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EXECUTIVE SUMMARY

Booth, J.D.; McKenzie, A.; Forman, J.S.; Stewart, R.A.; Stotter, D.R. (2007). Monitoring the settlement of red rock lobsters (*Jasus edwardsii*) in New Zealand, with settlement levels to 2004. *New Zealand Fisheries Assessment Report 2007/43*. 49 p.

This report provides a history to the estimation of the levels of puerulus settlement in the main red rock lobster (*Jasus edwardsii*) fishing areas of New Zealand, with settlement levels updated to 2004. These data formed part of a Final Research Report already provided to the Ministry of Fisheries for project CRA2004-02, one objective of which was 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).

We describe the settlement-recording project from its beginnings in 1974 and statistically evaluate the data through to 2004 by exploring spatial and temporal consistencies, examining how precise the measurements of settlement are, and estimating the loss in precision should the numbers of collectors be reduced. We concluded that there are statistically significant correlations in settlement that strongly suggest that what is being measured on the collectors can be considered indices of actual settlement. Our analyses showed that 1) for most sites, the current array of collectors has very high power to reliably detect 100% changes in levels of settlement between successive years with 95% confidence, and 2) some reduction in the size of the monitoring project (numbers of collectors at sites) can be made without much loss in this precision.

At most east coast North Island sites, from Gisborne to Wellington, standardised settlement in 2004 was lower than in 2003 (about average compared with the time series of previously estimated settlement levels), but well up on the particularly low settlement of 1999. Settlement in 2004 at Kaikoura was much lower than in 2003, and closer to the long-term average. Along the southeast coast of the South Island no settlement was registered in 2004, whereas settlement during 2001–03 was the highest seen since the early 1980s. Settlement in 2004 was also very low in the southwest of the South Island.

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 help in interpreting changes in levels of recruitment to the fishery and also allow the usefulness of the settlement data in predicting changes in trends in recruitment to the fishery to be conclusively tested for the first time outside the constraints and assumptions of a population model. Such information can improve the usefulness of fishery assessment models, particularly their predictive capability.

1. INTRODUCTION

1.1 Background

Red rock lobsters (*Jasus edwardsii*) support one of New Zealand's most valuable fisheries. 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, knowledge of seasonal, annual, and geographic variation in settlement will help us to better understand larval recruitment processes. For example, geographically different settlement patterns may come about through differential survival, or transport by different water masses in which the larvae and postlarvae occur. Information on year-to-year settlement levels may be used to indicate the extent to which recruitment varies from year to year, predict trends in recruitment, interpret changes in levels of recruitment to the fishery, and provide early warning of overfishing. Such information can improve the usefulness of fishery assessment models, particularly their predictive capability, and so greatly assist management of this fishery. In particular, prediction of trends in catch levels at least 4 years in advance allows timely implementation of management and fishing strategies.

This report updates and extends the previously reported patterns of spatial and temporal settlement on crevice collectors in New Zealand (Booth et al. 2007). It also describes the history of the settlement-monitoring project, and examines its statistical design. The settlement indices remain the only widespread fishery-independent data collected in the New Zealand rock lobster fishery.

Rock lobsters spend several months as phyllosoma larvae in waters tens to hundreds of kilometres offshore. Final-stage phyllosomas metamorphose at or a little beyond the shelf break and the postlarvae (pueruli) swim towards shore. The puerulus is the settling stage: it resembles the juvenile in shape and is 9–13 mm in carapace length, but it is at first transparent. Pueruli settle when they cease extensive forward swimming and take up residence on the substrate. The puerulus moults into the first juvenile instar (sometimes referred to as the first-moult postpuerulus) a few days to 3 weeks after settlement, earlier moulting occurring at higher water temperatures. Depending on sex and locality, the rock lobster then takes between 4 and 11 years to reach minimum legal size.

Some pueruli and young juveniles (mainly first instar) move after having settled: post-settlement migration (secondary dispersal) such as this is not uncommon among invertebrates (e.g., Reyns & Eggleston 2004), the young possibly redistributing from high-density settlement habitats thereby reducing density-dependent mortality. We cannot distinguish between initial puerulus settlement and the capture of first-instar lobsters after post-settlement migration in our monthly collector checks, so we use the term 'settlement' to encompass both these groups of lobsters.

Developing sampling programmes to estimate levels of postlarval settlement that can be used to predict fishery performance is a goal in both palinurid (e.g., Phillips et al. 2000, Gardner et al. 2001) and homarid fisheries (e.g., Wahle et al. 2004), with, according to project, encouraging or well-demonstrated success. 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 (a detailed history of settlement-monitoring is given later). The indices of settlement are now reported annually, for stock assessment, research, and management purposes. It has become clear from this and other sampling that settlement is not uniform in time or space. Settlement is 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 in New Zealand 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 abundance of phyllosoma larvae in adjacent offshore waters (Booth 1994).

The settlement-monitoring programme has been reduced in extent in recent years. Critics have claimed that the data may be no more than a series of random observations of settlement that bear no relation to actual settlement numbers. Although it is technically difficult – if not impossible – to categorically define any relationship between settlement levels estimated from collector catches and the actual numbers of pueruli settling or the subsequent abundance of juveniles, existence of spatial and temporal patterns and consistencies in the settlement data provide a strong basis for rejecting this claim. In this report, therefore, not only is the history of the settlement project recorded, but also the patterns and strong consistencies in settlement between sites and over time are described.

Also there has been little consistency between the settlement record and the levels of recruitment estimated in the stock assessment models (e.g., Bentley et al. 2004a): 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 conclusively tested for the first time outside the constraints and assumptions of a population model.

Below we first update the recent literature on *J. edwardsii* recruitment. Then we describe the settlement-monitoring project from its beginnings, updating the settlement record to the end of 2004. We examine the spatial and temporal consistencies in the settlement record, and look at the power of the present array of collectors to discern changes in settlement levels and the effects on the precision of our estimates of settlement of reducing the numbers of collectors. Finally we discuss the implications of the results and suggest avenues for further investigation.

1.2 Literature

The following publications refer to larval recruitment and early life history in *J. edwardsii* which have appeared since those given by Booth et al. (2007). Booth & Webber (2005) and Webber & Booth (2005) are popular articles that show how the phyllosomas and postlarvae of New Zealand palinurids and scyllarids can be distinguished. Kittaka et al. (2005) described the full larval development of *J. edwardsii* from laboratory culture: there were 17 instars and the phyllosoma phase lasted 212–303 days. Bradford et al. (2005) described the vertical distribution of *J. edwardsii* phyllosomas off SENI: most mid- and late-stage larvae were taken in the upper 100 m of the water column, the mid-stage ones being mainly in the top 20 m both day and night, and the late-stage ones in the top 20 m at night but mainly at 20–100 m during the day. Chiswell & Booth (2005a) examined data on the horizontal distribution of larvae off SENI: overall, late-stage larvae were found about 50 km further inshore than mid-stage larvae, providing further evidence that late phyllosoma stages – particularly the final stage – can swim horizontally towards shore before they metamorphose. Booth & Chiswell (2005) hypothesised that food availability was the factor that led to most *J. edwardsii* larvae off SENI metamorphosing near the shelf break rather than further out to sea. Chiswell & Booth (2005b) used satellite-derived ocean currents in numerical modelling of larval dispersion in the ocean around New Zealand to address the main sources of larvae for *J. edwardsii* that subsequently recruit to the shore. They estimated where larvae hatched in each CRA area settled, and conversely, where settlement in each CRA area was sourced. Booth (2005) examined sociality among puerulus and young juvenile *J. edwardsii* and concluded that, whereas pueruli showed no tendency to associate with, or dissociate themselves from, other pueruli, small juveniles associated with similar-sized conspecifics. Booth & Ayers (2005) characterised shelter preferences of young juvenile *J. edwardsii* in terms of gap shape and size, and the numbers of entrances. Bentley et al. (2005) used a delay-difference approach to examine the relationship between settlement and subsequent CPUE in the recruited fishery for selected CRA areas and found little correspondence. Breen et al. (2005) presented a medium-term research plan for *J. edwardsii*, according high importance to knowledge of larval sources and very high importance for predictive settlement indices. Phillips et al.

(2006) and Booth (2006) discussed palinurid larval recruitment processes in general, with frequent reference to *J. edwardsii.*

2. HISTORY OF SETTLEMENT MONITORING IN NEW ZEALAND

First trials into the development of a puerulus collector for *J. edwardsii* began in 1974. The first era of formal sampling (1979–88) involved small numbers of collectors (usually 3–6) set at many sites. Later, sampling was consolidated to a few key sites, but the numbers of collectors were increased with the reasonable expectation of reducing the error associated with the estimates of settlement level. At most of these key sites, the collectors checked in the first era continued to be checked through to the present. This sequence in the development of this fishery-independent settlement-monitoring programme is described in detail below.

Our fundamental premise is that levels of settlement among regions can be compared when the same collection techniques have been used at several sites within each region over a number of years. Indeed, it is not unreasonable to assume that these monthly checks of the collectors provide an index to the actual levels of settlement. (This has been shown to be so in Western Australia, the place with longest record of settlement, and where settlement events are highly correlated along almost the entire coast.)

2.1 Earliest trials

The stimulus to develop a collector for estimating settlement levels of *J. edwardsii* pueruli in New Zealand was the ability to predict Western Australian rock lobster catches based on previous collector catches of pueruli. In the late 1960s, Phillips (1972) developed a collector effective in catching the puerulus stage of the western rock lobster, *Panulirus cygnus*, off Western Australia. Using six of these artificial seaweed collectors (the so-called 'Phillips' collectors) at one site to estimate relative levels of settlement from year to year, strong links were found between settlement levels and the subsequent catches of new recruits for nearly the entire 800-km long Western Australian fishery 4–5 years later (e.g., Morgan et al. 1982). It had long been known that there was high *J. edwardsii* settlement in the intertidal zone at the eastern end of Castlepoint Bay (Kensler 1966, Booth & Forman 1995), so the first trials of a collector in New Zealand took place there, in the early 1970s. Both an artificial seaweed collector and early versions of the crevice collector were tested (Booth 1974, 1979).

The artificial seaweed collector design tested was based on, and similar to, the Phillips collector. The 'crevice-type' collectors, developed following the observation that pueruli at Castlepoint were most often found in holes, crevices, and depressions in rocks, and between rocks and the sandy substrate, were of two main types: 1) sheets of marine grade plywood held in a metal frame, spaced to give a gap size of 10–15 mm, and 2) untreated lengths of 10 x 10 cm timber drilled with 1.0–1.6 cm diameter holes. Collectors of these three types were moored near the sea surface (based on the Western Australian approach) in Castlepoint Bay during 1974–77 and checked about monthly. Although all designs of collector caught pueruli (Booth 1979), each was difficult to sample and was too often washed ashore in storms.

The big step forward was the trial setting in July 1979 of a modified version of the crevice collector on the seafloor – instead of up in the water column or at the surface – in shallow water among rocks at the eastern end of Castlepoint Bay. This collector had crevice-like gaps rather than parallel-sided ones (and had been found to work well in trials under the Gisborne Wharf) and was held in place with a concrete base weight. The result was unexpected and encouraging: although the collectors were covered by only a few centimetres of water at low water, they caught well. It now seemed possible to set collectors at almost any site where there was at least some shelter, with one person able to carry out the checks without the need for boats or scuba.

This refined 'crevice collector' (Booth & Tarring 1986) – the design of collector currently used along most of the main rock lobster fishing shores of New Zealand – consisted of eight plywood sheets, each 38 cm square and 0.9 cm thick, held in a galvanised steel frame to give seven wedge-shaped crevices, each 2.5 cm high at its widest part. The crevice collector satisfied the key design criteria of being sturdy, relatively inexpensive and easy to construct, easily handled by one person, and effective. 'Shore crevice collectors' are those in which the collector is threaded onto a 10-cm high nipple in the top centre of a concrete weight; 'suspended crevice collectors' are those in which the collector is suspended in the water column by rope or attached directly under a buoy; and 'closing crevice collectors' are those in which the collector is fixed to a steel base, and during hauling a mesh-based metal box rises to surround the collector to prevent the loss of lobsters (Booth & Stewart 1993, Booth & Tarring 1986, Phillips & Booth 1994). Development of the closing crevice collector (Booth et al. 1991) was an advance that meant crevice collectors could be set virtually anywhere, irrespective of the amount of exposure to the sea, providing the water is deep enough for the collector to be beneath the main surface turbulence during storms (normally below about 7 m).

Crevice collectors on the sea floor (shore and closing crevice collectors) provide a combined index of 1) the number of pueruli in the water column which are settling, and 2) 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), minus mortality that has taken place among both groups over the interval since the last collector check. 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 over time. 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 (together with mortality) 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 sometimes take place into suspended collectors over a scale of metres – Booth & Forman (1995)). But for both seafloor 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 were present on the collector at some time during that month.

2.2 The first era of sampling, 1979–88

Crevice collectors were used to explore broad patterns of settlement around New Zealand during 1979–88. The focus was the main rock lobster fishing coasts, but collectors were also set in areas with small fisheries because a global picture of spatial variability in settlement season, and interannual variability that might be linked to the oceanography, was sought. At the same time, because very little was known about settlement in *J. edwardsii*, studies were undertaken into the ecology of settlement, mainly at Castlepoint and in the ports of Gisborne and Napier. Visits by Japanese scientists in 1986 and 1989 under the direction of Professor Jiro Kittaka of Kitasato University did much to advance understanding of the settlement process, showing for the first time for any palinurid, for example, that significant post-settlement migration can take place, and that the puerulus is essentially a non-feeding stage (Hayakawa et al. 1990, Nishida et al. 1990, 1995; also see Booth et al. 2002). Daily rates of settlement could not be correlated with any of the environmental variables measured (water temperature, salinity, wind speed and direction, and moon phase), the conclusion being that factors most important in determining settlement patterns take effect mainly offshore (Hayakawa et al. 1990, Booth & Stewart 1993).

This early New Zealand-wide sampling took place against a background of very little being known about how and where to set collectors. It generally took at least 2 years of trial and error to have collectors at any one site placed 'successfully' – where they would not be washed out by storms and yet were effective in catching pueruli. Checking frequencies were at first about three-monthly, then every 1–2 months, and later, where possible, monthly. By 1980, 40 exploratory sites had been investigated, with 26 being monitored more or less regularly using 3–6 collectors, each collector separated from its neighbour by 2–3 m (Booth & Tarring 1982). The number and spread of sites continued to increase, and Figure 1 shows the distribution of the 76 exploratory sites – right through to the present – for which there had been at least one full year of sampling (but excluding those sites that were found to be clearly inappropriate because of such things as low salinity, remoteness from the open ocean, or inexplicably high levels of settlement). (Many other sites checked for less than one year are not included in Figure 1. The settlement records from the 76 sites are used to derive both a regional mean settlement index and a CRA area mean settlement index in Section 4.2 below.)

This initial work allowed identification of sites suitable for long-term monitoring of settlement (Booth & Tarring 1982), and by 1989 eight key sites had been established within the main rock lobster fishery (Gisborne, Napier, Castlepoint, Wellington, Kaikoura, Moeraki, Halfmoon Bay, and Chalky Inlet), most with one group of 3–6 collectors.

As a result of the studies referred to above, together with those described by Booth et al. (1991), Booth & Forman (1995), and Booth et al. (1998), the following conclusions about collector deployment and sampling were reached. (Appendix 1 gives the written protocols currently used for setting and checking collectors.)

