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EXECUTIVE SUMMARY

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This report addresses the two objectives of the Ministry of Fisheries project CRA2003/02 (To correlate trends in puerulus settlement with trends in abundance for selected rock lobster fisheries):

1. 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, Wellington, Kaikoura, Moeraki, Halfmoon Bay, Chalky Inlet, and Jackson Head).
2. To investigate correlation between trends in settlement and trends in stock abundance for at least two rock lobster fishery (CRA) management areas.

We update and extend the information on spatial and temporal patterns of settlement of the red rock lobster, *Jasus edwardsii*, on crevice collectors around New Zealand. Both raw and standardised indices are presented. Levels of settlement in 2003 on the east coast of the country, at least from Gisborne to Wellington, were generally about average compared with the time series of previously estimated settlement levels. At most sites, settlement in 2003 was higher than in 2002, in turn greater than the particularly low settlement of 1999. Settlement in 2003 was very high at Kaikoura, similar to the levels last seen there in 1991–93. Although still low along the southeast coast of the South Island compared with the long-term average seen further north, the significantly higher settlement levels of 2000, the highest since the early 1980s, continued during 2001–03. Settlement in 2003 was high in the southwest of the South Island.

The relationship between levels of settlement and subsequent stock abundance is investigated. Because the recent change in trend in settlement along the east coast (low settlement indices in the late 1990s, with an improvement from 2000) cannot yet be expected to have been manifested in changes in stock abundance, the present analyses were confined to the historic data. The lag between settlement and stock abundance was 5–7 years for most areas, with several correlations over 0.7 and all associated p-values less than 0.10. These results are encouraging for the hypothesis that large-scale patterns in puerulus settlement are indeed manifested in the stock and, therefore, the fishery. The reasons for the disparity in this regard with the stock assessment model, which concluded that the settlement indices showed little similarity with the estimated assessment model recruitments and were therefore of little value to stock assessment, are yet to be settled. In the meantime it is important that analyses of settlement versus subsequent stock abundance indices continue to be made as new fishery data become available year-by-year so that any impact of the increasing settlement levels on stock abundance on the east coast from 2000 can be discerned.

1. INTRODUCTION

1.1 Background

Rock lobsters support one of New Zealand's most valuable fisheries. Understanding larval recruitment processes will greatly assist management of this fishery because it may explain changes in levels of recruitment to the fishery and enable prediction of trends in catch levels at least 4 years in advance, allowing management and commercial strategies to be implemented. This report updates and extends the previously reported patterns of spatial and temporal settlement of *Jasus edwardsii* on crevice collectors in New Zealand (Booth et al. 2004). It also reports preliminary exploration into correlations between trends in settlement levels and trends in stock abundance. In so doing, we address the two objectives of the Ministry of Fisheries project CRA2003/02 (To correlate trends in puerulus settlement with trends in abundance for selected rock lobster fisheries):

1. 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, Wellington, Kaikoura, Moeraki, Halfmoon Bay, Chalky Inlet, and Jackson Head).
2. To investigate correlation between trends in settlement and trends in stock abundance for at least two rock lobster fishery (CRA) management areas.

The estimates of settlement have been made available to the National Rock Lobster Management Group (NRLMG) and the Rock Lobster Working Group (RLWG) during 2004: they were presented to the Rock Lobster Research Planning Group Meeting (at which most NRLMG members were present) on 10 August 2004, and to the RLWG on 16 September 2004. The correlation results were also presented to the RLWG on 16 September 2004.

Rock lobsters spend several months as phyllosoma larvae in waters tens to hundreds of kilometres offshore. They return to the shore as postlarval pueruli after metamorphosing near the shelf break. The puerulus stage is the settling stage: it resembles the juvenile in shape and is 9–13 mm in carapace length (CL), 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 such as this is not uncommon among invertebrates. The puerulus moults into the first juvenile instar (sometimes referred to as the first-moult postpuerulus) a few days to 3 weeks after settlement, according to water temperature. Depending on sex and locality, the rock lobster then takes several years to reach minimum legal size.

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 rock lobster fishery since the early 1980s. The indices of settlement are now reported annually, for stock assessment and research purposes. It has become clear from this and other monitoring that settlement is not uniform in time or space. Settlement is mainly at night and at any lunar phase, is usually seasonal, and levels of settlement can vary by an order of magnitude or more from year to year (Booth & Stewart 1993). Since monitoring began, highest mean annual settlement has been along the east coast of the North Island south of East Cape (= southeast North Island or SENI), in the general region of highest offshore abundance of phyllosoma larvae.

The relationships between settlement and both pre-recruit and recruit abundance have been investigated using unstandardised data, with some promising early indications of significant correlation (Booth et al. 2000). However, the settlement data were unhelpful in explaining changes in the fishery in the later investigation of Bentley et al. (2004a). They compared standardised indices of settlement with estimates of recruitment obtained from recent stock assessments, and also used a simple length-based model of the rock lobster fishery to examine correspondence between settlement indices and the catch-sampled males, and concluded that the settlement indices were of little value to stock assessment. Also, Starr & Bentley (2003) found little correlation between settlement and pre-recruit numbers (but they pooled all undersized lobsters of both sexes caught, and so combined several year classes).

In this report we are particularly interested in how useful the recent, large-scale changes in trend in puerulus settlement are in predicting recruitment or explaining changes in the fishery. A change in trend is where a consistent settlement pattern (e.g., decline) over a period of years has changed to another consistent pattern (e.g., increase) over a period of years, which is different from year to year changes. It is only since the early to mid 1990s that several fisheries have become largely male fisheries, thereby reducing the confounding influence of males and females recruiting at very different ages (although this is now changing again along east coast North Island – see Section 3.4). Further, it is only recently that for the east coast (at least from Gisborne to Kaikoura) a trend in settlement level over time became established and then changed: among the highest-recorded settlement occurred in the early 1990s, declining to among the lowest-recorded settlement in the late 1990s, followed by a recovery in settlement levels beginning in 2000. A change in trend in settlement also took place in the southeast of the country. At Moeraki, settlement was low until a marked increase began in 2000. A similar, though somewhat muted, pattern was apparent further south, at Halfmoon Bay in northeast Stewart Island. But because these changes in trend in puerulus settlement are recent, it is unlikely that they will yet be fully manifested in the pre-recruit data or the fishery landings; thus the investigation of relationships between settlement and recruitment to the fishery in this report focuses on examining correlations, with various lags, over earlier years, using standardised settlement and CPUE data.

1.2 Literature

The following are publications on early life history and larval recruitment in *J. edwardsii* and *Sagmariasus verreauxi* which appeared since those referred to by Booth et al. (2004). Cox & Johnston (2003a, 2003b) reviewed the mouthparts and feeding behaviour of palinurid phyllosomas, particularly *S. verreauxi* (as *Jasus verreauxi*), with large-scale culture of larvae in mind. Cox & Johnston (2004) described the development of foregut structure and digestive function in *S. verreauxi* (as *Jasus (Sagmariasus) verreauxi*). Jeffs et al. (2004) attempted to identify potential prey of *J. edwardsii* phyllosomas using signature lipids, and concluded that the phyllosomas are opportunistic predators that feed on a variety of prey and are preferentially retaining specific diet-derived fatty acids. MacDiarmid & Booth (2003) produced a popular account of New Zealand rock lobsters, including the early life history of *J. edwardsii*. Bentley et al. (2004a) found that the settlement data were unhelpful in explaining changes in the fishery as seen in the context of their stock assessment model. Bentley et al. (2004b) calculated standardised settlement indices for *J. edwardsii* based on the settlement record.

1.3 Why estimate relative abundance of early life history stages?

Knowing the relative abundance of the early life history stages (phyllosomas, pueruli, and young juveniles) will enhance understanding of the factors that drive fishery recruitment. It may be possible to relate changes in levels of settlement to changes in breeding stock abundance, abundance of advanced-stage larvae, and to changes in the ocean climate. In particular, a knowledge of seasonal, annual, and geographic variation in puerulus settlement will help us to better understand larval recruitment processes. For example, geographically different settlement patterns may come about through differential survival or transport in the different water masses in which the postlarvae occur. Information on year to year settlement levels may be used to predict trends in recruitment, provide early warning of overfishing, and indicate the extent to which recruitment varies from year to year. Such information can improve the usefulness of fishery assessment models, particularly their predictive capability.

The benefits of accurate prediction of recruitment trends are well demonstrated in Western Australia, where there are more than 30 years of settlement data (Phillips et al. 2000). Accurate forecasts allow improved financial planning and investment by fishers and processors, and proactive rather than reactive fisheries management. Using collectors set in sufficient numbers to deal with the spatial variability in settlement is the most cost-effective means of measuring puerulus settlement. Almost every major rock lobster fishery now has in place or is developing such a programme.

The settlement indices remain the only widespread fishery-independent data collected in the New Zealand rock lobster fishery. Continuation of the settlement time series will allow the usefulness of the settlement data in predicting changes in trend in recruitment to the fishery to be tested.

2. SPATIAL AND TEMPORAL PATTERNS OF SETTLEMENT

2.1 Introduction

Key sites are sampled to follow levels of settlement on crevice collectors along the main rock lobster fishing coasts of New Zealand (Figure 1), these sites having been finalised after trials lasting several years. Each key site is separated from its neighbour by 150–400 km, its location chosen based on the distance from the neighbouring site, accessibility, and level of puerulus catch. Other details were given by Booth & Stewart (1993).

At the key sites, crevice collectors are set in groups of 3–9, with a minimum spacing of 2 m between individual collectors. There is usually a core group at each key site; additional groups of collectors are set in both directions along the coast, as conditions allow, 0.1–25 km from the core collectors.

The crevice collectors are either shore, closing, or suspended (see Booth & Tarring (1986) and Phillips & Booth (1994) for collector design) (Table 1). Collectors are checked approximately monthly, at least over the main settlement season, and all lobsters removed (details of methods were given by Booth & Stewart (1993)).

Crevice collectors on the sea floor (shore and closing crevice collectors) provide a combined index of (a) the number of pueruli in the water column which are settling, and (b) the result of post-settlement migration, the net number of older animals (older pueruli, and less often, young juveniles) moving onto the collector after having lived on the surrounding sea floor, and animals of similar age moving from the collector to the surrounding sea floor (Booth & Stewart 1993). Most of the animals on the collectors are from the first group and we assume that, for each collector, the proportion of each of these groups that make up the index is more or less constant among years. In contrast, crevice collectors suspended above the sea floor or at the surface (suspended crevice collectors) provide an index to the number of pueruli in the water column minus the number of older animals that settled on the collector and then emigrated from it. Immigration from the sea floor into suspended collectors is much less likely to take place than into collectors on the seafloor (although it can take place into suspended collectors over a scale of metres – Booth & Forman (1995)). But for both bottom and suspended collectors, migration means that the numbers of lobsters on a collector at each monthly check are less than the total numbers of lobsters that have been present on the collector at some time during that month. Booth & Forman (1995) estimated that, on average, lobsters remain in a collector for about two weeks from settlement.

We cannot distinguish post-settlement migration from puerulus settlement in our monthly checks. We therefore use the term 'settlement' to encompass both initial puerulus settlement and the capture of animals after post-settlement migration (see Booth & Stewart (1993) and Booth & Forman (1995)). The presence in a collector of a puerulus at any stage of development, or a first-instar juvenile, is taken to mean that there has been settlement. Secondary dispersal by new recruits to the seafloor such as this has been observed among other invertebrates (e.g., Reyns & Eggleston 2004). The young redistributing from high-density settlement habitats may be a way in which metapopulations promote persistence.

There is variation in levels of settlement within and among sites. Monthly catches of adjacent collectors within groups at any particular check are often very different, but the average catches of these individual collectors measured over several months or years are usually similar (Booth & Stewart 1993). These results are consistent with spatially uniform settlement over a scale of metres to tens of metres over time intervals of months to years.

Levels of settlement among areas can be compared when the same collection techniques have been used at several sites within each area over a number of years: settlement over the past almost two decades has generally been several times higher in SENI than in most other parts of the country (Booth et al. 2004). Further, year-to-year settlement is correlated between several widespread sites (Booth et al. 2004), with changes in the large-scale ocean climate possibly contributing to the patterns of puerulus recruitment. For example, there is significant positive correlation between El Niño–Southern Oscillation (ENSO) events and levels of settlement off Western Australia (Pearce & Phillips 1988), and a similar (but negative) correlation off the east coast of New Zealand (Booth et al. 2000).

2.2 Seasonality in settlement

The main settlement season varies according to location, but with large stretches of coast (regions) having the same general settlement seasons. These were reported by Booth (1994) for observations to the end of 1992 and are updated to 2003 in Figure 2, the seasonality having remained the same. Adjacent sites have similar seasons, except for those pairs of sites that straddle regional boundaries. Winter is the most widespread main settlement season, but on the east coast of central New Zealand (Castlepoint to Kaikoura) there is often also high settlement in summer and autumn. The reasons for these seasonalities, and their variation between areas, remain unclear but may be related to the differential transport alluded to in Section 1.3.

2.3 Calculating indices

Two different interannual indices of settlement are now produced each year. The *settlement season index* of annual settlement is a raw index based only on the main settlement season and is the mean catch per collector of pueruli, plus juveniles up to and including 14.5 mm CL (the maximum size for a first-instar juvenile observed in laboratory studies), of the core collectors over the main settlement season ± 1 s.e. of that mean. The main settlement season varies between 6 and 10 months according to site (Table 1), so the nominal values of the annual index are not always directly comparable between sites. The *standardised index* of annual settlement differs most from the settlement season index of annual settlement in that it incorporates all settlement, irrespective of month. The approach taken to the standardisation was based on that of Bentley et al. (2004b), but with the adjustments noted by Booth et al. (2004). This index takes into account changes in collector location and when sampling took place. In brief, a Generalised Linear Model framework is used, in which the response (dependent) variable is the log of numbers of settlers per collector sample. All independent variables are treated as factors. The year variable is included in all models; the other independent variables (group/collector and month) are added to the model in a stepwise process. At each step the variable that most improves the fit of the model is included. (The final set of variables included in each model is shown in Table 4.) Each set of indices is presented as the annual value divided by the geometric mean of all annual values, allowing indices to be interpreted as deviations from the overall mean in log space. Thus a value for the index above 1 represents above average settlement for that year, and a value below 1 less than average settlement. For comparison, a raw form of this index is also given.

Residual plots from the standardisation models used for each CRA area, and other diagnostics, are given in Appendix A.

2.4 Collector catches, 2003

The numbers of collectors at each site and the checking details are summarised in Table 1. Annual settlement season indices for key sites by group are given in Table 2; these and the standardised and raw annual data are given in Figures 3–18.

2.4.1 Gisborne

Settlement in 2003 was up on 2001–02, and well up from the record low of 1999 (Figures 3 and 4). As in previous years, settlement on all collectors peaked in winter and there was little summer settlement. Whangara had the highest levels of settlement (Table 2).

2.4.2 Napier

Settlement during 2003 was about the same as in 2002, and well up on 1999 (the record recent low year) and 2000. The Harbour collectors had the highest catches of all groups (Figures 5 and 6, Table 2). Settlement peaked during winter.

2.4.3 Castlepoint

Settlement in 2003 remained moderate to low, at levels similar to 2001–02 but up on the record low year of 1999 (Figures 7 and 8, Table 2). On all groups of collectors, there were both summer and winter peaks. The Castlepoint and Orui collectors had the highest settlement rates, those at Mataikona the lowest.

2.4.4 Wellington

Settlement took place throughout much of the year (Figure 9). Catch rates during 2003 were moderate, and up on the recent record low year of 1999 (Figures 9 and 10). Highest settlement was again recorded at Island Bay, the lowest at Breaker Bay (Table 2).

2.4.5 Kaikoura

Catch rates were very high in 2003, similar to those seen in 1991–93. Settlement was mainly during summer-autumn-winter (Figures 11 and 12, Table 2).

2.4.6 Moeraki

The upturn in settlement levels seen in 2000–02 continued into 2003 – to levels not seen before (Figures 13 and 14, Table 2). Most settlement was in mid winter. There was poor precision in the standardised index derived from the above model because of collector catch variability and the data not fitting the model well because of the large number of zero catches.

2.4.7 Halfmoon Bay

The improvement in settlement levels seen in 2000–02 continued into 2003, to levels not seen since the early 1980s (Figures 15 and 16, Table 2). Most settlement took place in late winter. Again there was poor precision in the standardised index derived from the above model because of collector catch variability and the data not fitting the model well because of the large number of zero catches.

2.4.8 Chalky Inlet

2003 was a high settlement year (Figure 17, Table 2). The poor precision of the standardised index is due mainly to collector catch variability and several missed monthly checks – a result of the remoteness of the site.

