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Review of red rock lobster (*Jasus edwardsii*) recruitment processes and the puerulus collector programme

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PLAIN LANGUAGE SUMMARY

The red rock lobster supports the most valuable inshore commercial fishery in New Zealand. This fishery has been managed with catch quotas in nine Quota Management Areas (QMAs), which are usually treated as independent populations or stocks.

Since at the late-1970s, the settlement rate of puerulus (early-life stage) red rock lobsters has been monitored at several sites around New Zealand. These data were once used by the stock assessments of some QMAs to inform annual recruitment (the appearance of young lobsters in the fishery), which was thought to help with making short-term predictions about future stock biomass. However, puerulus data have not been used by any of the most recent assessments for any QMA for different reasons.

This document describes a review of the puerulus monitoring data and their utility, along with climatic data, for predicting New Zealand red rock lobster recruitment.

EXECUTIVE SUMMARY

Roberts, J.O.[1]; Webber, D.N.[2] (2024). Review of red rock lobster (*Jasus edwardsii*) recruitment processes and the puerulus collector programme.

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This document reviewed rock lobster (Palinuridae) recruitment processes, the utility of the New Zealand red rock lobster (*Jasus edwardsii*) puerulus collector programme, and climatic indices to predict inter-annual recruitment estimated by stock assessment models.

A review of Australian rock lobster fisheries by this study, found that puerulus data do better at predicting fishery recruitment when: there is a consistent approach to monitoring through time; when there is a short time lag between puerulus settlement and recruitment to the fishery; and density dependent effects on post-settlement mortality/growth are minimal or are accounted for in some way. These studies also highlighted some potentially useful climatic predictors of puerulus settlement rate.

A spatial characterisation of the New Zealand puerulus collector data was undertaken. This concluded that the puerulus monitoring sites were generally well-situated relative to the main centres of fishing effort, based on recent geolocated data. However, some monitoring sites were situated closer to fishing areas in other QMAs, rather than the QMA that they are actually located in (e.g., the monitoring site at Napier (in CRA 4) is located closer to areas that are fished in CRA 3 than it is to the centre of fishing effort in CRA 4). Also, raw settlement rates were positively correlated among northern monitoring sites (in CRA 3, CRA 4, and CRA 5) and among southern sites (CRA 7 and at least part of CRA 8).

An analysis of climatic predictors of puerulus settlement found that the Southern Oscillation Index (SOI) was a potentially useful predictor for northern sites, with higher levels of puerulus settlement occurring during cooler El Niño conditions. This trend is consistent with previous research of New Zealand and Australian stocks. Wind velocity also appeared useful for predicting puerulus settlement at the northern monitoring sites and at Moeraki, with increased settlement in the year following a strong south-westerly flow.

The puerulus catch rate data were independently analysed, and revised settlement rate series were generated for each site. The resulting standardised settlement indices were not very different from those estimated previously from the same data. In addition, new combined-site settlement series were developed and compared with recruitment strength indices estimated by the CRA 3 and CRA 7&8 stock assessment models.

Puerulus settlement series and sea surface temperature (SST) were trialled as predictors of stock assessment model estimated recruitment deviates, using non-linear regression models (i.e., assessed outside of the stock assessment models). When assuming plausible time lags between settlement and recruitment, there was some agreement between puerulus series and recruitment deviates for CRA 5 and to a lesser extent CRA 4. However, these relationships disappeared when uncertainty was included both in the settlement series and the recruitment deviates. For the other stocks, there was no discernible relationship. Stronger relationships were generally obtained when assuming no time lag between settlement and recruitment to the model, which could only be plausible if stock assessment growth estimates are consistently negatively biased for smaller individuals. Also based on this analysis, there was evidence for an optimal temperature range for red rock lobster recruitment, where

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relatively warm years were associated with poorer recruitment in northern QMAs and better recruitment in southern QMAs.

Overall, for the stocks where it was determined that the puerulus settlement data appeared to be representative of regional recruitment patterns, the utility of the puerulus series for predicting recruitment was likely to have been compromised by processes impacting on stock assessment estimates of recruitment, including (but not limited to): uncertainty in or biased estimates of growth at small size, as estimated by stock assessments; and factors affecting the growth and mortality rates of pre-recruitment lobsters, including density dependence and/or climate effects.

Given these processes/uncertainties, the additional management benefit of ongoing puerulus collector monitoring is likely to be limited. Even if the puerulus settlement information were consistent with stock assessment recruitment, the main benefit (i.e., making short-term predictions) would be less beneficial to a management procedure-based regime than to an assessment/prediction paradigm. Furthermore, the requirement for short-term predictors of recruitment is currently partially alleviated by the annual rapid update assessments of New Zealand red rock lobster stocks.

Suggestions are made for improving the prediction of recruitment experienced by the fishery including the development of a pre-recruit relative abundance index series.

1. INTRODUCTION

1.1 Background

Red rock lobsters (*Jasus edwardsii*) are fished around the North and South Islands of New Zealand and the Chatham Islands and are assessed using bespoke length-based assessment models developed for each stock (Webber et al. 2023). This species has a pelagic phyllosoma larval stage, with individuals spending 18–24 months swimming and drifting in surface waters before metamorphosing into puerulus stage lobsters and settling on coastal reefs (Chiswell & Booth 2017). Based on the available growth information, it takes around 4–5 years after settlement for the lobsters to become vulnerable to commercial pot fisheries, with some regional variation (Roberts & Webber 2022). A summary of the body sizes, in terms of tail-width (TW), at which some of the key life stages of New Zealand red rock lobsters occur is given in Figure 1.

Since stock assessment models are fitted to fishery data, there is a corresponding 4–5-year period when lobsters are at-large on the reef, but for which stock assessments lack any information about their relative recruitment strength. Therefore, population projections, which are required to estimate future catch quotas, lack information about the most recent 4–5 years of post-settlement recruitment.

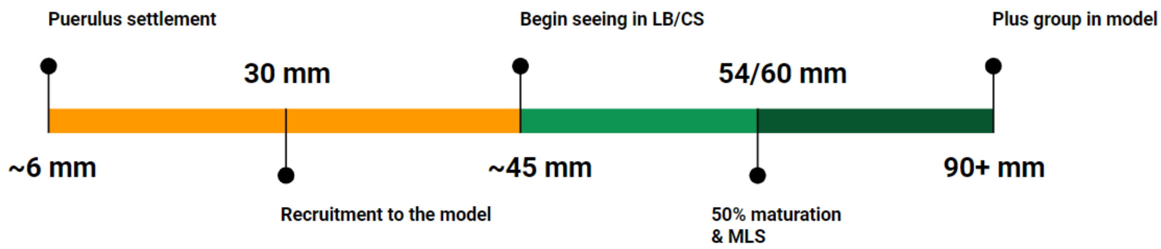

Figure 1: Approximate tail-width sizes at which New Zealand red rock lobsters reach key life stages with respect to recruitment and stock assessment. 'MLS' = minimum legal size, 'LB/CS' = logbook and catch sampling data.

For the New Zealand red rock lobster and Australian stocks of rock lobster species, e.g., Western rock lobster (*Panulirus cygnus*) and packhorse rock lobster (*Sagmariasus verreauxi*), the standard approach for informing recruitment strength (ahead of lobsters recruiting to the fishery) has been to monitor puerulus settlement rates through time. This has proven useful for predicting the future recruitment of Western rock lobster along the West Coast of Australia, where puerulus settlement series are routinely included in stock assessment models (e.g., de Lestang et al. 2016).

In New Zealand, puerulus settlement has been monitored at numerous sites around the North and South Islands since the late-1970s (Booth & Tarring 1986), with seven sites routinely monitored at the time of this review (Figure 2). The annual puerulus settlement series produced from these data (e.g., Forman et al. 2023) were included in historical stock assessment runs for CRA 3, CRA 4, and CRA 5 (e.g., Haist et al. 2015; Starr & Webber 2016; Breen et al. 2017). However, at the time of this analysis, puerulus settlement series have not been included in the most recent base case assessment model runs for any of the New Zealand red rock lobster stocks, due either to: a lack of agreement with recruitment deviates estimated by the stock assessment models, or the requirement for implausible growth rates in order to achieve acceptable agreement (Table 1). This is despite a recent effort to improve the estimation of juvenile growth and, so, to inform the plausible time lag between settlement and recruitment in the stock assessment models (Roberts & Webber 2022).

In addition, previous studies have found that climatic indices may also have potential for predicting the recruitment strength of red rock lobster and other rock lobster species (e.g., Caputi et al. 2001; Hinojosa et al. 2017). For example, puerulus settlement rates around Australia and New Zealand appear to be at least loosely related to El Niño Southern Oscillation (ENSO) phase (Hinojosa et al. 2017). Also, the most recent CRA 2 stock assessment found that sea surface temperature (SST) may have utility for predicting inter-annual recruitment strength (Rudd et al. 2023).

Previous analyses have reviewed the utility of puerulus settlement data or climate indices to predict recruitment patterns or catch-per-unit-effort (CPUE) trends experienced by New Zealand fisheries (Bentley et al. 2004; Booth & McKenzie 2009; Cockroft 2011). Taken together, these reviews have provided mixed information as to the usefulness of the collector-based puerulus data to inform recruitment patterns estimated by stock assessment models. However, the most recent review is now more than ten years old, and we now have a longer time series of information available for reviewing the utility of the puerulus and climate data to inform recruitment.

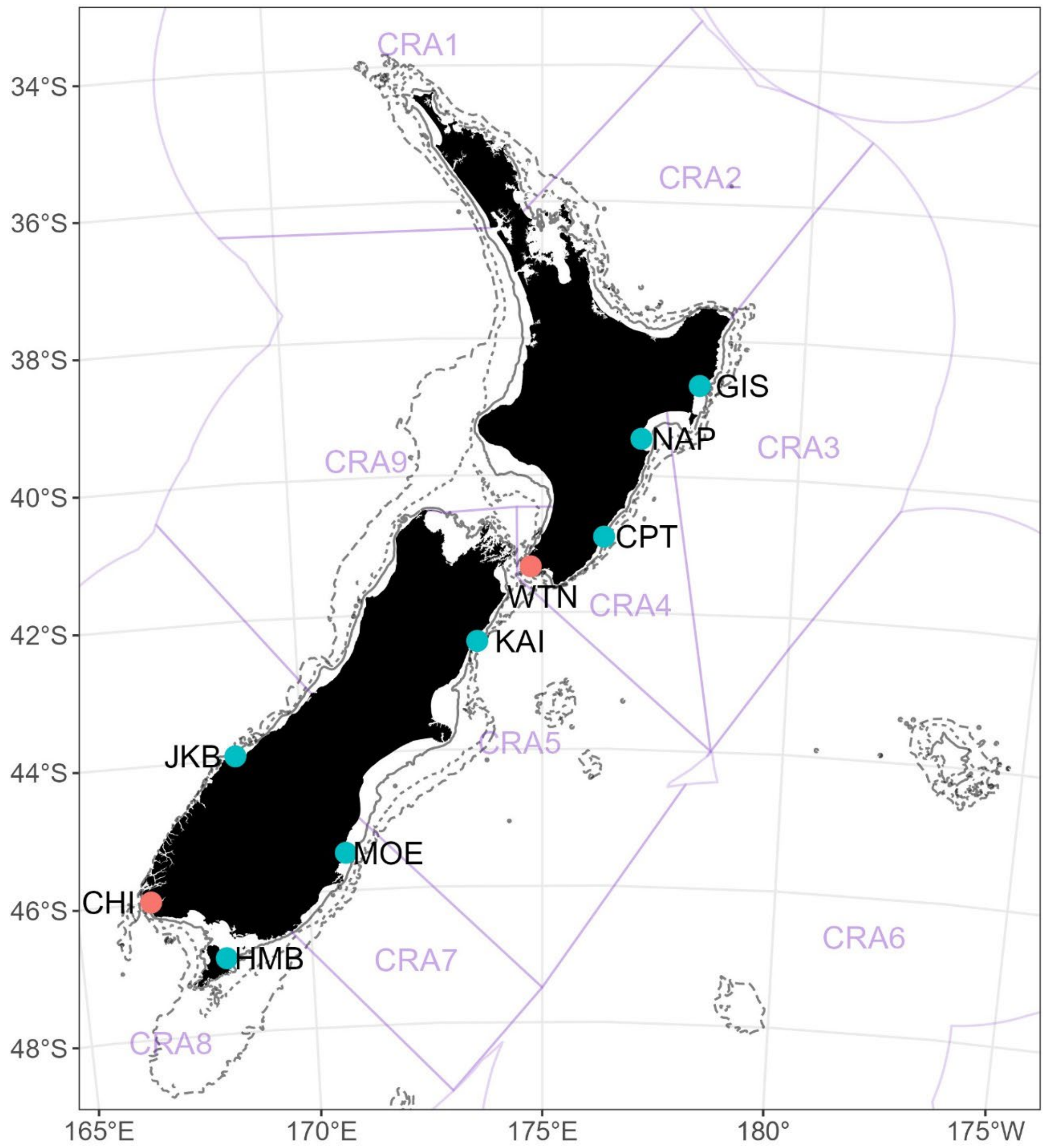

Figure 2: Map of current (blue points) and other major puerulus monitoring sites (red points) for New Zealand red rock lobster. Monitoring sites codes are: 'GIS' = Gisborne, 'NAP' = Napier, 'CPT' = Castlepoint, 'WTN' = Wellington, 'KAI' = Kaikoura, 'MOE' = Moeraki, 'HMB' = Halfmoon Bay, 'CHI' = Chalky Inlet, and 'JKB' = Jackson Bay. The purple lines represent Quota Management Area boundaries.

Table 1: Summary of puerulus randomisation trials attempted for the most recent red rock lobster assessments by stock. The randomisation trials are a method for testing the hypothesis that puerulus settlement series contain a signal for predicting the annual recruitment estimated by stock assessment models. For each assumed lag period between settlement and recruitment to the model, several hundred additional stock assessment model fits were made, using a randomised puerulus settlement vector obtained by resampling the data without replacement. A result was considered significant when the function value using the settlement series was in the lower 5% of the distribution of function values generated by the randomised series, based on a one-tailed test.

Stock assessment (year)	Results of puerulus randomization trials and RLWG decisions	Included in base run?	Source
CRA 3 (2014)	The function value was not close to the tail for the base case runs, when using any of the trialed lag periods. Simple correlations between the puerulus series and recruitment deviates were weak. Hence, puerulus was not included in the base run, though they were included in an MCMC sensitivity (with 2-year lag time from settlement to recruitment in the model).	No	Haist et al. (2015)
CRA 3 (2019)	No randomisation trials undertaken, due to shortage of time. Also justified by the findings of the 2014 assessment.	No	Webber et al. (2020)
CRA 4 (2011)	Trials indicated a strongly significant signal and the puerulus series was included in the base run with a three-year lag, noting that "the short lags that give the best relation with settlement are too short to be biologically realistic, suggesting that the model over-estimates the time lobsters take to grow from 32 mm TW to MLS."	Yes	Breen et al. (2012)
CRA 4 (2016)	The trails were skipped because of lack of time and confidence that the puerulus series contain a signal, based on the 2011 assessment. The base run was fit to puerulus with a lag of 2 years.	Yes	Breen et al. (2017)
CRA 4 (2020)	All lag options from 0–4 years were found to be significant in the puerulus randomisation trials. However, the puerulus series was only used in a sensitivity run, because using a 3-year lag time resulted in non-credible growth parameter estimates and MCMC posterior bimodality, which was overcome by modifying the growth parameter inputs. However, the RLWG agreed that model behaviour when this data series was included was less satisfactory and, given small differences in model fits and parameter estimates, the base case run did not include the puerulus series.	No	Rudd et al. (2021)
CRA 5 (2010)	The results of the randomisation trials indicated a strong signal in the puerulus settlement series when assuming no lag time.	Yes	Haist et al. (2011)
CRA 5 (2015)	Trials found that the puerulus series contained a coherent signal when using a 1-year lag time.	Yes	Starr & Webber (2016)
CRA 5 (2020)	Trials identified lag times of 0–2 years as significant, consistent with the puerulus data containing a signal, but "failed to accept the three-year lag option which was determined from external juvenile growth modelling to be the most likely lag period between settlement and model recruitment." The puerulus series did not match model estimates of peak recruitment estimated by the stock assessment model, when assuming a 3-year lag, informed by the juvenile growth information. The puerulus series was included in a sensitivity run.	No	Webber et al. (2021)
CRA 7&8 (2012)	Trials determined that the puerulus series contained a signal, particularly with no lag, but there was a lack of predictive power due to a lack of precision in the series, and the base case did not include puerulus.	No	Haist et al. (2013)
CRA 7&8 (2015)	No randomisation trials were attempted. Based on the outcome of the 2012 assessment, there was no attempt to use the puerulus data in this assessment.	No	Haist et al. (2016)
CRA 7&8 (2021)	No randomisation trials were attempted, because the model would not converge when attempting to fit to the puerulus series. Ultimately the puerulus series was "discarded because there were too many inconsistencies between the series and recruitment to the model…".	No	Webber et al. (2022)

1.2 Objectives of this analysis

The overall objective of this project was to review information available to inform the estimation of annual recruitment deviates of New Zealand red rock lobster stock assessment models. The specific science objectives were:

1. to explore potential climatic covariates that could be used to explain annual recruitment strengths estimated by recent stock assessments for each of the New Zealand red rock lobster stocks and to inform short term projections provided by these models; and
2. to review the utility of settlement series provided by the puerulus collector programme for stock assessment purposes.

This document summarises the work under these science objectives, which was organised under the key research activities, summarised below.

- A literature review of predictors of recruitment to rock lobster stocks (e.g., Australian species/stocks) (Section 2).
- A spatial characterisation and reanalysis of New Zealand puerulus settlement data (Sections 3 and 4).
- An exploration of potential climate predictors of puerulus settlement rate (Section 5).
- Using the above, explore predictors of stock assessment-based recruitment deviates (Section 6).
- Trial the inclusion of density dependent mortality of juveniles in a stock assessment model (Section 7).

2. REVIEW OF AUSTRALIAN ROCK LOBSTER PUERULUS COLLECTOR PROGRAMMES AND PREDICTORS OF RECRUITMENT

The purpose of this section was to:

- provide a brief overview of Australian puerulus monitoring programmes,
- review predictors of inter-annual recruitment strength of rock lobsters as experienced by fisheries,
- identify the conditions under which these predictors are likely/unlikely to be reliable, and
- identify plausible climatic drivers of inter-annual recruitment strength.

2.1 Western rock lobster (*Panulirus cygnus*)

The Australian western rock lobster fishery targets *Panulirus cygnus* along the West Coast of Australia and is the largest Australian commercial fishery in terms of economic value. This pot-based fishery targets migratory immature (‘white phase’) lobsters (approximately three- or four-years post-settlement) as well as mature lobsters, which are distributed in deeper offshore reef habitat (summarised by de Lestang et al. 2016).

Monitoring of puerulus settlement rates commenced in 1968 using collectors that mimic seaweed habitat suspended from a float, with around five collectors at each of nine monitoring sites spaced out along the West Coast. Settlement at another eight sites has been monitored in the past. Monthly sampling occurs during the full moon period, approximately two weeks after the peak settlement period, which occurs during the new moon. A ‘R Shiny’ application has been developed to facilitate the exploration of spatiotemporal patterns based on the raw puerulus catch rate data (Department of Primary Industries and Regional Development 2024).

To help with consistency, only data from the longest-deployed collectors were used to inform stock assessment (de Lestang et al. 2016). The settlement series was calculated as the annual average of monthly counts for each site or was standardised when aggregating across sites (de Lestang et al. 2016). The stock assessment model was fitted to the puerulus settlement series for each stock area. Interannual variability in the abundance of fishery recruits appeared to be much less than seen in puerulus settlement rates and this was thought to be due to density dependent mortality occurring between settlement and recruitment (Caputi et al. 1995). Thus, the puerulus settlement series were converted to ‘observed recruitment variations’ using an area-specific density-dependence relationship – a power function fitted between annual puerulus series and catches 3–4 years later, consistent with the period from settlement to the fishery on targeting juvenile lobsters (de Lestang et al. 2016).

Puerulus settlement rates were determined to be positively correlated with the strength of the Leeuwin Current and westerly winds (Caputi et al. 2001). However, this relationship appears to have broken down since around 2007, apparently driven by warming waters affecting the timing of the spawning season (de Lestang et al. 2016).

2.2 Southern rock lobster (*Jasus edwardsii*)

The Australian southern rock lobster fishery targets *Jasus edwardsii* around the coasts of South Australia, Victoria, and Tasmania. There has been monthly monitoring of puerulus settlement rate using Booth & Tarring (1986) style collectors (the type used in New Zealand for the same species) since the 1970s, with monitoring at around 15 sites. There is a comparable number of monitoring sites to that of New Zealand puerulus monitoring, with a similar spatial dispersion and longevity of data collection (Linnane & Walsh 2011).

The annual puerulus series was calculated as the annual (unstandardised) average of monthly puerulus catch data, not accounting for density dependence (McGarvey et al. 2024). In addition, an annual pre-recruit abundance index series is calculated from the outputs of a fixed-site survey (Linnane et al. 2020).

The same stock assessment model structure is used to separately assesses different zones of the southern rock lobster fishery, which is divided into South Australia (Northern & Southern Zones), Victoria (Western & Eastern) and Tasmania. For the Northern Zone of South Australia, McGarvey et al. (2024) identified a three-year lagged relationship between puerulus settlement and fishery recruitment (where the minimum legal size is 105 mm carapace length). But for the Southern Zone, there is no apparent relationship. It is suspected that the relatively high density of lobsters here (evident from the CPUE data) causes density dependent mortality, retarded growth, and a longer lag period to recruitment – confounding the relationship between puerulus settlement rate and recruitment to the fishery (A. Linnane pers. comm.).

In Tasmania, puerulus monitoring has been done since 1990 at three main sites. Annual puerulus settlement series were calculated using a negative binomial regression model fitted to the data from all months (IMAS 2024). A tool has been developed for exploring the resulting annual puerulus series (see IMAS 2024). However, the link between puerulus settlement and subsequent recruitment to the fishery was found to be weak and this was considered to be due to a range of poorly-understood factors affecting post-settlement survival rates. The puerulus monitoring program in Tasmania was suspended indefinitely in 2020 following an assessment of the cost-effectiveness of this programme (IMAS 2024).

An analysis of climatic predictors of puerulus settlement rate of *J. edwardsii* in different regions of Australia and New Zealand was undertaken by Hinojosa et al. (2017). This identified ENSO phase as being the best predictor of settlement rates, although with opposing relationships comparing the northern regions (higher settlement rate in years with higher rainfall, storms in spring and El Niño conditions) and southern regions (higher settlement during La Niña conditions).

