**Fisheries New Zealand**

Tini a Tangaroa

# Settlement indices for the 2018 fishing year for the red rock lobster (*Jasus edwardsii*)

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**New Zealand Government**

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# EXECUTIVE SUMMARY

**Forman, J.S.; McKenzie, A.; Stotter, D.R. (2020). Settlement indices for the 2018 fishing year for the red rock lobster (*Jasus edwardsii*).**

*New Zealand Fisheries Assessment Report 2020/08*. 41 p.

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

Information on annual patterns of settlement for the red rock lobster (*Jasus edwardsii*) on crevice collectors is updated for 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 2018 fishing year, two groups of collectors in Gisborne, Napier, and Castlepoint, four groups in Kaikoura, and one group in Moeraki, 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 key site.

The 2018 settlement year was notable for very high settlement at Moeraki and very low settlement at Gisborne, Napier, Kaikoura, and Halfmoon Bay. At Moeraki, this was the third highest recorded settlement and a continuation of very high settlement from the previous three years. Settlement at Napier, Kaikoura, and Gisborne were the second, fourth, and fifth lowest on record respectively. Jackson Bay was above the long-term mean and Castlepoint was close to its long-term mean.

## 1. INTRODUCTION

The rock lobster fishery is 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 eight 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 background information on the puerulus sampling programme 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 objective

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. Table 1 gives a summary of the collector sites, the number of collectors by site, the method of collector deployment, and the years of operation. 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, as directed by the National Institute of Water and Atmospheric Research (NIWA). 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.
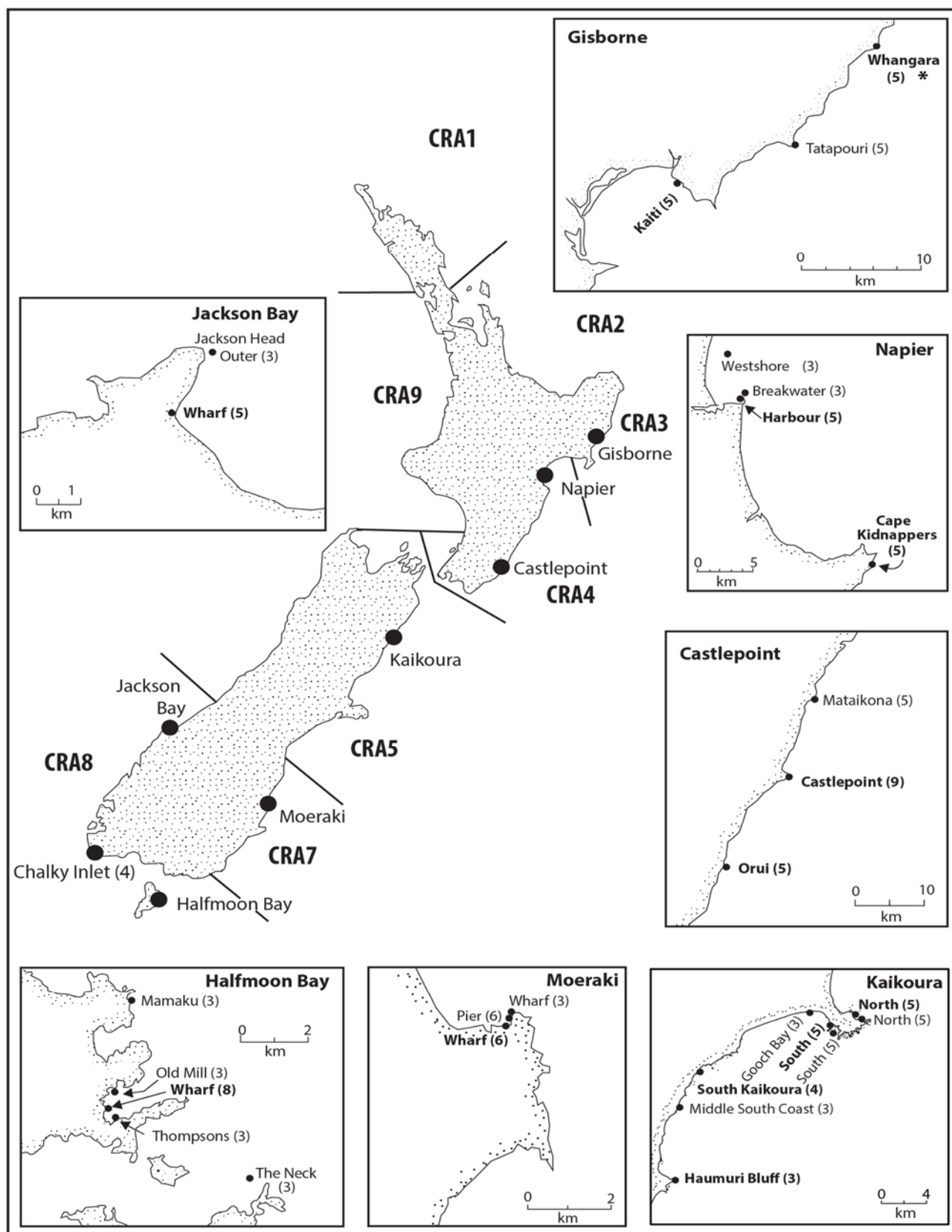
**Figure 1: Map of New Zealand showing the location of collectors at the key monitoring sites (although not all groups are now checked). The sites that are checked are in bold and the number of collectors in that set is in brackets. Also shown are the CRA areas; CRA 6 the Chatham Islands and CRA 10 the Kermadec Islands (to the northeast of the North Island) are not shown.**

**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 (JKB001) | Suspended | 1999–Present |
| | 3 | Jackson Head (JKB002) | Closing | 1999–2006 |
| Chalky Inlet | 3 | 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, and 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 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 (fewer 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).

**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) |

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.

Because the new site at Moeraki (MOE008) is the only site operating in this area and still has fewer than 36 samples, the standardisation was modified to allow a preliminary standardised index to be calculated for the 2018 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. For either method, 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) and 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 2018 fishing year (i.e., data are complete up to 31 March 2019).

## 3.    RESULTS

### 3.1    Standardised indices

Standardised indices were produced for the following 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 (see 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 3: Standardised annual indices for each site. Year is fishing year (1 April–31 March), where the 2018/19 fishing year is labelled as 2018. '–': 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 | – | 0.80 | – | – | – | – | – | – |
| 1980 | – | 1.28 | – | – | – | – | – | – |
| 1981 | – | 2.11 | – | 0.56 | – | 7.98 | – | – |
| 1982 | – | 1.18 | 2.37 | 0.75 | – | 0.38 | – | – |
| 1983 | – | 1.36 | 1.15 | 0.16 | – | 3.87 | – | – |
| 1984 | – | 0.42 | 0.71 | 0.38 | – | 0.30 | – | – |
| 1985 | – | 0.22 | 0.57 | 0.24 | – | 0.00 | 0.36 | – |
| 1986 | – | – | 0.81 | 0.09 | – | 0.11 | 0.21 | – |
| 1987 | 3.56 | – | 1.61 | 1.07 | – | 1.55 | 1.42 | – |
| 1988 | 3.02 | 1.40 | 0.93 | 0.40 | – | 0.22 | 1.31 | – |
| 1989 | 1.07 | 1.22 | 1.14 | 0.82 | – | 0.59 | 1.64 | – |
| 1990 | 0.48 | 1.07 | 1.08 | 1.61 | – | 0.42 | 1.84 | – |
| 1991 | 1.15 | 2.53 | 2.10 | 6.81 | 0.00 | 0.92 | 1.03 | – |
| 1992 | 3.08 | 2.16 | 2.12 | 5.40 | 0.06 | 0.53 | 0.52 | – |
| 1993 | 1.92 | 2.27 | 1.06 | 2.08 | 0.00 | 0.00 | 0.14 | – |
| 1994 | 3.29 | 1.57 | 0.87 | 1.09 | 0.00 | 1.17 | 1.64 | – |
| 1995 | 1.17 | 1.08 | 0.91 | 0.61 | 0.04 | 0.39 | 0.40 | – |
| 1996 | 1.79 | 1.58 | 1.27 | 0.65 | 0.38 | 0.33 | 1.76 | – |
| 1997 | 1.08 | 1.10 | 1.68 | 2.02 | 0.16 | 0.55 | 1.41 | – |
| 1998 | 1.95 | 1.00 | 1.07 | 2.00 | 0.22 | 0.29 | 0.50 | – |
| 1999 | 0.30 | 0.44 | 0.34 | 1.31 | 0.04 | 0.23 | 1.70 | 0.23 |
| 2000 | 0.98 | 0.75 | 0.52 | 1.32 | 1.71 | 1.19 | 1.26 | 0.51 |
| 2001 | 1.22 | 1.26 | 0.71 | 0.54 | 0.70 | 1.72 | 0.60 | 0.20 |
| 2002 | 1.03 | 1.48 | 0.77 | 3.31 | 0.36 | 1.44 | 1.42 | 1.21 |
| 2003 | 2.97 | 1.34 | 0.92 | 3.39 | 3.03 | 3.90 | 1.56 | 0.46 |
| 2004 | 0.78 | 1.08 | 0.49 | 1.04 | 0.16 | 0.15 | 0.30 | 0.36 |
| 2005 | 2.70 | 1.31 | 1.27 | 2.29 | 0.03 | 0.00 | – | 1.03 |
| 2006 | 0.30 | 0.66 | 0.48 | 1.12 | 0.02 | 0.13 | – | 0.23 |
| 2007 | 0.40 | 0.95 | 1.03 | 1.67 | 0.03 | 0.47 | – | 0.20 |
| 2008 | 0.69 | 0.66 | 1.03 | 1.61 | 0.04 | 0.09 | – | 0.07 |
| 2009 | 1.85 | 0.90 | 1.06 | 0.51 | 0.28 | 1.00 | – | 0.13 |
| 2010 | 0.66 | 0.96 | 1.17 | 1.26 | 0.60 | 1.64 | 7.03 | 1.70 |
| 2011 | 0.20 | 0.50 | 0.88 | 0.55 | 0.43 | 0.14 | 1.44 | 1.92 |
| 2012 | 0.72 | 0.71 | 0.59 | 1.11 | 0.53 | 0.18 | 4.37 | 6.48 |
| 2013 | 1.00 | 0.98 | 1.70 | 0.74 | 0.77 | 0.74 | – | 11.40 |
| 2014 | 0.42 | 1.04 | 0.69 | 1.32 | 0.23 | 0.85 | – | 18.78 |
| 2015 | 1.62 | 1.08 | 1.65 | 0.83 | 5.15 | 0.55 | – | 4.37 |
| 2016 | 1.25 | 0.70 | 1.85 | 2.76 | 1.80 | 1.36 | – | 11.38 |
| 2017 | 0.18 | 1.03 | 1.04 | 0.90 | 6.79 | 1.99 | – | 0.99 |
| 2018 | 0.35 | 0.39 | 1.07 | 0.38 | 4.48 | 0.62 | – | 2.28 |

## 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. For montly puerulus settlement plots, where there is a plot icon present (e.g., square or circle) this represents a check for that month, and when the icon is absent there was no check.

### Gisborne
Settlement at Gisborne in the 2018 fishing year was the fourth lowest on record (Figure 2). This follows the record low from the previous year and makes it six out of the last nine years where settlement was below the long-term mean. The monthly settlement pattern between Whangara and Kaiti were very similar, peaking in July and with low levels from September through to March (Figure 3).

### Napier
Settlement at Napier was the second lowest on record (Figure 4). Over the last 13 years, settlement has been close to or below the long-term mean, and no substantial high settlement has occurred since the 1990s. The monthly settlement patterns between the Port of Napier and Cape Kidnappers were very similar (Figure 5) and similar also to the pattern for the Gisborne collectors with a sharp peak in July but low for the rest of the year.

### Castlepoint
Settlement at Castlepoint was close to its long-term mean (Figure 6). The monthly settlement patterns between Castlepoint and Orui were very similar (Figure 7). Very high levels of settlement were recorded at both of these sites in February, but generally settlement was average to below average for the rest of the year.

### Kaikoura
Settlement at Kaikoura was well below its long-term mean and the lowest since 1986 (Figure 8). Settlement was very low at all sites throughout the year (Figure 9).

### Moeraki
This was the third highest year of settlement at Moeraki (Figure 10). High levels of settlement were recorded from April through to August, with July being the peak month (Figure 11). Settlement was also recorded in all other months of the fishing year which is unusual for Moeraki. This is the fourth consecutive year of above average settlement at Moeraki.

### Halfmoon Bay
Settlement was below the long-term mean in Halfmoon Bay (Figure 12). Settlement peaked in July and was low in all months that were checked however, only a limited number of checks were made during the year due to access problems (Figure 13).

### Jackson Bay
Above average settlement was recorded at Jackson Bay (Figure 14). This was due to a large pulse of settlement in June and July (Figure 15).

