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Settlement indices for 2012 for the red rock lobster (*Jasus edwardsii*)

New Zealand Fisheries Assessment Report 2014/47

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EXECUTIVE SUMMARY

Forman, J.S.; McKenzie, A.; Stotter, D.R. (2014). Settlement indices for 2012 for the red rock lobster (*Jasus edwardsii*)

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This report addresses objective one of the Ministry for Primary Industries project CRA201202B (Estimating settlement) and objective two, milestone 8 of project CRA201202A (Analyse staging data).

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, Chalky Inlet, and Jackson Bay). In 2012, two new groups of collectors in Kaikoura and a reintroduced site from Chalky Inlet have been included in the analyses. The new Kaikoura collectors have been effectively operating since 2008 and Chalky Inlet was reintroduced in 2010 after a five year hiatus. These new groups are financed and managed by their associated CRAMACs. There are now two groups of collectors in Gisborne, Napier, and Castlepoint; four groups in Kaikoura; and one group in Moeraki, Chalky Inlet, Halfmoon Bay, and Jackson Bay. Each group has at least three collectors that are checked monthly when possible and a monthly mean catch per group of collectors is calculated. An annual raw and standardised index is produced from the groups of collectors at each site.

Puerulus settlement in 2012 was below the long-term mean in Gisborne, Napier, Castlepoint, Moeraki, and Halfmoon Bay, and above the long-term mean in Kaikoura, Chalky Inlet, and Jackson Bay. Chalky Inlet and Jackson Bay recorded extremely high levels of settlement, especially Jackson Bay, which was ten times above its long-term mean. High levels of settlement have now been recorded in Jackson Bay over the last three years and for two of the last three years in Chalky Inlet. In the sites from the North Island, settlement continues to be low and, with a few exceptions, has been low now for several years.

The relationship between aspects of settlement and the lunar cycle are examined. There was found to be no relationship between the proportion of pueruli that are newly settled and the lunar cycle, or the number of pueruli that settle and the lunar cycle.

For the sites Halfmoon Bay and Moeraki there are a large number of zero settlement observations in the sample data. Restricting the data used in the standardisations to that from the months May to October (inclusive) reduces the number of samples by about 40%, and gives standardised indices that are very similar and with reduced confidence intervals.

1. INTRODUCTION

Rock lobsters support 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 3 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 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). Since monitoring began, the highest mean annual settlement has been along the east coast of the North Island south of East Cape (referred to as the southeast North Island or SENI), in the general region of highest abundance of phyllosoma larvae in adjacent offshore waters (Booth 1994).

For detailed further information on the puerulus sampling program in New Zealand see Booth et al. (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 and 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 a year. A standard result form is filled out 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. The Chalky Inlet site (CHI001) is under the management of CRAMAC 8 and is checked by lobster fishers whenever they are in the vicinity of the collectors. Because of the remoteness of this site, these collectors can only be checked opportunistically by the fishers and cannot be checked on a regular basis. 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.

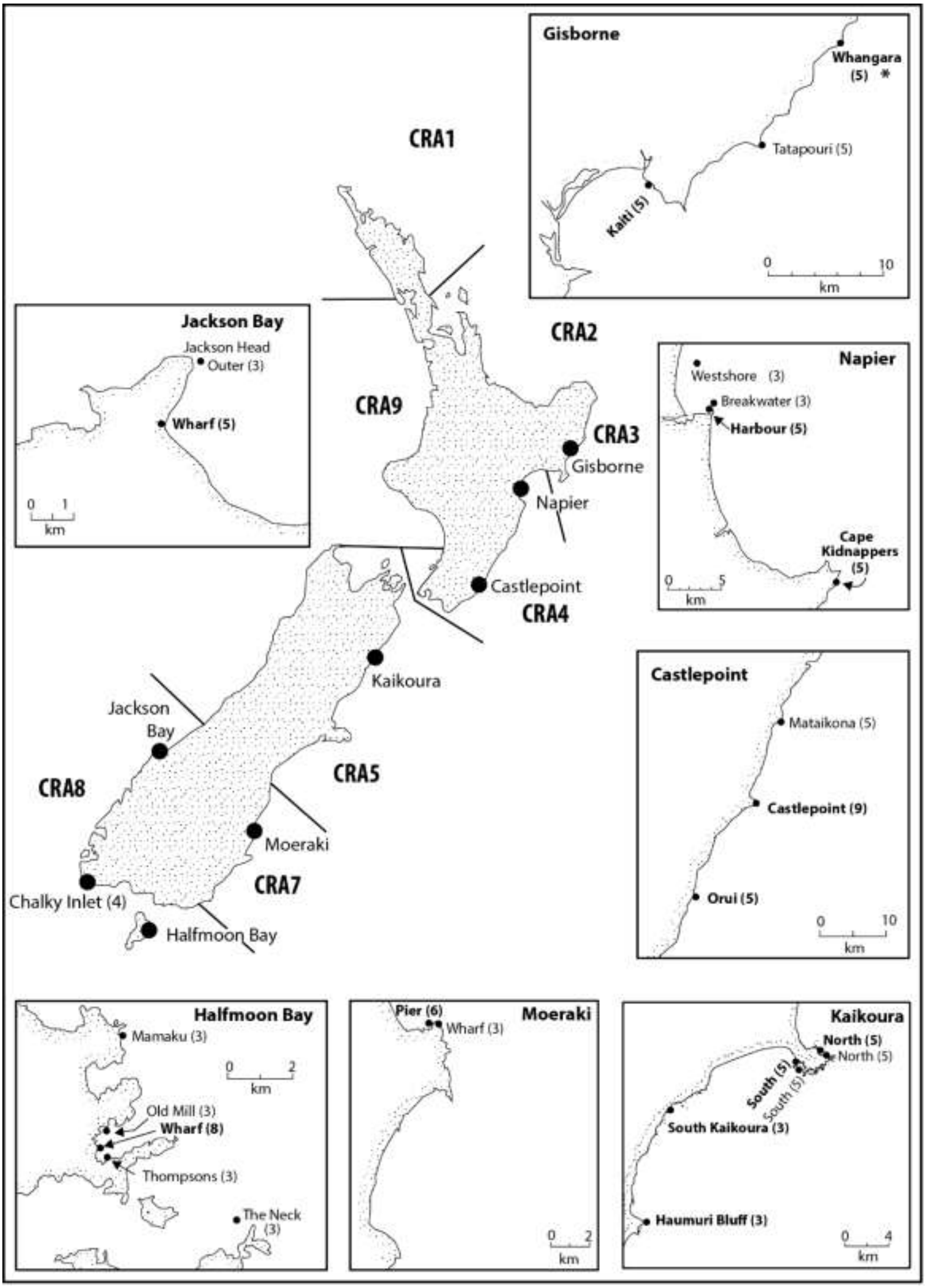

Figure 1: Map of New Zealand showing the location of collectors at the key monitoring sites (although not all groups are now checked). The sites that are checked are in bold and the number of collectors in that set is in brackets. Also shown are the CRA areas; CRA 6 is the Chatham Islands and CRA 10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

Table 1: Number of collectors (presently used), 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	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
	3	South Kaikoura KAI005)	Shore	2008–Present
	3	Haumuri Bluff (KAI006)	Shore	2008–Present
Moeraki	3	Wharf (MOE002)	Closing	1990–2006
	6	Pier (MOE007)	Suspended	1998–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	2010–Present

2.1 Calculating indices of settlement (continued)

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’ to 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, it was not considered reasonable to allocate the month of settlement to the nominal month. Instead, if the check took place up to the 7th 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.

At three sites (Gisborne, Jackson Bay, and Moeraki) some groups of collectors were dropped. At Gisborne the group of harbour collectors GIS001 was dropped because of the peculiar nature of settlement there, in particular, extraordinarily large catches. For Jackson Bay and Moeraki some pilot study groups of collectors were dropped as they did not catch pueruli very well, and even the best groups of collectors at these two sites often recorded very low counts (Appendix 1).

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 Poisson distribution with dispersion is assumed. All independent variables were treated as factors. The year variable was included in all models; the other independent variables (group/collector 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 Aikake Information Criterion (AIC) was included (Akaike 1974).

The standardisation method was the same as in previous years. Some recommendations were made in a review of the puerulus settlement program (Cockcroft 2011), including some aspects of the standardisation process, and it is anticipated that these will be investigated in the next set of standardisations (under a different project from this update).

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 less than average settlement. For comparison, a raw form of these indices are also given (arithmetic mean for each year), which are also scaled to have an average value of 1 over all years.

2.2 Reactivation of the Chalky Inlet Site

Chalky Inlet is a puerulus collector site located in CRA 8 between Halfmoon Bay and Jackson Bay. It currently consists of a single group of four collectors and was sampled by NIWA from 1985 to 2004 (when the site was closed). Opportunistic sampling by industry started again in the 2010 calendar year. A review of the puerulus sampling program agreed with this reactivation of the site as it would help fill out sampling coverage for the western part of CRA 8 (Cockcroft 2011).

For the standardisation data a collector must have at least 36 samples taken, and any year with fewer than 10 samples is dropped. Under these criteria all collectors for Chalky Inlet are retained, but the 1985 year is dropped (Table 2). The sampling in the last two years has been low with 11 and 16 samples taken over the four collectors.

A descriptive plot was made of the count data from the site. It shows the proportions for the number of pueruli counted in a sample, the percentage of samples taken by month, the proportion of non-zero counts for each month, and the mean count value by month (Figure 2). All months show a significant amount of settlement with higher counts tending to occur from May through to August.

Although the sampling for the last three years has been opportunistic, sampling has taken place in the months of January, August, and November, continuing the pattern of previous years (Figure 3). Other months are more sporadically sampled in the last three years.

The Rock Lobster Working Group decided to include Chalky Inlet in the sites for which standardised puerulus indices are calculated, while acknowledging the opportunistic nature of the sampling and the low number of samples.

Table 2: Number of samples by year and collector. The 1985 year is dropped for the standardisation as it has fewer than 10 samples.

	1	2	3	4	5	6	Total
1986	12	12	12	0	0	0	36
1987	9	11	9	0	0	0	29
1988	5	6	6	0	0	0	17
1989	6	6	9	0	0	0	21
1990	6	8	8	0	0	0	22
1991	8	8	8	0	0	0	24
1992	9	9	9	0	0	0	27
1993	6	6	6	0	0	0	18
1994	7	7	7	0	0	0	21
1995	8	8	8	0	0	0	24
1996	6	6	6	6	6	6	36
1997	8	8	8	8	8	8	48
1998	9	9	9	9	9	9	54
1999	5	5	5	5	5	5	30
2000	5	6	6	6	6	6	35
2001	7	7	7	7	7	7	42
2002	4	4	4	4	4	4	24
2003	6	6	6	6	6	6	36
2004	3	3	3	3	3	3	18
2010	6	6	6	6	0	0	24
2011	2	3	3	3	0	0	11
2012	4	4	4	4	0	0	16

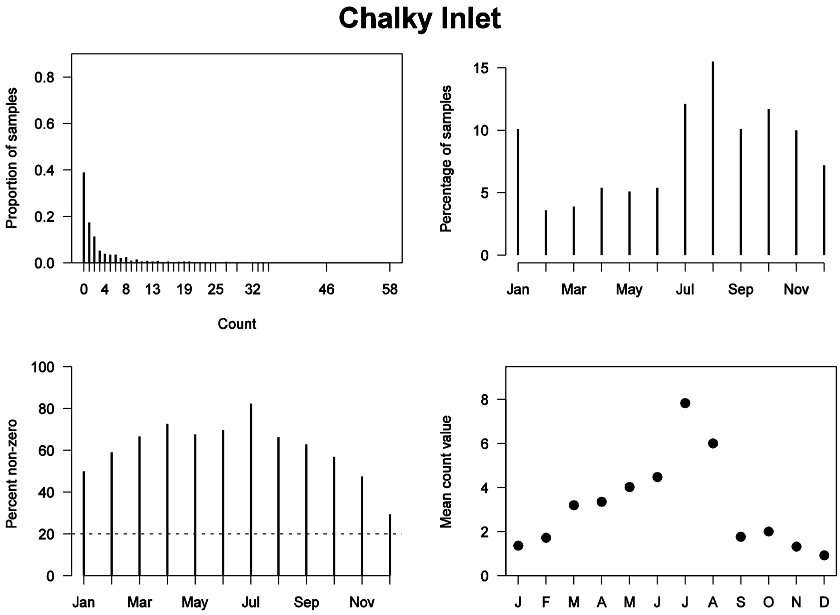

Figure 2: Characteristics of the Chalky Inlet samples.

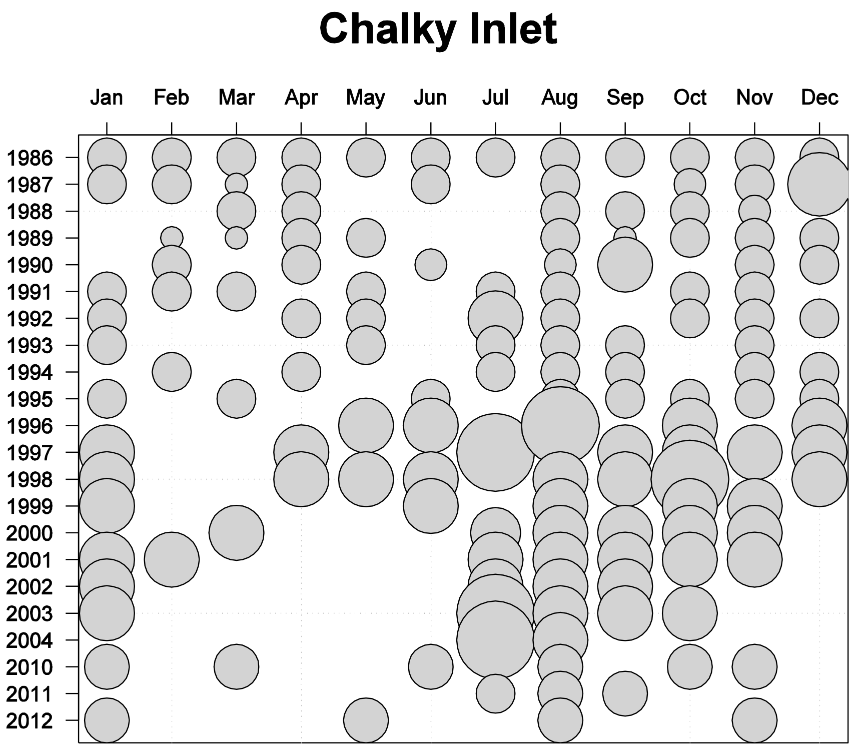

Figure 3: Number of samples taken by year and month for Chalky Inlet. The area of the circles is proportional to the number of samples.

3. RESULTS

The results are presented in three sections: (i) an update of the standardised indices, (ii) an examination of aspects of settlement and the lunar cycle, (iii) and an exploratory investigation into reducing the number of zeros for the sites Moeraki (CRA 7) and Jackson Bay and Halfmoon Bay (CRA 8) by restricting the months of sampling used.

3.1 Standardised Indices

In the initial data set there were 499 collectors over all sites. Applying the requirement that a collector must have been sampled at least 36 times left 179 collectors (Figure 4). The annual numbers of samples for the final groups of collectors used in the standardisation are given in Appendix 2. Any year for a site where there were fewer than 10 samples was removed from the standardisation. This occurred for the first year from four sites (Kaikoura, Moeraki, Halfmoon Bay, and Chalky Inlet). For the final data set used in the standardisation there are still many monthly samples for Moeraki and Halfmoon Bay where no puerulus were recorded (Figure 5).

Month was selected by the AIC criterion for all standardisations, and for most sites collector was selected instead of group (Table 3). Regression diagnostics are given in Appendix 3, and these indicate that for Moeraki, Halfmoon Bay, and Jackson Bay there is an excess of zeros relative to the assumed Poisson distribution.

The standardised annual collector indices up to 2012 are shown in Table 4. In the following sections site-by-site descriptions of puerulus settlement for 2012 are given, as well as standardised annual graphs from each key site and the monthly mean catch graphs for 2012 from each group.

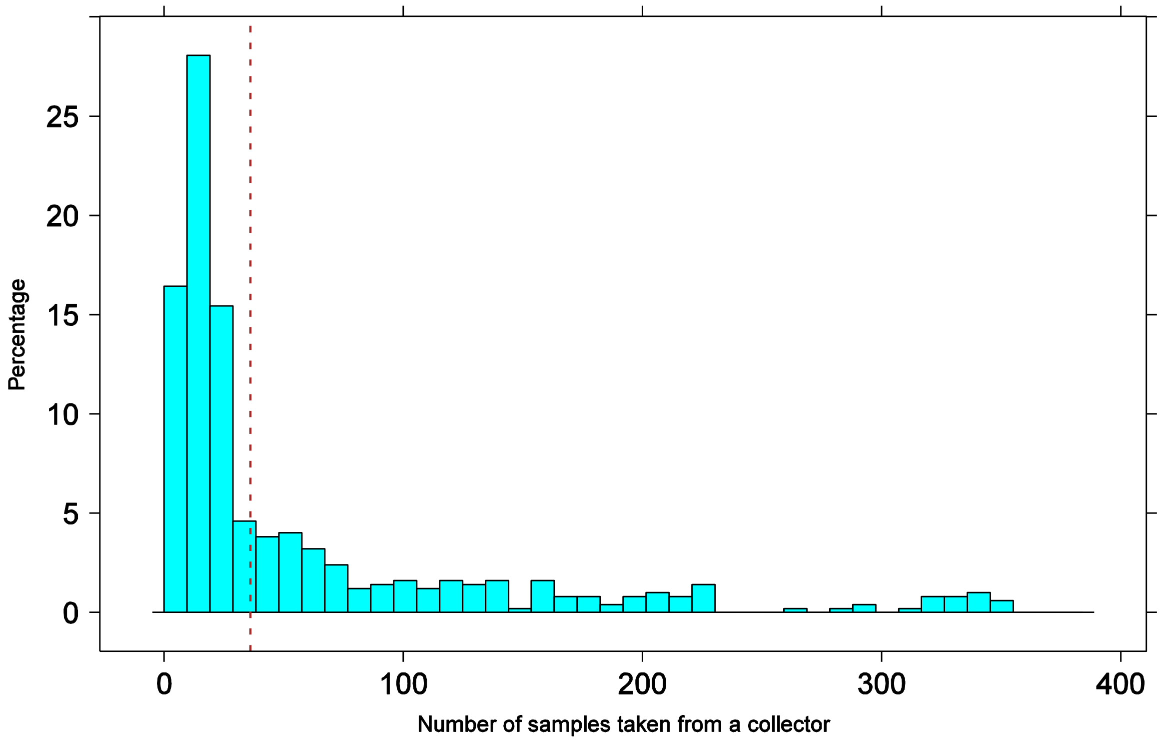

Figure 4: Distribution for the number of samples taken from a collector. The vertical dashed line is at 36 samples.

