settlement was very low at all sites during winter but increased over summer, peaking around January and February with all sites dropping to low levels in March (Figure 9).

Moeraki

Although disrupted with a change in location of sites within Moeraki, record high settlement was conditionally recorded in 2017/18 (Figure 10). For the first three months, there was a very similar pattern and level of settlement between the pier group (MOE007) and the new wharf group (MOE008) suggesting comparability between groups, though this has yet to be formally analysed. The highest levels of settlement were recorded in March, a period where settlement is usually very low and outside the months used for the standardisation (Figure 11). This is the third consecutive year of above average settlement at Moeraki.

Halfmoon Bay

Settlement was above the long-term mean in Halfmoon Bay (Figure 12). Most of the settlement occurred in winter, peaking in August (Figure 13). This is the second consecutive year of above average settlement.

Jackson Bay

After seven consecutive years of very high settlement, Jackson Bay was close to its long-term mean (Figure 14). Settlement peaked in September and, like previous years, showed no clear pattern of settlement (Figure 15).

Chalky Inlet

No new data were received in the 2017/18 fishing year.

Monthly settlement comparisons for all key sites are shown in Figure 16.

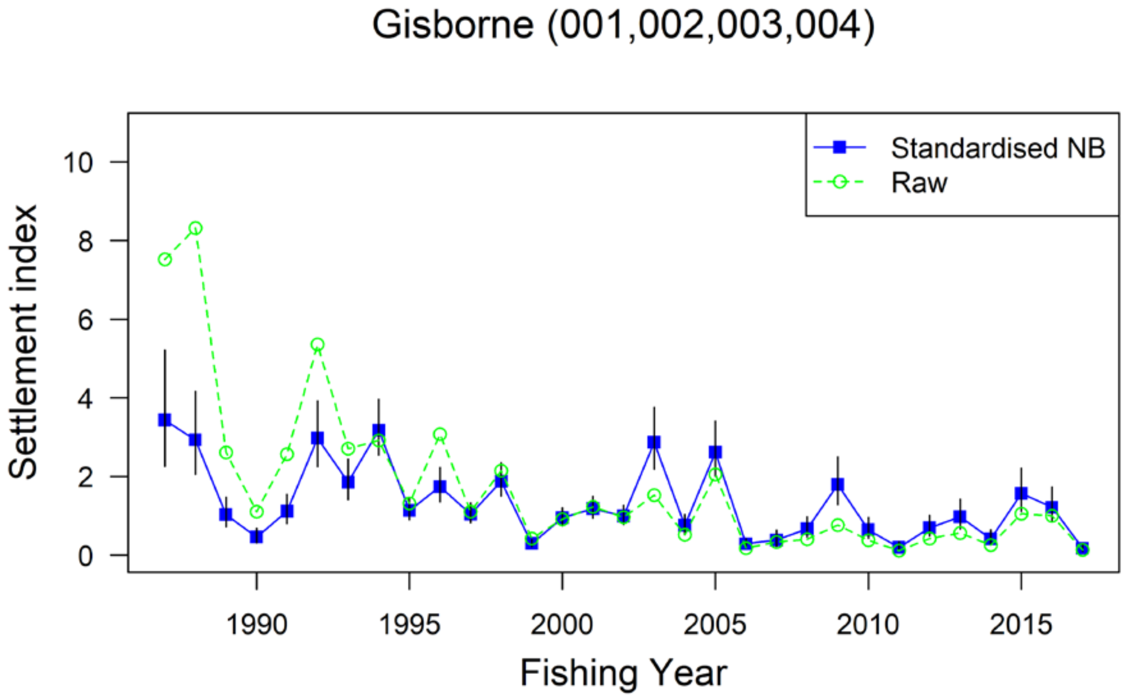

Figure 2: Standardised and raw indices of annual settlement for Gisborne with 95% confidence intervals.

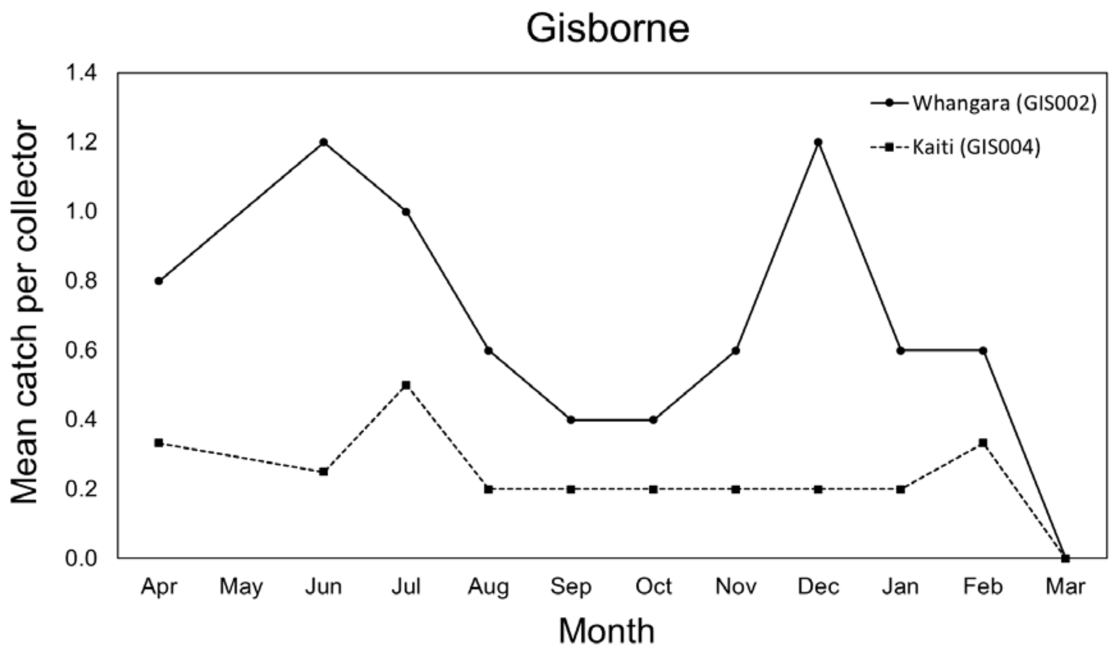

Figure 3: Whangara and Kaiti monthly settlement, 2017/18 fishing year. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

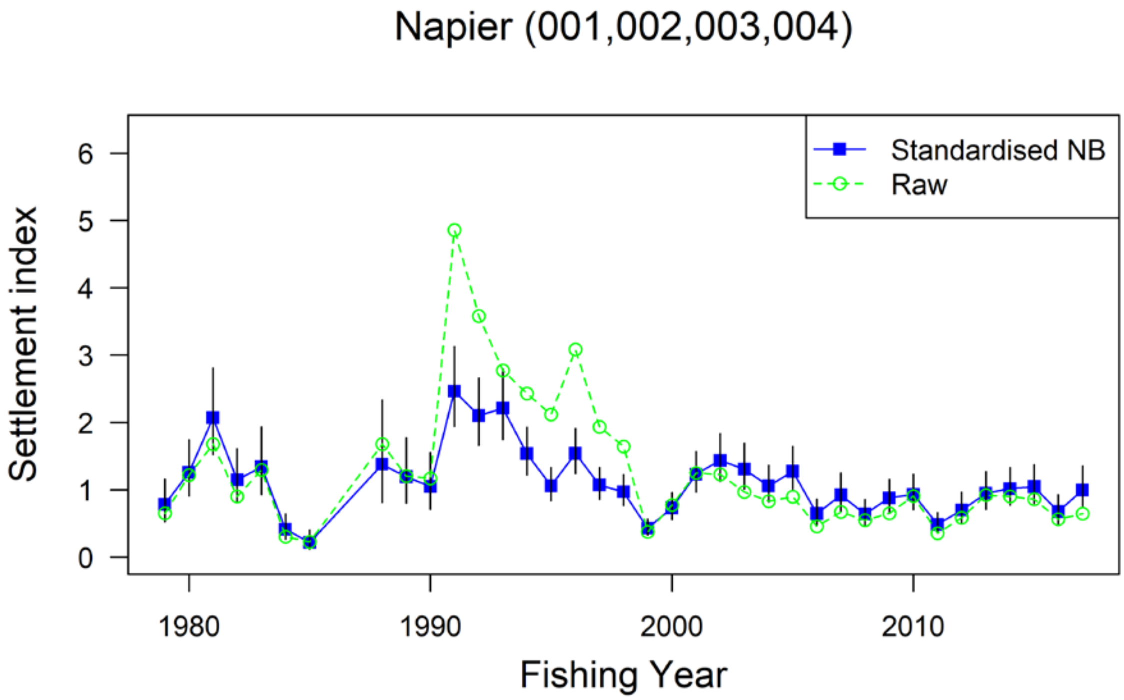

Figure 4: Standardised and raw indices of annual settlement for Napier with 95% confidence intervals. Note that there were no checks in 1986–87.

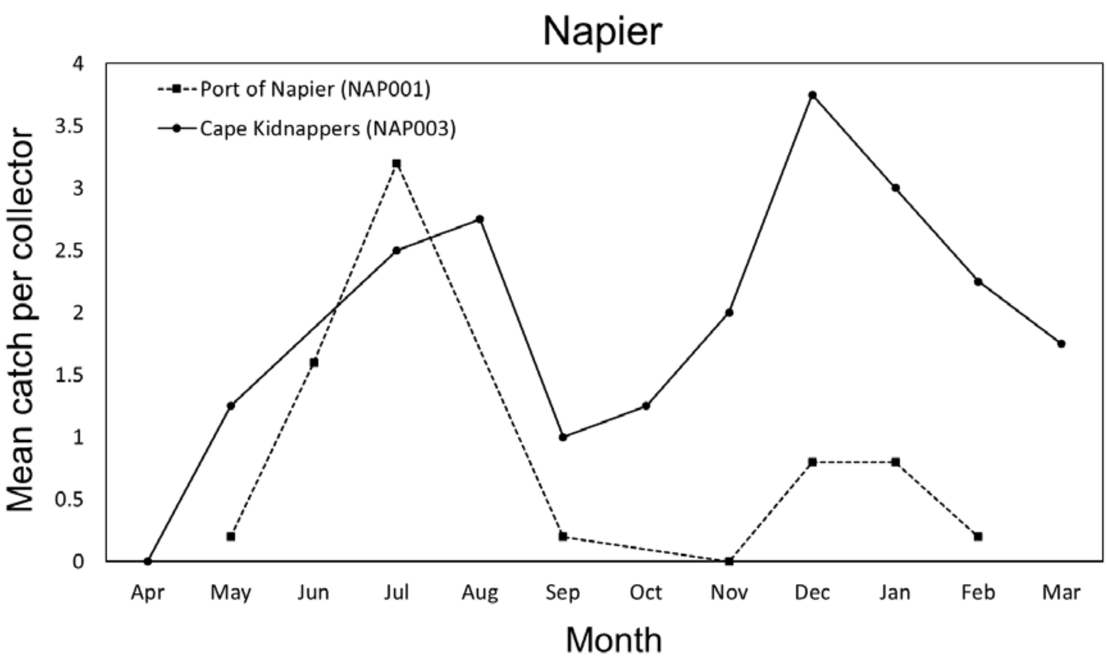

Figure 5: Port of Napier and Cape Kidnappers monthly settlement, 2017/18 fishing year. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

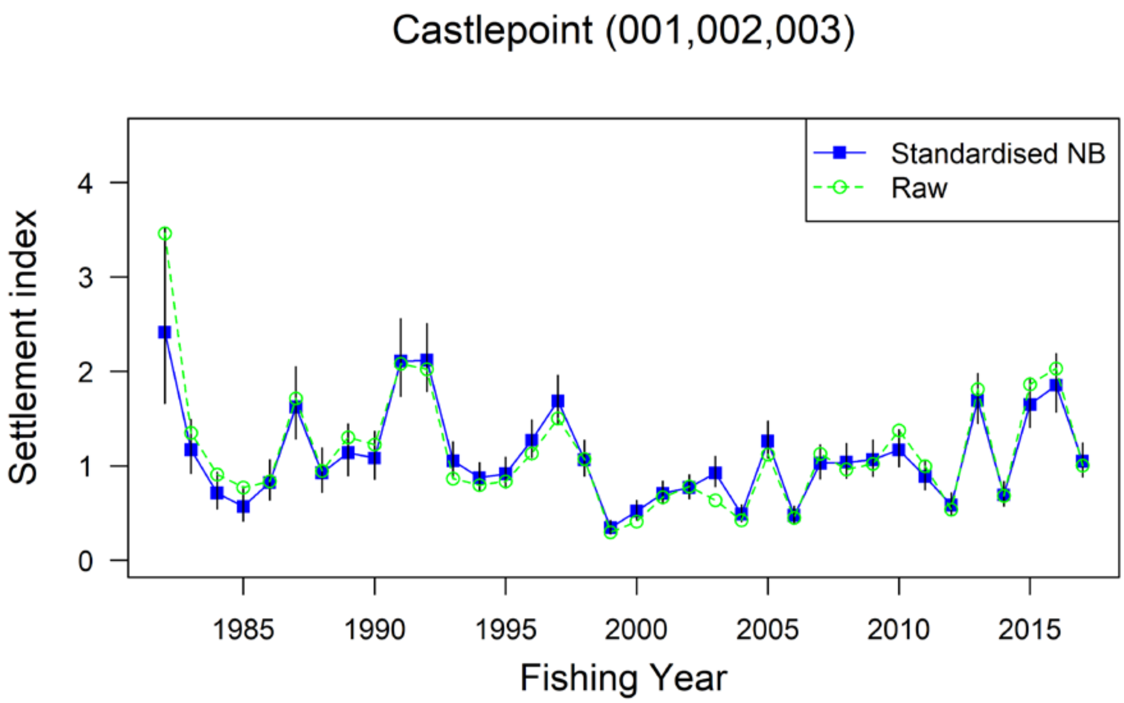

Figure 6: Standardised and raw indices of annual settlement for Castlepoint with 95% confidence intervals.