### Chalky Inlet
No new data were received in the 2018 fishing year.

Monthly settlement comparisons for all key sites are shown in Figure 16.
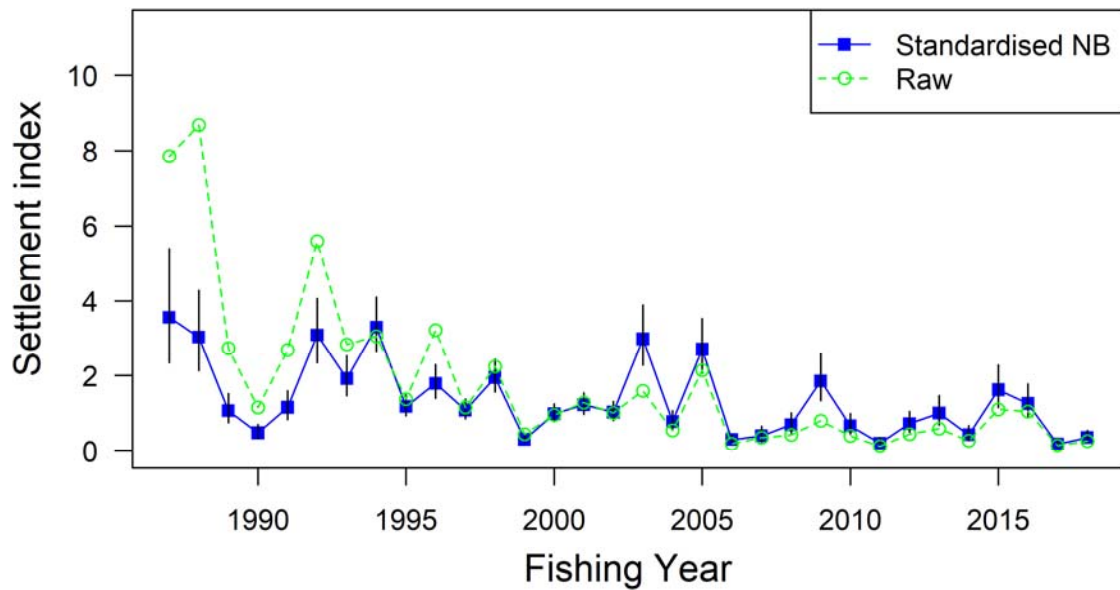
**Figure 2: Standardised negative binomial (NB) and raw indices of annual settlement for Gisborne, with 95% confidence intervals, for the 1987–2018 fishing years.**
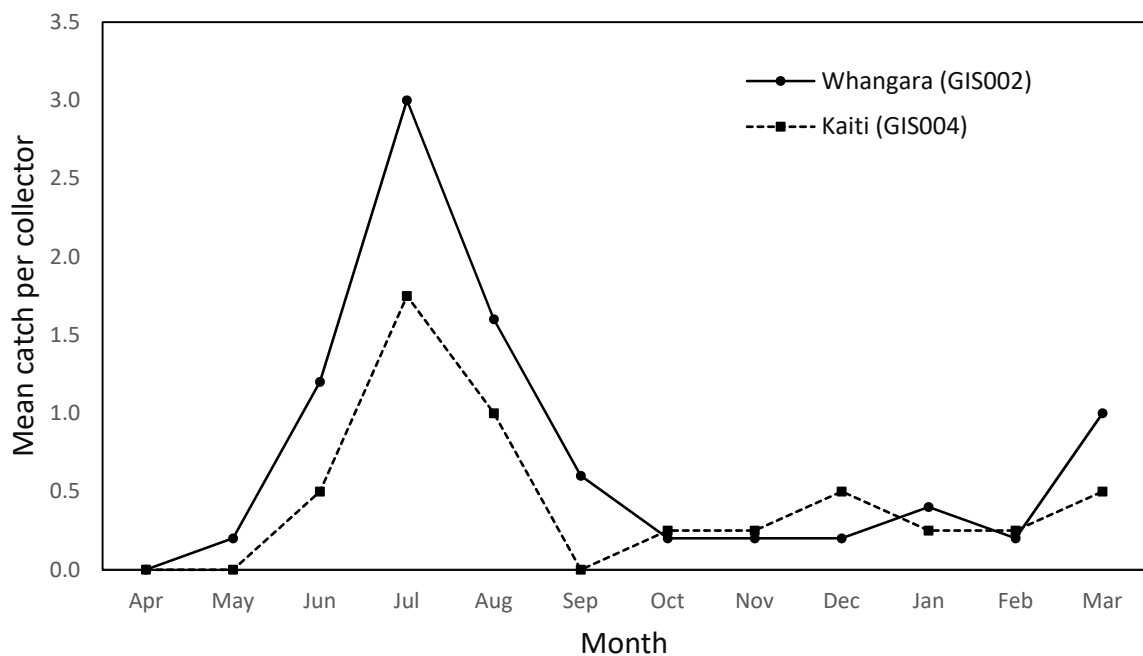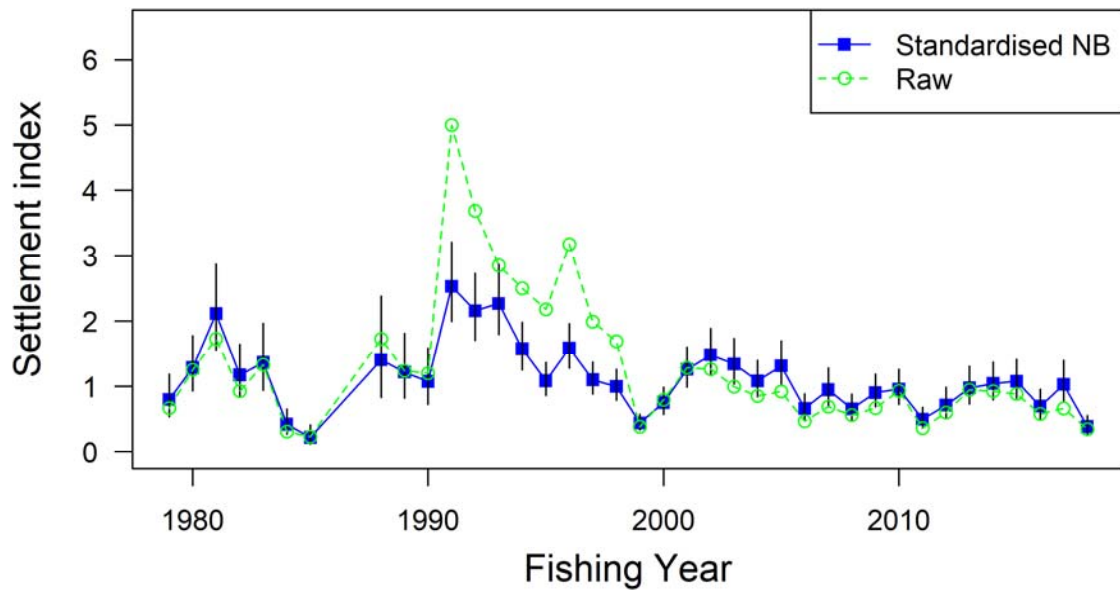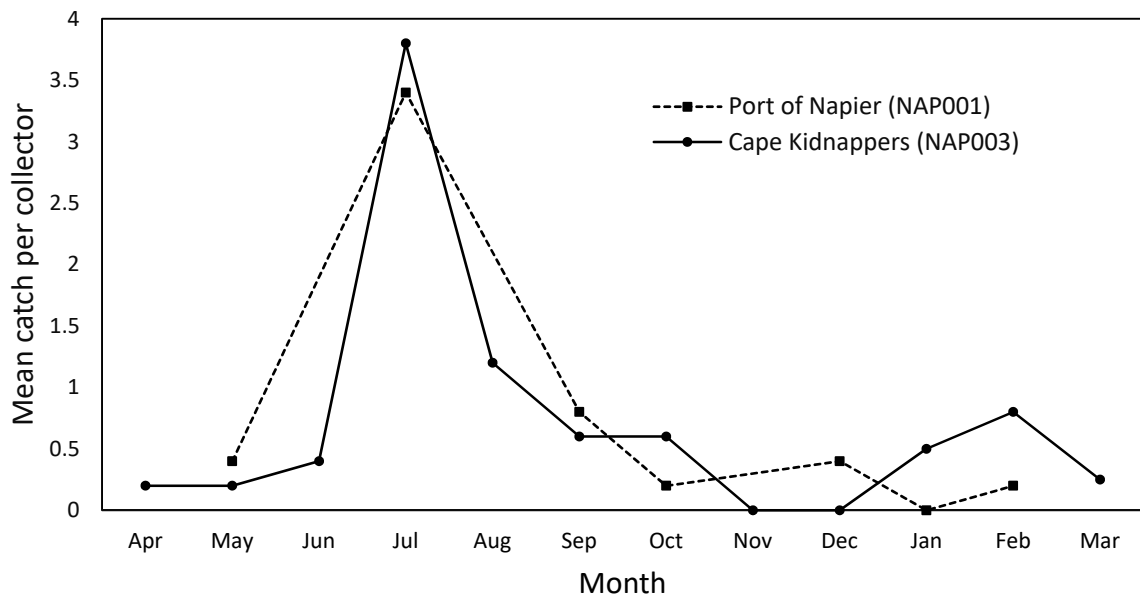


**Figure 3: Whangara and Kaiti monthly settlement, 2018 fishing year, showing the mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.**

## Napier (001,002,003,004)
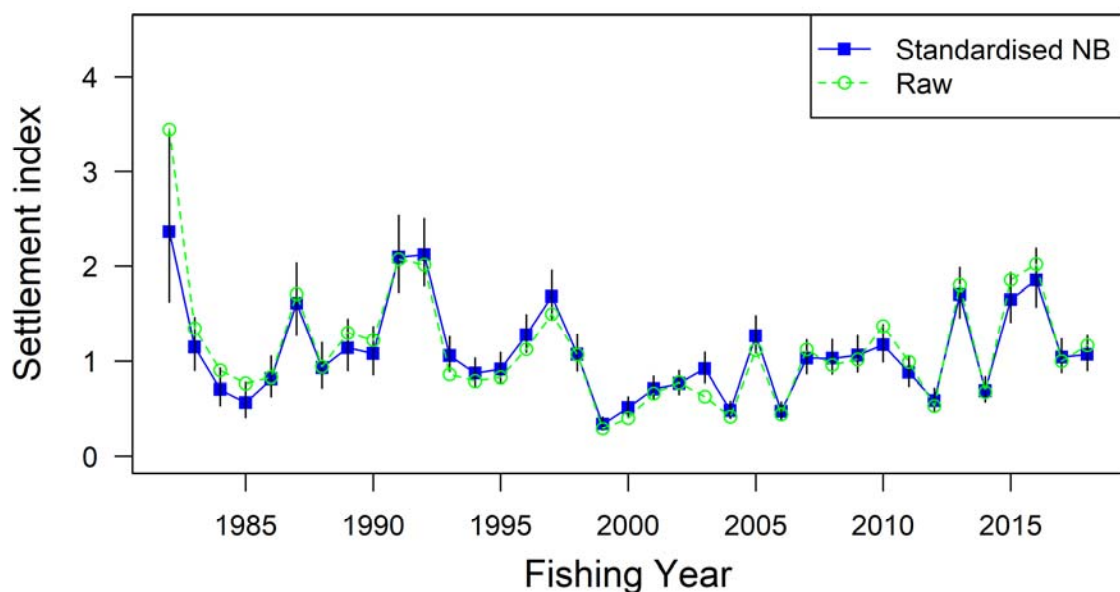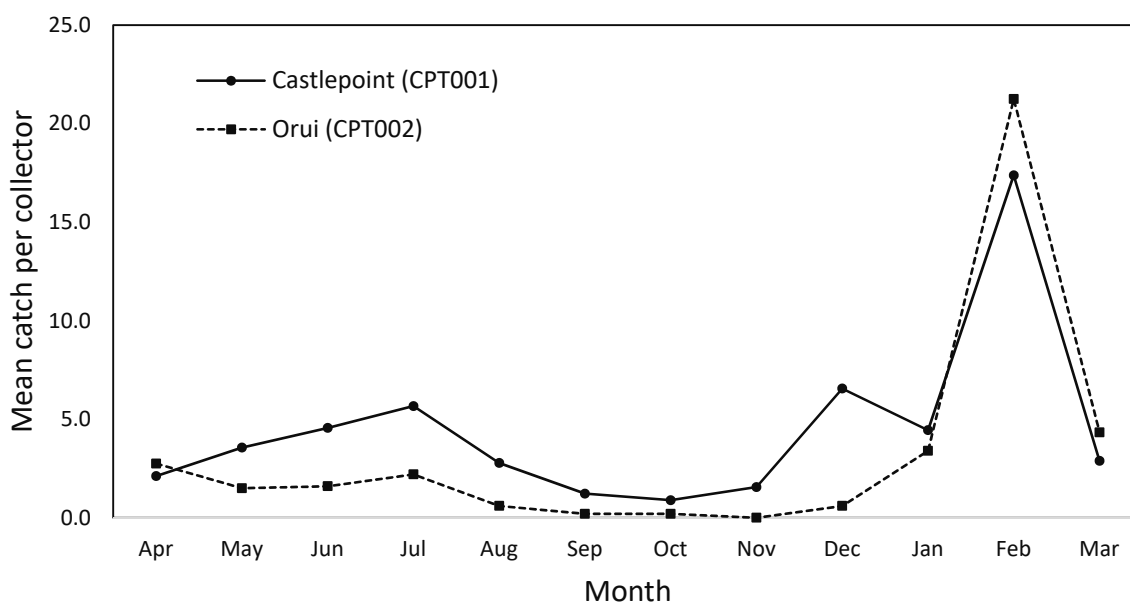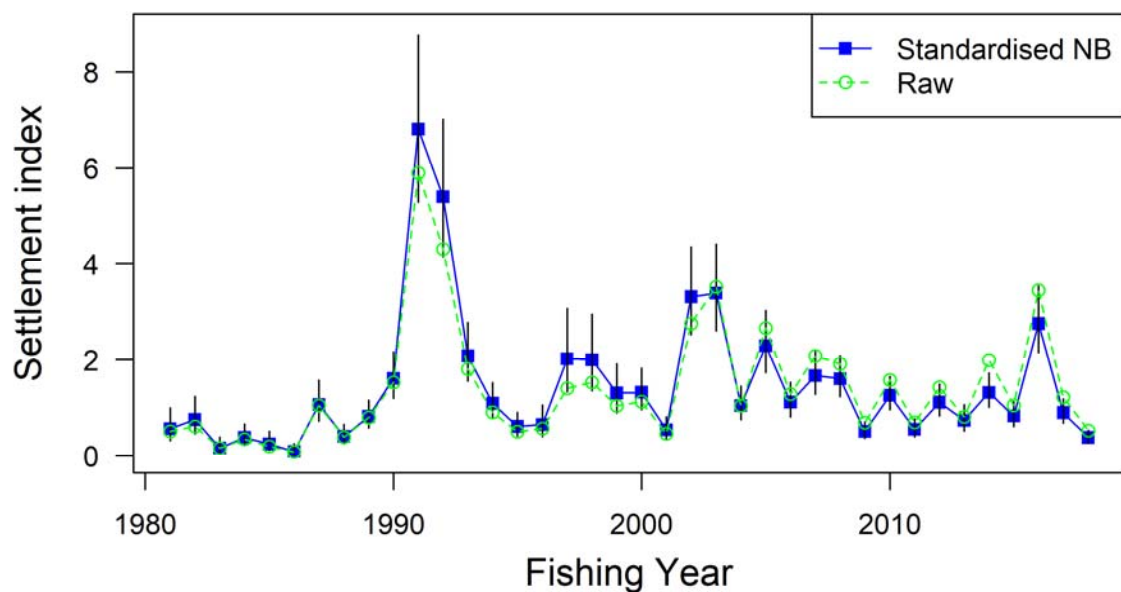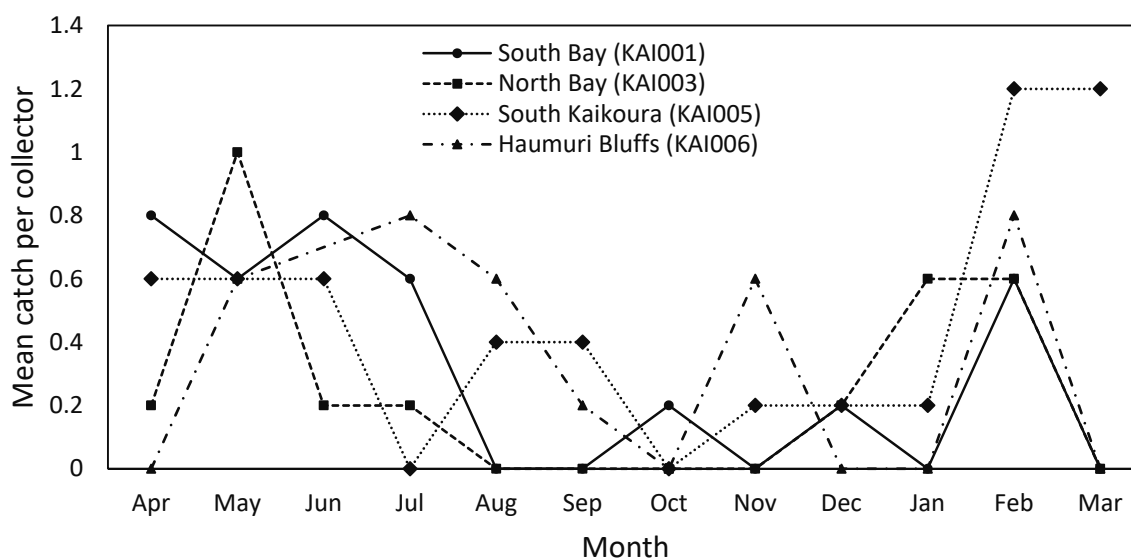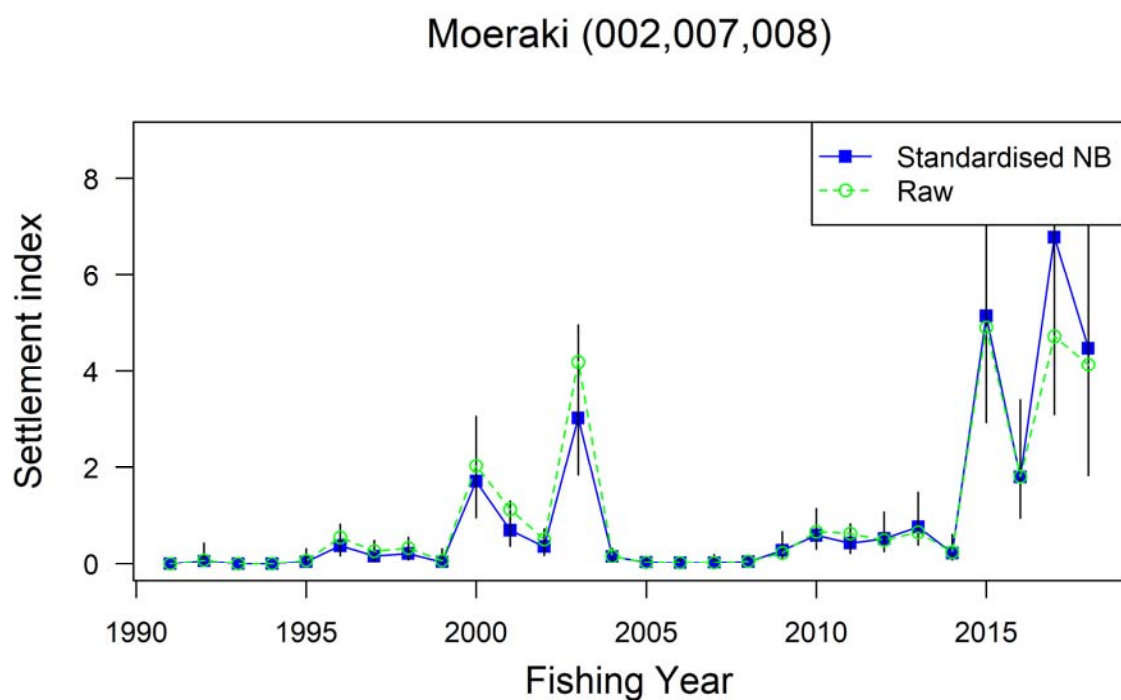
**Figure 4: Standardised negative binomial (NB) and raw indices of annual settlement for Napier, with 95% confidence intervals, for fishing years between 1979 and 2018. Note that there were no checks in 1986 or 1987.**