- Highest catches are usually made on sheltered shores that are directly adjacent to oceanic waters.
- Settlement levels generally increase with depth to 10–12 m, then decrease with increasing depth (and distance from shore).
- Collectors catch best when on or close to the seafloor. It appears that relatively few pueruli settle at the extreme surface of the sea.
- Collectors must be away from surface dilution and away from high freshwater runoff.
- Collectors should be conditioned on site for at least 4 months before use and collector replacement during the main settlement season should be minimised because unconditioned collectors catch less well.
- Collectors should not be allowed to dry during a check.
- Collector saturation appears to be rarely approached. The greatest number of pueruli plus first-instar juveniles found on a crevice collector has been 667; in contrast, individual collector catches of less than 20 are most common. However, it remains unresolved whether each additional puerulus in a collector reduces the likelihood of another puerulus entering or remaining on that collector; if collectors become increasingly attractive, up to some threshold, as puerulus numbers increase; or if settlement numbers are unaffected by the animals already present in a collector.
- Monthly checks give an index to the level of settlement of the preceding 2 weeks and are not the sum of the month's settlement. Lobsters appear, on average, to remain in a collector for up to about 2 weeks from settlement; animals of any stage may also move into or leave the collector during this time. First-instar juveniles usually leave collectors before they moult to the second instar.
- The horizontal fishing radius of the crevice collector for newly settled pueruli appears to be small – about the size of the collector itself. This means that collectors at the standard spacing of 2–3 m can be considered independent replicates.
- The standard gap of the crevice entrance (25 mm) appears to be preferred by the lobsters over smaller or larger gaps.

- Monthly catches of neighbouring 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. These results are consistent with spatially uniform settlement over a scale of metres to tens of metres over time intervals of months to years.

Several other designs of collector were developed during this first era (and through until 1990) and compared for performance with the crevice collector. Many were of the 'artificial seaweed' type referred to above, employing various types of fibre. In all comparisons the alternative design caught fewer (although not always significantly fewer) pueruli than did the crevice collectors set nearby and checked at the same times (Booth & Stewart 1993). (Subsequently several other designs were developed, mainly for the capture of pueruli for aquaculture trials. However, the crevice collector remains the only collector used for scientific monitoring of settlement both in New Zealand and Australia, and also has been the only collector used in New Zealand in collections for aquaculture.)

2.3 The recent era, 1989 onwards

The first era of sampling showed that there were similar settlement seasons and year-to-year settlement patterns over long stretches of coastline which strongly suggested that what were being observed were real changes in levels of settlement. After 1988 the number of groups of collectors at each key site was increased (and there were one or two additions and deletions to the list of key sites – see below) so as to increase the precision (reduce the error) of the settlement estimates. The numbers of additional groups of collectors to add, and the numbers of collectors in each group, were never formally estimated, but our rule of thumb was to have at least three groups of at least three collectors at each key site. (The effect of the increased numbers of collectors and groups of collectors on the precision of the estimates of settlement for each site can be seen below in analyses where groups of collectors were serially withdrawn.) The collector groups and types, and recent changes to them, are given in Table 1.

2.4 Overview

Key sites are sampled to follow levels of settlement on crevice collectors along the main rock lobster fishing coasts of New Zealand (Figure 2), 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 its neighbouring site, accessibility, and level of settlement. Levels of settlement at *exploratory sites* (sites at which settlement was followed for only one or just a few years, and where monitoring no longer continues) are summarised in Figure 1 and Tables 3 and 4 and include Sites A–D, F, H, and M in Booth (1994). At both the key (Table 1) and exploratory sites, crevice collectors were set in groups of 3–9, with a minimum spacing of 2–3 m between individual collectors. For each key site there is a *core group* of collectors (usually the group with the longest checking record); *additional groups* of collectors are set in both directions along the coast, as conditions allow, 0.1–25 km from the core collectors; standard distancing of these additional groups from the core group has not been possible.

The crevice collectors are either shore, closing, or suspended (see Booth & Tarring 1986, Phillips & Booth 1994) (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)).

The number and location of a couple of the key sites changed between 1999 and 2005, reflecting in particular the difficulty in maintaining sampling in the very remote southwest of the South Island. The key sites in 1986 were Gisborne, Napier, Castlepoint, Wellington, Kaikoura, Moeraki, Halfmoon Bay, and Chalky Inlet. Attempts were made to establish Caswell Sound, and then Doubtful Sound and later Punakaiki, as key sites to give better coverage of the northern part of the very important CRA 8 fishery, but these were unsuccessful; Jackson Bay became the new key site in this area, in 2000. Also in 2000 there was a temporary expansion in the number of key sites to include some in CRA 1 (Houhora and Whangarei) and CRA 2 (Bowentown and Maketu).

Regular reports of settlement have been produced since 1992, placing the settlement data for each site for the most recent year into the context of the long-term record (Booth & Stewart 1993, Booth & Forman 1995, Booth et al. 1998, 1999, 2000a, 2001, 2002, 2003, 2004, 2006, in press,). This primary settlement record is given in Table 2.

3. CALCULATING SETTLEMENT INDICES

In recent years, two different interannual indices of settlement have been produced for each key site. The *settlement season index* of annual settlement is a raw index based only on the main settlement season: the mean catch per collector of pueruli, plus juveniles up to and including 14.5 mm carapace length (the maximum size for a first-instar juvenile observed in laboratory studies) (together sometimes referred to as 'settlers'), of the core collectors over the main settlement season ± 1 s.e. of that mean. The *standardised index* of annual settlement differs most from the settlement season index of annual settlement in that it incorporates all settlement for a year, 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 and a Poisson distribution is assumed. 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. 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. (Although it can be argued that an arithmetic mean may be more appropriate, the geometric mean was used here to be consistent with the previous work.)

The standardised indices, not settlement season indices, are presented in this report because 1) the nominal values of the settlement season index are not always directly comparable between sites as the duration of the main settlement season varies between 6 and 10 months according to site (see Table 1), and 2) only the standardised index is currently used in the correlations with fishery performance indicators. For comparison, a raw form of standardised indices is also given. Residual plots from the standardisation models used for each CRA area, and other diagnostics, are given in Appendix 2.

Table 1: Collector type and number by key site, and main settlement season. Groups not monitored after 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 group. Note that the open-coast GIS002 became the core group for Gisborne because the GIS001 group in the port at times and for unknown reasons had phenomenally high catches usually well out of line with the catches of nearby groups of collectors.

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 Bay	~~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*

4. COLLECTOR CATCHES, 2004

The numbers and types of collector at each key site are summarised in Table 1. The standardised annual data for the key sites are given in Table 2 and in Figures 3–10 up to and including 2004.

4.1 Gisborne

Settlement in 2004 was similar to that in 2000–02, considerably down on that in 2003 but up from the record low of 1999 and close to the long-term average (Figure 3). Whangara had the highest levels of settlement (not shown).

4.2 Napier

Settlement during 2004 was about the same as in 2001–03, up on 1999, the record recent low year, and near the long-term average (Figure 4). The Harbour collectors had the highest catches of all groups (not shown).

4.3 Castlepoint

Settlement in 2004 remained moderate to low, at levels similar to 2001–03, up on the record low year of 1999 but below the long-term average (Figure 5). The Castlepoint and Orui collectors had the highest settlement rates, those at Mataikona the lowest (not shown).

4.4 Wellington

Catch rates during 2004 were moderate, up on the recent record low year of 1999, and near the long-term average (Figure 6). Highest settlement was again recorded at Island Bay, the lowest at Breaker Bay (not shown).

4.5 Kaikoura

Catch rates in 2004 were much lower than the very high value seen in 2003, but still above the long-term average (Figure 7).

4.6 Moeraki

The high settlement levels in 2000–03, to levels not before seen, did not continue into 2004 (Figure 8). There was poor precision in the standardised index derived from the above model because of high collector catch variability and the data not fitting the model well because of the many zero catches.

4.7 Halfmoon Bay

The improvement in settlement levels seen in 2000–03, to levels not seen since the early 1980s, did not continue into 2004 (Figure 9). 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 many zero catches near the beginning of the time series.

4.8 Chalky Inlet

2004 was a low settlement year (Figure 10). The poor precision of the standardised index is due mainly to collector catch variability and missing data resulting from missed checks at this remote site.

4.9 Jackson Bay

Settlement levels in 2004 were similar to those in 2000–01; 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.

Table 2: Standardised annual settlement data for each key site. As in Booth et al. (2007), 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). The groups of collectors used were GIS (002, 003, 004) for Gisborne, NAP (001, 002, 003, 004) for Napier, CPT (001, 002, 003) for Castlepoint, WGT (001, 002, 003, 004) for Wellington, KAI (001, 002, 003, 004) for Kaikoura, MOE (001, 002) for Moeraki, HMB (001, 002, 003, 004, 005) for Halfmoon Bay, and CHA (001) for Chalky Inlet, the numbers referring to collector sites and groups in Table 1. See Booth et al. (2007) for further detail.

	Gisborne	Napier	Castlepoint	Wellington	Kaikoura	Moeraki	Halfmoon Bay	Chalky Inlet
1979	-	0.78	-	-		-	-	-
1980	-	1.40	-	-	0.00	-	0.61	-
1981	-	1.87	-	-	1.87	-	2.56	-
1982	-	0.91	-	-	0.05	-	0.12	-
1983	-	1.13	1.41	-	1.51	-	1.39	-
1984	-	0.37	1.35	-	0.44	-	0.11	-
1985	-	0.18	0.87	-	0.61	-	0.00	0.67
1986	-	-	0.50	-	0.19	-	0.04	0.08
1987	-	-	1.69	-	2.09	-	0.44	2.51
1988	-	1.38	0.98	-	0.94	-	0.07	1.81
1989	-	0.99	1.52	-	1.60	-	0.17	2.68
1990	-	1.05	0.93	-	0.52	0.22	0.14	2.31
1991	1.36	2.13	1.94	-	10.48	0.00	0.27	1.25
1992	1.94	2.26	2.37	-	12.13	0.05	0.20	0.47
1993	1.46	1.74	1.43	0.84	6.07	0.00	0.00	0.15
1994	2.56	1.32	0.92	0.69	1.66	0.00	0.35	2.86
1995	0.96	0.97	0.87	0.54	1.93	0.04	0.10	0.65
1996	0.91	1.57	1.27	0.67	1.42	0.37	0.10	2.93
1997	0.93	1.19	1.13	3.39	2.98	0.23	0.17	1.89
1998	1.28	1.00	1.64	0.71	3.84	0.21	0.08	0.55
1999	0.09	0.27	0.34	0.48	2.62	0.04	0.08	1.35
2000	0.83	0.62	0.48	1.43	2.33	1.35	0.38	1.59
2001	1.11	1.21	0.75	1.31	0.90	1.00	0.54	1.28
2002	0.98	1.09	0.72	1.62	2.34	0.54	0.42	0.87
2003	1.88	1.17	0.74	1.17	10.88	2.37	1.16	2.01
2004	0.67	1.00	0.63	1.16	2.96	0.00	0.00	0.26

4.10 Summary of 2004

For the east coast of the North Island of New Zealand, at least from Gisborne to Wellington, settlement in 2004 was a little below or near the long-term average of estimated levels for the time series (mainly since the 1980s) associated with each site. It was usually significantly higher than the record low year (1999) and well below the high years of 1991–92/93 at all sites. Settlement at Kaikoura in 2004 was well down on the high level seen in 2003. The increase in settlement levels in the southeast of New Zealand (southeast South Island and east coast Stewart Island, SENZ), particularly at Moeraki, beginning in 2000, did not persist into 2004. For the southwest of the South Island, 2004 was a low settlement year, following on from one well above the long-term average.

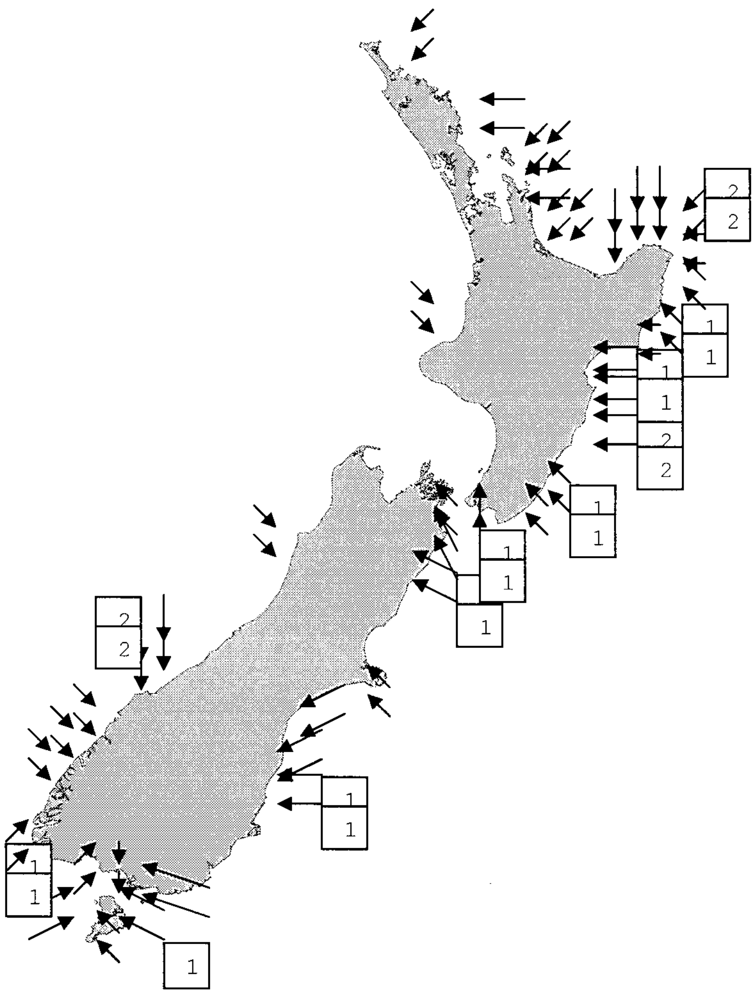

Figure 1: Distribution of settlement monitoring sites around New Zealand (also see Table 1). Numbers in squares: 1, denotes a primary monitoring site with several groups of collectors monitored for at least 10 years; 2, fewer groups of collectors monitored for at least 5 years; all others, a few collectors monitored for 1–4 years (the map excludes four such Grade 3 sites around the Chatham Islands). More than one collector site is indicated by several of the arrows.