2.3 Eastern rock lobster (*Sagmariasus verreauxi*)

The Australian eastern rock lobster fishery targets *Sagmariasus verreauxi* (known as packhorse rock lobster in New Zealand) centred on coast of New South Wales (NSW). Information on the monitoring of recruitment to this fishery was obtained from NSW Total Allowable Fishing Committee (2019) and from personal communication with Geoffrey Liggins (NSW Department of Primary Industries).

Since 1995–96, Puerulus settlement data have been collected by seaweed-type collectors (comparable to those used for Western rock lobster monitoring) set at the surface in three groups of collectors at each of four locations along the coast of NSW. Sampling occurs during the first quarter of each lunar month, during the peak settlement period from August to February. Puerulus settlement has increased since the mid-2000s, coincident with increasing recruitment to the fishery and spawning biomass.

In addition, fishery information on pre-recruit abundance in the fishery is collected from sub-legal and legal-size lobsters caught in shallow waters. This information is combined with the puerulus settlement series with an assumed two-year time lag between settlement and the sub-legal catch rate series, and a three-year time lag to the legal juvenile catch rate series. The three series (puerulus, sub-legal juveniles, and legal juveniles) provide an independent check on the results of stock assessment modelling rather than being fitted to by stock assessments.

2.4 Summary of processes impacting on recruitment

Based on Australian experiences with puerulus monitoring and the usage of these data in stock assessments, the resulting puerulus settlement series appear to do best at predicting fishery recruitment when:

- there is a consistent approach to monitoring through time;
- there is a relatively short time lag time between settlement and recruitment to the fishery (e.g., Western rock lobster, Northern Zone southern rock lobster, and Eastern rock lobster); and
- density dependent effects on post-settlement mortality/growth are minimal (e.g., northern zone southern rock lobster) or are accounted for by stock assessments (such as for western rock lobster).

Potential climatic predictors include ENSO indices, and oceanographic indices, though note the breakdown of apparent relationships in West Australia.

Informed by this review, a schematic diagram summarising the processes potentially impacting on the estimation of recruitment by stock assessment models is shown in Figure 3.

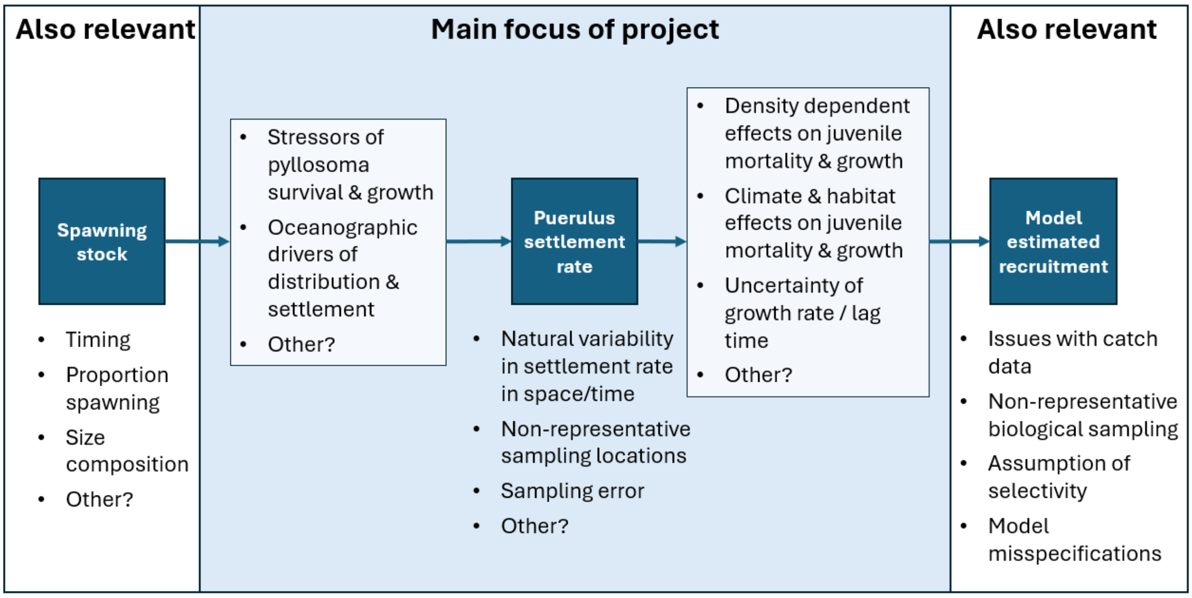

Figure 3: Schematic diagram of processes potentially impacting on stock assessment model estimates of recruitment.

3. SPATIAL CHARACTERISATION OF NEW ZEALAND PUERULUS MONITORING DATA

The purpose of this section was to:

- compare the locations of puerulus monitoring sites with the spatial distribution of commercial fishing effort;
- characterise puerulus settlement monitoring through time; and
- assess the spatial correspondence of puerulus settlement rate data comparing monitoring sites.

3.1 Development of the puerulus collector programme

Crevice collectors have been used to explore broad patterns of puerulus settlement rate around New Zealand since 1979. These collectors consist of plywood sheets, each 38 cm square and 0.9 cm thick, held in a galvanised steel frame, creating seven wedge-shaped crevices, each 2.5 cm high at their widest point (Figure A.1).

The collectors are located at puerulus monitoring **sites**, which are located 150–400 km distant from each other (Figure 2). Site selection historically focused on achieving proximity to the main fishing areas, although some sites were in areas with relatively small fisheries, since it was recognised that temporal settlement patterns vary around the coast of New Zealand. Seven sites are currently monitored (Forman et al. 2023), although many more were trialled in the past and abandoned due to logistical issues, low puerulus catch rates, or over concerns that the resulting puerulus settlement rates were not representative of regional patterns.

At each site, there are typically around 3–5 collector **groups** (ranging from 1–8 groups), along coastlines spanning up to 50 km, although much less than this at some sites. At a given monitoring site, collector groups may be situated in different coastal habitat types across a range of exposure levels, including groups located in harbours or in more open coastal habitat. The placement of collector groups typically proceeded on an experimental basis, aiming to identify locations that were effective at achieving a good catch rate without puerulii being washed out of the collectors by stormy sea conditions, with access being another major consideration. It could take around two years to settle on optimal group locations within a monitoring site (Booth et al. 2007).

Each group comprises around 5 **individual collectors** (ranging from 3–9 collectors), spaced 2–3 m apart. Different deployment types have been used in the past, including: shore crevice collectors, which are attached to a concrete weight set on the seafloor; suspended crevice collectors, suspended in the water column by a rope or attached directly to a buoy; and 'closing crevice collectors', which are fixed to a steel base with a mesh surrounding the collector on hauling to prevent the loss of puerulii (summarised by Booth et al. 2007). Closing crevice collectors are less affected by exposure to sea conditions which increases the options for group placement. Shore crevice collectors are typically placed just below the extreme spring tide low water mark, whereas the other collector types may be set in deeper water, with settlement levels generally peaking at around 10–12 m depth (Booth et al. 2007). Individual collectors have historically been treated as independent replicates (Forman et al. 2023), although the extent of overlapping coverage provided by adjacent collectors with each other has not been explored and is unknown.

The evolution of the New Zealand puerulus monitoring program for red rock lobsters is described by Booth et al. (2007) and can be divided into different phases. The **first phase** (from 1979 to 1988) involved experimentation with the design of collectors, gaining an understanding of temporal and spatial settlement dynamics, and a trial-and-error approach to the identification of prime monitoring sites. During this period, it was learnt that the highest catches were on sheltered shores directly adjacent to oceanic waters, that collector saturation by puerulii was unlikely to occur, and that counts were likely to be representative of settlement over the previous two weeks. Towards the end of this phase, it was determined that there were consistent temporal (seasonal and inter-annual) puerulus settlement patterns at adjacent monitoring sites, which were considered representative of regional patterns.

During the **second phase** (from 1989 to 2006), encouraged by the confirmation of regional settlement patterns, the number of groups at each site was expanded with the aim of increasing the precision of the inter-annual settlement series estimated from these data. During this phase it was determined that at least three groups of at least three collectors was optimal for a given monitoring site.

During the **third phase** (2007-current), puerulus settlement series developed using the puerulus settlement data were included in the base case stock assessment runs for some stocks (CRA 4, and CRA 5) (Haist et al. 2011; Breen et al. 2012; Table 1). However, there was increasingly conflicting evidence of the utility of puerulus monitoring for predicting inter-annual recruitment rates given rates independently estimated from fishery data, depending on which approach was used: i.e., poorer agreement when using stock assessment estimated recruitment deviates, and better agreement when comparing with fishery CPUE series (Booth & McKenzie 2009). At the beginning of this phase, it was determined that there would only be a minor loss of precision in standardised settlement series when pruning out non-core collector groups, which led to the cessation of monitoring at several collector groups (Booth et al. 2007). Also, there was a cessation of sampling at the Wellington monitoring site, due to concerns about the local oceanographic features affecting the representativeness of puerulus settlement patterns relative to the main CRA 4 fishing grounds (Booth et al. 2007).

3.2 Spatial distribution of monitoring relative to fishing effort

This sub-section assesses the spatial proximity of puerulus monitoring sites relative to locations of elevated fishing intensity ('centres of fishing effort'). The aim of this is to explore the basis for the hypothesis that potential disagreement between the puerulus data and fishery-based recruitment information could be caused by spatial dislocation (in conjunction with different settlement patterns in the respective areas).

Nearly all the catch and effort data collected under the electronic reporting system (ERS), the primary method of data collection since the spring/summer period of the 2019 fishing year[3], are geolocated. Catch and effort data collected on paper forms before the advent of the ERS did not contain geolocated data (Starr 2024). This means that a relatively comprehensive recent summary of the spatial distribution of red rock lobster potting effort around New Zealand can be obtained from these data. The commercial potting ERS data were extracted from the CRACE database (Bentley et al. 2005), which was based on an extract obtained in November 2023 from the *edw* database (rep log 15425). This extract included records collected up until the end of the autumn/winter period of the 2023 fishing year. In using these data to assess spatial fishing effort patterns, it was assumed that the distribution of effort from the ERS data was approximately unchanged from previous years, although some long-term shifts in the distribution of effort are known to have occurred between statistical areas in some QMAs (Starr 2024).

The geolocated ERS effort data were summarised by fishing year and statistical area (Table A.2). The ERS data were filtered to remove fishing events with CRACE error codes with a value greater than 1 associated with: the attribution of statistical area, or the number of pot lifts per fishing event (see Bentley et al 2005 for a description of the error codes). The total number of pot lifts was then calculated by fishing year and 20 km grid cell. The aggregated effort data were then plotted spatially, displaying square root transformed pot lifts, so that the relative intensity of effort in each grid cell could be visualised more easily (Figure A.2 to Figure A.4). Based on these plots:

- The Gisborne puerulus monitoring site (‘GIS’) is located close to fishing effort in CRA 3 (Statistical Areas 909 to 911);
- The Napier site (‘NAP’) is located closer to fishing in CRA 3 (close to the Mahia Peninsula in Statistical Area 911) than it is to the main centre of fishing effort in CRA 4, which is located in Statistical Area 914, some way to the south of Napier;
- The Castlepoint site (‘CPT’) is at the northern end of the main fishing area in CRA 4. The main centre of fishing in CRA 4 is near to Cape Palliser, which is located closer to the Wellington monitoring site (‘WTN’) (which is no longer monitored) than it is to Castlepoint;
- The Kaikoura site (‘KAI’) is located on one of the two main centres of fishing effort in CRA 5, in Statistical Area 917. The other centre of fishing is at the bottom of the same statistical area;
- The Moeraki (‘MOE’) and Chalky Inlet (‘CHI’) sites (the latter of which is no longer monitored) are located close to the main centres of fishing effort in CRA 7 (MOE) and CRA 8 (CHI).
- The Halfmoon Bay (‘HMB’) site on Stewart Island and Jackson Bay (‘JKB’) site at the northern end of Fiordland (both located inside CRA 8) have minimal fishing effort around them.

This summary guided the development of puerulus settlement series in the re-analysis described in Section 4 and the analysis of predictors of stock assessment recruitment series in Section 6.

3.3 Spatiotemporal characterisation of puerulus data

A spatiotemporal characterisation of the puerulus monitoring data was undertaken. The purposes of this data characterisation were to:

- inform model structures that might be considered as part of a re-analysis of the puerulus catch rate data (Section 3); and

[3] Throughout this document, fishing year (which runs from 1 April to 31 Marh) is referred to by the start year (e.g., ‘2019’ represents the 2019–20 fishing year).

- identify any potential discontinuities in monitoring that might cause issues with the standardisation of these data.

The puerulus data were extracted from the *rocklob* database (rep log 15459). This extract included puerulus monitoring data from crevice collectors up until September 2023 (Table A.1). These data were summarised in terms of:

- the monthly sampling effort by calendar year and monitoring site (including sites that are not currently monitored; plotted spatially in Figure A.5);
- the mean (raw) catch rate for individual collectors by calendar year (for collector-year combinations with at least six months of sampling);
- the degree of correlation comparing pairs of individual collectors within groups (for collector-year combinations with at least six months of sampling); and
- the degree of correlation comparing pairs of collector groups.

Monthly sampling effort by collector group and fishing year

A summary of the monthly sampling effort by year and fishing group is given for puerulus monitoring sites on the North and South Islands, respectively (Figure A.6, Figure A.7). These plots show that the period of sampling was relatively short outside of the main monitoring sites. Also, the number of monthly samples per year was generally lower at Moeraki, Halfmoon Bay, Chalky Inlet, and Jackson Bay, compared with Gisborne, Napier, Castlepoint, and Kaikoura (comparing Figure A.6 and Figure A.7). At the Gisborne site, there was a very short period of overlap in the monitoring of the earlier (before 1990) groups (e.g., 'GIS005') with the main collector groups that were monitored after 1990 ('GIS001', 'GIS002', 'GIS003', and 'GIS004') (Figure 4). Likewise, at Moeraki, there was a very brief temporal overlap in 2017 for monitoring of the most recently monitored group ('MOE008') and the previously monitored groups (e.g., 'MOE007') (Figure 5). In both cases, it is likely that this limited temporal overlap will be detrimental to the estimation of relative catch rates before and after the switch in monitoring sites.

Figure 4: The number of months of puerulus sampling by collector group and calendar year, for Gisborne Coast collector groups.

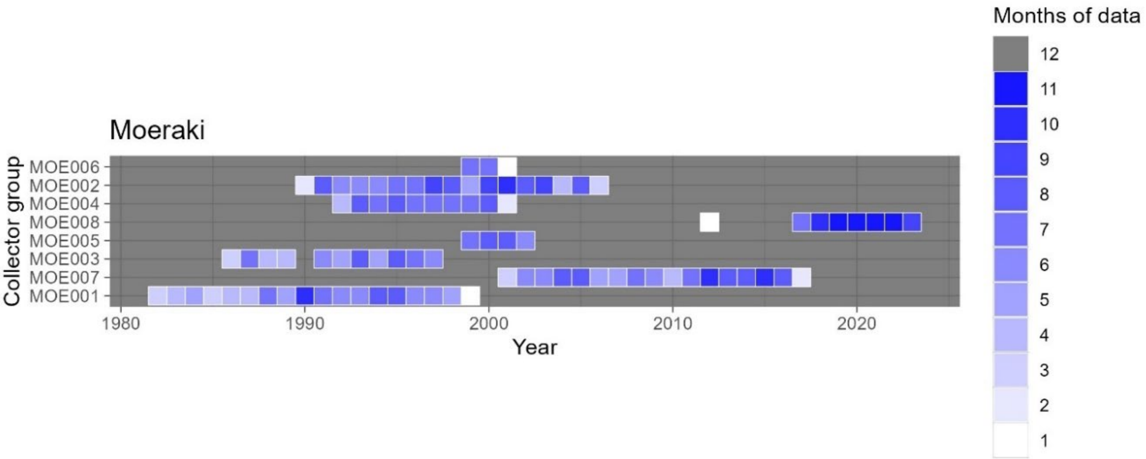

Figure 5: The number of months of puerulus sampling by collector group and calendar year, for Moeraki collector groups.

<u>Annual catch rate by individual collector and fishing year</u>

The annual mean catch rate of individual collectors was summarised by fishing year, for collector-year combinations with at least six months of sampling. The resulting annual average catch rates were plotted separately for each respective collector site (Figure A.8 to Figure A.15). Based on these plots:

- there was generally good agreement in the catch rate of individual collectors within a group (e.g., comparing 'GIS001_01', 'GIS001_02', etc in Figure A.8);
- there were major differences in catch rate when comparing different collector groups within a site (e.g., comparing e.g., 'GIS001' and 'GIS002' in Figure A.8); and
- despite contrasting catch rates of different groups within a site, the relative temporal pattern in puerulus catch rates by year were similar across groups within a site (e.g., comparing 'KAI001', 'KAI002', 'KAI003', 'KAI004', and 'KAI005' in Figure A.12).

<u>Correlative analysis of catch rate comparing adjacent collector groups</u>

Previous analyses (e.g., by Booth et al. 2007) identified a positive correlation between the monthly puerulus catch rate data of adjacent monitoring sites (e.g., comparing Gisborne and Napier, or Castlepoint and Kaikoura). This is consistent with the puerulus settlement rate data at a given monitoring site being representative of regional patterns. The degree of spatial correspondence in the temporal settlement patterns of adjacent sites was re-analysed here.

In the first step, the catch rates of **individual collectors** were compared, using a subsample of collectors with at least 10 years of at least 6 monthly samples. The mean annual count values were calculated per collector, which were then normalised by rescaling to the mean puerulus catch for each collector. The Pearson product moment correlation coefficient (*r*) was then calculated for the normalised mean annual counts for each pair of collectors. Based on this analysis, nearly all of the annual catch rates of individual collector pairings within each respective monitoring site were positively correlated, although the estimated coefficients were often less than 0.5 (Figure A.16 to Figure A.22).

In the next step, the catch rates of **collector groups** were compared. The puerulus catches were averaged across individual collectors within each group (e.g., 'GIS001', 'GIS002', etc) and the annual average catch was calculated across all months within each year. The Pearson product moment correlation coefficient (*r*) was then calculated for each pairing of the normalised mean annual counts for each collector group. Based on this analysis: nearly all the catch rates of collector group pairs within each respective site were positively correlated (Figure A.23). Inter-annual catch rate patterns were also positively correlated comparing adjacent monitoring sites, e.g., Gisborne, Napier, Castlepoint, and Kaikoura were all broadly positively correlated. Also, Moeraki, Halfmoon Bay, and Chalky Inlet were generally positively correlated. The main outliers were Wellington and Jackson Bay, where the raw annual mean catch rate patterns were different to the other collector sites. A clustering analysis provided a slightly different grouping of the collector sites with three main clusters: one that was mostly comprised of groups from Gisborne, Castlepoint, and Kaikoura monitoring sites, another cluster with just Jackson Bay, and a third cluster primarily comprised of groups at Halfmoon Bay, Wellington and Chalky Inlet. The Napier and Moeraki collector groups were spread across the two largest clusters (Figure A.24).

Summary of spatiotemporal characterisation

There were generally consistent and positively correlated temporal patterns in puerulus settlement rates across collector groups across regions of New Zealand, for example:

- across monitoring sites in CRA 3 and CRA 4 (comparing 'GIS', 'NAP', and 'CPT'),
- across some but not all sites in CRA 4 and CRA 5 (comparing 'CPT', 'KAI', but not 'WTN'),
- across some but not all sites in CRA 7&8 (comparing 'MOE', 'HMB', 'CHI', but not 'JKB').

This suggests that puerulus catch rate at monitoring sites should be representative of regional settlement rates, although with some caveats. There was almost no agreement in the temporal puerulus settlement patterns comparing Jackson Bay and the other monitoring sites. Sampling error is likely to be exacerbated for collector sites with generally low puerulus catch rate – as is the case for most of the CRA 7&8 monitoring sites (e.g., Moeraki, Halfmoon Bay, and Chalky Inlet). Furthermore, there are at least some temporal gaps in the monthly monitoring of all sites. A comparison of model-based series of annual puerulus settlement (see Section 4) will be more robust to temporal gaps in puerulus monitoring and would account for seasonality in settlement rate when comparing settlement patterns at different sites.

4. RE-ANALYSIS OF PUERULUS SETTLEMENT DATA

The purpose of the re-analysis of the puerulus catch rate data in this section was to:

- explore alternative model structures for generating standardised catch rate series;
- explore different spatial (site-based) groupings; and
- generate puerulus settlement series that can be used to predict stock assessment recruitment deviates (Section 6).

4.1 Methods

The same puerulus data described in the previous section were used to independently analyse the puerulus catch rate data. This analysis was restricted to monitoring sites subject to current active monitoring, with the addition of Chalky Inlet (Figure 2), which was monitored consistently in the past and was located close to the centre of fishing in the Fiordland region of CRA 8 (Figure A.4). Consistent with previous puerulus catch rate analyses (e.g., Forman et al. 2023), only collector groups with at least 36 monthly measurements across all collectors were retained by the analysis. However, there were some deviations from the approach of Forman et al. (2023):

- calendar year was used instead of using fishing year (as recommended by Jeff Forman and Andy McKenzie, NIWA), since the fishing year cut-off at 1 April can cut the 'year' midway through the peak settlement season; and

- instead of only using peak settlement months (designed to minimise zero count data), all months with data were used, since the distributional assumptions were met while using all months of data (see below).

All models for this analysis were developed using a Bayesian hierarchical regression model fitted to puerulus count data using *brms* in *R* (Bürkner 2017; R Core Team 2024).

An initial exploration of model structures and assumed statistical error distributions was done using the puerulus catch rate data from the eight monitoring sites included in this analysis. In the first exploratory step, model fits to the puerulus catch rate data were compared when using alternative statistical error distributions. In the next exploratory step, alternative model structures were compared while using the optimal statistical error distribution. The exploratory models (and for all final runs) were compared using the LOO IC, the expected log predictive density (ELPD) difference (δ-ELPD), and the standard error of this difference (SE δ-ELPD) – where models were differentiated when δ-ELPD was at least four-times greater than SE δ-ELPD (based on the recommendation of A. Vehtari, Aalto SCI Computer Science). The default *brms* priors were used for all estimated model parameters.

The degree of correspondence in the settlement rates of different monitoring sites was assessed by calculating the Pearson product moment correlation coefficient (*r*), comparing the annual predictions of different site pairings. Hierarchical clustering of these predictions was done using the '*heatmap.2*' function in the *gplots R* package (Warnes et al. 2024).

4.2 Results

The model structures trialled by the initial exploration were informed by the data characterisation described in Section 3. All model terms were offered as random effects, which resulted in improved mixing and faster model run times.