## Napier

**Figure 5: Port of Napier and Cape Kidnappers monthly settlement, 2018 fishing year, showing the mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.**

## Castlepoint (001,002,003)



**Figure 6: Standardised negative binomial (NB) and raw indices of annual settlement for Castlepoint, with 95% confidence intervals, for the 1982–2018 fishing years.**
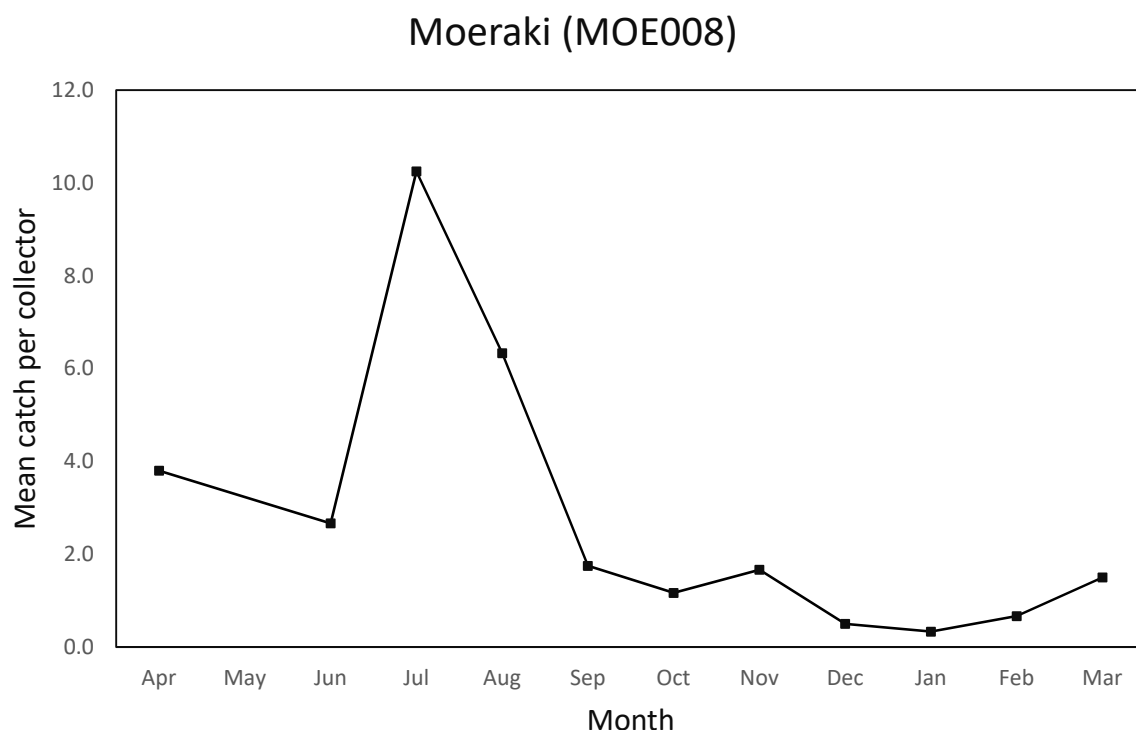
## Castlepoint



**Figure 7: Castlepoint and Orui monthly settlement, 2018 fishing year, showing the mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.**
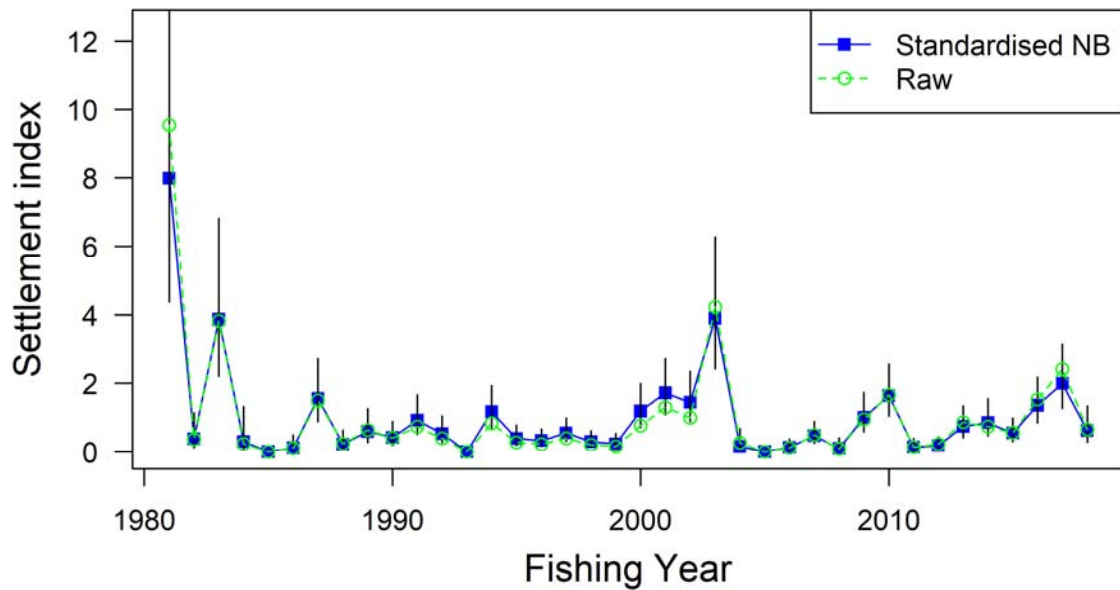
## Kaikoura (001,002,003,004,005,006,008,009)



**Figure 8: Standardised negative binomial (NB) and raw indices of annual settlement for Kaikoura, with 95% confidence intervals, for the 1981–2018 fishing years.**

## Kaikoura



**Figure 9: South Bay, North Bay, South Kaikoura, and Haumuri Bluffs monthly settlement, 2018 fishing year, showing the mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.**

**Figure 10:** **Standardised negative binomial (NB) and raw indices of annual settlement for Moeraki, with 95% confidence intervals (where collectors with fewer than 36 samples were used), for the 1991–2018 fishing years.**
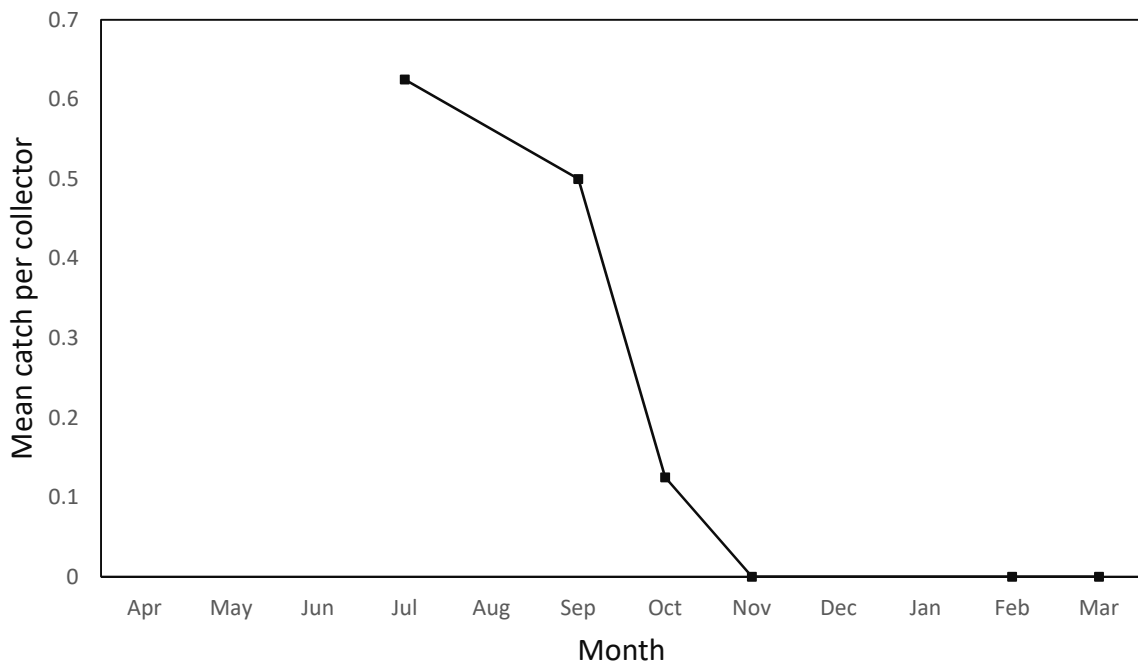


**Figure 11:** **Moeraki monthly settlement, 2018 fishing year, showing the mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.**
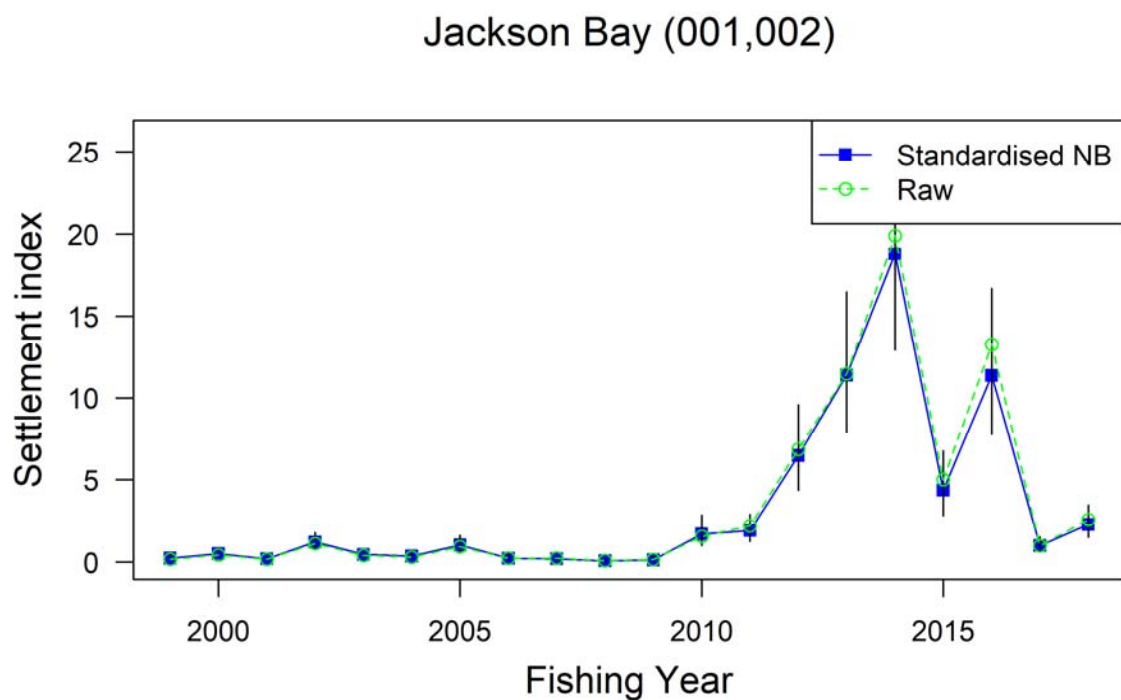
**Figure 12: Standardised negative binomial (NB) and raw indices of annual settlement for Halfmoon Bay, with 95% confidence intervals, for the 1981–2018 fishing years.**
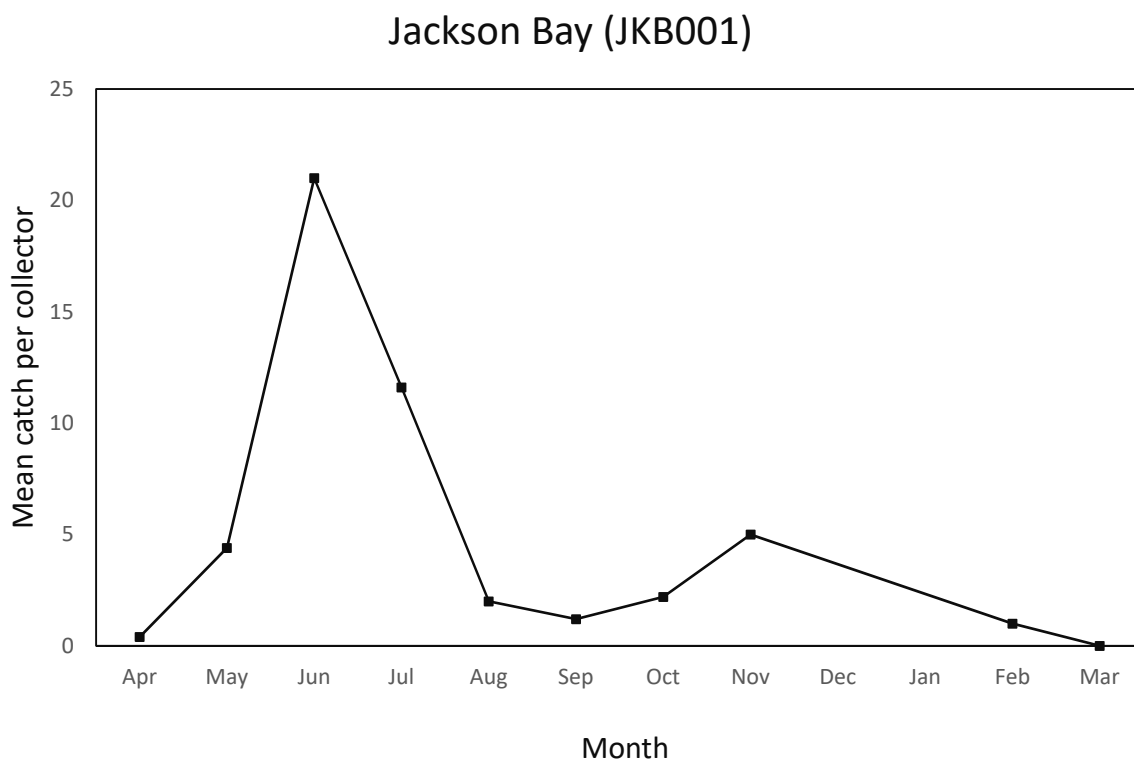