2.4.9 Jackson Bay

Settlement levels in 2003 were down on those in 2002, and similar to those in 2000–01 (Table 2); the most successful collectors were the wharf ones. This is a relatively new site, for which the logistics of monthly checks of all groups of collectors are still being determined.

2.4.10 Summary

For the east coast of New Zealand, at least from Gisborne to Wellington, 2003 was an average settlement year compared with the time series (mainly since the 1980s) of estimated settlement levels for each site, with significantly higher settlement than in the record low year of 1999. Settlement at Kaikoura in 2003 was very high. The increase in recent settlement levels in the southeast of New Zealand (southeast South Island and east coast Stewart Island, SENZ), particularly at Moeraki, persisted dramatically into 2003. For the southwest of the South Island, 2003 was a high settlement year.

The within-site settlement patterns reported by Booth et al. (2004) persisted: there were often significant differences in the levels of settlement between groups of collectors within sites and sometimes this difference was large. The standardisation addressed this concern. Seasonality among groups at particular sites was, however, generally consistent.

2.5 Variability among sites over the long term

The geographic pattern in settlement on the collectors in 1994–98 and 2001–02 was similar to that seen through the 1980s, in that settlement on the east coast was generally high as far south as about Cook Strait. In contrast, during 1991–93 and in 2003, the area of high settlement extended further south, to at least Kaikoura (but apparently not as far south as Banks Peninsula – see Booth et al. (1994)). In 1999, settlement along the east coast of the North Island was exceptionally low, about the same as that typically seen on the east coast of the South Island, but improved slightly in 2000 and still further in 2001–03. These features can be seen, for example, in the standardised settlement for CRA 3 (Figure 4), CRA 4 (Figure 19), and CRA 5 (Figure 12).

In 2000–03 there was a marked increase in settlement levels in SENZ, particularly at Moeraki, to a level not seen before (see Figures 13, 14, and 16).

In the southwest of the South Island, at Chalky Inlet (Figure 18), the levels of settlement on the collectors for most years have been moderate to high compared with those in SENZ.

2.6 Reasons for spatial variation in settlement

The much higher levels of settlement usually seen on collectors along SENI compared with those along SENZ is consistent with the pattern of phyllosoma abundance found in all widespread sampling (Booth 1994) and with the later plankton surveys, in April 1994, March 1995, and February 1998. Advanced phyllosomas (those at and beyond Stage 5) were widespread and abundant off SENI, catches being orders of magnitude greater than off SENZ. It was concluded that regional differences in phyllosoma abundance were likely to be a major determinant of the differences in levels of settlement seen between SENI and SENZ. This in turn seemed to be closely related to the abundance of breeders, the oceanography (particularly the presence of the large and persistent Wairarapa Eddy – Chiswell & Booth (1999)), and certain environmental factors such as the persistence of southerly storms (see Booth et al. 2000). Unfortunately, there are no recent data on phyllosoma distribution or abundance, but we contend that the low-to-moderate levels of settlement along SENI during and after 1999 were more to do with the La Niña conditions than to any reduced abundance offshore of phyllosomas.

The increased settlement off SENZ in 2000–03 (but not into 2004 – not shown) could have been a result of increased numbers of advanced phyllosomas there, but there are no data to address this further. The southwest of the South Island – with its relatively high levels of settlement – may receive larvae from southern Australia (Chiswell et al. 2003).

2.7 Year to year variation in settlement over the long term

Indices of year-to-year settlement on the core collectors at the key sites given above and in Table 2 update those given by Booth et al. (2004). Levels of annual settlement remained significantly correlated among sites along the east coast from Gisborne south (Gisborne-Napier-Castlepoint; Napier-Castlepoint-Kaikoura; Castlepoint-Kaikoura; Moeraki-Halfmoon Bay) (Table 3). Interannual levels of settlement between groups of collectors within the key sites with sufficient data are usually highly correlated (not shown).

Because of these correlations, and because, for example, 1991 and 1992 were very high settlement years, and 1998 a very low settlement year, along much of the east coast of northern and central New Zealand, factors that drive larval recruitment appear to affect wide areas (Figure 20).

Settlement in SENZ has been low, except in the early 1980s, and in 2000–03 when it increased markedly, particularly at Moeraki.

Settlement was moderate to high in the southwest of the South Island during 1987–91, in 1994, during 1996–97 and 2000–01, and in 2003; it was low in 1985–86, 1992–93, and 1998.

3. CORRELATIONS BETWEEN SETTLEMENT LEVELS AND FISHERY CPUE

Indices of stock abundance available to us include CPUE in the overall commercial fishery, and, from sampled commercial pots, CPUE (lobster numbers) for selected groupings of pre-recruit lobsters and for new recruits to the commercial fishery. The CPUE data used here for the total commercial fishery are mainly the CRACE database of groomed data used in the decision rule and management procedures (Sullivan 2004), believed to be the most accurate CPUE data available (Bentley et al. 2005).

In this section, changes in the settlement indices are compared with changes in the indices of abundance of recruited lobsters by means of correlation analysis. Eventually our focus will be on whether the large change in trend in the settlement indices recently seen along parts of the east coast – from very low values in the late 1990s to increasing levels from 2000 – is reflected in changes in stock abundance, but as discussed in the Introduction, it is too early for any such changes yet to be manifested in the fishery. (Lobsters rarely enter pots until about 40 mm tail width and are not fully selected until a much greater size – Sullivan (2004).) Therefore we confine ourselves here to analyses of correlations between more historic settlement and stock abundance records, but undertaken more formally than previously (Booth et al. 2000) in that we use standardised data. Issues with the earlier commercial CPUE data to bear in mind include a) they are probably less reliable than CPUE data collected after the introduction of the QMS, and b) in areas where males and females recruit at different ages, recruitment to the fishery in those earlier years will contain a mix of several year classes; in general, the longer the interval between settlement and recruitment the greater the number of year classes to overlap. Also, the stock abundance indices based on commercial potting are entirely fishery-dependent.

Because of the long interval between settlement and recruitment to the fishery in some areas, forecasts of fishery performance are likely to be most accurate in areas where there is a short interval between settlement and recruitment to the fishery, and where, for areas with very different ages at recruitment between males and females, the CPUE associated with the first of the sexes to recruit – usually males – can be identified. Such fisheries are on the east coast: the southeast of the North Island (SENI, and particularly CRA 3) and the southeast of the South Island/east coast Stewart Island (southeast New Zealand (SENZ), and particularly CRA 7). However, even for areas where accurate prediction of year-to-year fishery performance is unlikely because of the delay between settlement and recruitment and because of the different ages of males and females at recruitment, knowing the relative levels of settlement over time can be helpful in interpreting recent changes in fishery performance. Large peaks in settlement can quite reasonably be expected to be felt in such fisheries, even though the signal may be blurred through unknown levels of variability in juvenile growth. Further, even in the absence of detailed information on the variability in juvenile growth (within and between years), it would be possible to model recruitment to the fishery resulting from changing trends in settlement by incorporating various levels of cohort-growth variability by sex.

It has been argued that such analyses are best made within the context of the stock assessment model, but, as outlined in Section 1.1, there appear to be as yet unresolved disparities between the assessment model picture of the fishery and that suggested by the settlement data. Bentley et al. (2004a) concluded that the settlement indices showed little similarity with the estimated model recruitments and also did not produce good fits to a simplified version of the stock assessment model. An alternative view, indeed raised by Bentley et al. (2004a) in their discussion, is that although *possibly* the 'best available' interpretation of the fishery, the assumptions of the stock assessment model – including of the simplified model – may be incorrect and some of the model estimates (such as recruitment) imprecise. In the meantime, it is important that analyses of settlement versus subsequent stock abundance indices continue to be made as new fishery data become available year-by-year so that any impact on stock abundance of the increasing settlement levels on the east coast from 2000 can be discerned.

The approach in this section is to 1) correlate CRACE database standardised CPUE with standardised puerulus settlement at selected sites; 2) fit a linear curve between the CPUE and puerulus settlement data, and 3) to investigate the effect of matching the settlement year (1 January–31 December) with the rock lobster fishery year (1 April–31 March).

3.1 Correlating settlement indices with fishery CPUE by CRA area

Standardised settlement indices are available for CRA 3 (settlement site Gisborne), CRA 4 (Napier, Castlepoint, and Wellington), CRA 5 (Kaikoura), CRA 7 (Moeraki), and CRA 8 (S – Stewart Island; F – Fiordland). The CRACE database contains standardised CPUE indices for the recruited fishery for each of these CRA areas.

Because growth rates vary according to sex and location, recruitment to the fishery occurs at various intervals after settlement. There are also various regional minimum legal size (MLS) restrictions: the MLS for males is 54 mm tail width (TW) for the whole country, except for CRA 3 where for most of the year it is 52 mm TW and CRA 7 where for most of the fishing year it is 127 mm tail length. For females, the MLS is 60 mm TW, except for the 127 mm tail length in CRA 7 that applies most of the year, and 57 mm TW in CRA 8. Age at recruitment is poorly known for any area but is within the range of about 5–8 years according to the studies of McKoy & Esterman (1981), Annala & Bycroft (1985), and Street & Booth (1985).

The settlement data might be correlated with CPUE associated only with the statistical area in which the collectors are sited. Standardised values of this are not available, and anyway Starr & Bentley (2005) showed that the statistical area CPUE values were largely – and closely – reflected in the CPUE of the associated CRA area.

Spearman's correlation coefficient was used as the measure of correlation. It is a rank-based measure of correlation that has the advantage over the Pearson's correlation coefficient in being able to detect non-linear increasing or decreasing trends. Associated with any correlation is a p-value that measures how statistically significant a correlation is. Lower p-values indicate higher statistical significance and the less likely a correlation is due to chance.

The procedure for determining correlations was to: (1) lag (move to the right) the standardised puerulus over the range 2–10 years, (2) find the correlation coefficient between the lagged puerulus index and the standardised CPUE for that site and, (3) retain the lag and correlation for a site which had the lowest p-value.

Best lags and their associated p-values are shown in Table 5. The shortest best lag was 3 years (Wellington) and the longest 9 years (Kaikoura), but most best lags were in the range 5–7 years and generally consistent with the juvenile growth studies mentioned above. (Note that Wellington, with the most anomalous lag, is a site with a short settlement record.) The correlations between settlement and fishery CPUE having the highest coefficients (over 0.70) were similar to those seen in similar analyses of the Western Australian rock lobster fishery (Phillips et al. 2000). All p-values were less than 0.10, indicating that all the correlations were significant at the 10% level. However, the significance level of each test should be scaled to take into account the number of lags that were searched over before finding the best correlation (the Bonferroni correction). A plausible Bonferroni correction factor for scaling the alpha level for each test is five, and four out of nine of the correlations are significant at the 10% level with the Bonferroni correction applied.

Plots of the standardised CPUE versus the standardised puerulus index at the best lag are shown in Figure 21. Plots of the CPUE and the puerulus index at the best lag, but as functions of the fishing year, are shown in Figure 22. These figures with the best lag illustrate for each site the level of correlation between settlement and fishery CPUE.

3.2 Fitting a linear relationship

A linear relationship between the standardised CPUE and the standardised puerulus indices (at the best lag) was fitted in the form:

$$CPUE = a + b * puerulus(at\ the\ best\ lag)$$

The "a" coefficient of the fit scales the puerulus data to have the same mean as the CPUE data; the "b" coefficient scales the size of deviations from this mean so as to more closely follow the size of deviations from the mean observed in the CPUE data. Therefore fitting a linear relationship is an effective technique to overlay two plots, as well as a method for determining to what extent two quantities are linearly related. Plots of the CPUE and the fitted values are shown in Figure 23, showing the level of correspondence. For several sites the match is better in recent years than in earlier ones, this probably reflecting more mixed-sex (and therefore mixed-age) catches in the older data, as referred to in Section 1.1.

3.3 Matching settlement and fishing years

The fishing year is 1 April to 31 March, and yet for most of the country settlement takes place mainly in winter (Figure 2); the exception is the east coast of central New Zealand where settlement is summer-autumn-winter. In this section we better align the settlement year with the CPUE year, to see what effect this has on the correlation analysis of Section 3.1. The puerulus standardisations were redone using the fishing year definition: 1995 = 1 April 1994–31 March 1995. Note that because of the redefinition of "1995", all puerulus plots are moved one year to the right; what was formerly 1994 becomes 1995. So all best lag values are reduced by one, even if the reanalysis of the standardisation for the puerulus data does not change the shape of the curves.

Under the reanalysis of the puerulus standardisation, all curves have nearly the same shape as before, except for Castlepoint and Wellington. The correlation analysis for Castlepoint and Wellington was redone with the new puerulus standardisations giving as follows.

For Castlepoint the correlation is slightly worse (the best lag remains at 7 years).

Before: Spearman correlation = 0.46, p-value = 0.051

After: Spearman correlation = 0.44, p-value = 0.059

For Wellington the correlation is worse (the best lag is reduced to two years).

Before: Spearman correlation = 0.52, p-value = 0.098

After: Spearman correlation = 0.40, p-value = 0.15

Therefore, while aligning the settlement year with the CPUE year clarifies the interpretation of the correlation, it has on the whole only a minor effect on the correlations obtained.

3.4 Future correlation analyses

Useful ways forward for the correlation analyses might include the following. First, signals may soon be apparent in the pre-recruit data as a result of the increased settlement from 2000 at many east coast sites and so indices of abundance of undersized lobsters should be examined. Next, a recruited-fishery CPUE based on periods less than a full fishing year might be investigated. For example, CPUE associated with the first, say, 4 months of a new fishing year, soon after lobsters have emerged from their autumn moulting, mating, and egg-extrusion activities, may best represent the fishery. Fishery CPUE later in the fishing year may reflect fishers 'mopping-up' uncaught quota or, in years with constraining TACCs, highgrading to secure best return. CPUE values for periods less than those associated with the full fishing year are not available from the CRACE database so we would need to use unstandardised values; the data of Bentley & Starr (2005) indicate that in general the standardised and unstandardised CPUE data by CRA area are very similar.

A third approach might use a correlation analysis that gives greater weight to the more recent fishery CPUE data – which is seen as being more accurate than the older data (discussed earlier), and which is not such a mix of cohorts. To reiterate, the fishery – particularly that off the east coast of the North Island – has recently undergone change in the manner it is prosecuted. Before 1990, it was for both sexes mainly during spring and summer, becoming largely a male-only, winter fishery in the 1990s to early 2000s (Kim et al. 2004). (From 2004, it has returned to being a winter male and spring/summer female fishery – RLWG data). This can have a large bearing on the outcome of the correlations between settlement and recruitment because males and females recruit at very different ages along the east coast, at least as far south as about Kaikoura. For example, it is estimated that in CRA 3 males recruit at least 6 years before females (based on McKoy & Esterman (1981)). It is possible to weight more highly the data associated with the essentially male-only fishery in the 1990s to early 2000s than the mixed-sex fishery data before 1990.

Last, estimates of year-to-year recruitment derived from the stock assessment model, which incorporates both the CPUE and length data, in relation to the settlement index, could be explored.

4. MANAGEMENT IMPLICATIONS

The correlation results are encouraging for the hypothesis that large-scale patterns in puerulus settlement are indeed manifested in the stock and therefore the fishery. The reasons for the disparity in this regard with the stock assessment model, which concluded that the settlement indices showed little similarity with the estimated assessment model recruitments and were of little value to stock assessment, remain unresolved, as discussed above. In the meantime, it is important that analyses of settlement versus subsequent stock abundance indices continue as new fishery data become available year-by-year so that any impact of the increasing settlement levels on the east coast from 2000 can be discerned.

Whereas the 1999 settlement level for nearly all SENI sites was very low in relation to the time series of settlement estimates – about 30% or less of those of the recent peak years 1991–92 – settlement in 2002–03 was closer to the average. In most areas the fishery is still largely dependent on just a few newly recruited year classes (Ministry of Fisheries and SeaFIC data). Nowhere else are the implications of the recent settlement estimates likely to be more marked than at Gisborne, where the fishery is mainly directed at small, young, newly recruited males (Sullivan 2004). The record low settlement observed in CRA 3 in 1999 is likely to contribute to further low recruitment to the fishery (and perhaps fishery CPUE) in 2005 (based on an average 5–7 years for males to recruit – McKoy & Esterman (1981) – and the above correlations). The much improved settlement in 2001–03 over that in 1999 should mean, however, improving recruitment to the fishery from about 2006. In CRA 4, where males have a larger minimum legal size (MLS), male recruitment to the fishery is likely to remain low, or even further reduce, until at least 2007. In CRA 5, where males have the same MLS as in CRA 4, the Kaikoura settlement data suggest that male recruitment to the fishery will decline until about 2007 before any improvement begins. In CRA 7, with its lower MLS for much of the fishing year for both males and females, the much improved settlement from 2000 may mean improved recruitment to the fishery of both sexes from about 2005–06, based on the growth estimates of Street & Booth (1985) and Annala & Bycroft (1985) and the correlations above. As always, however, the validity of such predictions can be confounded by variable growth and survival (including density-dependence which can smooth peaks and troughs in recruitment), predation, migration, and high levels of illegal fishing.