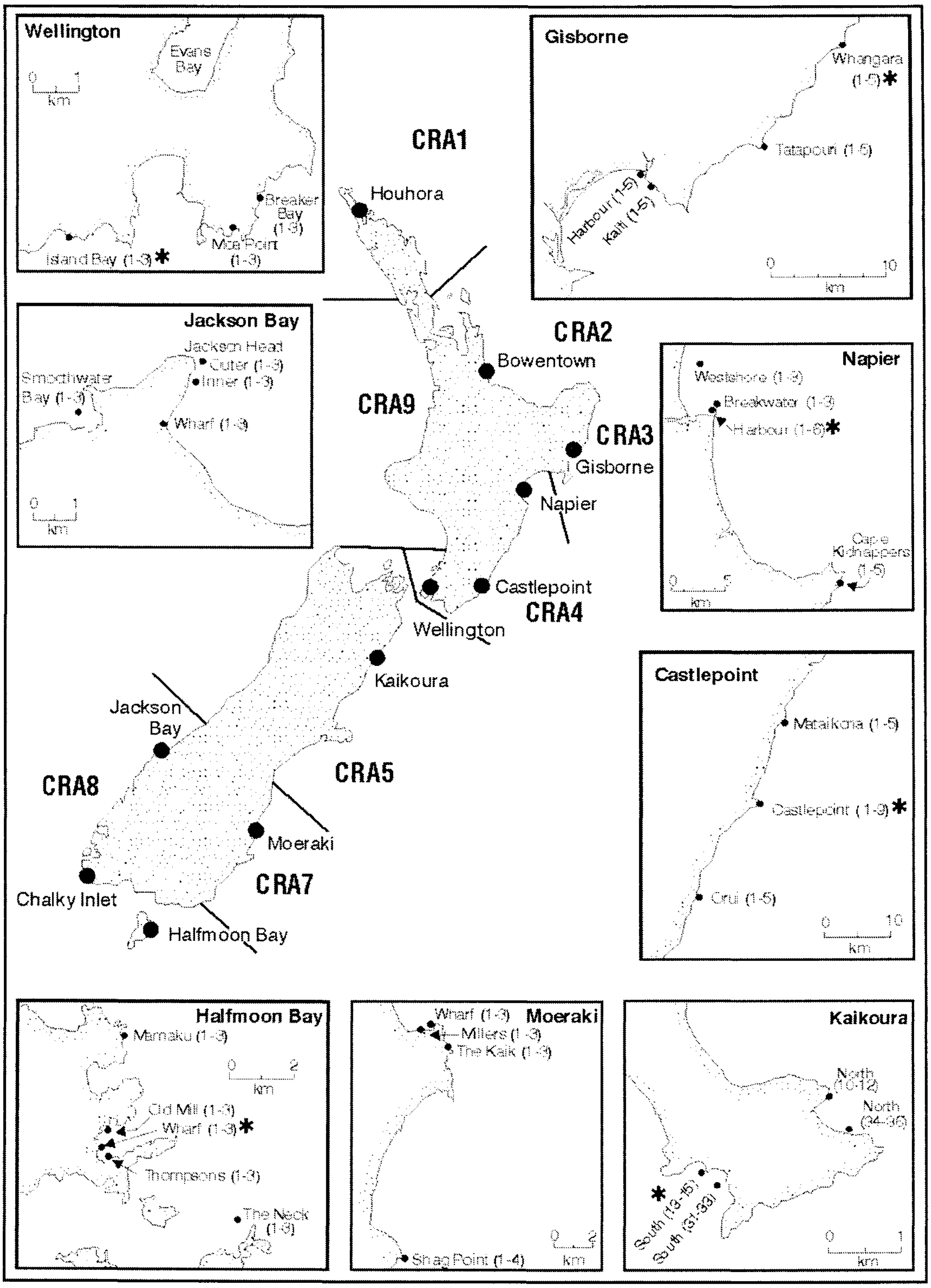

Figure 2: Map of New Zealand showing location of collectors at the key monitoring sites (although not all groups are now checked (see Table 1)). The insets show the numbers and arrangement of collectors at sites with more than one group of collectors. *, core group of collectors where one has been nominated. Also shown are the CRA areas; CRA 6 is the Chatham Islands.

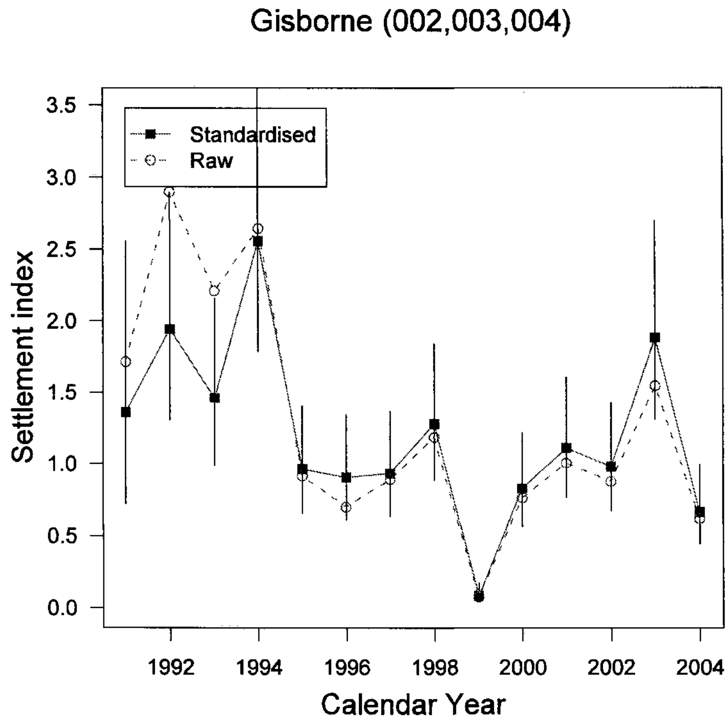

Figure 3: Gisborne – standardised and raw indices of annual settlement with 95% confidence bounds. The index for 1991 was based on just a few collectors checked late in the year only, leading to an imprecise estimate of settlement.

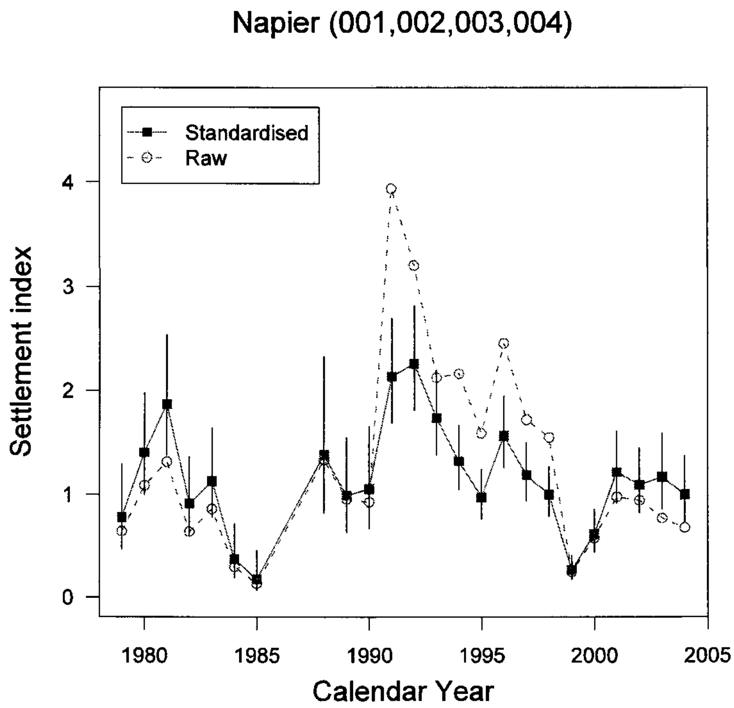

Figure 4: Napier – standardised and raw indices of annual settlement with 95% confidence bounds. Note that there were no checks in 1986–87.

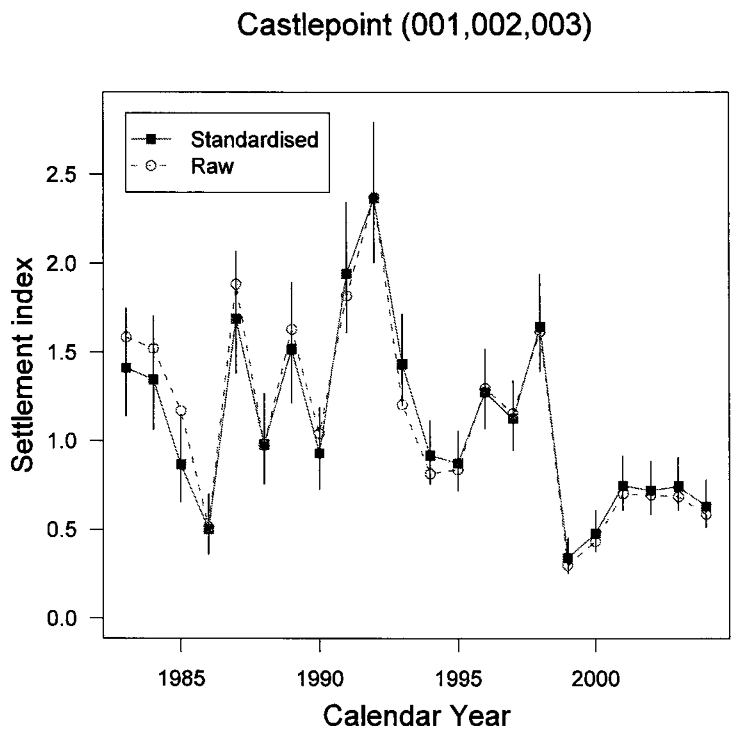

Figure 5: Castlepoint – standardised and raw indices of annual settlement with 95% confidence bounds.

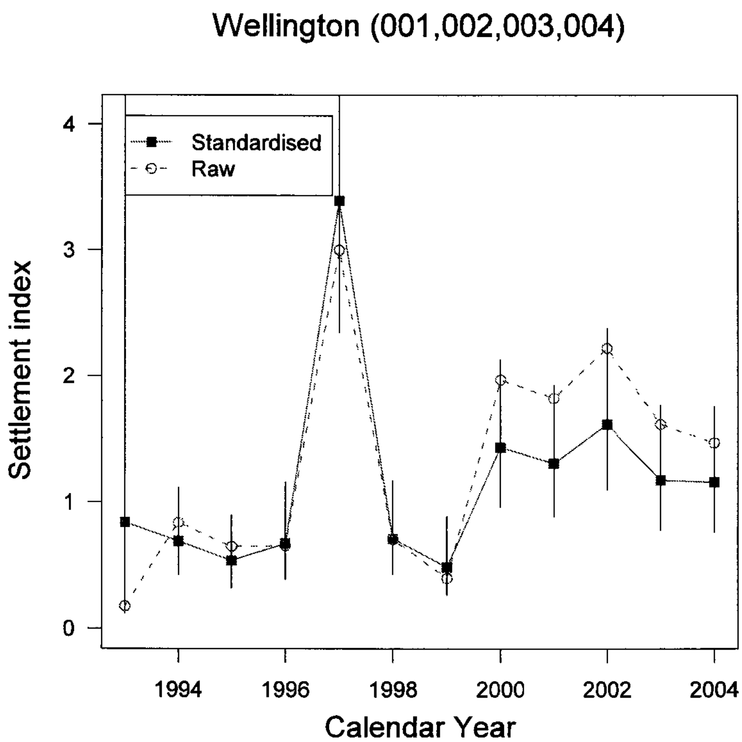

Figure 6: Wellington – standardised and raw indices of annual settlement with 95% confidence bounds.

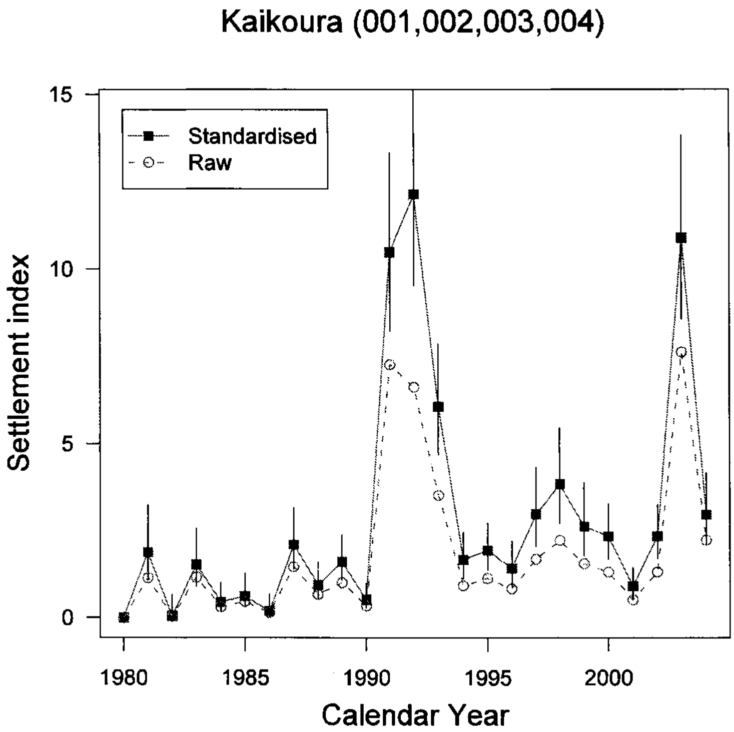

Figure 7: Kaikoura – standardised and raw indices of annual settlement with 95% confidence bounds.

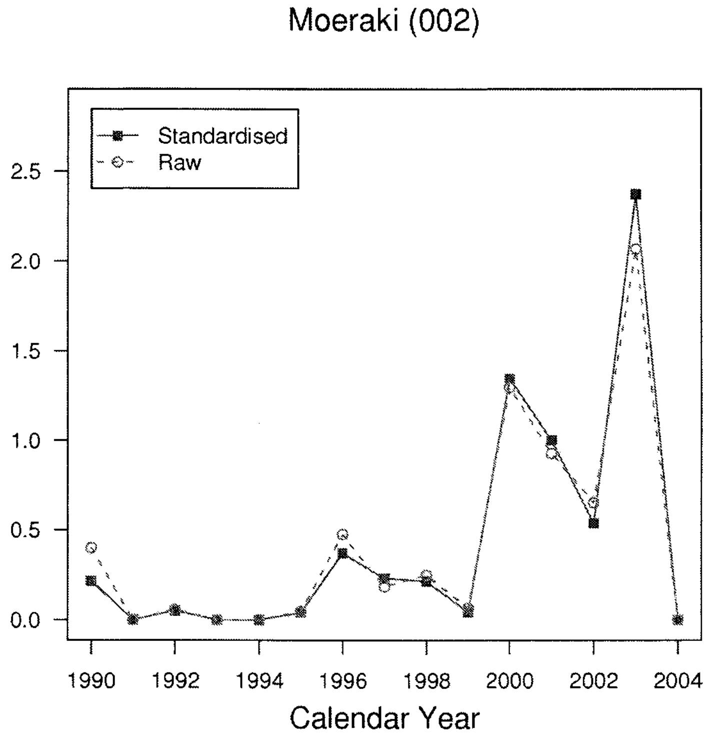

Figure 8: Moeraki – standardised and raw indices of annual settlement. The 95% confidence bounds cannot be calculated for the standardisation model due to sparse data coverage over the years and months, but are expected to be large.

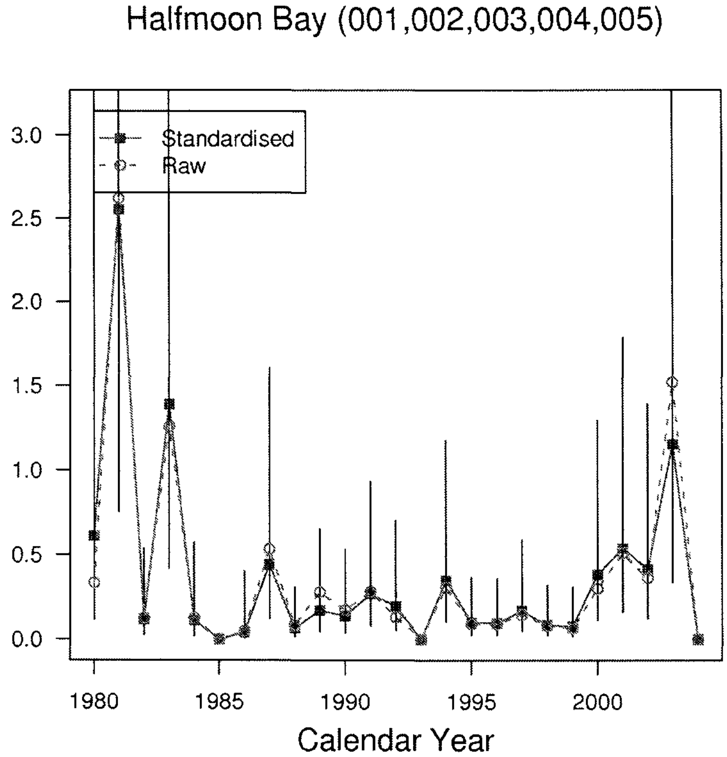

Figure 9: Halfmoon Bay – standardised and raw indices of annual settlement with 95% confidence bounds. The 95% confidence bounds were large because of high collector catch variability and the data not fitting the standardisation model well because of the large number of zero catches.