**Figure 13: Halfmoon Bay monthly settlement, 2018 fishing year, showing the mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.**

## Jackson Bay (001,002)



**Figure 14:** **Standardised negative binomial (NB) and raw indices of annual settlement for Jackson Bay, with 95% confidence intervals, for the 1999–2018 fishing years.**

## Jackson Bay (JKB001)



**Figure 15:** **Jackson Bay monthly settlement, 2018 fishing year, showing the mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.**
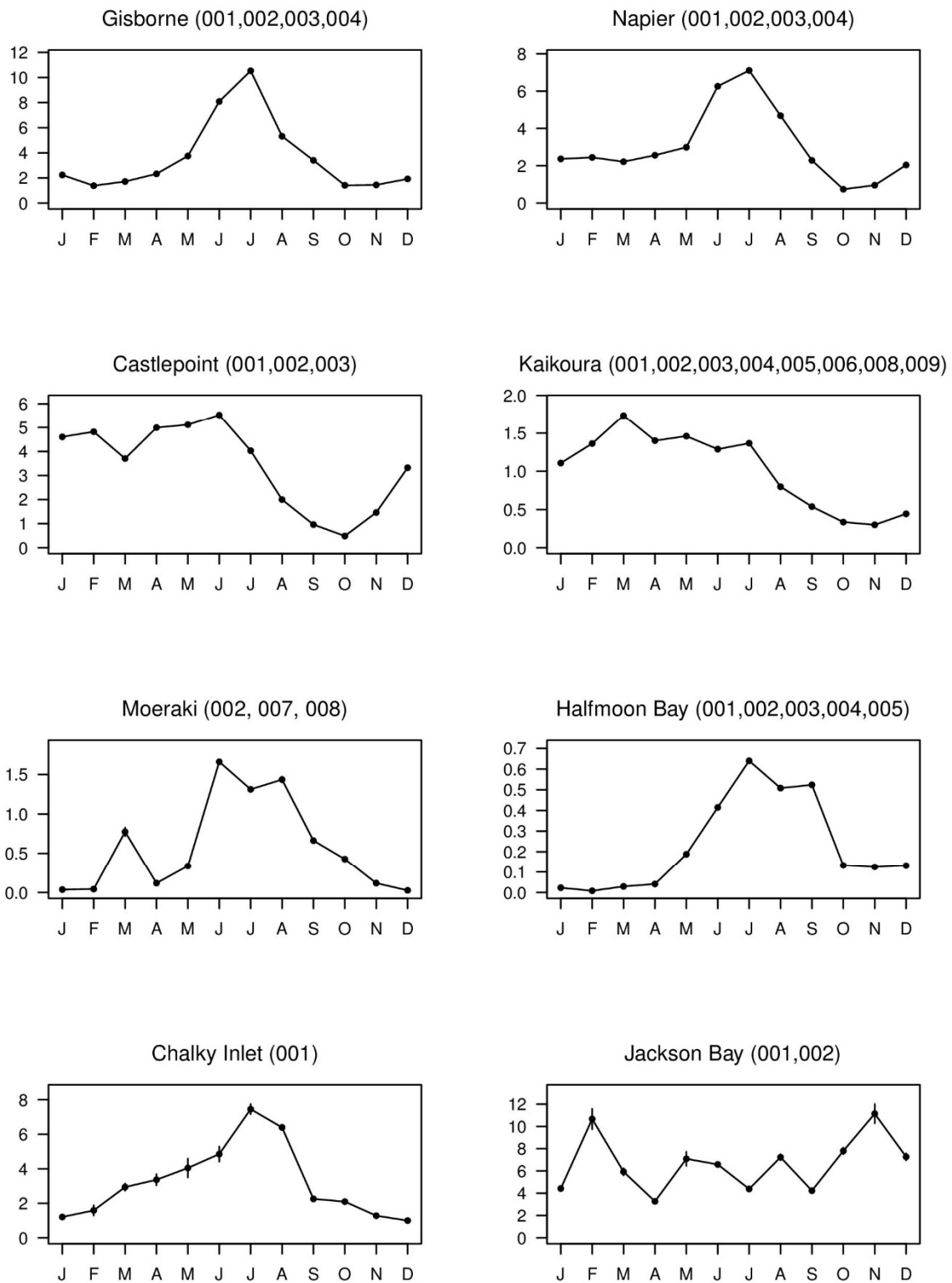
**Figure 16:** **The mean settlement by month for the calendar year, over all years, for each key collector site. See Table 1 for the collector groups. Vertical lines show 95% confidence intervals for the mean value (for many months this interval is very tight and will not be apparent on the figure).**

## 5.    CONCLUSIONS

The 2018settlement year was notable for very high settlement at Moeraki and very low settlement at Gisborne, Napier, Kaikoura, and Halfmoon Bay. At Moeraki (CRA 7), this was provisionally the third highest recorded settlement and a continuation of very high settlement from the previous three years. Settlement at Gisborne (CRA 3) was the fifth lowest on record and only just higher than the record low from last year. Six of the last nine years have been below average. At Napier (CRA 4), settlement was the second lowest on record. The last 13 years have now been below or close to the long-term mean. At Castlepoint (CRA 4), settlement was close to the long-term mean, however, recent high levels of settlement were recorded in 2013, 2015, and 2016. At Kaikoura (CRA 5), settlement was the fourth lowest on record. At Jackson Bay (CRA 8), settlement was above the long-term mean, but below the very high settlement years of 2012–16. Halfmoon Bay (CRA 8), after two years of above average settlement, was below its long-term mean.

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

## 7.    REFERENCES

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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. The diagnostics show that the negative binomial is a good model for the distribution of puerulus counts, although at Jackson Bay this model is not as good compared with the other sites. The deviance residuals tend to be less for higher predicted count values, but the difference is not of a size that would lead to biased parameter estimates in the standardisations (more than two-fold difference).

The following plots and tables are presented by site: Gisborne (Figures 17–20, Table 4); Napier (Figures 21–24, Table 5); Castlepoint (Figures 25–28, Table 6); Kaikoura (Figures 29–32, Table 7); Moeraki (Figures 33–36, Table 8); Halfmoon Bay (Figures 37–40, Table 9); and Jackson Bay (Figures 41–44, Table 10).
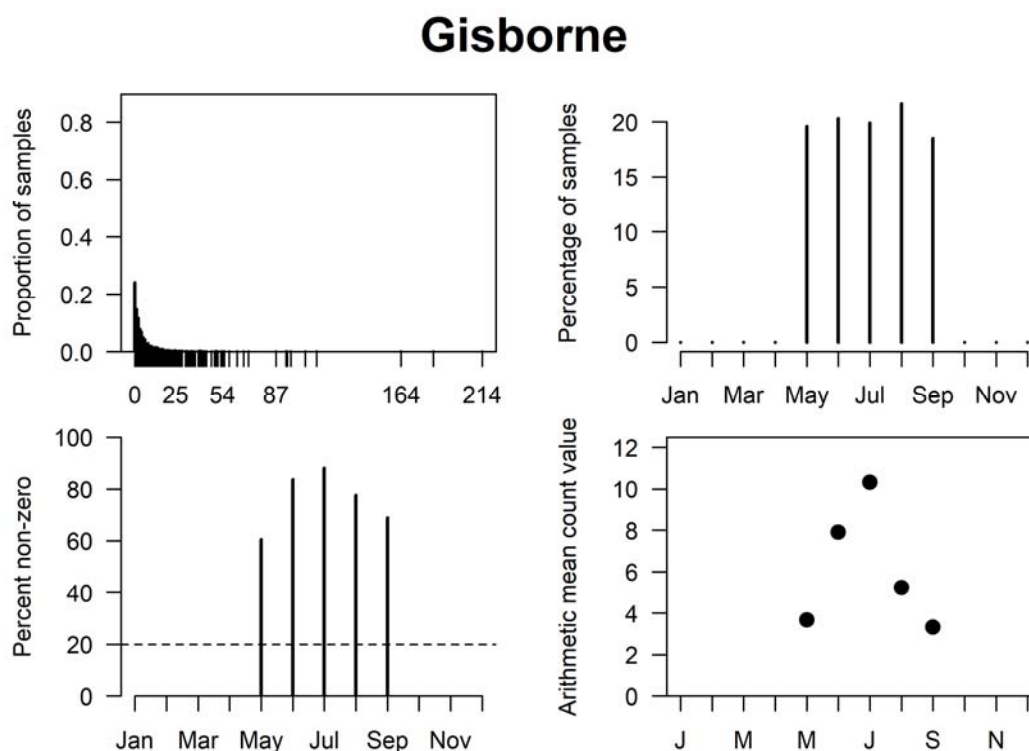


**Figure 17: Characteristics of the Gisborne puerulus standardisation data. The top-left figure shows the distribution of puerulus counts, and the bottom-left shows the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.**
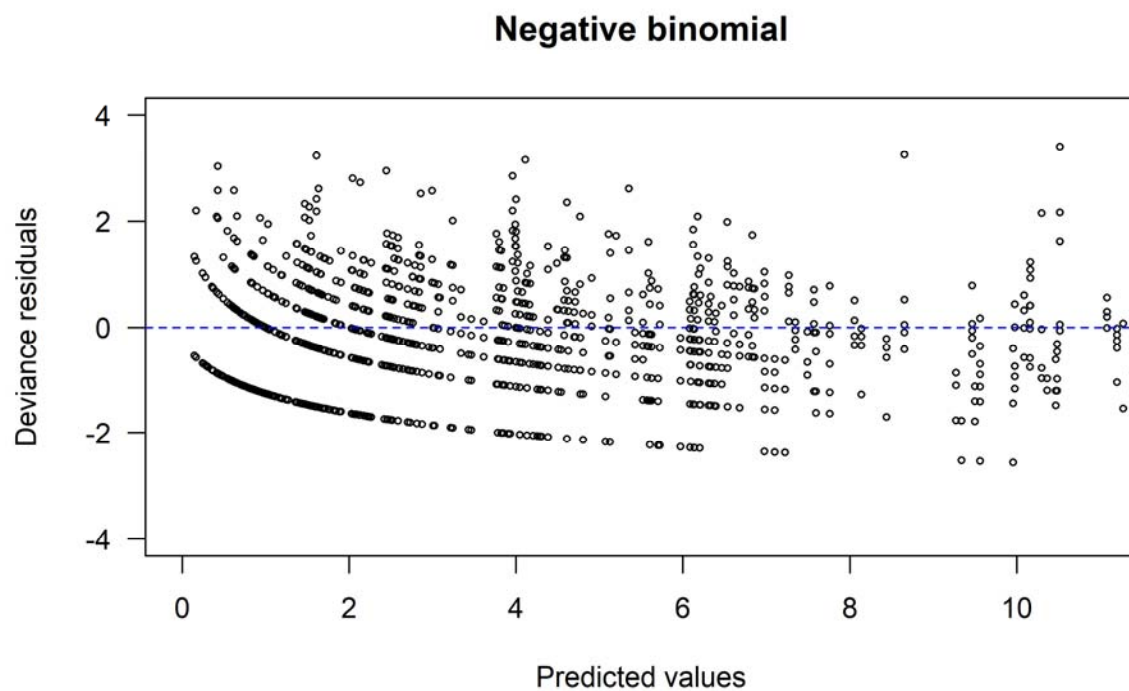
**Figure 18: Deviance residuals for the negative binomial model for Gisborne. Predicted values are in natural space.**
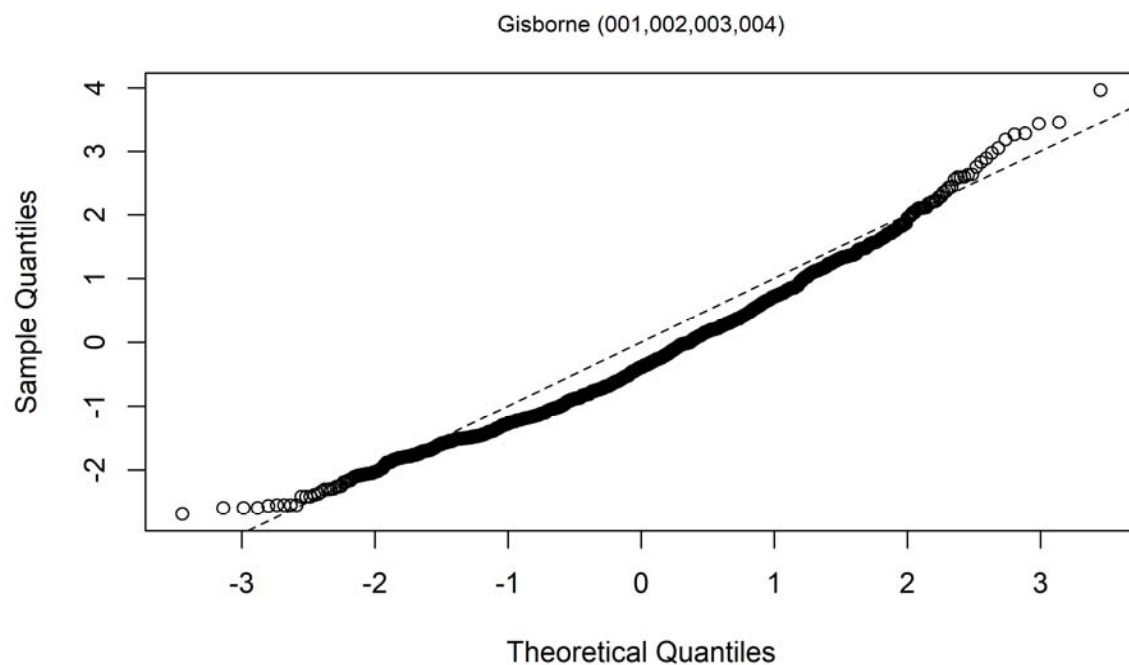