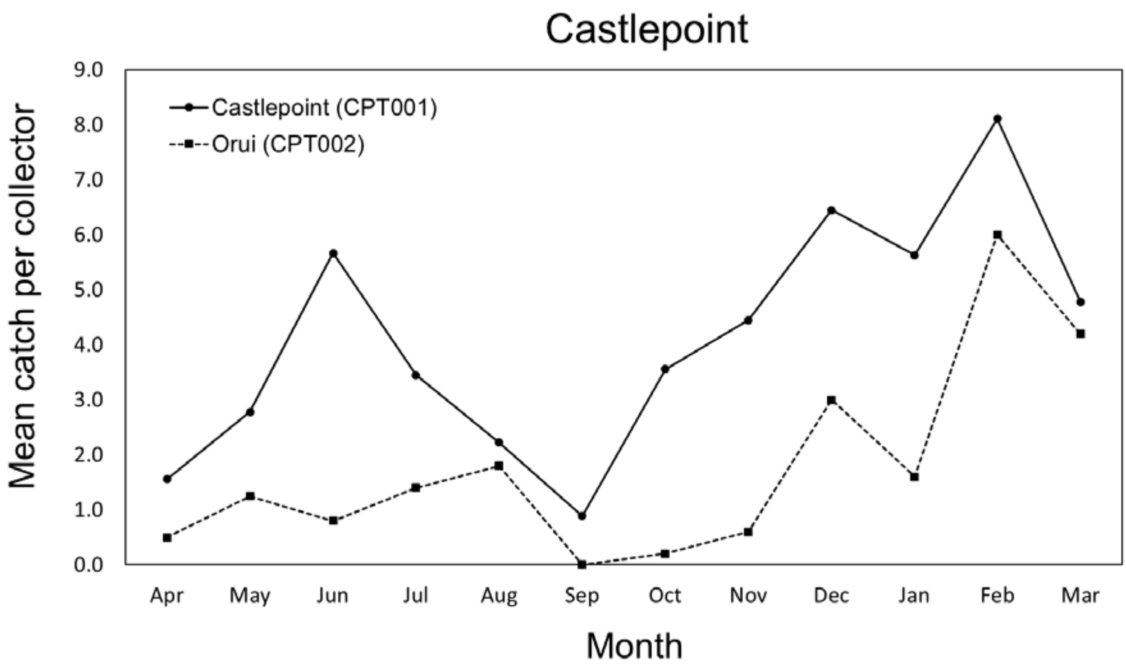

Figure 7: Castlepoint and Orui monthly settlement, 2017/18 fishing year. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

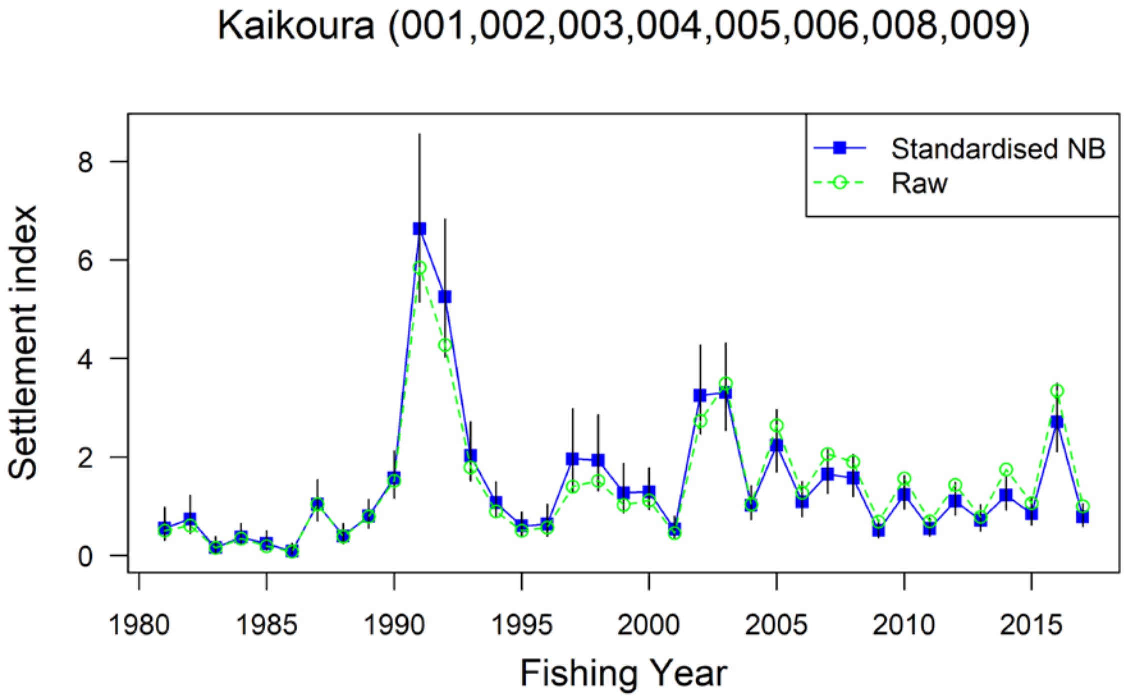

Figure 8: Standardised and raw indices of annual settlement for Kaikoura with 95% confidence interval.

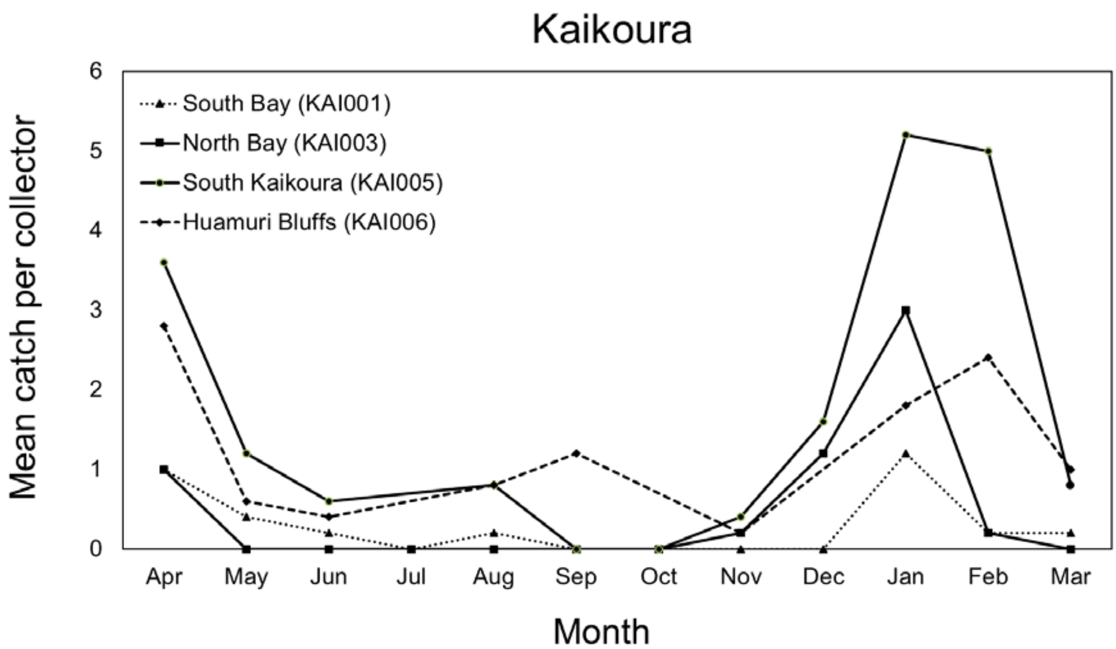

Figure 9: South Bay, North Bay, South Kaikoura, and Haumuri Bluffs monthly settlement, 2017/18 fishing year. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

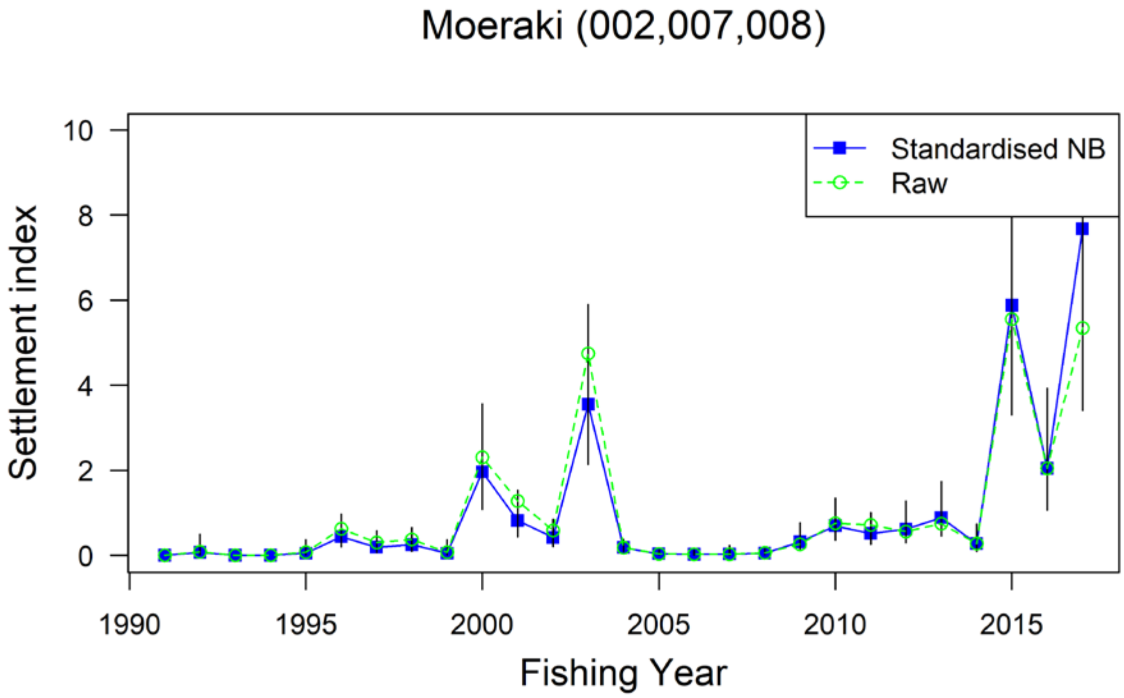

Figure 10: Standardised and raw indices of annual settlement for Moeraki with 95% confidence intervals (where collectors with less than 36 samples were used).

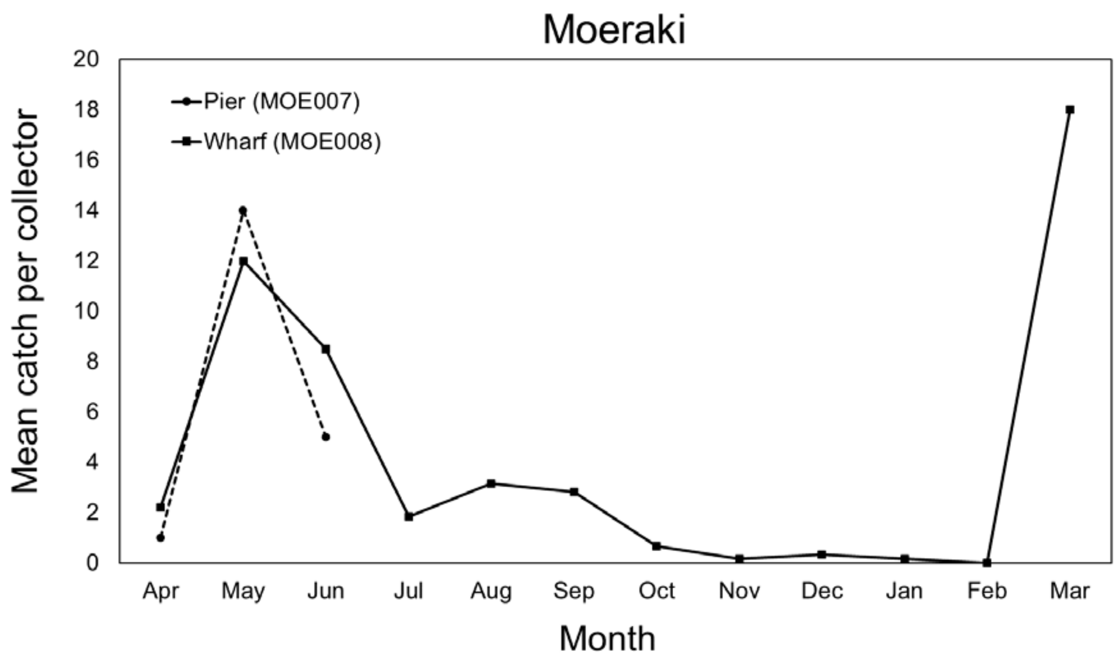

Figure 11: Moeraki monthly settlement, 2017/18 fishing year. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

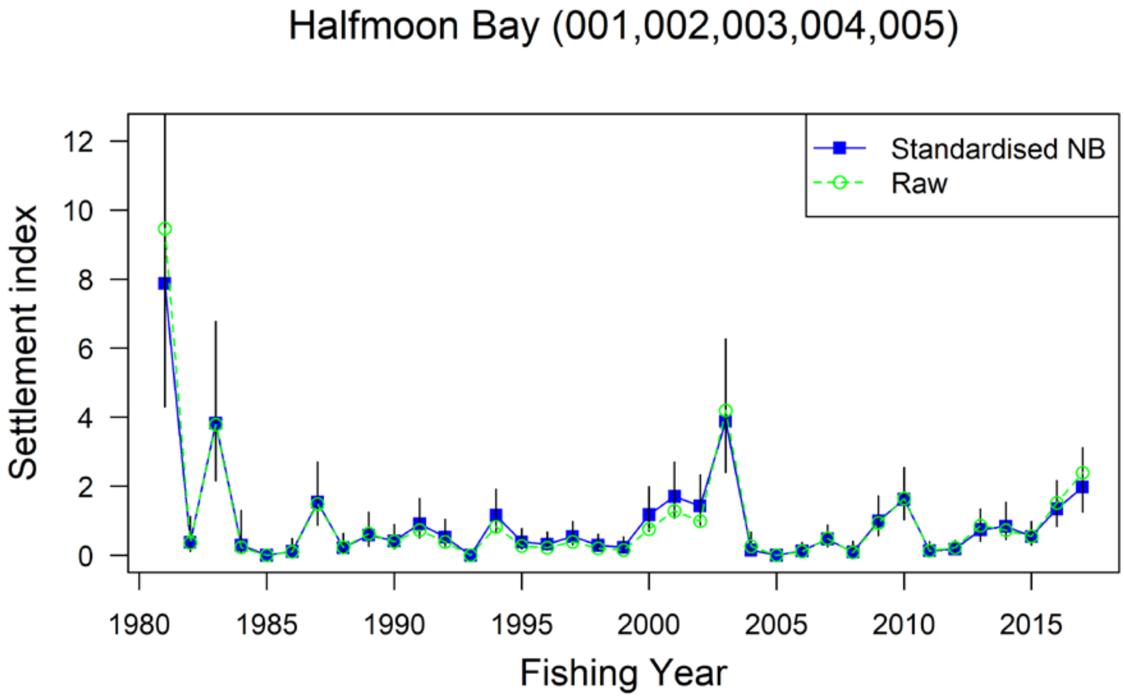

Figure 12: Standardised and raw indices of annual settlement for Halfmoon Bay with 95% confidence intervals.