For the exploration of statistical error structures, the model structure was as follows:

catch ~
(1 | site) +
(1 | site:year) +
(1 | site:month) +
(1 | site:group) +
(1 | site:group:collector_id)

where 'catch' is the number of puerulus caught per observation, 'site' is the monitoring site, and 'year', 'month', and 'group' were nested within the site random effect. In addition, 'collector_id' (individual collectors) was nested within the site:group random effect. The alternative error distributions trialled included negative binomial and Poission, with or without zero-inflation, i.e., which are all appropriate for count data.

Based on LOO IC, the negative binomial models were superior to the Poisson models (Table B.1). The δ-ELPD comparing the best negative binomial model and the best Poisson model was around twenty-times the SE δ-ELPD, considerably better than the four-fold threshold used here to differentiate between models. Also based on δ-ELPD and SE δ-ELPD, there was no advantage gained by zero-inflation. The negative binomial error assumption (without zero-inflation) (*fit_error_nb*) was used for all subsequent model runs. The trace plots for *fit_error_nb* did not indicate any issues with model convergence and the posterior predictive check plot indicated that the distributional assumption was appropriate for these data (Figure B.1, Figure B.2). There was a slight underestimation of events where one puerulus was counted, but a good fit overall across all monitoring sites (Figure B.2).

In the next round of model exploration, there was a comparison of model structures. The most complex model structure trialled was the model used for the exploration of error distributions, except that there was a group:month interaction term instead of a site:month term. This allowed the monthly distribution of catch rate to vary by groups within each site.

catch ~
(1 | site) +
(1 | site:year) +
(1 | group:month) **+**
(1 | site:group) +
(1 | site:group:collector_id)

The most complex model structure (*fit5*) was the best in terms of LOO IC (Table B.2). This model allowed the month effect to vary by collector group and was marginally better than the model allowing the month effect to vary by site (*fit4*), based on δ-ELPD and SE δ-ELPD. The trace plots and posterior predictive check plot for model run *fit5* did not indicate any issues with model convergence or the distributional assumption (Figure B.3, Figure B.4). The month effect by collector group (Figure B.5) revealed some differences in seasonal patterns comparing collector groups within some sites, e.g., the seasonality of catch rate at 'NAP002' (in the 'NAP' group) was more like that of the 'CPT' or 'KAI' monitoring sites than of the other 'NAP' groups.

The effect of model structure on the predicted year effect were compared for all models (Table B.2). the addition of the site:group term had the greatest effect on the model predictions (comparing *fit3* and *fit2*) and the addition of subsequent terms had a relatively minor effect (Figure B.6 and Figure B.7).

In the next phase, the optimal model from the previous phase (*fit5*) was compared with a model using the same structure, except defining year as fishing year instead of calendar year (*fit6*). Because using calendar year (*fit5*) resulted in a slight improvement in model fit over using fishing year, the calendar year model was retained for all subsequent model runs (Table B.3).

Because calendar year was specified as a random effect in *fit5*, the resulting model predictions will be close to the average value when there is little data for a given site-year combination. Consequently, it was decided to refit the *fit5* model structure separately to the northern and southern groupings of collector sites because the temporal patterns in puerulus settlement were correlated within the northern and southern groupings of monitoring sites (Section 3.3):

- northern sites (GIS, NAP, CPT, KAI) (model run *fit5_north*); and
- southern sites (MOE, HMB, CHI, JKB) (model run *fit5_south*).

The trace plots and posterior predictive check plots for these runs did not indicate any issues with model convergence or with the assumed distributional assumption (Figure B.8 to Figure B.11). Note the large proportion of observations with no puerulus observed in the southern sites compared to the northern sites (comparing Figure B.9 and Figure B.11).

These models were used to generate the final model predictions by calendar year for the respective monitoring sites (Figure 6 and Figure 8), which were log-transformed for the purposes of comparing to the recruitment deviates estimated by the respective stock assessment models (Figure B.12). Note the comparatively wide uncertainty in predictions for years with little or no data (e.g., Jackson Bay for most of the 1990s).

The final predictions by monitoring site and year were very similar to the series produced by Forman et al. (2023), despite the current analysis using calendar year (instead of fishing year), differences in model structure (e.g., allowing the monthly effect to vary by collector group instead of site), a different modelling approach (e.g., Bayesian instead of frequentist and the use of random effects), and some differences in the data included in the models (Figure B.13). Probably the main exception to this conclusion was for the Moeraki series ('MOE' in Figure B.13), with this analysis predicting relatively low settlement in recent years compared with the index series produced by Forman et al. (2023). The model predictions for Moeraki had a very similar interannual pattern compared with raw (unstandardised) catch rates of mesh collectors located at Moeraki Wharf (Lucy Coyle, University of Otago, unpublished data) (Figure B.14).

A correlation matrix was produced comparing the annual standardised settlement series by collector site (Figure 7). Compared with the comparison of unstandardised monthly data by collector site, the standardised series for Kaikoura ('KAI') and Napier ('NAP') were more similar once seasonality in catch rate had been included in the model. Kaikoura and Castlepoint ('CPT') were more similar based on raw monthly catch rate data, which was primarily driven by similar seasonality in catch rates (Figure B.5), rather than by inter-annual patterns. The clustering analysis separated out Gisborne, Napier, and Kaikoura into one group based on the standardised annual series and put the remaining sites (Castlepoint, Moeraki, Halfmoon Bay, Chalky Inlet, and Jackson Bay) in another group (Figure 7). Thus, Castlepoint was a geographical outlier, since this is located on the North Island, but had interannual puerulus settlement patterns that were overall more like those observed at the southern monitoring sites.

Informed by the spatial characterisation of the puerulus monitoring data, puerulus series were produced across the following groupings of monitoring sites, using the *fit5* model structure:

- Gisborne/Napier ('GIS_NAP') – for relating to recruitment patterns estimated by the CRA 3 assessment model (model run *fit5_gisnap*); and
- Moeraki/Halfmoon Bay/Chalky Inlet ('MOE_HMB_CHI') – for relating to recruitment estimated by the CRA 7&8 assessment (model run *fit5_moehmbchi*). This model was used to minimise the effects of sampling error, which is likely to be exacerbated by the relatively low catch rates of puerulus at these monitoring sites.

The trace plots and posterior predictive check plots for these runs are shown in Figure B.15 to Figure B.18. The model predictions by year were similar to those of the predictions for the respective sites in each grouping (comparing Figure 6 with Figure 8). As with the site-specific series, the annual predictions were log-transformed for the purpose of relating to stock assessment model recruitment deviates (Figure B.19).

The final puerulus settlement series for relating to stock assessment recruitment deviates are tabulated in Table B.4 to Table B.13.

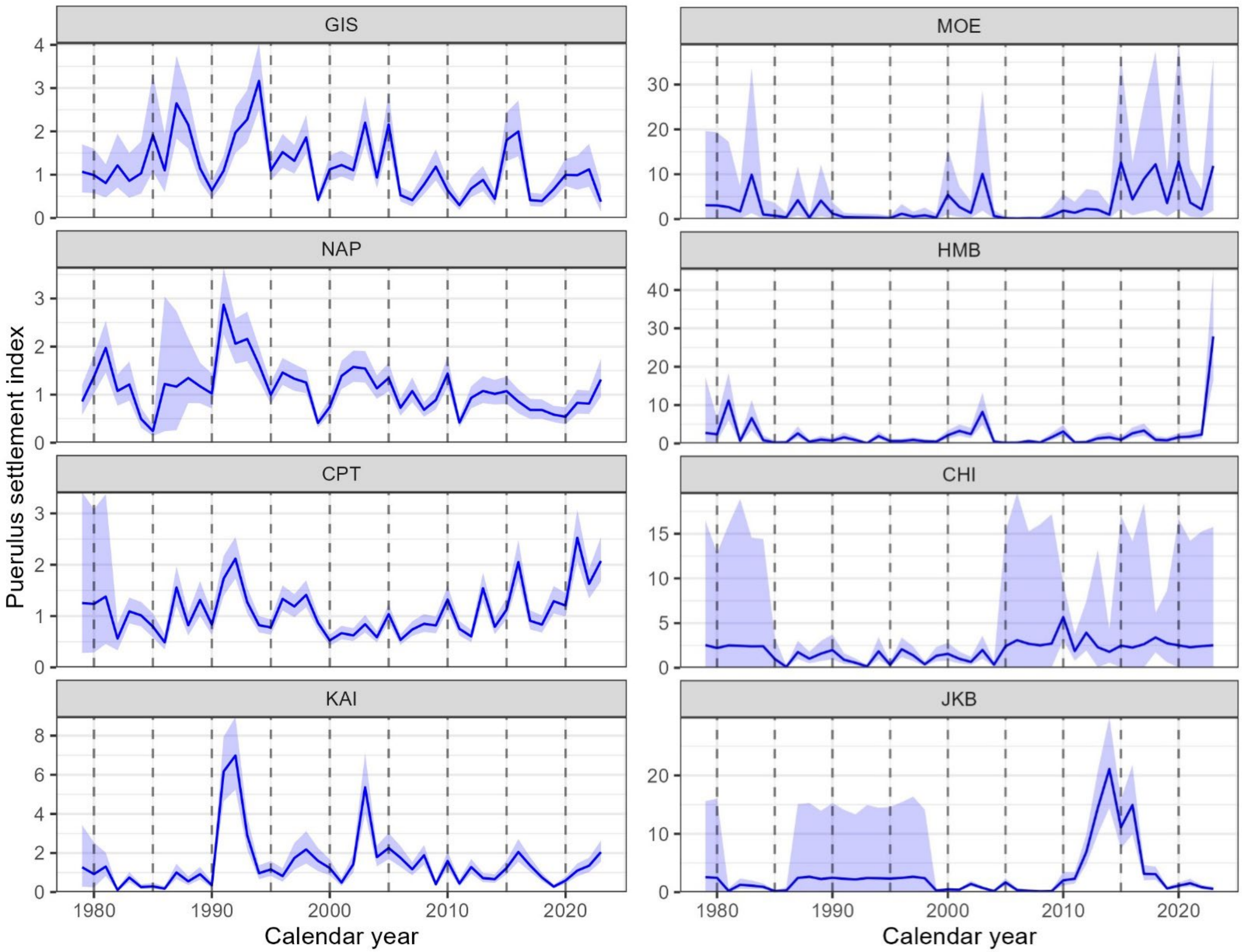

Figure 6: The final standardised puerulus settlement series by calendar year and collector site, scaled to respective geometric mean values. Blue points and lines are the average predictions, blue shaded areas are 95% credible intervals. Predictions generated from model runs *fit5_north* and *fit5_south*.

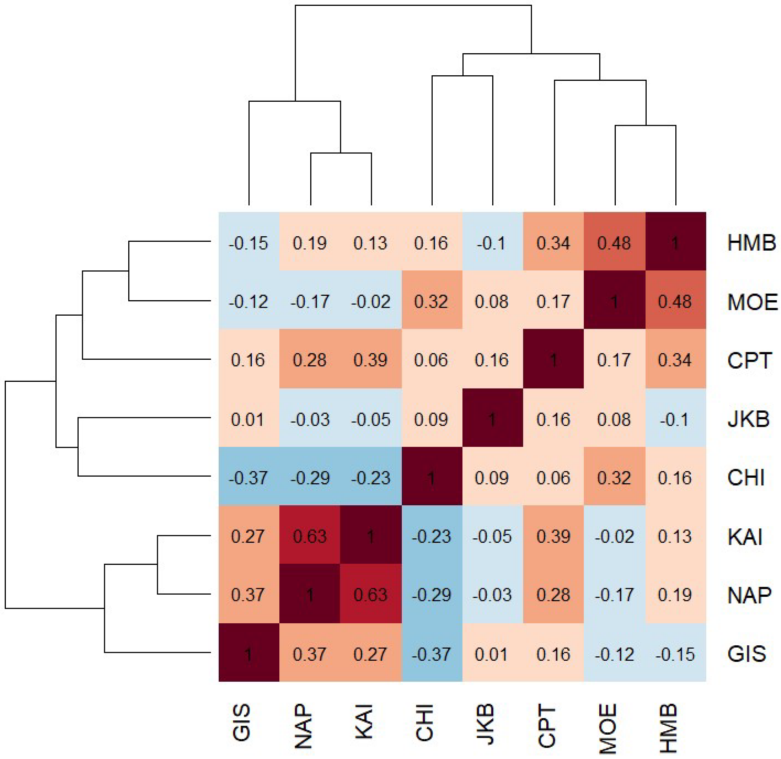

Figure 7: **Pearson product moment correlation index of annual standardised puerulus settlement rate series by collector site. The dendrogram above the correlation matrix represents the results of hierarchical clustering analysis based on the puerulus series.**

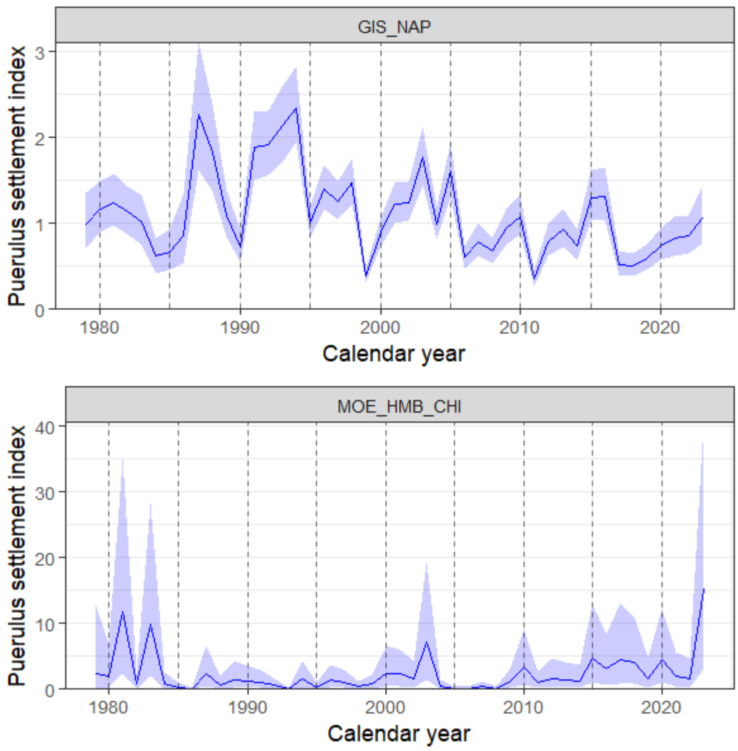

Figure 8: **The final standardised puerulus settlement series by calendar year for combined-sites (‘GIS_NAP’ = Gisborne-Napier index series; ‘MOE_HMB_CHI’ = Moeraki-Halfmoon-Bay-Chalky-Inlet index series), scaled to respective geometric mean values. Blue points and lines are the average predictions, blue shaded areas are 95% credible intervals.**

5. CLIMATIC DRIVERS OF PUERULUS SETTLEMENT RATES

5.1 Methods

In this section, alternative climate predictors of puerulus settlement rate were trialled. A summary of the different climate indices prepared for this analysis is given in Table C.1. These included spatially aggregated indices – sea surface temperature and wind velocity; and non-spatial indices – Southern Oscillation Index (SOI; an ENSO index) and the M1 Trenberth index (Trenberth 1976). One and two-year lag periods, consistent with the phyllosoma life stage duration (Chiswell & Booth 2017), were trialled for the better performing indices only, based on initial model explorations, for SOI and wind velocity climatic indices. Other climatic indices were developed for this analysis but were discarded during the exploratory phase of model development. These included: wind speed, sea altimetry data, Kidson weather type indices (Kidson 1997), Southern Annular Mode (SAM), and the Inter-decadal Pacific Oscillation (IPO).

For all climate series, the annual index value was calculated as the mean of the monthly indices for a calendar year. For the spatially aggregated climatic series (SST and wind velocity), the monthly values were calculated as the mean across all 0.25-degree grid cells within the statistical area polygons of each respective QMA (i.e., a single value across all statistical areas within a QMA) (e.g., Figure C.1). The resulting annual climate series produced for this analysis are plotted in Figure C.2 to Figure C.6.

For the analysis of climatic predictors of puerulus settlement rate, the optimal *brms* model structure for generating puerulus settlement series (*fit5*) was modified by replacing the year:site interaction term with a linear interaction term between the respective climatic series and monitoring site:

catch ~
(1 | site) +
(1 | site:month) +
(1 | site:group) +
(1 | site:group:collector_id) +
climate_index:site

This allowed the direction and slope of the relationship between the climate term and the puerulus catch rate to vary by site. Both the u- and v-wind velocity terms were included at the same time, since it is the combination of these observations that gives wind direction (Table C.1). All other climatic terms were added individually. As before, model comparison was based on δ-ELPD and SE δ-ELPD.

5.2 Results

A comparison of models including climatic series is given in Table C.2. The best models in terms of δ-ELPD and SE δ-ELPD included wind velocity (with no lag or a 1-year lag) or SOI (no lag). Model diagnostic plots were shown for the better models in terms of LOO IC: wind velocity with a 1-year lag (*fit_cli_7*) and SOI with no lag (*fit_cli_1*), which did not indicate any issues with model convergence or fit (Figure C.7, Figure C.10).

The predicted puerulus catch rate in response to the climatic indices in models *fit_cli_7* and *fit_cli_1* are shown in Figure C.11 and Figure C.12. At four of the eight assessed monitoring sites (Gisborne, Napier, Kaikoura, and Moeraki), increased puerulus settlement rates were predicted in the year following relatively strong south-westerly winds. Westerly winds also appeared conducive to settlement at Castlepoint and Jackson Bay, and increased settlement rates were predicted with higher southerly winds for Chalky Inlet (although note the shorter time series of monitoring at this site, increasing the likelihood of spurious relationships). Halfmoon Bay was anomalous in that increased settlement was predicted in response to years with relatively low wind flow (Figure C.11). For most sites, increased puerulus settlement rates were predicted for years in which SOI was in its negative phase (El Niño conditions) (Figure C.12).

6. PREDICTORS OF STOCK ASSESSMENT MODEL RECRUITMENT

The purpose of this research activity was to assess the utility of puerulus and climate indices for predicting stock assessment model recruitment deviates and, specifically, to assess the utility of individual puerulus collector sites in this context. A predictive regression model approach was implemented using *brms*, modelling the effect of puerulus settlement and climatic indices (generated in previous sections) on the recruitment deviates estimated by the base case assessment model for each rock lobster stock (i.e., this analysis is outside of the stock assessment model).

6.1 Methods

Stock assessment model estimates of annual recruitment deviates (*recdevs*) were taken from different sources, depending on the stock. For CRA 1, CRA 2, CRA 3, CRA 4, CRA 5, and CRA 7&8, the recruitment deviates (for each model region and including uncertainty) were taken from the 2023 round of rapid update assessments that were based on the most recent full assessment base case model for each of these stocks (Pons et al. 2024). For CRA 3, the *r1_qdrift* model was used (subset of tag data spending at least one year at liberty). For CRA 6 (which was yet to be included in the rapid updates at the time of this analysis), the annual recruitment deviates were taken from the 2023 stock assessment of this stock (Rudd et al. 2024). The recruitment deviates were initially restricted to the years 1975 to 2020 (years for which recruitment would be relatively well-informed by the fisheries data) (Figure 9 and Table D.1 to Table D.10), although shorter time periods than this were used when relating to the predictors when assuming lag periods.

Based on the outputs of the CRA 2 stock assessment (Rudd et al. 2023), which found that QMA-specific SST was a promising predictor of recruitment for this stock (with no lag time to recruitment in the model), SST was also trialled as a covariate. This was extended to QMAs other than CRA 2, based on the outputs of Breen & Starr (2010), which indicated that SST may also be useful for predicting recruitment to the CRA 3 and CRA 4 stocks. Other indices trialled during initial generalised additive modelling (GAMs) included the M1 Trenberth index and SOI, although these did not perform as well as SST, so were not included in the runs shown here. The selection of the most appropriate puerulus settlement series to use for each stock-region is shown in Table 2, which required some assumptions to be made. No suitable puerulus series were available for CRA 1, CRA 2, or CRA 6. For CRA 3 (regions 1 & 2), the combined Gisborne/Napier index series was deemed most appropriate, given the proximity of the Napier monitoring site to Mahia Peninsula (in CRA 3; see Section 3.2). The selection of puerulus series for Castlepoint and Kaikoura was more straightforward, with the site inside each respective stock area being selected. For CRA 7&8 (regions 1 & 2), the combined Moeraki/Halfmoon Bay/Chalky Inlet index series was used, which was developed to alleviate issues associated with low puerulus catch rates at these monitoring sites.

Table 2: Selection of puerulus settlement and sea surface temperature series that were related to recruitment deviates for each stock-region.