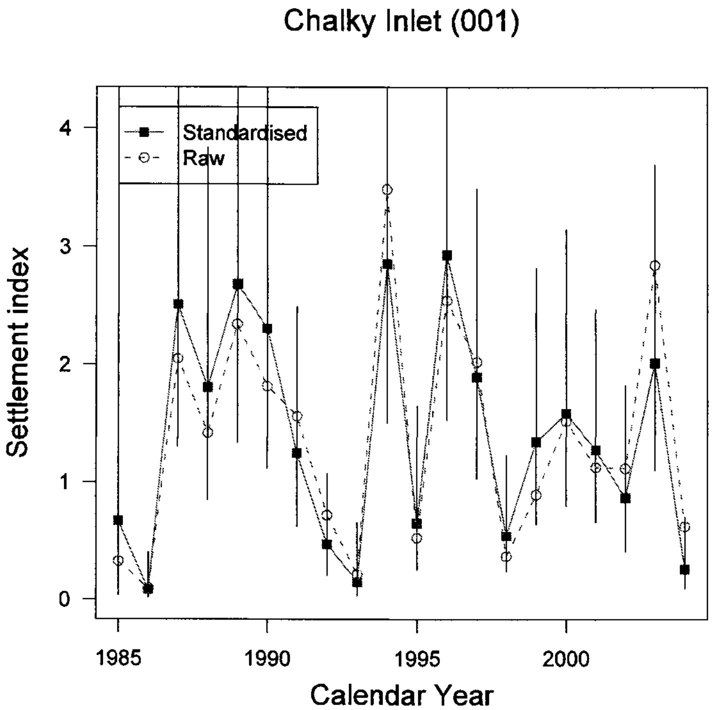

Figure 10: Chalky Inlet – standardised and raw indices of annual settlement with 95% confidence bounds.

5. SPATIAL AND TEMPORAL PATTERNS OF SETTLEMENT

5.1 Introduction

Consistency in collection technique at several sites within each region over a number of years means that levels of settlement among regions can be compared. Settlement over the past two decades has generally been several times higher in SENI than in most other parts of the country (Booth et al. 2007). Further, year-to-year settlement is correlated between several widespread sites (explored in detail later in this report), with changes in the large-scale ocean climate possibly contributing to the patterns of puerulus recruitment. For example, there is significant negative correlation between El Niño–Southern Oscillation (ENSO) events and levels of settlement off the east coast of New Zealand (Booth et al. 2000b), and a similar (but positive) correlation off Western Australia (Pearce & Phillips 1988).

5.2 Spatial variation in levels of settlement

The settlement records from the 76 sites shown in Figure 1 allow calculation of regional and CRA area mean settlement indices (Tables 3 and 4). Because there was considerable variation in the quality of the settlement data – the numbers of sites and numbers of collectors, temporal extent, and the number and frequency of checks – the quality of data from each site was qualitatively assessed (Grade 1, 2, or 3), as indicated in Figure 1.

Table 3: Summary of mean settlement – the mean catch per collector check of pueruli, plus juveniles up to and including 14.5 mm carapace length – by region. The confidence intervals are based on a normal approximation to the sampling distribution for the mean; the lower 95% confidence interval is bounded at zero. Region 1 is Cape Reinga to Cape Runaway, Region 2 is Cape Runaway to East Cape, Region 3 is East Cape to Cape Turnagain, Region 4 is Cape Turnagain to Flat Point, Region 5 is Flat Point to Kaikoura, Region 6 is Kaikoura to Southwest Cape, Region 7 is Southwest Cape to Cape Providence, Region 8 is Open Bay Islands to Cape Providence, Region 9 is Cape Reinga to Open Bay Islands, and Region 10 is the Chatham Islands. Excluded were calendar years 1981, 1983, 1987, 1991, 1992 (all with high settlement) and 1999 (very low settlement). Only the main settlement months are included (January to September inclusive for regions 4 and 5 and April to September inclusive for all other areas).

Region	1	2	3	4	5	6	7	8	9	10
Number of measurements	315	130	1984	2058	2594	1741	277	191	19	26
Lower 95% CI	0.11	1.41	3.87	3.1	0.82	0.25	3.58	0.61	0.00	0.00
Mean puerulus settlement	0.17	1.86	4.17	3.26	0.90	0.29	4.42	0.81	0.11	0.08
Upper 95% CI	0.23	2.31	4.47	3.42	0.98	0.33	5.26	1.01	0.25	0.18

Table 4: Mean settlement – the mean catch per collector check of pueruli, plus juveniles up to and including 14.5 mm carapace length – by CRA area from the beginning of sampling through to 2004 for sites shown in Figure 1. The confidence intervals are based on a normal approximation to the sampling distribution for the mean; the lower 95% confidence interval is bounded at zero. Excluded were calendar years 1981, 1983, 1987, 1991, 1992 (all with settlement much higher than average) and 1999 (very low settlement). Only the main settlement months are included (January–September inclusive for CRAs 4 and 5 and April–September inclusive for all other areas).

CRA area	1	2	3	4	5	6	7	8	9
Number of measurements	102	343	885	4508	1791	26	545	1612	4
Lower 95% CI	0.00	0.66	3.35	2.99	0.68	0.00	0.17	0.9	0.00
Mean settlement	0.02	0.86	3.67	3.15	0.76	0.08	0.27	1.07	0.00
Upper 95% CI	0.05	1.06	3.99	3.31	0.84	0.18	0.37	1.24	0.00

The data used in Tables 3 and 4 included only the main settlement months and excluded the extreme settlement years – and were the most conservative among a number of alternative indices of mean settlement by CRA area investigated. These others investigated included the full record of collector catches, the full record minus the extreme years irrespective of the month of settlement, and the full record but with only the main settlement months. There was little difference in the results by region or CRA area under each of these different scenarios (not shown).

In addition to the collector sites shown in Figure 1 were others checked for less than a full year. Results from those collectors allowed subjective qualification to the estimates of CRA area settlement given in Table 4. The main points are that:

- CRA 1 and CRA 9 settlement is underestimated: there were only three or two (grade 3) sites within each of these CRA areas among the sites followed for at least one year; shorter time series of settlement at additional sites suggested that the mean settlement should be higher than that indicated in Table 4.
- CRA 2 settlement is overestimated: the relatively high settlement in the region of Hicks Bay, which oceanographically and for other reasons is more aligned with CRA 3, leads to too high an overall CRA 2 mean settlement.

If these qualifications are to be accorded weight, then the mean settlement index in Table 4 for CRA 1, CRA 2, and CRA 9 might be taken to be about 0.50 (referred to as 'modified'). Using an estimate of the length of the coastline, these settlement data (estimated and modified) can be used to estimate the percentage of New Zealand-wide recruitment taking place in each CRA area (Table 5).

Table 5: For each CRA area, the number of collector sites (Figure 1), approximate length of open coastline (excluding deep embayments and estuaries and all but the larger islands), indices of mean settlement (estimated and modified) per unit length of coastline, and percent contribution to total New Zealand recruitment (mean settlement x coastline length) up to and including 2004. Mean settlement is the mean catch per collector check of pueruli, plus juveniles up to and including 14.5 mm carapace length. Each collector site contained 3–9 collectors. (Note that some arrows on Figure 1 indicate the position of more than one site.)

CRA area	No. sites	Length of coastline (km)	Mean settlement (estimated)	Mean settlement (modified)	% recruitment (estimated)	% recruitment (modified)
CRA 1	3	519	0.02	0.50	1.8	4.2
CRA 2	14	739	0.86	0.50	11.3	6.0
CRA 3	7	294	3.67	3.67	19.2	17.4
CRA 4	13	580	3.15	3.15	32.5	29.4
CRA 5	7	1016	0.76	0.76	13.8	12.4
CRA 6	4	277	0.08	0.08	0	0.4
CRA 7	6	287	0.27	0.27	0.4	1.3
CRA 8	20	1112	1.07	1.07	21.2	19.1
CRA 9	2	1239	0.00	0.50	0	10.0

5.3 Consistency in catches between collectors

There are significant correlations in catches between groups of collectors and collector sites over time which are unlikely to be due solely to chance.

5.3.1 Consistencies in seasonality of settlement

The seasonality of settlement for the entire sampling record to the end of 2004 for the collector groups indicated is given Figure 11. The main settlement season varies according to location, but with large stretches of coast (regions) having the same general settlement seasons. Adjacent sites have the same seasons, except for those pairs of sites that straddle regional boundaries. Winter is the most widespread main settlement season, but from Castlepoint to Kaikoura, there is usually also high settlement in summer and autumn (and there is evidence for significant summer settlement in CRAs 1 and 2) (Booth 1994). The winter settlement tends to be a little later in the southeast of the South Island than elsewhere, extending into spring. Figure A3.1 (Appendix 3), showing the three months of highest mean settlement and the three months of lowest mean settlement, further illustrates this high level of consistency in settlement seasonality within regions. The reasons for these seasonalities (which is further explored later), and their variation between areas, remain unclear but may be related to differential larval and postlarval transport alluded to in Section 1.1.

5.3.2 Consistencies in annual settlement

Within CRA interannual plots (e.g., Figure 12), and visual examination of overlaid plots for the northern and southern sites (Figures 13 and 14) indicate there are correlations in annual settlement between sites. In the following we analyse these apparent correlations between sites for statistical significance.

Tables 6 and 7 give the Spearman rank correlations, and the associated p-values, for interannual patterns in settlement between sites. (Figure A4.1 depicts these data pictorially.) There are high correlations and significant correlations in the pattern of year-to-year settlement among the sites along the coast of SENI (see also Figure 15), and among the sites in the southeast of New Zealand.

The geographic pattern in settlement on the collectors in 1990, 1994–98, 2001–02, and 2004 was similar to that seen through the 1980s: settlement on the east coast was generally high as far south as about Cook Strait and considerably lower to the south. In contrast, during 1991–93 and in 2003, there was high settlement further south, to at least Kaikoura (but apparently not as far south as Banks Peninsula in 1991–93 – see Booth et al. (1994); there were no equivalent data for 2003). 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. It improved slightly in 2000 and still further in 2001–03, but either stabilised or fell in 2004. These features can be seen, for example, in the standardised settlement for CRA 3 (see Figure 3), CRA 4 (Figure 12), and CRA 5 (see Figure 7).

In 2000–03 there was a marked increase in settlement levels in SENZ, particularly at Moeraki, where settlement in 2003 was at a level not before seen (see Figure 8). (A similar pattern is suggested for the coast further south, off northeast Stewart Island – see Figure 9.) This increased settlement did not, however, persist into 2004.

Table 6: Spearman correlations of year-to-year settlement between sites, using the same years and groups of collectors as shown in Figures 3–10. Also see Appendix 4. Site abbreviations are as in Table 1.

	GIS	NAP	CPT	WGT	KAI	MOE	CHA
NAP	0.690						
CPT	0.620	0.510					
WGT	0.080	0.120	-0.120				
KAI	0.390	0.300	0.240	0.190			
MOE	-0.140	-0.180	-0.310	0.510	-0.190		
CHA	-0.070	0.030	0.150	0.000	-0.240	0.430	
HMB	0.370	0.340	0.130	0.510	0.040	0.620	0.480

Table 7: The associated p-values for the Spearman correlations between sites (see Table 6). P-values ≤0.05 are highlighted. Also see Appendix 4. Site abbreviations are as in Table 1.

	GIS	NAP	CPT	WGT	KAI	MOE	CHA
NAP	**0.004**						
CPT	**0.010**	**0.012**					
WGT	0.396	0.354	0.646				
KAI	0.084	0.081	0.139	0.275			
MOE	0.684	0.747	0.873	**0.044**	0.755		
CHA	0.593	0.456	0.264	0.500	0.848	0.054	
HMB	0.093	0.056	0.275	**0.044**	0.421	**0.008**	**0.016**

Kaikoura appears to be an interesting intermediary site, showing greatest connection with the east coast of the North Island in terms of its settlement peaks, and increasingly lower association with distance south (Figure A4.1). Further, the variability in settlement at Kaikoura is remarkable (see Figure 7). Against a background of relatively low settlement, there were very high settlements – about ten times greater than the long-term average – in 1991–93 and then again in 2003. (Kaikoura's possible sources of larval recruitment are discussed later.)

5.4 Reasons for the spatial variation in settlement

The same high (e.g., 1991 and 1992) and low (e.g., 1999) settlement years being seen over broad areas of coastline have a plausible oceanographic basis: the northern sites are all within the influence of the East Cape Current System and the Wairarapa Eddy (e.g., Heath 1985, and also see Chiswell & Booth (1999)) and the southern sites are all within the influence of the Southland Current (Heath 1985). Clearly these widespread patterns strongly suggest that factors that drive larval recruitment affect quite vast areas.

The much higher levels of settlement usually seen on collectors in SENI compared with those in 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 (Booth et al. 1995, 1998, Chiswell & Booth 1999). Advanced phyllosomas (those at and beyond Stage 5) were widespread and abundant off SENI, catches being orders of magnitude greater than off 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 that can bring about high settlement (see Booth et al. 2000b). 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 soon after 1999 were more to do with the ocean climate (La Niña condition) than to any reduced abundance offshore of phyllosomas.

The increased settlement off SENZ in 2000–03 (but not into 2004) could have also been the result of a changed oceanography, but it might also have been contributed to by increased numbers of advanced phyllosomas present as a result of the rebuild of what had been a very reduced stock of mature lobsters upstream, in CRA 8 (see Sullivan et al. 2005), together with suitable oceanographic circumstances. There are no recent larval data to help resolve this.

The southwest of the South Island and western Stewart Island – with relatively high levels of settlement – may receive larvae from southern Australia (Chiswell et al. 2003). If this is the case then vagaries in flow across the Tasman Sea could quite well account for the high interannual variability in settlement seen there. (The potential role on larval recruitment of an eddy in this region is discussed later.)

5.5 Summary

Settlement levels of the red rock lobster (*J. edwardsii*) have been estimated for much of the coast of New Zealand since the 1980s to 1990s. For several sites there are more than 20 years of data, 25 years for Halfmoon Bay. The programme continues to be the only widespread fishery-independent monitoring undertaken for rock lobsters.

The examination of the settlement data undertaken in this section, showing consistent patterns in settlement season and in year-to-year settlement between sites, strongly suggests that the sampling is measuring real changes in settlement levels. The data suggest that recruitment events take place over large stretches of the New Zealand coastline, with plausible oceanographical bases, just as they do off Western Australia (e.g., Phillips et al. 1991). Such data can be expected to be useful in the management of the fishery, particularly if the peaks and troughs in settlement are later manifested in the fishery.

6. POWER AND PRECISION OF COLLECTOR DATA

This section examines power to discern changes in settlement levels with the present collector array, and what the loss in precision of our estimate of settlement levels would be if the numbers of collectors were to be reduced.

6.1 Power to discern changes in settlement levels

There is an inherent uncertainly in the estimates of the mean settlement index for a year, the size of this indicated by the 95% confidence interval assigned to the year. Consequently, a change in the settlement index in a following year may reflect real changes in settlement, or may simply be a consequence of random variation, or both. In this section we investigate what levels of change in estimated settlement are statistically significant for a site; i.e., the power of a statistical test that the settlement differs from a mean level of 1 (where for a site the settlement is scaled so as to have an arithmetic mean of 1).

The power of a test of the null hypothesis H_0, against the alternative hypothesis H_A, is defined as

$$P = P(\text{reject } H_0 \mid H_A).$$

The null hypothesis in this case is taken to be that the settlement is 1, versus the alternative hypothesis that it differs from 1. Let S_1 be the probability distribution for a settlement of 1, with $S_{1\,(2.5\%)}$ and $S_{1\,(97.5\%)}$ the 2.5% and 97.5% quantiles of this distribution. For a statistical test of H_0 at the 95% level, and a settlement level of S, the power is

$$P = P(S < S_{1\,(2.5\%)} \text{ or } S > S_{1\,(97.5\%)}).$$

The logs of the settlement indices distribution are approximately normally distributed, so the settlement is taken to have a lognormal distribution. For each site, the standard deviation of the lognormal distribution in log-space (σ_{Log}), is calculated as a function of the settlement from a robust linear fit: $\log(\sigma_{Log}) = \text{constant} + \log(S)$. The power of the test is calculated on a per site basis as a function of the settlement S.

These analyses show that for most sites the current array of collectors has very high (100% or approaching 100%) power to reliably detect a 100% change in settlement between years with 95% confidence (Figure 16). For Moeraki the power cannot be calculated from the standardisation model due to the sparse data coverage over the years and months, but it may be lower.