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Table 1: Collector type and number by site, and main settlement season. Groups no longer monitored from 1 October 2002 (or earlier in a few instances) are given in italics; changes after 1 October 2002 to monitored groups are denoted with strikethrough and underline. For definitions of collector type, see Booth & Tarring (1986) and Phillips & Booth (1994). Not all sites have a designated core set.

Site	No. collectors	Core group	Additional groups	Location	Type	Main settlement season
Houhora	*5*		*HOU001*	*Heads*	*Suspended*	*?*
	5		*HOU002*	*Henderson*	*Shore*	*?*
Bowentown	*5*		*BOW001*	*Papatu*	*Shore*	*?*
	5		*BOW002*	*Yellow*	*Shore*	*?*
Gisborne	5	GIS002		Whangara	Shore	Apr–Oct
	5		*GIS001*	*Harbour*	*Shore*	*Apr–Oct*
	5		GIS003	Tatapouri	Shore	Apr–Oct
	5		GIS004	Kaiti	Shore	Apr–Oct
Napier	6	NAP001		Harbour	Suspended	Apr–Sep
	3		*NAP002*	*Westshore*	*Closing*	*Apr–Sep*
	5		NAP003	C. Kidnappers	Shore	Apr–Sep
	3		*NAP004*	*Breakwater*	*Shore*	*Apr–Sep*
Castlepoint	9	CPT001		Castlepoint	Shore	Dec–Sep
	5		CPT002	Orui	Shore	Dec–Sep
	5		CPT003	Mataikona	Shore	Dec–Sep
Wellington	3		WGT001	Island Bay	Shore	Jan–May
	3		*WGT002*	*Lyall Bay*	*Shore*	*Jan–May*
	3		WGT003	Breaker Bay	Shore	Jan–May
	3		WGT004	Palmer Head	Shore	Jan–May
Kaikoura	~~3~~ 5	KAI001		South 13–15	Shore	Jan–Sep
	3		*KAI002*	*South 31–33*	*Shore*	*Jan–Sep*
	~~3~~ 5		KAI003	North 10–12	Shore	Jan–Sep
	3		*KAI004*	*North 34–36*	*Shore*	*Jan–Sep*
Moeraki	*4*	*MOE001*		*Shag Point*	*Shore*	*Mar–Oct*
	3		MOE002	Wharf	Closing	Mar–Oct
	3		*MOE004*	*Millers Beach*	*Shore*	*Mar–Oct*
	3		*MOE005*	*The Kaik*	*Shore*	*Mar–Oct*
	3		*MOE006*	*Kakanui*	*Shore*	*Mar–Oct*
	15		MOE007	Pier	Suspended	Mar–Oct
Halfmoon Bay	~~3~~ 15	HMB001		Wharf	Suspended	May–Oct
	3		*HMB002*	*Thompsons*	*Closing*	*May–Oct*
	3		*HMB003*	*Old Mill*	*Closing*	*May–Oct*
	3		*HMB004*	*The Neck*	*Closing*	*May–Oct*
	3		*HMB005*	*Mamaku Point*	*Closing*	*May–Oct*
Chalky Inlet	6	CHA001		Shallow Passage	Closing	Mar–Oct
Jackson Head	~~3~~5		JAC001	Jackson Bay Wharf	Suspended	Mar–Oct
	3		JAC002	Jackson Head Inner	Closing	Mar–Oct
	3		*JAC003*	*Jackson Head Outer*	*Closing*	*Mar–Oct*
	3		*JAC004*	*Smoothwater Bay*	*Closing*	*Mar–Oct*

Table 2: Settlement season indices of annual settlement (mean number of pueruli + juveniles at least 14.5 mm carapace length per collector during the main settlement season – see Table 2) on core (usually, but not always, 001) and additional groups of collectors at the key sites to 2003. Collectors are all crevice collectors. GIS001 is Harbour 1–5 at Gisborne, GIS002 is Whangara 1–5, GIS003 is Tatapouri 1–5, and GIS004 is Kaiti 1–5; NAP001 is Harbour 1–6 at Napier, NAP002 is Westshore 1–3, NAP003 is Cape Kidnappers 1–5, and NAP004 is Breakwater 1–3; CPT001 is Castlepoint 1–9 at Castlepoint, CPT002 is Orui 1–5, and CPT003 is Mataikona 1–5; WGT001 is Island Bay 1–3, WGT002 is Lyall Bay 1–3, WGT003 is Breaker Bay 1–3, and WGT004 is Palmer Head 1–3; KAI001 is South 13–15 on the Kaikoura Peninsula, KAI002 is South 31–33, KAI003 is North 10–12, and KAI004 is North 34–36; MOE001 is Shag Point 1-4 near Moeraki, MOE002 is Wharf 1–3, MOE005 is The Kaik 1–3, MOE007 is suspended collectors on pier, Overall is an index usually based on at least nine collectors each month, but the collectors checked were not always the same; HMB001 is Wharf 1–3 in Halfmoon Bay, Stewart Island, HMB002 is Thompsons 1–3, HMB003 is Old Mill 1–3, HMB004 is The Neck 1–3, and HMB005 is Mamaku Point 1–3; CHA is Chalky Inlet 1-6. Settlement (Overall) at Houhora (HOU), Bowentown (BOW), and Jackson Head (JAC) was usually based on at least six collectors checked each month but more rigorous treatment of these results was not appropriate. Columns give mean catch across the collectors ± 1 s.e. of that mean; –, no data.

Houhora	Overall
2001	0.5

Bowentown	Overall
2001	3.2

Gisborne	GIS001	GIS002	GIS003	GIS004
1987	170 ± 8.9	–	–	–
1988	177.7 ± 15.4	–	–	–
1989	58.4 ± 4.5	–	–	–
1990	29.4 ± 3.5	–	–	–
1991	64.4 ± 5.9	–	–	–
1992	171.2 ± 27.7	70.3 ± 7.6	–	–
1993	107.8 ± 11.3	33.7 ±2.6	–	–
1994	131.2 ± 10.7	48.6 ± 10.4	77.4 ± 11.4	23.8 ± 1.9
1995	66.4 ± 6.4	40.8 ± 6.2	16.4 ± 2.2	5.0 ± 1.73
1996	165.8 ± 38.9	30.3 ± 1.5	–	13.4 ± 3.1
1997	53.8 ± 9.1	19.6 ± 3.2	25.2 ± 2.0	7.6 ± 1.3
1998	114.4 ± 45.3	33.1 ± 3.4	24.4 ± 1.9	16.6 ± 2.8
1999	31.2 ± 3.7	2.4 ± 0.8	0	1.00 ± 0.5
2000	40.8 ± 8.8	16.6 ± 3.6	23.2 ± 3.1	4.6 ± 1.4
2001	61 ± 11.3	35.0 ± 7.2	15.6 ± 3.0	14.6 ± 5.6
2002	–	37.0 ± 7.7	8.4 ± 1.4	5.2 ± 2.2
2003	–	60.3 ± 7.1	21.9 ± 1.0	30.8 ± 5.1

Table 2 -continued

Napier	NAP001	NAP002	NAP003	NAP004
1979	10.7 ± 1.5	–	–	–
1980	26.5 ± 6.4	–	–	–
1981	39.2 ± 2.9	–	–	–
1982	18.8 ± 2.3	–	–	–
1983	22.8 ± 4.7	–	–	–
1984	6.5 ± 1.2	–	–	–
1985	4.4 ± 0.6	–	–	–
1986	–	–	–	–
1987	–	–	–	–
1988	22.0 ± 1.2	–	–	–
1989	16.0 ± 2.5	–	–	–
1990	15.8 ± 1.9	–	–	–
1991	48.7 ± 6.7	173.3 ± 9.5	–	–
1992	29.0 ± 2.7	224.3 ± 4.4	–	97.2 ± 5.9
1993	23.3 ± 4.8	–	–	55.7 ± 4.9
1994	32.8 ± 1.8	115.0 ± 19.6	–	25.5 ± 3.4
1995	20.2 ± 1.5	103.3 ± 7.2	13.0 ± 1.9	23.2 ± 5.3
1996	26.0 ± 3.4	173.3 ± 51.4	11.6 ± 1.4	82.5 ± 15.0
1997	12.2 ± 0.8	137.7 ± 3.3	15.4 ± 2.4	54.7 ± 8.0
1998	19.1 ± 1.5	88.0 ± 11.3	30.8 ± 5.7	43.0 ± 8.7
1999	6.0 ± 1.4	–	2.4 ± 0.7	6.3 ± 0.3
2000	13.0 ± 1.7	–	7.8 ± 1.2	18.7 ± 1.5
2001	37.2 ± 3.8	–	18.2 ± 4.7	20.17 ± 3.4
2002	15.2 ± 3.3	–	21.8 ± 3.2	15.3 ± 0.3
2003	30.3 ± 2.7	–	13.6 ± 1.9	–

Castlepoint	CPT001	CPT002	CPT003
1983	70.2 ± 7.5	–	–
1984	54.8 ± 3.1	–	–
1985	35.0 ± 7.1	–	–
1986	15.9 ± 2.0	–	–
1987	62.4 ± 5.1	–	–
1988	42.3 ± 3.0	–	–
1989	51.4 ± 3.4	–	–
1990	31.4 ± 8.6	–	–
1991	81.6 ± 6.0	–	–
1992	93.7 ± 5.8	118.0 ± 8.6	30.0 ± 3.8
1993	50.6 ± 7.2	65.8 ± 5.9	20.2 ± 2.5
1994	40.2 ± 1.9	22.8 ± 3.8	6.8 ± 1.0
1995	47.7 ± 5.2	22.9 ± 3.5	8.8 ± 1.2
1996	51.6 ± 6.1	42.6 ± 5.6	25.8 ± 2.9
1997	43.1 ± 3.8	54.6 ± 2.1	37.2 ± 3.4
1998	64.2 ± 4.0	65.2 ± 6.5	28.5 ± 2.4
1999	11.9 ± 1.5	Sanded	5.2 ± 0.7
2000	18.8 ± 2.2	Sanded	15.4 ± 1.5
2001	22.2 ± 2.7	Sanded	12.8 ± 2.3
2002	28.6 ± 3.1	23.9 ± 1.5	8.4 ± 2.2
2003	25.7 ± 3.3	29.3 ± 5.0	9.6 ± 1.9

Table 2 -continued

Wellington	Overall	WGT001	WGT002	WGT003	WGT004
1981	6.3	6.3	–	–	–
1982	0.2	0.2	–	–	–
1983	3.7	3.7	–	–	–
1984	0.4	0.4	–	–	–
1985	–	–	–	–	–
1986	–	–	–	–	–
1987	–	–	–	–	–
1988	–	–	–	–	–
1989	–	–	–	–	–
1990	–	–	–	–	–
1991	–	–	–	–	–
1992	–	–	–	–	–
1993	–	–	–	–	–
1994	6.6	11.7 ± 2.0	2.3 ± 0.3	–	5.7 ± 0.9
1995	4.9	4.7 ± 1.8	3.0 ± 1.5	–	7.0 ± 1.5
1996	4.2	7.3 ± 1.2	0.7 ± 0.7	4.7 ± 1.5	–
1997	22.8	57.0 ± 5.6	2.7 ± 0.7	8.7 ± 2.3	–
1998	5.3	10.0 ± 1.0	0.7 ± 0.7	5.3 ± 0.9	–
1999	3.0	7.0 ± 2.3	0	2.0 ± 0.6	–
2000	14.2	19.7 ± 1.2	–	6.3 ± 0.9	16.7 ± 1.9
2001	12.3	21.3 ± 4.9	–	4.3 ± 0.3	11.3 ± 1.5
2002	16.2	24.7 ± 4.2	–	15.3 ± 3.4	8.7 ± 3.1
2003	10.1	11.7 ± 4.9	–	8.0 ± 1.5	10.7 ± 2.2

Kaikoura	KAI001	KAI002	KAI003	KAI004
1981	–	–	8.4 ± 1.2	–
1982	0	–	0	–
1983	7.2 ± 1.2	–	4.2 ± 1.2	–
1984	1.7 ± 0.3	–	2.3 ± 1.0	–
1985	2.0 ± 0.6	–	3.7 ± 0.4	–
1986	0.3 ± 0.3	–	1.2 ± 0	–
1987	15.2 ± 0.6	–	2.0 ± 0.3	–
1988	6.7 ± 0.9	–	1.3 ± 0.3	–
1989	9.7 ± 1.5	4.0 ± 1.5	4.0 ± 1.5	–
1990	2.3 ± 1.5	1.7 ± 0.9	0.7 ± 0.7	–
1991	60.7 ± 2.2	35.3 ± 1.2	24.0 ± 2.1	–
1992	68.5 ± 5.7	34.3 ± 2.7	22.7 ± 0.3	–
1993	35.7 ± 1.2	12.3 ± 0.9	14.7 ± 0.9	10.7 ± 0.9
1994	7.8 ± 2.1	1.8 ± 0.3	1.3 ± 0.9	1.0 ± 1.0
1995	12.0 ± 1.2	4.3 ± 0.9	4.0 ± 0.6	3.3 ± 2.0
1996	8.0 ± 1.3	4.5 ± 1.2	2.9 ± 0.6	1.3 ± 1.0
1997	16.3 ± 2.7	5.8 ± 0.9	5.0 ± 0.3	7.0 ± 1.5
1998	24.5 ± 1.2	11.0 ± 2.5	4.2 ± 1.2	11.8 ± 1.5
1999	12.5 ± 0.7	6.7 ± 0.6	5.5 ± 1.2	5.2 ± 1.9
2000	13.5 ± 2.4	3.0 ± 0.9	10.7 ± 2.2	3.2 ± 1.5
2001	5.0 ± 2.1	0	6.3 ± 2.7	0.3 ± 0.3
2002	8.3 ± 2.0	0.7 ± 0.3	7.0 ± 0.6	1.3 ± 0.9
2003	39.5 ± 3.2	–	44.5 ± 3.5	–

Table 2 -continued

Moeraki	Overall	MOE001	MOE002	MOE005	MOE007
1981	6.6	–	–	–	–
1982	0.2	–	–	–	–
1983	3.8	4.3 ± 1.9	–	–	–
1984	0.3	0.7 ± 0.3	–	–	–
1985	0	0	–	–	–
1986	0	0	–	–	–
1987	2.5	3.3 ± 1.0	3.7 ± 1.0	–	–
1988	0.1	0	0	–	–
1989	2.8	4.7 ± 1.2	2.0 ± 0.6	–	–
1990	2.2	0.8 ± 0.7	–	–	–
1991	0.4	0	0	–	–
1992	0.3	0.5 ± 0.3	0.5 ± 0.3	–	–
1993	0.3	0	0	–	–
1994	0.3	0.5 ± 0.3	0	–	–
1995	0.3	0	0.3 ± 0.6	–	–
1996	1.1	0.4 ± 0.3	3.3 ± 2.3	–	–
1997	0.4	0	1.7 ± 0.3	–	–
1998	1.0	–	2.0 ± 0	–	–
1999	0.3	–	0.3 ± 0.3	0	–
2000	6.1	–	11.7 ± 0.3	1.3 ± 1.0	–
2001	6.4	–	8.7 ± 4.1	0.7 ± 0.3	–
2002	3.4	–	4.7 ± 1.5	–	–
2003	21.5	–	22.8 ± 3.1	–	