**Figure 19: Quantile-quantile plot for the negative binomial standardisation model for Gisborne.**

**Figure 20: Distribution of data and of fitted data from the negative binomial model for Gisborne.**

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

| Fishing 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 |
| 2018 | 0 | 25 | 0 | 19 | 44 |

## Napier



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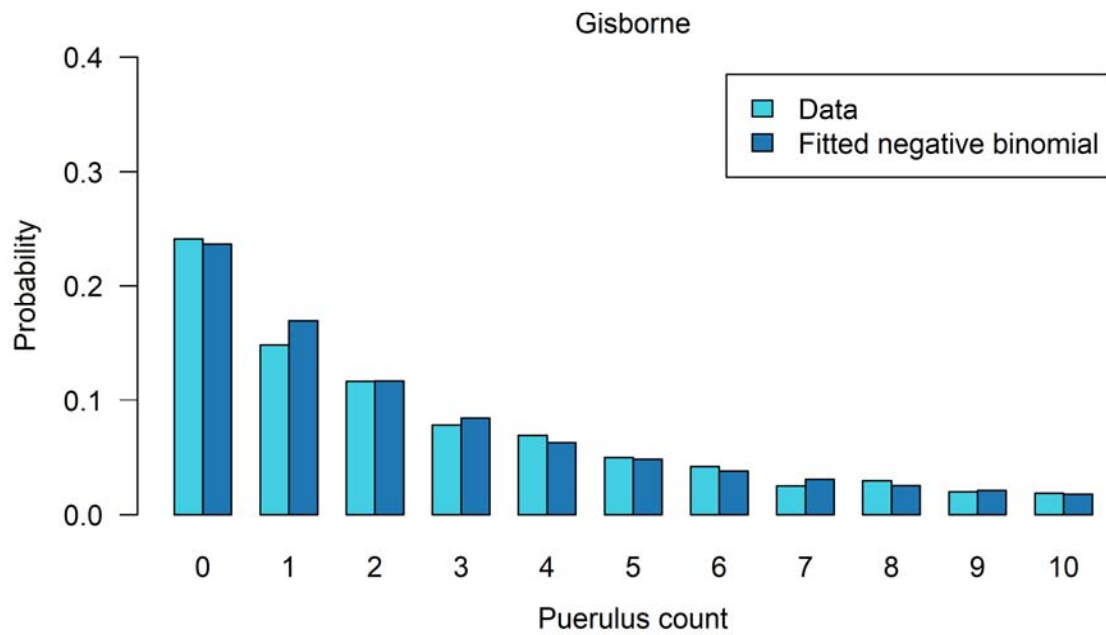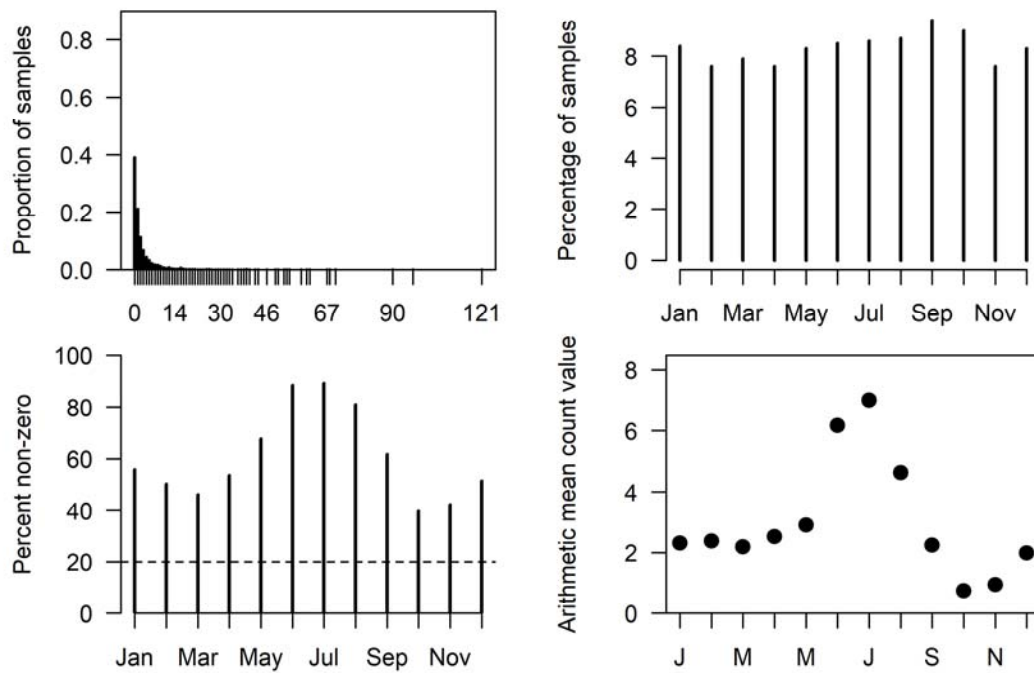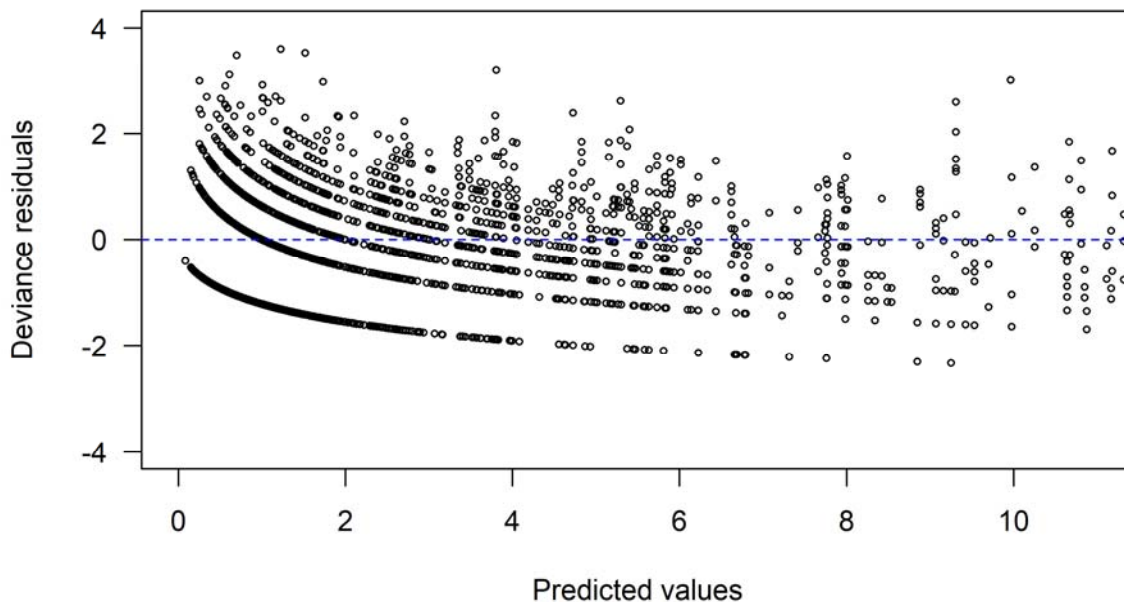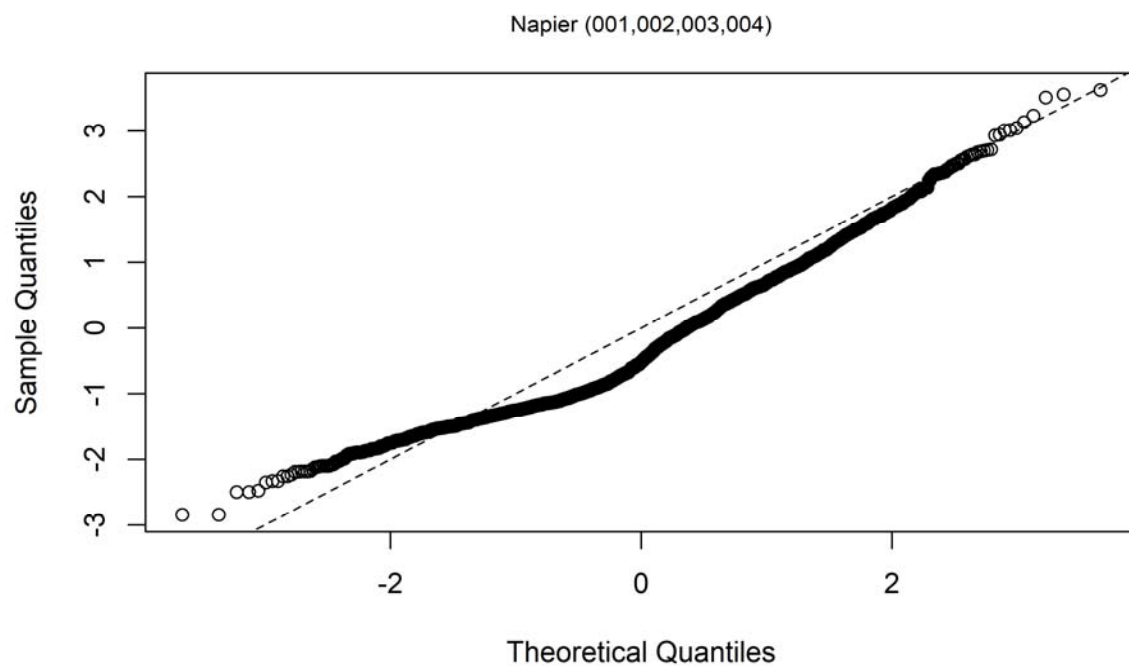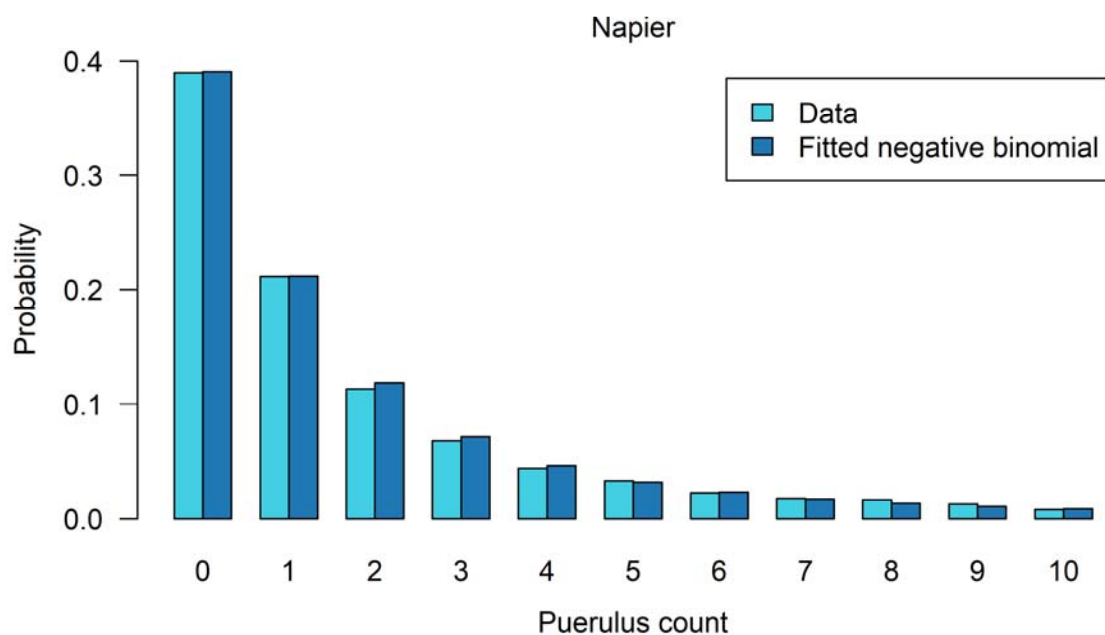
## Negative binomial



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

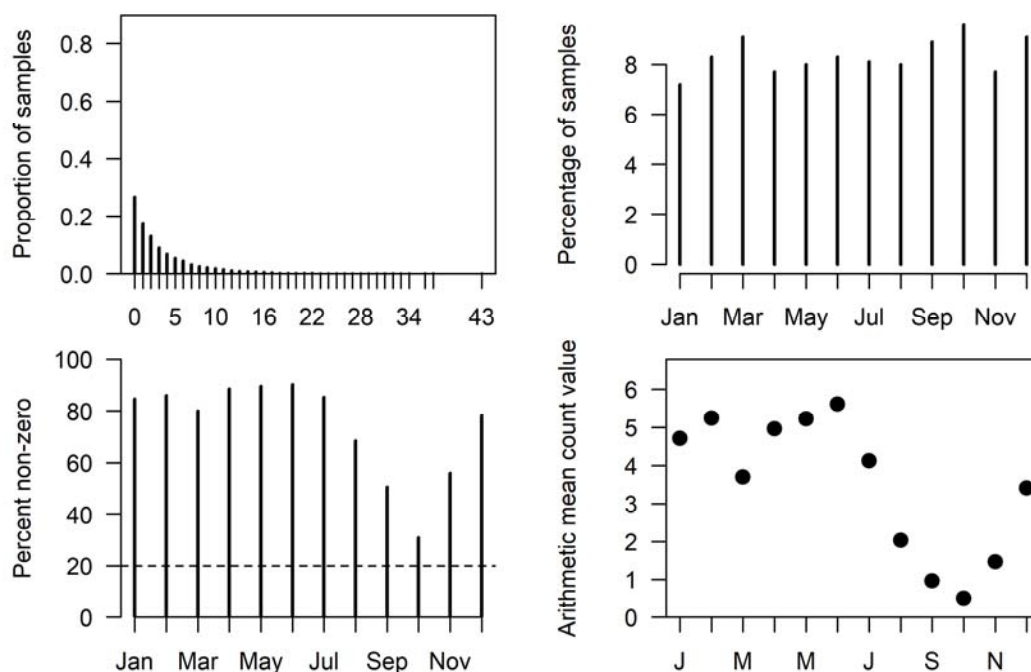**Figure 23: Quantile-quantile plot for the negative binomial standardisation model for Napier.**



**Figure 24: Distribution of data and of fitted data from the negative binomial model for Napier.**

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

| 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 |
| 2018 | 35 | 0 | 57 | 0 | 92 |

# Castlepoint



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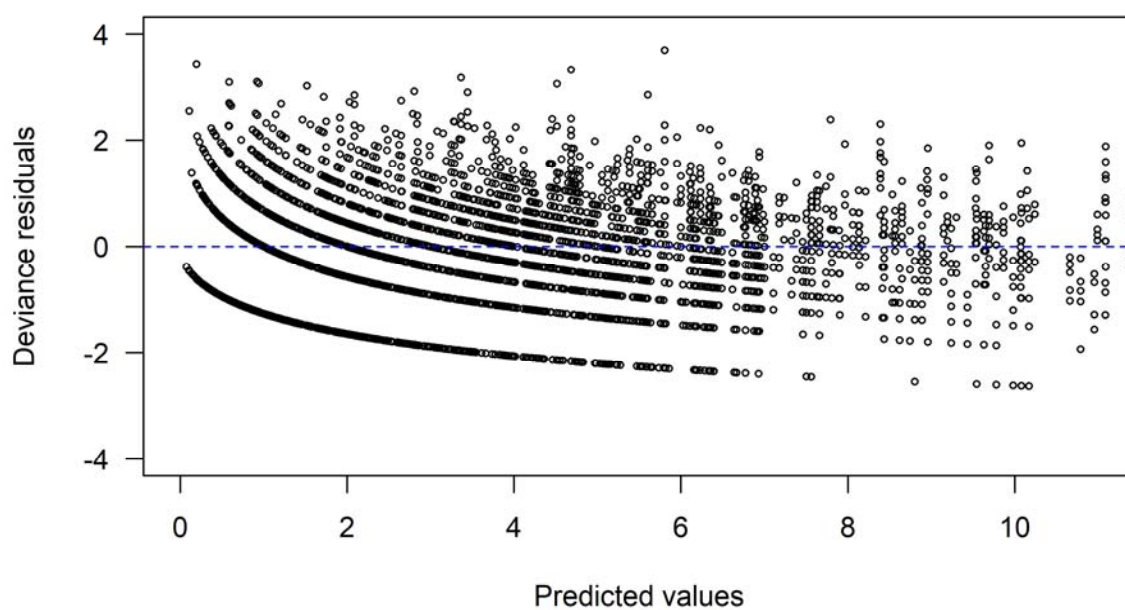
# Negative binomial