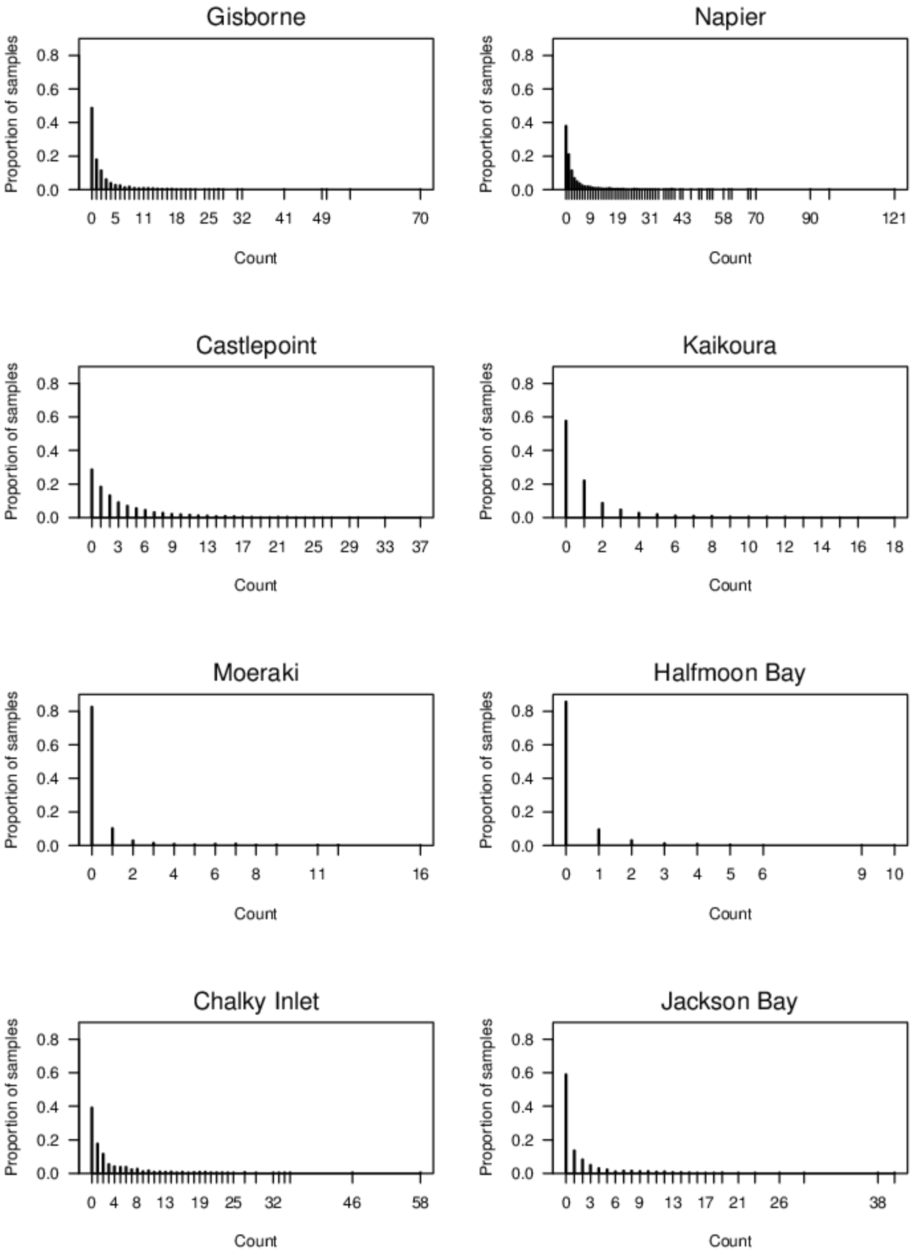

Figure 5: Distribution of number of puerulus collected at monthly samples by site.

Table 3: Group of collectors used in standardisations, additional factors (all included year and month), and estimated dispersion.

Site	Groups	Additional factors	Estimated dispersion
Gisborne	002, 003, 004	Collector	2.80
Napier	001, 002, 003, 004	Collector	3.59
Castlepoint	001, 002, 003	Collector	2.68
Kaikoura	001, 002, 003, 004, 005, 006	Collector	1.71
Moeraki	002, 007	-	1.56
Halfmoon Bay	001, 002, 003, 004, 005	Group	1.09
Jackson Bay	001, 002	Collector	3.45
Chalky Inlet	001	Collector	1.09

Table 4: Standardised annual indices for each site. Year is calendar year (January–December).

	Gisborne	Napier	Castlepoint	Kaikoura	Moeraki	Halfmoon Bay	Jackson Bay	Chalky Inlet
1979	-	0.84	-	-	-	-	-	-
1980	-	1.52	-	-	-	-	-	-
1981	-	2.05	-	1.17	-	8.06	-	-
1982	-	1.00	-	0.02	-	0.38	-	-
1983	-	1.24	1.43	0.74	-	4.50	-	-
1984	-	0.41	1.37	0.24	-	0.38	-	-
1985	-	0.19	0.88	0.34	-	0.00	-	-
1986	-	-	0.51	0.11	-	0.11	-	0.07
1987	-	-	1.72	1.18	-	1.61	-	1.95
1988	-	1.50	0.99	0.52	-	0.20	-	1.61
1989	-	1.08	1.55	0.86	-	0.54	-	2.19
1990	-	1.14	0.95	0.28	-	0.44	-	1.92
1991	1.67	2.27	1.98	5.71	0.00	0.84	-	1.06
1992	2.41	2.41	2.46	6.57	0.15	0.62	-	0.39
1993	2.05	1.91	1.49	3.31	0.00	0.00	-	0.13
1994	3.13	1.43	0.95	0.90	0.00	1.11	-	2.33
1995	1.22	1.06	0.90	1.05	0.12	0.32	-	0.56
1996	1.14	1.69	1.33	0.79	1.13	0.32	-	2.26
1997	1.18	1.30	1.16	1.63	0.67	0.53	-	1.52
1998	1.62	1.10	1.70	2.20	0.66	0.27	-	0.43
1999	0.11	0.29	0.35	1.49	0.14	0.24	0.61	1.04
2000	1.06	0.66	0.50	1.30	3.88	1.20	0.62	1.26
2001	1.28	1.33	0.77	0.48	2.42	1.71	0.73	0.99
2002	1.24	1.18	0.73	1.26	0.95	1.31	2.37	0.69
2003	2.47	1.34	0.77	5.31	7.42	3.50	1.25	1.59
2004	0.86	1.06	0.66	1.82	0.45	0.15	0.27	0.21
2005	2.79	1.29	1.18	2.37	0.11	0.00	2.72	-
2006	0.41	0.59	0.65	1.98	0.06	0.13	0.62	-
2007	0.35	1.04	0.90	1.30	0.04	0.45	0.35	-
2008	0.77	0.59	0.90	2.51	0.09	0.09	0.27	-
2009	1.07	0.76	0.93	0.50	0.52	0.96	0.21	-
2010	0.62	1.31	1.63	2.03	1.43	1.70	3.77	5.50
2011	0.25	0.36	0.90	0.47	0.93	0.13	3.49	1.49
2012	0.67	0.79	0.66	1.67	0.86	0.21	10.54	4.25

Gisborne

Settlement at Gisborne in 2012 was again low. This continues a series of below average settlement, with six of the seven lowest settlement years occurring within the last seven years (Figure 6). Settlement at Whangara and Kaiti both peaked early, in May, but the normally high winter settlement never arrived and settlement continued to be low for the rest of the year (Figure 7).

Napier

Settlement at Napier was also low. In five of the last seven years, settlement has been below the long-term mean (Figure 8). Settlement at Napier Port and Cape Kidnappers peaked in June and was especially high at Napier Port but most other months were average to below average (Figure 9).

Castlepoint

At Castlepoint, settlement was well below the long-term mean. Below average settlement has occurred in 12 of the last 14 years (Figure 10). Settlement between the Castlepoint and Orui sites was generally consistent except for in February where there was high settlement for Castlepoint, and low settlement at Orui. Both sites were generally low throughout the other months of the year. (Figure 11).

Kaikoura

Settlement in 2012 was above average (Figure 12). The South Bay collector group had the highest settlement, peaking in May. The South Kaikoura and Haumuri Bluff groups peaked in February and March respectively but for the rest of the year settlement was generally low. In the North Bay collectors, settlement was generally low throughout the year and was without any major peaks (Figure 13).

Moeraki

Moeraki was just below the long term mean in 2012 (Figure 14). Settlement peaked in March and another lesser peak occurred in October (Figure 15).

Halfmoon Bay

Settlement was well below average in Halfmoon Bay (Figure 16). May, June, and July were the only months where settlement occurred. Settlement peaked in June (Figure 17).

Jackson Bay

Extraordinarily high levels of settlement occurred during the entire year at Jackson Bay and 2012 was the third year in a row of very high settlement (Figure 18). Settlement was lowest in January and February but was consistently high from March to November and then increased dramatically in December (Figure 19).

Chalky Inlet

Above average settlement has been recorded in the last three years of this re-established site (Figure 20). Settlement in 2010 and 2012 was particularly high which corresponds well with the very high settlement recorded in Jackson Bay over the same period. Collectors were only checked four times during the year with the peak settlement recorded in August (Figure 21).

Mean settlement by month over all years is shown in Figure 22. With the exception of Jackson Bay, where settlement is irregular, highest settlement generally occurs in winter and the lowest settlement is in spring.

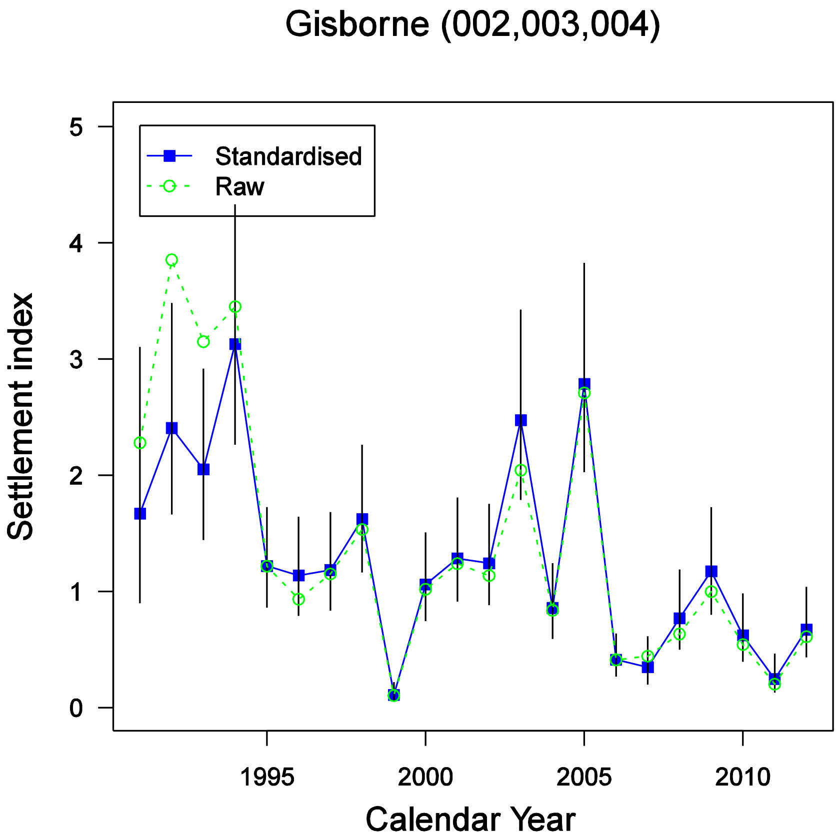

Figure 6: Gisborne–standardised and raw indices of annual settlement with 95% confidence intervals.

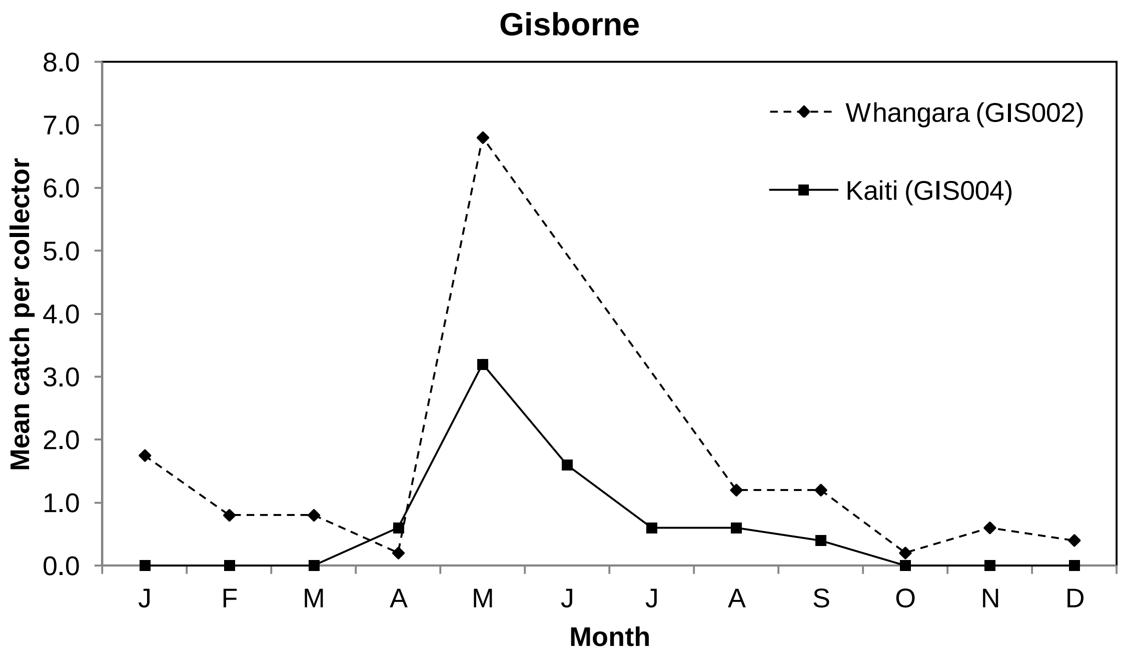

Figure 7: Whangara and Kaiti monthly settlement, 2012. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

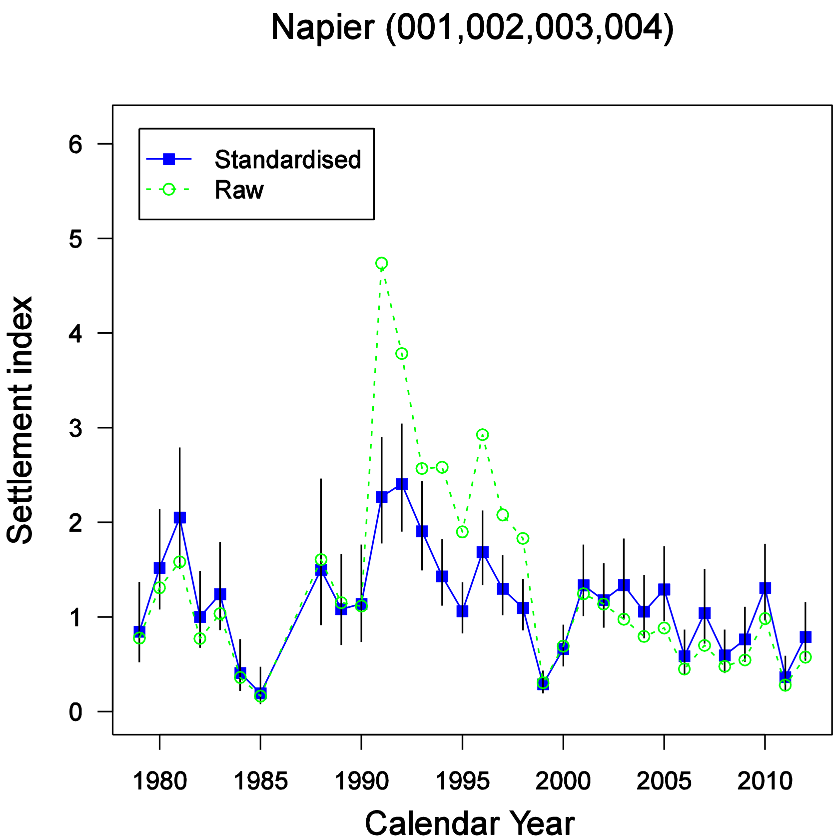

Figure 8: Napier—standardised and raw indices of annual settlement with 95% confidence intervals. Note that there were no checks in 1986–87.

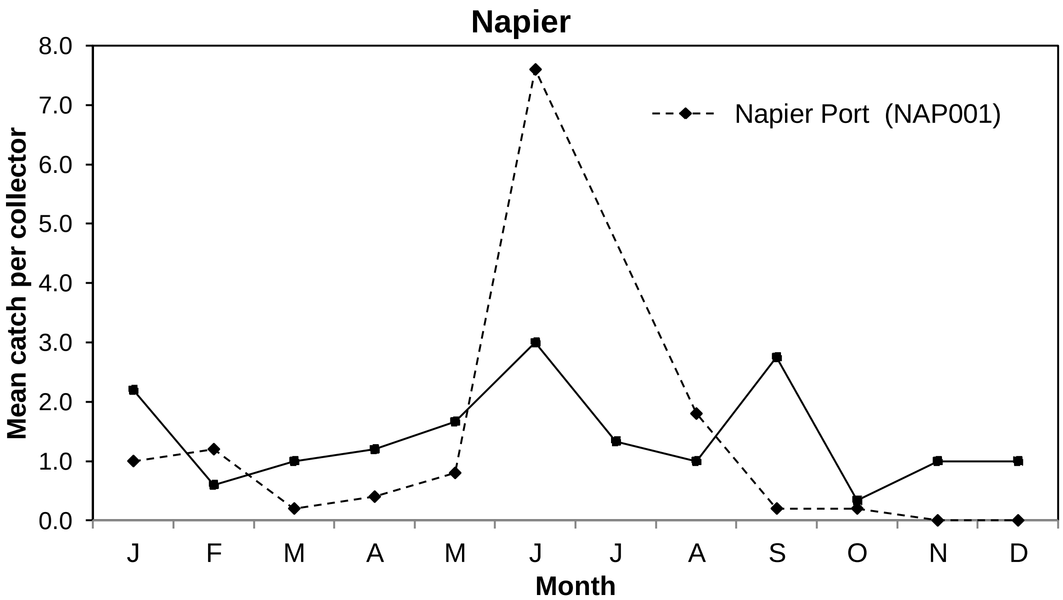

Figure 9: Napier harbour and Cape Kidnappers monthly settlement, 2012. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

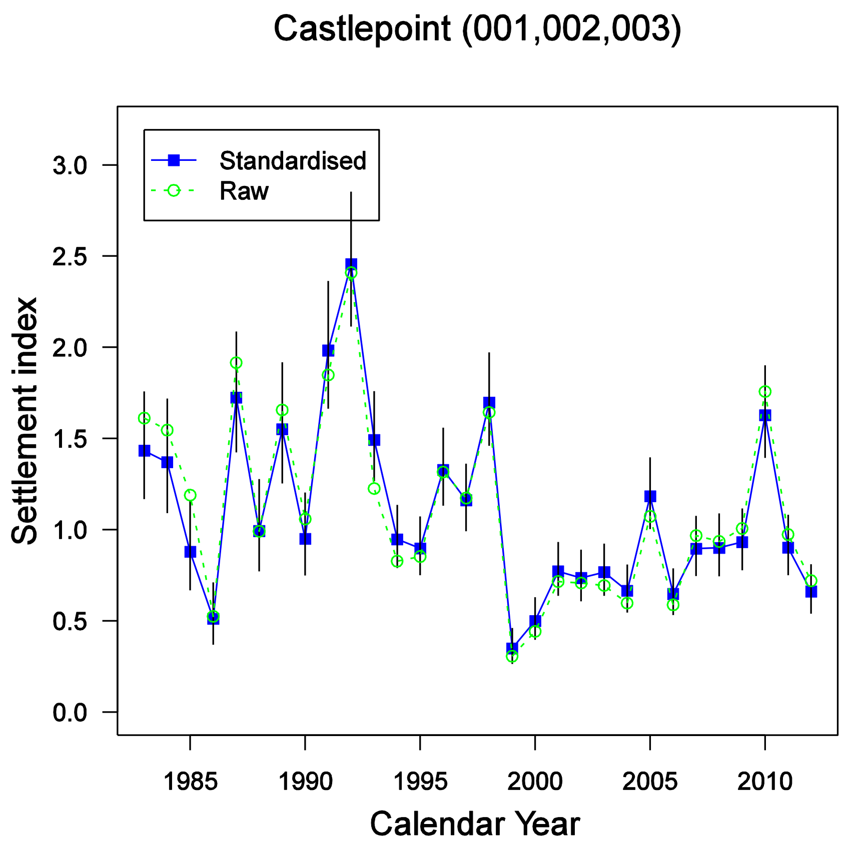

Figure 10: Castlepoint—standardised and raw indices of annual settlement with 95% confidence intervals.