Halfmoon Bay	HMB001	HMB002	HMB003	HMB004	HMB005
1981	29.9 ± 3.5	–	–	–	–
1982	1.8 ± 0.7	–	–	–	–
1983	14.3 ± 1.8	–	–	–	–
1984	0.7 ± 0.3	–	–	–	–
1985	0	–	–	–	–
1986	0.5 ± 0.3	–	–	–	–
1987	5.0 ± 1.0	–	–	–	–
1988	0.7 ± 0.3	0.7 ± 0.7	–	–	–
1989	2.0 ± 1.0	1.3 ± 0.7	–	–	–
1990	2.8 ± 0.2	0.5 ± 0.3	1.2 ± 0.6	–	–
1991	1.0 ± 0	5.2 ± 0.9	1.7 ± 0.7	–	–
1992	4.0 ± 0.3	2.0 ± 0.6	0.3 ± 0.3	0.3 ± 0.3	0.7 ± 0.3
1993	0	0	0	0	0
1994	2.2 ± 0.6	5.0 ± 0.6	2.0 ± 1.5	1.3 ± 1.3	3.3 ± 2.0
1995	2.3 ± 0.7	1.0 ± 1.0	0.3 ± 0.3	0.3 ± 0.3	0
1996	1.5 ± 0	1.0 ± 0.6	0	0.3 ± 0.3	0.7 ± 0.7
1997	2.0 ± 0.9	1.7 ± 0.9	0	0.3 ± 0.3	2.7 ± 1.2
1998	0.7 ± 0.3	1.0 ± 1.0	0.7 ± 0.3	0.7 ± 0.3	0.3 ± 0.3
1999	0.3 ± 0.3	1.5 ± 0.7	0.3 ± 0.3	0	0.5 ± 0.3
2000	4.0 ± 1.5	5.0 ± 0.3	2.2 ± 0.6	0.7 ± 0.3	1.8 ± 0.3
2001	7.0 ± 1.5	3.3 ± 0.7	2.3 ± 1.2	2.0 ± 1.0	3.7 ± 1.2
2002	2.3 ± 0.9	3.3 ± 1.5	6.7 ± 2.0	3.0 ± 0.6	1.7 ± 0.3
2003	8.7 ± 1.2	–	–	–	–

Table 2 -continued

Chalky Inlet	CHA001		CHA001		CHA001
1987	53.3 ± 5.3	1993	5.3 ± 0.7	1999	12.3 ± 1.7
1988	49.1 ± 5.2	1994	90.5 ± 21.3	2000	33.7 ± 2.9
1989	67.0 ± 9.0	1995	19.0 ± 2.9	2001	29.6 ± 4.8
1990	35.5 ± 4.2	1996	37.6 ± 4.7	2002	–
1991	37.9 ± 6.1	1997	47.3 ± 9.5	2003	51.7 ± 13.2
1992	13.5 ± 1.7	1998	5.0 ± 1.1		

Jackson Head	Overall
2000	5.9
2001	6.3
2002	22.8
2003	9.4

Table 3: Pearson correlation coefficients for the pattern of year-to-year settlement based on the settlement season index of annual settlement among some key sites (insufficient data for Jackson Bay). GIS, Gisborne (1992–2003); NAP, Napier (1979–85, 1988–2003); CPT, Castlepoint (1983–2003); KAI, Kaikoura (1982–2003); MOE, Moeraki overall (1981–2003); HMB, Halfmoon Bay (1981–2003); CHA, Chalky Inlet (1987–2003); degrees of freedom are given in parentheses; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; other correlations not significant.

	GIS	NAP	CPT	KAI	MOE	HMB
NAP	0.71(9)*					
CPT	0.76(9)**	0.46(16)*				
KAI	0.58(9)	0.53(17)*	0.70(18)***			
MOE	–0.19(9)	0.26(18)	–0.27(18)	–0.20(19)		
HMB	0.30(9)	0.42(18)	0.22(18)	–0.06(19)	0.69(20) ***	
CHA	0.10(9)	0.17(13)	–0.09(14)	–0.38(14)	0.07(14)	0.15(14)

Table 4: Further details of puerulus standardisation. All standardisations used Poisson error with dispersion (and the log link). All collectors 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 (Bentley et al. (2004b) removed outliers, but the effect on the standardised indices was minor). GIS (002, 003, 004) etc. refer to collector sites and groups in Table 1.

Standardisation	Additional factors (all had Year and Month)
GIS (002, 003, 004)	Collector
NAP (001, 002, 003, 004)	Collector
CPT (001, 002, 003)	Collector
WGT (001, 002, 003, 004)	Collector
KAI (001, 002, 003, 004)	Group
MOE (001, 002)	Group
HMB (001, 002, 003, 004, 005)	Group
CHA (001)	Collector

Table 5: Spearman correlation coefficients (ρ) for the correlation between standardised puerulus indices by site and standardised CPUE indices in the corresponding quota management area (Area). The p-value is for the correlation at the best lag and is a one-sided p-value (ρ>0). A tick (√) signifies that a correlation is significant, a cross (X) that it is not significant. Puerulus settlement year is the calendar year; CPUE year is the rock lobster fishing year (e.g., fishing year 2000 is 1 April 1999 to 31 March 2000).

Site	Area	Best lag	ρ	p-value (HA: ρ > 0)	α = 0.10	α/3	α/5
Gisborne	CRA 3	6	0.71	0.044	√	X	X
Napier	CRA 4	7	0.70	0.002	√	√	√
Castlepoint	CRA 4	7	0.46	0.051	√	X	X
Wellington	CRA 4	3	0.52	0.098	√	X	X
Nap, Cpt, Wgt	CRA 4	7	0.43	0.024	√	√	X
Kaikoura	CRA 5	9	0.74	0.001	√	√	√
Moeraki	CRA 7	5	0.65	0.076	√	X	X
Halfmoon Bay	CRA 8	5	0.48	0.020	√	√	√ or X
Chalky Inlet	CRA 8	7	0.61	0.020	√	√	√ or X

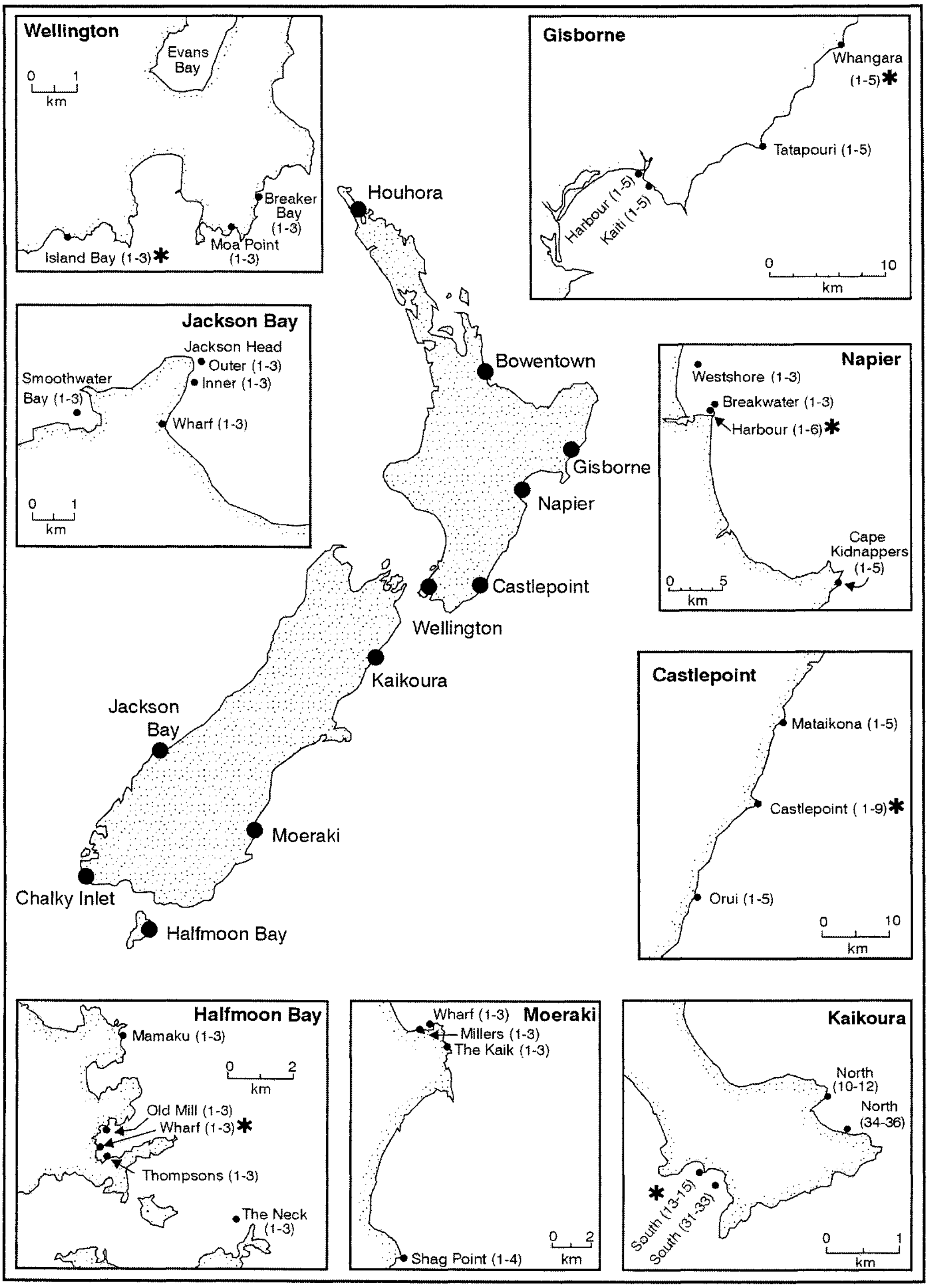


Figure 1: Map of New Zealand showing location of collectors at the key monitoring sites, although not all groups are now checked (see Table 1). The insets show the numbers and arrangement of collectors at sites with more than one group of collectors. *, core group of collectors where one has been nominated.

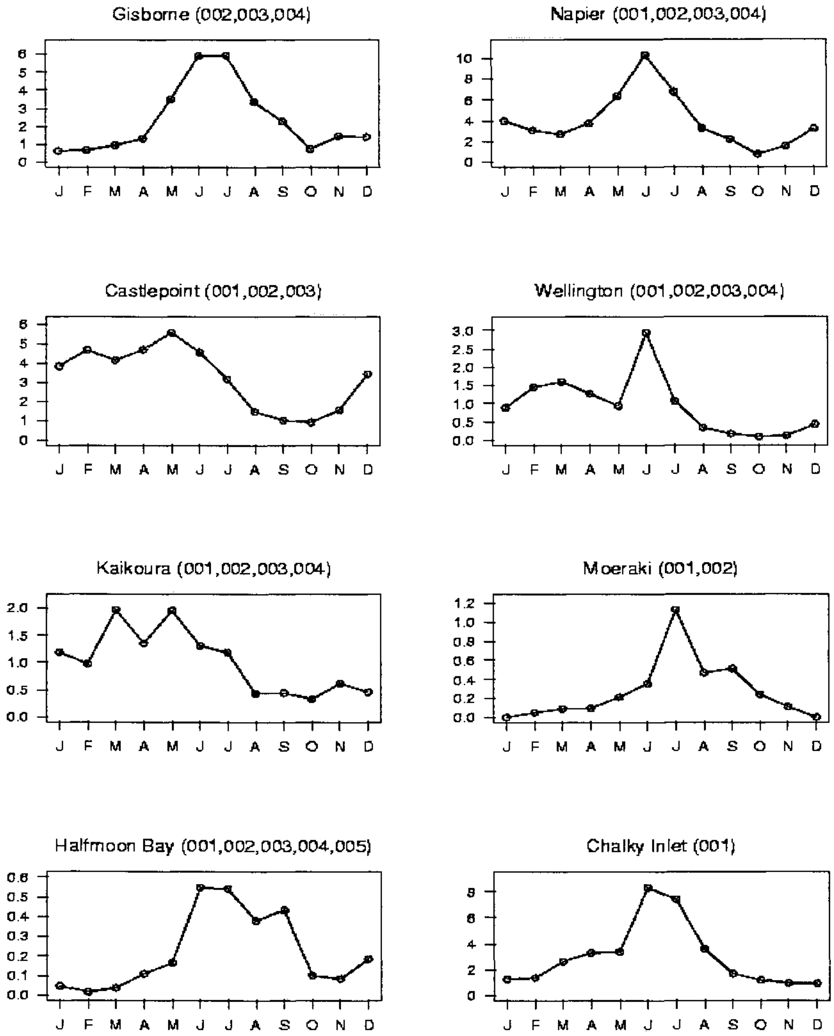


Figure 2: Patterns of monthly mean annual settlement for key collector sites, based on entire record. The numerals in the title to each graph refer to the collector groups listed in Table 1.

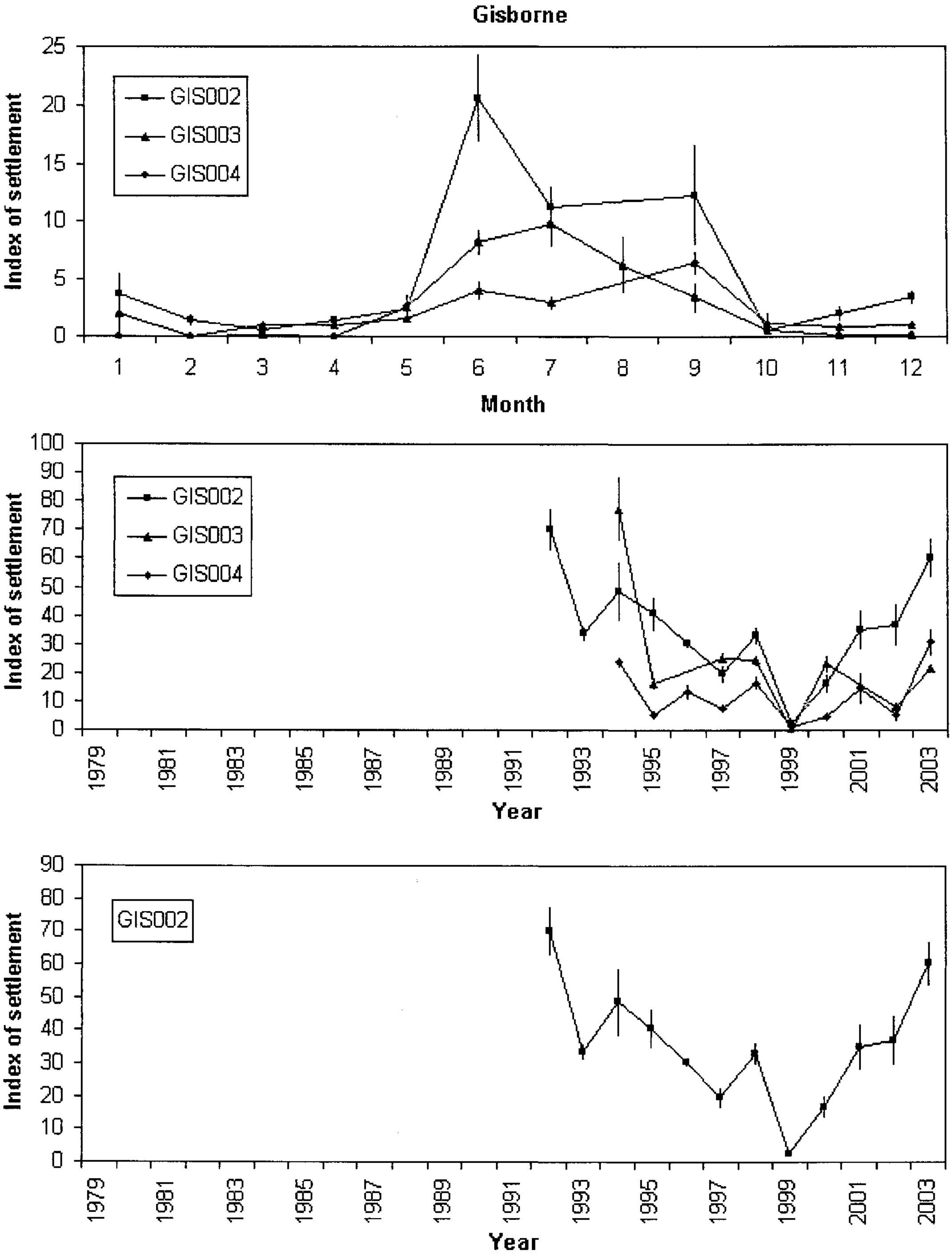


Figure 3: Gisborne – mean number of *Jasus edwardsii* pueruli + juveniles at least 14.5 mm carapace length per collector. Monthly index of settlement, 2003, ± 1 standard error (*upper*). Annual indices of settlement (settlement season index, based on the main settlement period, April to October) on groups of collectors ± 1 standard error (*middle*) and on the core group (*lower*). GIS002 is Whangara (core); GIS003 is Tatapouri; GIS004 is Kaiti (see Figure 1). GIS001, the harbour group, is not shown on the middle panel because it obscures and confuses the interannual pattern (see Booth et al. 1998).