Stock-region	Puerulus settlement series	Sea surface temperature index
CRA 1	None	CRA 1
CRA 2	None	CRA 2
CRA 3 region 1	Gisborne/Napier index series (‘GIS_NAP’)	CRA 3
CRA 3 region 2	Gisborne/Napier index series (‘GIS_NAP’)	CRA 3
CRA 4	Castlepoint index series (‘CPT’)	CRA 4
CRA 5 region 1	Kaikoura index series (‘KAI’)	CRA 5
CRA 5 region 2	Kaikoura index series (‘KAI’)	CRA 5
CRA 6	None	CRA 6
CRA 7&8 region 1	Moeraki/Halfmoon Bay/Chalky Inlet index series (‘MOE_HMB_CHI’)	CRA 7&8
CRA 7&8 region 2	Moeraki/Halfmoon Bay/Chalky Inlet index series (‘MOE_HMB_CHI’)	CRA 7&8

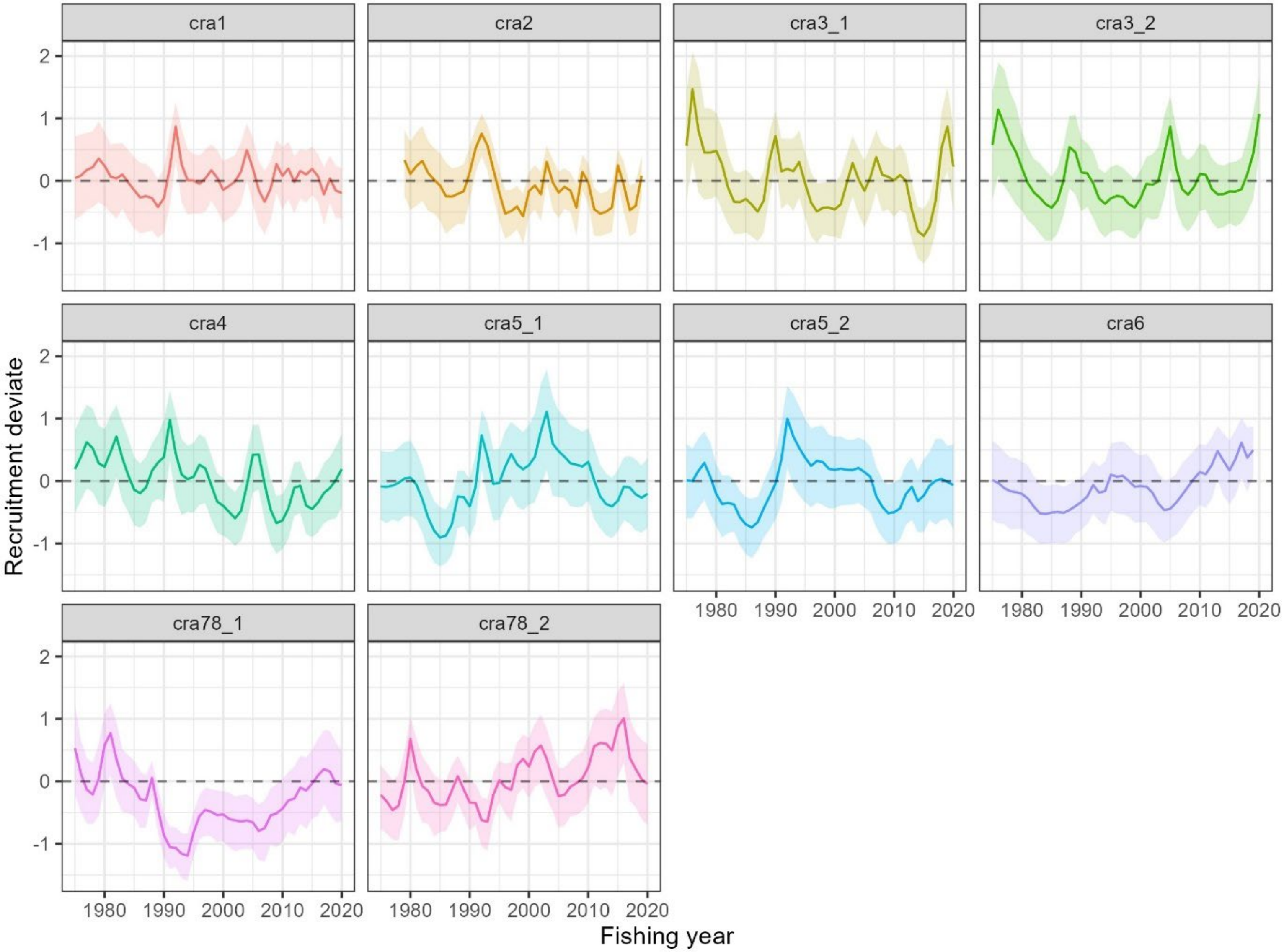

Figure 9: Stock assessment model estimated recruitment deviates by fishing year and QMA/stock assessment region.

All regression models for predicting stock assessment recruitment deviates were fitted using *brms* in *R*. Modelling was done across each stock-region simultaneously (if present), although the shape of the response was allowed to vary by stock-region in some model runs. The most complex model structure was

$$recdev \sim puer \times qma\_region + s(sst,\ k = 4,\ bs = \text{“cs”})$$

where *recdev* (the response) is the series of annual recruitment deviates, *puer* is the puerulus settlement series and *puer* × *qma*_region is an interaction term between the puerulus series and QMA-Region, *sst* is the SST index series and a cubic shrinkage spline on SST was also offered, with the basis dimension smooth value constrained to $k = 4$, to prevent overly wiggly responses to SST. There was no requirement to allow a non-linear response to the puerulus series, given that these were both in log-space, which would allow non-linear relationships when transformed back into natural space. When including the puerulus index series as a predictor, stock-regions missing a puerulus settlement index series (CRA 1, CRA 2, and CRA 6) were removed from the analysis.

Alternative time lags were trialled between the puerulus/SST series and the recruitment deviates, which were informed by a prior exploratory GAM-based analysis. For the puerulus series, lag periods of 2–3 years were initially trialled, which were considered the most plausible lag periods based on the juvenile growth information (Roberts & Webber 2022), of which the 2-year lag was found to be optimal across the stock-regions based on the exploratory GAM analysis. In addition, a model assuming no lag period between the puerulus index series and recruitment in the model was also trialled, based on the results of historical puerulus randomisation trials, which frequently suggested that using no lag gave the best stock assessment model fit to the respective puerulus series (Table 1). For the SST comparison, the exploratory GAM-based analysis found that a lag time of one year was optimal (i.e., SST in the year before recruitment to the model) and this was used for all model runs.

There were three steps in this modelling analysis:

1. In the first step, uncertainty in the puerulus series *was not* included;
2. In the second step, uncertainty in the puerulus series *was* included; and
3. In the third step, puerulus series were not included in the model, so that SST relationships could be estimated for all stock-regions (i.e., including those lacking a suitable puerulus settlement index series).

6.2 Results

Step 1 – not including uncertainty in the puerulus series

Firstly, the comparison of model structures and then model outputs are shown when assuming a **two-year lag period between the puerulus series and recruitment to the model** (consistent with the pre-recruitment growth information) (Table D.11). In terms of LOO IC, the best model was the most complex one offered (*fit_puer2yr_4*), which included the puerulus relationship varying by stock-region and a non-linear relationship with SST. However, based on δ-ELPD and SE δ-ELPD, none of the models were statistically distinguishable from the null model (*fit_puer2yr_0*), leading to the conclusion that the puerulus or the SST series provided no additional information informing the pattern of recruitment deviates. Model diagnostic plots are shown for the best model in terms of LOO IC (*fit_puer2yr_4*), which did not indicate any issues with model convergence or disagreement with the assumed statistical distribution (Figure D.1, Figure D.2) and residual plots were shown for the same model which do not indicate any issues with lack of fit, except for a minor residual pattern with respect to year (Figure D.5 to Figure D.7).

The model predictions from *fit_puer2yr_4* were consistent with between stock-region variation in the relationship between puerulus settlement and recruitment, with a positive asymptotic relationship for

CRA 5 (regions 1 & 2) and relatively weak evidence for a positive relationship for all other stock-regions (Figure D.3). The predicted response to SST was bimodal and highly uncertain (Figure D.4).

Model structures were then compared when assuming **no lag period between the puerulus series and recruitment to the model** (i.e., an assumption consistent with some of the puerulus randomisation trials used by previous stock assessments – Table 1) (Table D.12). In terms of LOO IC, the best model was still the most complex one (*fit_puer0yr_4*), although this model was still not distinguishable from the null model based on δ-ELPD and SE δ-ELPD. The Bayesian R-squared values were higher for all model runs (comparing Table D.11 and Table D.12).

The model diagnostic plots are shown for *fit_puer0yr_4*, which did not indicate any obvious issues of convergence or fit (Figure D.8, Figure D.9) and the residual plots were similar to those of model *fit_puer2yr_4* (not shown).

The model predictions from *fit_puer0yr_4* are consistent with a stronger positive relationship between puerulus settlement and recruitment for most stock-regions including CRA 4, CRA 5 regions 1&2, and CRA 7&8 region 2 (comparing Figure D.3 with Figure D.10). The predicted response to SST indicated a weaker relationship with recruitment than was previously predicted (comparing Figure D.4 with Figure D.11).

Step 2 –including uncertainty in the puerulus series

When comparing models including measurement error in the puerulus series and assuming a 2-year lag period between puerulus settlement and recruitment to the model, the null model became the best model in terms of LOO IC, and none of the models could be differentiated based on δ-ELPD and SE δ-ELPD (Table D.13). This was also the case when assuming no lag period between the puerulus index series and recruitment (Table D.14). This indicates that any conclusions based on the previous step 1 are no longer valid when uncertainty is added to the puerulus series.

Step 3 – focus on sea surface temperature

In the third step of model fits, the puerulus series were excluded, which resulted in CRA 1, CRA 2, and CRA 6 being added to the analysis, which now only included stock-region and SST as candidate predictors. In terms of LOO IC, the most complex model (*fit_sst_3*) was the best, which included stock-region and a spline on SST as predictors (Table D.15). However, this model could still not be differentiated from the null model based on δ-ELPD and SE δ-ELPD. The model diagnostic plots for model run *fit_sst_3* are shown in Figure D.12 to Figure D.15, which do not indicate any issues with model convergence or fit. Using this model run, the recruitment deviates were predicted in response to SST. The predicted response to SST had a unimodal shape with a peak at around 13°C and relatively low recruitment predicted at lowest SST value (an annual mean SST of ~10°C) and the highest SST values (annual mean SST > 16°C) (Figure D.16).

7. INCLUSION OF DENSITY DEPENDENT EFFECTS ON JUVENILES IN STOCK ASSESSMENT MODEL

Based on the analysis in Section 6, CRA 5 appeared to have the most useful puerulus index series ('KAI') for predicting recruitment. Guided by the approach of Australian stock assessments of western rock lobster (e.g., Caputi et al. 1995), a power function was added to the latest rapid update stock assessment model for region 1 of CRA 5 (Pons et al. 2024), for representing density dependence in model predictions of the puerulus index series (using the 'KAI' index series from the re-analysis in Section 4):

$$\text{puerulus index} = q \times \text{recruitment}^b$$

where q is a catchability term for scaling model estimated recruitment to the puerulus index series, and b is the power term (smaller values dampen peaks in recruitment). A three-year lag period was assumed between settlement and recruitment in the model, consistent with the juvenile growth information (Roberts & Webber 2022).

However, estimating the power function (b = 0.844) resulted in no apparent improvement in fit to the puerulus index series (Figure 10). Note that b values near to a value of 1 are consistent with no density dependent effect. The stock assessment model did not fit at all well to the peaks in settlement, which did not coincide with peaks in recruitment estimated from the fishery data in CRA 5 region 1.

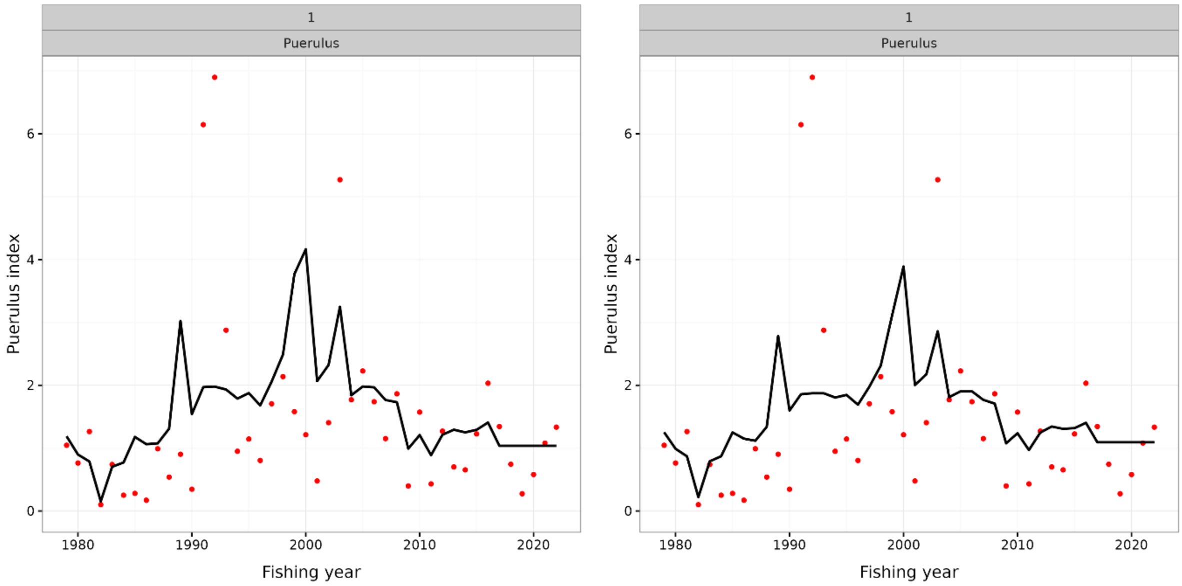

Figure 10: Fit of the CRA 5 region 1 stock assessment recruitment time series to the KAI puerulus settlement index series without the power function (left) and with the power function (right). The model estimates are represented by the black line and the puerulus data are represented by red points.

8. DISCUSSION

8.1 Limitations of this analysis

There was not time within this project to redo the puerulus randomisation trials with the latest data, although the outputs of the most recent trials were summarised for each stock (Table 1) and are still likely to be valid, given the incremental annual additions of new information since these trials.

Stock assessment estimates of recruitment are likely to alias for multiple processes in addition to fishery recruitment, including (but not limited to): biased estimates of or temporal changes in growth of small lobsters, and misspecification of the magnitude of catch or selectivity through time. In addition, several other processes are likely to affect the growth and mortality rates of post-settlement, pre-recruitment lobsters, for which we have limited or no information, including density dependent and/or climate effects. These processes will confound the relationship between puerulus settlement series and stock assessment model estimates of recruitment strength.

8.2 Puerulus settlement patterns

Based on the analysis described in Section 3, the annual puerulus settlement series appear to be representative of local settlement, with at least weakly positively correlated annual settlement rates within the northern monitoring sites (GIS, NAP, CPT, KAI) and southern sites (MOE, HMB, CHI). The temporal puerulus settlement pattern at Jackson Bay (JKB), on the West Coast, is quite different from any of the other sites and probably is not representative of settlement across the wider Fiordland region.

Some improvements were made by this review to the standardisation of the puerulus settlement data, although these changes made very little difference to the resulting settlement series by stock. Probably the largest change from the previous approach (Forman et al. 2023) was the development of combined site settlement series, although the resulting series still did not correspond well with stock assessment model estimated recruitment deviates.

Puerulus settlement rate appears to be affected by environmental conditions during and in the year before settlement, and (at most sites) to be greatest during/following El Niño years and following strong south-westerly winds. This is consistent with previous analyses, which determined that settlement rates at northern monitoring sites across New Zealand and Australia were greatest during El Niño conditions (Hinojosa et al. 2017, J. Forman, pers. comm.). Also, the latest CRA 2 assessment trialled the inclusion of an SST-based covariate of recruitment and found evidence for cooler temperatures positively affecting the survival of post-settlement lobsters (Rudd et al. 2023), which is also consistent with cooler El Niño conditions driving improved recruitment in the north.

8.3 Predicting stock assessment model recruitment

The stock assessment model recruitment deviates related only very loosely to the puerulus settlement and sea surface temperature series. For those stocks with the strongest relationships (e.g., recruitment in CRA 5 regions 1 and 2, and the Kaikoura settlement series), the shape of this relationship is consistent with density dependent dampening of peaks in settlement. However, including density dependence in stock assessment model run for CRA 5 did not help at all with fitting peaks in the puerulus series, which did not coincide in time with fishery peaks in recruitment when assuming plausible juvenile growth rates. Stronger positive relationships were obtained when no time lag was specified, which is only plausible if stock assessments for the stocks have consistently underestimated the growth of smaller lobsters. However, when uncertainty in the puerulus series is included, no predictive model could be differentiated from the null model. This indicates that the recruitment information in the puerulus settlement series is not consistent with the recruitment information from the fisheries data, as estimated by the stock assessment model. For the CRA 3 and CRA 8 recruitment deviates, there was no relationship with the puerulus series.

While the peaks and troughs in the puerulus settlement series did not coincide with those of the annual recruitment estimated by the stock assessment models, there was better agreement for some QMAs when comparing the longer-term trends of both series. For example, the CRA 5 puerulus and recruitment series have similar patterns through time, with a shared low period in the 1980s followed by around 15 years of relatively good recruitment, and both ending in a period relatively poor recruitment (Figure D.17, Figure D.18). Likewise, the CRA 4 series followed broadly similar patterns through time, although this was clearly not the case for CRA 3.

Based on a clustering analysis, the estimated recruitment deviates for each stock-region were most like those of adjacent stock-regions, with the strongest correspondence between CRA 6 / CRA 7&8 and the other QMAs (Figure D.19), but we note that this correspondence was moderate or weak in terms of the calculated correlation coefficients. This is consistent with regional patterns in recruitment strength around New Zealand. Similarly, the puerulus settlement patterns of adjacent monitoring sites were most alike (Figure A.24). Therefore, there are likely to be consistent changes in both puerulus settlement and fishery recruitment observed across regions. However, within each QMA, the changes in puerulus settlement and recruitment to the fishery do not appear to coincide in time, once growth is accounted for.

The predicted response of recruitment to SST was consistent with an optimal temperature range for post-settlement survival (Figure D.16), which may have implications for oceanic warming, although this relationship was also not very strong when estimated across all stocks (Bayesian R-squared for model run *fit_sst_3* = 0.183; 95% credible interval = 0.122 – 0.245) (Table D.15).

Overall, for the stocks where it was determined that the puerulus settlement data appear to be representative of regional patterns, the utility of the respective puerulus series for predicting recruitment has likely been compromised by other confounding processes impacting on stock assessment estimates of recruitment, including (but not limited to): uncertainty in or biased estimates of growth at small size, as estimated by stock assessments; and factors affecting the growth and mortality rates of pre-recruitment lobsters, including density dependence and/or climate effects. However, even where the puerulus settlement information was consistent with stock assessment recruitment, the main benefit (i.e., making short term predictions) would be less beneficial to a management procedure-based regime (e.g., Webber & Starr 2020) than to an assessment/prediction paradigm (Bentley & Stokes 2009). Furthermore, the requirement for short-term predictors of recruitment is currently partially alleviated by the annual rapid update assessments of New Zealand stocks, noting that the CPUE indices generally contain the best information on recruitment strength and would ideally also be updated for the rapid update assessments.

Alternative options for forecasting fishery recruitment include the development of climatic predictors, which may have utility for predicting the future trends in recruitment for some QMAs, and the development of pre-recruit relative abundance time series. Pre-recruit abundance series have not yet been developed for New Zealand red rock lobsters but are routinely developed and used for the assessment of Australian rock lobster stocks, where they typically provide recruitment information that is only one year ahead of the fishery information.

9. POTENTIAL RESEARCH

- The growth rates of juvenile and smaller recruited lobsters remain a major uncertainty for most QMAs, confounding the analysis of predictors of recruitment. New approaches or data for estimating the growth rate of smaller lobsters may be helpful in this regard.
- Should new information result in very different estimates of juvenile growth, or in the event of other changes that substantially alter the stock assessment recruitment estimates, then the utility of the puerulus data could be re-evaluated, focusing on the more promising puerulus monitoring sites (e.g., Castlepoint and Kaikoura).
- The development of a pre-recruit abundance index series could help with forecasting recruitment one year ahead of the fishery-based information.
- Exploration of the potential relationship between sea surface temperature and recruitment may help with predicting the recruitment of northern and southern stocks, given forecasted anthropogenic warming.

10. FULFILLMENT OF BROADER OUTCOMES

As required under Government Procurement rules[4], Fisheries New Zealand considered broader outcomes (secondary benefits such as environmental, social, economic or cultural benefits) that would be generated by this project. This section discusses the broader outcomes that were delivered:

Whakapapa links all people back to the land, sea and sky, and our obligations to respect the physical world. This research aims to ensure the long-term sustainability of red rock lobster stocks, for the good of the wider community (including stakeholders and the public) and the marine ecosystems that lobsters inhabit. This project supports both Māori and regional businesses, and our research is inextricably linked to the moana from the work it carries out and the tangata whenua it supports.

To support the wider fisheries science community and enable more value to be extracted from the limited resources (time and money) available for fisheries research we make as much code as possible open source (i.e., publicly available). Furthermore, this project has built capacity and capability in fisheries science and stock assessment by employing researchers with a range of experience so that those with a long history of working in fisheries science can pass on their knowledge. This approach has meant that rock lobster stock assessments have consisted of a team with some members that have been involved for many years and some newer team members. This approach further mitigates risk associated with team members not being able to participate any longer.

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Appendix A. Additional tables and figures from the spatial characterisation of the New Zealand puerulus monitoring

Table A.1: Summary of monitoring sites, including: the respective numbers of collector groups with data in the *rocklob* database and the period of data collection. Bolded monitoring sites are currently being monitored.

Site code	Site name	Number of collector groups	Years of monitoring
NTH	Northland	4	2000 – 2002
BOP	Bay of Plenty	12	1984 – 1988
TAI	Te Awaiti	1	1985 – 1987
BTN	Bowentown	2	1999 – 2003
HKB	Hicks Bay	5	1981 – 1989
TKB	Tokomaru Bay	3	1979 – 1984
GIS	**Gisborne**	**10**	**1979 – 2023**
NAP	**Napier**	**5**	**1979 – 2023**
CPT	**Castlepoint**	**3**	**1981 – 2023**
POU	Pourerere	3	1982 – 1984
WTN	Wellington	4	1993 – 2006
MHG	Mahanga Bay	1	1988 – 1989
PUD	Port Underwood	5	1980 – 1982, 1992 – 1993
CCB	Cape Campbell	3	1983 – 1985
KAI	**Kaikoura**	**10**	**1980 – 2023**
TMU	Timaru	5	1979 – 1983
OMU	Oamaru	4	1979 – 1984
MOE	**Moeraki**	**8**	**1982 – 2023**
BLF	Bluff	1	1981 – 1983
RVN	Riverton	2	1982 – 1984
STW	Stewart Island	4	1979 – 1989
HMB	**Halfmoon Bay**	**7**	**1980 – 2023**
CHI	Chalky Inlet	1	1985 – 2004, 2010 – 2012, 2014, 2018 – 2019
CAS	Caswell Sound	2	1982 – 1992
GEO	George Sound	1	1982 – 1988
LGB	Looking Glass Bay	1	1990 – 1992
JKB	**Jackson Bay**	**5**	1981 – 1986, 1999 – 2023
OBI	Open Bay Islands	1	1985 – 1988
PUN	Punakaiki	1	1998
CHT	Chatham Islands	4	1982 – 1985

Table A.2: Summary of the total number of geolocated pot lifts by fishing year and statistical area recorded in the ERS data extract.

Statistical Area	Fishing year 2019	2020	2021	2022	2023
901	5 717	8 321	11 151	10 646	7 076
902	9 884	23 834	21 399	21 092	4 647
903	6 392	7 476	7 074	5 344	2 486
904	8 389	340	789	658	909
905	12 545	20 359	16 222	15 730	9 046
906	14 449	32 109	26 563	31 603	19 481
907	2 020	24 692	26 853	25 925	13 933
908	17 235	22 699	19 509	26 232	8 665
909	4 206	23 640	16 552	16 002	10 084
910	23 984	88 823	87 784	84 481	41 684
911	17 833	59 974	72 323	84 641	26 660
912	14 114	32 399	19 605	18 123	8 507
913	29 588	67 535	43 524	35 304	14 147
914	110 742	160 169	108 132	85 361	39 990
915	27 828	45 386	36 200	35 661	17 099
916	6 626	25 363	20 242	12 190	6 737
917	52 580	135 575	122 646	117 880	85 441
918	4	7 527	9 443	9 629	9 183
919	0	264	452	0	0
920	54 120	65 718	72 858	54 370	42 743
921	10 127	13 479	15 776	17 505	22 900
923	2 943	10 659	10 102	11 747	4 045
924	17 165	33 316	31 477	33 326	22 301
926	29 676	94 556	75 682	54 730	46 001
927	29 054	69 594	45 946	48 372	34 059
928	19 190	62 015	50 069	42 573	32 099
929	202	982	0	0	0
930	812	2 373	1 690	45	0
931	2 205	10 365	10 613	12 890	10 353
933	9 110	43 727	41 371	41 477	11 424
934	1 902	2 316	168	2 604	1 224
935	17 450	15 903	11 241	11 719	8 822
936	1 022	5 757	2 835	2 392	1 379
937	1 152	0	43	0	0
938	0	66	0	0	0
939	3 156	18 743	15 520	11 944	7 935
940	28 721	32 538	33 522	29 684	14 821
941	23 237	35 373	35 826	27 383	11 155
942	44 721	63 626	61 694	65 160	19 814
943	13 594	15 147	15 255	20 678	8 905

Figure A.1: Example of a crevice collector used to monitor the settlement rate of puerulus stage red rock lobster around New Zealand. Image reproduced with permission from John Booth.