6.2 Effect on precision of settlement indices of reducing collector numbers

As part of the standardisation procedure to calculate the standardised indices, confidence intervals are calculated, these giving a measure of the sampling variability present in the estimates of indices after mean month and group/collector effects are accounted for. To what extent would the removal of non-core groups of collectors at key sites affect the ability of the sampling programme to track changes in mean settlement, and how would this affect the sampling variability?

These questions were addressed by doing retrospective standardisations of the settlement data, with the non-core (*additional*) collectors removed, and comparing these to the standardisations with the non-core collectors included. The results are shown in Figures 17 and 18, where standardised settlement indices and the ratio of the length of the 95% confidence intervals are compared on an annual basis for each CRA area. For all CRA areas there were only minor changes in the estimated settlement indices. The pattern for the sampling variability in the estimates is more complex: for CRA 5 and CRA 8 the confidence intervals remained about the same; for CRA 3 and CRA 4 the confidence intervals increased in length by about 20–40% after 1994.

6.3 Summary

The settlement data show that for most sites the current array of collectors has very high power to reliably detect a 100% change in settlement between years with 95% confidence. The extent to which this power is reduced when the non-core collectors at each site are removed varies between sites, but is mostly small.

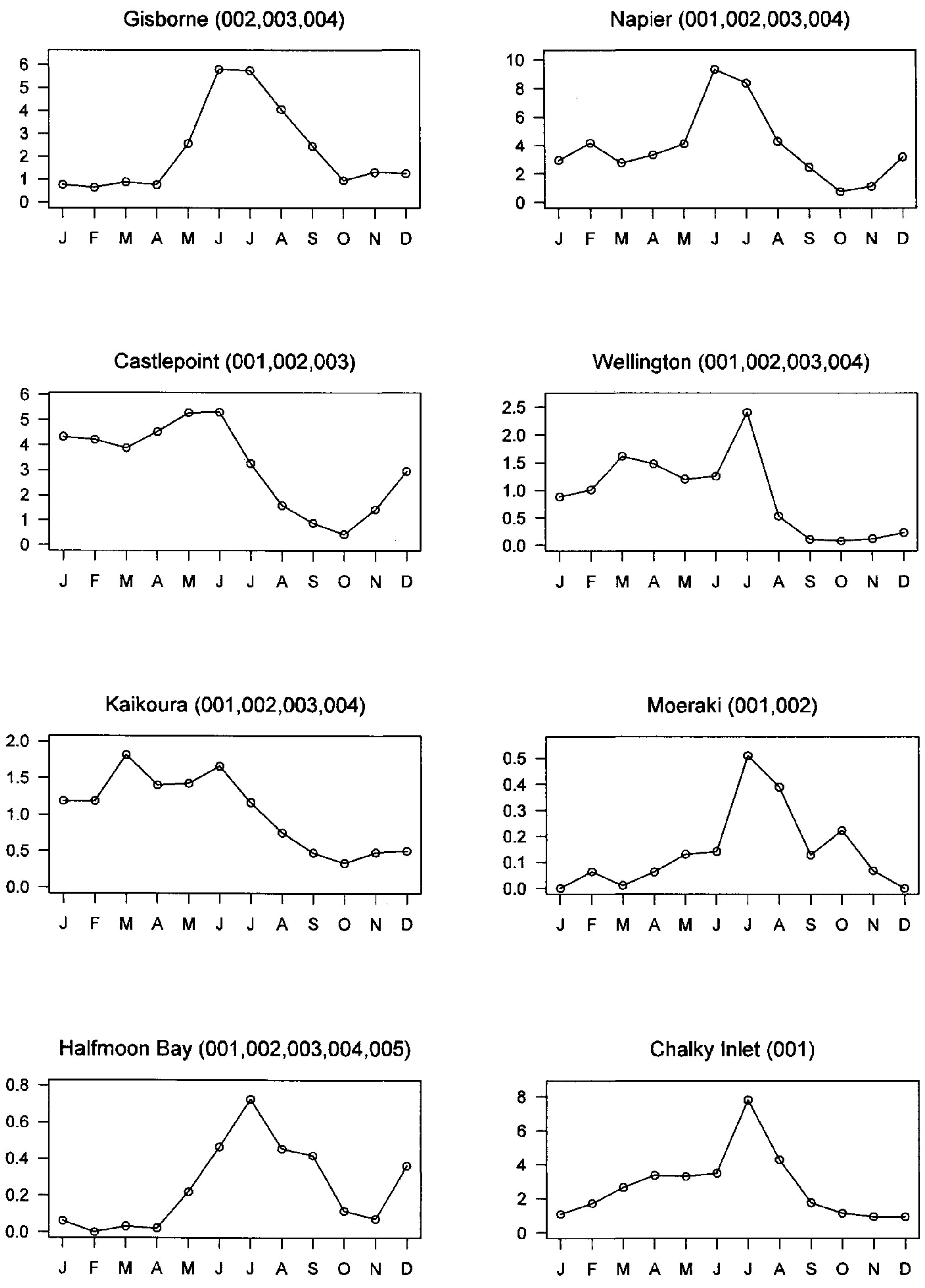

Figure 11: Mean settlement by month for each key collector site. See Table 1 for collector groups.

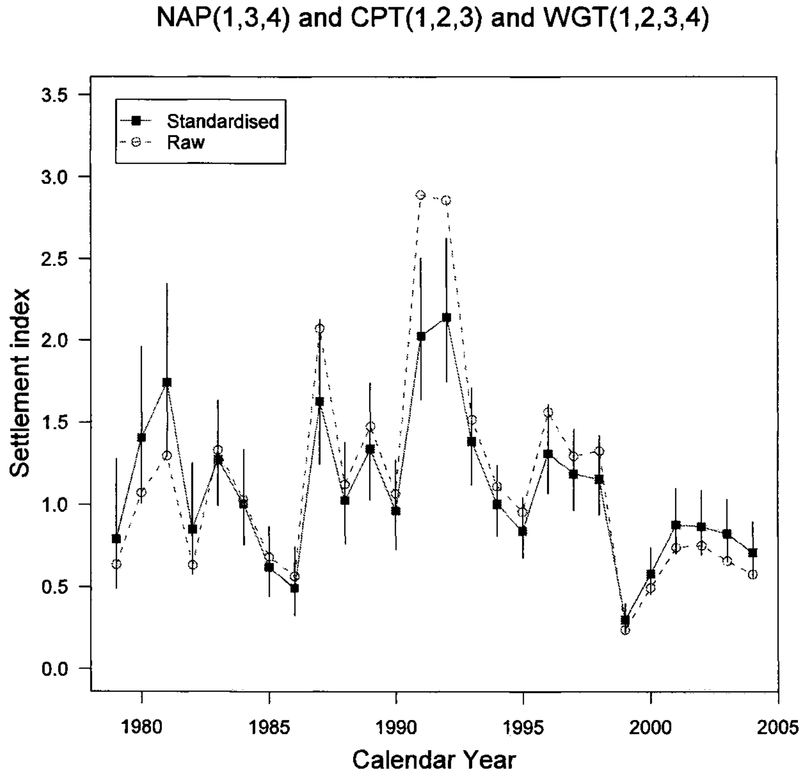

Figure 12: CRA 4 – standardised and raw indices of annual settlement with 95% confidence bounds.

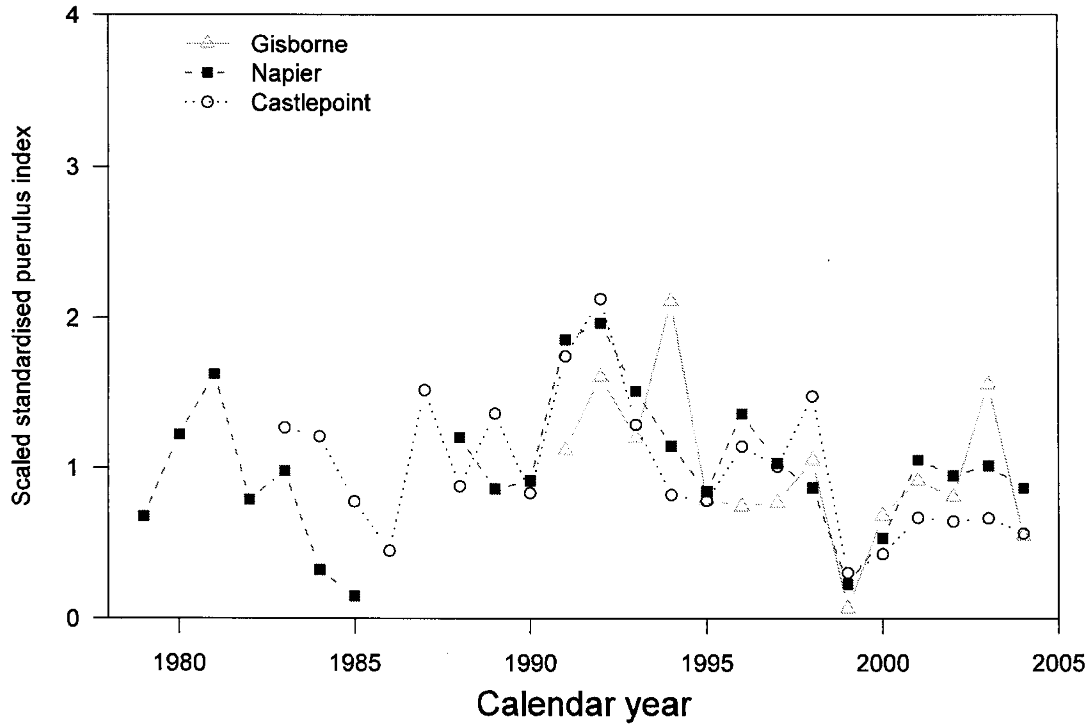

Figure 13: The Gisborne, Napier, and Castlepoint standardised indices. All indices are scaled so as to have a mean of one.

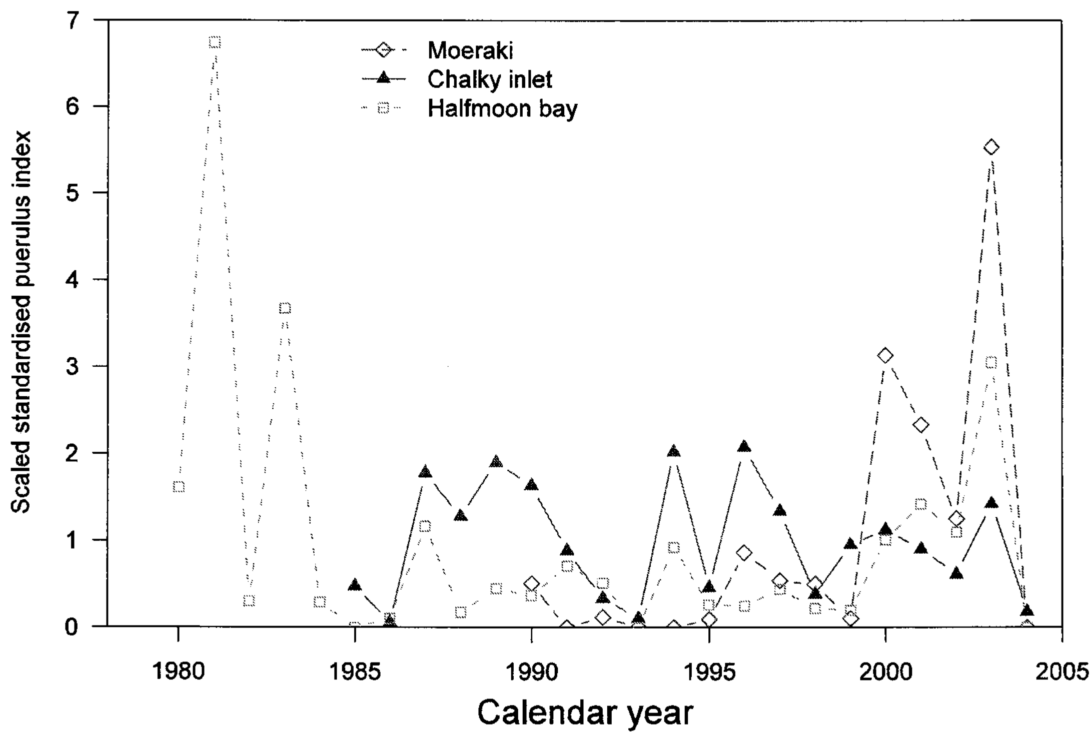

Figure 14: The Moeraki, Chalky Inlet, and Halfmoon bay standardised indices. All indices are scaled so as to have a mean of one.

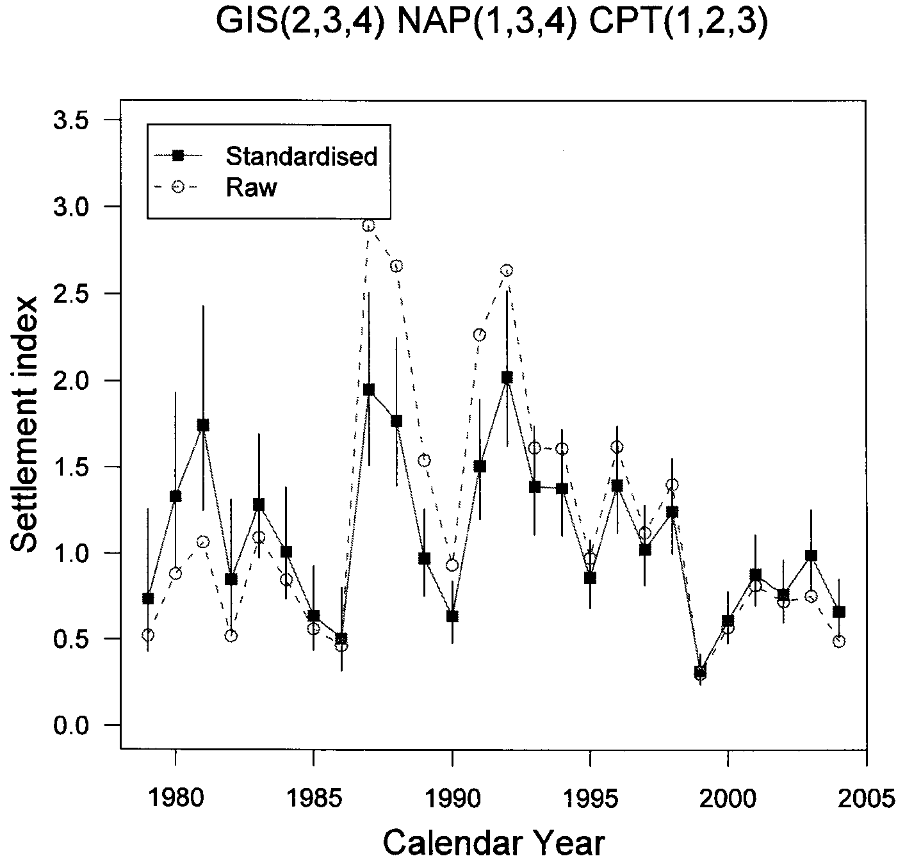

Figure 15: East coast North Island, Gisborne to Castlepoint – standardised and raw indices of annual settlement with 95% confidence bounds.