Gisborne (002,003,004)

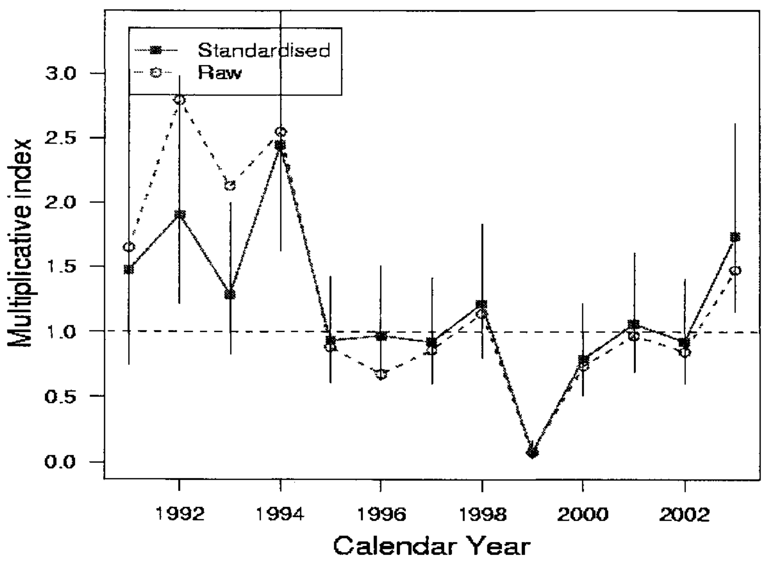


Figure 4: Gisborne – standardised and raw indices of annual settlement with 95% confidence bounds. The index for 1991 was based on few collectors checked late in the year only, leading to an imprecise estimate of settlement.

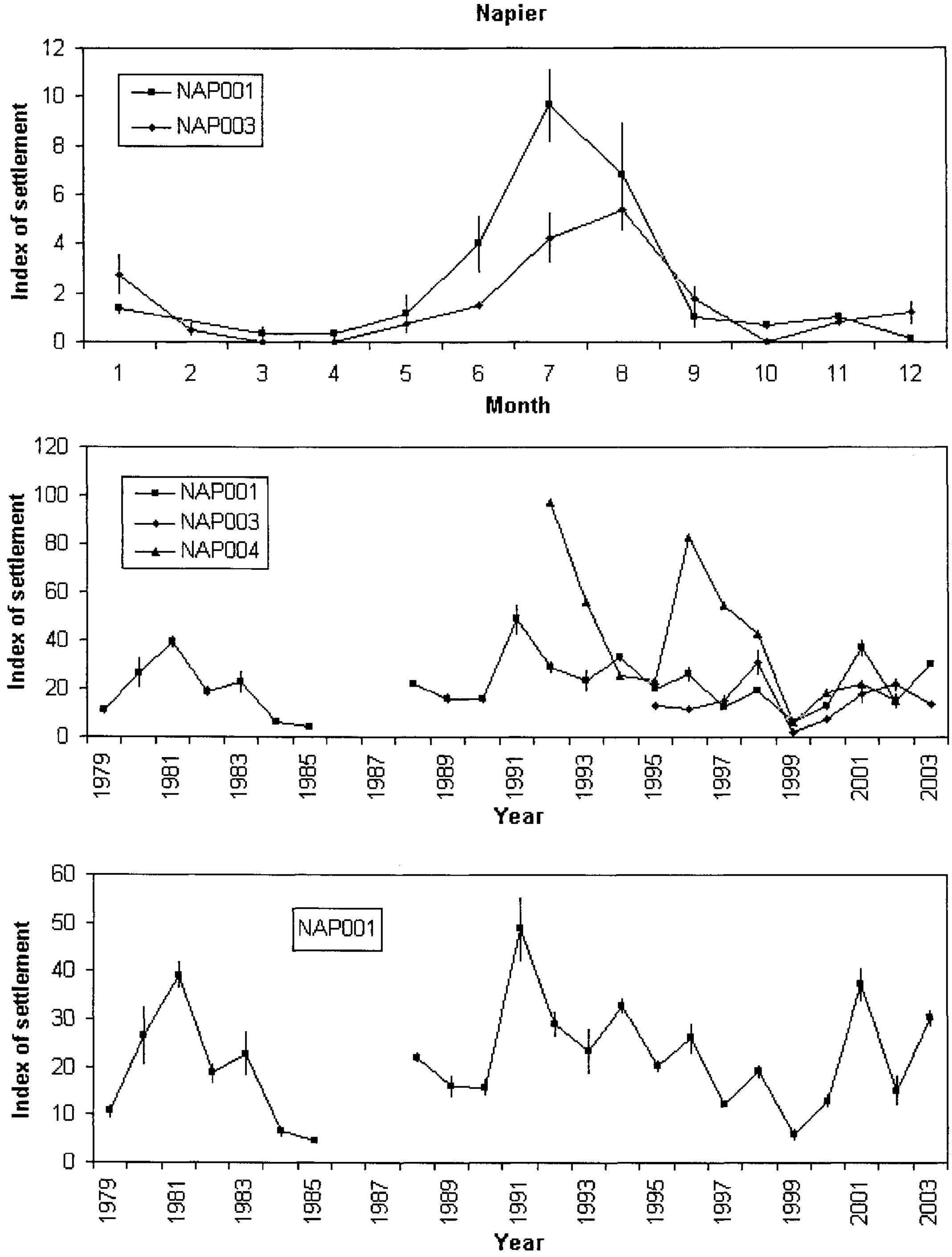


Figure 5: **Napier – mean number of *Jasus edwardsii* pueruli + juveniles at least 14.5 mm carapace length per collector. Monthly index of settlement, 2003, ± 1 standard error (*upper*). Annual indices of settlement (settlement season index, based on the main settlement period, April to September) on each group of collectors ± 1 standard error (*middle*) and on the core group (*lower*). NAP001 is the Harbour group (core); NAP003 is Cape Kidnappers; NAP004 is Breakwater (see Figure 1). Collector positions and deployment changed after 1985; no data available for 1986–87.**

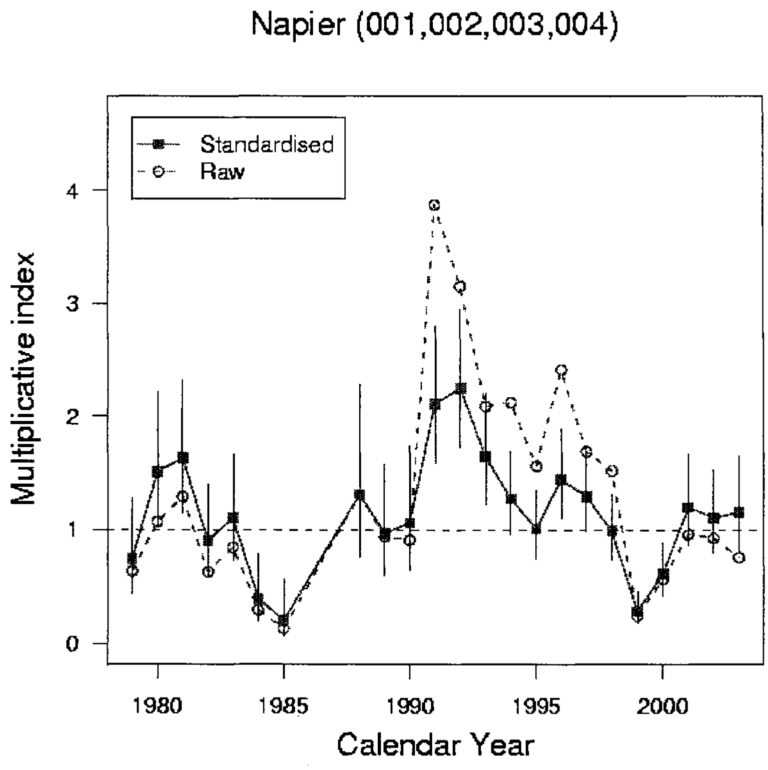


Figure 6: Napier – standardised and raw indices of annual settlement with 95% confidence bounds.

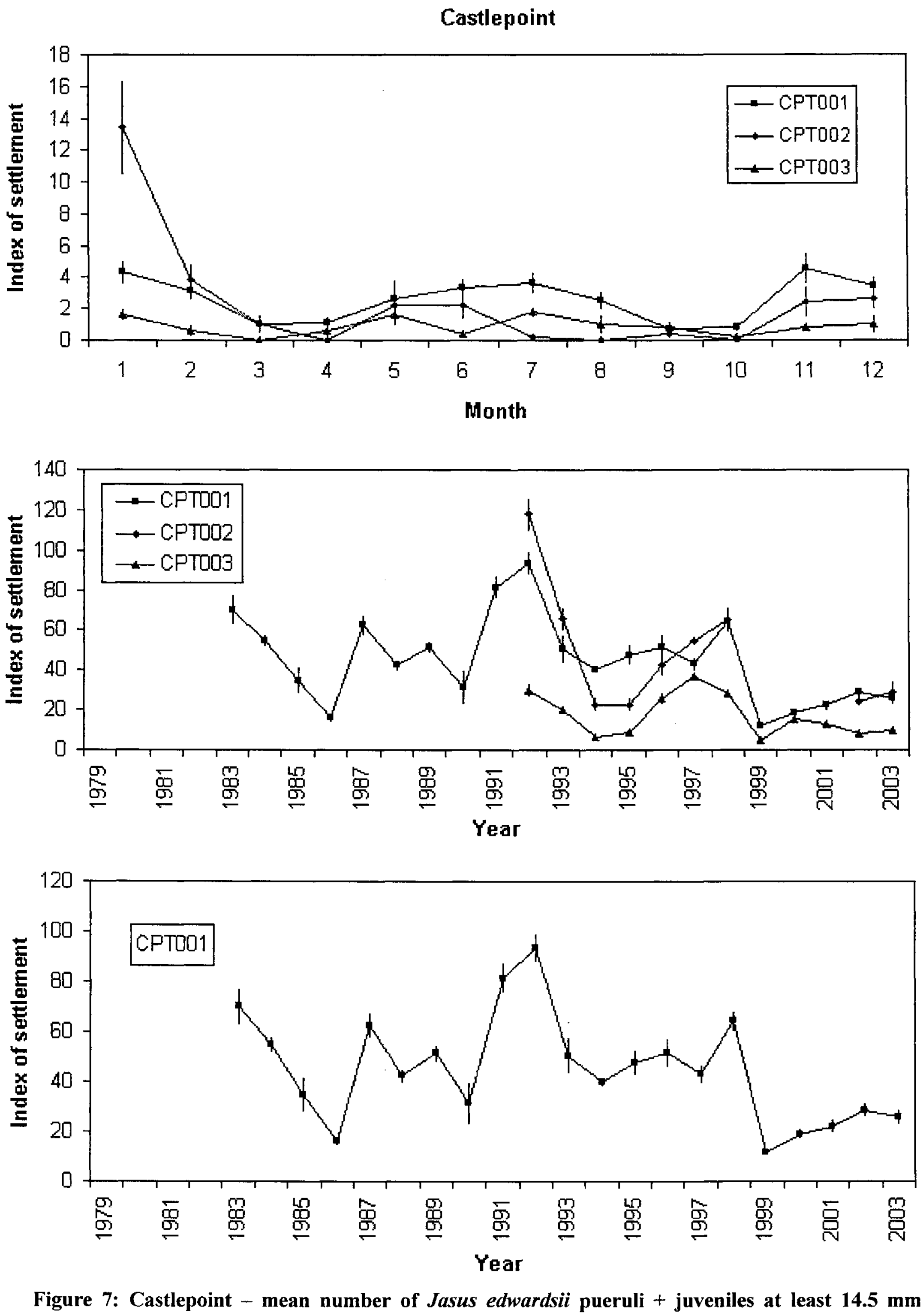


Figure 7: Castlepoint – mean number of *Jasus edwardsii* pueruli + juveniles at least 14.5 mm carapace length per collector. Monthly index of settlement, 2003, ± 1 standard error (*upper*). Annual indices of settlement (settlement season index, based on the main settlement period, December to September) on each group of collectors ± 1 standard error (*middle*) and on the core group (*lower*). CPT001 is the core group at Castlepoint; CPT002 is Orui; CPT003 is Mataikona (see Figure 1). There were no data for CPT002 for 1999–2001 because the collectors were sanded over.

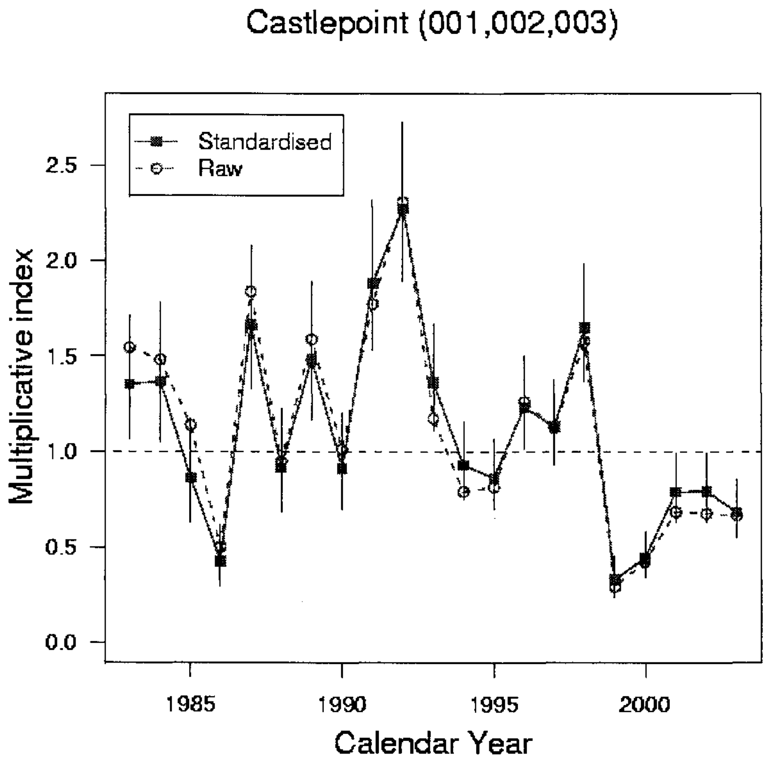


Figure 8: Castlepoint – standardised and raw indices of annual settlement with 95% confidence bounds.

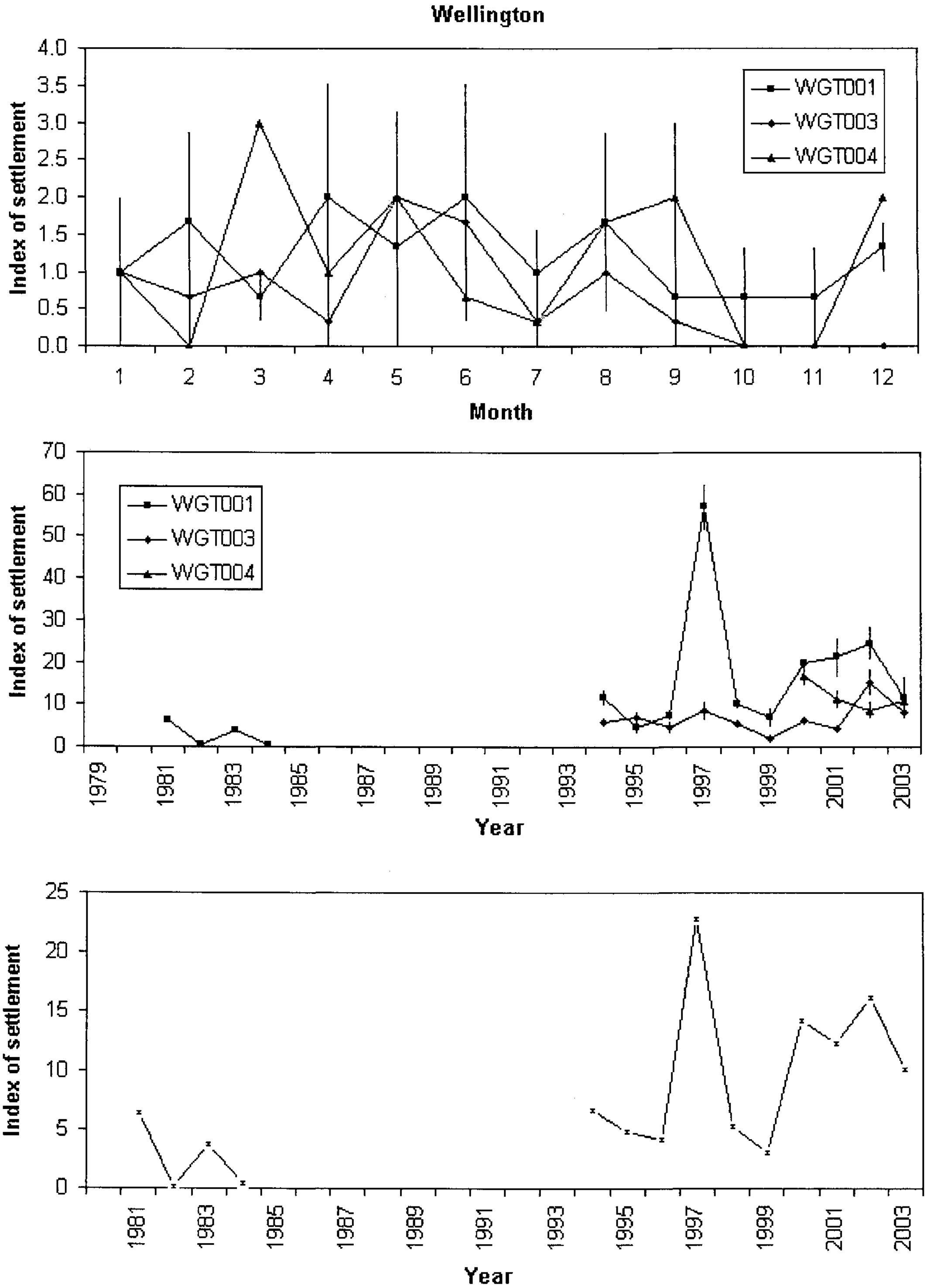


Figure 9: Wellington – mean number of *Jasus edwardsii* pueruli + juveniles at least 14.5 mm carapace length per collector. Monthly index of settlement, 2003, ± 1 standard error (*upper*). Annual indices of settlement (settlement season index, based on the main settlement period, January to May) on each group of collectors ± 1 standard error (*middle*) and an index based on all collectors each month (but the collectors checked were not always the same) (*lower*). WGT001 is Island Bay (core); WGT003 is Breaker Bay; WGT004 is Palmer Head (see Figure 1).