**Figure 26: Deviance residuals for the negative binomial model for Castlepoint. Predicted values are in natural space.**
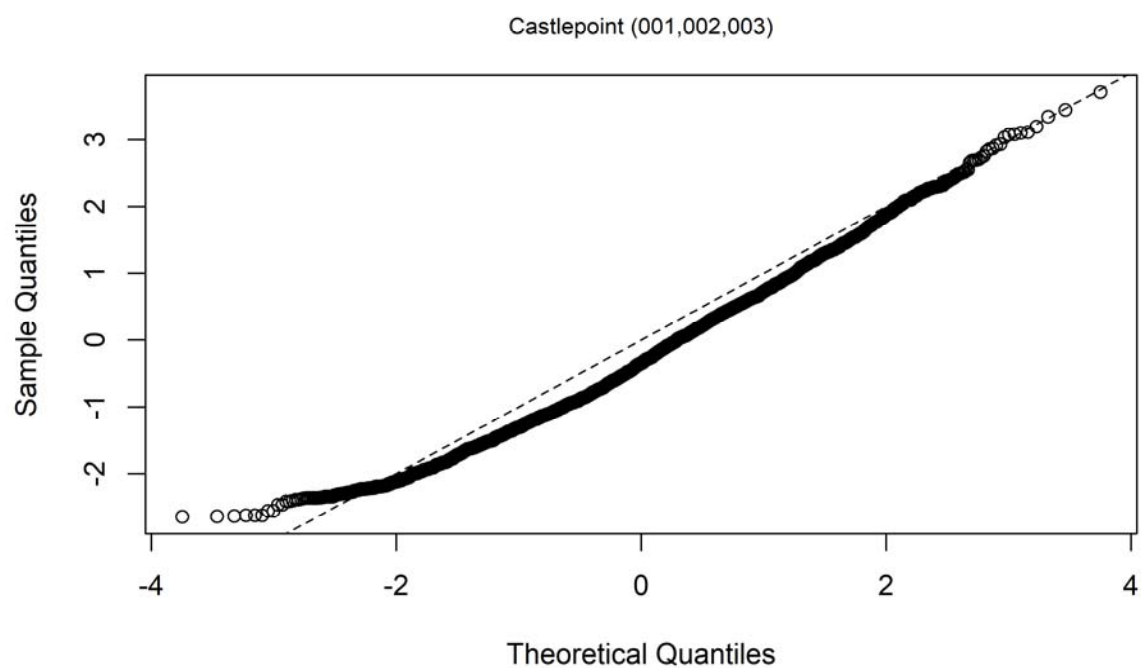
**Figure 27: Quantile-quantile plot for the negative binomial standardisation model for Castlepoint.**
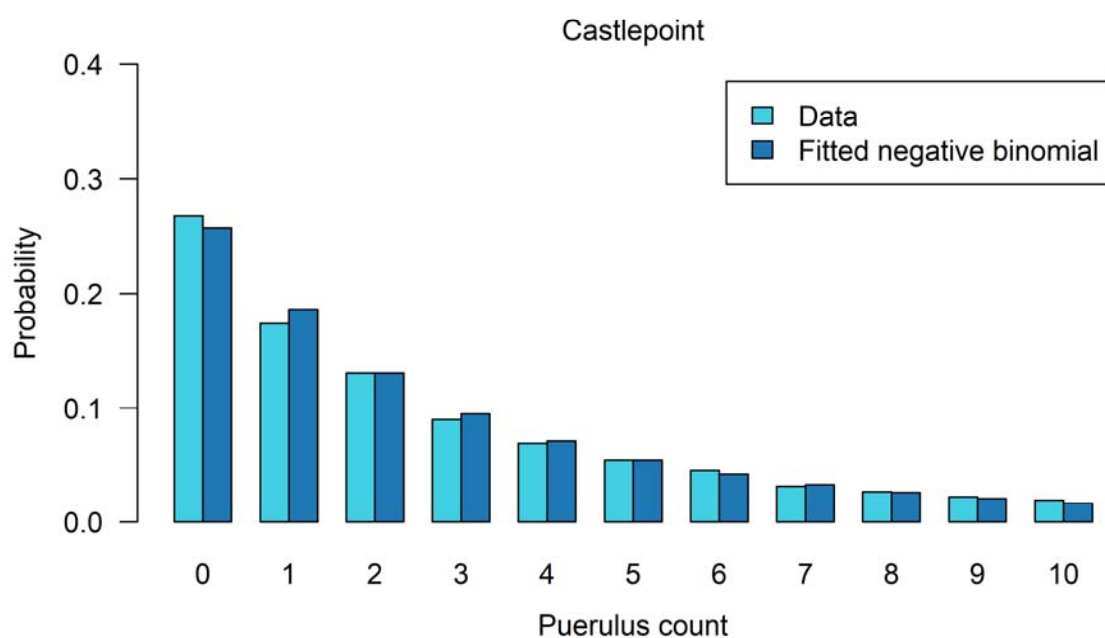


**Figure 28: Distribution of data and of fitted data from the negative binomial model for Castlepoint.**

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

| 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 |
| 2018 | 107 | 55 | 0 | 162 |

## Kaikoura
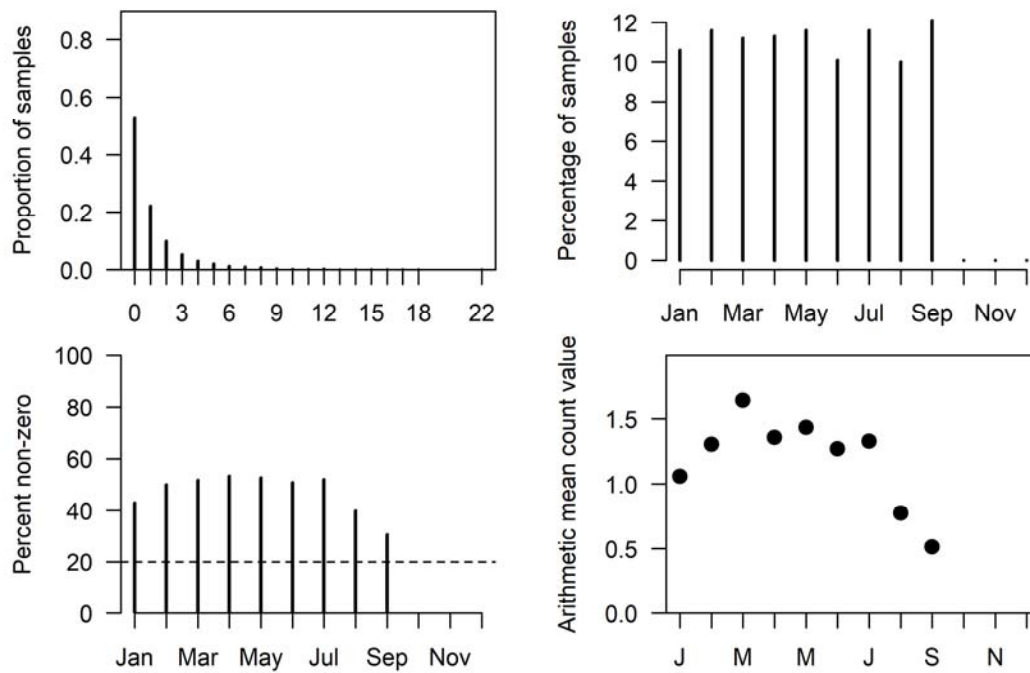


**Figure 29: Characteristics of the Kaikoura puerulus standardisation data. The top-left figure shows the distribution of puerulus counts, and the bottom-left shows the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.**
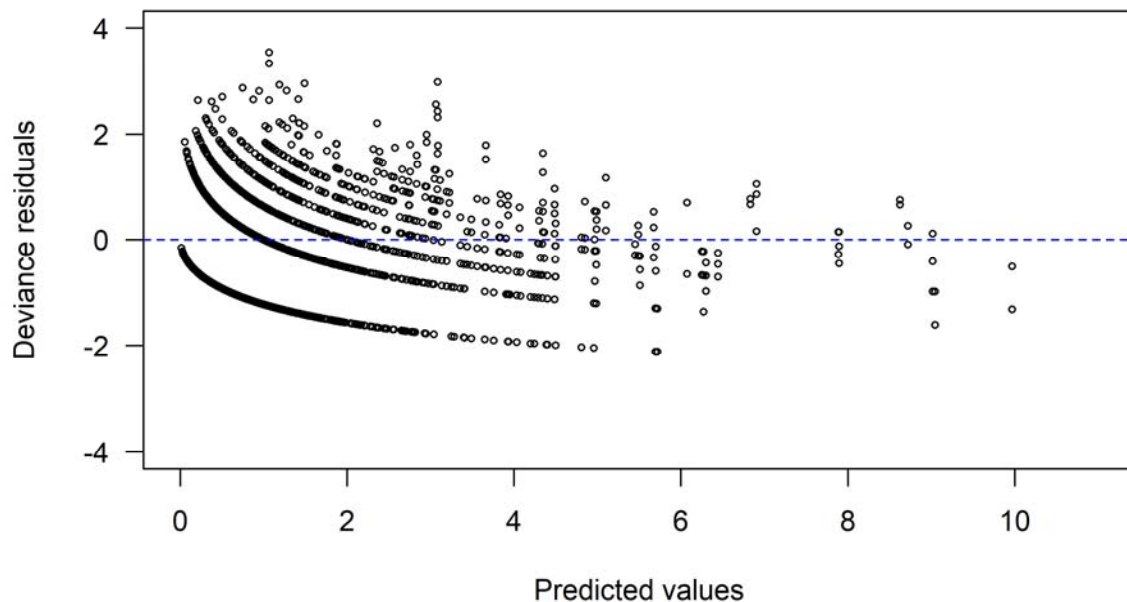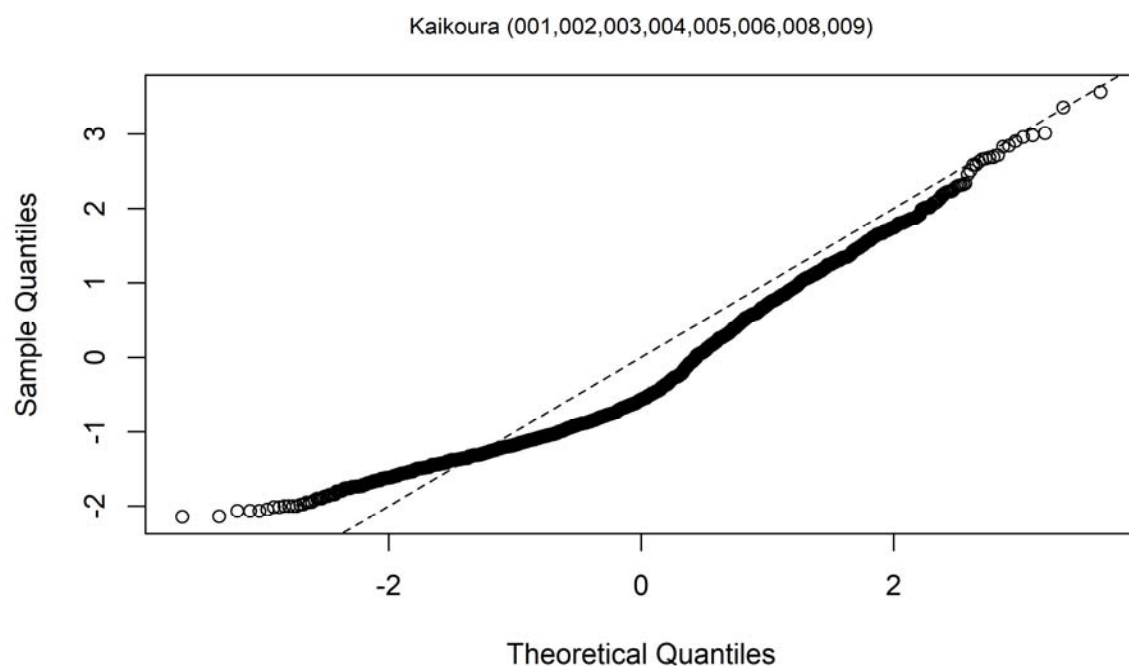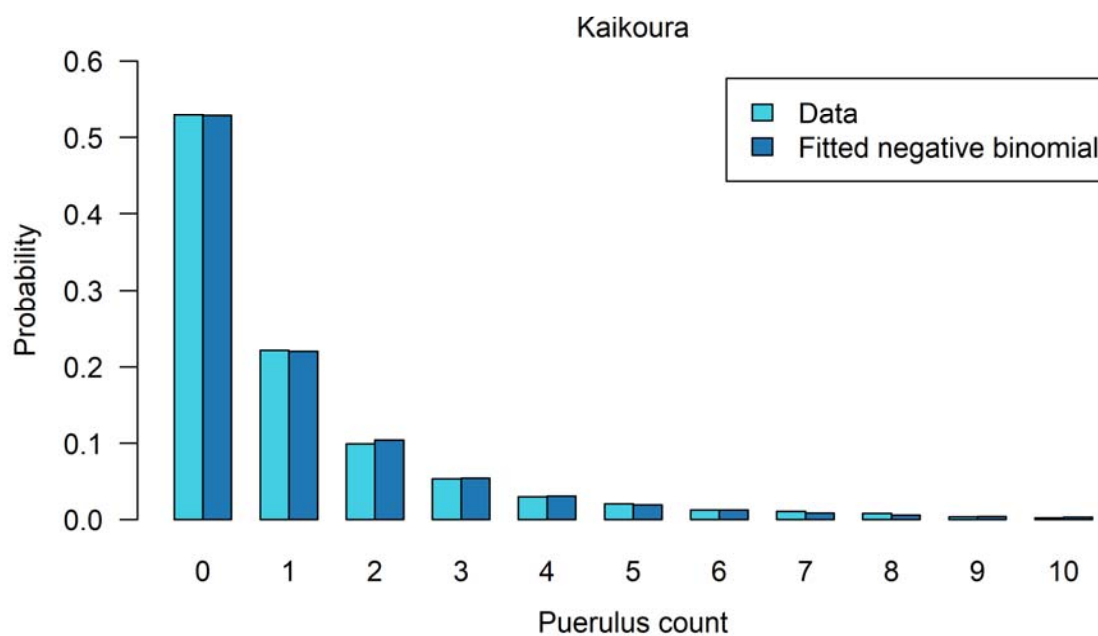
## Negative binomial