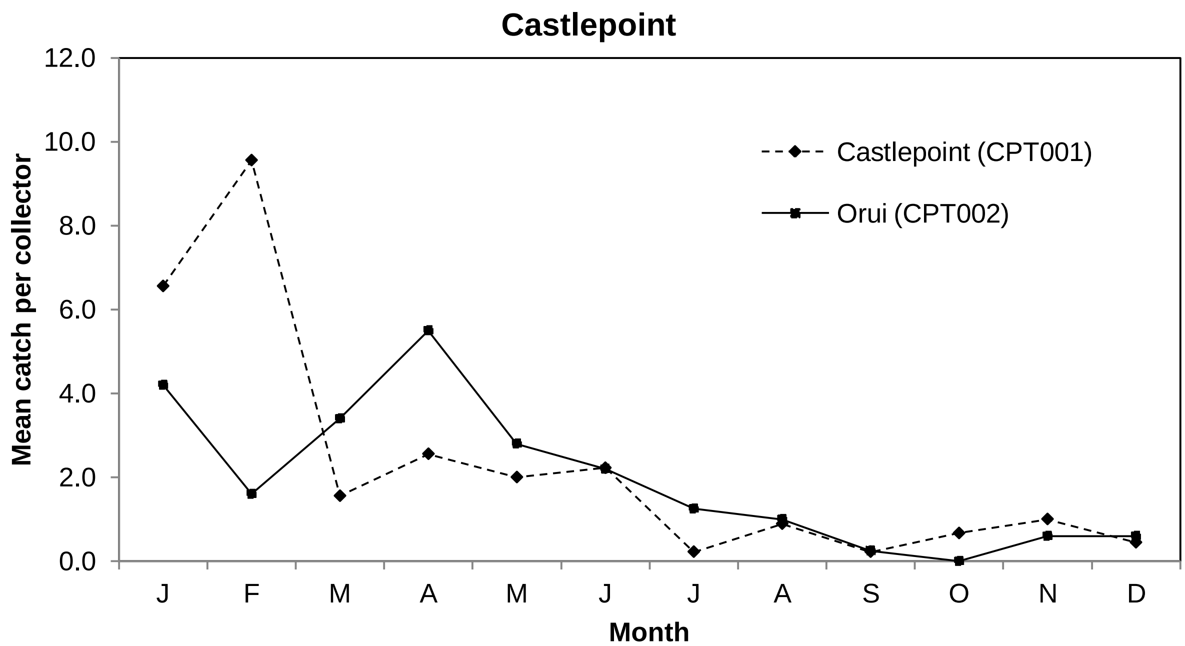

Figure 11: Castlepoint and Orui monthly settlement, 2012. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

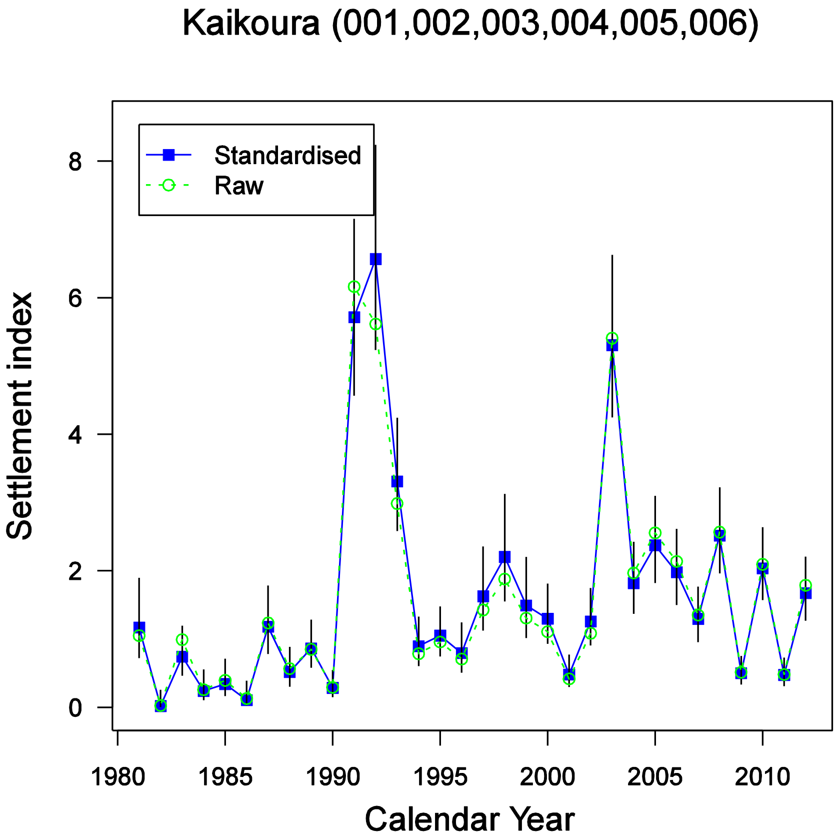

Figure 12: Kaikoura—standardised and raw indices of annual settlement with 95% confidence intervals.

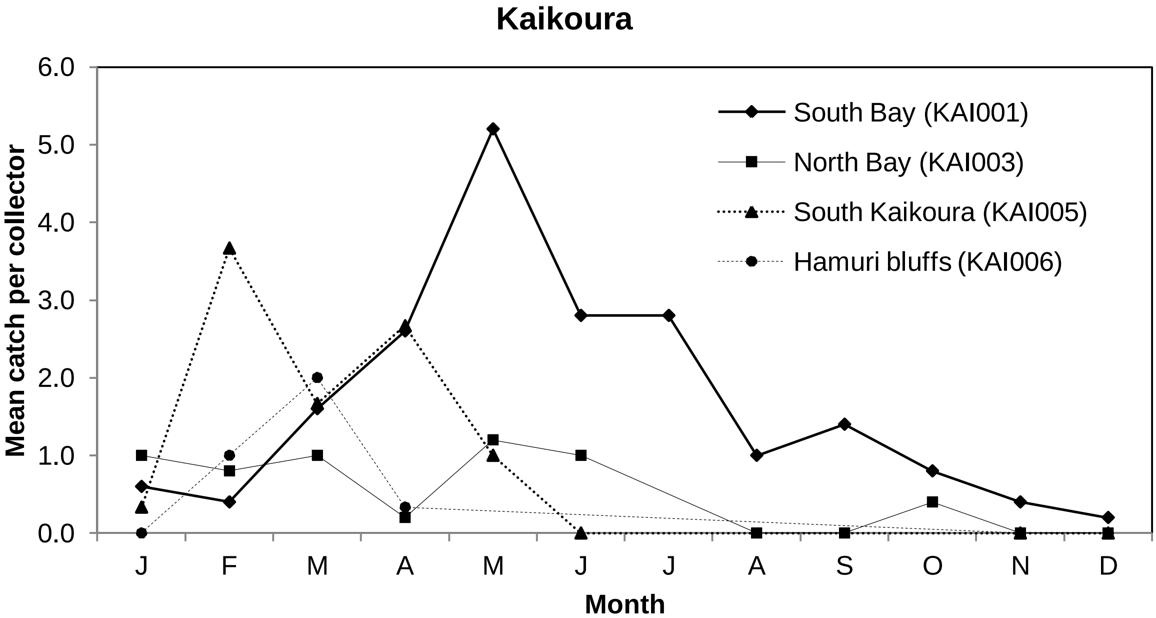

Figure 13: South Bay, North Bay, South Kaikoura, and Haumuri Bluff monthly settlement, 2012. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

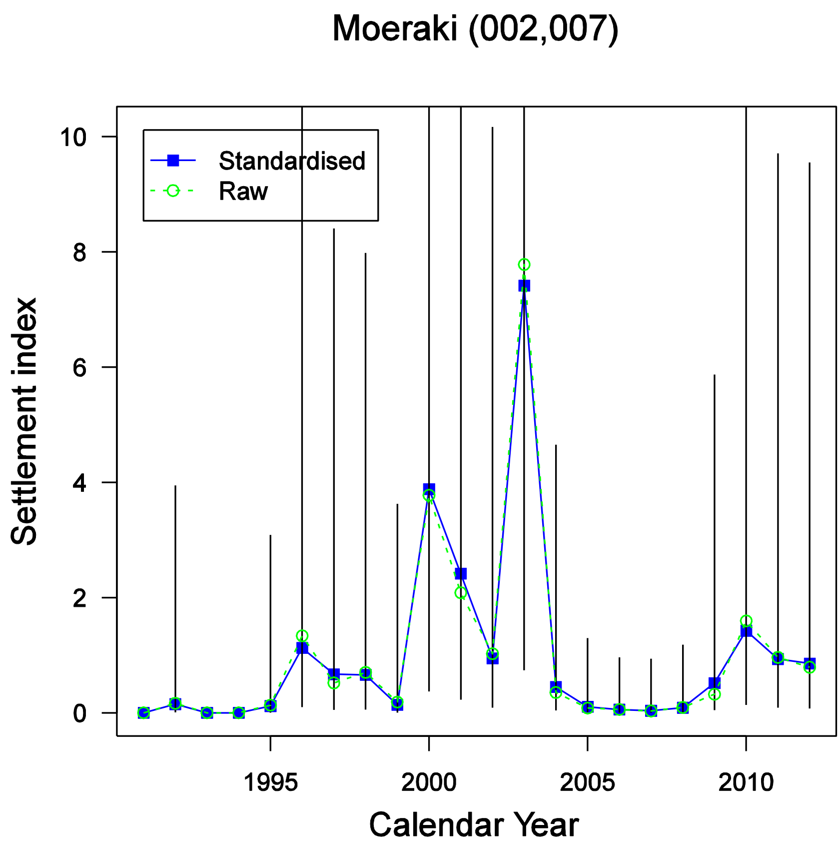

Figure 14: Moeraki—standardised and raw indices of annual settlement with 95% confidence intervals.

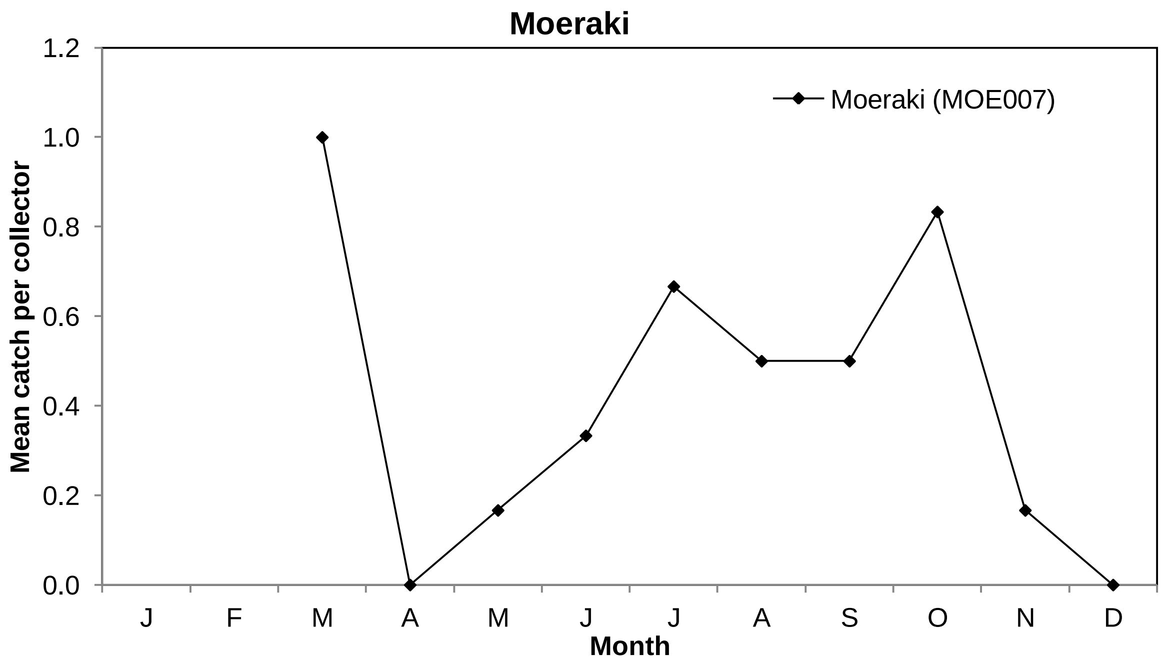

Figure 15: Moeraki monthly settlement, 2012. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

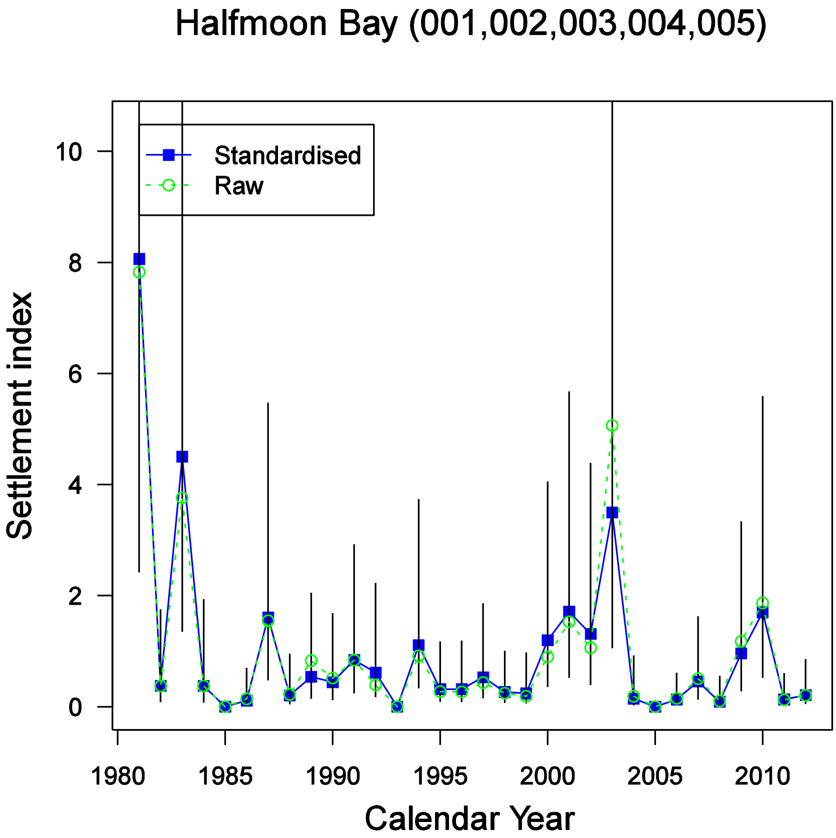

Figure 16: Halfmoon Bay—standardised and raw indices of annual settlement with 95% confidence intervals. The 95% confidence bounds were large because of high collector catch variability and the data not fitting the standardisation model well because of the large number of zero catches.

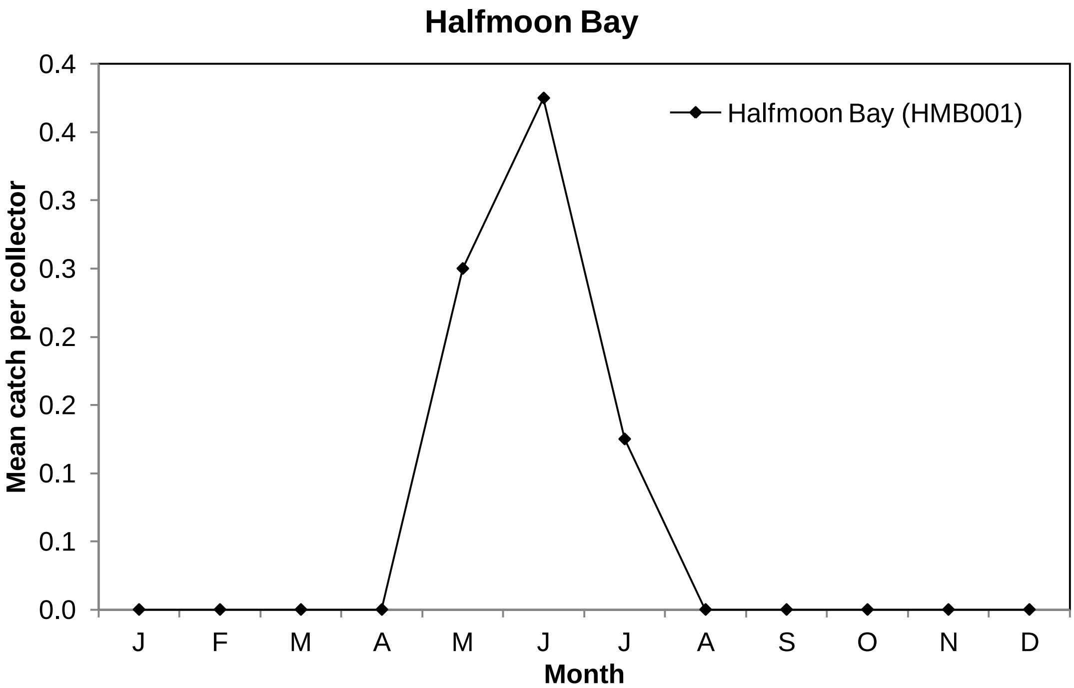

Figure 17: Halfmoon Bay monthly settlement, 2012. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

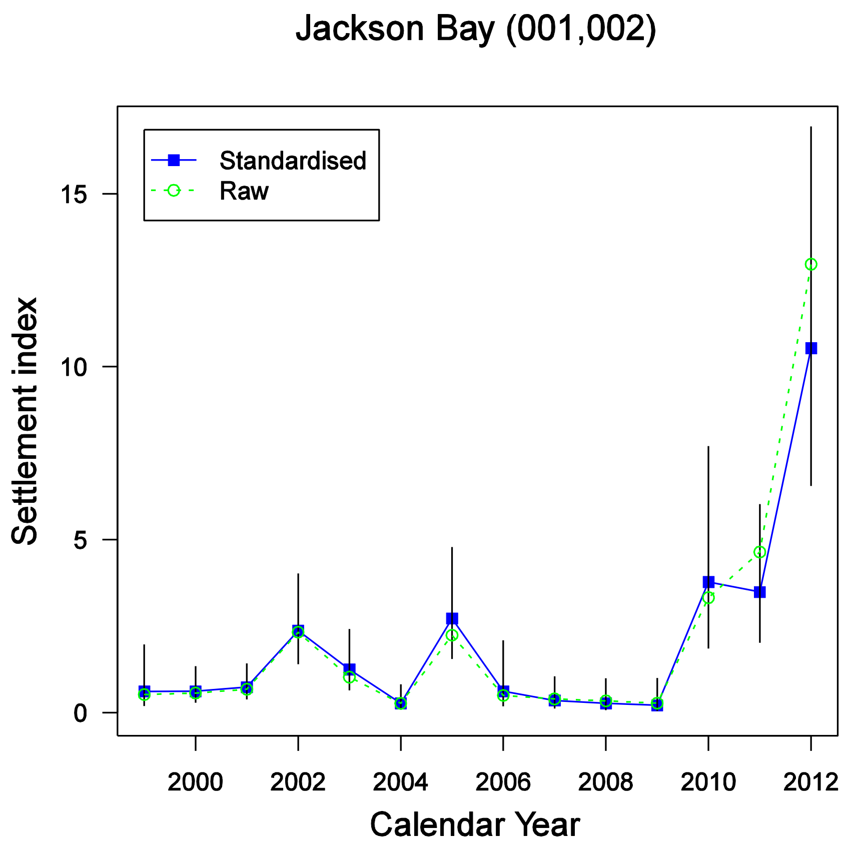

Figure 18: Jackson Bay—standardised and raw indices of annual settlement with 95% confidence intervals.