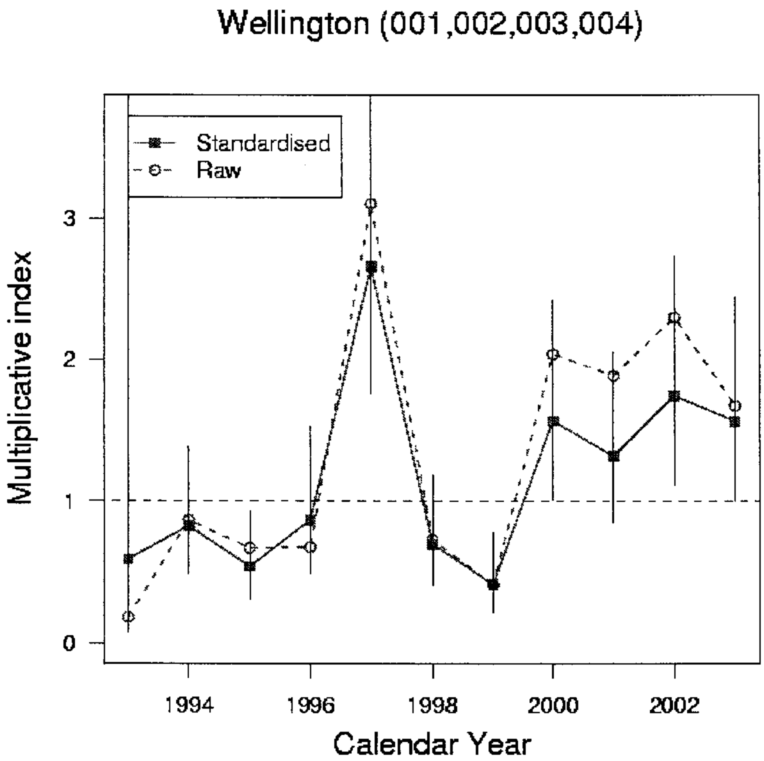


Figure 10: Wellington – standardised and raw indices of annual settlement with 95% confidence bounds.

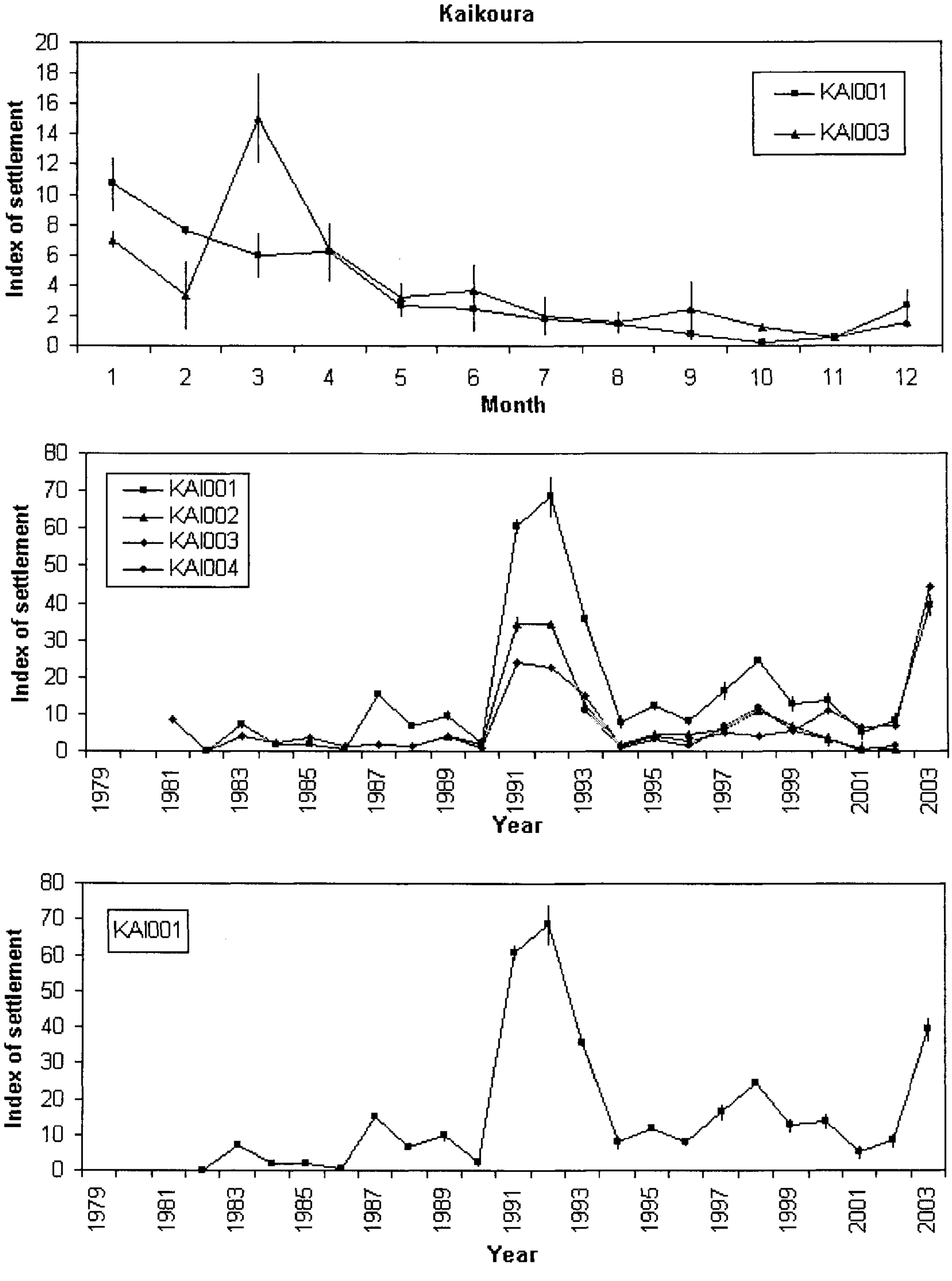


Figure 11: Kaikoura – mean number of *Jasus edwardsii* pueruli + juveniles at least 14.5 mm carapace length. Monthly index of settlement, 2003, ± 1 standard error (*upper*). Annual indices of settlement (settlement season index, based on the main settlement period, January to September) on each group of collectors ± 1 standard error (*middle*) and on the core group (*lower*). KAI001 is 13–15 on the south side of the peninsula (core); KAI002 is 31–33 on the south side of the peninsula; KAI003 is 10–12 on the north side of the peninsula; KAI004 is 34–36 on the north side of the peninsula (see Figure 1).

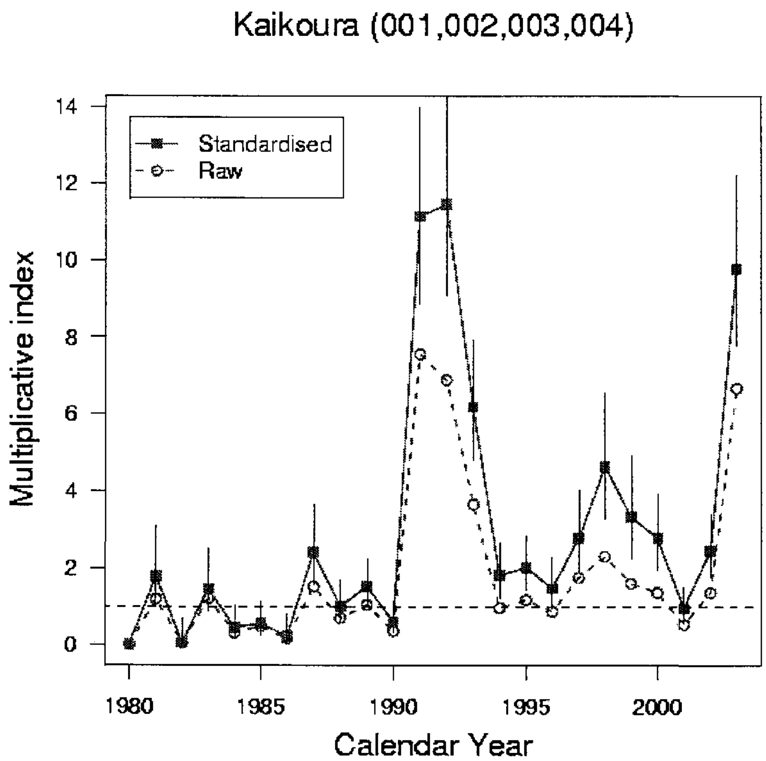


Figure 12: Kaikoura – standardised and raw indices of annual settlement with 95% confidence bounds.

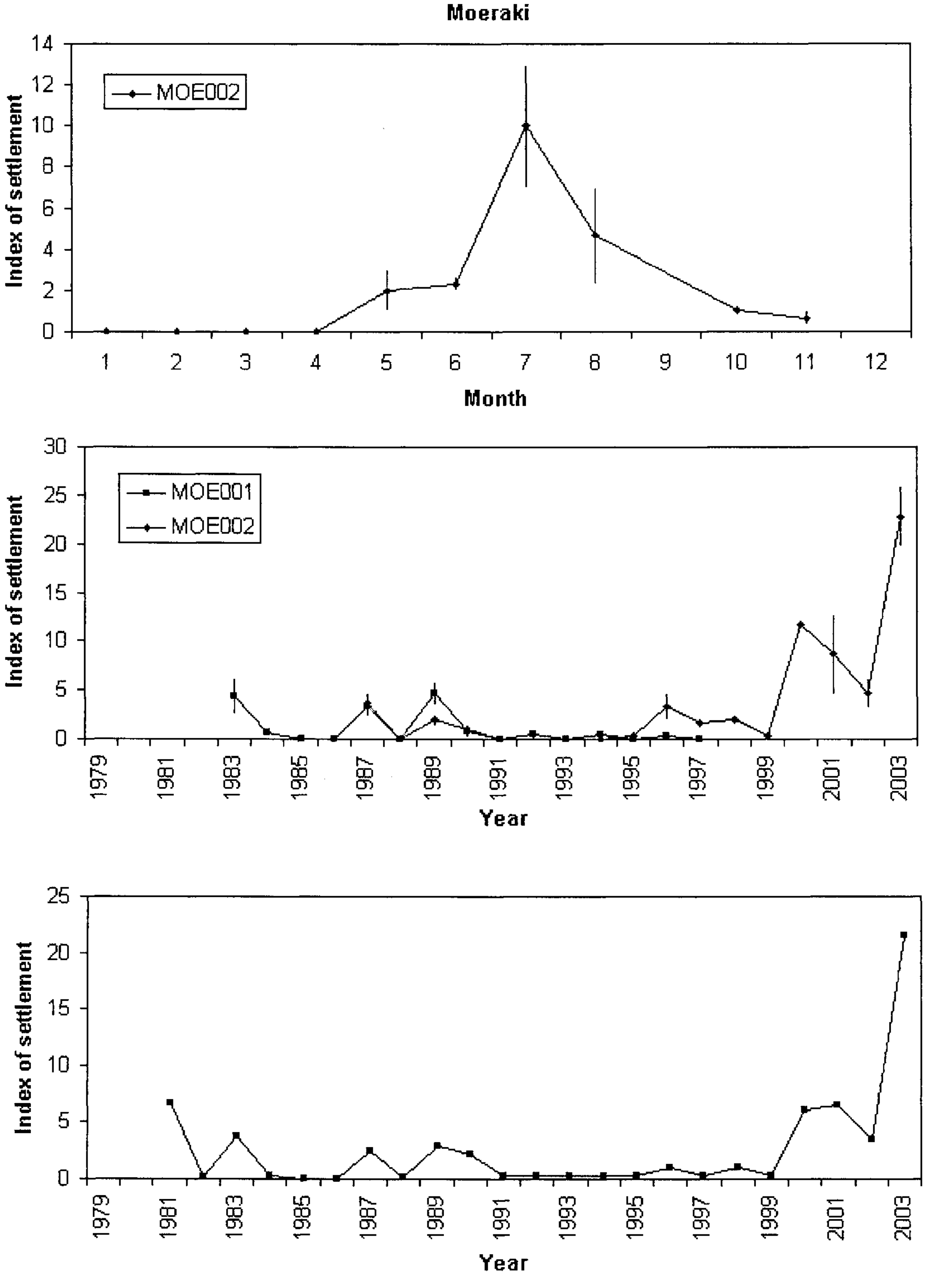


Figure 13: Moeraki – mean number of *Jasus edwardsii* pueruli + juveniles at least 14.5 mm carapace length per collector. Monthly index of settlement, 2003, ± 1 standard error (*upper*). Annual index of settlement (settlement season index, based on the main settlement period March to October) (*middle*) and an index based on at least nine collectors each month (but the collectors checked were not always the same) (*lower*). MOE001 is Shag Point 1-4, MOE002 is Pier 1-3, MOE004 is Millers Beach 1-3, MOE005 is The Kaik 1-3, MOE006 is Kakanui 1-3 (see Figure 1). No data since 1998 for MOE001.

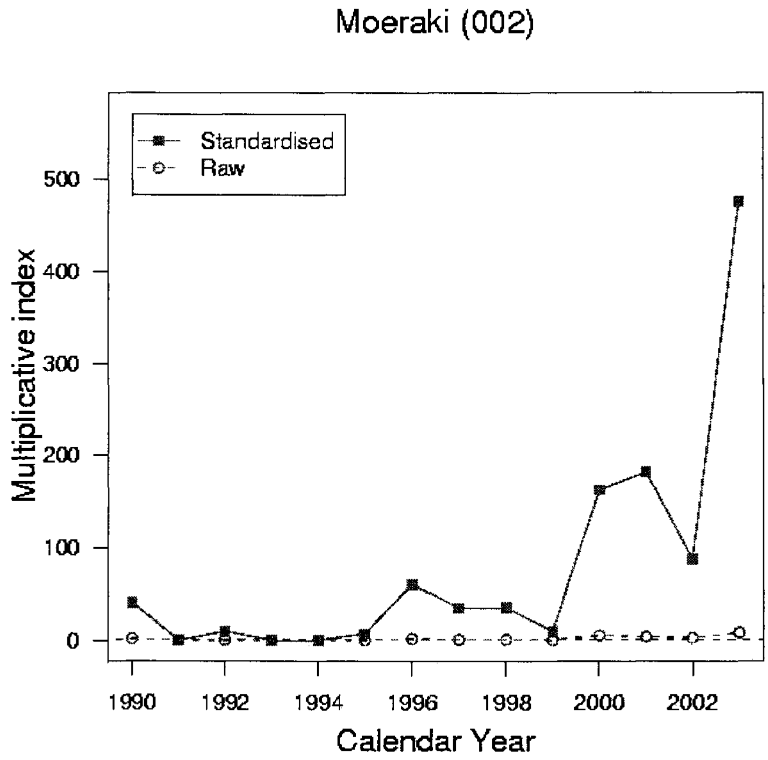


Figure 14: Moeraki – standardised and raw indices of annual settlement. The 95% confidence bounds are large.