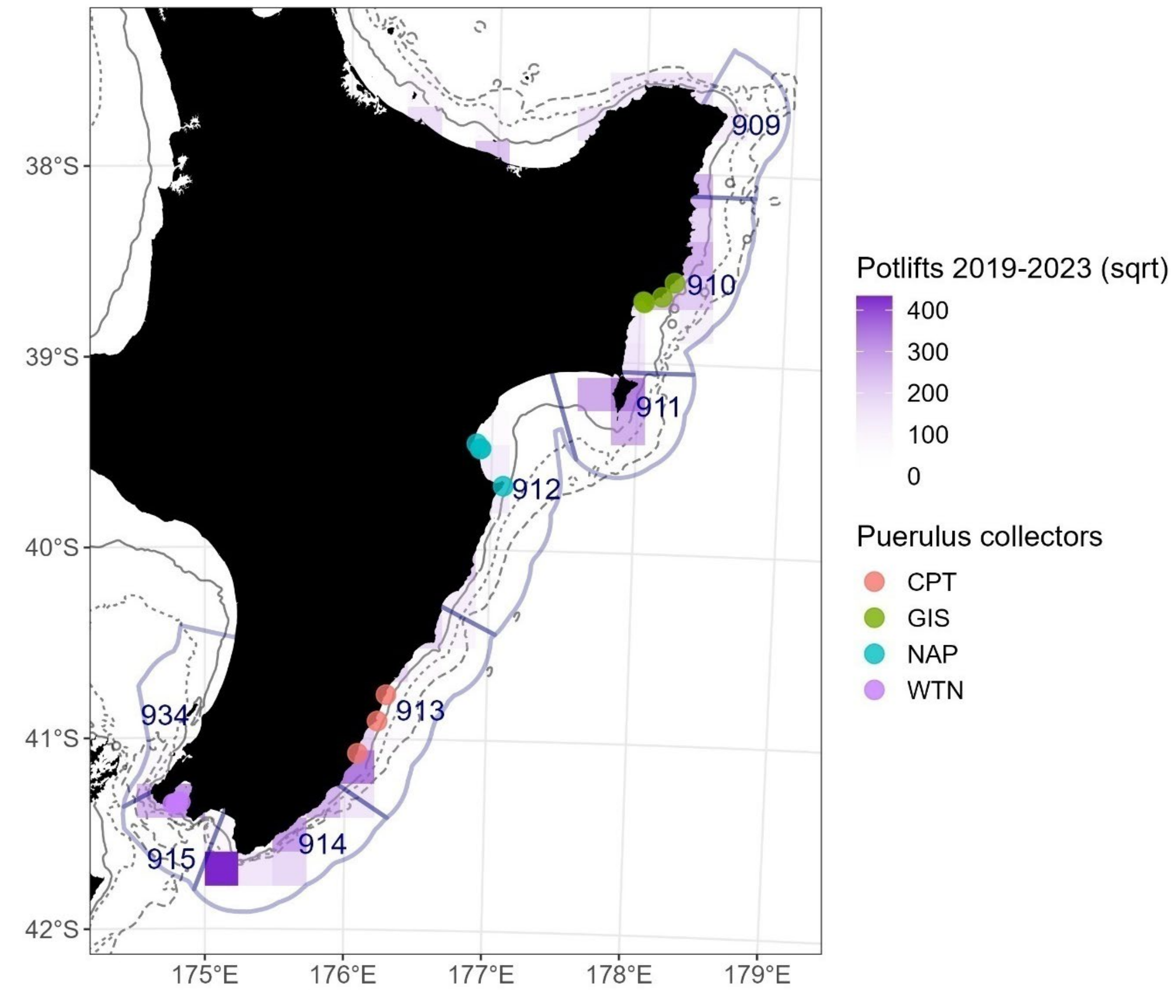

Figure A.2: The spatial distribution of major puerulus monitoring sites ('CPT' = Castlepoint, 'GIS' = Gisborne, 'NAP' = Napier, and 'WTN' = Wellington) and the spatial intensity of commercial fishing effort (square-root of the number of potlifts from the 2019–2023 fishing years; source = ERS data) recorded as occurring inside the CRA 3 and CRA 4 QMAs. Lines represent the boundaries of fisheries statistical areas within these QMAs. The 50 m, 100 m, and 200 m depth contours are represented by different line types.

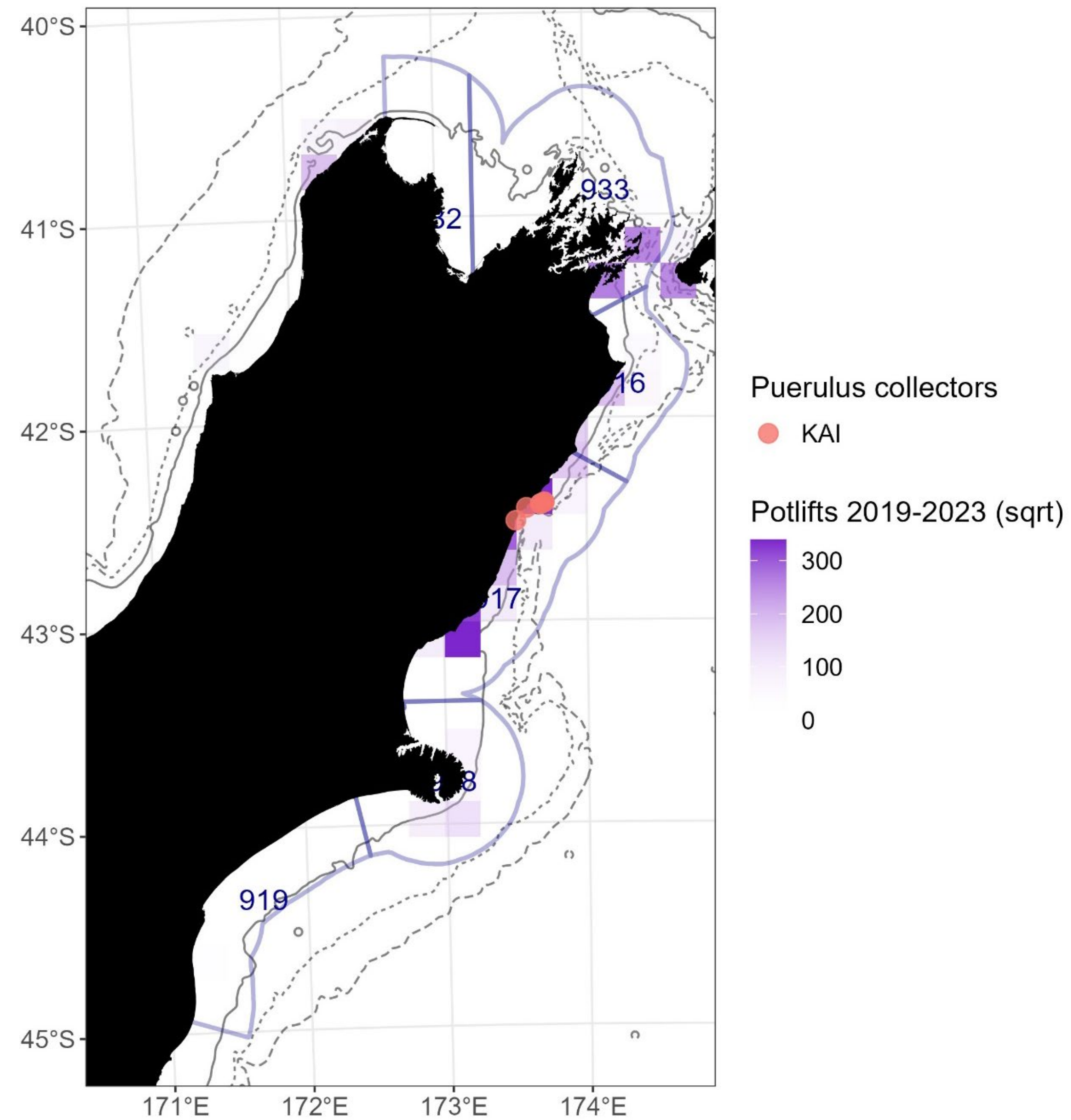

Figure A.3: The spatial distribution of major puerulus monitoring sites ('KAI' = Kaikoura) and the spatial intensity of commercial fishing effort (square-root of the number of potlifts from the 2019–2023 fishing years; source = ERS data) recorded as occurring inside the CRA 5 QMA. Lines represent the boundaries of fisheries statistical areas within this QMA. The 50 m, 100 m, and 200 m depth contours are represented by different line types.

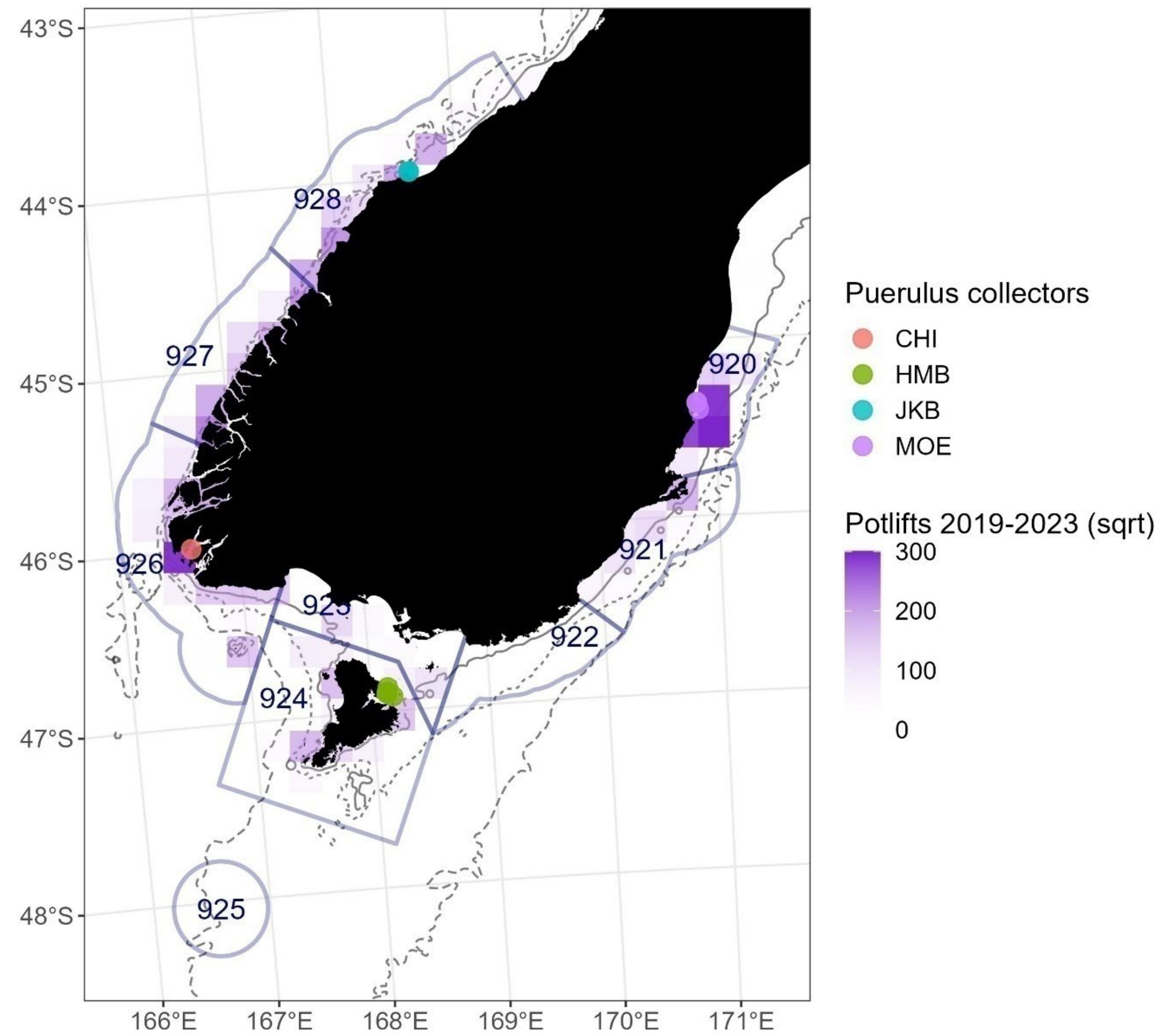

Figure A.4: The spatial distribution of major puerulus monitoring sites ('CHI' = Chalky Inlet, 'HMB' = Halfmoon Bay; 'JKB' = Jackson Bay, 'MOE' = Moeraki) and the spatial intensity of commercial fishing effort (square-root of the number of potlifts from the 2019–2023 fishing years; source = ERS data) recorded as occurring inside the CRA 7 and CRA 8 QMAs. Lines represent the boundaries of fisheries statistical areas within these QMAs. The 50 m, 100 m, and 200 m depth contours are represented by different line types.

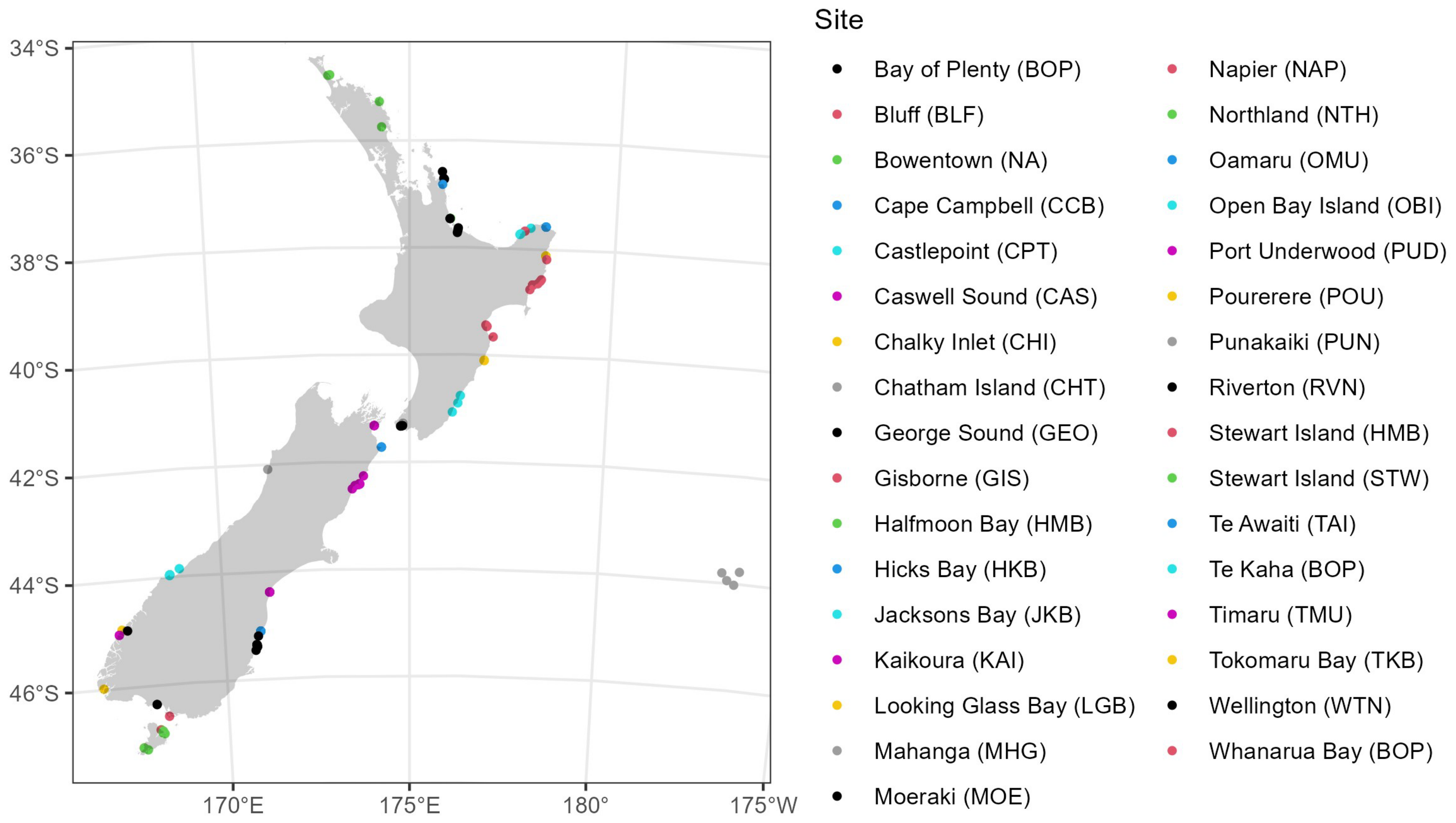

Figure A.5: The location of puerulus collector groups around New Zealand, including current and historical sites.

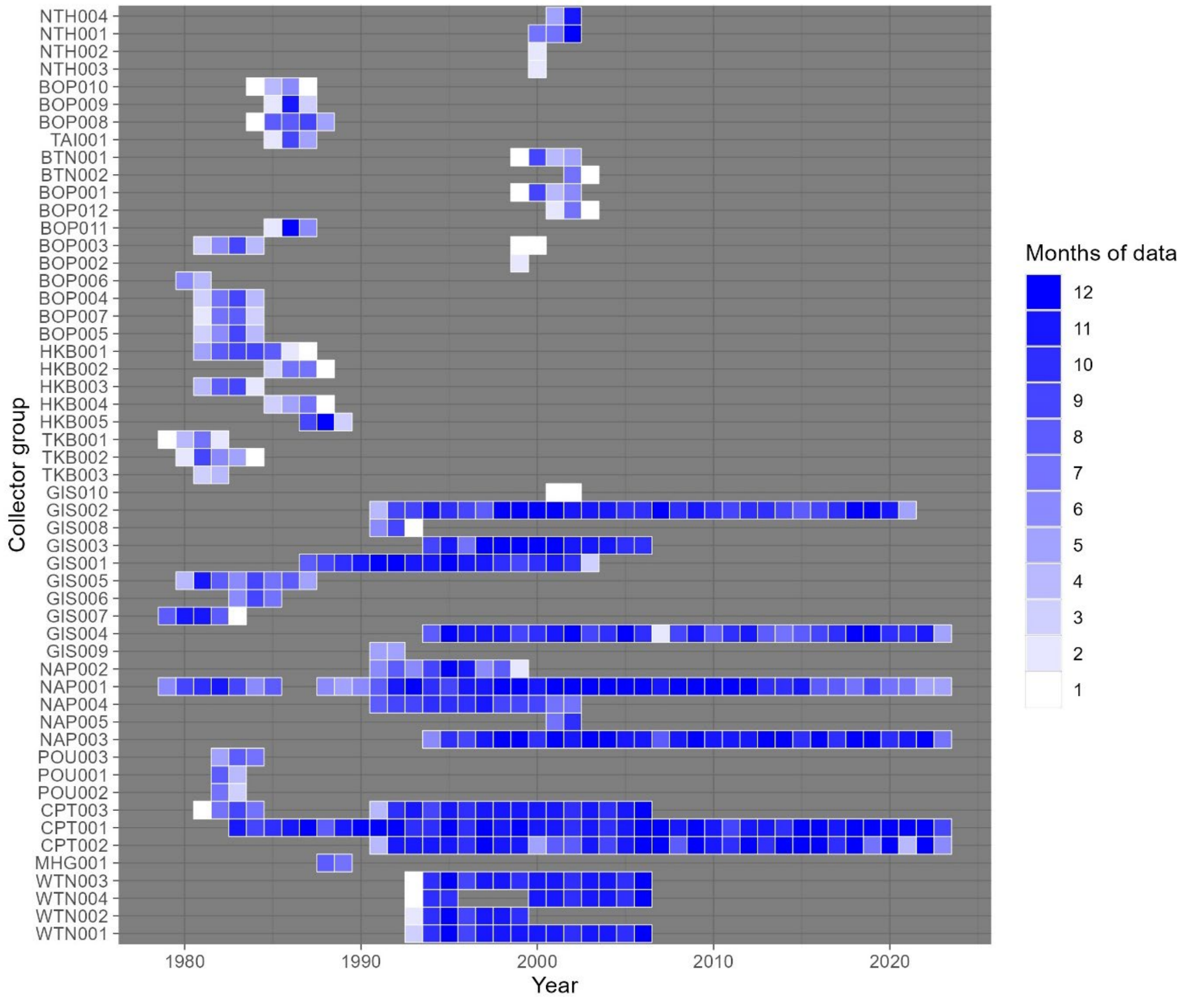

Figure A.6: The number of months of puerulus sampling by collector group and calendar year, for <u>North Island</u> collector groups. Collector groups are organised from north to south.