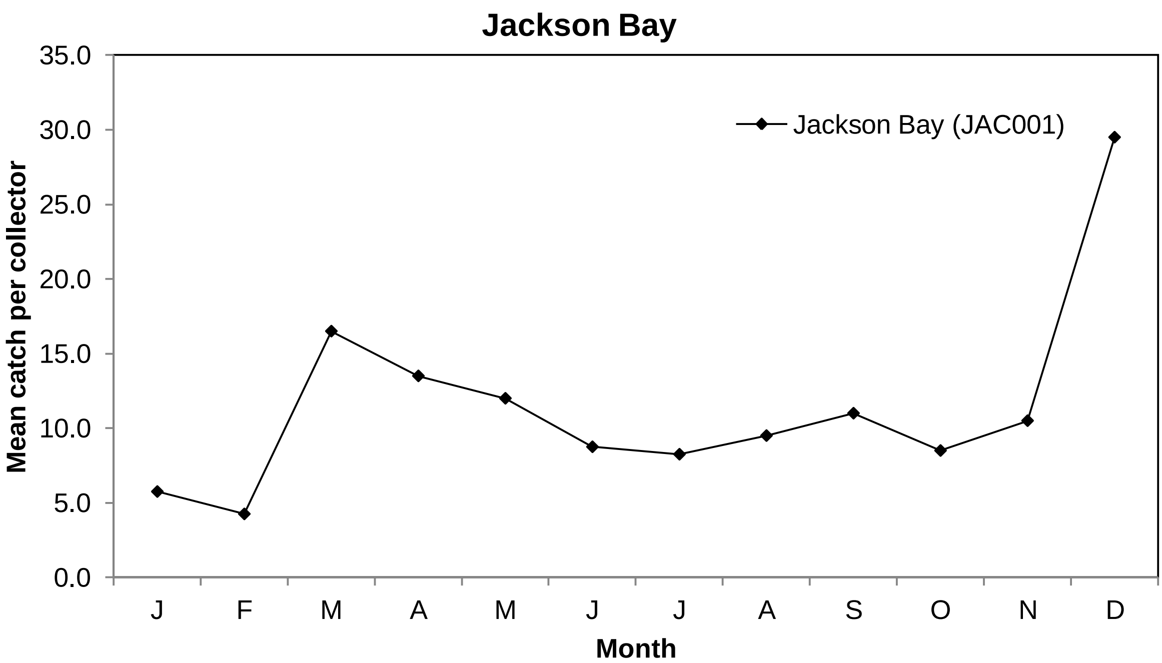

Figure 19: Raw monthly settlement, 2012. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

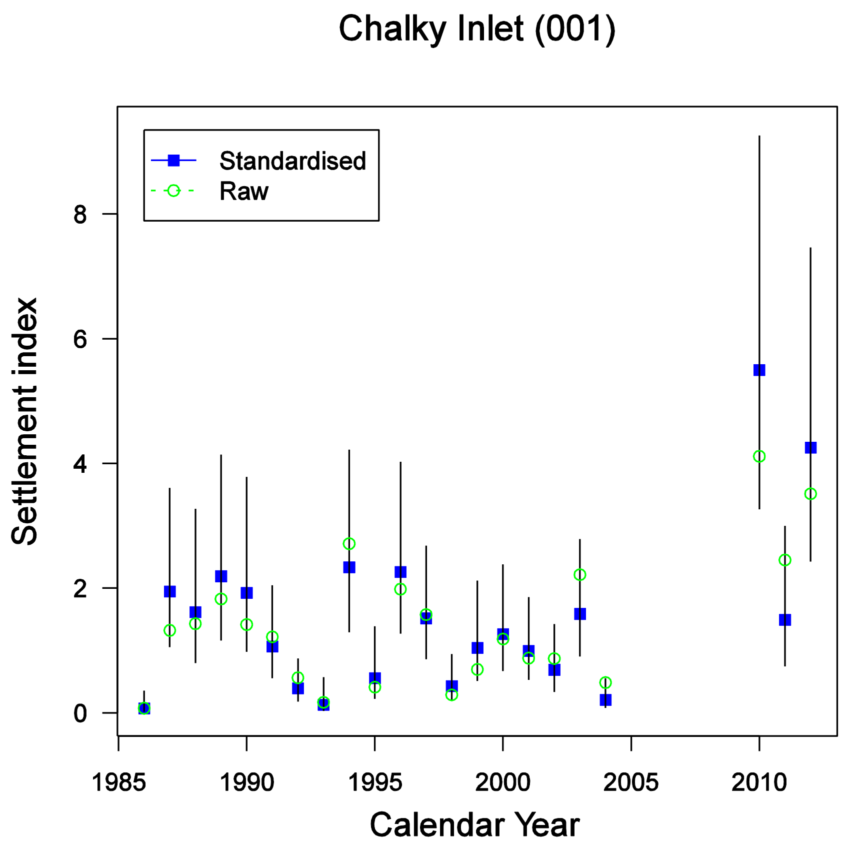

Figure 20: Chalky Inlet—standardised and raw indices of annual settlement with 95% confidence intervals.

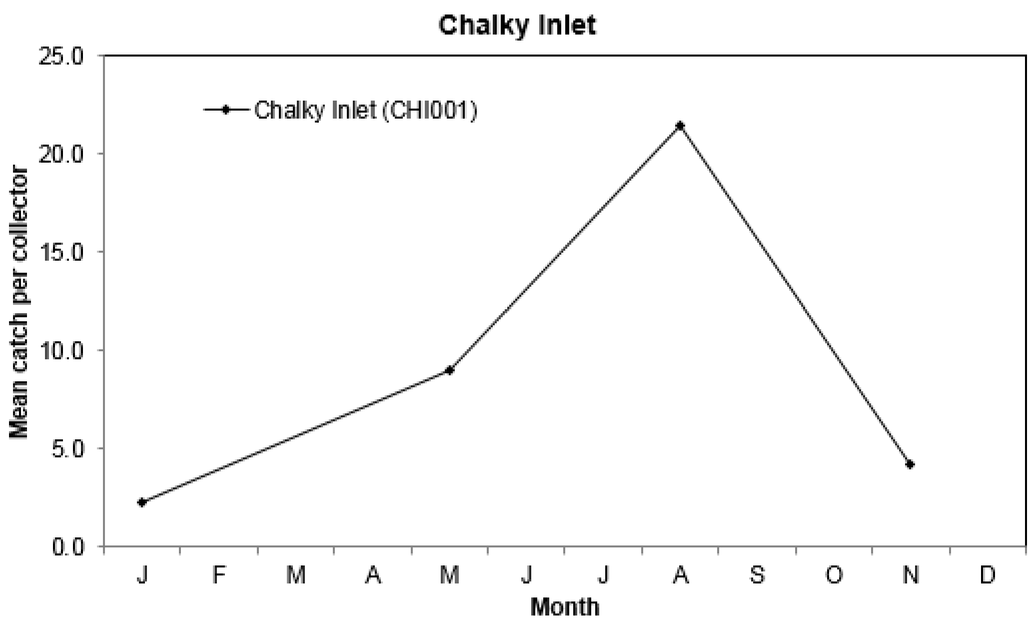

Figure 21: Raw monthly settlement, 2012. Mean number of *Jasus edwardsii* pueruli plus juveniles less than 14.5 mm carapace length per collector.

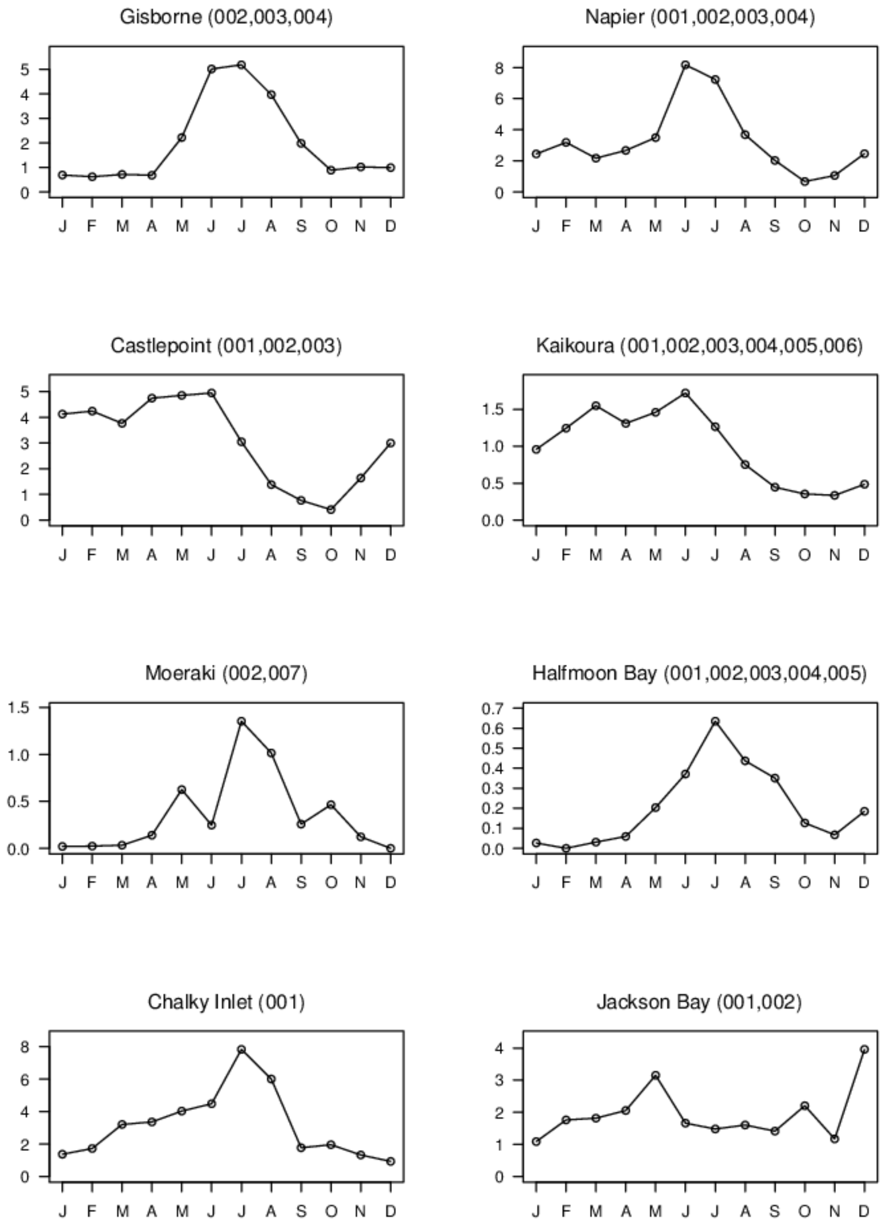

Figure 22: The mean settlement by month, over all years, for each key collector site. See Table 1 for the collector groups.

3.2 Puerulus staging data, settlement data, and the lunar cycle

3.2.1 Introduction

A collector is sampled approximately monthly, and pueruli are assigned to one of four age stages (S1 → S4) where S1 is the youngest and S4 is the oldest (Booth 1979). The total number of pueruli across all four stages (for a sample) is used to calculate the standardised yearly indices. In the review of the puerulus settlement program (Cockcroft 2011) one of the recommendations was that:

"*The extensive puerulus-staging data that are collected during routine monthly settlement sampling are not currently being used. These data may provide valuable insights into the puerulus settlement process including the influence of the lunar cycle on settlement.*

A desktop study should be initiated to ascertain if any obvious trends or patterns can be identified in the dataset. The entire settlement record could be examined to determine whether the stage of lunar cycle explains the proportions of newly settled pueruli at each service of the collectors. The staging data would also be essential for the condition factor study (see above) and may also be linked to a desktop study investigating the effect of lunar stage on settlement."

In this section two aspects of the puerulus settlement data and lunar cycle are examined:

1. The relationship between the proportion of newly settled pueruli and the lunar cycle. If there is a relationship then this could have implications for predicted recruitment to the fishery, as different stages of pueruli may have different condition factors and chances of surviving to recruitment to the fishery.

2. The relationship between total settlement (i.e. the total across the numbers at stages S1 to S4) and the lunar cycle. If there is a relationship then the standardised indices may need to account for this.

3.2.2 Available staging data

Staging data is in the table *t_puer_stage* of the data base *rocklob* (Appendix 4). Each record (i.e row of data after an extract) is for a single sample from a collector and has the collector number, the group of collectors that the collector is from (e.g CPT001), date the sample was taken, puerulus stage, and number of puerulus in the puerulus stage.

The available data of 22 783 records covers the calendar years 1998 to 2012 for the three sites Castlepoint, Gisborne, and Napier. Some grooming was done to remove records with missing values for the number of pueruli (819 records). Most collector groups had 200 or more records in each year, which is equivalent to 50 or more samples in a year (Tables 5–6). There were a low number of records for the collector group CPT002 in 1999 as they were covered with sand that year (Jeff Forman, NIWA, pers. comm.) The GIS004 group was discontinued in 2007 in a contraction of the sampling program, so there are no records for that year, but the group was started up again in 2008.

Table 5: Number of records by collector group and calendar year.

	CPT001	CPT002	GIS002	GIS004	NAP001	NAP003	Total
1998	360	180	240	220	220	252	1 472
1999	352	12	240	192	240	216	1 252
2000	388	88	236	220	196	168	1 296
2001	428	140	236	220	180	216	1 420
2002	316	172	240	260	192	192	1 372
2003	432	216	212	240	160	172	1 432
2004	392	203	180	160	236	240	1 411
2005	420	228	160	228	180	236	1 452
2006	396	212	196	240	240	167	1 451
2007	395	236	216	0	176	128	1 151
2008	420	180	172	216	200	232	1 420
2009	396	240	260	220	220	236	1 572
2010	396	220	180	220	240	208	1 464
2011	432	240	180	216	240	212	1 520
2012	432	224	176	240	220	176	1 468

Table 6: Number of samples by collector group and calendar year.

	CPT001	CPT002	GIS002	GIS004	NAP001	NAP003
1998	90	45	60	55	55	63
1999	88	3	59	48	60	54
2000	97	22	59	55	49	42
2001	107	35	59	55	45	54
2002	79	43	60	65	48	48
2003	108	54	53	60	40	43
2004	98	51	45	40	59	60
2005	105	57	40	57	45	59
2006	99	53	49	60	60	42
2007	99	59	54	0	44	32
2008	105	45	43	54	50	58
2009	99	60	60	55	55	59
2010	99	55	45	55	60	52
2011	108	60	45	54	60	53
2012	108	56	44	60	55	44

3.2.3 The lunar cycle

The lunar cycle (or moon phase) for a date was determined using the R package *phenology*. For a given date this package will give the moon phase as a value from 0 to 100 inclusive. Values for the moon phase of 0 and 100 represent full moon; 50 new moon; 25 the last quarter and 75 the first quarter. Moon phase values were cross-checked with some online moon phase web sites. A sample at a collector is thought to be a snapshot of settlement over the previous two weeks, so all dates were shifted back by seven days before the moon phase was calculated.

New and full moons are associated with spring tides (i.e. maximal tidal range). The first and last quarter moon are associated with neap tides (minimal tidal ranges).

3.2.4 Newly settled pueruli and the lunar cycle

Younger pueruli (S1 and S2) generally make up a small percentage of pueruli collected in samples, with the majority of pueruli being in stage S3 or S4 (Table 7).

Table 7: Percentage in each stage (S1 → S4) by collector group

	S1	S2	S3	S4
CPT001	8	5	43	44
CPT002	3	5	33	59
GIS002	4	14	20	62
GIS004	3	5	42	51
NAP001	2	8	39	52
NAP003	18	18	22	41

There is an association between the time of puerulus sampling and the moon phase (Figure 23). Shore collectors are most easily accessed when the tide is at its lowest, which occurs during new and full moons (i.e. moon phase near to 50 or 100), whereas for wharf collectors this is less important. The Castlepoint point collectors are shore collectors, and are sampled in the afternoon by NIWA as a day trip from Wellington. These collectors show a pronounced clustering of sampling near new and full moons. The Gisborne collectors are also shore collectors, with clustering of sampling near new moon (but this is less pronounced than for Castlepoint). Of the two groups of collectors at the Napier site, one is a group of shore collectors (NAP003) and shows a clustering of sampling near the full moon, while the other is a wharf collector (NAP001) and sampling is more spread out with respect to moon phase.

There is no obvious relationship between the percentage of younger pueruli (S1 or S2) in a sample and the moon phase (Figure 24). For the collector group CPT002 there are hints that the percentage increases as the moon phase gets nearer to 100, but this seems to be due to a few points in some years (Figure 25). More formal statistical tests for CPT002, in which this percentage was modelled as a function of moon phase or other predictors, gave no statistically significant relationship with moon phase (Table 8).

Table 8: Summary of glm models to predict the proportion of sampled pueruli in stages S1 or S2 for the group of collectors CPT002. The quasibinomial family for the glm function in R was used (Crawley 2005, p. 257). Year is the calendar year (January to December).

model: moonphase + factor(year) + factor(month)

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			463	466.38			
moonphase	1	2.334	462	464.04	1.9546	0.1628032	
factor(year)	14	44.693	448	419.35	2.6738	0.0009073	***
factor(month)	11	30.144	437	389.21	2.2953	0.0097621	**

model: poly(moonphase,4) + factor(year) + factor(month)

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			463	466.38			
poly(moonphase, 4)	4	4.628	459	461.75	0.9596	0.4294561	
factor(year)	14	45.895	445	415.85	2.7191	0.0007407	***
factor(month)	11	29.283	434	386.57	2.2080	0.0132645	*

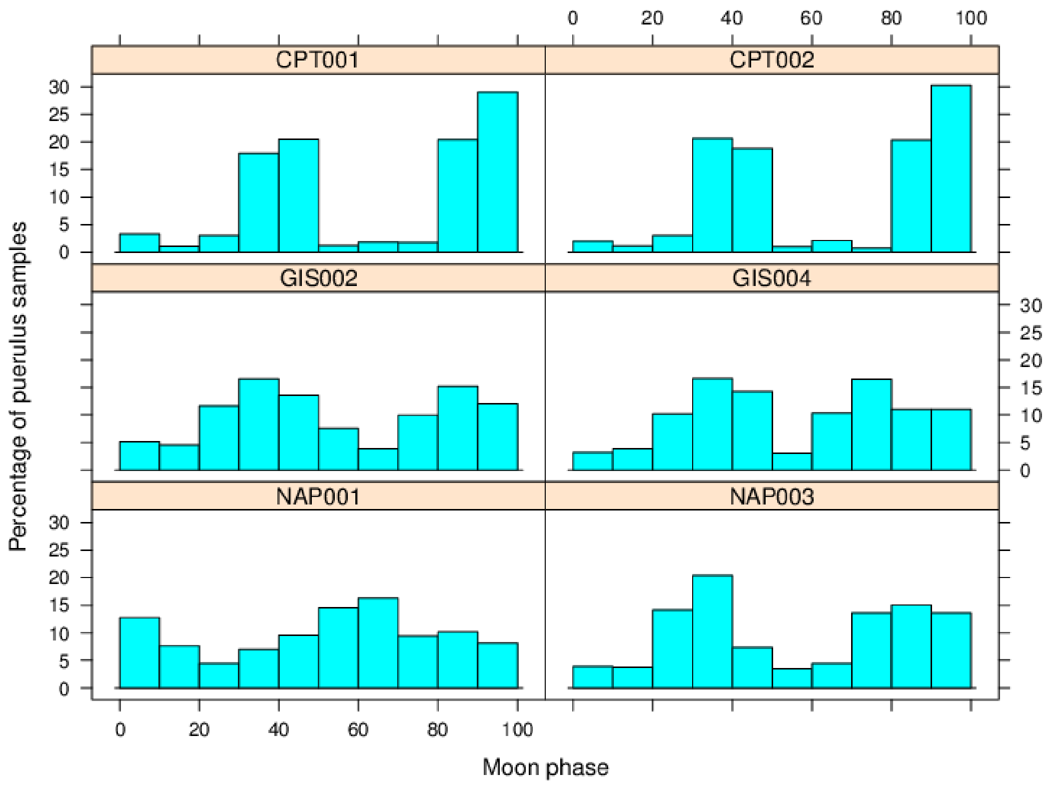

Figure 23: Percentage of samples taken by moon phase when they were sampled.

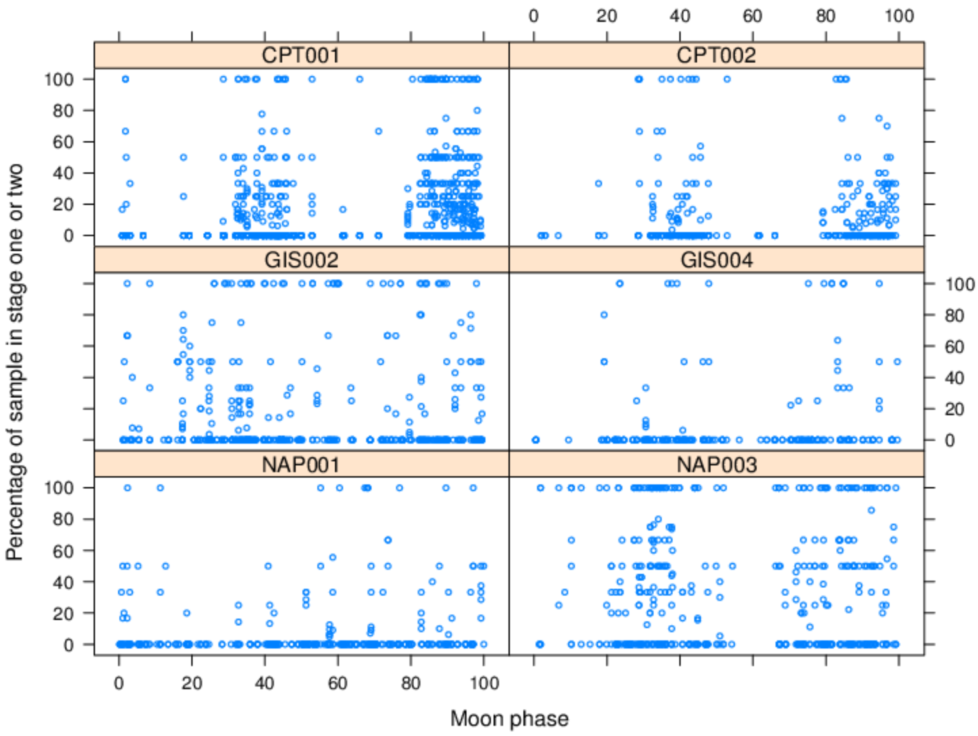

Figure 24: Percentage of newly settled pueruli by moon phase.