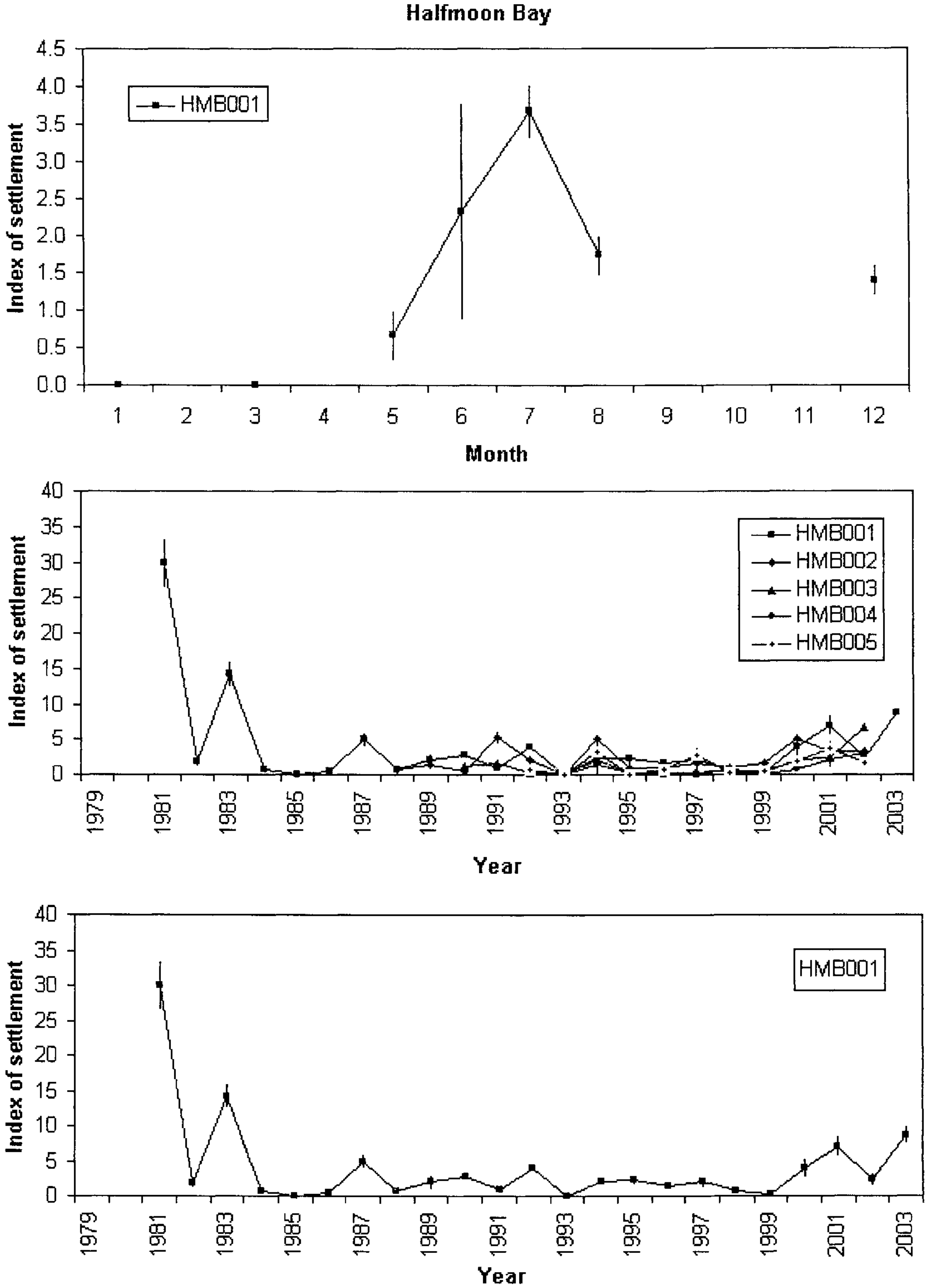


Figure 15: Halfmoon Bay – mean number of *Jasus edwardsii* pueruli + juveniles at least 14.5 mm carapace length. Monthly index of settlement, 2003, ± 1 standard error (*upper*). Annual indices of settlement (settlement season index, based on the main settlement period, May to October) on each group of collectors ± 1 standard error (*middle*) and on the core group (*lower*). HMB001 is under the wharf (core); HMB002 is Thompson's Nugget; HMB003 is Old Mill; HMB004 is the Neck; HMB005 is Mamaku Point (see Figure 1).

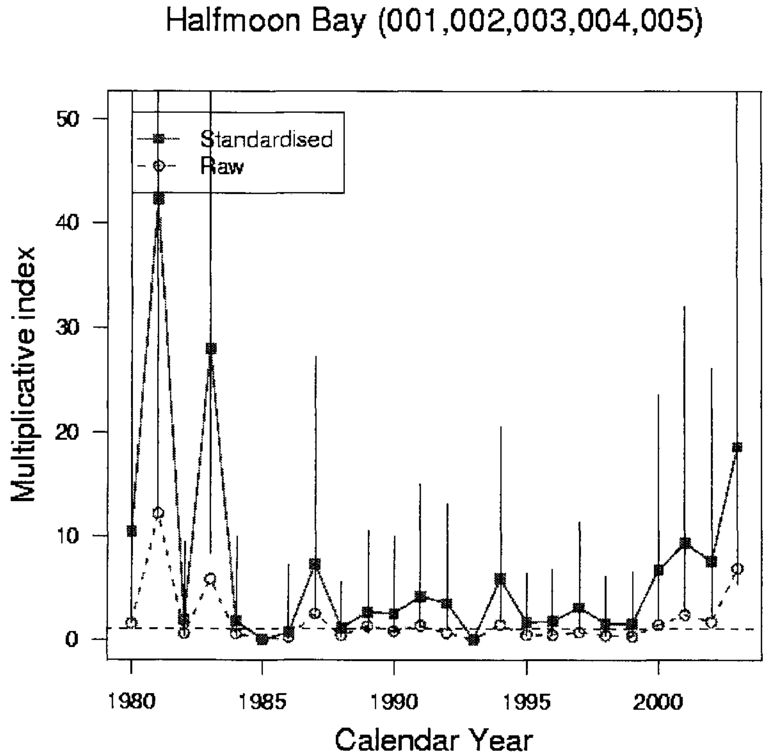


Figure 16: Halfmoon Bay – standardised and raw indices of annual settlement with 95% confidence bounds.

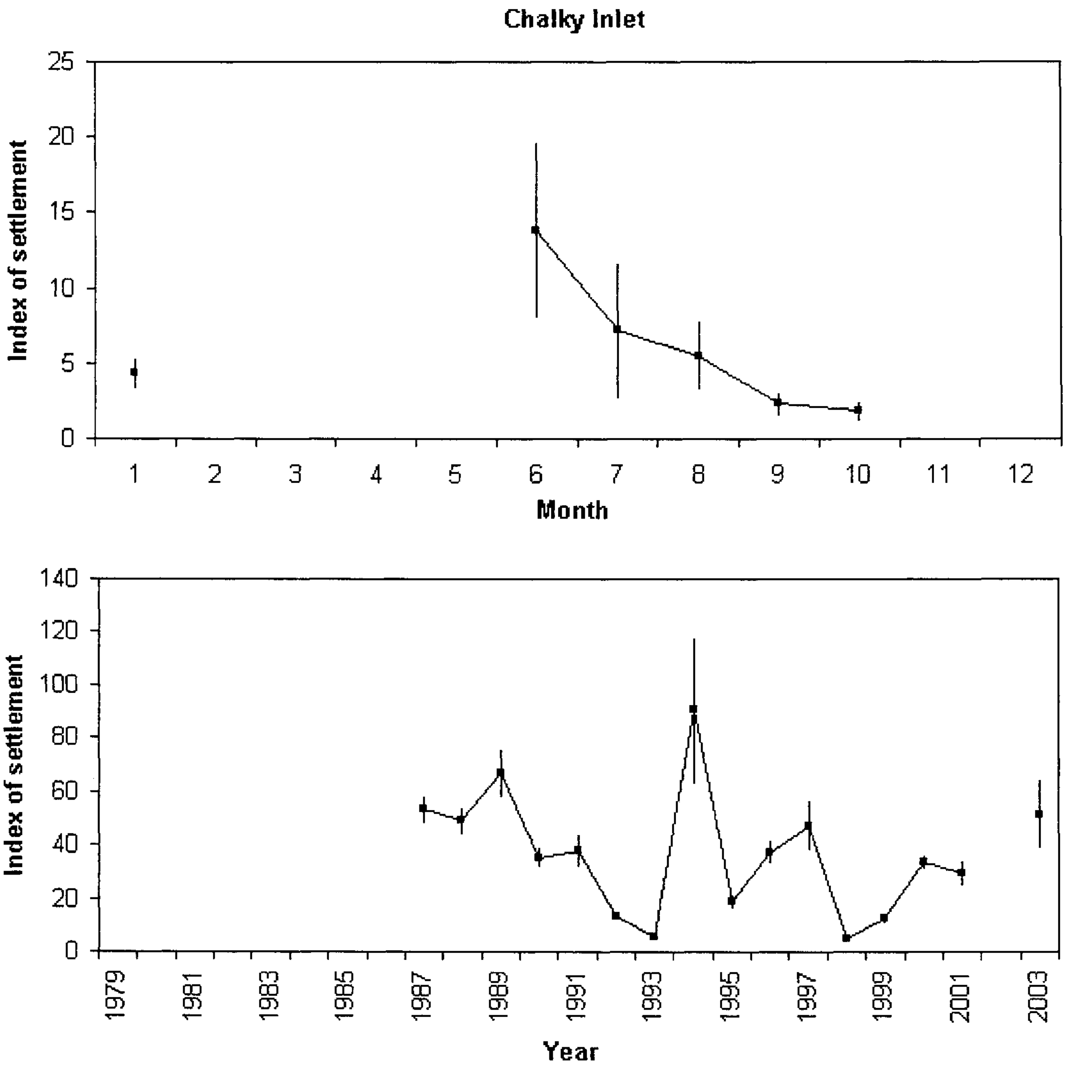


Figure 17: Chalky Inlet – mean number of *Jasus edwardsii* pueruli + juveniles at least 14.5 mm carapace length. Monthly index of settlement, 2003, ± 1 standard error (*upper*). Annual indices of settlement (settlement season index, based on the main settlement period, March to October) on the one group of collectors (± 1 standard error, *lower*). There were insufficient data for 2002.

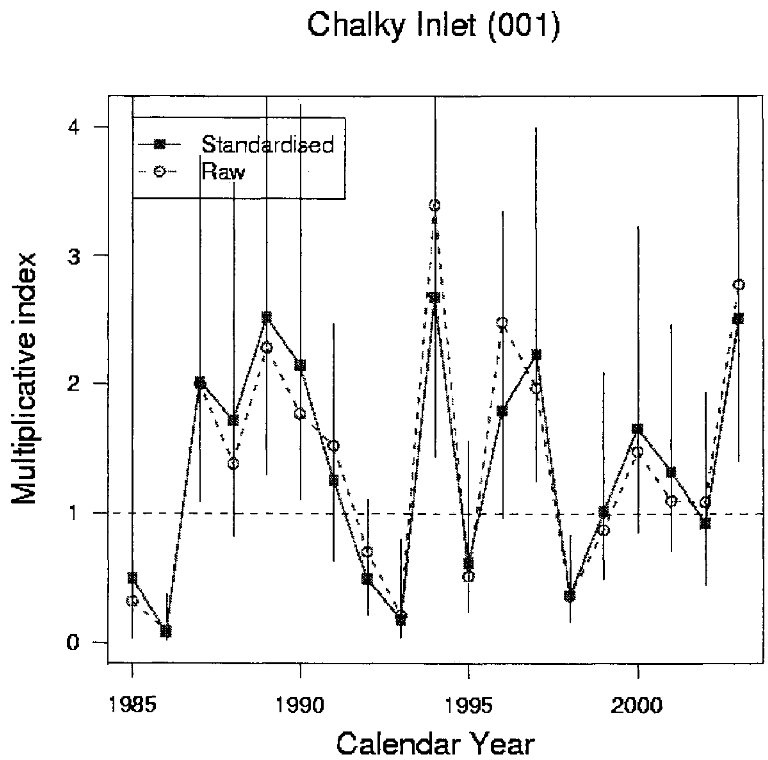


Figure 18: Chalky Inlet – standardised and raw indices of annual settlement with 95% confidence bounds.

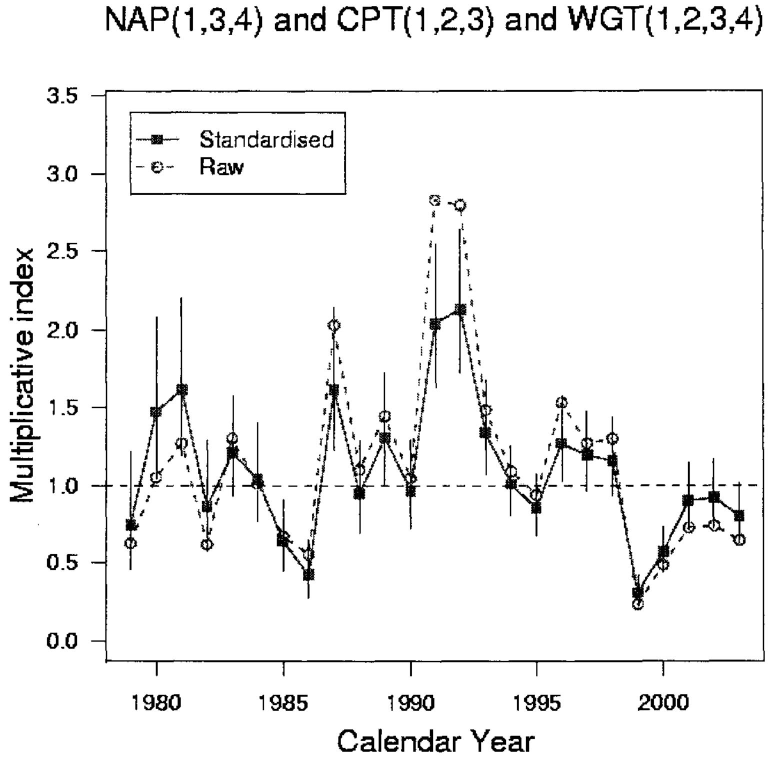


Figure 19: East coast North Island, Napier to Wellington – standardised and raw indices of annual settlement with 95% confidence bounds.

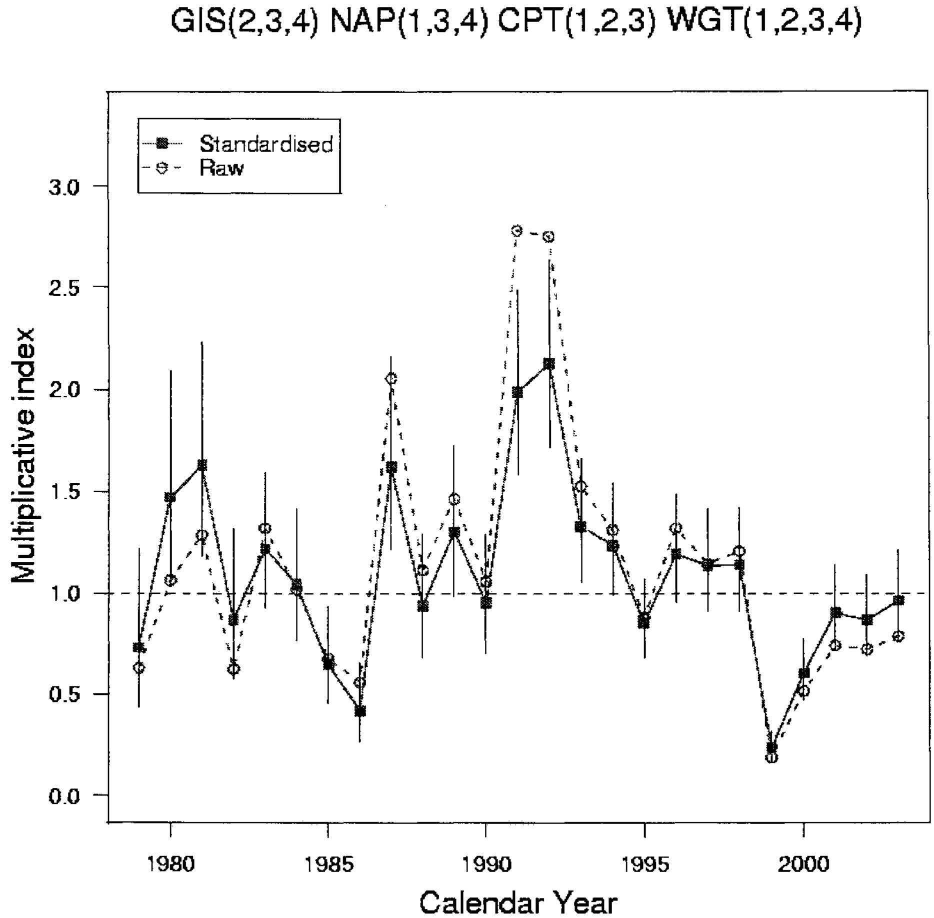


Figure 20: East coast North Island, Gisborne to Wellington – standardised and raw indices of annual settlement with 95% confidence bounds.