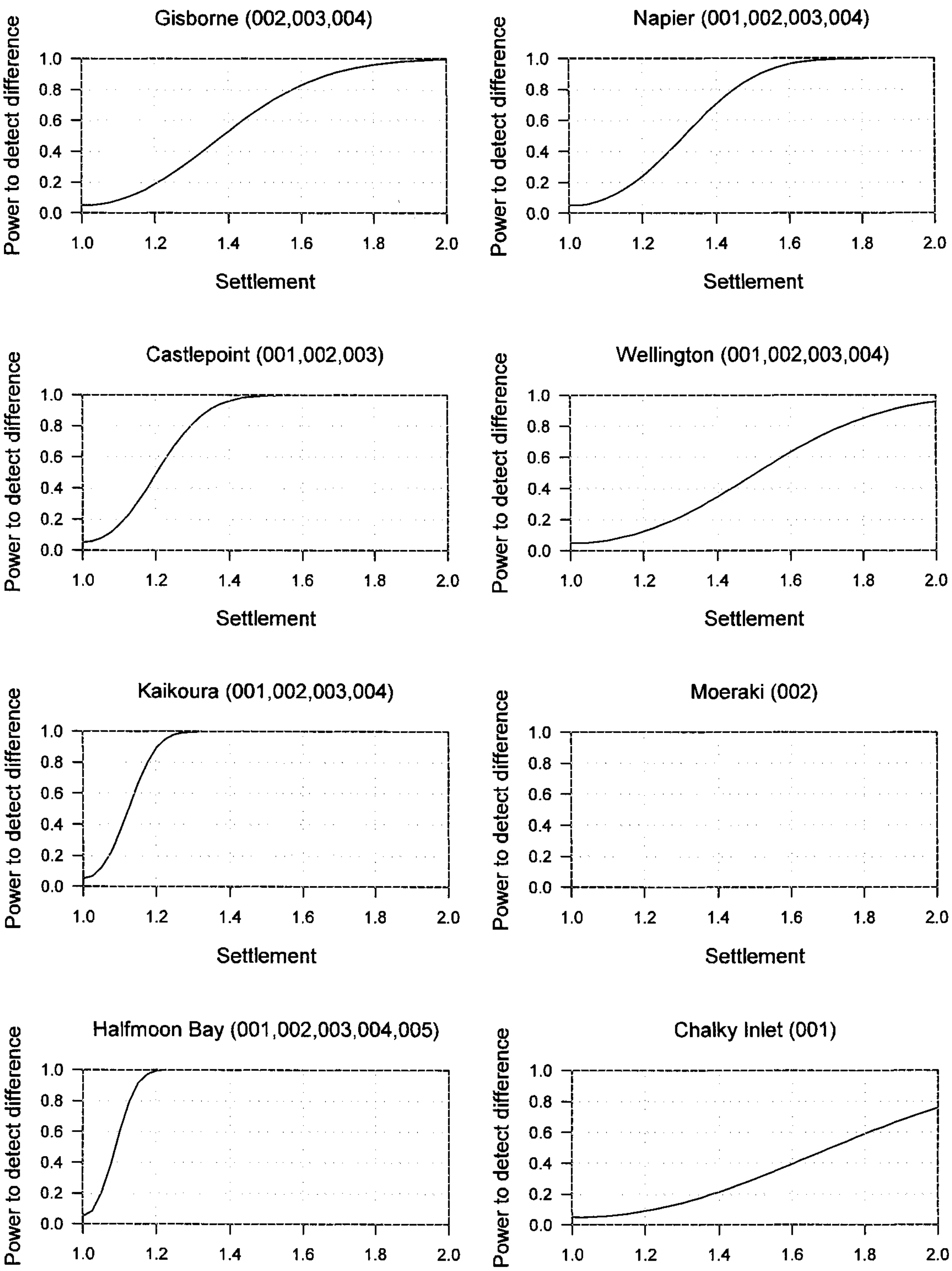

Figure 16: Power to discern a change in settlement between consecutive years from a baseline settlement of 1, where all sites have their settlement scaled to have an arithmetic mean of 1. For Moeraki the power cannot be calculated from the standardisation model due to the sparse data coverage over the years and months, but may it be lower.

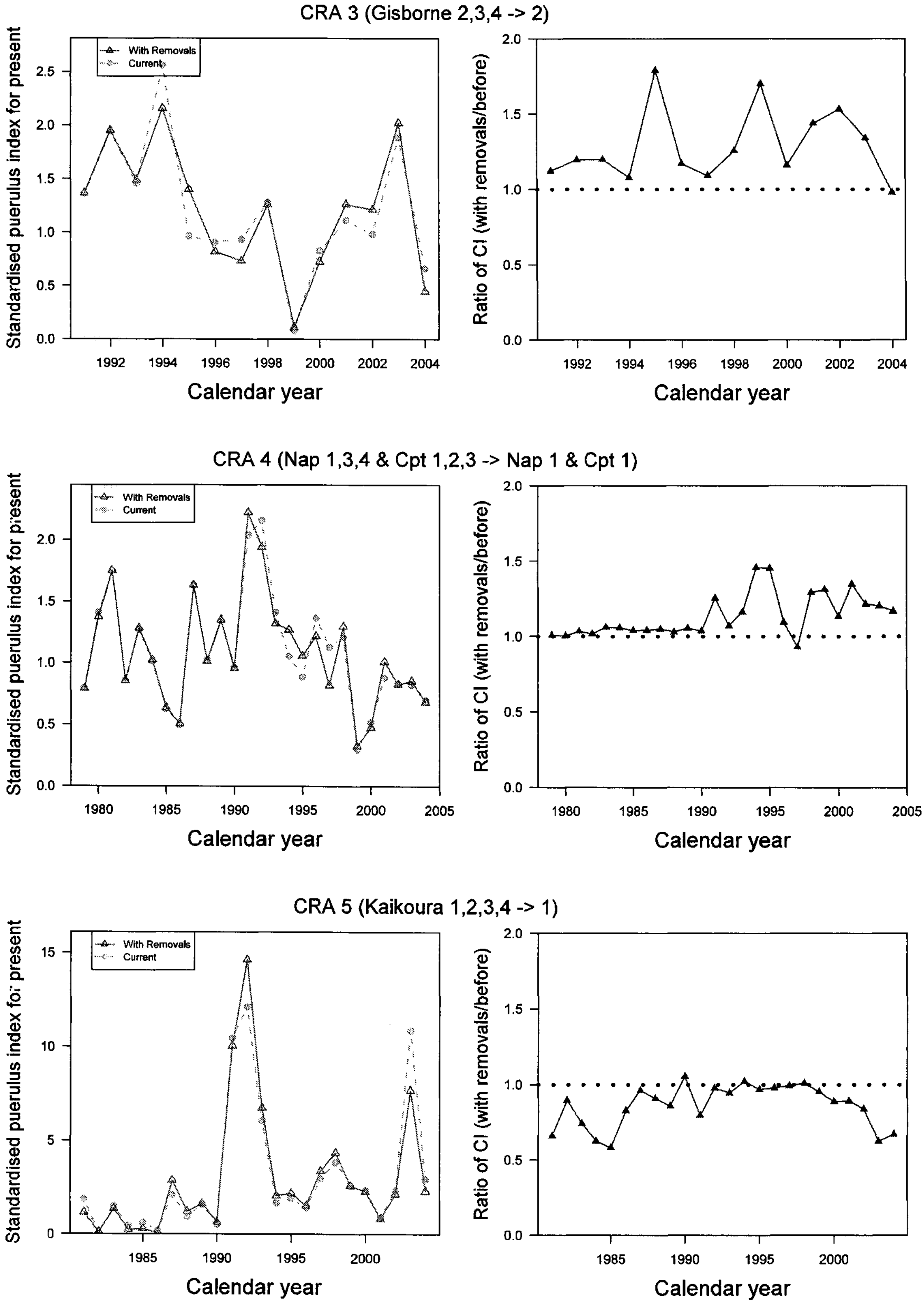

Figure 17: Effect of removing selected collectors on standardised settlement indices and length of confidence intervals for CRA 3, CRA 4, and CRA 5.

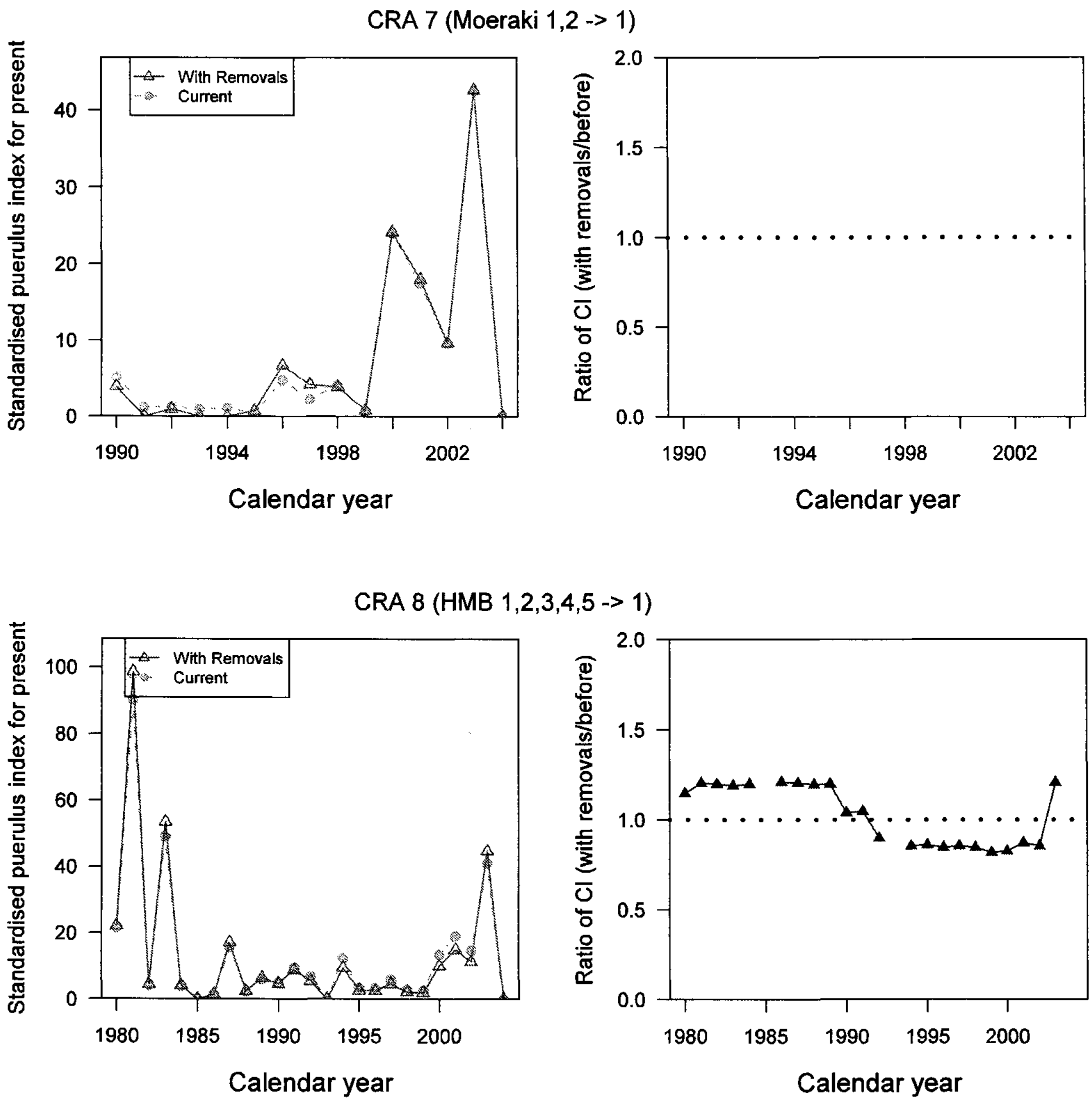

Figure 18: Effect of removing selected collectors on standardised settlement indices and length of confidence intervals for CRA 7 and CRA 8. The 95% confidence bounds can not be calculated for the Moeraki standardisation model due to sparse data coverage over the years and months.

7. MANAGEMENT IMPLICATIONS AND DISCUSSION

Our data show that there is considerable variability in levels of settlement between sites, but also that there are strong spatial and temporal consistencies present in the settlement record which make it highly likely that the observed settlements are closely related to actual settlements.

There is, however, disagreement between the settlement record and recruitment estimated in stock assessment models. Bentley et al. (2004a) suggested that the inconsistency could be due not only to the collector indices not providing good information on recruitment to the fishery, but also to the estimates of recruitment from the stock assessments being imprecise, and/or that the assumptions used in the simplified length-based model were incorrect. Until this is settled, and the reasons for the inconsistencies known for certain, the monitoring of settlement – at least at representative sites – should continue.

Although the costs of the settlement-monitoring programme might be viewed as high, it is a programme that takes place over virtually the entire main rock lobster coasts of New Zealand. The collectors themselves are inexpensive (generally under $50 each, installed) and yet durable (each can be expected to last between 5 and 10 years). Costs could be reduced, at the same time reducing little the precision of the settlement estimates, by reducing the numbers of collectors (Section 6.2). Also, the collector checks – the most costly part of the sampling – could be undertaken locally by volunteers, according to the well established protocols (see Appendix 1). (Indeed, most of the present checks of collectors around the country are made by local people.)

On the other hand, expansion of the settlement monitoring may be desirable. Suitable localities for monitoring settlement are known for many of the statistical areas not currently monitored (see Table 12). There would be the need to commit to long-term monitoring, sometimes with long gaps between significant settlement events (e.g., see Figure 7, for Kaikoura).

Observations of large settlement events taking place over quite broad areas of coast every few years raise the question as to what sort of settlement regime – low background level or occasional heavy settlement year(s) – has most influence in driving recruitment in the fishery. Although cohort biomass in high settlement years possibly erodes through density-dependent reduction in growth and increase in mortality, the degree of 'levelling' that occurs is still unclear. In Western Australia, where males and females recruit 4–5 years after settlement, peaks and troughs in settlement are clearly maintained in the fishery CPUE (Phillips et al. 2000). For the east coast of the South Island, from Banks Peninsula south, the peaks and troughs in settlement can be expected to persist into the fishery more noticeably than on the east coast north of Banks Peninsula, and the entire west coast. This is because in the southeast of New Zealand, males and females recruit at about the same age. In contrast, except for the east coast of the South Island from Banks Peninsula south, age at recruitment differs a lot between sexes (males recruiting at about 6 years and females at about 10 years in most places (Annala et al. 1980)). In such areas, high settlement year(s) may be manifested as a longer and lower wave of recruitment to the fishery. Variable growth rates would also reduce the effect of any density-dependence in growth and mortality.

There can be management, fishery, and social implications to disregarding information on levels of settlement. Breen & Kendrick (1997) essentially ignored the SENI settlement record when describing the upturn in the CRA 3 fishery between 1992 and 1996, and industry was ill-prepared for the dramatic downturn in the fishery that followed, between 1998 and 2004. CRA 3 CPUE increased during the mid to late 1990s to reach a peak of 2.18 kg/potlift in the 1997–98 fishing year and then steadily declined to 0.52 kg/potlift in 2004–05, a CPUE about the same as in the early 1990s before the management measures were introduced (Sullivan et al. 2005). Subsequent stock assessments pointed to a large pulse of recruitment having taken place along almost the entire east coast from CRA 1 to CRA 5, in the early 1990s (Breen et al. 2002, Starr et al. 2003, Kim et al. 2004), entirely consistent with the SENI settlement record. Unfortunately Breen & Kendrick's mis-interpretation of events – that management intervention was the key to the (short-lived) upturn in the CRA 3 fishery – not only misled managers, but has also become entrenched in the world literature (e.g., Lipcius & Eggleston 2000, Figure 8a). Even subsequently, after the CRA 3 assessment model fitted to an index of recruitment based on settlement provided a much more accurate prediction of fishery CPUE than the base case (Breen et al. 2002, Figure 16), the settlement record remained largely ignored in the more recent CRA 3 stock assessment (Haist et al. 2005).

8. FURTHER WORK

A number of productive directions for further work on larval recruitment processes in *J. edwardsii* flow on from this document. We deal first with ways to understand what brings about the geographic variation in seasonality in settlement shown in Figure 11; then we consider the statistical areas of the main fishery that do not yet have collector coverage and how that could be rectified; next we discuss the need for information on juvenile growth rates; and finally we deal with some local regional recruitment quandaries. Improved understanding of all/any of these issues will enhance our understanding of larval recruitment in general, which can flow on to improved management.