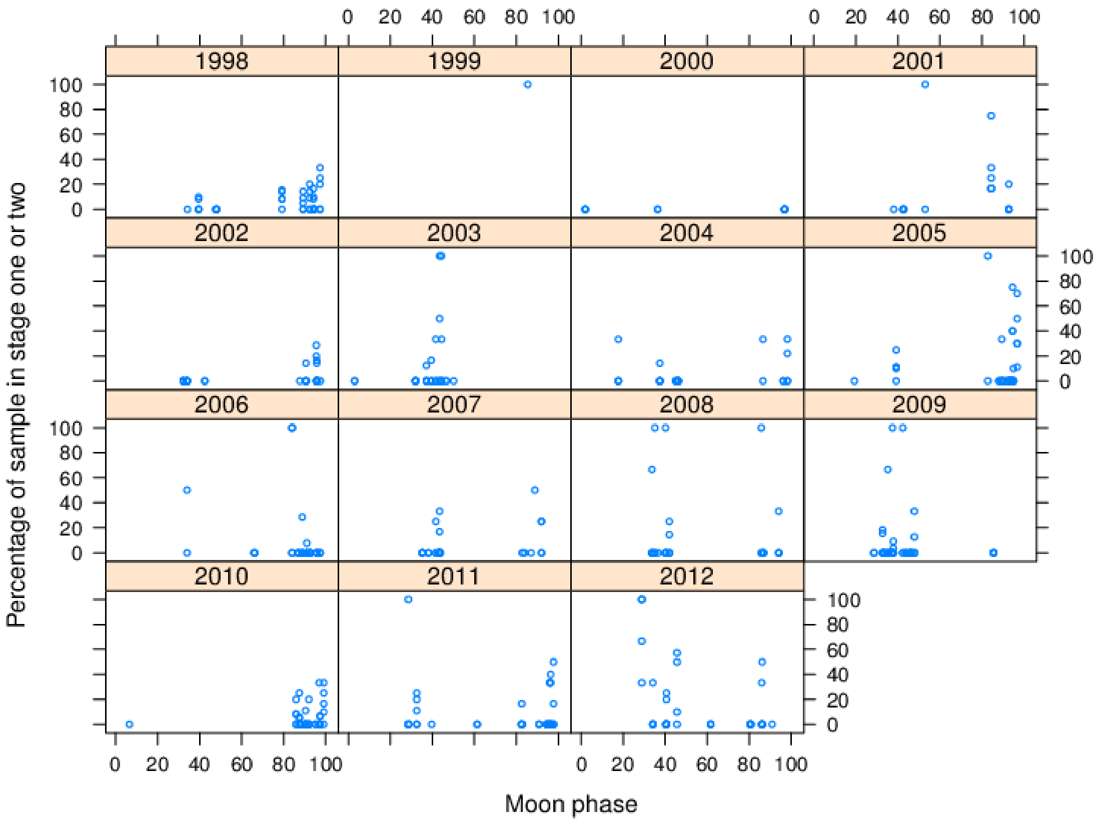

Figure 25: Percentage of newly settled pueruli by moon phase for collector group CPT002.

3.2.5 Total settlement and the lunar cycle

Total settlement is the total number of pueruli recorded at a sampling for a month from a collector, and is the sum of the number at stages S1 to S4. Yearly indices of settlement for a site are calculated as a geometric mean over the months for a year. To adjust for differences in settlement due to differences in the months sampled from or the collector/group of collectors sampled from, standardised yearly indices are also calculated where month and collector/group of collectors are offered as predictor variables in the standardisations. Do the standardised yearly indices also need to be adjusted for the moon phase at which sampling takes places? Before addressing this question directly in the standardisations, some exploratory analyses of the settlement data with respect to moon phase are given.

The moon phases at which sampling takes place for the groups of collectors used in the standardisation are shown in Figure 26. Some sites show a clustering around the moon phases of 50 and 100 for a new moon and full moon (e.g. Castlepoint) while for other sites the sampling is more evenly spread across the moon phases (e.g. Kaikoura). Some explanations for these patterns are given in Section 3.2.4. Plotting the number of pueruli versus the moon phase shows no consistent correlations with moon phase (Figure 27).

For the purposes of exploring the standardisation and the impact of moon phase, sites with a long sequence of data (sampling taking place from 1983 or earlier) and unproblematic standardisations are selected: Castlepoint, Napier, and Kaikoura (Figure 28). For these sites moon phase was offered to the standardisations as a fourth degree polynomial, this polynomial form was chosen for flexibility and to accommodate the peaks in the lunar cycle at 50 and 100. For the standardisations moon phase was accepted as the last predictor variable for all three sites, and made very little difference to the standardised indices (Figures 29–31).

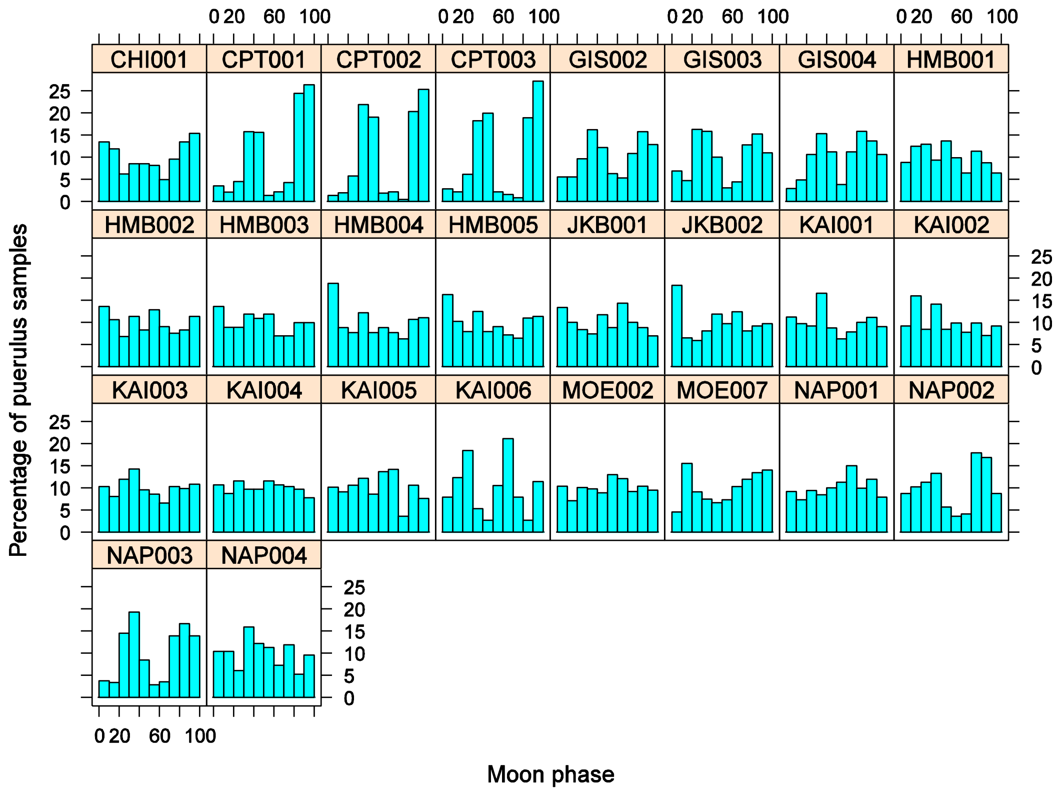

Figure 26: Percentage of puerulus samples taken by moon phase for the collector groups (see Table 1) and data used in the standardised puerulus indices calculations.

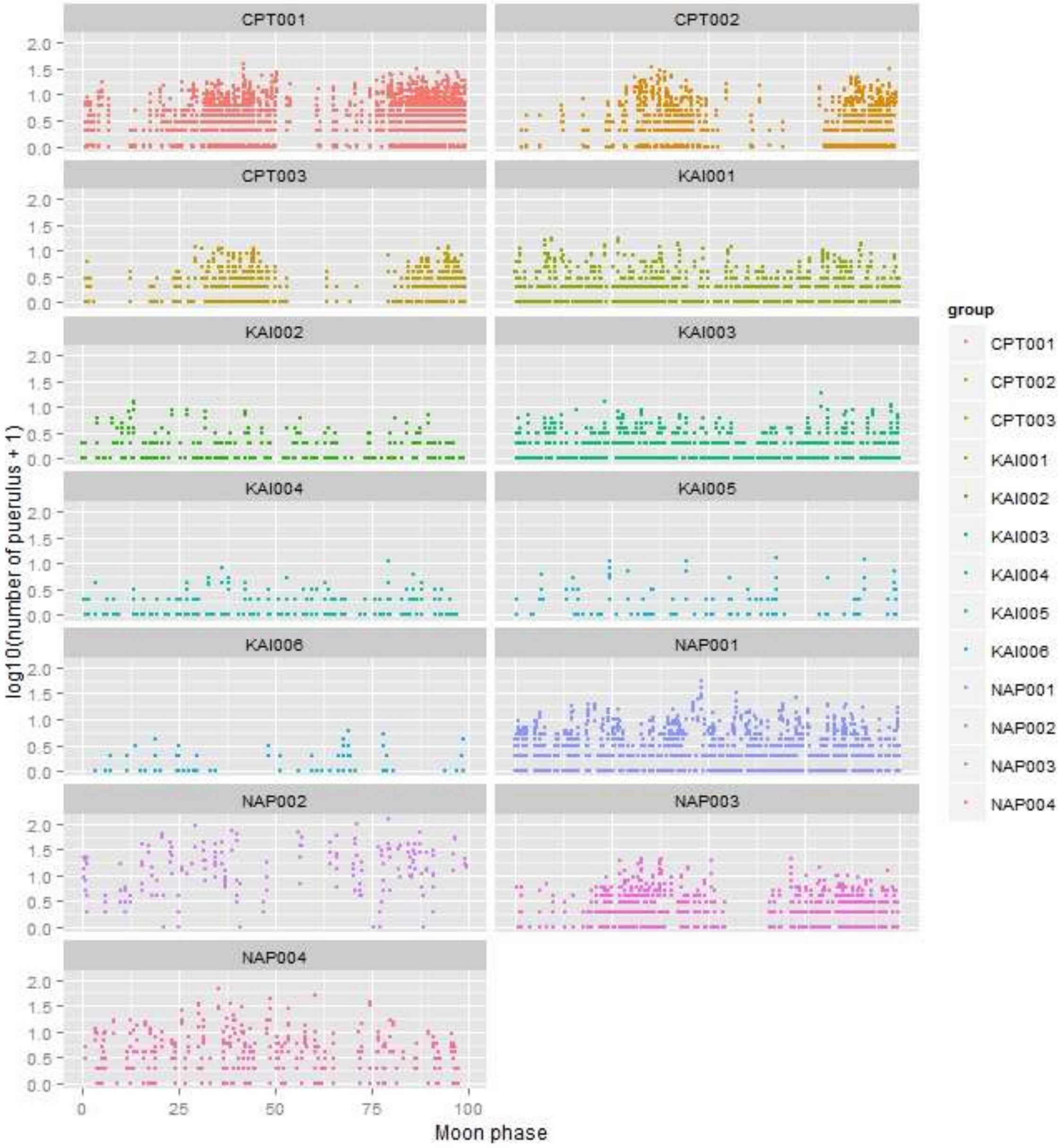

Figure 27: Number of pueruli for a sample versus the moon phase for selected collector groups used in the standardisations. The y-axis is on a log scale.

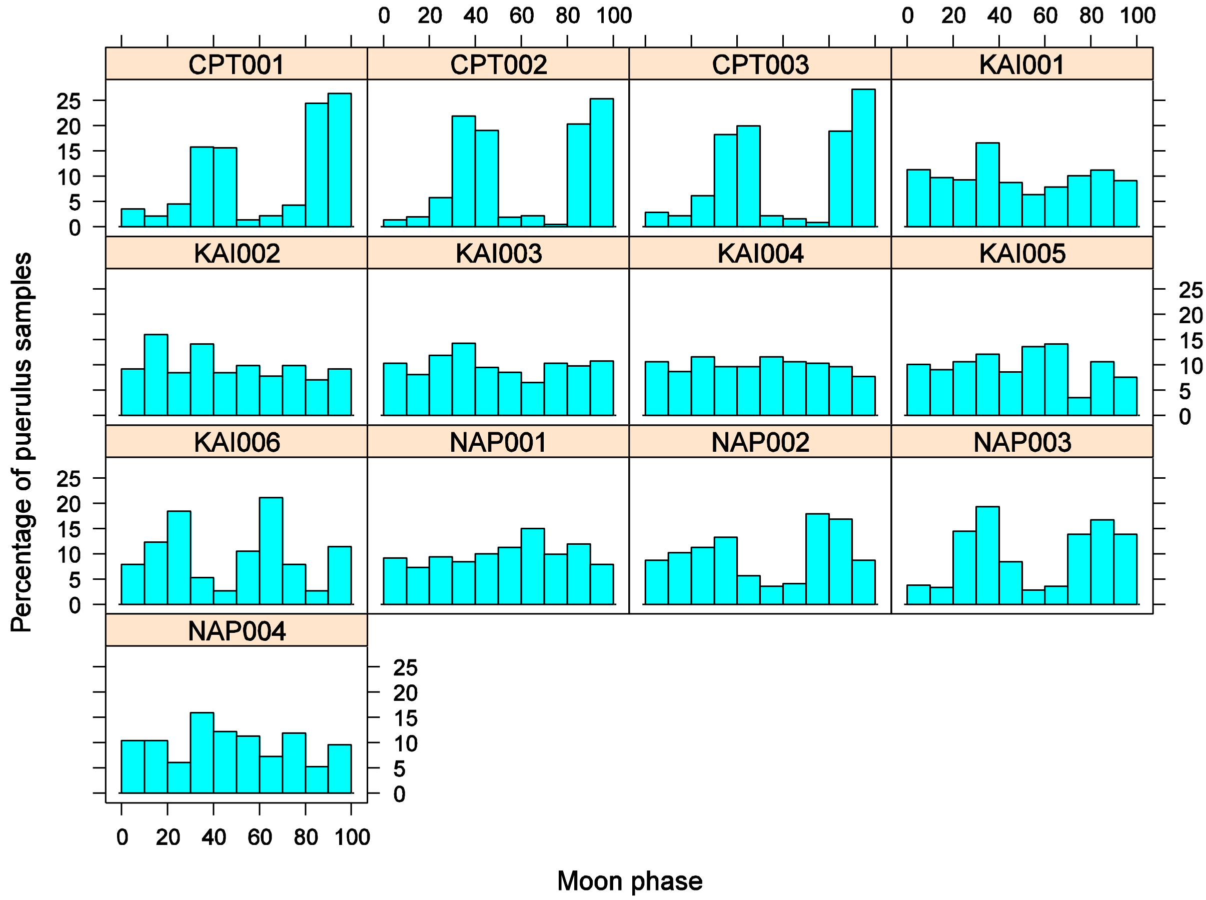

Figure 28: Percentage of puerulus samples taken by moon phase for selected groups used in the standardised puerulus indices calculations.

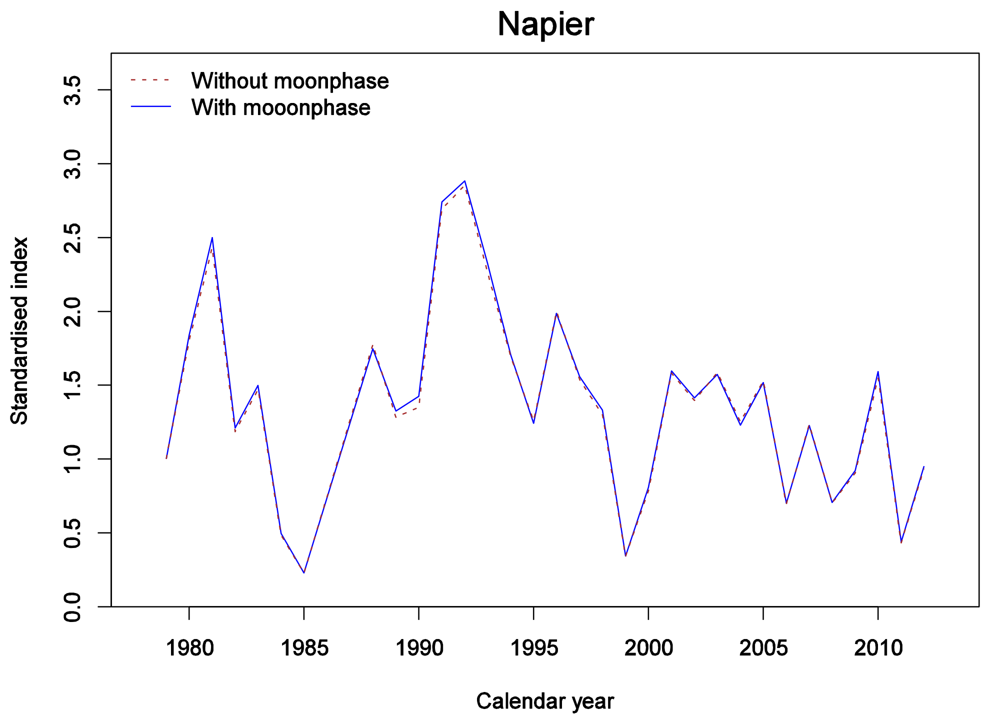

Figure 29: Standardised indices for Napier with and without the moon phase as a predictor variable. Both indices are scaled to have the value one in the first year.

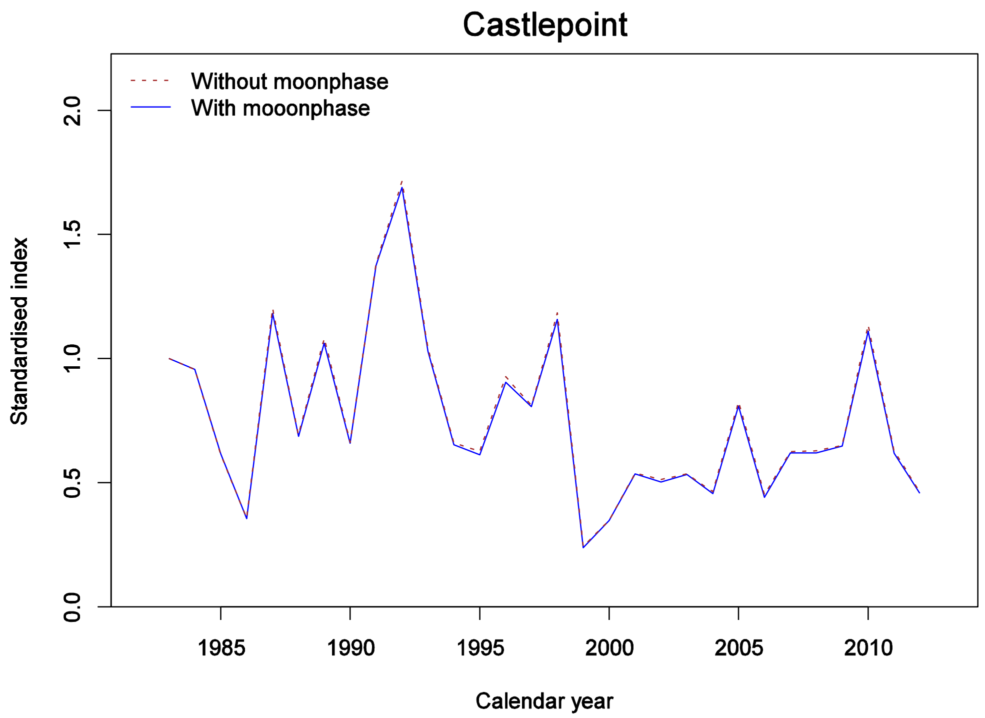

Figure 30: Standardised indices for Castlepoint with and without the moon phase as a predictor variable. Both indices are scaled to have the value one in the first year.