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

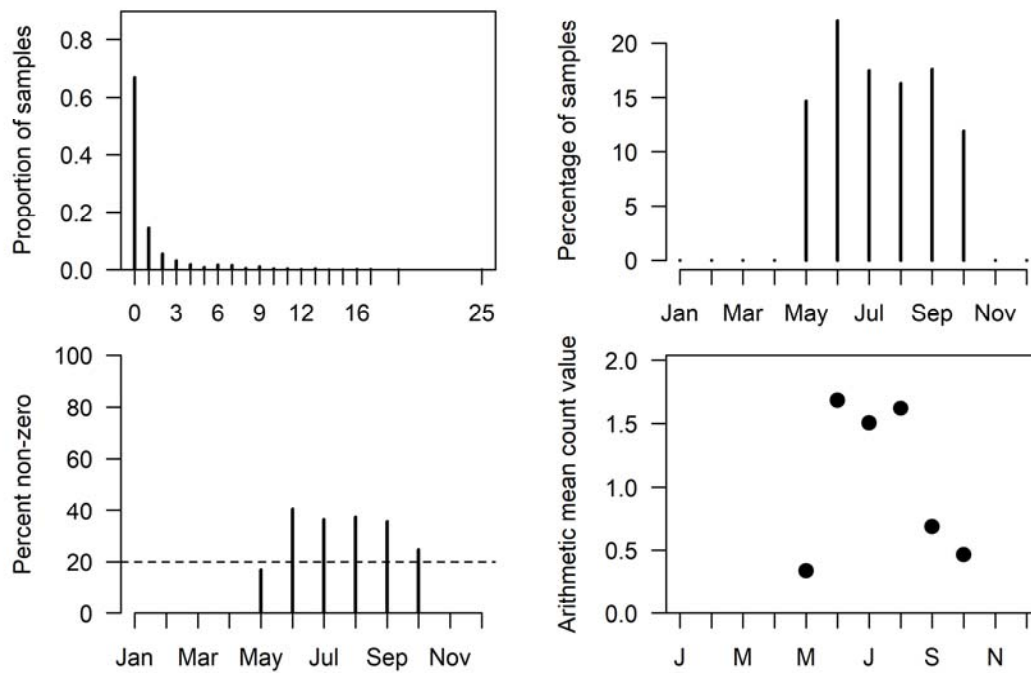**Figure 31: Quantile-quantile plot for the negative binomial standardisation model for Kaikoura.**



**Figure 32: Distribution of data and of fitted data from the negative binomial model for Kaikoura.**

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

| Fishing year | KAI001 | KAI002 | KAI003 | KAI004 | KAI005 | KAI006 | KAI007 | KAI008 | 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 | 12 | 6 | 0 | 0 | 103 |
| 2013 | 39 | 0 | 40 | 0 | 4 | 3 | 0 | 0 | 86 |
| 2014 | 40 | 0 | 40 | 0 | 32 | 24 | 0 | 0 | 136 |
| 2015 | 45 | 0 | 45 | 0 | 16 | 9 | 0 | 0 | 115 |
| 2016 | 45 | 0 | 45 | 0 | 12 | 9 | 0 | 0 | 111 |
| 2017 | 45 | 0 | 45 | 0 | 32 | 24 | 0 | 0 | 146 |
| 2018 | 45 | 0 | 45 | 0 | 36 | 24 | 0 | 0 | 150 |

# Moeraki



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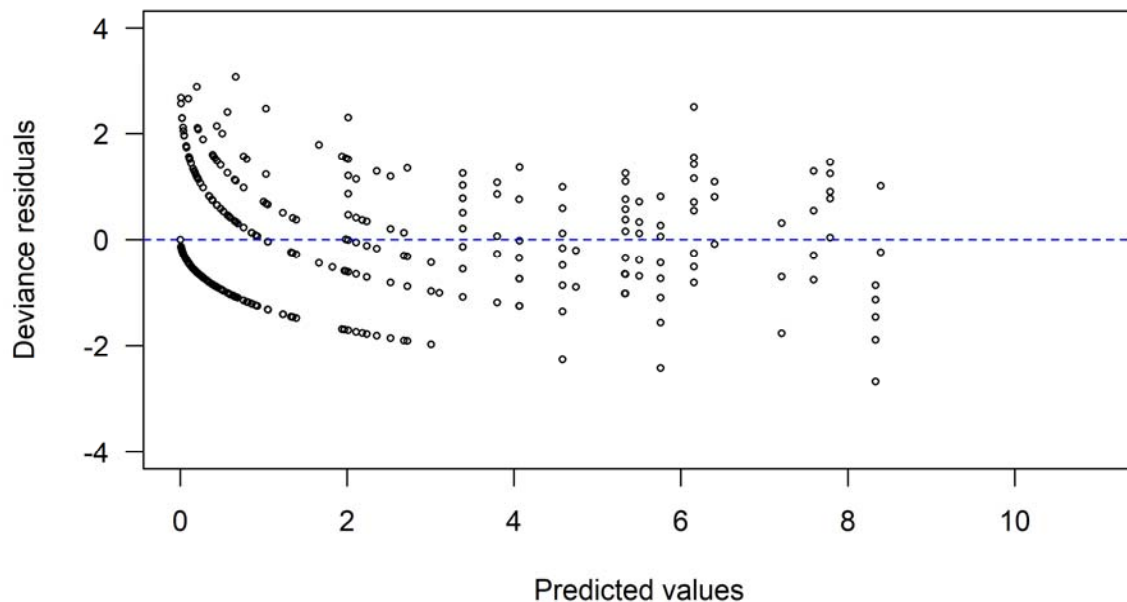
# Negative binomial



**Figure 34:** **Deviance residuals for the negative binomial model for Moeraki. Predicted values are in natural space.**
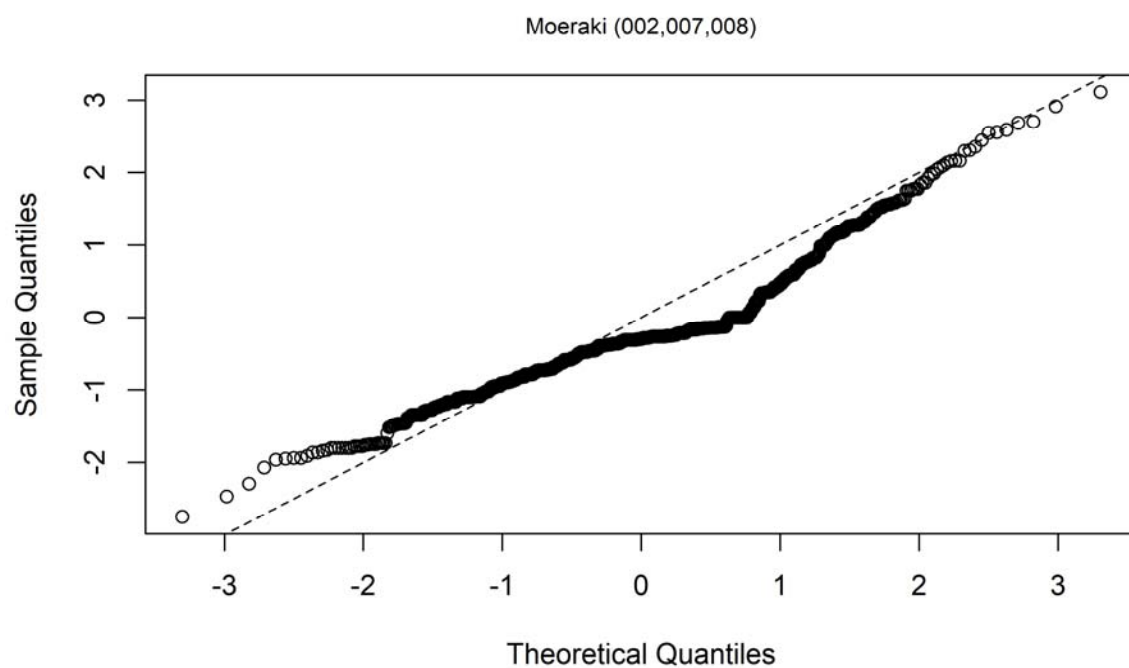
**Figure 35: Quantile-quantile plot for the negative binomial standardisation model for Moeraki.**
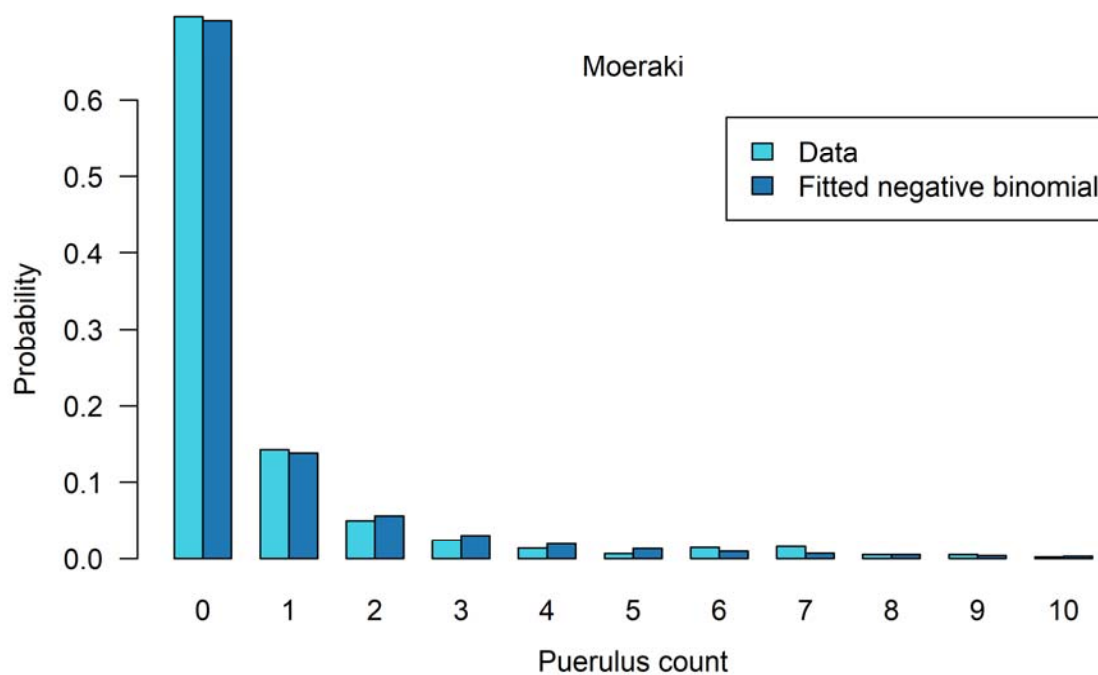


**Figure 36: Distribution of data and of fitted data from the negative binomial model for Moeraki.**

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

| 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 |
| 2018 | 0 | 0 | 26 | 26 |

# Halfmoon Bay
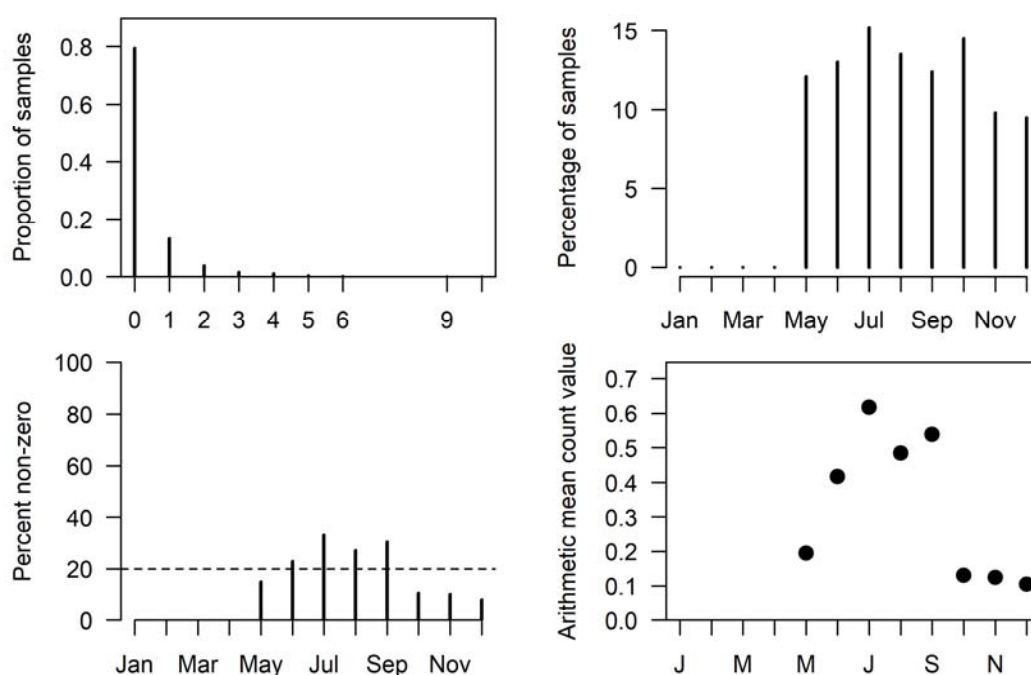


**Figure 37: Characteristics of the puerulus standardisation data for Halfmoon Bay. The top-left figure shows the distribution of puerulus counts, and the bottom-left shows the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.**
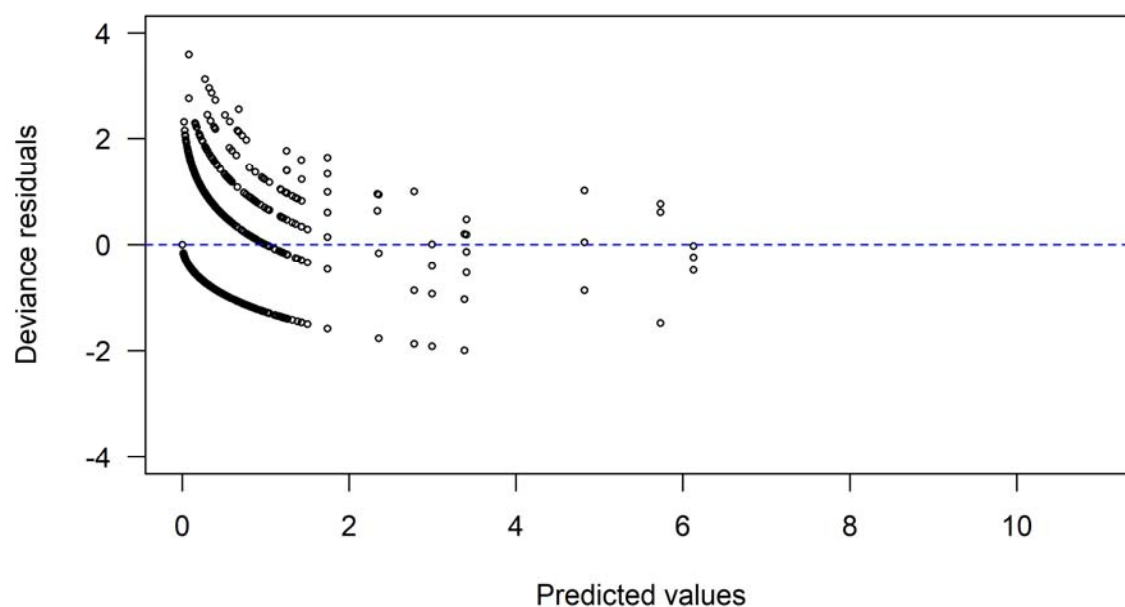
# Negative binomial