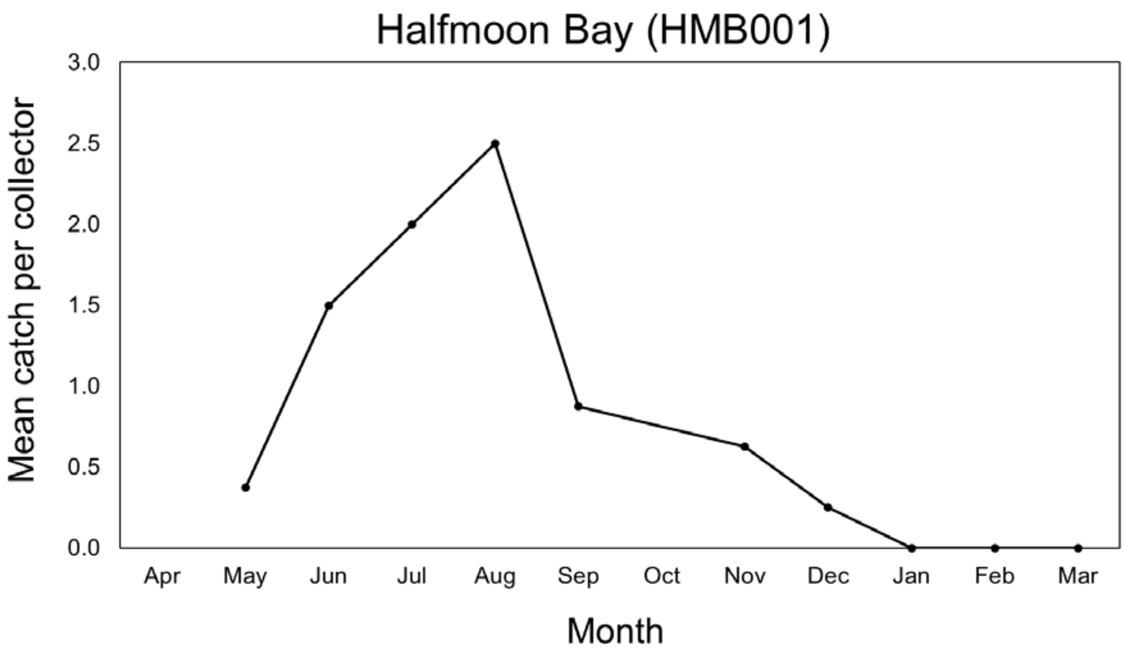

Figure 13: Halfmoon Bay monthly settlement, 2017/18 fishing year. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

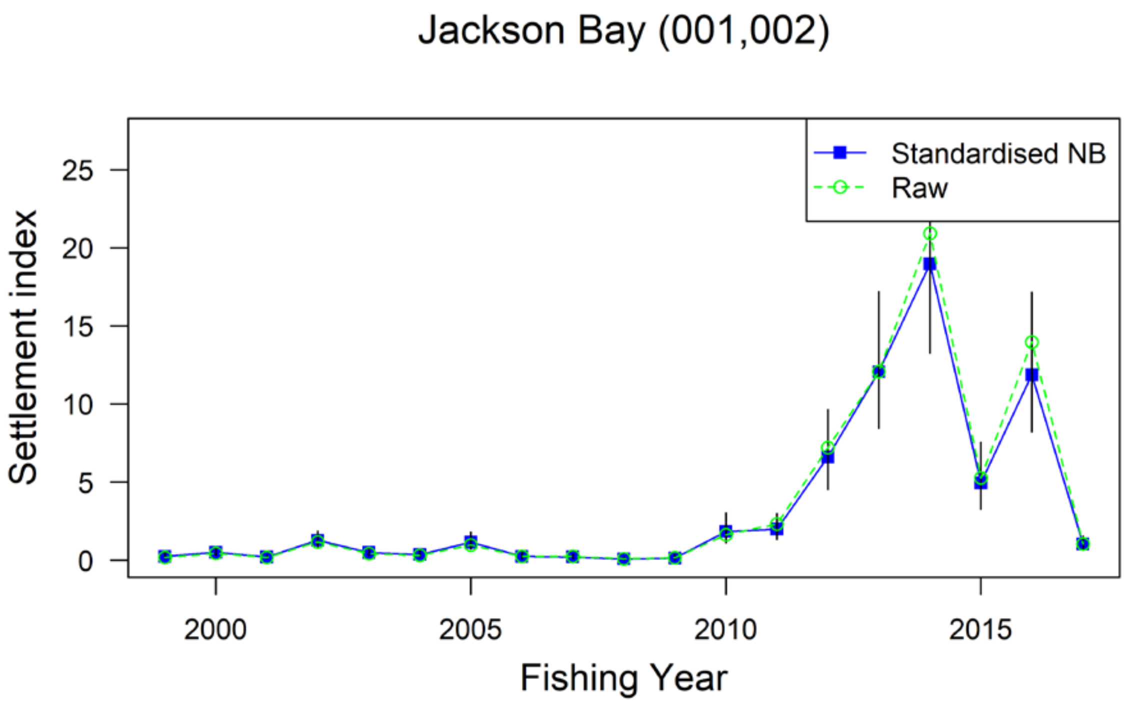

Figure 14: Standardised and raw indices of annual settlement for Jackson Bay with 95% confidence intervals.

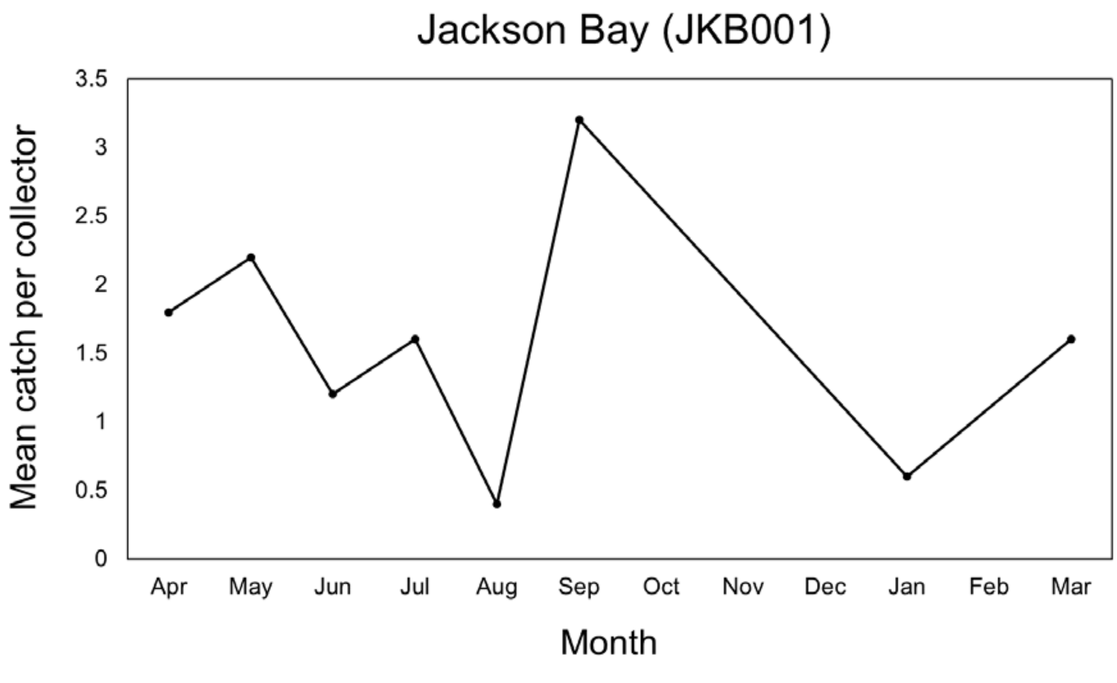

Figure 15: Jackson Bay monthly settlement, 2017/18 fishing year. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

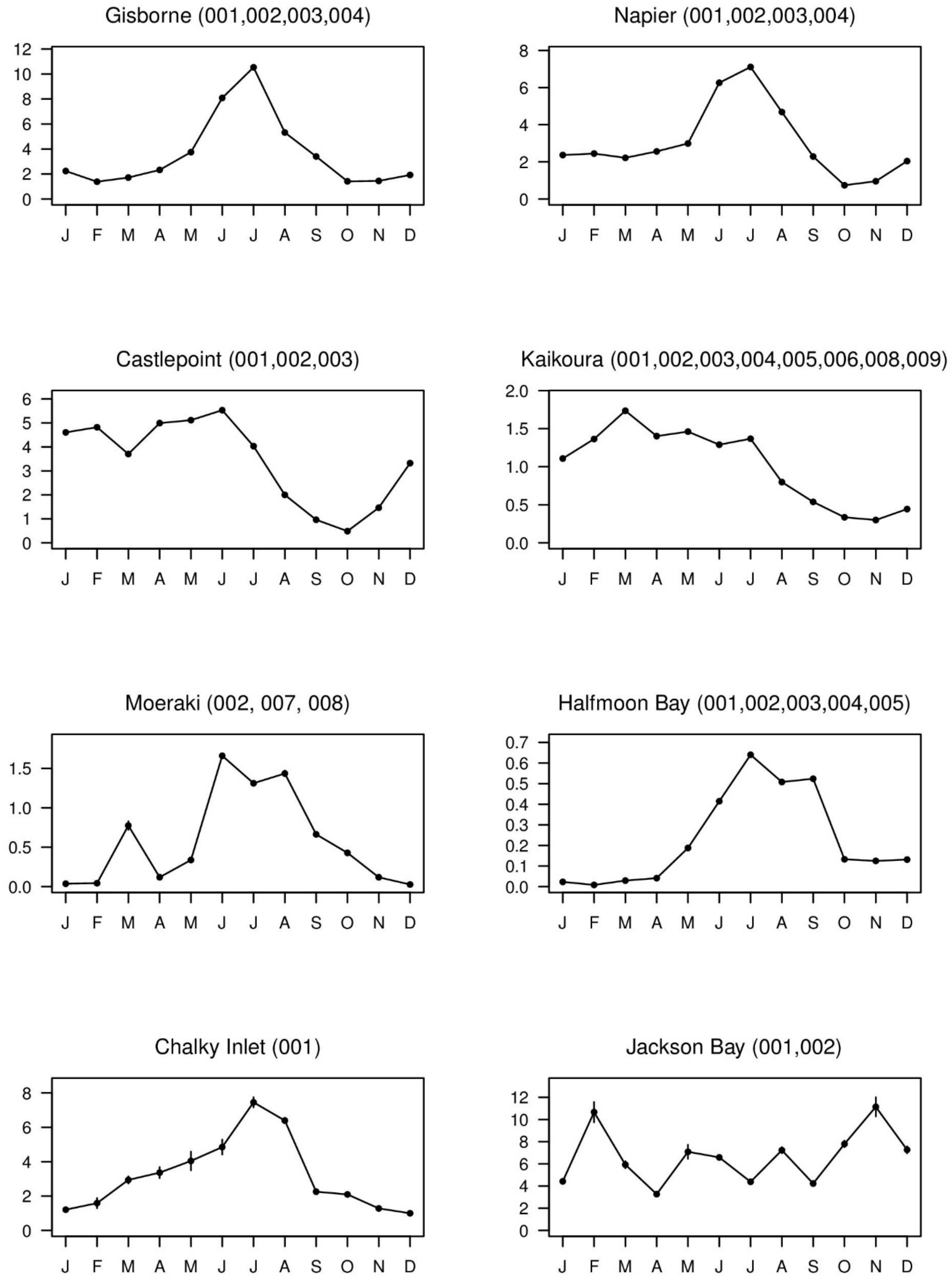

Figure 16: The mean settlement by month, over all years, for each key collector site. See Table 1 for the collector groups. Vertical lines show 95% confidence intervals for the mean value (for many months this interval is very tight, and will not be apparent on the figure).

5. CONCLUSIONS

The 2017/18 settlement year was notable for provisionally high settlement at Moeraki and record low settlement at Gisborne. Above average settlement was recorded at Halfmoon Bay and below average settlement was recorded at Kaikoura. Napier, Castlepoint, and Jackson Bay were all very close to their long-term means.

At Gisborne, five of the last eight years have been below average, and at Napier, the last 12 years have been average or below average. Although settlement was only average this year at Castlepoint and below average at Kaikoura, there has been some recent high settlement in 2013, 2015, and 2016 at Castlepoint, and in 2014 and 2016 at Kaikoura. Moeraki has recorded three consecutive years of high settlement and Halfmoon Bay has recorded two, and although only average this year at Jackson Bay, the last seven years have all been well above average including three exceptional years in 2013, 2014, and 2016.

For Gisborne, Napier, and Castlepoint the puerulus index is potentially a signal for recruited abundance 4–6 years into the future. For Moeraki, the estimated interval is 4–5 years and for Halfmoon Bay it is 6–8 years (Booth & McKenzie 2008).

6. ACKNOWLEDGEMENTS

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APPENDIX 1: DATA CHARACTERISTICS AND DIAGNOSTICS

For each site plots are given for puerulus data characteristics, and standardisation diagnostics (Figures 17–44). To reduce the number of zeros a subset of months was used for many of the standardisations (see Table 2). The number of puerulus samples by group and fishing year at each site are given in Tables 4–10. Diagnostics look reasonable for all sites.

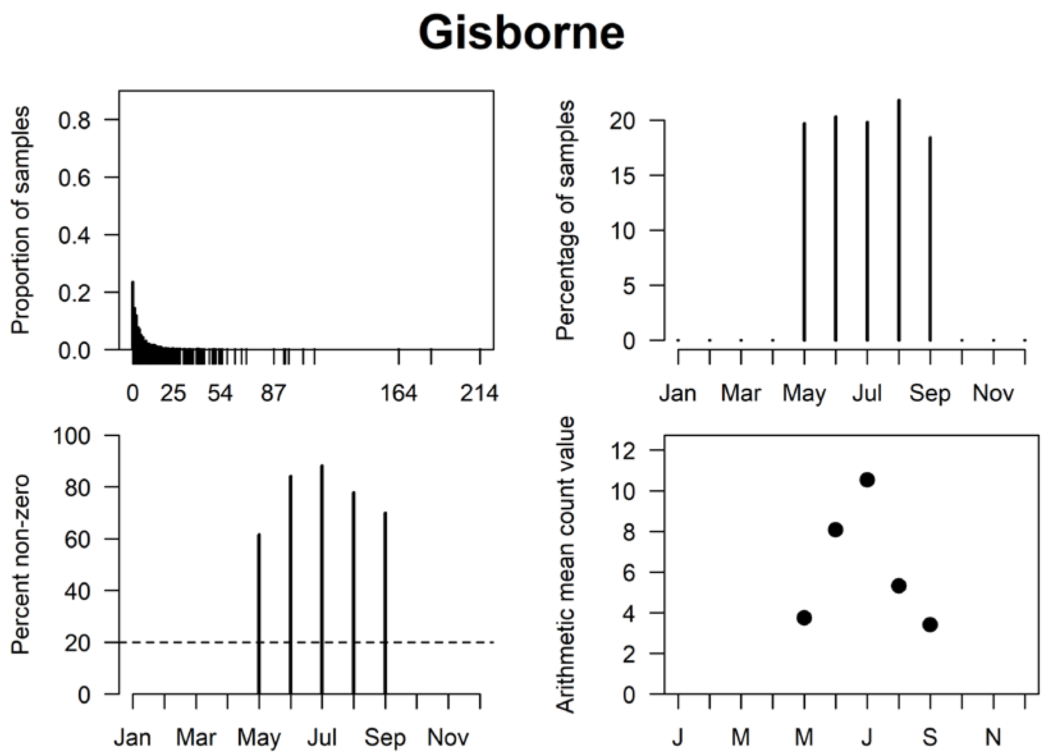

Figure 17: Characteristics of the Gisborne puerulus standardisation data. The top-left figure shows the distribution of puerulus counts, and the bottom-left the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.