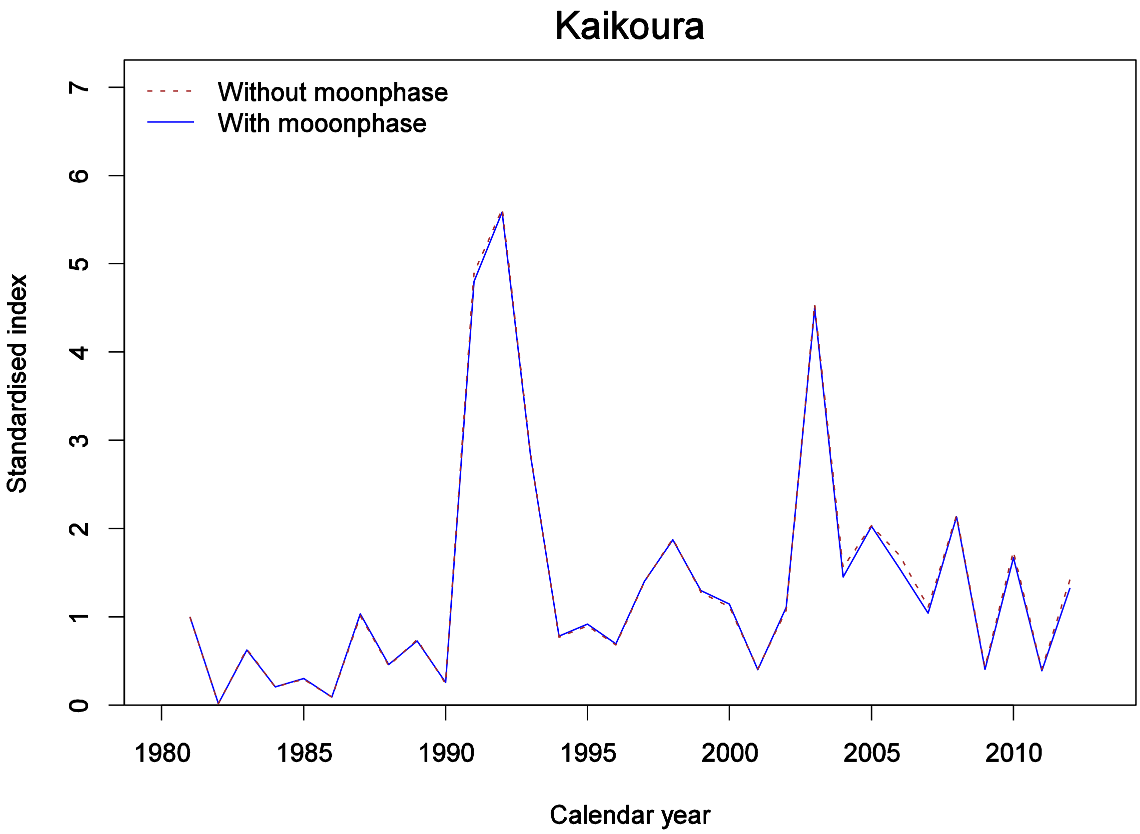

Figure 31: Standardised indices for Kaikoura with and without the moon phase as a predictor variable. Both indices are scaled to have the value one in the first year.

3.3 Reducing zeros for the puerulus settlement data in CRA 7 and CRA 8

3.3.1 Introduction

In the review of the puerulus settlement program (Cockcroft 2011) one of the recommendations was that:

"In order to reduce the large number of zeros in the settlement data in CRA7 and CRA8, it is recommended that the use of only data from peak settlement periods be examined."

This is examined for the sites Moeraki (CRA 7), Jackson Bay (CRA 8), and Halfmoon Bay (CRA 8). It was found that for Jackson Bay the number of zeros isn't particularly high and there is no period of peak settlement. For Moeraki and Jackson Bay restricting the data to the months May to October substantially reduces the number of samples required, but leaves the standardised indices very similar and with reduced confidence intervals.

3.3.2 Sample characteristics

Some descriptive plots were made of the count data from the three sites. They show the proportions for the number of pueruli counted in a sample, the percentage of samples taken by month, the proportion of non-zero counts for each month, and the mean count value by month (Figures 32–34).

Moeraki and Halfmoon Bay have over 80% zero counts for samples, and a broad peak period for non-zero settlement from about May to October. However, even over this peak period the proportion of non-zero samples is often 20% or less, and never more than 40%. This means that no matter what period of peak settlement is chosen the proportion of zero counts will be greater than 60%.

In contrast Jackson Bay doesn't have a particularly high proportion of zero counts (about 60%), and there is no period of peak settlement, so this site will not be considered further.

3.3.3 Using just the peak settlement period

One potential problem with the sampling is that the months of sampling may change over time, but not be overlapping, leading to difficulties separating year and month effects. This potential problem could be exacerbated if a subset of months is used in analysis. However, there is good overlap for months of sampling over time for both Moeraki and Halfmoon Bay (Figures 35–36).

Another potential problem is that the months of peak settlement could change over time, so that is difficult to discern a period of peak settlement, and the chosen peak period months may miss a block of settlement in a year. Which particular months have the highest counts certainly varies from year to year, but the months May to October encompass most of them from 1999 onwards (Figures 37–38).

Using only the months of settlement of May to October inclusive the standardisation for Moeraki was repeated (using the same predictor variable of month). This reduces the number of samples by 39% (from 1327 to 808) but the index is very similar and with smaller confidence intervals (Table 9, Figures 39–40). However, the number of samples before 2003 is small (before and after truncating the months).

The standardisation for Halfmoon Bay was also repeated using the months of May to October inclusive (using the same predictor variables). This reduces the number of samples by 37% (from 2499 to 1570) but the index is very similar and with smaller confidence intervals (Table 10, Figures 41–42). However, the number of samples left before 1986 is minimal.

In summary, restricting the months from May to October (inclusive) reduces the number of samples by about 40%, and gives standardised indices that are very similar and with reduced confidence intervals. Reducing sampling from May to October could reduce the cost of sampling, but runs the risk that if settlement shifted to outside these months it would be missed. However, if uniform sampling took place throughout the year, this restriction of the months used for the standardisation could still be used and be beneficial for the standardisation process.

Table 9: Number of Moeraki samples by year using all months, and truncating to the months May to October inclusive.

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Original	21	17	18	18	21	21	27	24	15	26	35	41
Truncated	18	14	12	12	15	18	18	18	12	15	21	27

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Original	128	151	169	98	87	121	87	58	105	39	1327
Truncated	82	77	86	79	52	73	39	46	50	24	808

Table 10: Number of Halfmoon Bay samples by year using all months, and truncating to the months May to October inclusive.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Original	21	32	27	24	21	42	54	54	36	58	75
Truncated	9	17	15	12	12	30	27	33	33	46	48
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Original	107	122	134	132	123	138	123	111	120	129	138
Truncated	59	88	87	75	84	87	84	78	75	90	87
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Original	36	32	56	80	83	58	61	88	96	88	2499
Truncated	22	16	32	48	47	40	45	48	48	48	1570

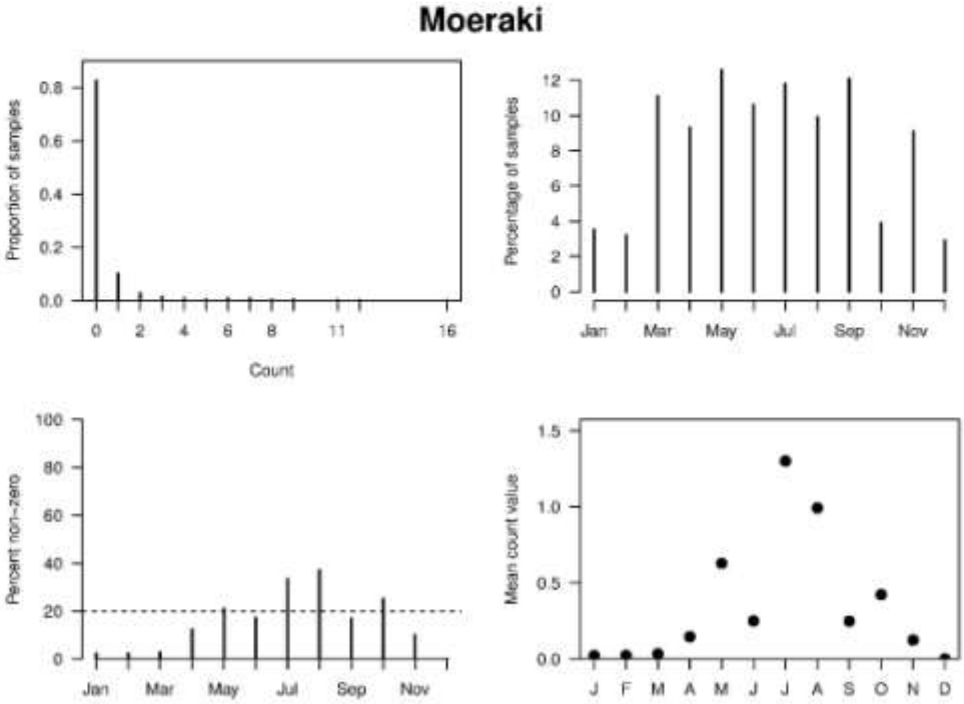

Figure 32: Characteristics of the Moeraki samples.

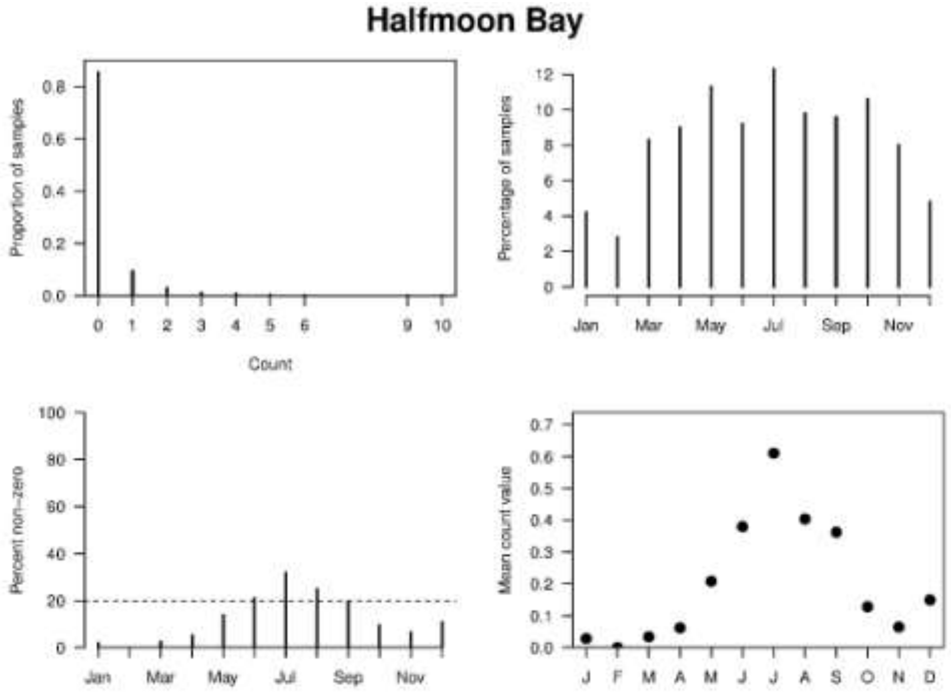

Figure 33: Characteristics of the Halfmoon Bay samples.

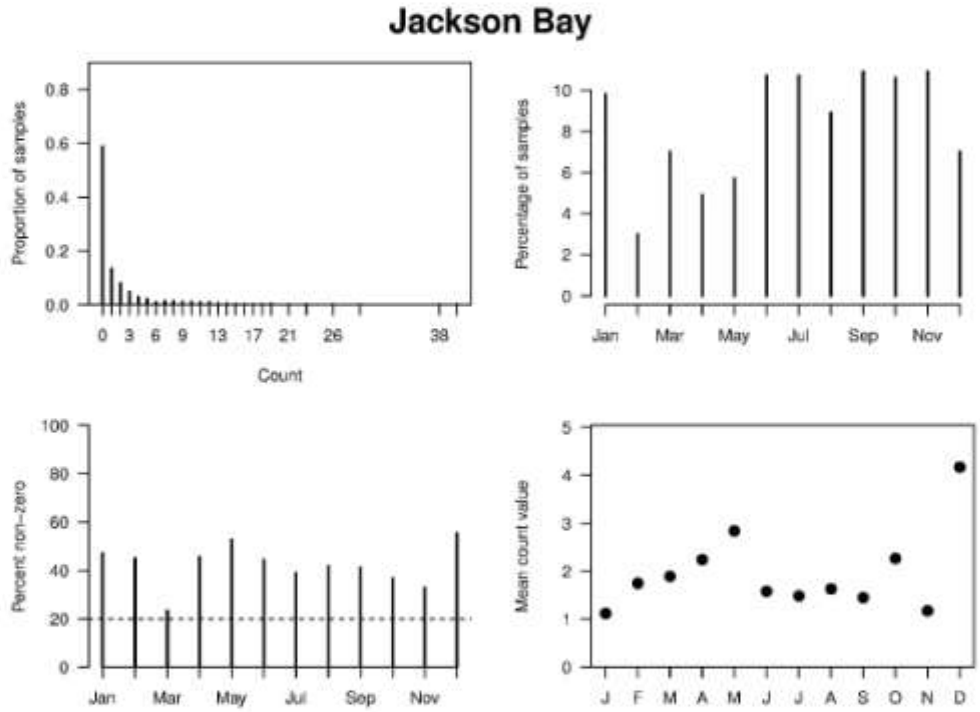

Figure 34: Characteristics of the Jackson Bay sample.

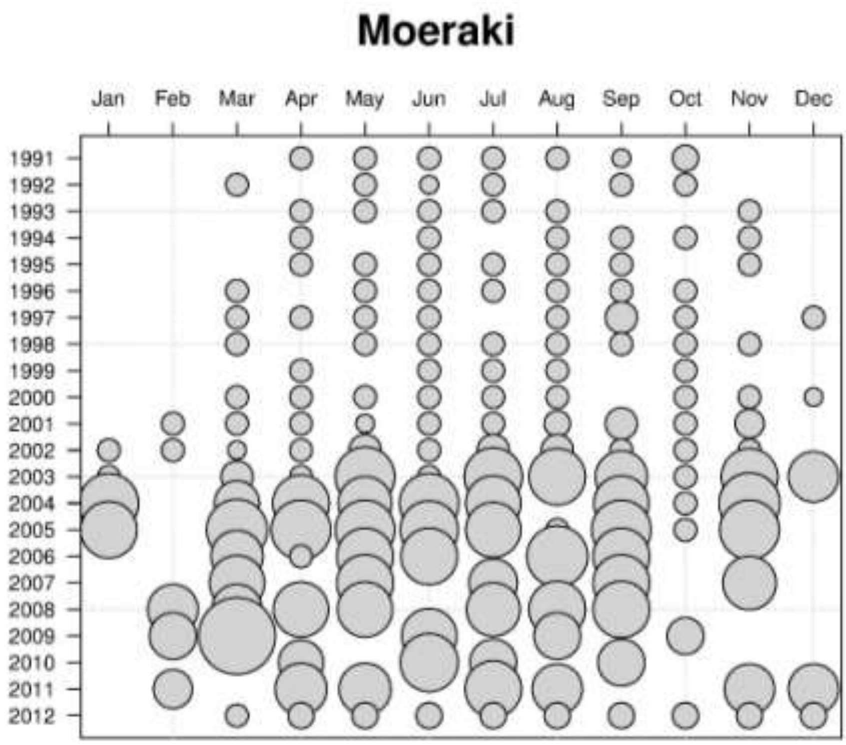

Figure 35: Number of samples taken by year and month for Moeraki. The area of the circles is proportional to the number of samples.

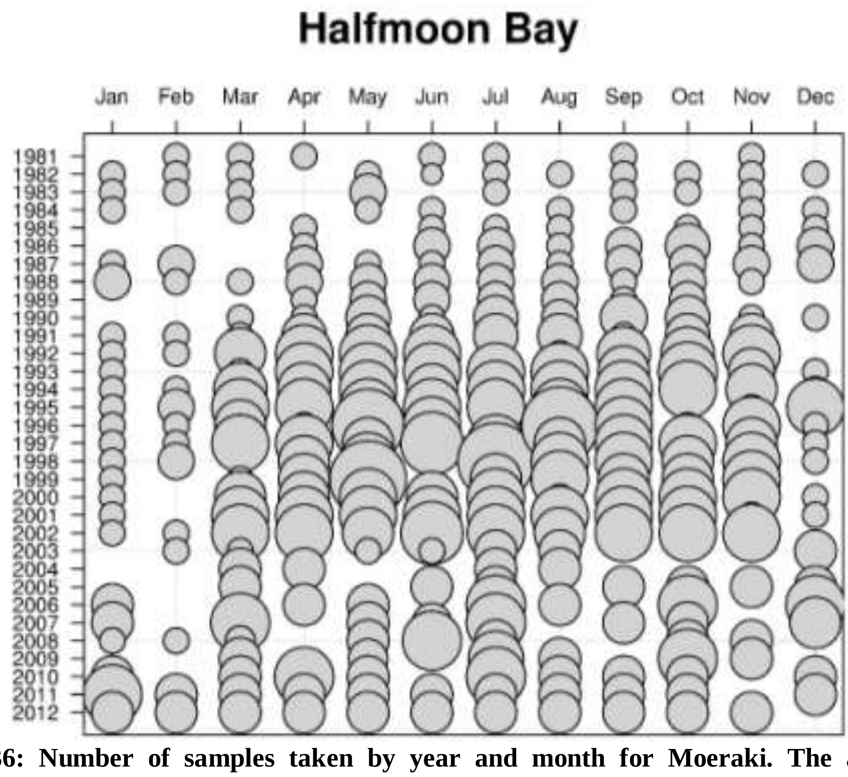

Figure 36: Number of samples taken by year and month for Moeraki. The area of the circles is proportional to the number of samples.