8.1 Settlement season

Although it takes a full year for phyllosomas to reach final stage, metamorphosis does not necessarily take place immediately after moulting to the final stage, with final-stage larvae being present in the plankton for up to another year (Booth 1994). So, why is settlement seasonal – mainly winter – and why does the main settlement period along the east coast of central New Zealand, at least from Castlepoint to Kaikoura, include not just winter but usually summer and autumn as well? (A very reduced summer peak is also seen further north, at Napier (Figure 11), and there can be both summer and winter settlement peaks in CRA 2 and the east coast of CRA 1 (Booth 1994)).

A possible explanation for this seasonality in settlement lies in whatever it is that initiates metamorphosis from the final-stage phyllosoma to the puerulus. The factor that controls metamorphosis has to explain both when (in the second year after the spring hatching, mainly in winter, but starting as early as early summer) and where (mainly just beyond the shelf break) metamorphosis takes place. Booth & Chiswell (2005) suggested that for the SENI, and for final-stage phyllosomas in the right phase of their moult cycle, metamorphosis to the non-feeding puerulus will take place after the larvae have accumulated sufficient energy reserve, and this is most often going to happen in the more highly productive waters – those inshore (waters near and just beyond the shelf break), as shown in sea colour imagery representing chlorophyll. The external factor implicated in metamorphosis is therefore the encounter by phyllosomas of productive inshore waters. The trigger is the accumulation of sufficient stored energy reserve. Advection of late-stage phyllosomas into the coastal zone occurs throughout the year, so metamorphosis can occur throughout the year. But chlorophyll generally shows a strong annual cycle, with peak values during April–May (unpublished NIWA ocean colour images). Peak settlement occurs about 1–2 months later than this. This lag could be explained by the delay between primary and secondary production, time for phyllosomas to amass energy, and time for the pueruli to reach the coast. Southerly winds and Ekman drift would assist the shoreward-directed swimming by the final-stage phyllosomas (Chiswell & Booth 1999, 2005a) and pueruli, so winter weather patterns may also influence settlement seasonality. However, these suggestions do little to explain the summer-autumn settlement along the east coast of central New Zealand.

Closer examination of the cycles of primary productivity (from ocean colour), and the ocean climate, in relation to settlement, may therefore provide better insight into the cause and nature of the seasonalities we have observed. Of particular interest to managers might be any differences in the relative survival of summer-settled versus winter-settled cohorts.

8.2 Statistical areas without coverage

Not all rock lobster statistical areas have collectors and effort might be put into establishing representative settlement-monitoring sites in each of those within the main rock lobster fishing area that are without. Table 8 gives the statistical areas, indicates whether there is an effective group of collectors present, and in statistical areas in which there is not, whether a suitable monitoring site is known.

Table 8: Whether collectors are currently present, and if the existence of a suitable site is known, for the main rock lobster fishing statistical areas. -, not applicable

Statistical area	Collectors present?	Suitable site known?	Statistical area	Collectors present?	Suitable site known?
909	X	√	917	√	-
910	√	-	923	X	√
911	X	√	924	√	-
912	√	-	926	√	-
913	√	-	927	X	√
914	X	X	928	√	-
916	X	√			

8.3 Growth rates of juveniles

Knowing 1) the time taken from settlement to recruitment to the fishery, and how it varies between individuals, and 2) the time taken from recruitment to the stock assessment model (at 32 mm tail width (TW) – equivalent to about 58 mm carapace length (CL), and about 2 years of age) until about 40 mm TW (about 75 mm CL and 3 years of age) when lobsters begin to be routinely taken in pots, would greatly assist interpretation and usefulness of the settlement data.

Juvenile growth rates will not be easy to determine. Growth information for juveniles up to about 75 mm CL is confined largely to modal progression analyses from Gisborne, Stewart Island, and Moeraki (McKoy & Esterman 1981, Annala & Bycroft 1985, Street & Booth 1985, Breen & Booth 1989) and none of these studies took into account individual variability in annual growth. Meanwhile it is becoming increasingly evident for invertebrates that early growth rates can vary a lot between individuals, often in line with very variable condition among settling larvae/postlarvae (particularly in species such as rock lobsters with postlarvae that do not feed).

To reveal growth variability between individuals it will be necessary to tag lobsters individually, preferably immediately after settlement, using such techniques as micro-wire tags and elastomer tags for those less than 30 mm CL, and mini T-bar tags for those larger. If all lobsters tagged are of about the same size and age after settlement, then batch tagging would suffice, with anniversary sampling of the tagged lobsters. Such studies are best undertaken first at places where large numbers of new settlers are available (e.g., Gisborne). Later, it would be desirable to also study growth variability at southern and intermediate sites.

Such information on growth of individual juvenile rock lobsters up to 75 mm CL will allow better use by managers of the settlement data and lead to more accurate estimates of juvenile growth for stock assessment.

8.4 Regional recruitment

8.4.1 Southwest New Zealand (southwestern CRA 8)

An interesting revelation from the larval sources and destinations study of Chiswell & Booth (2005b) was that larval recruitment for the southwest of New Zealand (southwest corner of the South Island and the west coast of Stewart Island) may depend not only on larval transport from Australia (Chiswell et al. 2003), but also on the apparent presence of a persistent eddy, identified for the first time only recently. This eddy appears to be held in place by Stewart Island and the Snares Shelf to the east, the northern end of the Macquarie Ridge to the west, the South Island to the north, and by the eastward flow of the Southland Current in the south (Chiswell & Booth 2005b). The region has variable but often high levels of settlement (e.g., Figure 10); there are extensive areas of sedimentary seafloor with overhangs that are likely to provide good cover for both juvenile and adult lobsters (Bob Street, pers. comm.); it is from time to time a source and/or transit place for north-migrating juvenile lobsters (e.g., Street 1995, Kendrick & Bentley 2003); and there is a very significant local fishery (Sullivan et al. 2005). Periodic manifestation and decay of this yet-to-be-named eddy may strongly influence levels of settlement in the region, although much more work needs to be undertaken to be sure. Understanding interannual variations in the persistence of this eddy, and the effects of these on local larval recruitment, together with a better understanding of how much contribution there is of pueruli sourced from Australia, would help in the management of this very important fishery.

The issue would be advanced by analysis of the September 2005 CTD transects through the eddy, sampling of the eddy for phyllosoma abundance in relation to surrounding areas at an appropriate time of the year, and establishment of additional sites in the region to follow settlement.

8.4.2 Kaikoura (central CRA 5)

The Kaikoura coast is another interesting region, with remarkable variability in year-to-year settlement (with periods of settlement up to about ten times greater than the long-term average) as described in Section 5.3.2

Kaikoura is influenced primarily by Southland Current water (Heath 1985), but there is evidence in the temperature field that the area is also bathed from time to time by subtropical water (Heath 1975). Indeed, satellite imagery shows that the Wairarapa Eddy periodically sheds bodies of water that are transported south; these probably contain phyllosomas from the larval-rich waters of the East Cape Current System. (The role in this process of what has been called the 'Hikurangi Eddy' (Barnes 1985), at the south entrance to Cook Strait, is unclear.) It may be that the 'normal' low background levels of settlement are associated with larval recruitment sourced from the south. Superimposed on this are, from time to time, significant larval recruitment events that may have a northern origin (e.g., as seems likely for 1991–92, when there was also high settlement to the north of Kaikoura, but not to the south), or a southern or mixed origin (as seems likely in 2003, when there was high settlement to the north and south).

This is a possible but probably over-simplistic interpretation of the larval recruitment mechanism for the Kaikoura region, but it does establish an hypothesis that could be tested through detailed analysis of local water movements as measured by Topex/Poseidon (and used for the broader New Zealand region by Chiswell & Booth (2005b)) in relation to the collector settlements. Note that in the high settlement years settlement is high not just for a month or two, but over most or all of the 9-month main settlement season.

Wilkin & Booth (NIWA, unpublished) examined in some detail one occurrence of what appeared to be larval transport towards the Kaikoura region. In plankton sampling during 8–12 February 2001, large numbers of mid- and late-stage phyllosomas were taken at the western end of the Chatham Rise, an area in which other quite extensive sampling had failed to locate phyllosomas (Booth 1994); soon after, during 22–23 February, pueruli were taken in significant numbers in the plankton inshore of this point (S. O'Shea, Auckland University of Technology, pers. comm.). Examination of the sea surface temperatures and sea level indicated that the Wairarapa Eddy had been 'normal' in mid January 2001, but at the time of the phyllosoma catches, an anticlockwise rotating feature was visible off the southern entrance to Cook Strait. At the time that the pueruli were taken, there was a strong flow indicated onto the south Wellington coast and the coast near Kaikoura. Subsequently this eddy weakened and broke up and the Wairarapa Eddy re-established itself to more or less normal condition. The monthly settlement record at Wellington and Kaikoura showed the highest settlement for the year to be in February and March, although the settlement levels were not particularly high compared to the long-term average. This unresolved picture (because the observations did not lead to particularly high settlement) simply indicates a potential mechanism for the periodic transport of significant quantities of phyllosomas to the Kaikoura area. Whether such events actually bring about significant settlement may depend on such things as 1) the particular oceanographic mechanism being present; 2) the larvae being present; and 3) the break-up of the eddy happening the right distance from shore. Possibly, if any components of this sequence, or others, are not appropriate/optimal, then settlement will not follow.

8.4.3 CRA 1 and CRA 2

Settlement in CRA 2 and along the east (and west) coast of CRA 1 remains poorly determined. There were trials with collectors in the early 2000s, with at least one suitable site found in CRA 2. But Table 4 suggests that the mean annual settlement levels in these CRA areas are low compared with others such as CRA 3 and CRA 4, and it is likely to be sporadic. For example, there have been large settlement events confirmed for Houhora in CRA 1, based mainly on mussel farm occurrences (NIWA unpubl. data), yet collectors set at Houhora (and the mussel farms) in 2000–01 caught few pueruli.

The recruitment pulse estimated from the stock assessment models for CRAs 3–5 (and seen in the collector record) was also apparent in the CRA 1 and CRA 2 assessments (Starr et al. 2003). This is consistent with large settlement events such as that seen in 1991–92 taking place over large tracts of coast. Thus CRA 3 settlement may constitute a useful de facto settlement record for CRAs 1 and 2.

8.4.4 CRA 3 and CRA 4

These two CRA areas lie within the influence of the East Cape Current system, and in turn the Wairarapa Eddy. Although there are strong spatial and temporal consistencies in the settlement record for sites within this region, there are nevertheless subtle differences. For example, the improvement in levels of settlement between 2000 and 2003 was seen much more strongly in the north of the region, near Gisborne, than it was further south at Castlepoint.

A way to understand such variation might be to analyse current flows derived from sea level observations (as Chiswell & Booth (2005b) did for the broad New Zealand region) to identify patterns that could explain these differences.

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APPENDIX 1A: PROTOCOLS FOR SETTING SHORE CREVICE COLLECTORS

1. Set collectors on sheltered shores that are directly adjacent to oceanic waters and away from surface dilution and high freshwater runoff. Minimum water depth over the top of the collector at ELWS should be 20 cm.
2. Collectors should be conditioned on site for at least 4 months before use and collector replacement during the main settlement season should be minimised because unconditioned collectors catch less well.
3. Collectors are usually set in groups of five, the collectors 2–3 m apart and linked by rope.
4. Collectors are checked and cleared approximately monthly.

APPENDIX 1B: PROTOCOLS FOR CHECKING SHORE CREVICE COLLECTORS

1. Place checking bag over collector, in one clean action if possible, making sure that the collector is completely contained. Pull tight the drawstring and unscrew the collector.
2. On a flat stable surface, open out the checking bag and position the collector within it so that three crevices open vertically. Check each crevice in turn, carefully removing lobsters with the clearer. Focus at all levels of the crevice – from top to bottom. Ensuring no loss of material, turn the collector over and repeat for the other four crevices.
3. Remove collector from checking bag, again making sure that no other material comes out of the bag.
4. Shake the checking bag vigorously and look through the debris at the bottom of the bag for lobsters, removing them as it is sorted. Repeat this process at least twice more.
5. Scrape clean each side of each of the seven crevices. Also clear growth from all six outer edges of the collector. Replace collector to the sea immediately.
6. Count, stage (and measure lobsters over 14.5 mm carapace length), and record catches for each collector.

APPENDIX 2: DIAGNOSTICS FOR PUERULUS STANDARDISATION MODELS

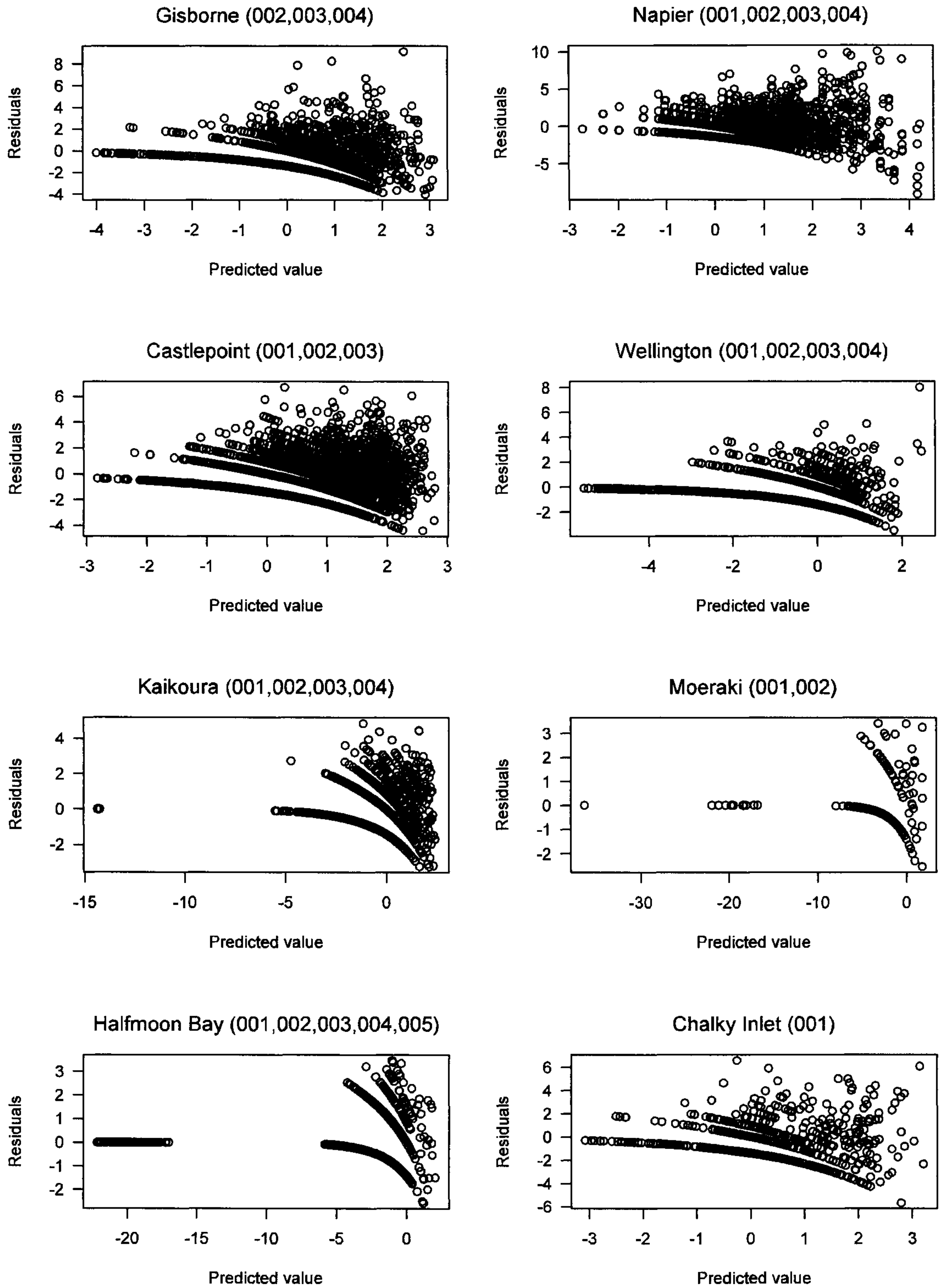

Figure A2.1: Residual plots from standardisation model for each site. The predicted values are in log space. See text for further details.