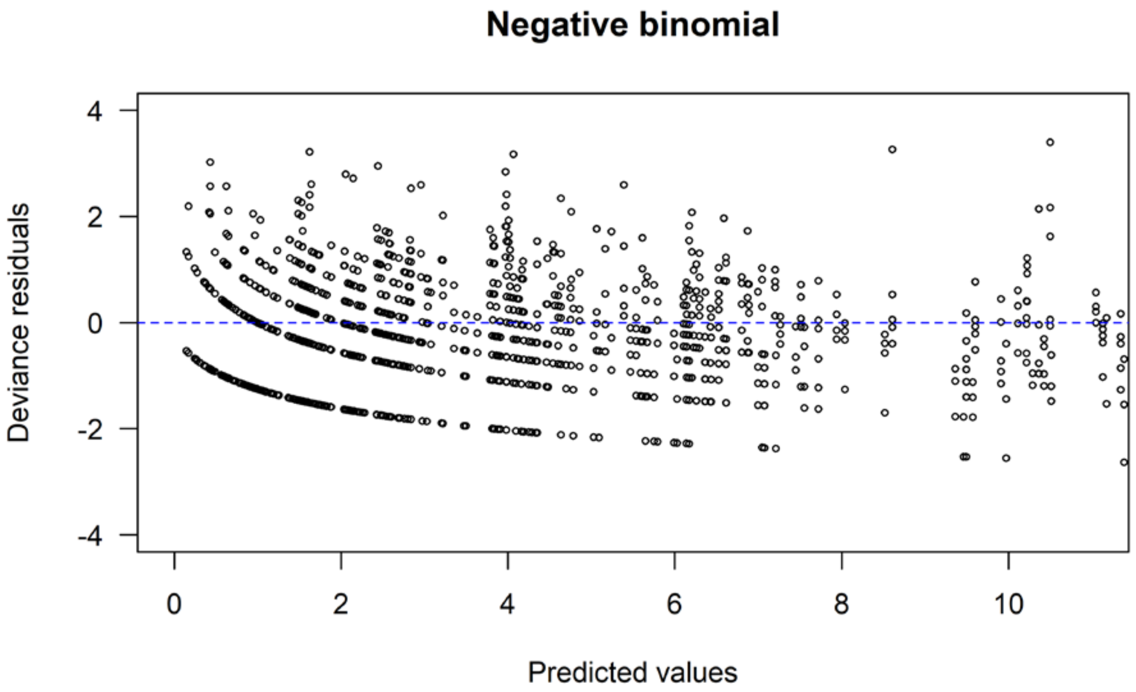

Figure 18: Deviance residuals for the negative binomial model for Gisborne. Predicted values are in natural space.

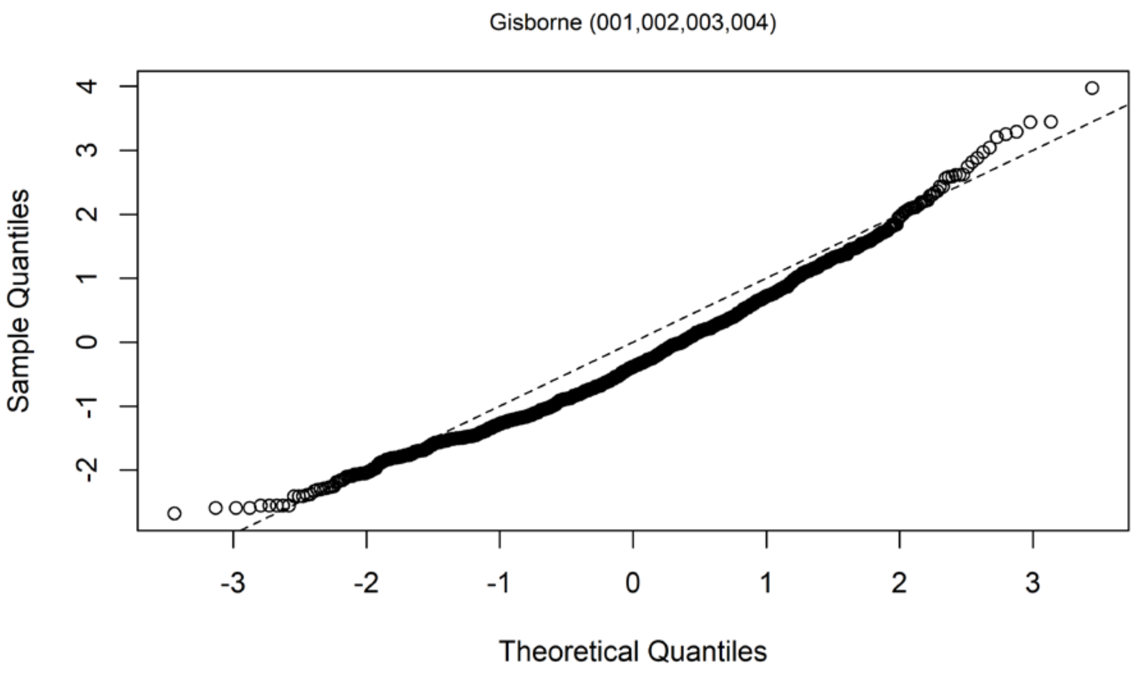

Figure 19: Quantile-quantile plot for the negative binomial standardisation model for Gisborne.

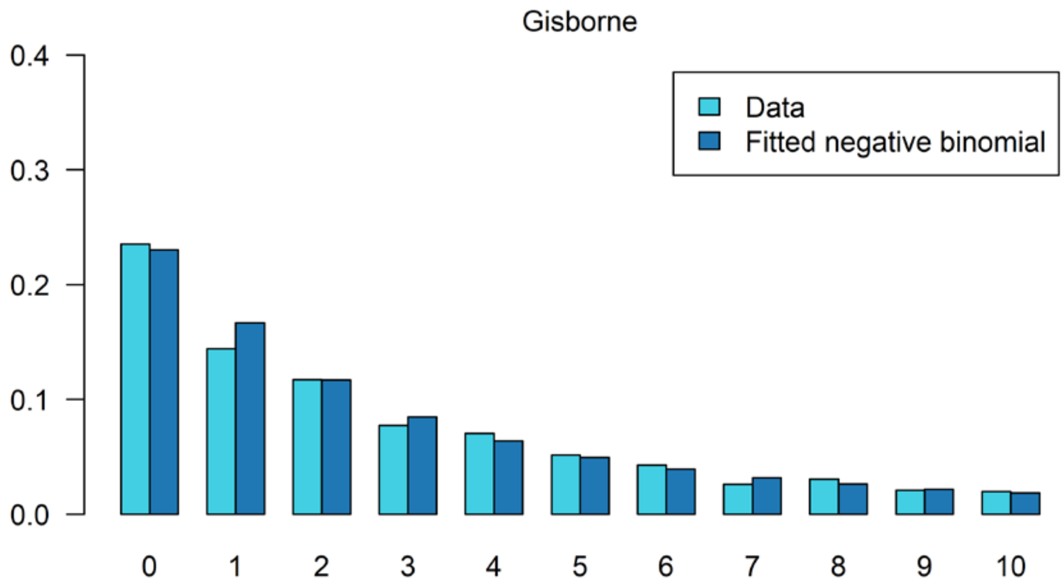

Figure 20: Data distribution and that from the fitted negative binomial model for Gisborne.

Table 4: Gisborne standardisation data set. Number of puerulus samples by group and fishing year.

Year	GIS001	GIS002	GIS003	GIS004	Total
1987	15	0	0	0	15
1988	23	0	0	0	23
1989	25	0	0	0	25
1990	25	0	0	0	25
1991	25	5	0	0	30
1992	24	17	0	0	41
1993	25	20	0	0	45
1994	25	20	25	23	93
1995	25	24	25	25	99
1996	25	20	0	25	70
1997	25	20	23	25	93
1998	25	25	25	25	100
1999	20	25	21	18	84
2000	23	25	25	25	98
2001	24	25	25	25	99
2002	20	25	19	25	89
2003	0	18	19	30	67
2004	0	20	20	25	65
2005	0	25	19	25	69
2006	0	23	24	30	77
2007	0	24	0	0	24
2008	0	20	0	25	45
2009	0	18	0	25	43
2010	0	15	0	25	40
2011	0	20	0	20	40
2012	0	20	0	25	45
2013	0	20	0	15	35
2014	0	20	0	18	38
2015	0	20	0	19	39
2016	0	20	0	19	39
2017	0	20	0	18	38

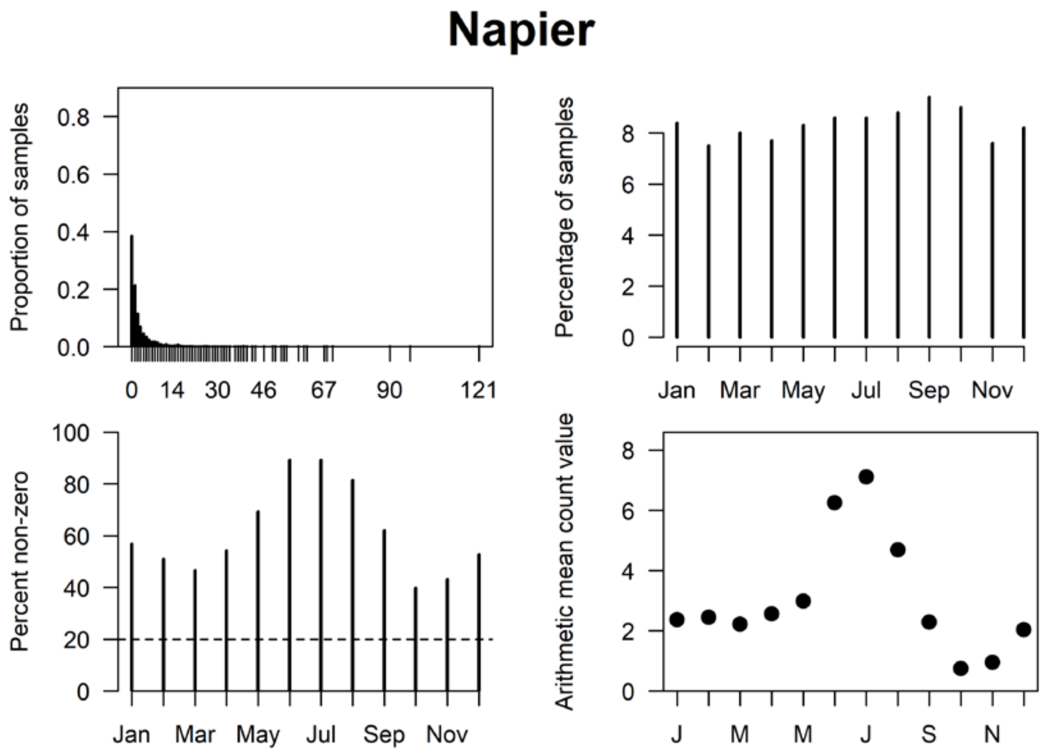

Figure 21: Characteristics of the Napier puerulus standardisation data. The top-left figure shows the distribution of puerulus counts, and the bottom-left the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.

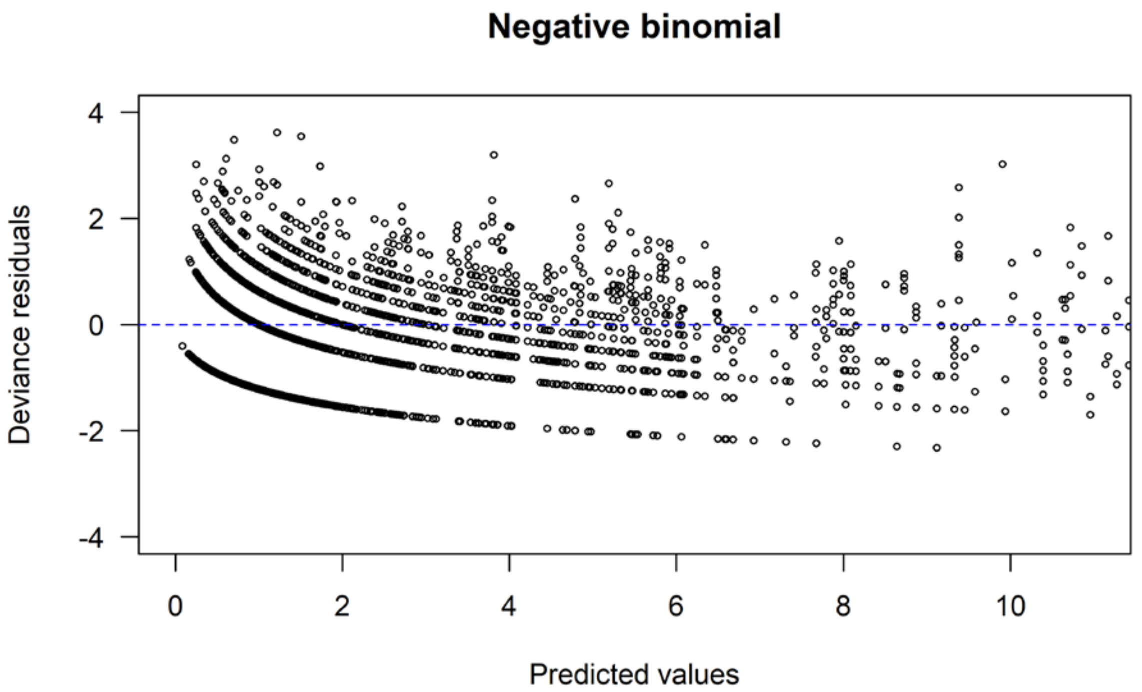

Figure 22: Deviance residuals for the negative binomial model for Napier. Predicted values are in natural space.

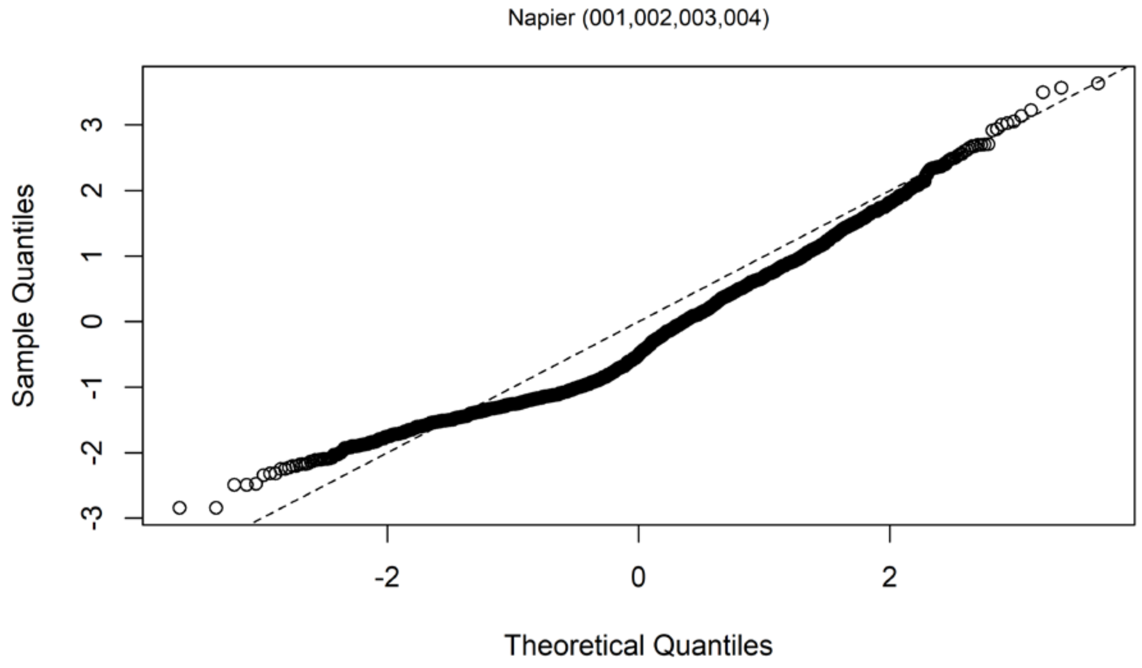

Figure 23: Quantile-quantile plot for the negative binomial standardisation model for Napier.