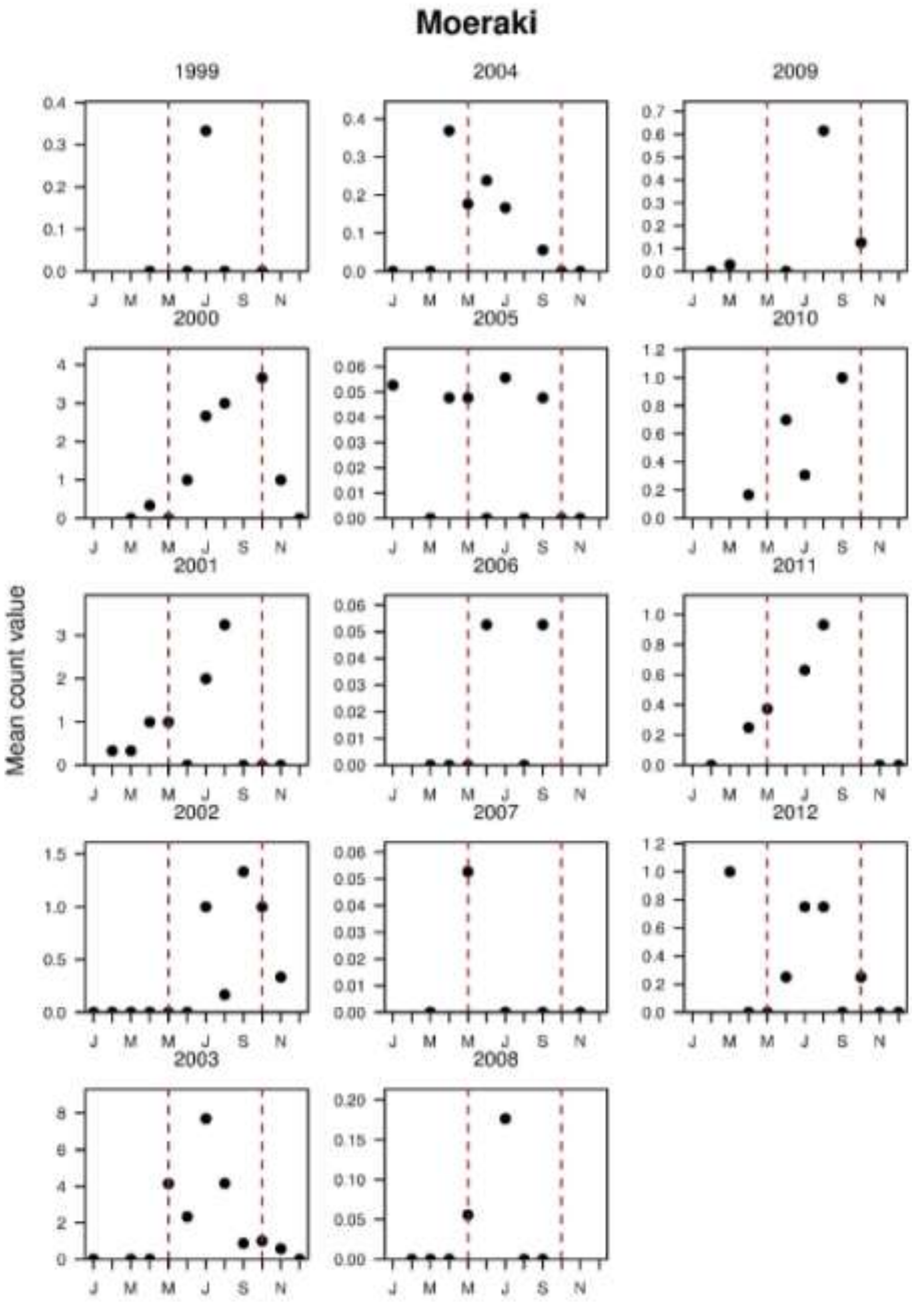

Figure 37: Mean count values by year from 1999 onwards for Moeraki. Note that the scale on the y-axis changes from year to year. Vertical lines are at May and October.

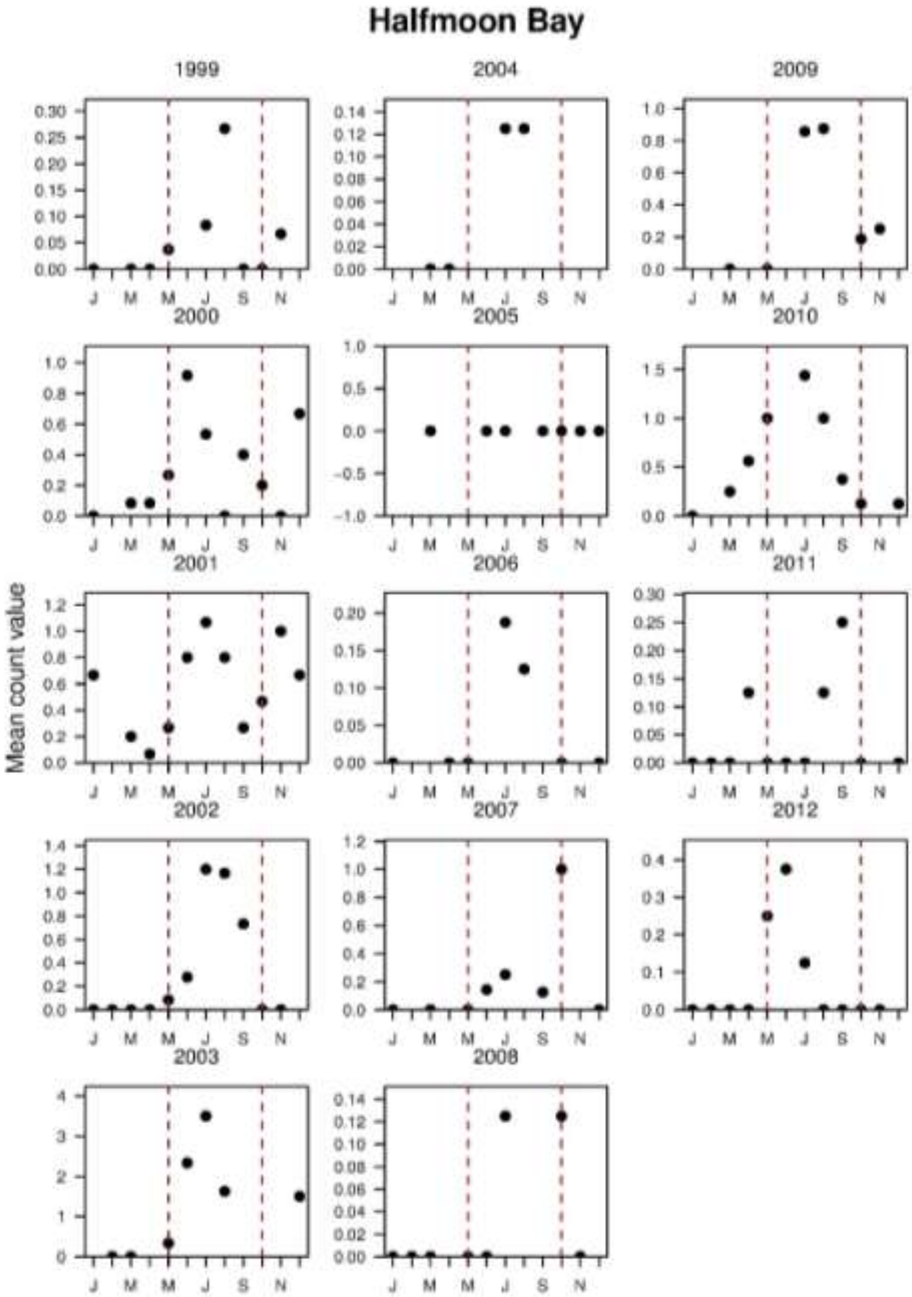

Figure 38: Mean count values by year from 1999 onwards for Halfmoon Bay. Note that the scale on the y-axis changes from year to year. Vertical lines are at May and October.

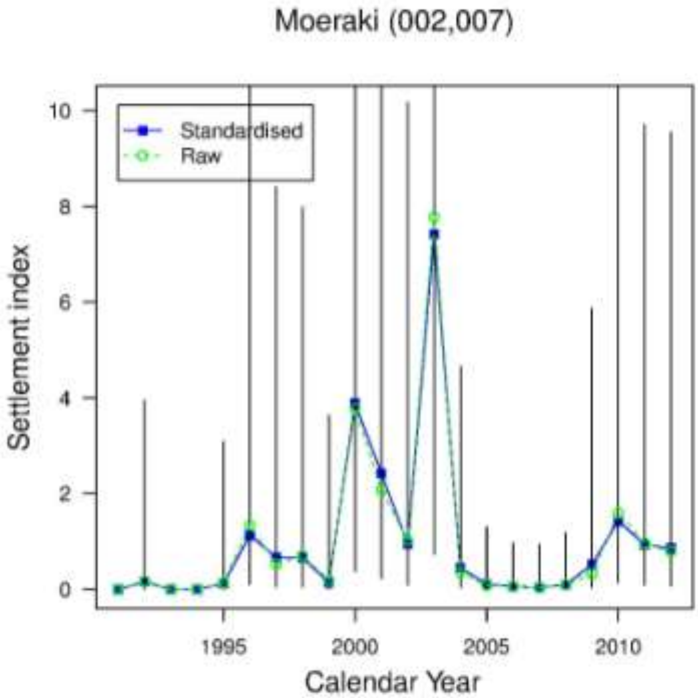

Figure 39: Moeraki - standardised and raw indices of annual settlement with 95% confidence interval (using all months).

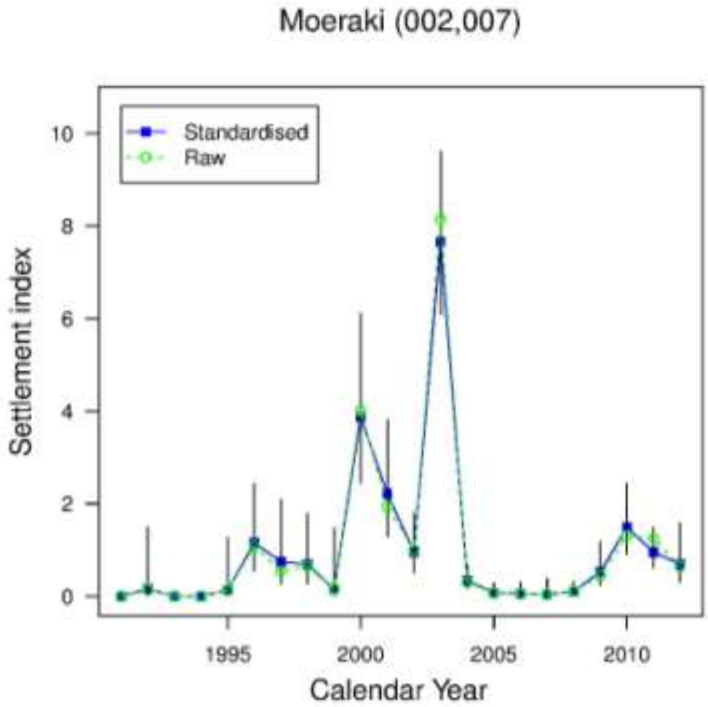

Figure 40: Moeraki - standardised and raw indices of annual settlement with 95% confidence interval (using the months May to October inclusive).

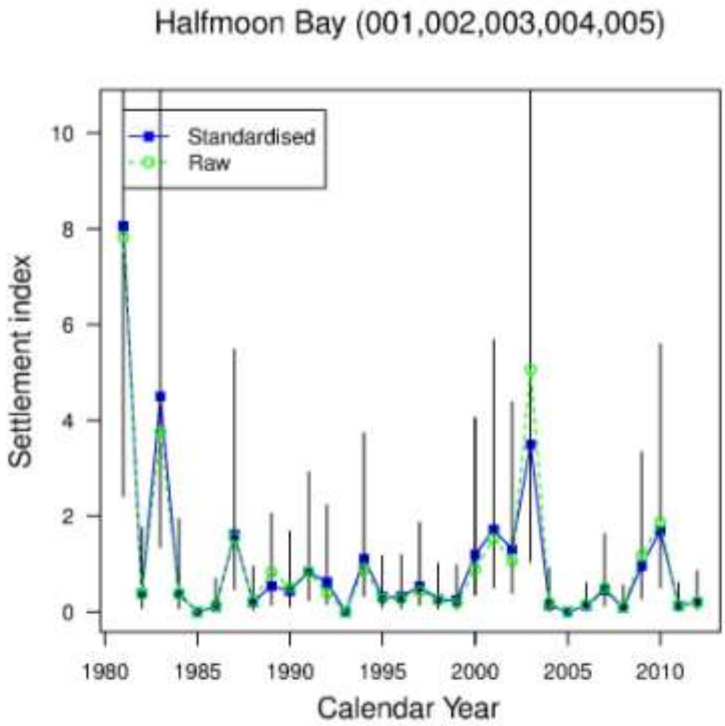

Figure 41: Halfmoon Bay - standardised and raw indices of annual settlement with 95% confidence interval (using all months).

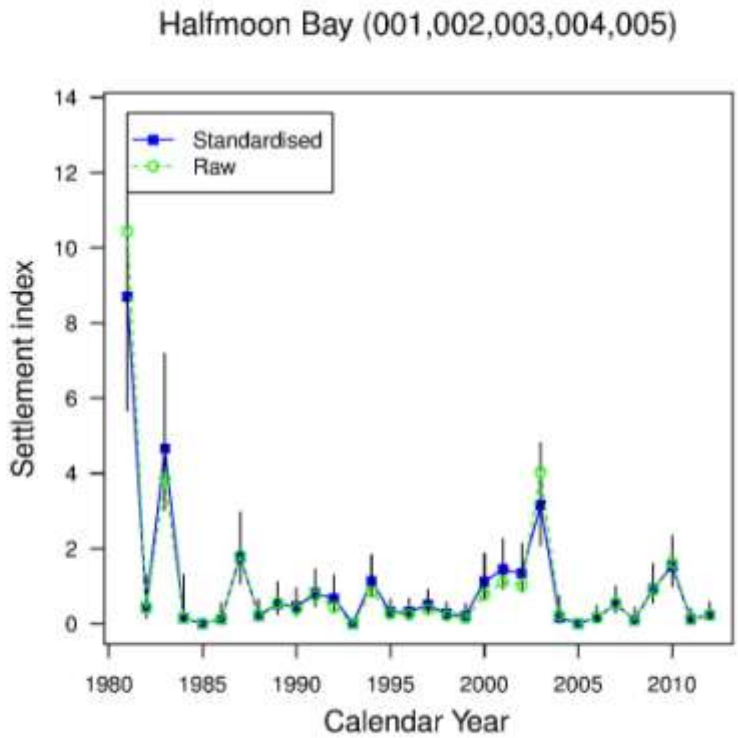

Figure 42: Halfmoon Bay - standardised and raw indices of annual settlement with 95% confidence interval (using the months May to October inclusive).

4. CONCLUSIONS

In 2012, Gisborne, Napier, Castlepoint, Moeraki, and Halfmoon Bay recorded levels of puerulus settlement that were below their long-term means. Kaikoura was above the long-term mean, and Jackson Bay was well above the long-term mean.

The low levels of settlement that were recorded in Gisborne (CRA 3) in 2012 are a continuation of below average settlement that has occurred over the last 7 years. With the exception of 1999, the next 6 lowest settlement years have occurred during this period.

In Napier and Castlepoint (CRA 4), settlement was below the long-term mean. This continues a series of mostly average to below average settlement since the record low of 1999. In Napier, 5 of the last 7 years have been below average and at Castlepoint, settlement has been above average only twice in the last 14 years.

Settlement at Kaikoura (CRA 5) was above the long-term mean in 2012 and apart from 2011 and 2009, settlement has been above average over the last 11 years.

Moeraki (CRA 7) was just below the long-term mean. Over the last 3 years, settlement has only been just below or just above average, but this compares well to the 6 years of very low settlement that preceded it.

In CRA 8, Halfmoon Bay again recorded low levels of settlement. In 8 of the last 10 years, settlement has been well below average. Jackson Bay, after four years of very low settlement between 2006 and 2009, has now recorded three consecutive years of very high settlement, with 2012 reaching a record high. This was matched with similar high levels of settlement in Chalky Inlet over the same period.

5. MANAGEMENT IMPLICATIONS

For Gisborne, Napier, and Castlepoint the puerulus index is potentially a signal for recruited abundance 4–6 years into the future (Booth & McKenzie 2008). For other sites estimated intervals from settlement to recruitment in the fishery are 4–5 years (Moeraki) or 6–8 years (Halfmoon Bay).

For Gisborne, the puerulus indices for six out of the last seven years are significantly below the long-term average, indicating a reduced abundance in the near future. Napier and Castlepoint show a similar pattern with five of the last seven years having below average puerulus indices at Napier, and six out the last seven years having been below average at Castlepoint.

For Kaikoura the puerulus index shows a decline since 2003, though settlement levels are mostly above or near the long-term average. For Moeraki levels of puerulus settlement have been low since 2004, although they show a substantial increase in the last three years. At Halfmoon Bay settlement has been low since 2004, then picked up substantially for 2009 and 2010, but then dropped back to low levels in 2011 and 2012. At Jackson Bay there was a period of low settlement from 2006 to 2009; subsequent to this period of low settlement there have been three years of above average settlement, and in particular in 2012 extremely high settlement was recorded. These high levels of settlement in Jackson Bay are backed up with strong settlement over the same period in Chalky Inlet. This suggests high settlement may have occurred across most of Fiordland and could result in increased abundance, at least to that area of CRA 8, in the near future.

6. ACKNOWLEDGMENTS

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Appendix 1: Proportion Of Zero Counts For Jackson Bay and Moeraki

N.B The analysis below was conducted in 2012

Jackson Bay

The number of puerulus samples taken by groups of collectors is shown in Table A1. Note that there is a large gap from 1986 to 1998 inclusive. The group of collectors JKB003 and JKB004 were dropped from the sampling programme as they did not catch pueruli very well (John Booth, pers. comm., e-mail 2009). This leaves the group of collectors JKB001 and JKB002 from 1999 onwards, as appears in the current updates.

To more directly evaluate the effectiveness of the group of collectors at catching pueruli plots are shown of the distributions for the number of pueruli counted from monthly sampling (Figure A1). The groups JKB003 and JKB004 have recorded zero counts about 70% of the time, and no counts over 8. The core group JKB001 is better at catching pueruli, with zero counts recorded about 60% of the time, and some counts over 8. The group JKB002 is similar to the two groups JKB003 and JKB004, and arguably could be dropped like them from the analysis (sampling from it stopped in 2007 in a reduction of the sampling programme).

Moeraki

The number of puerulus samples taken by groups of collectors is shown in Table A2. MOE002 and MOE007 were chosen for the standardisation as they were the best at collecting pueruli (John Booth, pers. comm., e-mail 2009), this giving an index that goes from 1990 onwards.

Plotting up the distribution of pueruli counts from samples, it does appear that MOE002 and MOE007 are the best of a bad bunch at catching pueruli (Figure A2). The group MOE004 was described as “hopeless” for collecting pueruli; the group MOE001 did catch some pueruli but was discontinued for safety reasons as a large bull sea lion would harangue the divers.

Table A1: Number of times a group is sampled by calendar year for Jackson Bay. This is after only including collectors that have been sampled at least 36 times.

	JKB001	JKB002	JKB003	JKB004
1981	0	0	0	6
1982	0	0	0	22
1983	0	0	0	23
1984	0	0	0	20
1985	0	0	0	5
1999	15	11	9	15
2000	38	32	32	26
2001	54	41	41	30
2002	51	30	30	24
2003	41	24	24	0
2004	34	21	0	0
2005	39	20	0	0
2006	19	6	0	0
2007	40	0	0	0
2008	30	0	0	0
2009	25	0	0	0
2010	23	0	0	0
2011	30	0	0	0

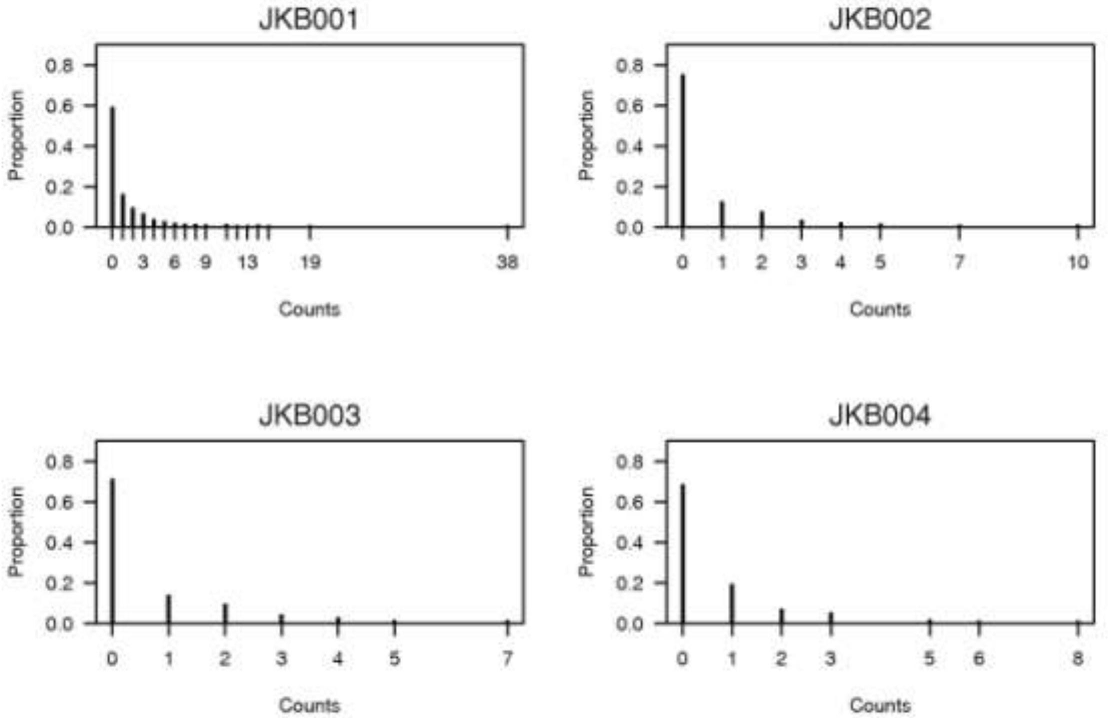

Figure A1: Number of pueruli counted in samples from Jackson Bay. This is after only including collectors that have been sampled at least 36 times.