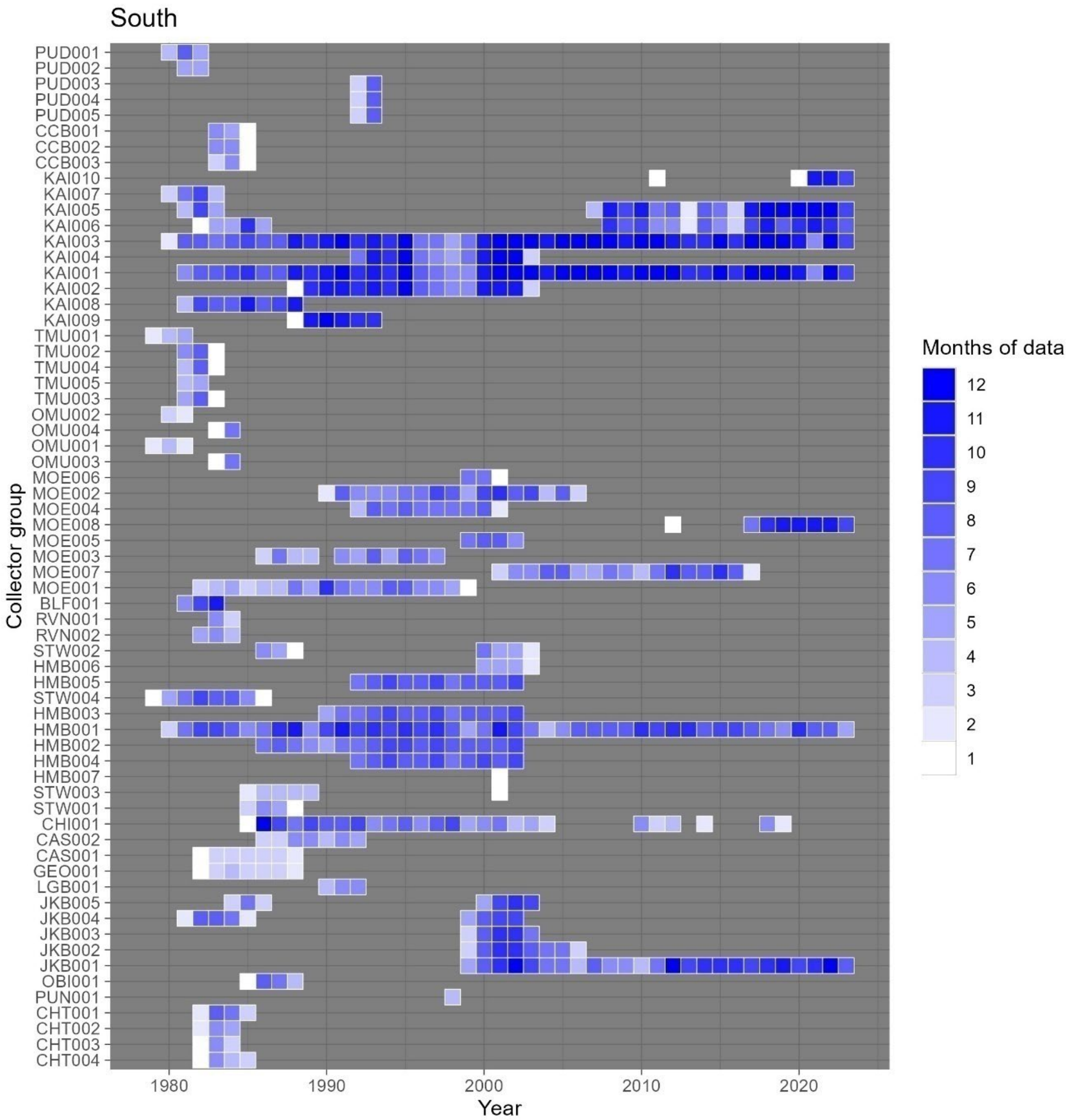

Figure A.7: The number of months of puerulus sampling by collector group and calendar year, for <u>South Island, Stewart Island and Chatham Islands</u> collector groups. Collector groups follow a clockwise direction around the coast starting at Port Underwood (PUD) in the North.

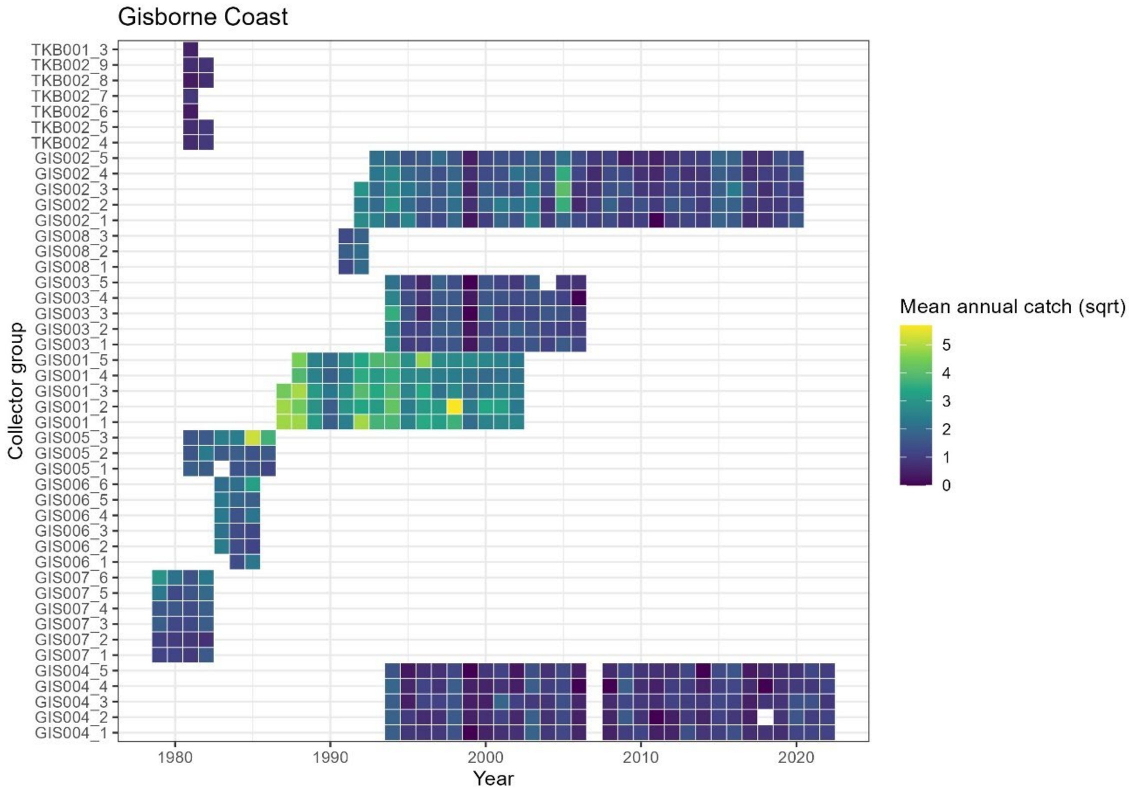

Figure A.8: The mean number of puerulus counted per collector group and calendar year (square root transformed) for Gisborne Coast collector groups. Collector groups are organised from north to south. Only collector group-year combinations with at least six months of sampling were included in this plot.

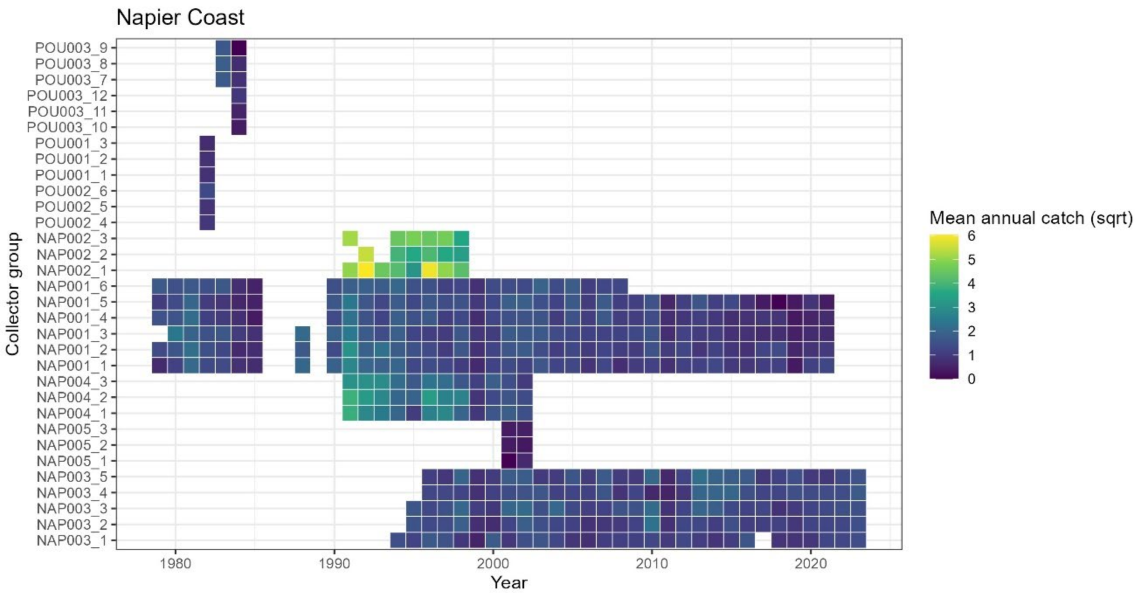

Figure A.9: The mean number of puerulus counted per collector group and calendar year (square-root transformed) for Napier collector groups. Collector groups are organised from north to south. Only collector group-year combinations with at least six months of sampling were included in this plot.

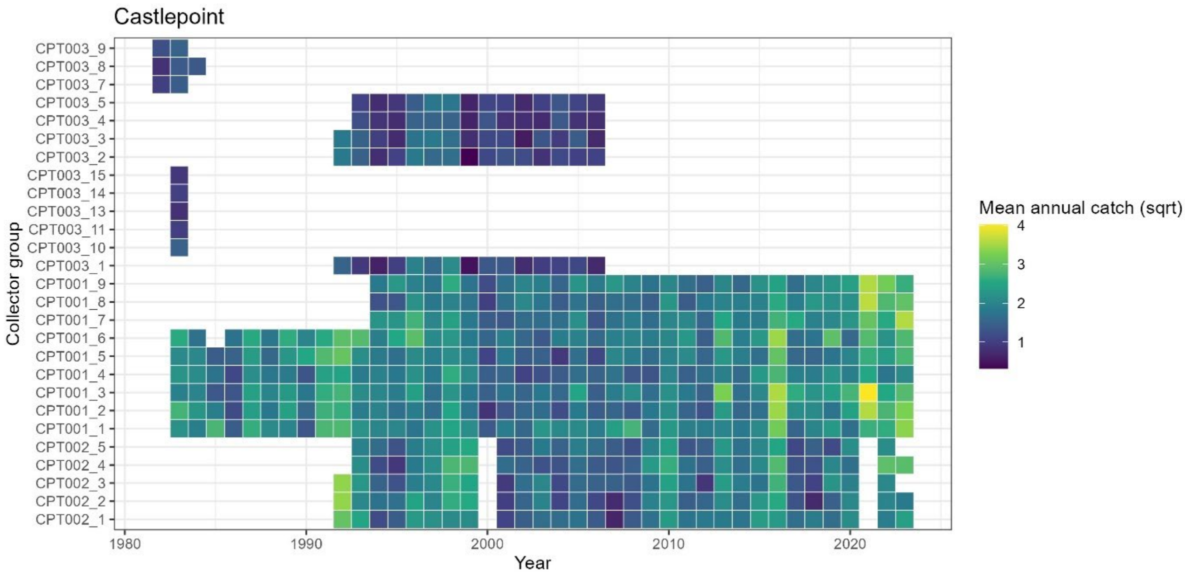

Figure A.10: The mean number of puerulus counted per collector group and calendar year (square-root transformed) for <u>Castlepoint</u> collector groups. Collector groups are organised from north to south. Only collector group-year combinations with at least six months of sampling were included in this plot.

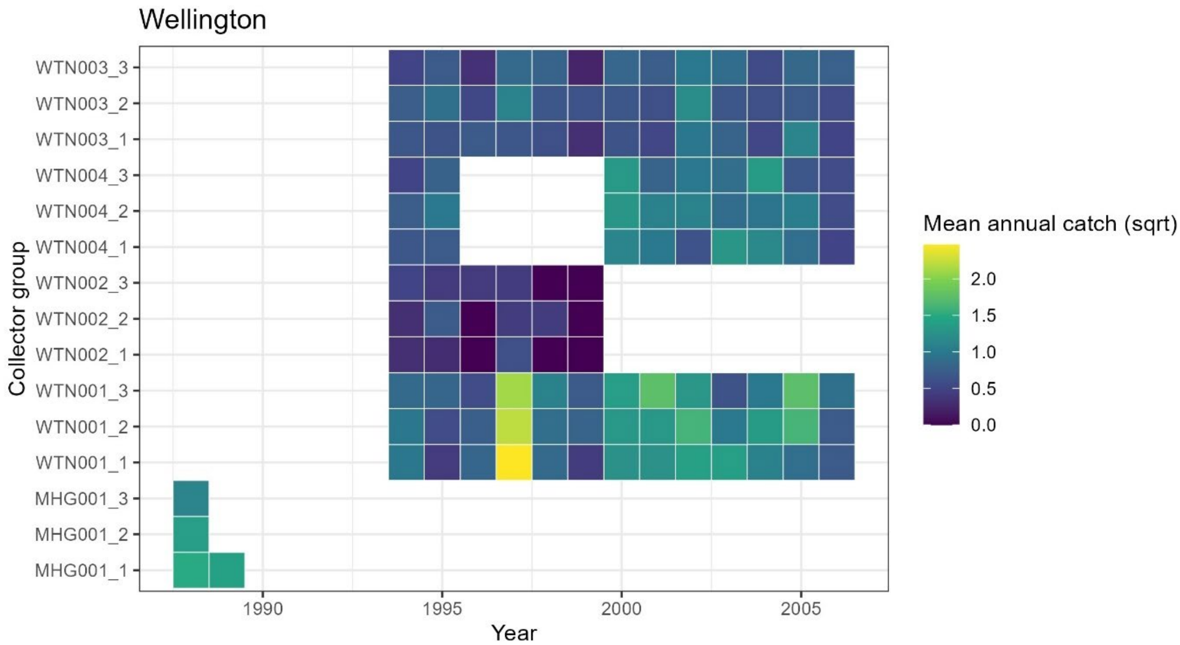

Figure A.11: The mean number of puerulus counted per collector group and calendar year (square-root transformed) for <u>Wellington</u> collector groups. Collector groups were organised from north to south. Only collector group-year combinations with at least six months of sampling were included in this plot.

Figure A.12: The mean number of puerulus counted per collector group and calendar year (square-root transformed) for <u>Kaikoura</u> collector groups. Collector groups are organised from north to south. Only collector group-year combinations with at least six months of sampling were included in this plot.

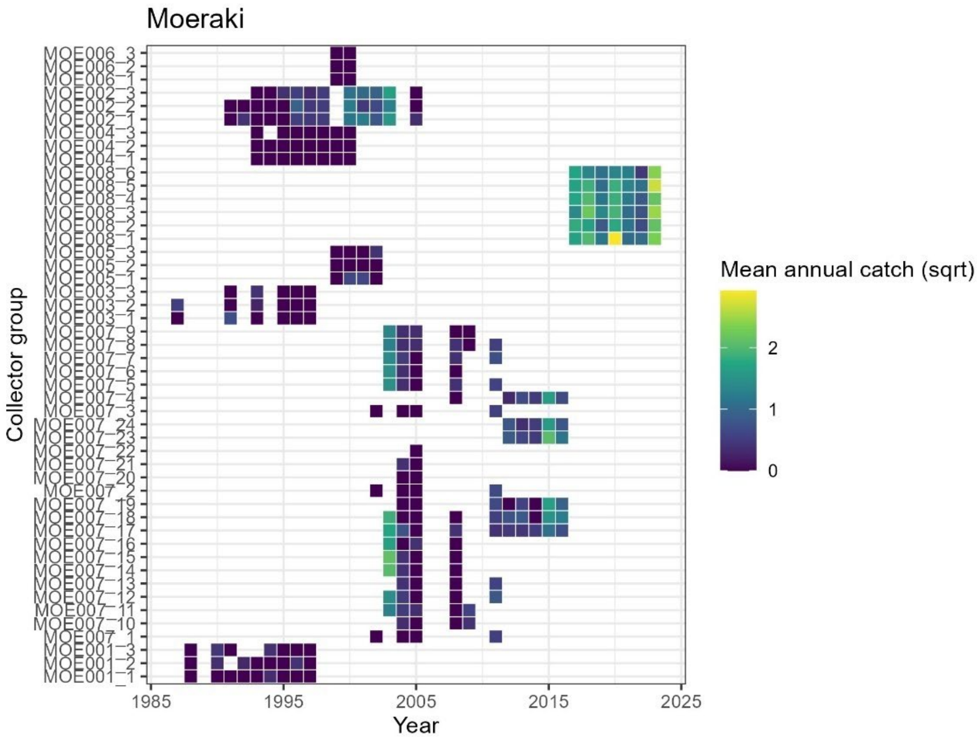

Figure A.13: The mean number of puerulus counted per collector group and calendar year (square-root transformed) for <u>Moeraki</u> collector groups. Collector groups are organised from north to south. Only collector group-year combinations with at least six months of sampling were included in this plot.

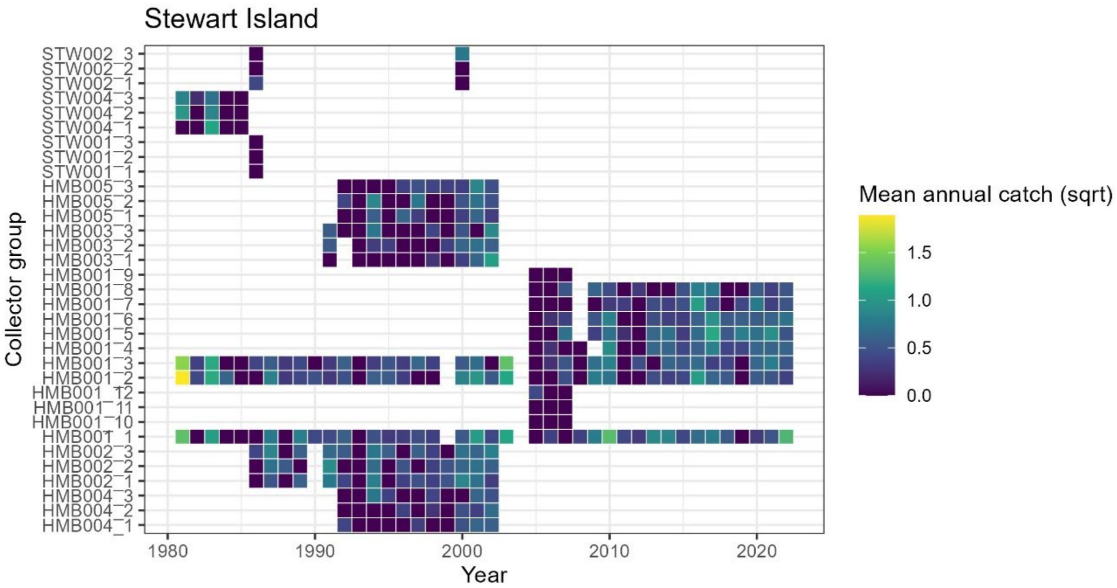

Figure A.14: The mean number of puerulus counted per collector group and calendar year (square-root transformed) for <u>Stewart Island</u> collector groups. Collector groups are organised from north to south. Only collector group-year combinations with at least six months of sampling were included in this plot.

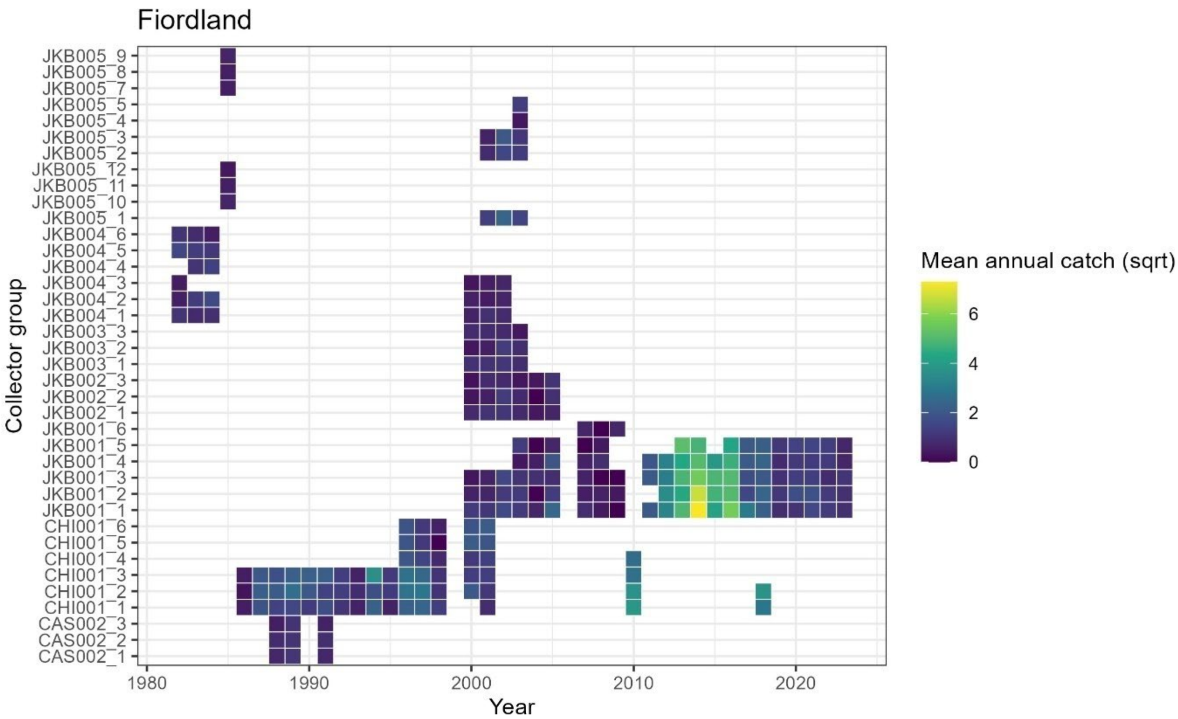

Figure A.15: The mean number of puerulus counted per collector group and calendar year (square-root transformed) for <u>Fiordland</u> collector groups. Collector groups are organised from north to south. Only collector group-year combinations with at least six months of sampling were included in this plot.