**Figure 38: Deviance residuals for the negative binomial model at Halfmoon Bay. Predicted values are in natural space.**
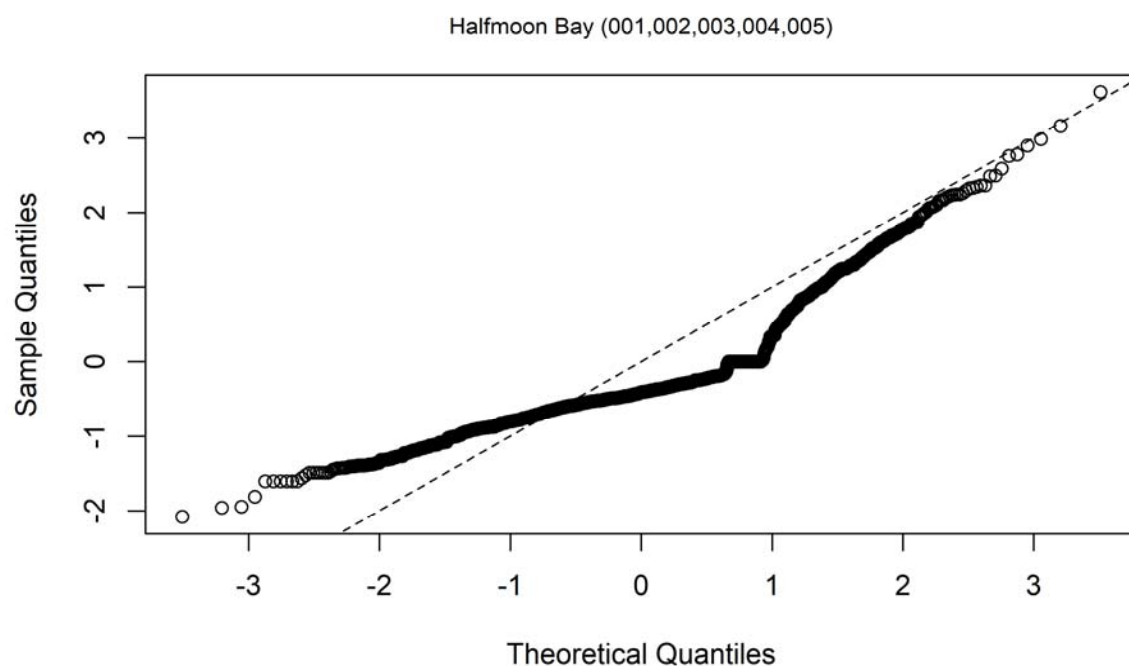
**Figure 39:** **Quantile-quantile plot for the negative binomial standardisation model for Halfmoon Bay.**
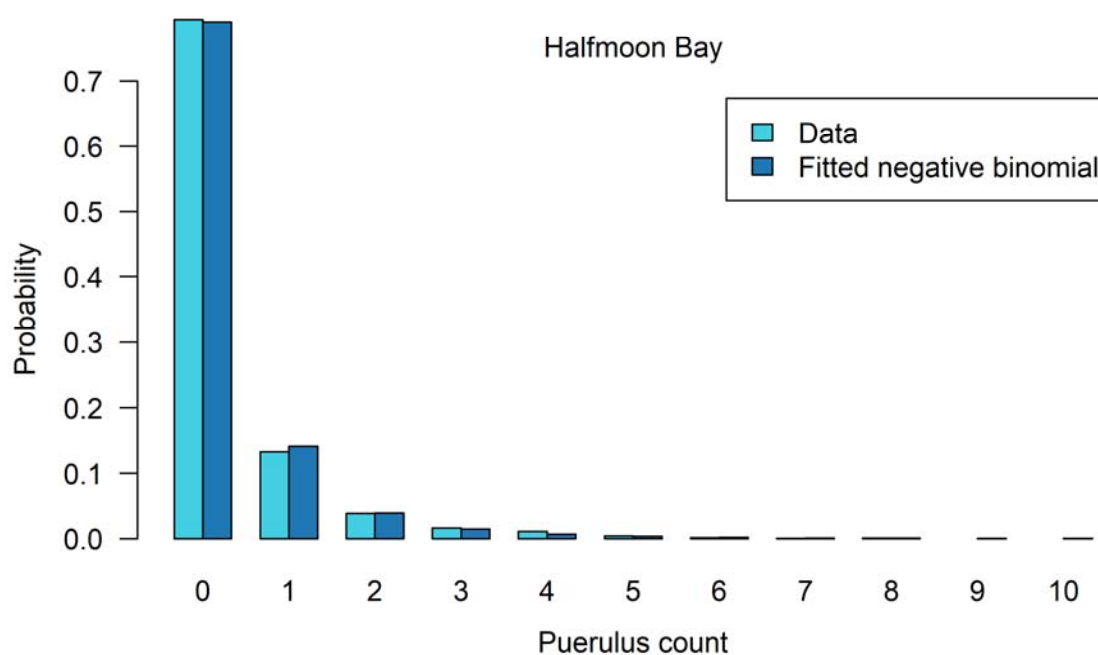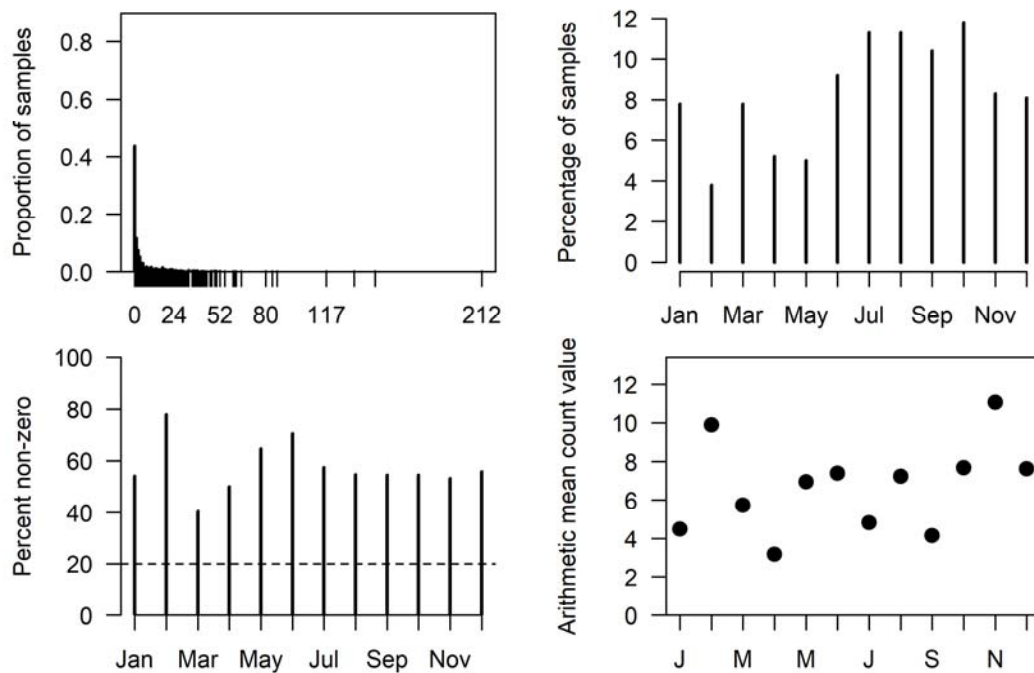


**Figure 40:** **Distribution of data and of fitted data from the negative binomial model for Halfmoon Bay.**

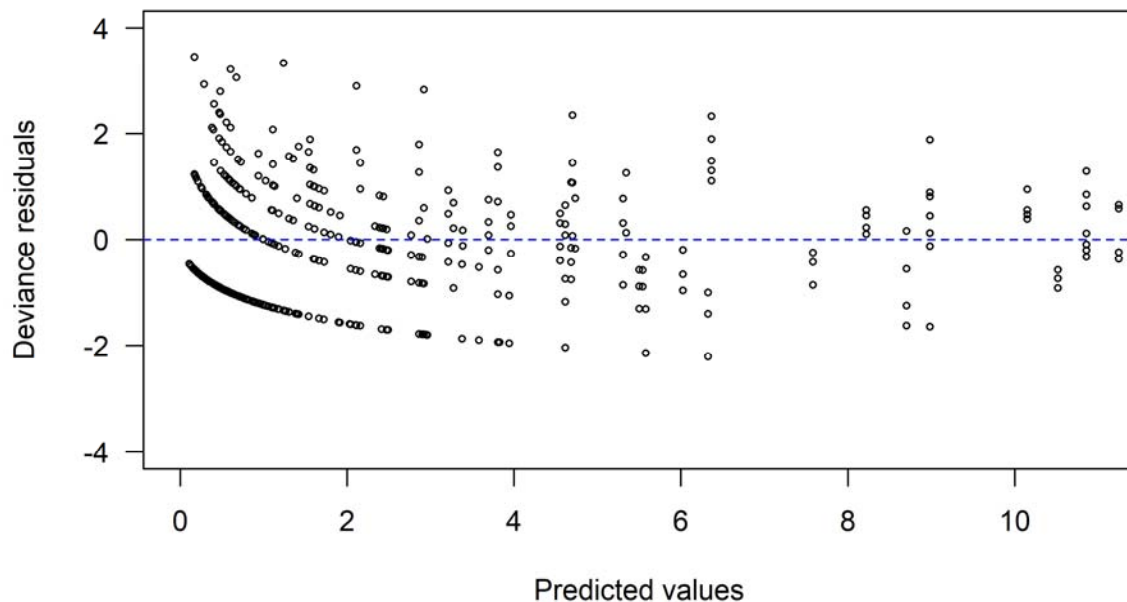**Table 9: Halfmoon Bay standardisation data set. Number of puerulus samples by group and fishing year.**

| 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 |
| 2018 | 32 | 0 | 0 | 0 | 0 | 32 |

## Jackson Bay



**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 shows the proportion of these that are non-zero. Count refers to the number of pueruli measured in a sample.**

## Negative binomial



**Figure 42:  Deviance residuals for the negative binomial model for the Jackson Bay site. Predicted values are in natural space.**
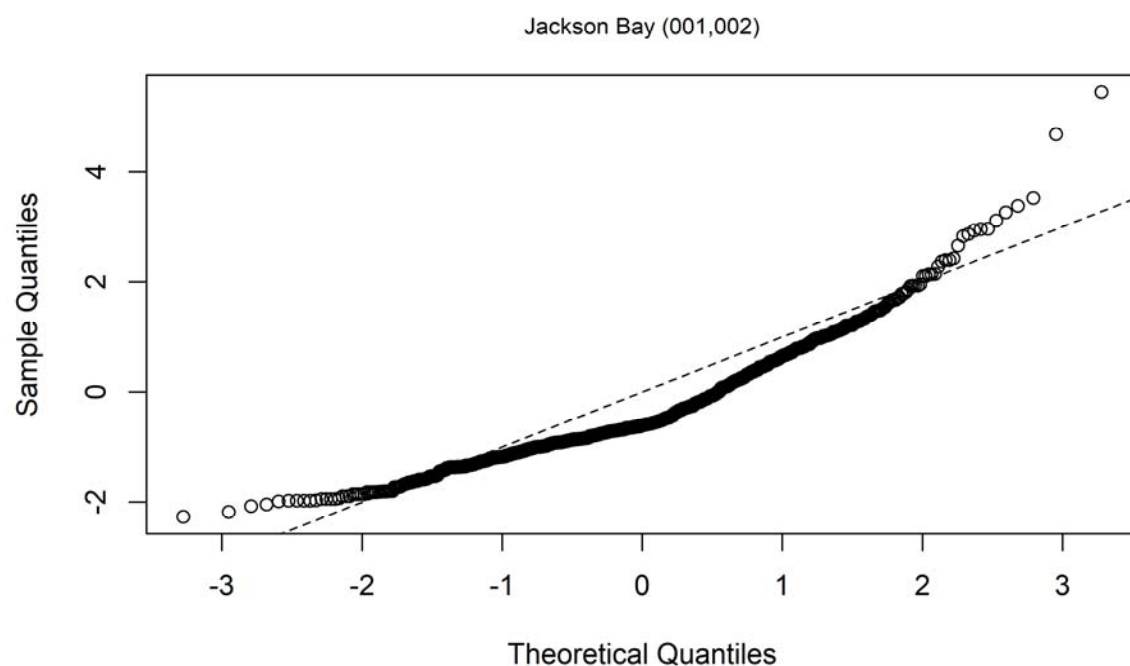
**Figure 43: Quantile-quantile plot for the negative binomial standardisation model for Jackson Bay.**
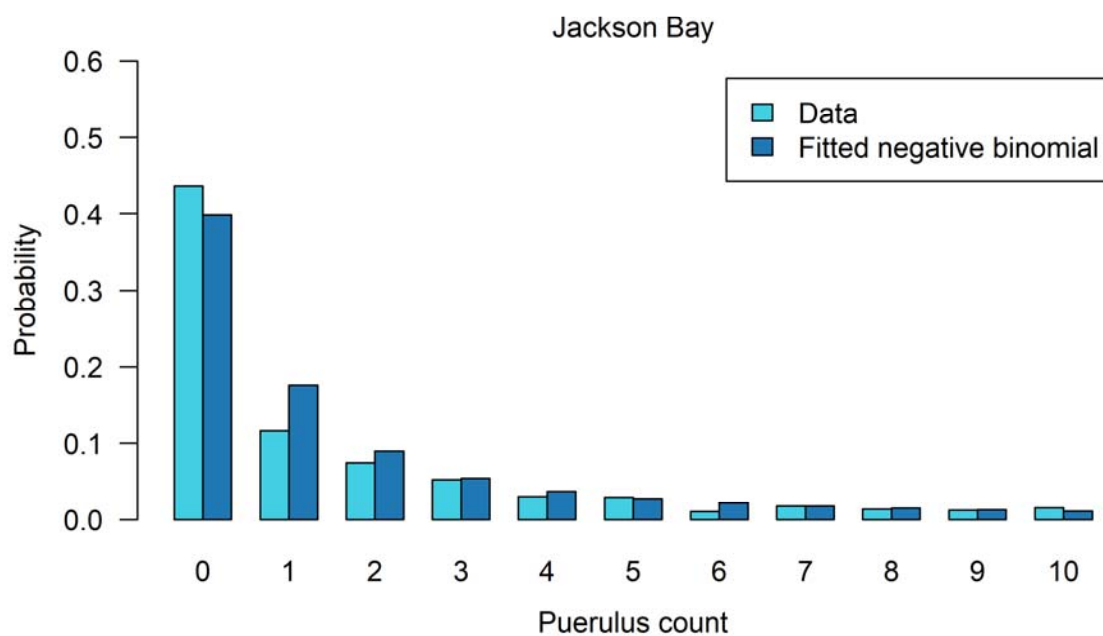


**Figure 44: Distribution of data and of fitted data from the negative binomial model for Jackson Bay.**

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

| 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 |
| 2018 | 47 | 0 | 47 |