Table A2: Number of times a group is sampled by calendar year for Moeraki. This is after only including collectors that have been sampled at least 36 times.

	MOE001	MOE002	MOE003	MOE004	MOE007
1982	8	0	0	0	0
1983	10	0	0	0	0
1984	14	0	0	0	0
1985	9	0	0	0	0
1986	12	0	11	0	0
1987	12	0	20	0	0
1988	20	0	12	0	0
1989	14	0	15	0	0
1990	28	5	0	0	0
1991	17	21	18	0	0
1992	19	17	9	12	0
1993	16	18	27	30	0
1994	23	18	14	19	0
1995	26	21	27	27	0
1996	18	21	21	21	0
1997	21	27	21	24	0
1998	15	24	0	24	0
1999	3	15	0	21	0
2000	0	26	0	27	0
2001	0	28	0	6	7
2002	0	23	0	0	18
2003	0	30	0	0	98
2004	0	12	0	0	136
2005	0	24	0	0	143
2006	0	9	0	0	86
2007	0	0	0	0	82
2008	0	0	0	0	114
2009	0	0	0	0	83
2010	0	0	0	0	53
2011	0	0	0	0	102

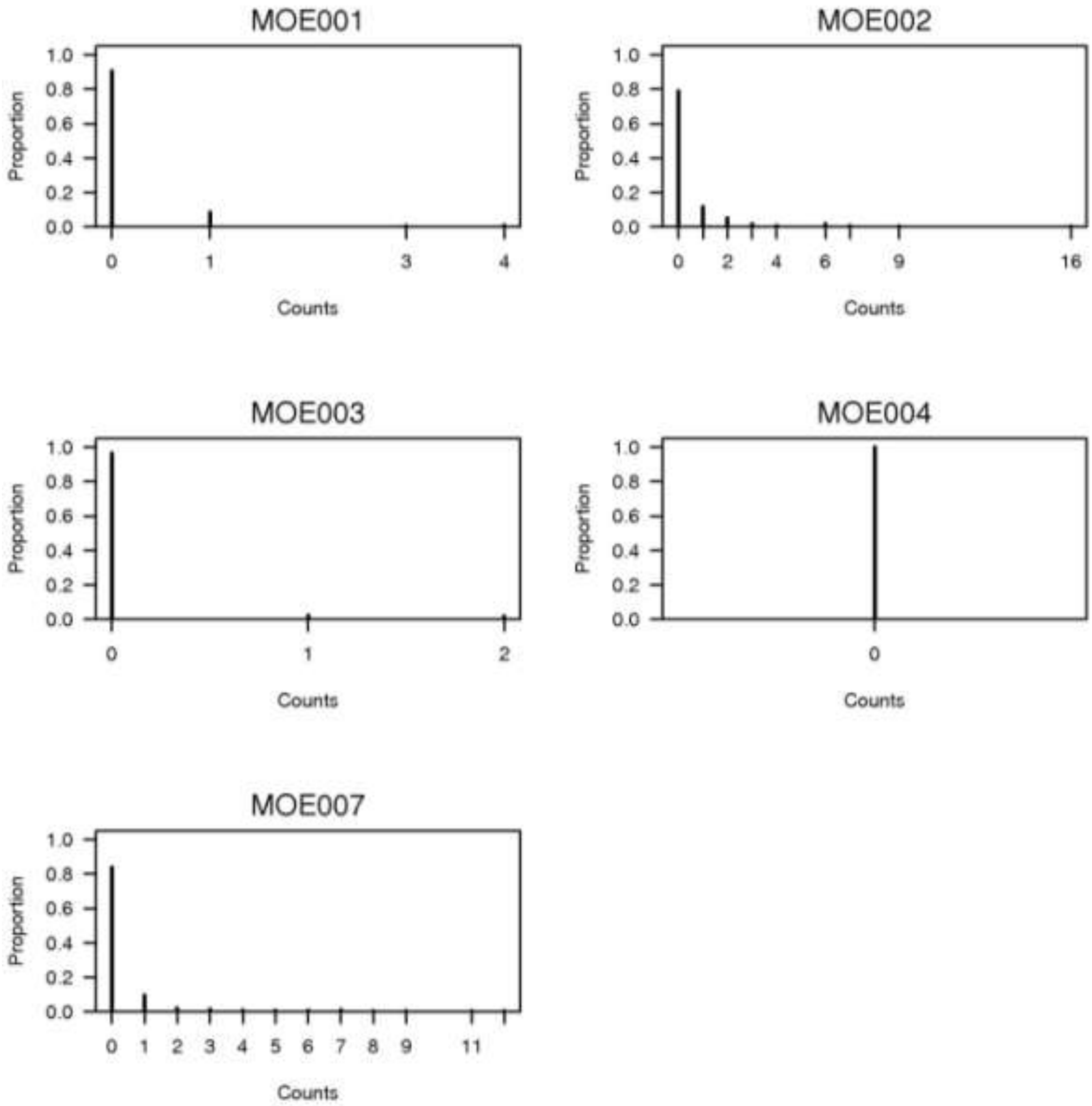

Figure A2: Number of pueruli counted in samples from Moeraki. This is after only including collectors that have been sampled at least 36 times.

Appendix 2: Number Of Samples By Calendar Year and Collector Group

Table A3: Gisborne.

Year	GIS002	GIS003	GIS004
1991	10	0	0
1992	35	0	0
1993	53	0	0
1994	50	43	38
1995	49	55	59
1996	45	35	60
1997	40	58	60
1998	60	60	60
1999	59	55	53
2000	58	60	55
2001	59	60	55
2002	60	48	65
2003	53	46	65
2004	55	46	55
2005	50	44	57
2006	48	48	60
2007	59	0	5
2008	48	0	60
2009	58	0	50
2010	45	0	55
2011	45	0	59
2012	49	0	55

Table A4: Napier.

	NAP001	NAP002	NAP003	NAP004
1979	40	0	0	0
1980	59	0	0	0
1981	66	0	0	0
1982	66	0	0	0
1983	60	0	0	0
1984	48	0	0	0
1985	48	0	0	0
1988	18	0	0	0
1989	36	0	0	0
1990	36	0	0	0
1991	48	17	0	20
1992	64	19	0	32
1993	69	14	0	30
1994	65	27	19	33
1995	58	31	37	33
1996	72	34	50	30
1997	71	21	60	36
1998	66	27	63	33
1999	72	6	54	27
2000	59	0	47	27
2001	59	0	59	21
2002	57	0	58	24
2003	60	0	47	0
2004	71	0	60	0
2005	72	0	59	0
2006	72	0	47	0
2007	53	0	34	0
2008	64	0	58	0
2009	55	0	59	0
2010	60	0	52	0
2011	60	0	53	0
2012	55	0	44	0

Table A5: Castlepoint.

	CPT001	CPT002	CPT003
1983	70	0	0
1984	55	0	0
1985	44	0	0
1986	68	0	0
1987	71	0	0
1988	66	0	0
1989	61	0	0
1990	72	0	0
1991	72	11	12
1992	72	37	27
1993	70	63	61
1994	92	60	50
1995	106	54	46
1996	99	54	51
1997	108	60	55
1998	108	51	44
1999	106	8	56
2000	106	22	60
2001	107	35	60
2002	95	48	55
2003	108	55	60
2004	107	51	60
2005	105	57	60
2006	108	58	60
2007	108	60	0
2008	105	45	0
2009	108	60	0
2010	108	60	0
2011	108	60	0
2012	108	56	0

Table A6: Kaikoura.

	KAI001	KAI002	KAI003	KAI004	KAI005	KAI006
1981	18	0	24	0	13	0
1982	24	0	24	0	22	0
1983	24	0	21	0	15	0
1984	33	0	33	0	0	0
1985	30	0	26	0	0	0
1986	27	0	26	0	0	0
1987	33	0	33	0	0	0
1988	36	6	36	0	0	0
1989	36	36	36	0	0	0
1990	33	33	33	0	0	0
1991	36	33	36	0	0	0
1992	30	30	30	21	0	0
1993	33	33	33	33	0	0
1994	29	30	30	30	0	0
1995	36	36	36	36	0	0
1996	24	24	24	24	0	0
1997	21	21	21	18	0	0
1998	18	18	15	15	0	0
1999	18	18	21	21	0	0
2000	33	33	33	33	0	0
2001	35	32	36	36	0	0
2002	36	33	36	36	0	0
2003	54	9	54	8	0	0
2004	60	0	60	0	0	0
2005	59	0	60	0	0	0
2006	60	0	60	0	0	0
2007	60	0	65	0	12	0
2008	60	0	60	0	32	30
2009	59	0	59	0	27	24
2010	60	0	60	0	33	27
2011	60	0	60	0	21	18
2012	60	0	55	0	23	15

Table A7: Moeraki.

	MOE002	MOE007
1991	21	0
1992	17	0
1993	18	0
1994	18	0
1995	21	0
1996	21	0
1997	27	0
1998	24	0
1999	15	0
2000	26	0
2001	28	7
2002	23	18
2003	30	98
2004	12	139
2005	24	145
2006	9	89
2007	0	87
2008	0	121
2009	0	87
2010	0	58
2011	0	105
2012	0	39

Table A8: Halfmoon Bay.

	HMB001	HMB002	HMB003	HMB004	HMB005
1981	21	0	0	0	0
1982	32	0	0	0	0
1983	27	0	0	0	0
1984	24	0	0	0	0
1985	21	0	0	0	0
1986	21	21	0	0	0
1987	30	24	0	0	0
1988	33	21	0	0	0
1989	18	18	0	0	0
1990	28	15	15	0	0
1991	33	21	21	0	0
1992	27	21	17	21	21
1993	30	24	24	24	20
1994	30	27	27	25	25
1995	33	27	24	24	24
1996	27	24	24	24	24
1997	30	27	27	27	27
1998	24	27	24	24	24
1999	15	24	24	24	24
2000	21	24	24	27	24
2001	33	24	24	24	24
2002	30	27	27	27	27
2003	36	0	0	0	0
2004	32	0	0	0	0
2005	56	0	0	0	0
2006	80	0	0	0	0
2007	83	0	0	0	0
2008	58	0	0	0	0
2009	61	0	0	0	0
2010	88	0	0	0	0
2011	96	0	0	0	0
2012	88	0	0	0	0

Table A9: Jackson Bay.

	JKB001	JKB002
1999	15	11
2000	36	32
2001	56	41
2002	51	30
2003	41	24
2004	34	21
2005	39	20
2006	19	6
2007	40	0
2008	30	0
2009	25	0
2010	19	0
2011	34	0
2012	48	0

Appendix 3: Regression Diagnostics

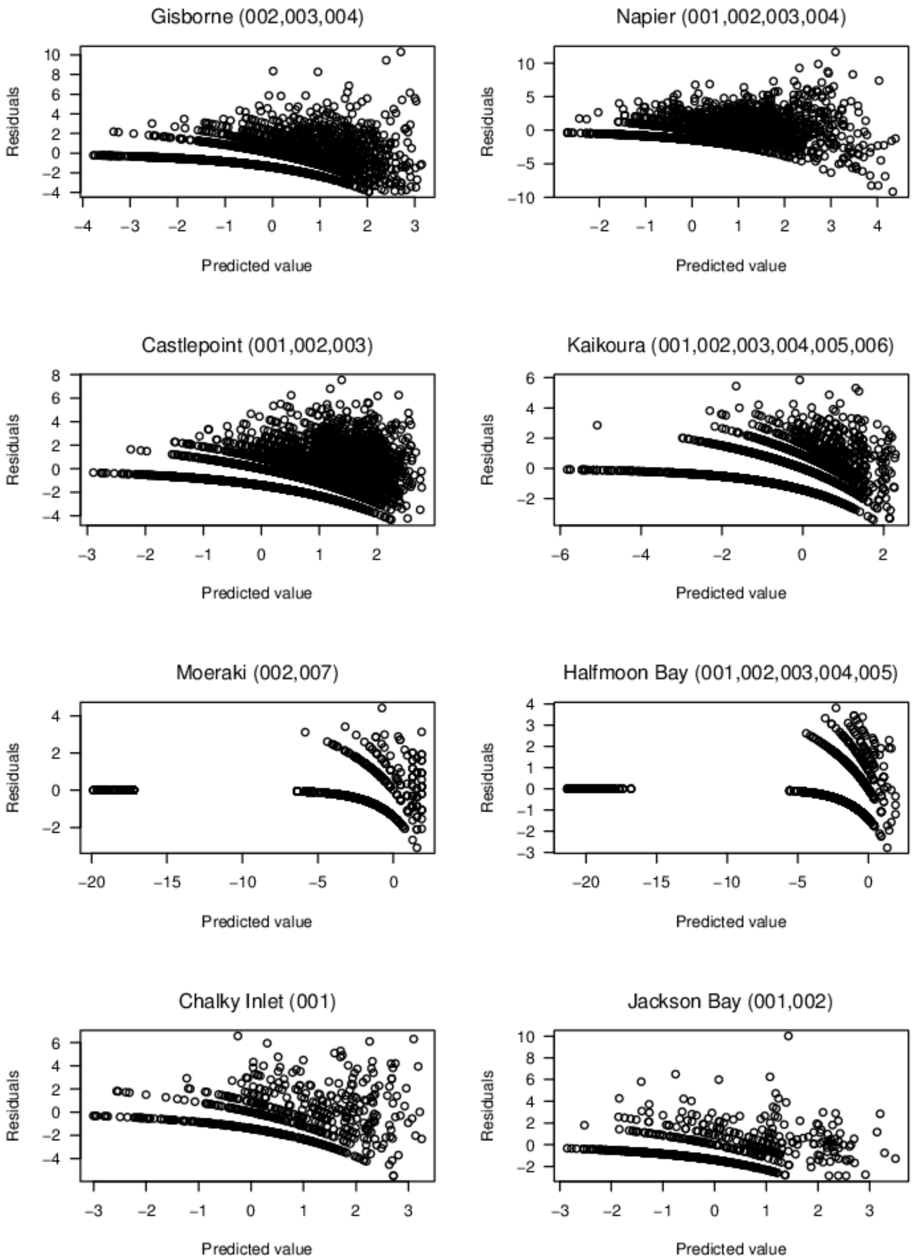

Figure A3: Residual plots from standardisation model for each site. The predicted values are in log space.

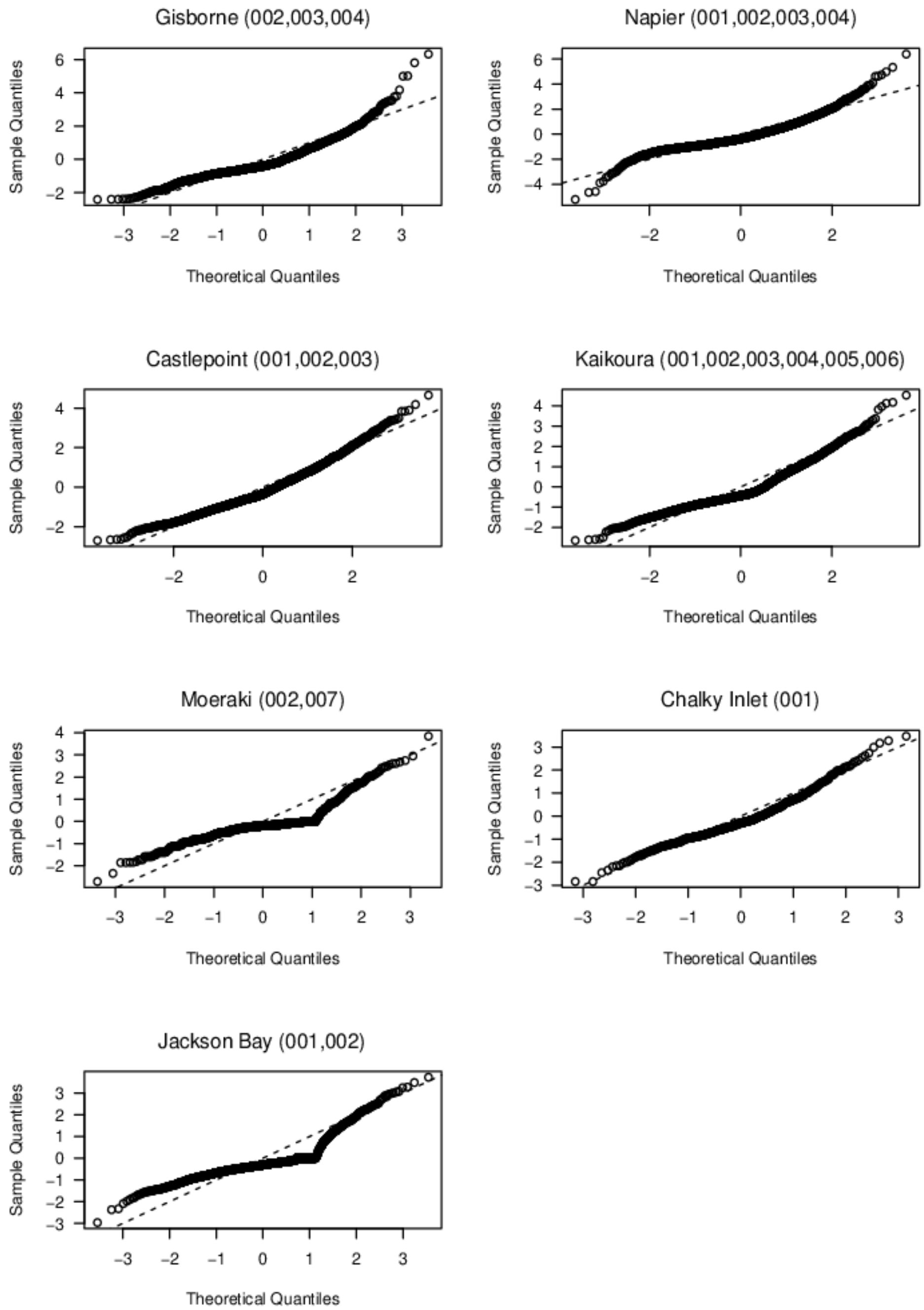

Figure A4: Quantile-quantile plots from standardisation models for each site.

Appendix 4: Puerulus staging data in *rocklob* data base

For reference purposes the data base table descriptions associated with the puerulus staging data are given here, extracted from MacKay 2000. The four stages under the field are *stage* are stored as characters P1 → P4, renamed to S1 → S4 for data analysis in this report.

5.4 Table 4: t_puer_stage

Comment: Table of pueruli life history stage data.

Attributes	Data Type	Null?	Comment
location	character(6,1)	No	6-char code for the location of the collector
date_checked	date(5)	No	Date the collector was checked
collector_no	smallint	No	Each collector has been given an unique number
stage	character(5,1)		Code for life history stage, refer v_puer_stage_codes (stage)
no_a	integer		Number of animals at this stage.

Creator: dba

Referential: no such catch (location, date_checked, collector_no) INSERT t_catch (location, date_checked, collector_no)
no such stage (stage) INSERT v_puer_stage_codes (stage)

Indices: NORMAL (2, 15) BTREE puer_stage_location_ndx ON (location)
NORMAL (2, 15) BTREE puer_stage_date_checked_ndx ON (date_checked)
NORMAL (2, 15) BTREE puer_stage_collector_no_ndx ON (collector_no)

5.11.1 v_puer_stage_codes

Comment: View of descriptions of development stages of rock lobsters from puerulus to juveniles.

View: select attr 'species', attr 'stage', attr 'descrptn' from 't_stage_codes' where (attr 'type' = 'PUERULUS')

Attributes	Data Type	Null?	Comment
species	character(3,1)	No	3-char species code, refer rdb:curr_spp
stage	character(5,1)	No	Development stage code.
descrptn	text(80,20,20,1)		Description of the puerulus development stage code