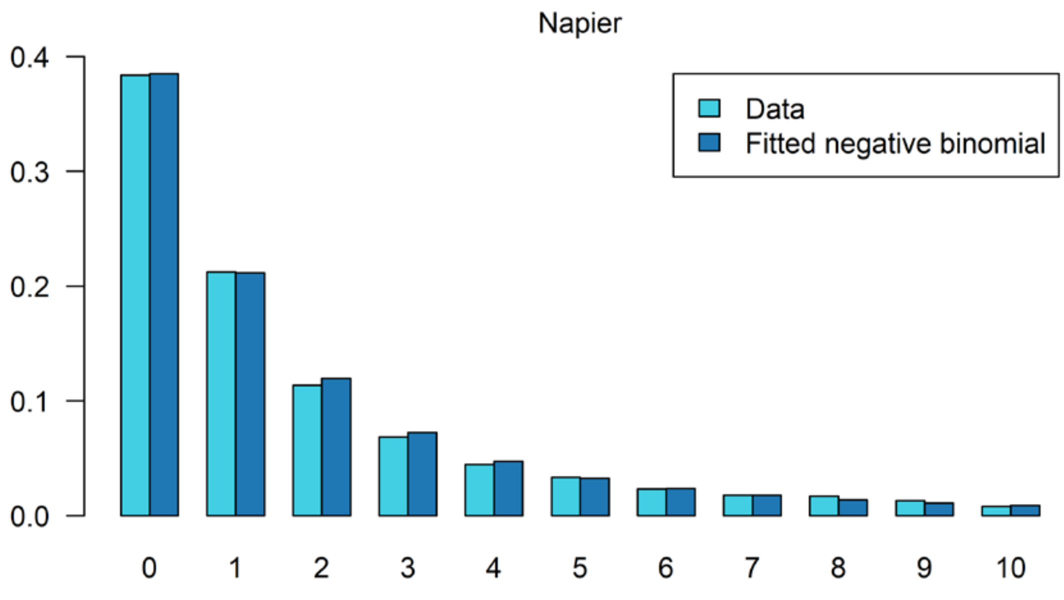

Figure 24: Data distribution and that from the fitted negative binomial model for Napier.

Table 5: Napier standardisation data set. Number of puerulus samples by group and fishing year.

	NAP001	NAP002	NAP003	NAP004	Total
1979	52	0	0	0	52
1980	65	0	0	0	65
1981	66	0	0	0	66
1982	60	0	0	0	60
1983	48	0	0	0	48
1984	60	0	0	0	60
1985	36	0	0	0	36
1988	18	0	0	0	18
1989	36	0	0	0	36
1990	36	0	0	3	39
1991	60	21	0	26	107
1992	69	21	0	32	122
1993	69	17	0	33	119
1994	65	27	25	33	150
1995	59	29	41	30	159
1996	72	33	50	33	188
1997	71	24	65	36	196
1998	66	18	58	27	169
1999	72	6	55	27	160
2000	47	0	48	27	122
2001	65	0	61	21	147
2002	57	0	52	18	127
2003	66	0	54	0	120
2004	71	0	59	0	130
2005	72	0	53	0	125
2006	72	0	47	0	119
2007	53	0	40	0	93
2008	56	0	59	0	115
2009	60	0	59	0	119
2010	60	0	52	0	112
2011	60	0	53	0	113
2012	50	0	36	0	86
2013	50	0	50	0	100
2014	50	0	59	0	109
2015	55	0	59	0	114
2016	40	0	53	0	93
2017	40	0	41	0	81

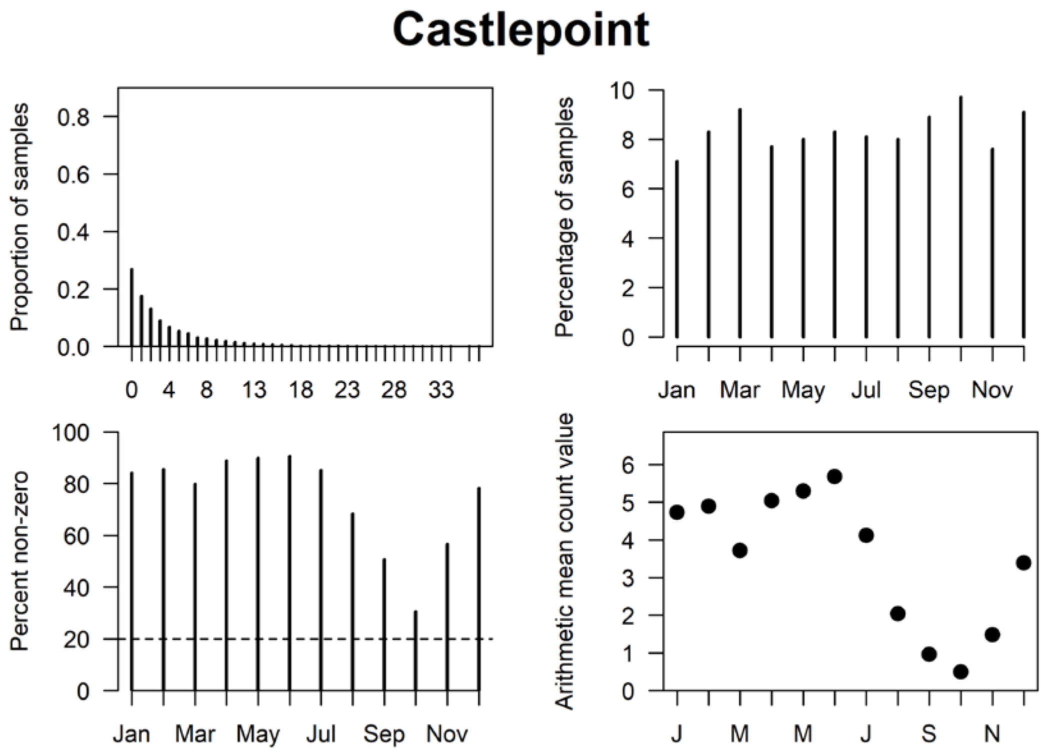

Figure 25: Characteristics of the Castlepoint puerulus standardisation data. The top-left figure shows the distribution of puerulus counts, and the bottom-left the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.

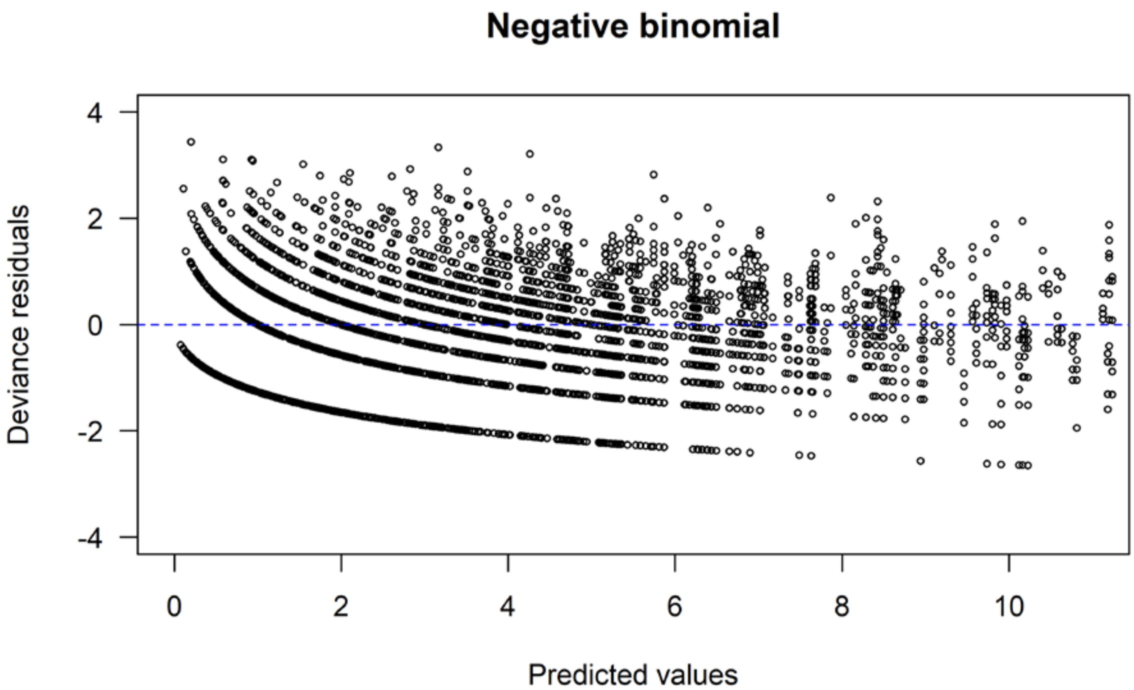

Figure 26: Deviance residuals for the negative binomial model for Castlepoint. Predicted values are in natural space.

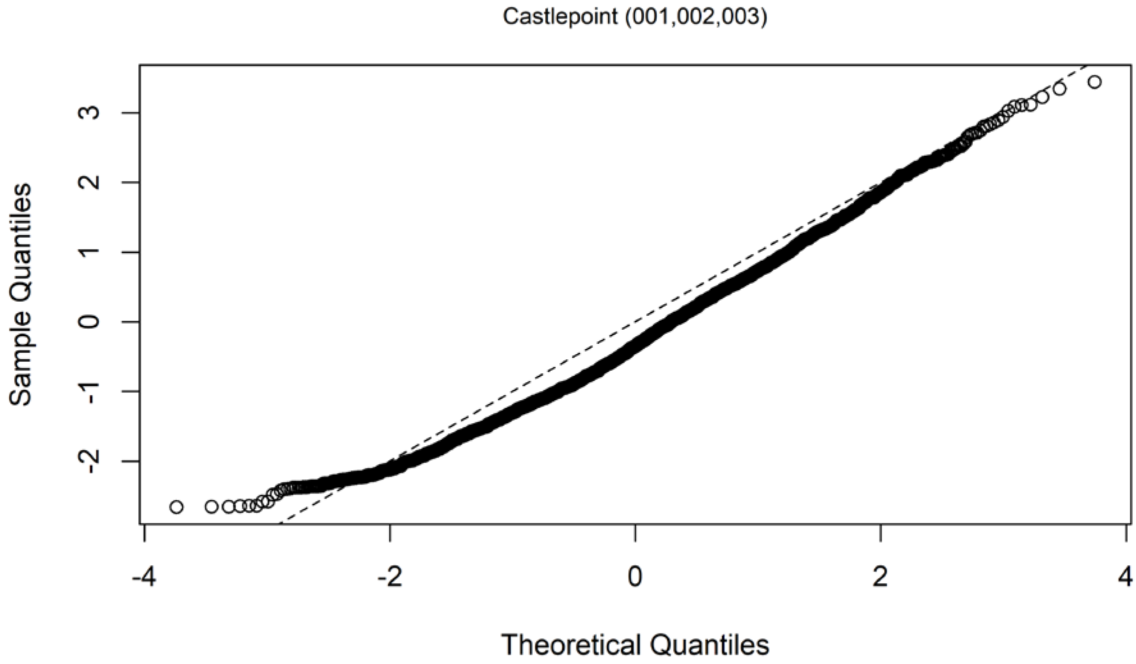

Figure 27: Quantile-quantile plot for the negative binomial standardisation model for Castlepoint.

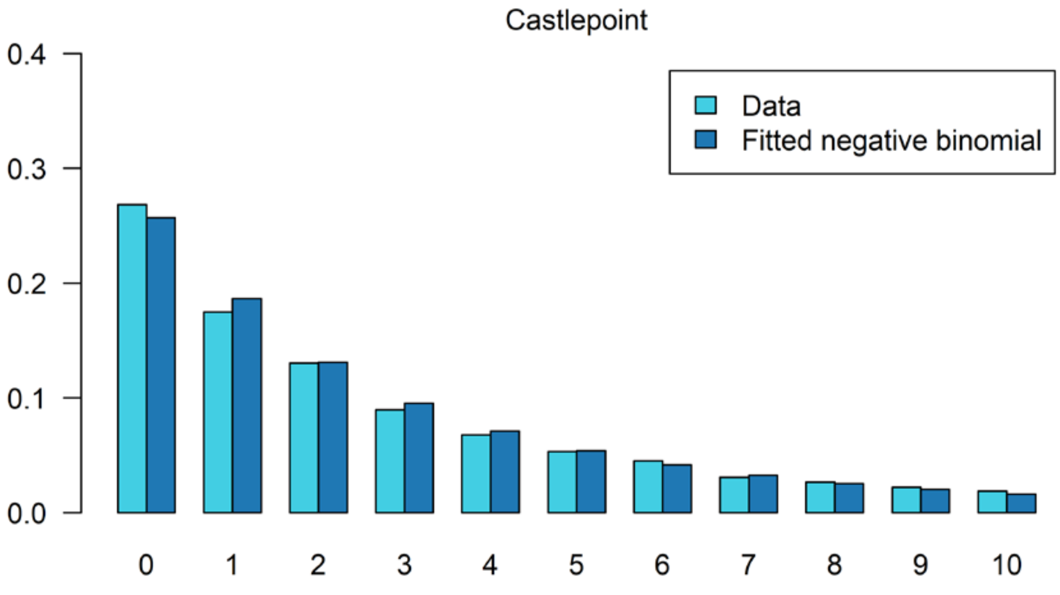

Figure 28: Data distribution and that from the fitted negative binomial model for Castlepoint.

Table 6: Castlepoint standardisation data set. Number of puerulus samples by group and fishing year.