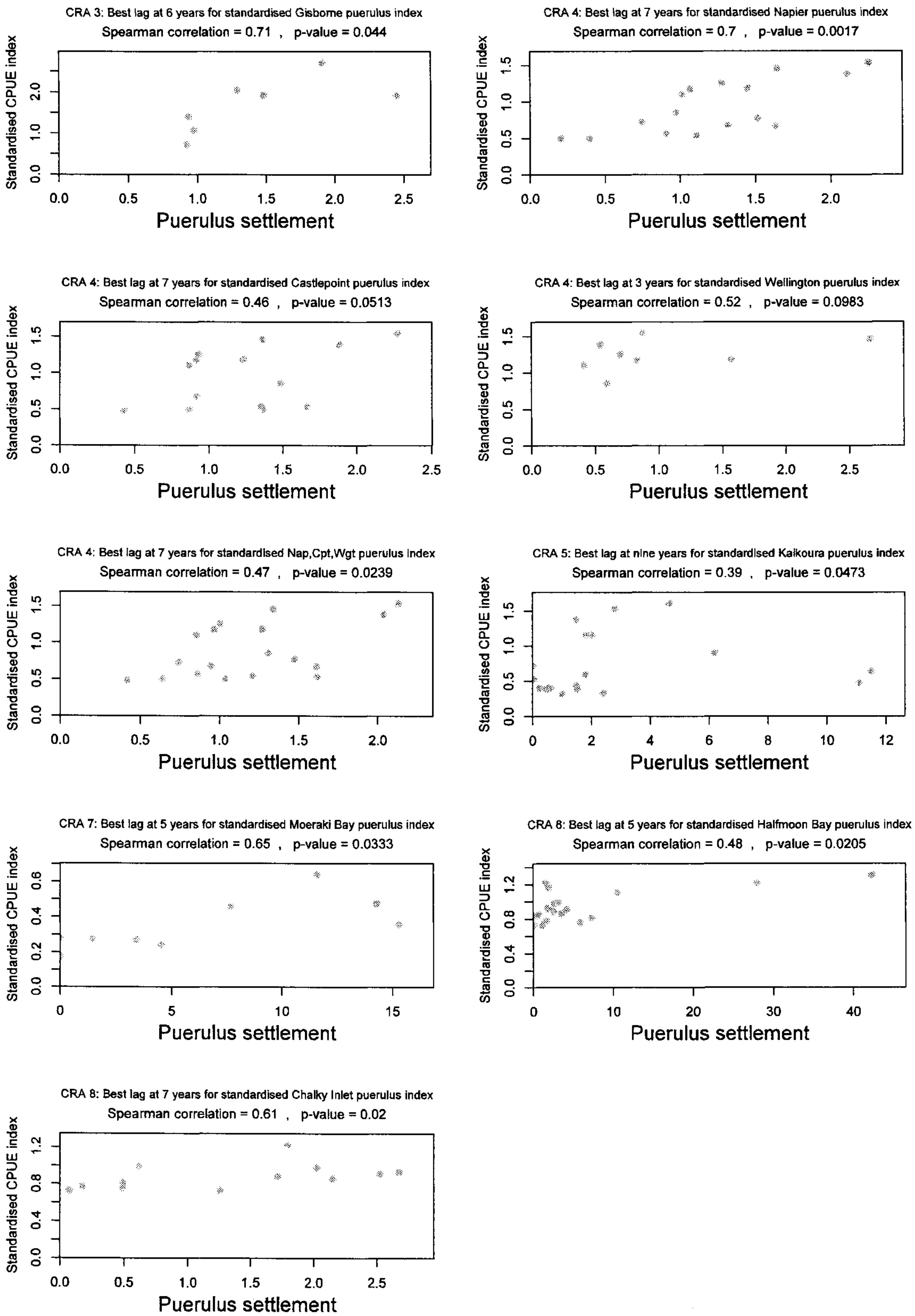


Figure 21: Standardised CPUE versus standardised puerulus settlement at the best lags. Puerulus settlement year is the calendar year; CPUE year is the rock lobster fishing year (e.g., fishing year 2000 is 1 April 1999 to 31 March 2000).

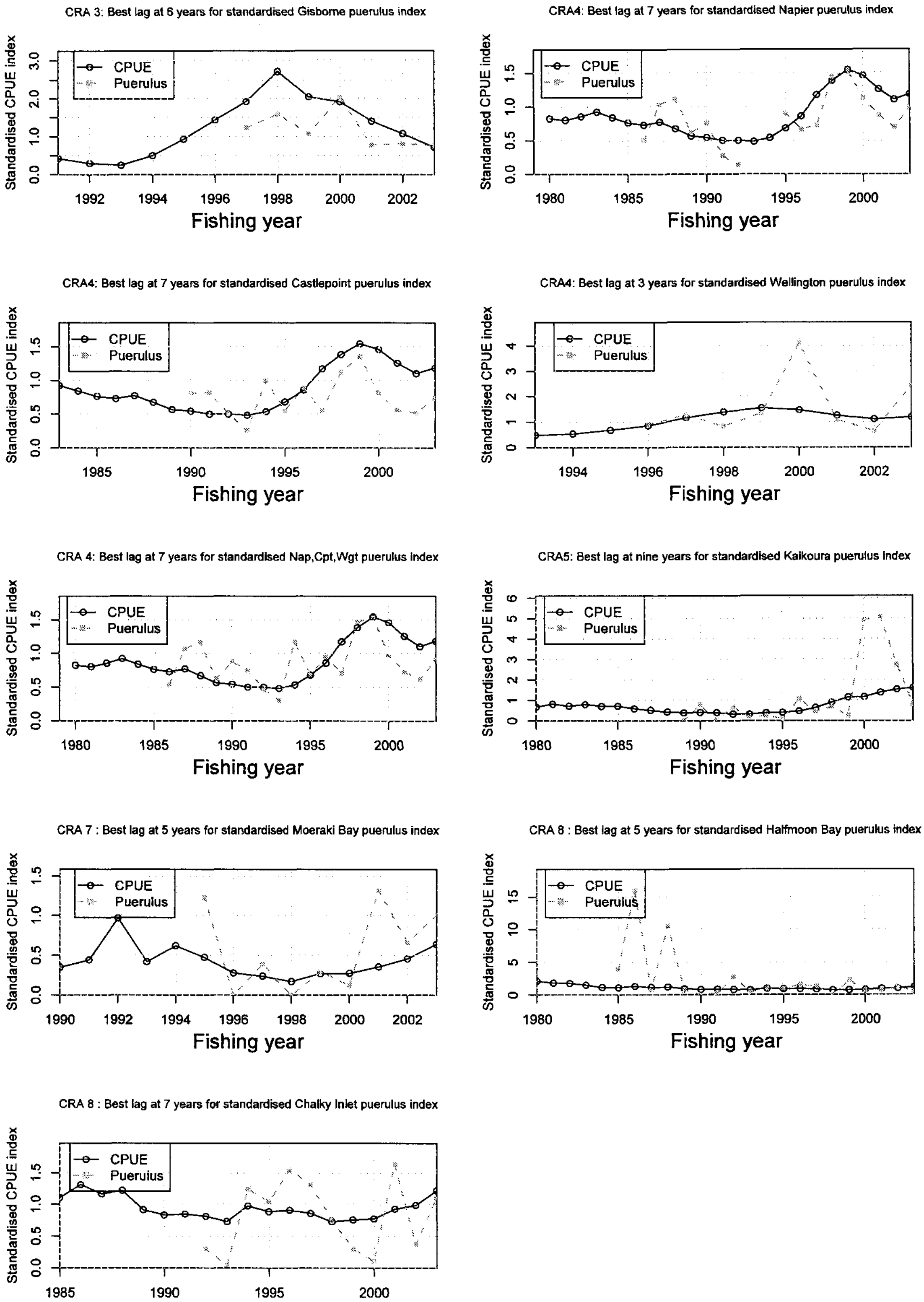


Figure 22: Standardised CPUE and standardised puerulus settlement (at the best lag) versus fishing year. The fishing year 2000 denotes 1 April 1999 to 31 March 2000. The puerulus settlement is scaled so as to have the same median as the CPUE.

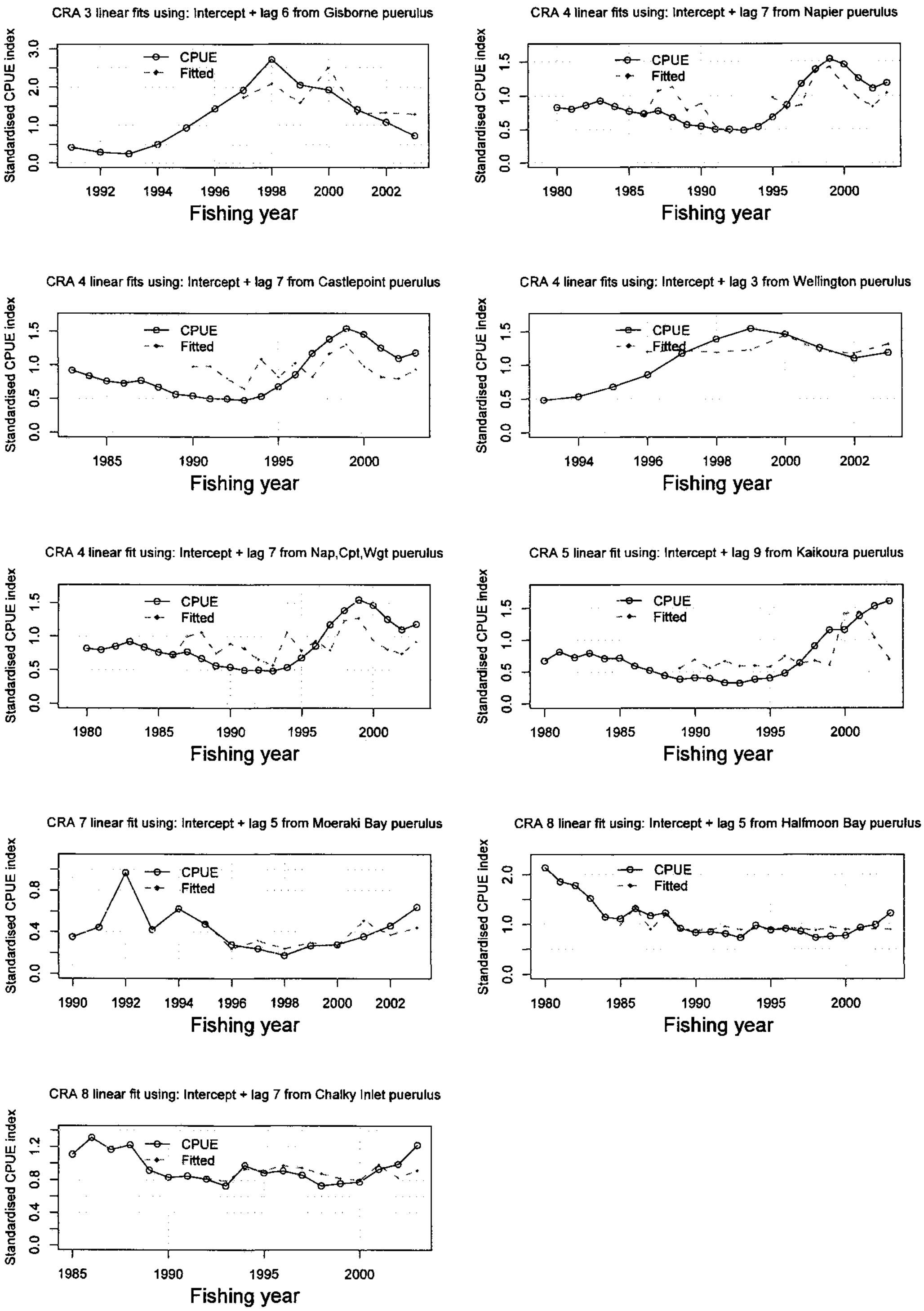
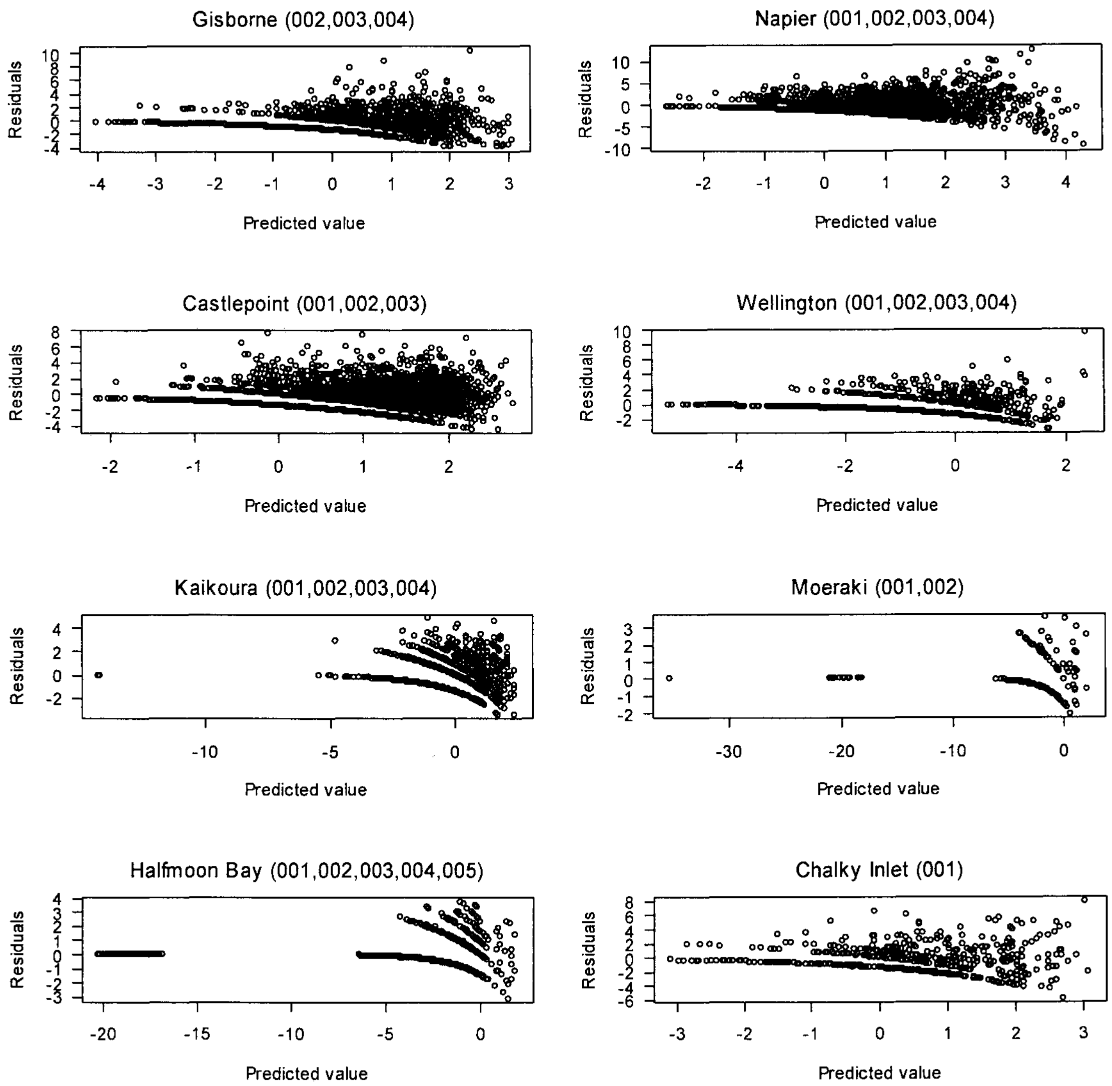


Figure 23: Standardised CPUE and fitted CPUE values as a linear function of the standardised puerulus settlement (at the best lag). The fishing year 2000 denotes 1 April 1999 to 31 March 2000

APPENDIX

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



APPENDIX cont.

Quantile-quantile plots from standardisation model for each site.