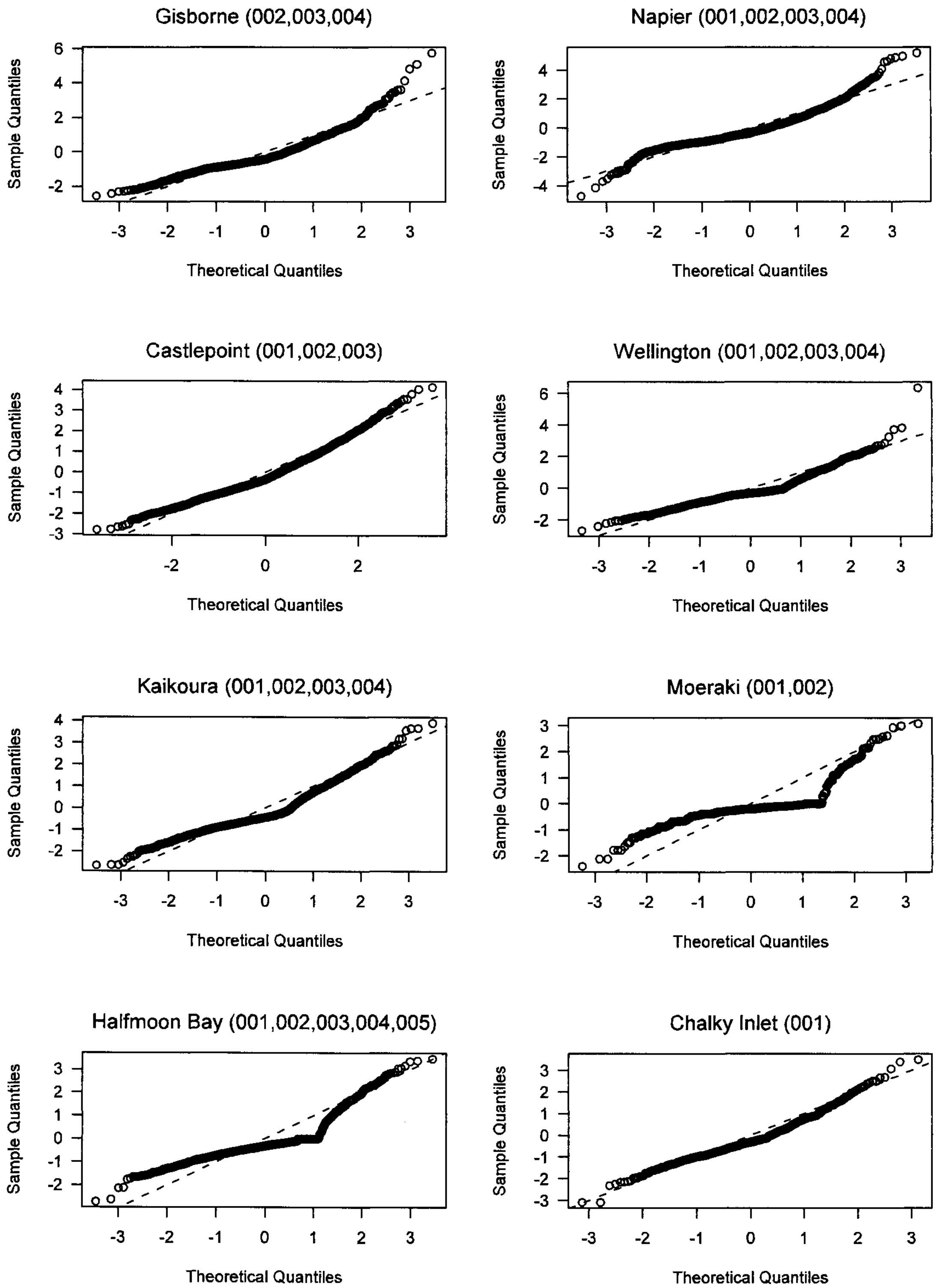

Figure A2.2: Quantile-quantile plots from standardisation model for each site. See text for further details.

APPENDIX 3: VARIATION AND CONSISTENCY IN SETTLEMENT SEASON BETWEEN SITES

There are consistencies in the seasonal pattern in settlement, winter being the most widespread settlement season. However, in central New Zealand there is usually also high settlement in summer and autumn (see Sections 5.3.1 and 8.1). Figure A3.1 further illustrates this point by showing the 3 months with highest and 3 months with lowest settlement for each site.

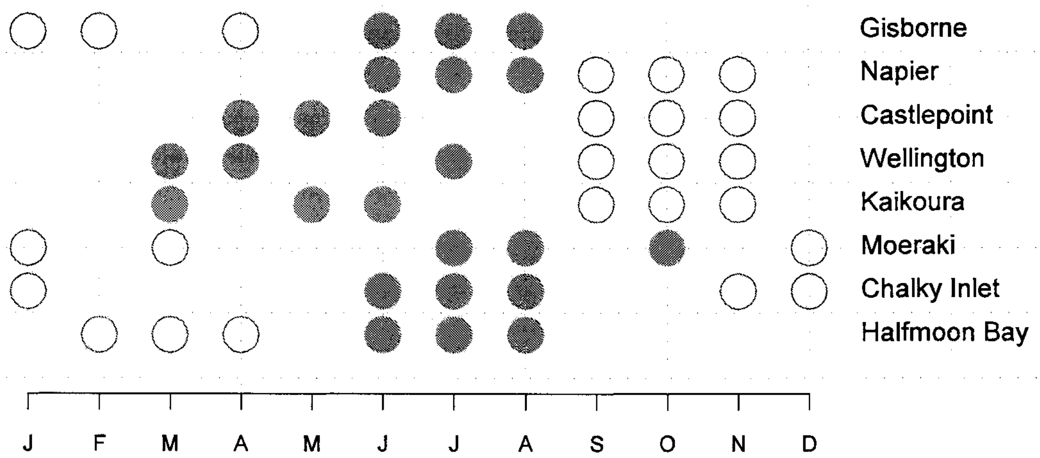

Figure A3.1: The 3 months of highest mean settlement (solid circles) and lowest mean settlement (open circles).

APPENDIX 4: SHOWING CONSISTENCY BETWEEN SITES IN SETTLEMENT LEVEL

There are consistencies and correlations between sites in the year-to-year levels of settlement (see Section 5.3.2). These are further illustrated in Figures A4.1–A4.3.

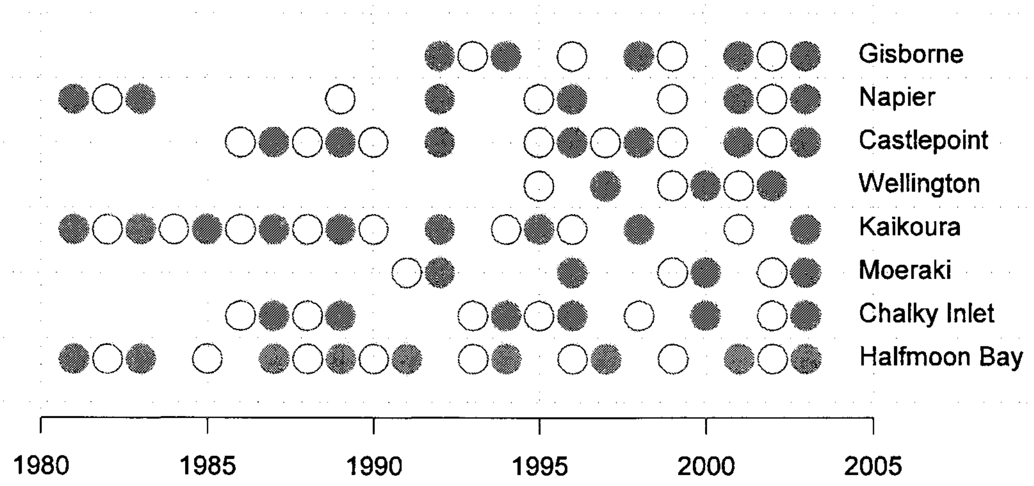

Figure A4.1: Years in which maxima in standardised settlement occurred (filled circles) and those when there were minima (open circles). Maxima are defined as years in which the standardised settlement in both adjacent years is less; minima as years in which the settlement in both adjacent years is more.

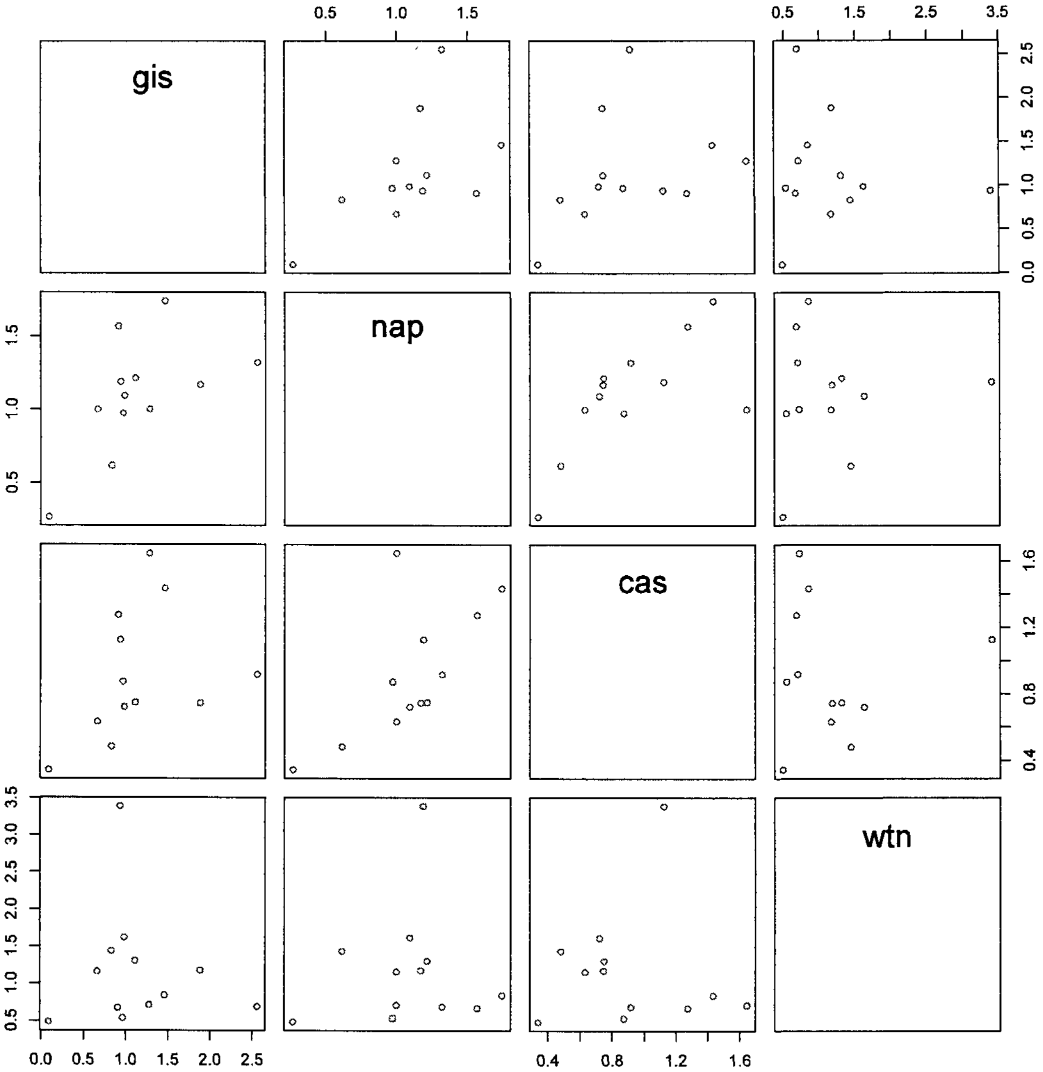

Figure A4.2: Standardised settlement for pairs of northern sites, year by year. gis, Gisborne; nap, Napier; cas, Castlepoint; wtn, Wellington.

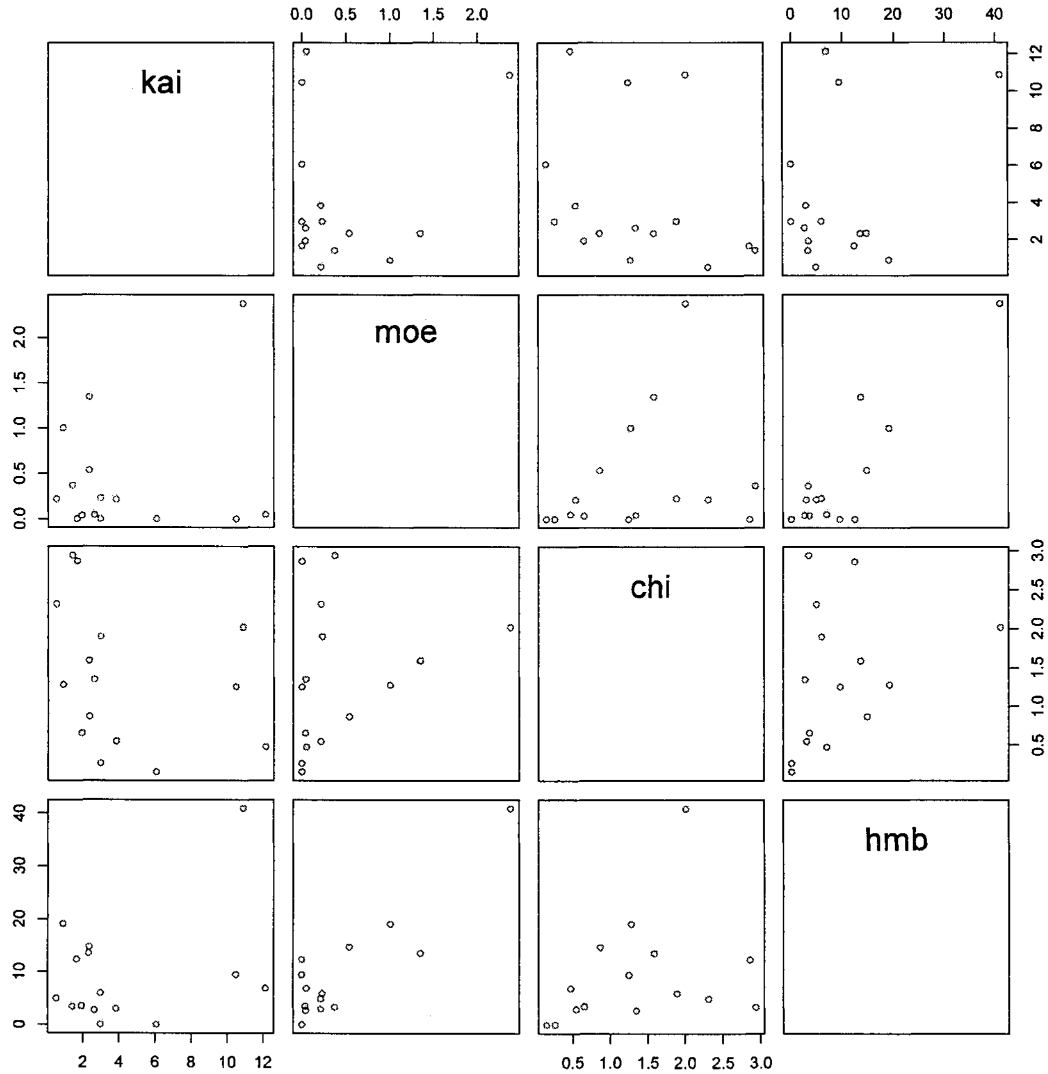

Figure A4.3: Standardised settlement for pairs of southern sites, year by year. kai. Kaikoura; moe, Moeraki; chi, Chalky Inlet; hmb, Halfmoon Bay.