	CPT001	CPT002	CPT003	Total
1982	18	0	0	18
1983	68	0	0	68
1984	57	0	0	57
1985	41	0	0	41
1986	70	0	0	70
1987	66	0	0	66
1988	66	0	0	66
1989	67	0	0	67
1990	72	0	0	72
1991	72	17	16	105
1992	71	46	38	155
1993	70	63	61	194
1994	102	60	50	212
1995	97	48	37	182
1996	108	60	60	228
1997	108	60	55	223
1998	98	36	35	169
1999	116	18	65	199
2000	105	21	60	186
2001	99	36	53	188
2002	104	52	62	218
2003	99	51	55	205
2004	114	53	65	232
2005	107	60	60	227
2006	108	58	45	211
2007	106	50	0	156
2008	107	55	0	162
2009	99	55	0	154
2010	117	65	0	182
2011	108	60	0	168
2012	108	46	0	154
2013	117	70	0	187
2014	99	59	0	158
2015	105	64	0	169
2016	103	52	0	155
2017	107	58	0	165

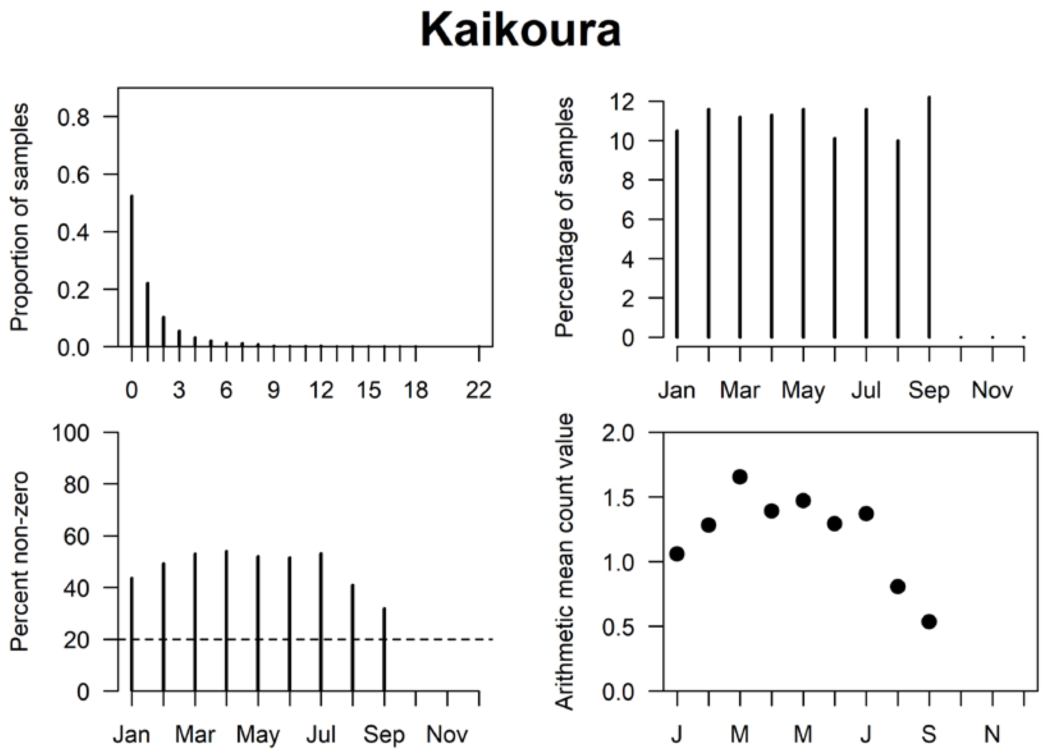

Figure 29: Characteristics of the Kaikoura puerulus standardisation data. The top-left figure shows the distribution of puerulus counts, and the bottom-left the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.

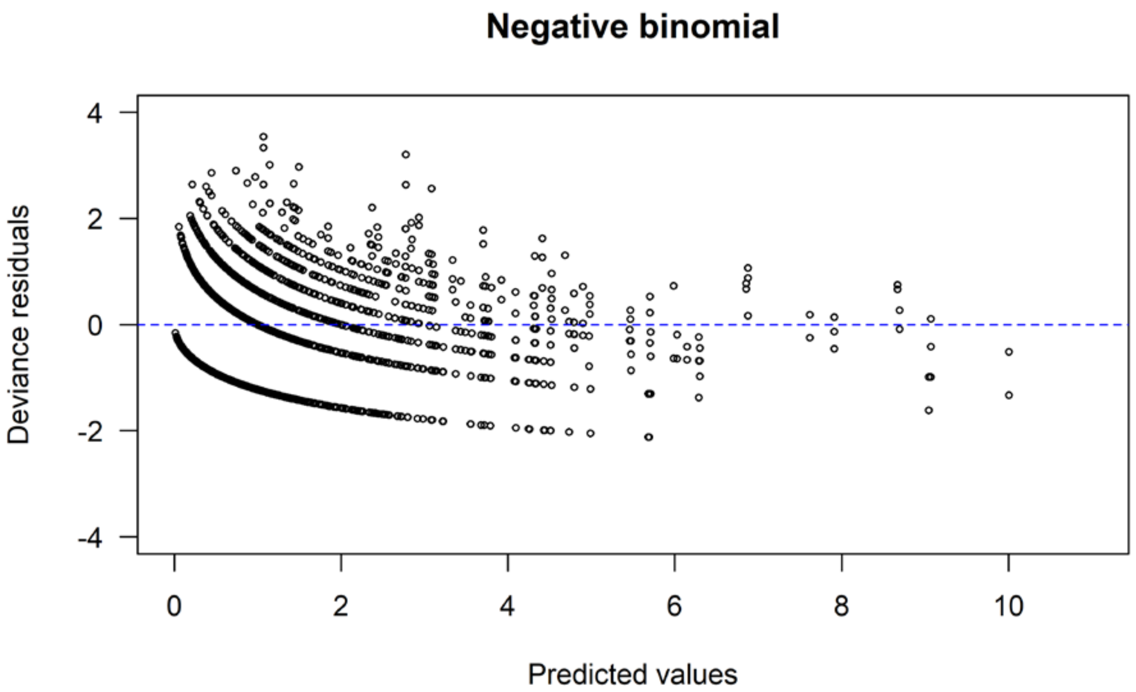

Figure 30: Deviance residuals for the negative binomial model for Kaikoura. Predicted values are in natural space.

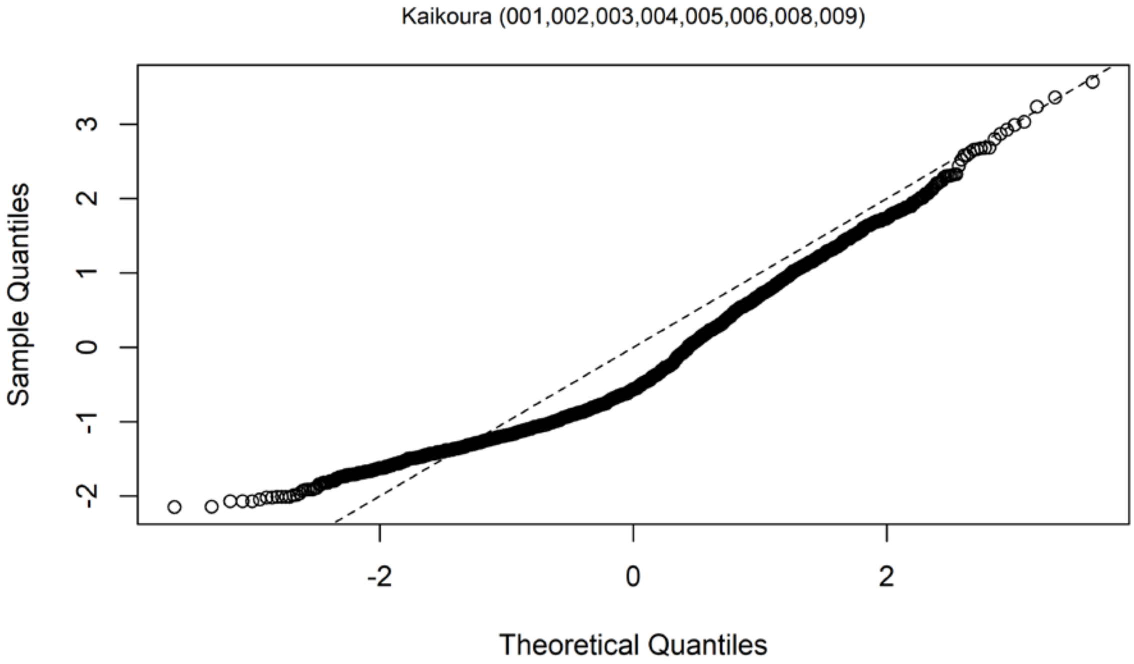

Figure 31: Quantile-quantile plot for the negative binomial standardisation model for Kaikoura.

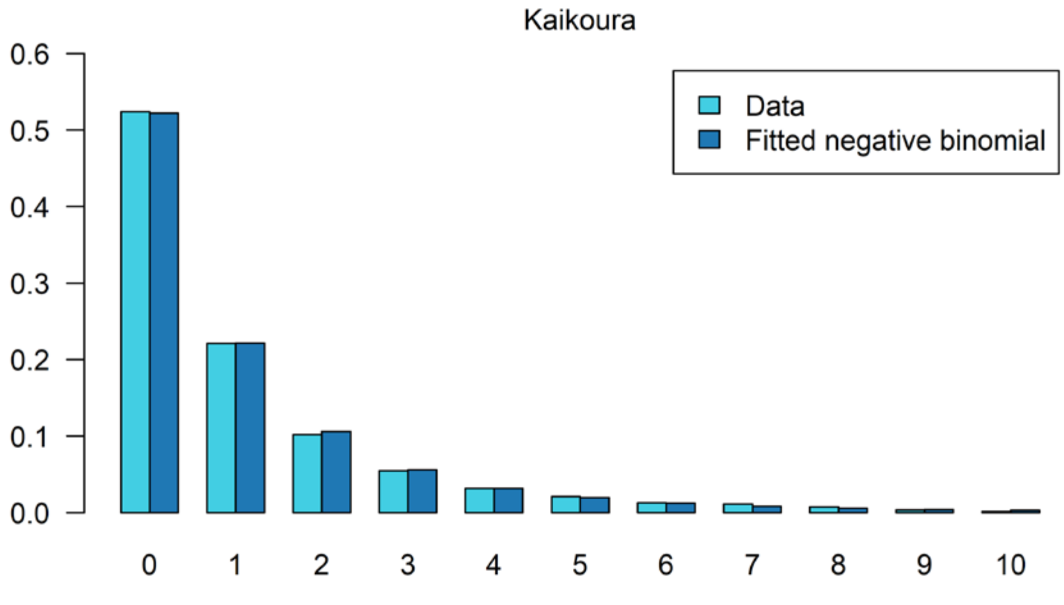

Figure 32: Data distribution and that from the fitted negative binomial for Kaikoura.

Table 7: Kaikoura standardisation data set. Number of puerulus samples by group and fishing year.

	KAI001	KAI002	KAI003	KAI004	KAI005	KAI006	KAI008	KAI009	Total
1981	15	0	15	0	0	0	15	0	45
1982	18	0	18	0	0	0	18	0	54
1983	15	0	15	0	0	0	18	0	48
1984	21	0	21	0	0	0	24	0	66
1985	18	0	17	0	0	0	24	0	59
1986	21	0	20	0	0	0	24	0	65
1987	24	0	24	0	0	0	27	0	75
1988	24	6	24	0	0	0	18	9	81
1989	24	24	27	0	0	0	0	27	102
1990	27	27	27	0	0	0	0	27	108
1991	27	24	27	0	0	0	0	24	102
1992	21	21	21	21	0	0	0	21	105
1993	24	24	24	24	0	0	0	15	111
1994	26	27	27	27	0	0	0	0	107
1995	27	27	27	27	0	0	0	0	108
1996	15	15	15	15	0	0	0	0	60
1997	12	12	12	9	0	0	0	0	45
1998	12	12	15	15	0	0	0	0	54
1999	15	15	18	18	0	0	0	0	66
2000	26	26	27	27	0	0	0	0	106
2001	27	27	27	27	0	0	0	0	108
2002	27	24	27	26	0	0	0	0	104
2003	45	0	45	0	0	0	0	0	90
2004	44	0	45	0	0	0	0	0	89
2005	45	0	45	0	0	0	0	0	90
2006	45	0	45	0	0	0	0	0	90
2007	45	0	50	0	12	9	0	0	116
2008	45	0	44	0	20	18	0	0	127
2009	44	0	45	0	24	21	0	0	134
2010	45	0	45	0	21	15	0	0	126
2011	45	0	45	0	15	15	0	0	120
2012	45	0	40	0	11	6	0	0	102
2013	39	0	40	0	3	3	0	0	85
2014	40	0	40	0	24	24	0	0	128
2015	45	0	45	0	12	9	0	0	111
2016	45	0	45	0	9	9	0	0	108
2017	45	0	45	0	24	24	0	0	138

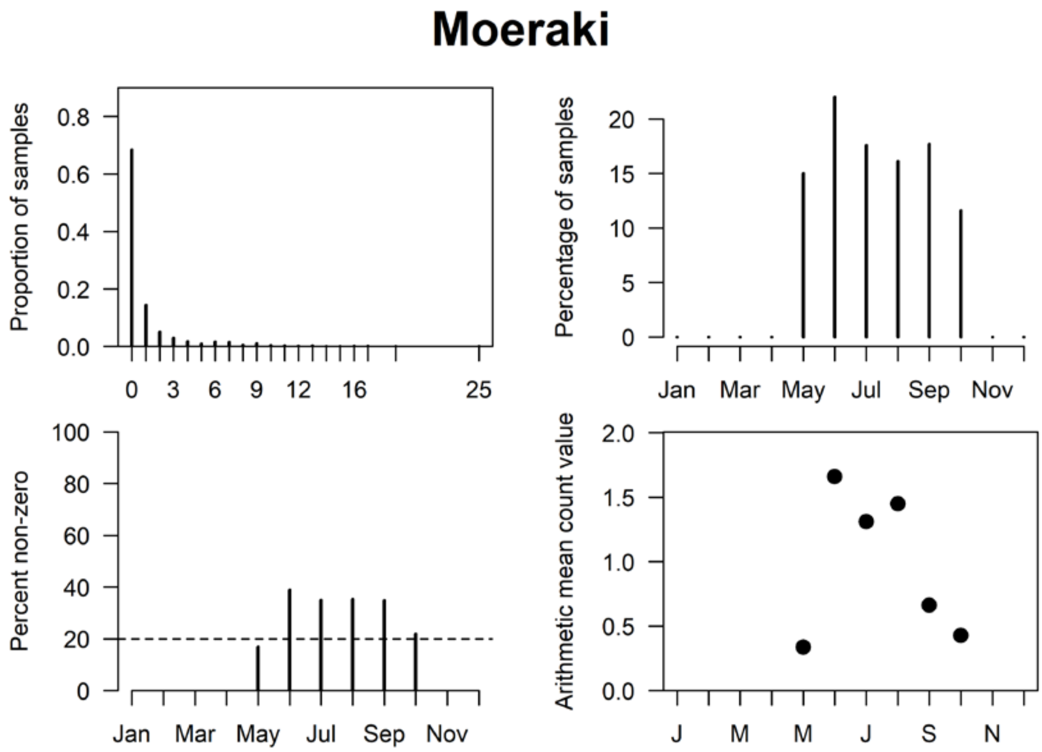

Figure 33: Characteristics of the puerulus standardisation data for Moeraki. The top-left figure shows the distribution of puerulus counts, and the bottom-left the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.