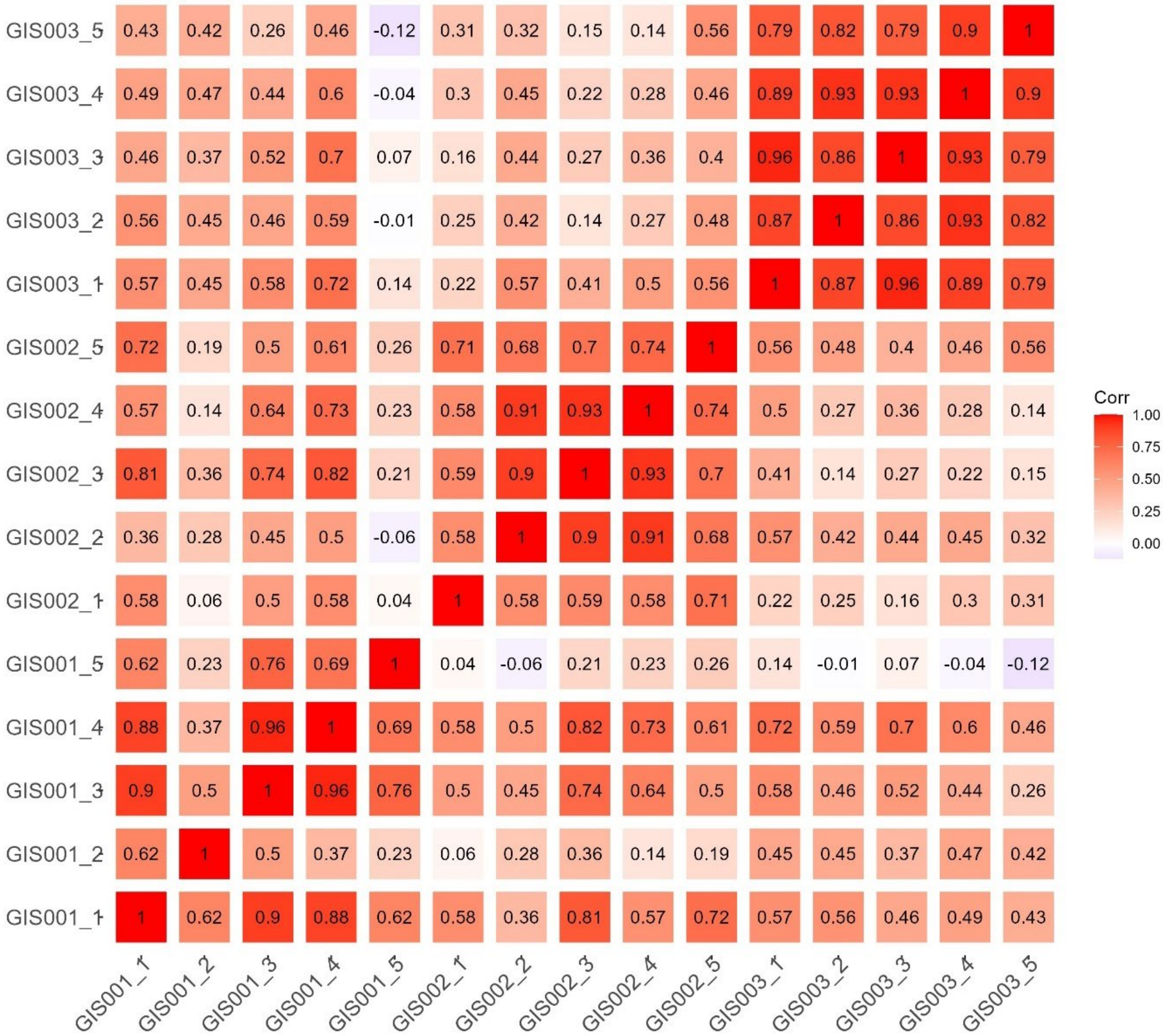

Figure A.16: The Pearson product moment correlation coefficient of mean annual puerulus counts comparing individual collectors in the <u>Gisborne</u> collector site. Only collectors with at least 10 years of measurements are included in this plot.

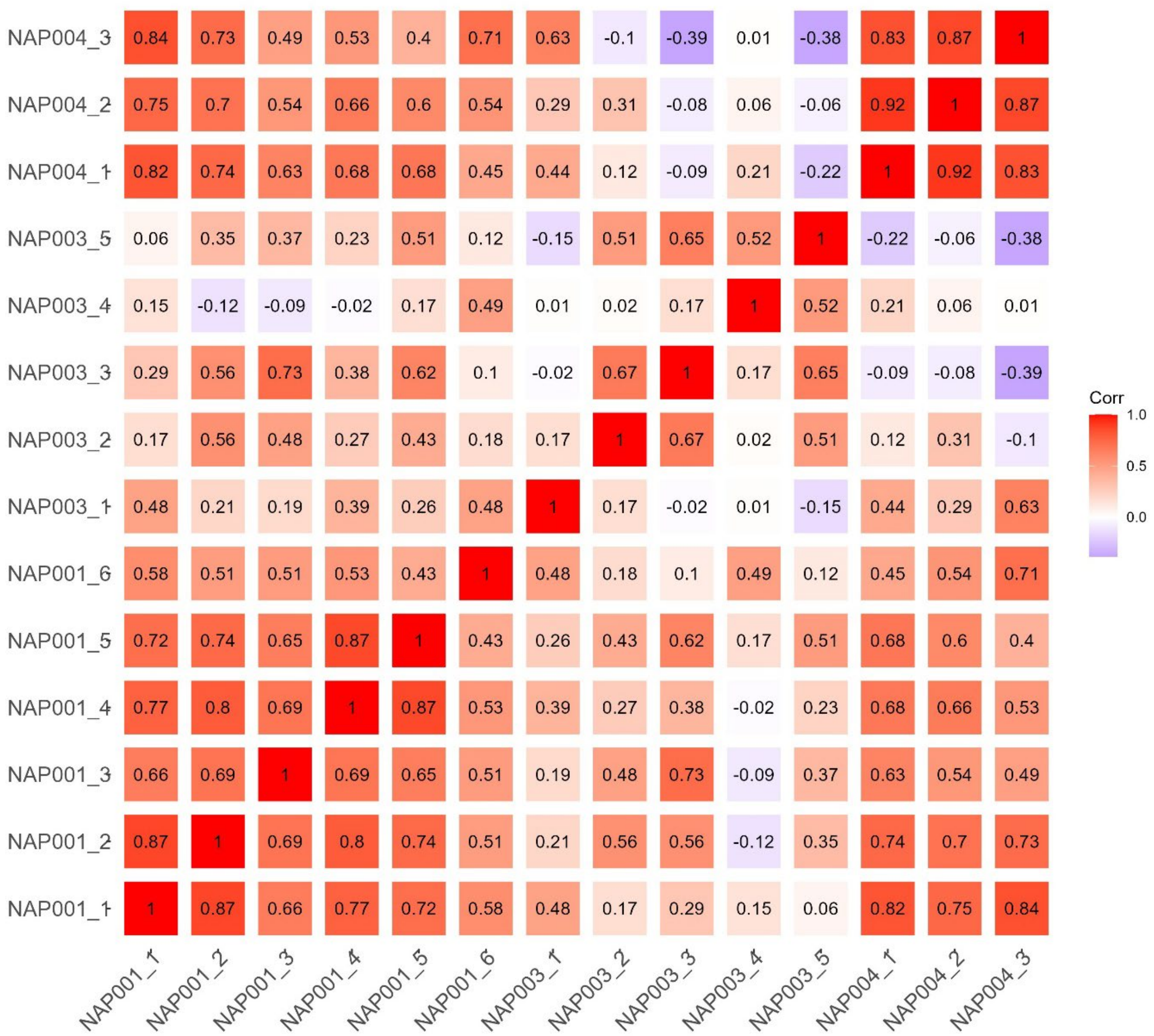

Figure A.17: The Pearson product moment correlation coefficient of mean annual puerulus counts comparing individual collectors in the <u>Napier</u> collector site. Only collectors with at least 10 years of measurements are included in this plot.

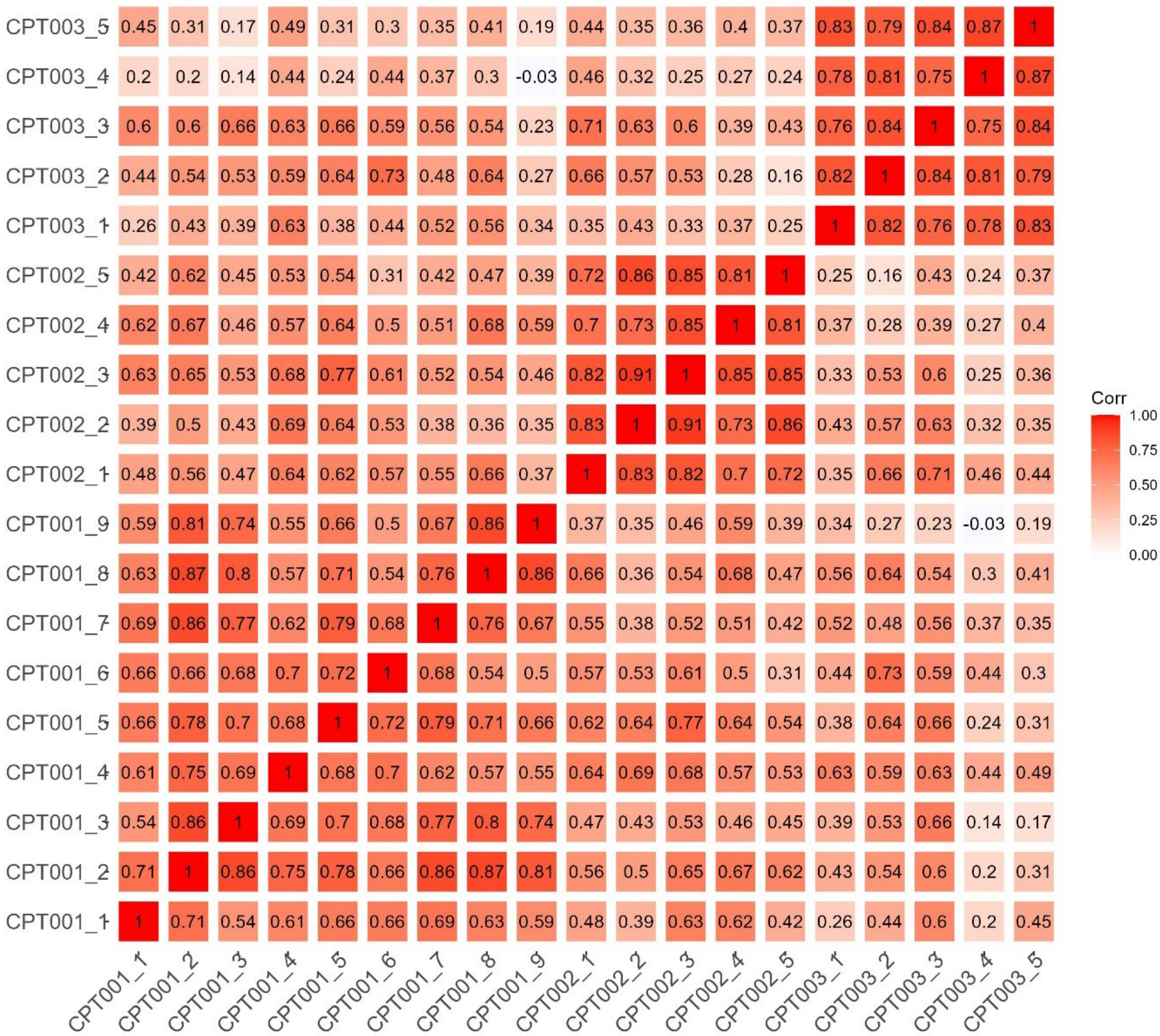

Figure A.18: The Pearson product moment correlation coefficient of mean annual puerulus counts comparing individual collectors in the Castlepoint collector site. Only collectors with at least 10 years of measurements are included in this plot.

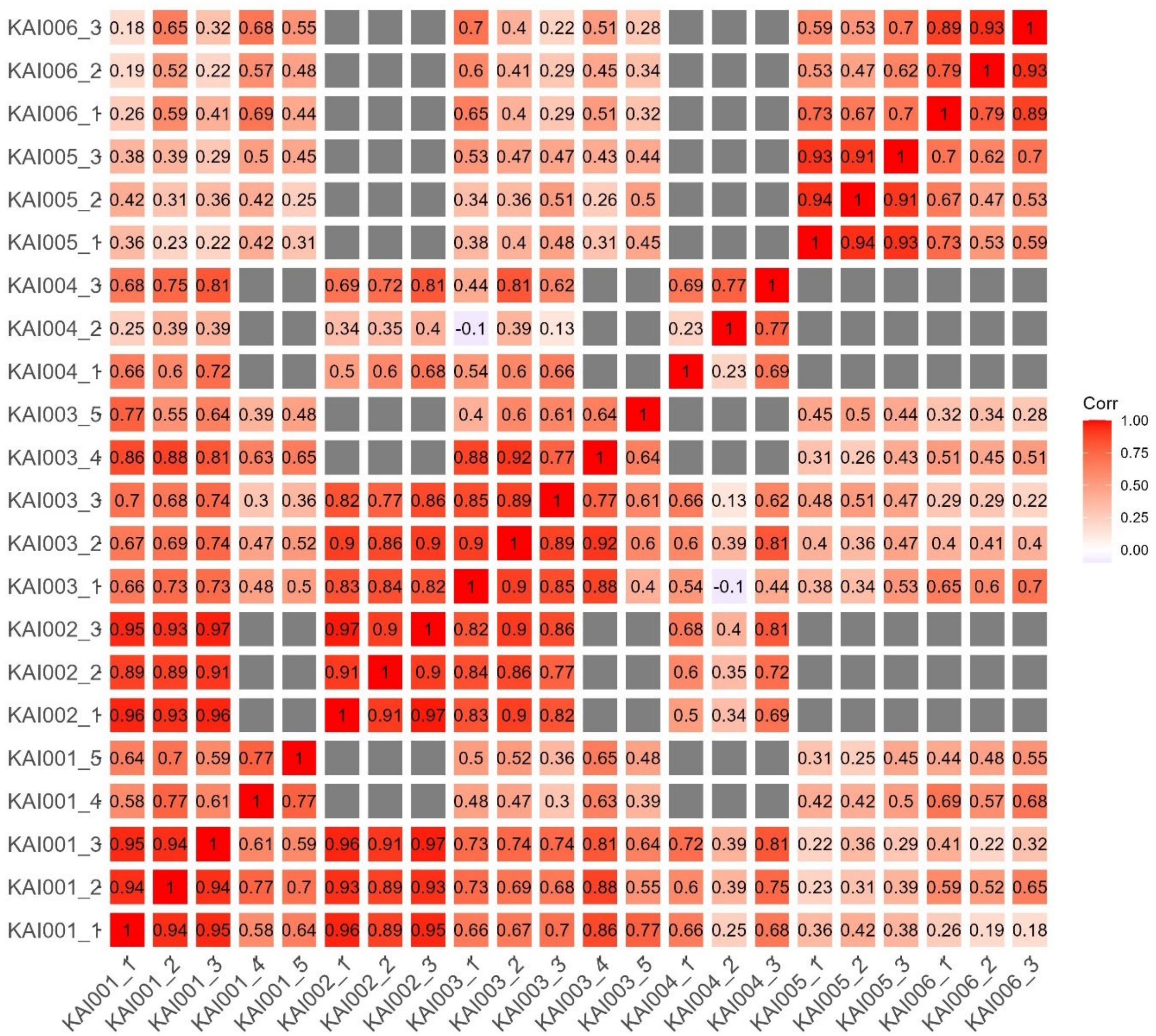

Figure A.19: The Pearson product moment correlation coefficient of mean annual puerulus counts comparing individual collectors in the <u>Kaikoura</u> collector site. Dark grey tiles indicate that the time periods for the respective pair of collectors were non-overlapping. Only collectors with at least 10 years of measurements are included in this plot.

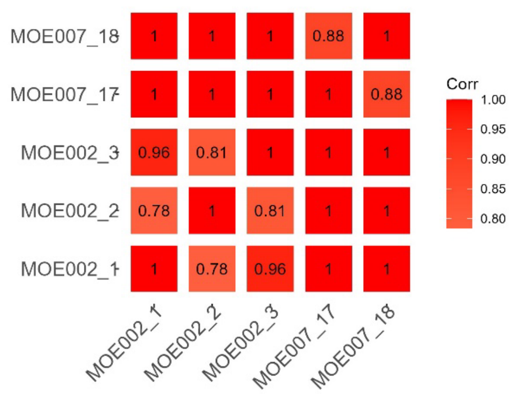

Figure A.20: The Pearson product moment correlation coefficient of mean annual puerulus counts comparing individual collectors in the <u>Moeraki</u> collector site. Only collectors with at least 10 years of measurements are included in this plot.

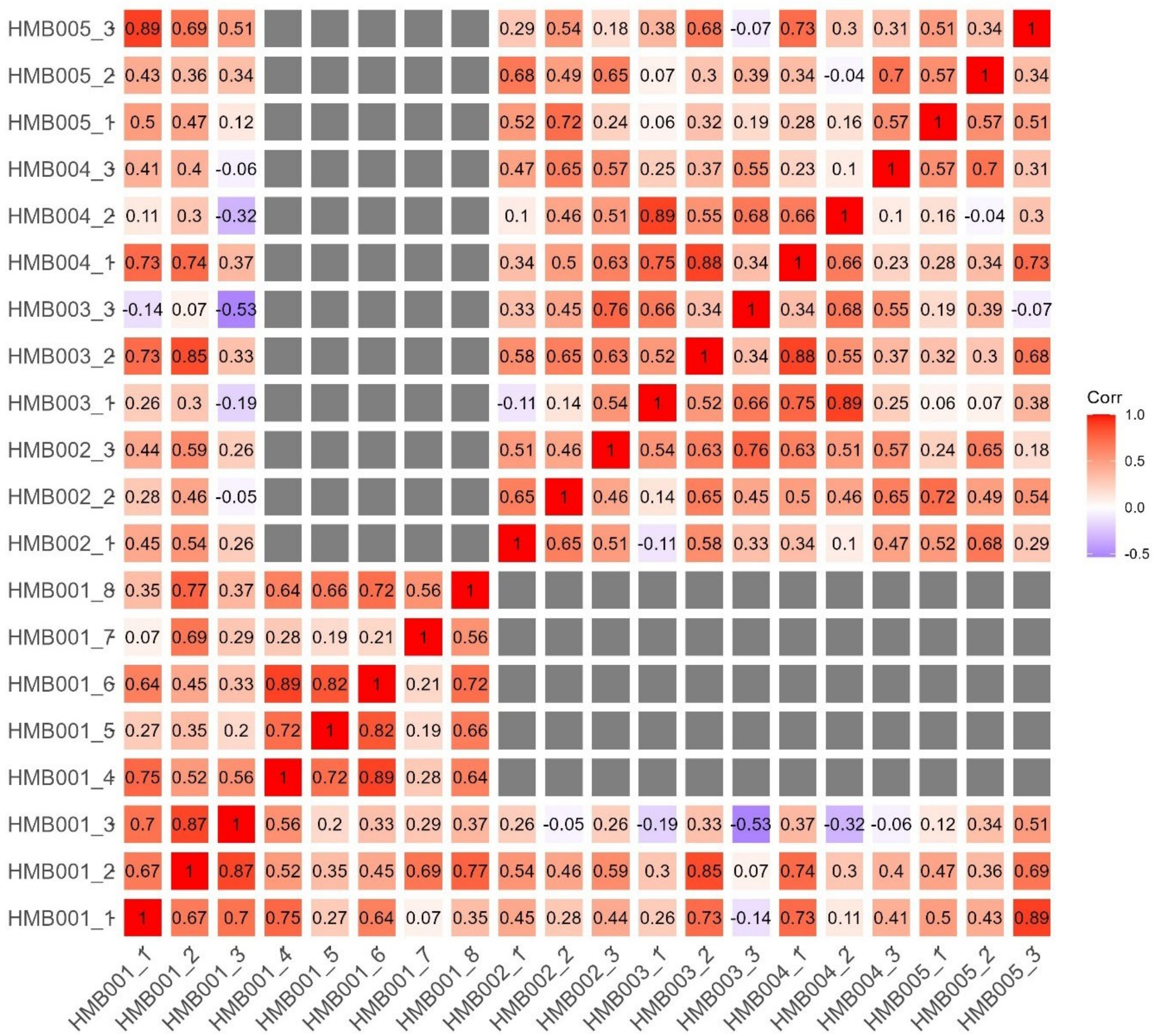

Figure A.21: The Pearson product moment correlation coefficient of mean annual puerulus counts comparing individual collectors in the Halfmoon Bay collector site. Dark grey tiles indicate that the time periods for the respective pair of collectors were non-overlapping. Only collectors with at least 10 years of measurements are included in this plot.

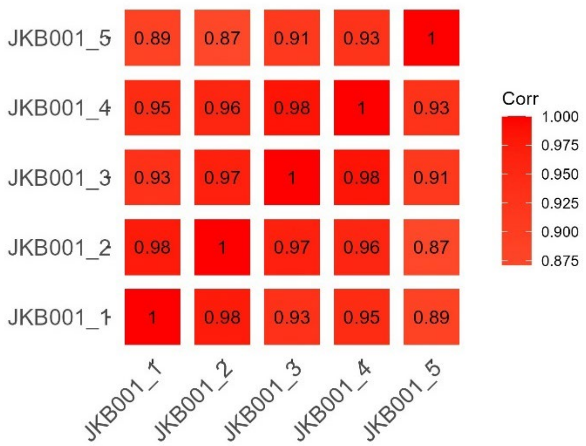

Figure A.22: The Pearson product moment correlation coefficient of mean annual puerulus counts comparing individual collectors in the Jackson Bay collector site. Only collectors with at least 10 years of measurements are included in this plot.

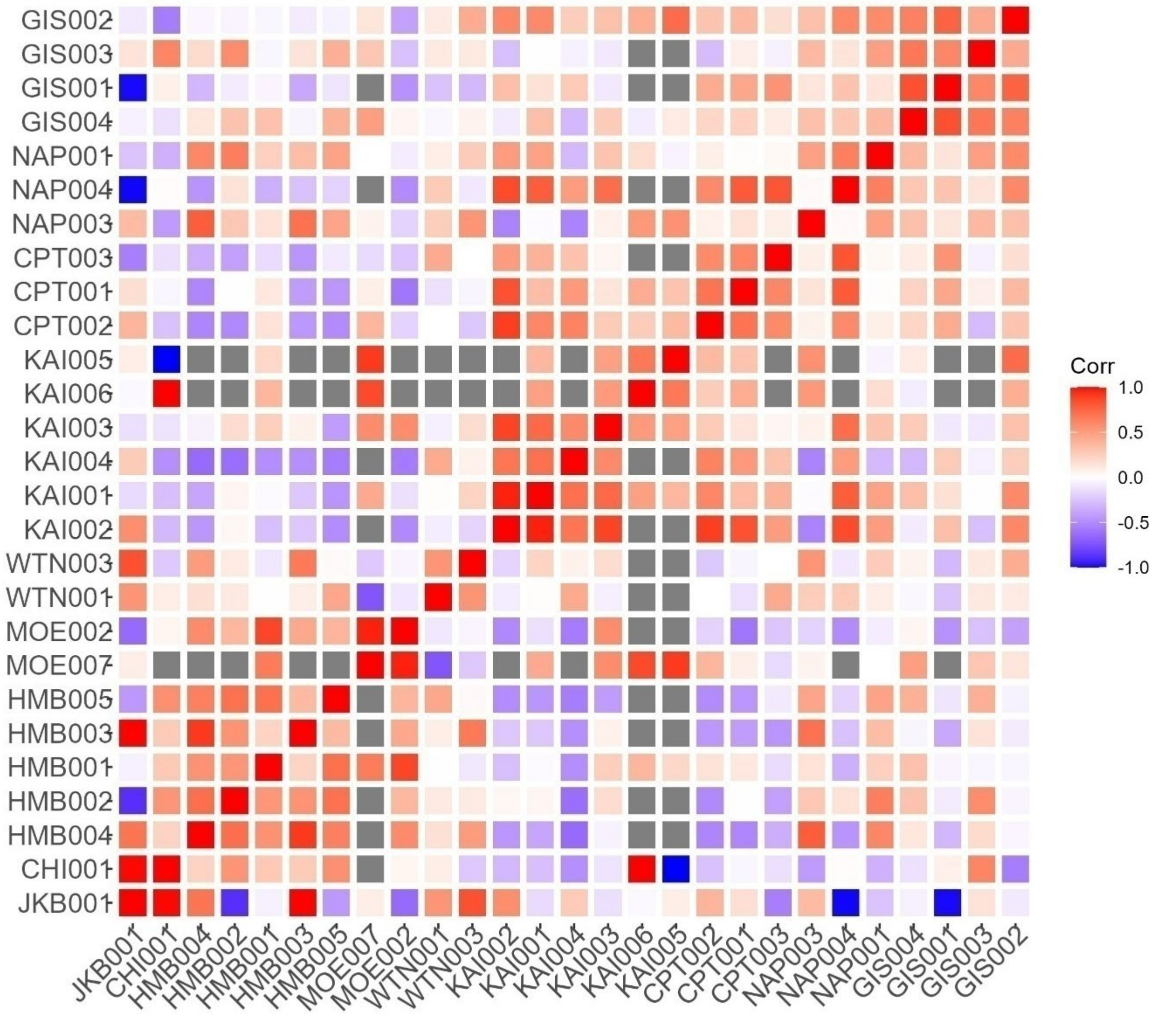

Figure A.23: The Pearson product moment correlation coefficient of mean annual puerulus counts comparing collector groups. Dark grey tiles indicate that the time periods for the respective pair of collector groups were non-overlapping.