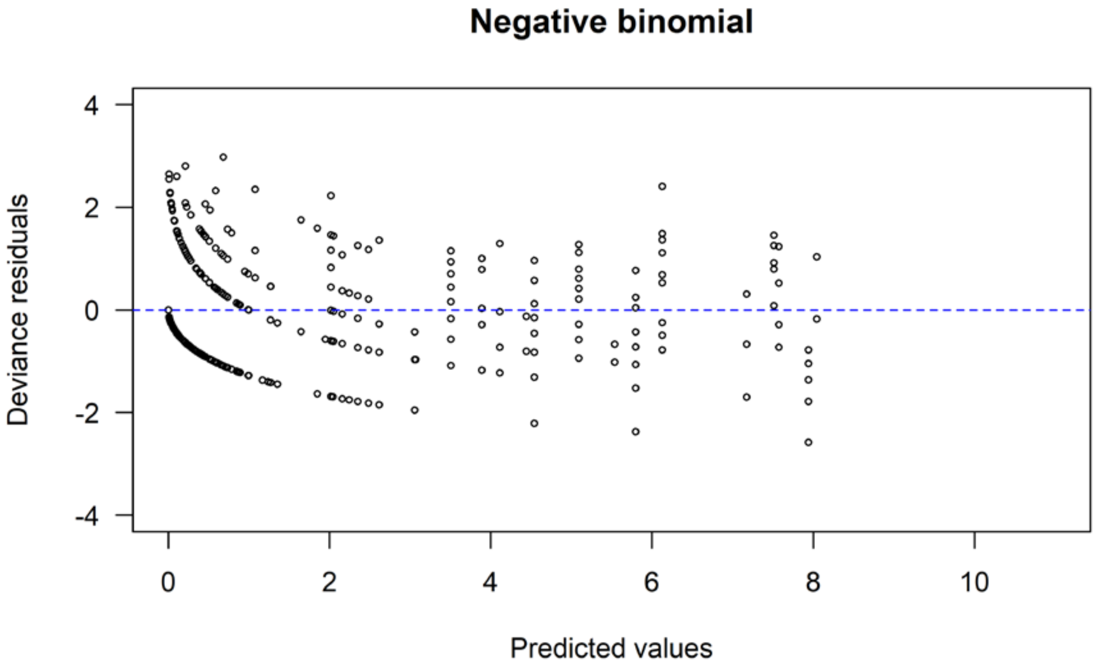

Figure 34: Deviance residuals for the negative binomial model for Moeraki. Predicted values are in natural space.

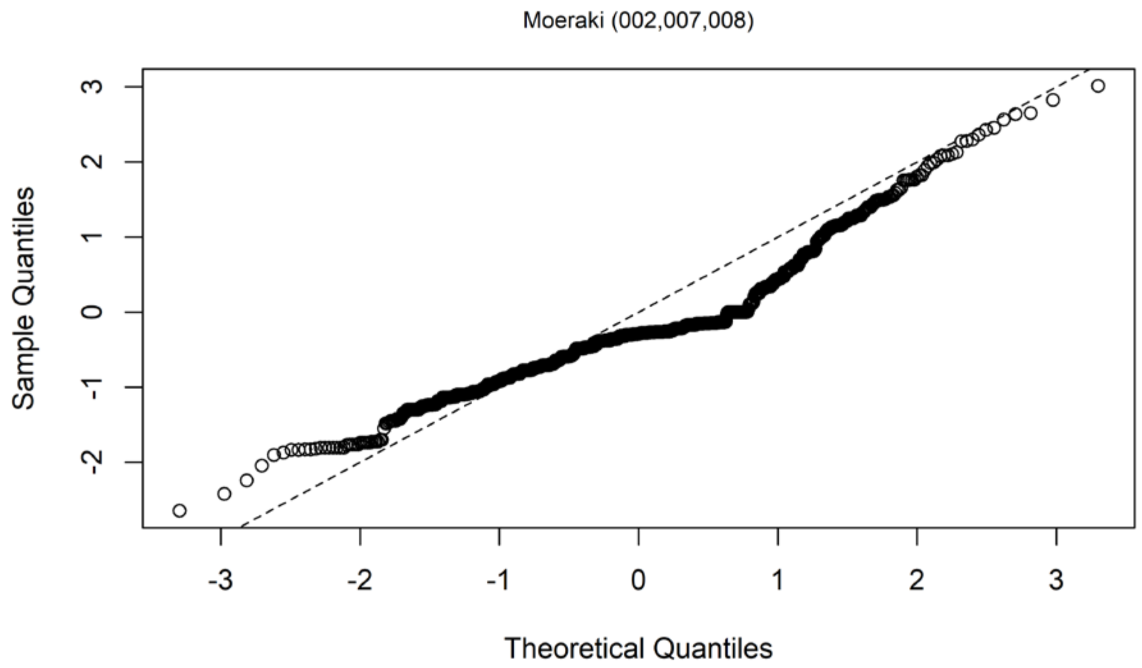

Figure 35: Quantile-quantile plot for the negative binomial standardisation model for Moeraki.

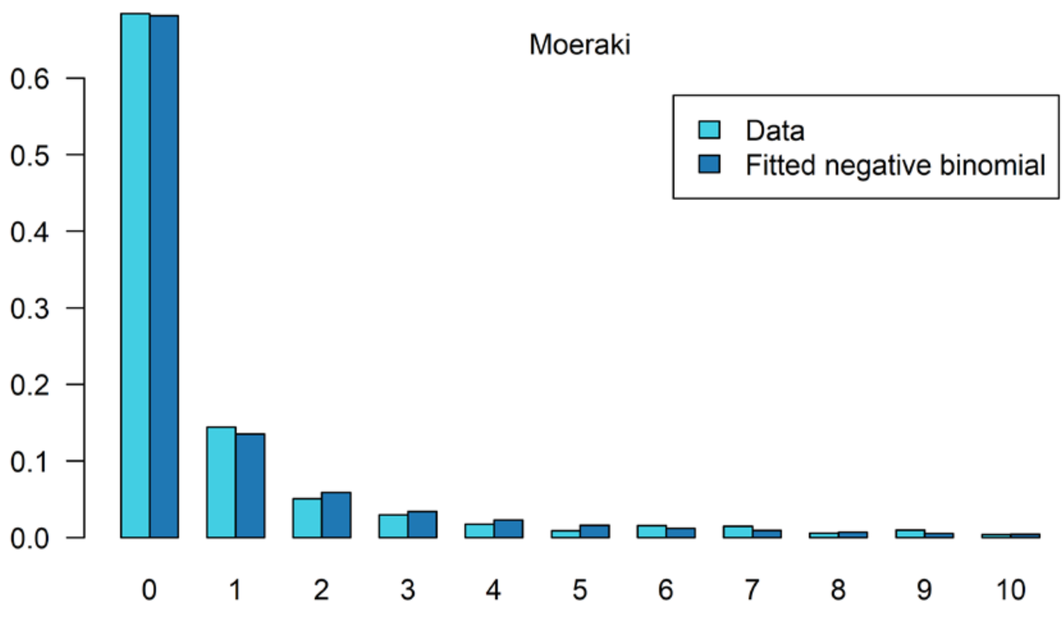

Figure 36: Data distribution and that from the fitted negative binomial for Moeraki.

Table 8: Moeraki standardisation data set. Number of puerulus samples by group and fishing year.

	MOE002	MOE007	MOE008	Total
1991	16	0	0	16
1992	14	0	0	14
1993	12	0	0	12
1994	15	0	0	15
1995	15	0	0	15
1996	18	0	0	18
1997	15	0	0	15
1998	18	0	0	18
1999	15	0	0	15
2000	15	0	0	15
2001	17	4	0	21
2002	18	9	0	27
2003	15	74	0	89
2004	6	81	0	87
2005	15	81	0	96
2006	6	77	0	83
2007	0	52	0	52
2008	0	73	0	73
2009	0	39	0	39
2010	0	46	0	46
2011	0	50	0	50
2012	0	36	0	36
2013	0	36	0	36
2014	0	24	0	24
2015	0	36	0	36
2016	0	30	0	30
2017	0	6	41	47

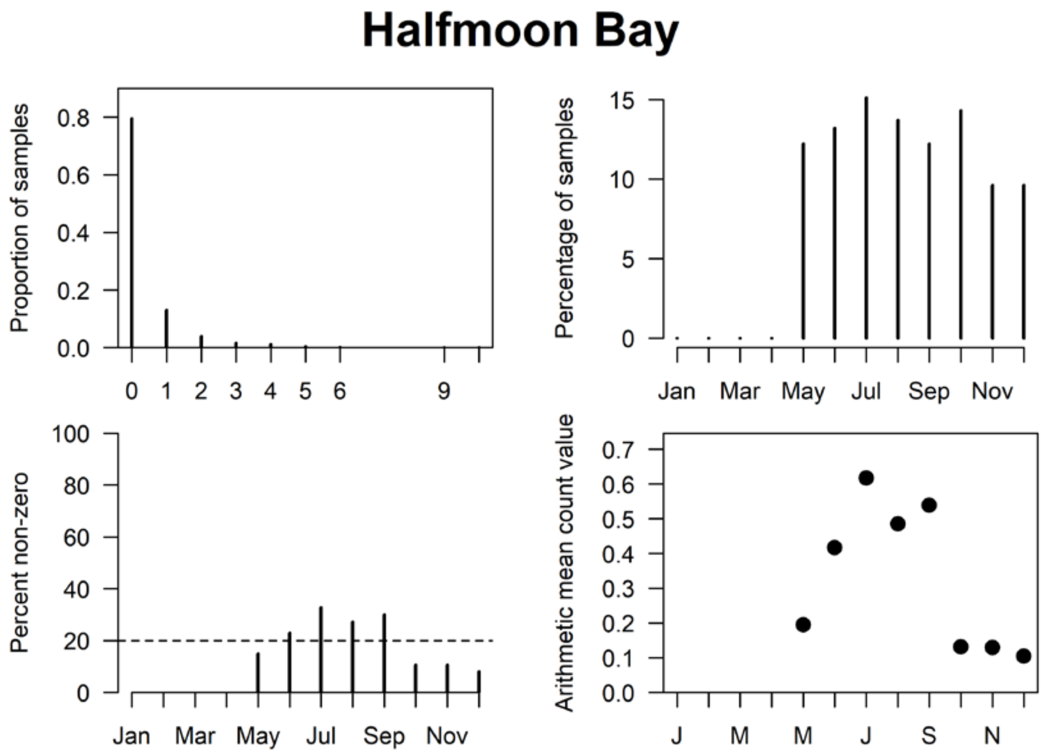

Figure 37: Characteristics of the puerulus standardisation data for Halfmoon Bay. The top-left figure shows the distribution of puerulus counts, and the bottom-left the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.

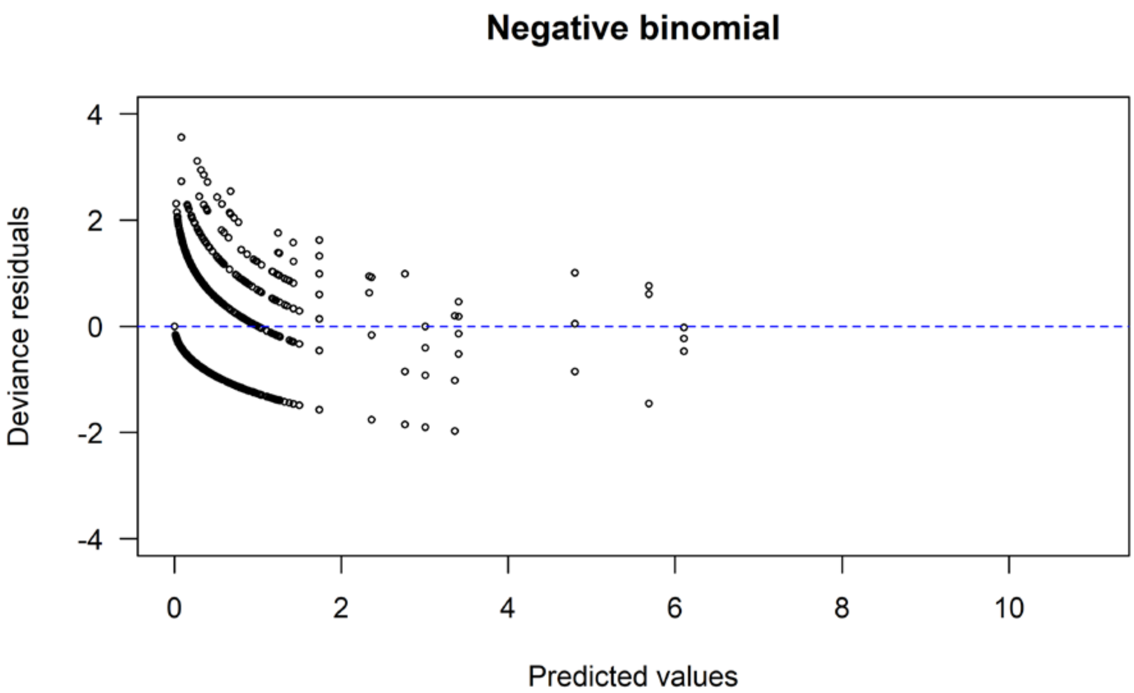

Figure 38: Deviance residuals for the negative binomial model at Halfmoon Bay. Predicted values are in natural space.

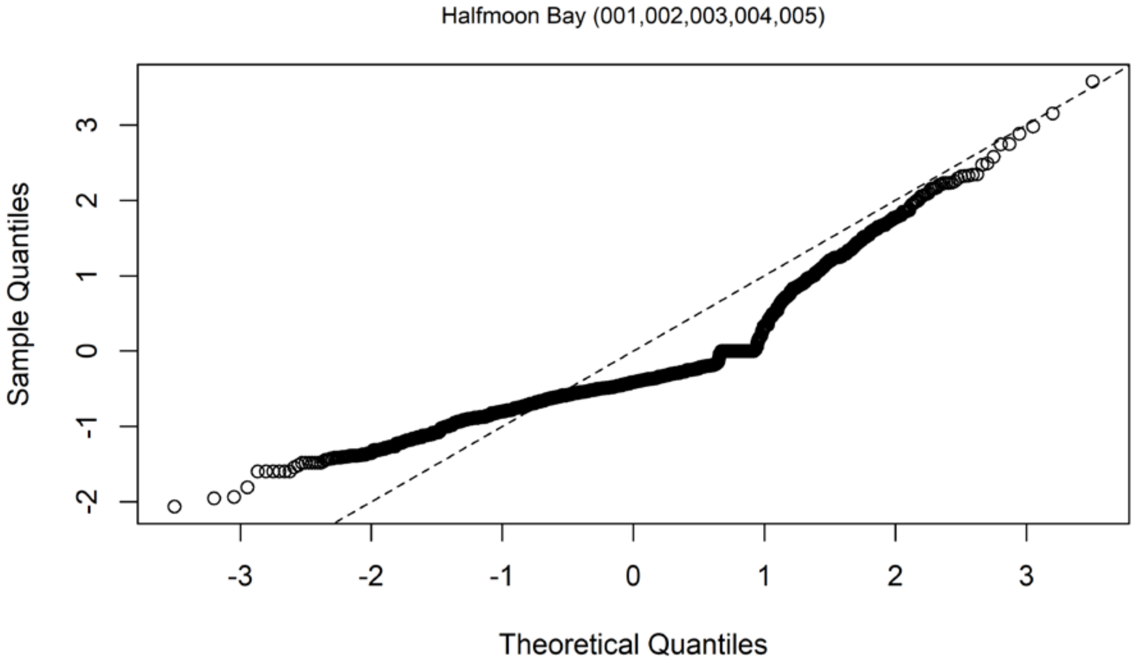

Figure 39: Quantile-quantile plot for the negative binomial standardisation model for Halfmoon Bay.

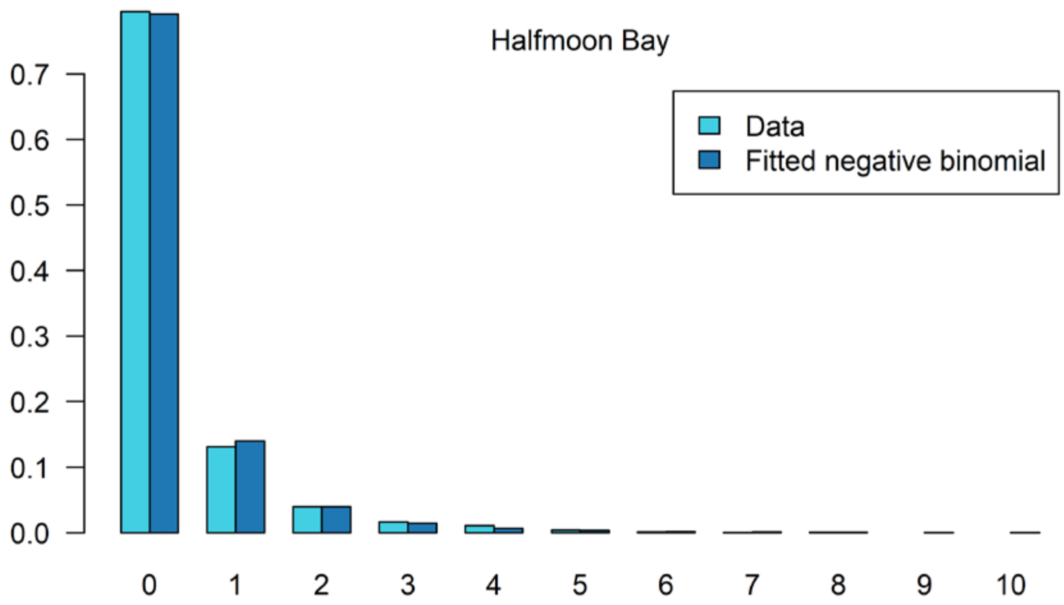

Figure 40: Data distribution and that from the fitted negative binomial model for Halfmoon Bay.

Table 9: Halfmoon Bay standardisation data set. Number of puerulus samples by group and fishing year.

	HMB001	HMB002	HMB003	HMB004	HMB005	Total
1981	12	0	0	0	0	12
1982	23	0	0	0	0	23
1983	18	0	0	0	0	18
1984	18	0	0	0	0	18
1985	18	0	0	0	0	18
1986	18	21	0	0	0	39
1987	24	15	0	0	0	39
1988	21	15	0	0	0	36
1989	18	15	0	0	0	33
1990	22	15	15	0	0	52
1991	21	18	18	0	0	57
1992	18	15	11	15	15	74
1993	21	21	21	21	17	101
1994	18	21	21	21	21	102
1995	21	18	18	18	18	93
1996	18	21	21	21	21	102
1997	21	21	21	21	21	105
1998	15	24	21	21	21	102
1999	9	21	21	21	21	93
2000	18	18	18	21	18	93
2001	24	18	18	18	18	96
2002	18	21	21	21	21	102
2003	30	0	0	0	0	30
2004	16	0	0	0	0	16
2005	40	0	0	0	0	40
2006	72	0	0	0	0	72
2007	59	0	0	0	0	59
2008	48	0	0	0	0	48
2009	53	0	0	0	0	53
2010	64	0	0	0	0	64
2011	64	0	0	0	0	64
2012	56	0	0	0	0	56
2013	48	0	0	0	0	48
2014	48	0	0	0	0	48
2015	64	0	0	0	0	64
2016	56	0	0	0	0	56
2017	56	0	0	0	0	56

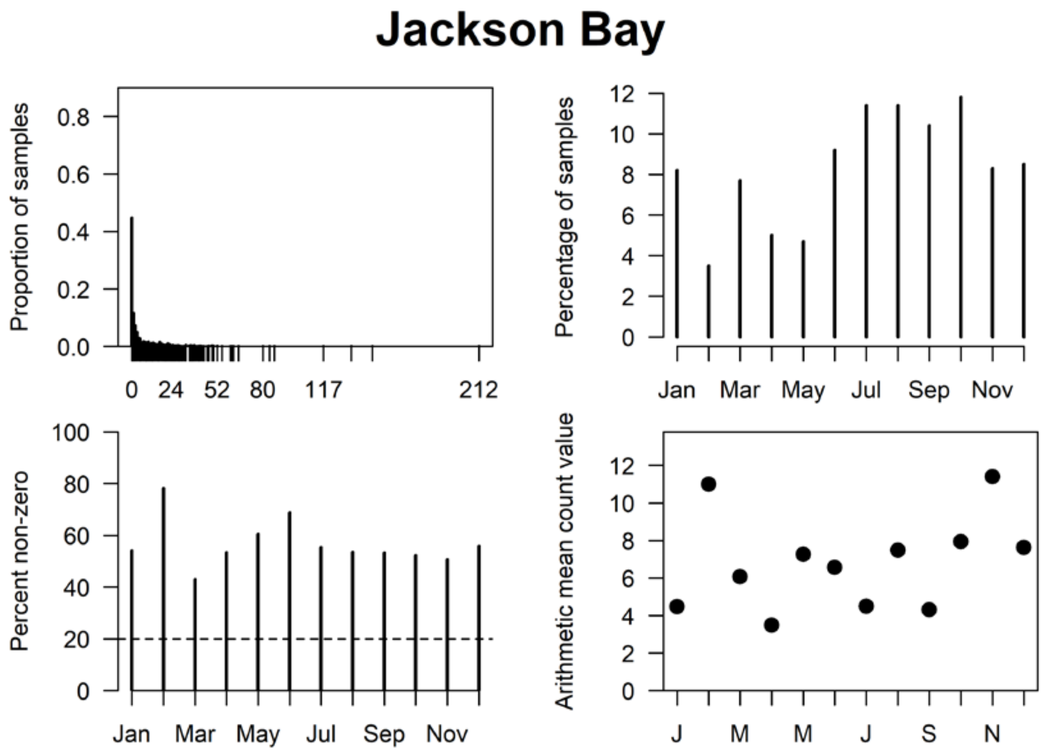

Figure 41: Characteristics of the puerulus standardisation data for Jackson Bay. The top-left figure shows the distribution of puerulus counts, and the bottom-left the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.

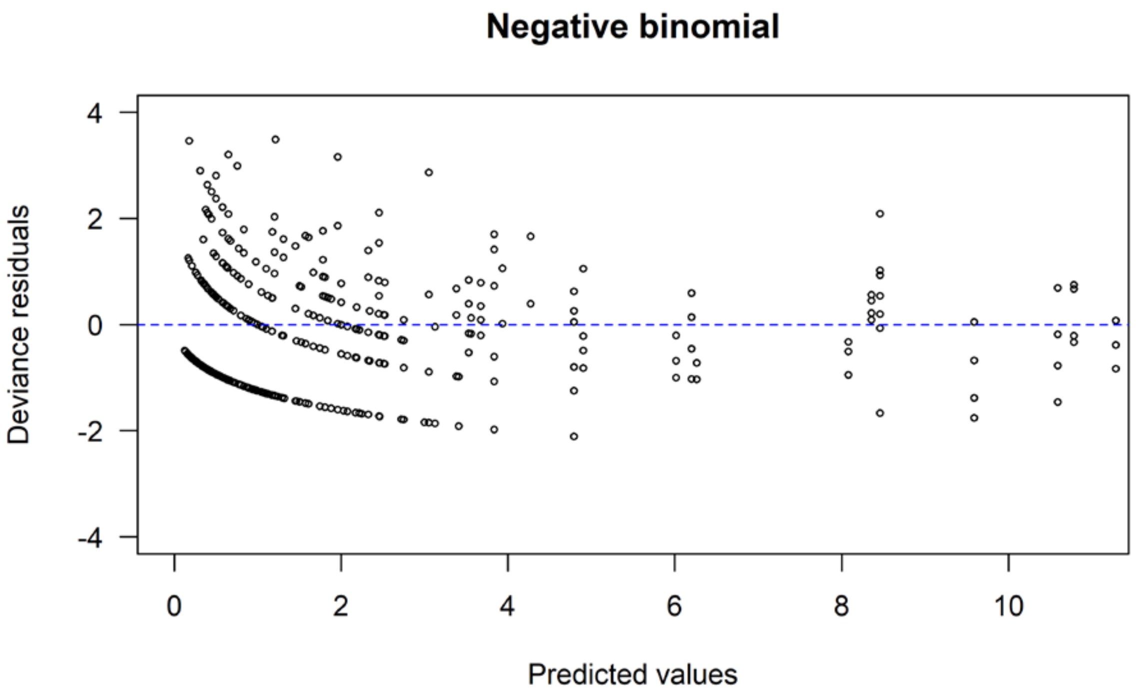

Figure 42: Deviance residuals for the negative binomial model for the Jackson Bay site. Predicted values are in natural space.

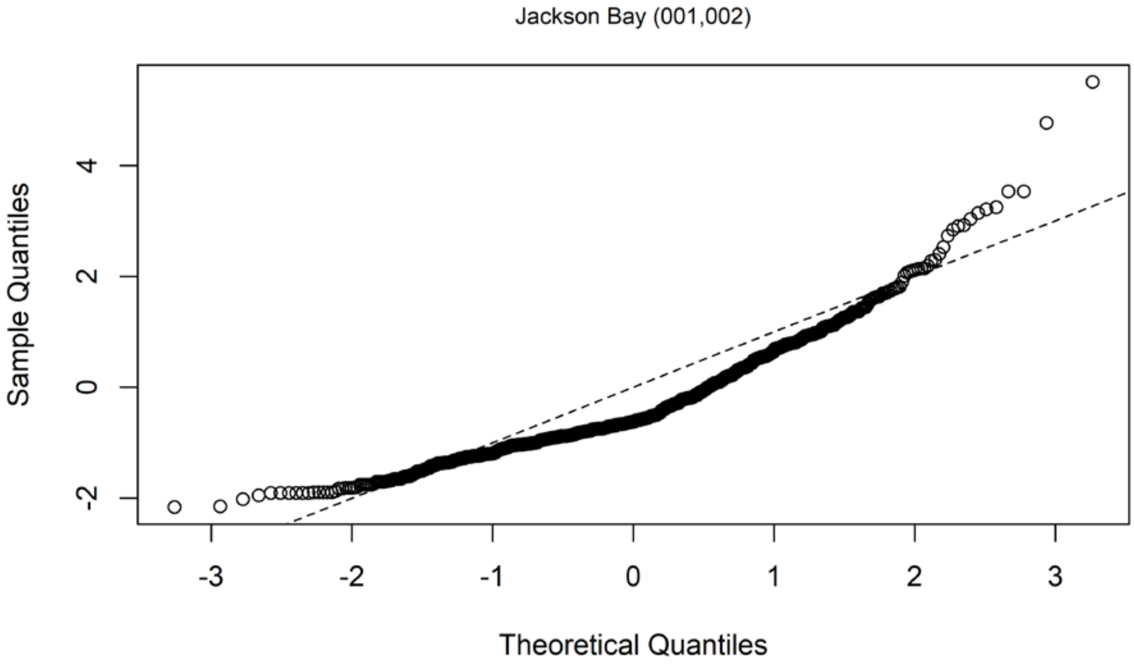

Figure 43: Quantile-quantile plot for the negative binomial standardisation model for Jackson Bay.

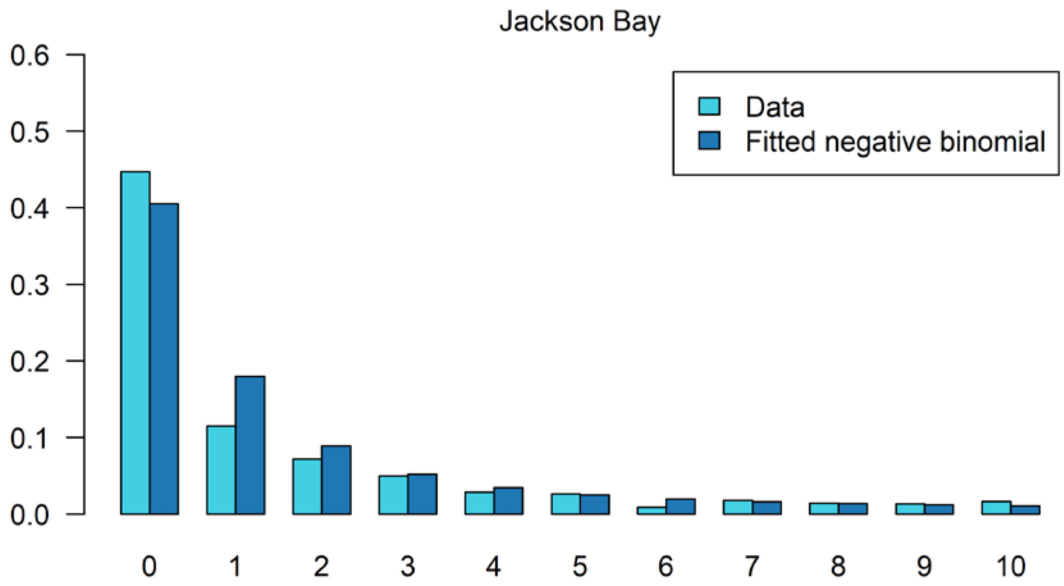

Figure 44: Data distribution and that from the fitted negative binomial for Jackson Bay.

Table 10: Jackson Bay standardisation data set. Number of puerulus samples by group and fishing year.

	JKB001	JKB002	Total
1999	18	20	38
2000	48	34	82
2001	50	36	86
2002	48	30	78
2003	40	21	61
2004	38	24	62
2005	35	16	51
2006	19	4	23
2007	40	0	40
2008	30	0	30
2009	20	0	20
2010	22	0	22
2011	39	0	39
2012	52	0	52
2013	49	0	49
2014	48	0	48
2015	34	0	34
2016	46	0	46
2017	45	0	45