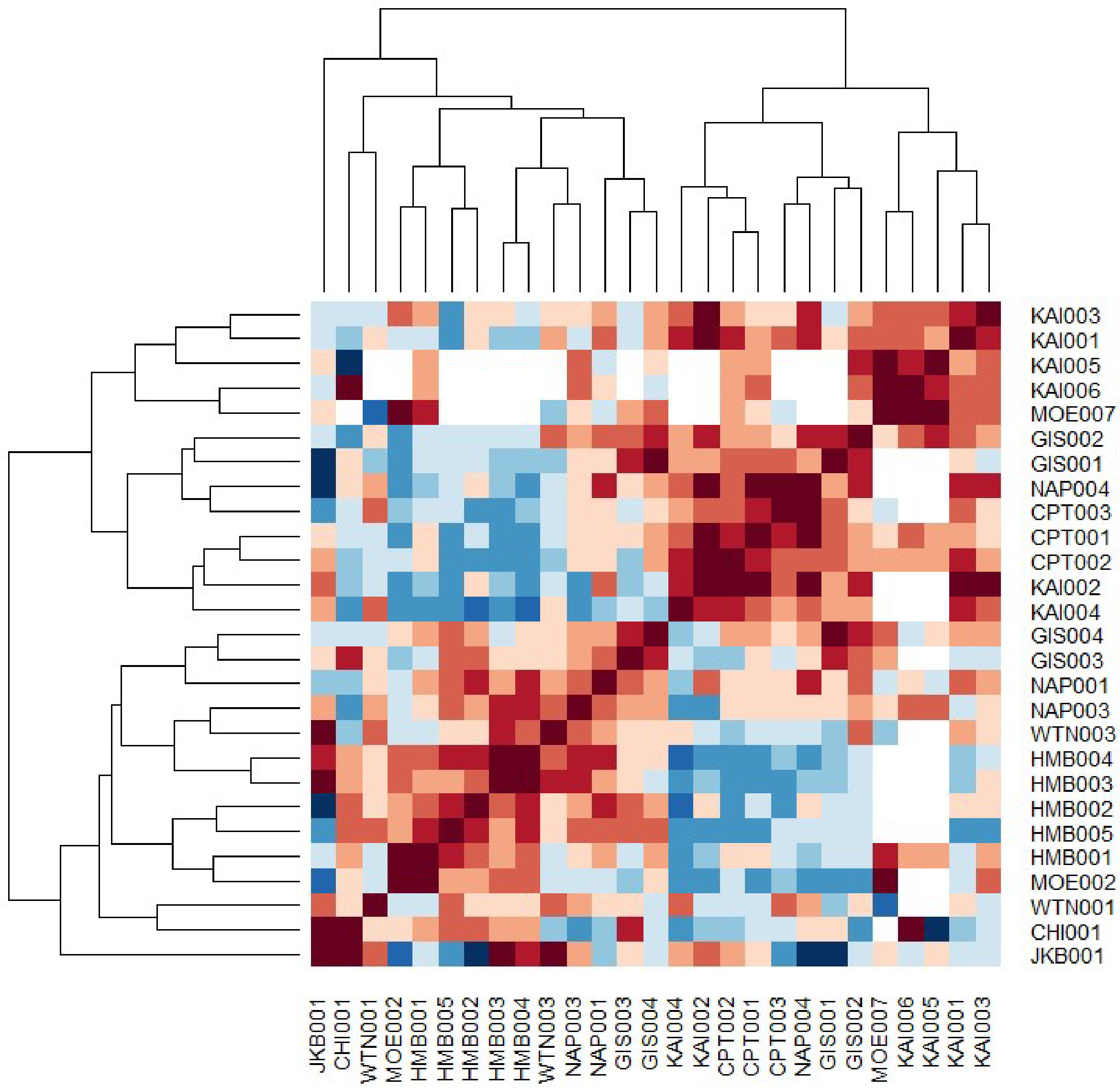

Figure A.24: Correlation matrix of monthly puerulus counts comparing collector groups. Collector groups within sites are organised based on similarity determined from hierarchical clustering, also represented by dendrograms. White tiles indicate that the time periods for the respective pair of collector groups were non-overlapping.

Appendix B. Additional figures and plots from the puerulus data re-analysis

Table B.1: Comparison of models used to explore alternative error distributions for generating puerulus settlement series. The shaded models were within 4 SE of the optimal model in terms of ELPD, so were not differentiated on this basis.

Model label	Assumed error distribution	Bayesian R-squared (95% credible interval)	δ-ELPD	SE δ-ELPD	δ-LOO IC	SE LOO IC
fit_error_nb	Negative binomial	0.510 (0.488 – 0.530)	0.0	0.0	0.0	477.5
fit_error_zinb	Zero-inflated negative binomial	0.504 (0.497 – 0.511)	-1.1	1.8	2.2	477.8
fit_error_pois	Zero-inflated Poisson	0.509 (0.489 – 0.528)	-9 896.1	446.8	19 792.1	1 146.1
fit_error_zip	Poisson	0.407 (0.398 – 0.416)	-12 257.4	477.6	24 514.8	1 221.2

Table B.2: Comparison of models used to explore alternative model structures for generating puerulus settlement series. The shaded models were within 4 SE of the optimal model in terms of ELPD, so were not differentiated on this basis.

Model label	Model structure	Bayesian R-squared (95% credible interval)	δ-ELPD	SE δ-ELPD	δ-LOO IC	SE LOO IC
fit5	catch ~ (1 | site) + (1 | site:year) + (1 | group:month) + (1 | site:group) + (1 | site:group:collector_id)	0.483 (0.458 – 0.507)	0.0	0.0	0.0	475.0
fit4	catch ~ (1 | site) + (1 | site:year) + (1 | site:month) + (1 | site:group) + (1 | site:group:collector_id)	0.509 (0.489 – 0.529)	-404.5	36.2	809.1	477.7
fit3	catch ~ (1 | site) + (1 | site:year) + (1 | site:month) + (1 | site:group)	0.501 (0.482 – 0.520)	-497.7	39.4	995.4	479.6
fit2	catch ~ (1 | site) + (1 | site:year) + (1 | site:month)	0.379 (0.353 – 0.406)	-2 172.5	75.2	4 345.0	496.0
fit1	catch ~ (1 | site) + (1 | site:year)	0.253 (0.225 – 0.287)	-5 069.0	95.7	10 138.0	503.8

Table B.3: Comparison of models exploring alternative year definitions for model structures for generating puerulus settlement series. The model structures for both models were as *fit5* in Table B.2. The shaded models were within 4 SE of the optimal model in terms of ELPD, so were not differentiated on this basis.

Model label	Year definition	Bayesian R-squared (95% credible interval)	δ-ELPD	SE δ-ELPD	δ-LOO IC	SE LOO IC

fit5	Calendar year	0.483 (0.458 – 0.507)	0.0	0.0	0.0	475.0
fit6	Fishing year	0.489 (0.463 – 0.516)	-140.3	48.2	280.5	476.5

Table B.4: Final puerulus settlement series by year for Gisborne ('GIS').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	1.070	0.295	1.040	0.591	1.700	0.027	0.244	0.039	-0.525	0.530
1980	0.991	0.263	0.958	0.575	1.600	-0.043	0.235	-0.043	-0.553	0.470
1981	0.808	0.201	0.784	0.474	1.240	-0.244	0.222	-0.244	-0.746	0.217
1982	1.220	0.311	1.190	0.704	1.940	0.163	0.228	0.173	-0.351	0.665
1983	0.858	0.272	0.811	0.467	1.500	-0.200	0.275	-0.210	-0.761	0.406
1984	1.030	0.305	0.984	0.562	1.770	-0.010	0.259	-0.016	-0.577	0.570
1985	1.910	0.565	1.810	1.070	3.320	0.609	0.259	0.593	0.070	1.200
1986	1.100	0.332	1.060	0.602	1.940	0.054	0.263	0.057	-0.508	0.662
1987	2.650	0.481	2.600	1.830	3.750	0.958	0.167	0.954	0.606	1.320
1988	2.150	0.335	2.110	1.600	2.870	0.755	0.145	0.749	0.472	1.060
1989	1.150	0.178	1.140	0.829	1.540	0.125	0.145	0.128	-0.187	0.433
1990	0.636	0.105	0.632	0.449	0.857	-0.466	0.153	-0.458	-0.801	-0.155
1991	1.090	0.160	1.080	0.815	1.440	0.078	0.137	0.076	-0.205	0.361
1992	1.970	0.268	1.960	1.500	2.560	0.671	0.127	0.672	0.405	0.938
1993	2.280	0.315	2.250	1.740	2.950	0.813	0.130	0.809	0.556	1.080
1994	3.170	0.400	3.140	2.500	4.040	1.140	0.119	1.140	0.916	1.400
1995	1.100	0.142	1.090	0.864	1.420	0.089	0.121	0.085	-0.146	0.347
1996	1.520	0.208	1.500	1.160	1.940	0.411	0.128	0.408	0.149	0.663
1997	1.320	0.169	1.310	1.030	1.690	0.269	0.120	0.269	0.025	0.522
1998	1.860	0.231	1.840	1.480	2.370	0.614	0.117	0.612	0.393	0.864
1999	0.417	0.057	0.414	0.320	0.548	-0.884	0.129	-0.883	-1.140	-0.602
2000	1.120	0.148	1.110	0.860	1.450	0.108	0.123	0.101	-0.151	0.369
2001	1.220	0.154	1.220	0.959	1.550	0.194	0.118	0.197	-0.042	0.441
2002	1.100	0.147	1.090	0.852	1.410	0.089	0.125	0.086	-0.160	0.346
2003	2.200	0.299	2.180	1.700	2.810	0.780	0.127	0.781	0.532	1.030
2004	0.935	0.142	0.922	0.691	1.230	-0.078	0.141	-0.081	-0.370	0.205
2005	2.160	0.308	2.130	1.650	2.880	0.761	0.133	0.757	0.501	1.060
2006	0.528	0.085	0.520	0.383	0.720	-0.651	0.149	-0.654	-0.960	-0.328
2007	0.411	0.083	0.404	0.266	0.587	-0.909	0.183	-0.906	-1.320	-0.532
2008	0.774	0.130	0.764	0.552	1.060	-0.270	0.155	-0.270	-0.595	0.057
2009	1.190	0.185	1.170	0.870	1.590	0.158	0.145	0.159	-0.139	0.463
2010	0.640	0.113	0.630	0.453	0.883	-0.462	0.163	-0.462	-0.791	-0.125
2011	0.297	0.066	0.295	0.183	0.437	-1.240	0.199	-1.220	-1.700	-0.827
2012	0.681	0.116	0.674	0.483	0.941	-0.398	0.157	-0.394	-0.727	-0.061
2013	0.880	0.151	0.876	0.618	1.200	-0.143	0.159	-0.132	-0.482	0.183
2014	0.445	0.087	0.435	0.293	0.633	-0.828	0.178	-0.832	-1.230	-0.457
2015	1.800	0.296	1.760	1.310	2.440	0.573	0.152	0.567	0.274	0.891
2016	2.000	0.323	1.970	1.420	2.710	0.678	0.150	0.678	0.354	0.998
2017	0.413	0.080	0.405	0.276	0.588	-0.902	0.177	-0.904	-1.290	-0.531
2018	0.392	0.075	0.386	0.264	0.557	-0.955	0.175	-0.952	-1.330	-0.585
2019	0.668	0.115	0.662	0.455	0.910	-0.418	0.159	-0.413	-0.789	-0.094
2020	0.995	0.164	0.980	0.738	1.370	-0.019	0.153	-0.021	-0.304	0.312
2021	0.988	0.202	0.969	0.654	1.440	-0.033	0.186	-0.031	-0.424	0.366
2022	1.120	0.246	1.100	0.723	1.710	0.094	0.198	0.095	-0.325	0.537
2023	0.375	0.158	0.350	0.150	0.766	-1.060	0.351	-1.050	-1.900	-0.267

Table B.5: Final puerulus settlement series by year for Napier ('NAP').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	0.858	0.158	0.849	0.581	1.210	-0.170	0.169	-0.164	-0.543	0.187
1980	1.370	0.208	1.360	1.020	1.820	0.305	0.141	0.304	0.022	0.599
1981	1.970	0.277	1.960	1.460	2.530	0.669	0.132	0.673	0.377	0.930
1982	1.080	0.169	1.070	0.770	1.420	0.061	0.146	0.066	-0.262	0.351
1983	1.210	0.201	1.190	0.875	1.690	0.178	0.153	0.174	-0.133	0.523
1984	0.494	0.108	0.486	0.310	0.727	-0.730	0.197	-0.722	-1.170	-0.318
1985	0.242	0.060	0.235	0.142	0.367	-1.450	0.223	-1.450	-1.950	-1.000
1986	1.220	0.940	1.030	0.238	3.040	-0.004	0.571	0.034	-1.430	1.110
1987	1.170	0.779	1.020	0.260	2.730	-0.020	0.512	0.016	-1.350	1.010
1988	1.350	0.325	1.300	0.825	2.180	0.270	0.216	0.260	-0.193	0.778
1989	1.170	0.217	1.150	0.821	1.660	0.143	0.170	0.143	-0.197	0.509
1990	1.020	0.188	1.010	0.715	1.440	0.006	0.169	0.006	-0.336	0.363
1991	2.870	0.349	2.840	2.250	3.640	1.050	0.115	1.040	0.811	1.290
1992	2.060	0.238	2.040	1.640	2.590	0.716	0.109	0.714	0.496	0.950
1993	2.160	0.261	2.150	1.700	2.720	0.762	0.114	0.765	0.529	1.000
1994	1.620	0.180	1.610	1.290	1.990	0.477	0.105	0.475	0.255	0.687
1995	0.998	0.111	0.988	0.809	1.240	-0.008	0.106	-0.012	-0.211	0.219
1996	1.460	0.149	1.450	1.200	1.760	0.373	0.097	0.374	0.183	0.566
1997	1.330	0.140	1.320	1.080	1.630	0.280	0.100	0.276	0.078	0.490
1998	1.250	0.125	1.240	1.030	1.510	0.220	0.095	0.218	0.029	0.413
1999	0.411	0.054	0.408	0.317	0.528	-0.897	0.123	-0.898	-1.150	-0.638
2000	0.744	0.085	0.743	0.584	0.927	-0.303	0.108	-0.297	-0.537	-0.076
2001	1.390	0.151	1.370	1.110	1.700	0.322	0.103	0.318	0.107	0.531
2002	1.580	0.169	1.570	1.260	1.920	0.449	0.102	0.453	0.234	0.651
2003	1.540	0.172	1.540	1.250	1.910	0.428	0.106	0.430	0.224	0.645
2004	1.130	0.123	1.120	0.914	1.400	0.117	0.103	0.117	-0.090	0.337
2005	1.350	0.151	1.340	1.070	1.660	0.291	0.106	0.293	0.069	0.509
2006	0.728	0.090	0.724	0.562	0.926	-0.325	0.116	-0.323	-0.576	-0.077
2007	1.080	0.133	1.070	0.842	1.360	0.065	0.117	0.063	-0.172	0.304
2008	0.685	0.079	0.681	0.540	0.846	-0.385	0.110	-0.384	-0.616	-0.167
2009	0.886	0.106	0.880	0.695	1.110	-0.128	0.113	-0.128	-0.364	0.100
2010	1.440	0.162	1.430	1.160	1.790	0.358	0.107	0.359	0.147	0.583
2011	0.419	0.058	0.412	0.323	0.535	-0.879	0.129	-0.887	-1.130	-0.626
2012	0.933	0.115	0.928	0.717	1.170	-0.077	0.117	-0.075	-0.333	0.158
2013	1.080	0.144	1.070	0.824	1.380	0.065	0.126	0.065	-0.193	0.325
2014	1.020	0.130	1.000	0.794	1.310	0.007	0.121	0.001	-0.231	0.267
2015	1.070	0.143	1.070	0.807	1.380	0.062	0.125	0.068	-0.214	0.320
2016	0.855	0.122	0.850	0.611	1.110	-0.167	0.134	-0.162	-0.493	0.104
2017	0.682	0.110	0.674	0.495	0.912	-0.396	0.150	-0.394	-0.703	-0.092
2018	0.681	0.105	0.671	0.496	0.899	-0.396	0.144	-0.399	-0.701	-0.107
2019	0.584	0.088	0.580	0.429	0.765	-0.550	0.141	-0.545	-0.846	-0.268
2020	0.540	0.090	0.533	0.384	0.739	-0.629	0.154	-0.629	-0.956	-0.302
2021	0.829	0.130	0.817	0.606	1.100	-0.200	0.146	-0.202	-0.502	0.098
2022	0.813	0.122	0.807	0.600	1.080	-0.218	0.140	-0.214	-0.511	0.080
2023	1.310	0.200	1.300	0.954	1.740	0.262	0.141	0.263	-0.047	0.555

Table B.6: Final puerulus settlement series by year for Castlepoint ('CPT').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	1.250	0.969	1.070	0.282	3.410	0.026	0.573	0.063	-1.270	1.230
1980	1.240	0.902	1.030	0.290	3.080	0.023	0.548	0.028	-1.240	1.130
1981	1.380	0.735	1.220	0.456	3.370	0.197	0.427	0.202	-0.785	1.220
1982	0.561	0.132	0.549	0.332	0.857	-0.605	0.212	-0.600	-1.100	-0.155
1983	1.090	0.128	1.080	0.858	1.360	0.081	0.111	0.081	-0.153	0.307
1984	1.010	0.123	1.000	0.798	1.280	0.006	0.115	0.003	-0.226	0.244
1985	0.794	0.119	0.785	0.582	1.050	-0.241	0.140	-0.242	-0.541	0.052
1986	0.487	0.078	0.484	0.351	0.647	-0.731	0.148	-0.725	-1.050	-0.436
1987	1.560	0.195	1.540	1.200	1.970	0.436	0.118	0.434	0.180	0.678
1988	0.821	0.113	0.812	0.622	1.060	-0.207	0.129	-0.208	-0.475	0.062
1989	1.320	0.179	1.310	1.000	1.680	0.265	0.127	0.270	0.003	0.519
1990	0.833	0.110	0.827	0.632	1.070	-0.192	0.124	-0.190	-0.459	0.067
1991	1.730	0.200	1.710	1.390	2.170	0.541	0.109	0.539	0.331	0.775
1992	2.120	0.206	2.110	1.730	2.540	0.746	0.093	0.745	0.549	0.933
1993	1.270	0.127	1.260	1.050	1.550	0.236	0.095	0.232	0.051	0.440
1994	0.823	0.082	0.818	0.682	0.999	-0.200	0.095	-0.201	-0.383	-0.001
1995	0.778	0.076	0.774	0.636	0.939	-0.255	0.093	-0.257	-0.452	-0.063
1996	1.330	0.128	1.330	1.110	1.600	0.284	0.092	0.283	0.104	0.469
1997	1.190	0.112	1.180	0.978	1.430	0.167	0.090	0.168	-0.022	0.355
1998	1.410	0.132	1.410	1.170	1.690	0.341	0.089	0.340	0.158	0.527
1999	0.870	0.077	0.867	0.727	1.030	-0.143	0.084	-0.142	-0.319	0.028
2000	0.525	0.055	0.523	0.424	0.638	-0.650	0.099	-0.648	-0.859	-0.449
2001	0.667	0.068	0.662	0.547	0.810	-0.410	0.097	-0.412	-0.604	-0.210
2002	0.623	0.065	0.618	0.514	0.763	-0.478	0.099	-0.482	-0.666	-0.271
2003	0.841	0.087	0.838	0.679	1.020	-0.178	0.098	-0.176	-0.388	0.021
2004	0.587	0.056	0.585	0.487	0.708	-0.537	0.091	-0.536	-0.720	-0.346
2005	1.040	0.093	1.030	0.869	1.230	0.033	0.086	0.033	-0.140	0.210
2006	0.536	0.053	0.532	0.441	0.644	-0.629	0.095	-0.631	-0.818	-0.440
2007	0.738	0.071	0.732	0.614	0.898	-0.308	0.092	-0.312	-0.488	-0.107
2008	0.849	0.089	0.842	0.692	1.040	-0.169	0.100	-0.171	-0.369	0.038
2009	0.818	0.083	0.819	0.665	0.989	-0.207	0.097	-0.199	-0.409	-0.011
2010	1.320	0.124	1.320	1.110	1.590	0.275	0.090	0.275	0.108	0.462
2011	0.752	0.072	0.747	0.622	0.902	-0.290	0.092	-0.292	-0.475	-0.103
2012	0.604	0.064	0.602	0.490	0.734	-0.510	0.101	-0.507	-0.714	-0.309
2013	1.540	0.146	1.530	1.280	1.850	0.429	0.090	0.425	0.248	0.615
2014	0.790	0.079	0.784	0.649	0.963	-0.240	0.096	-0.243	-0.432	-0.038
2015	1.120	0.110	1.120	0.935	1.350	0.113	0.094	0.109	-0.067	0.302
2016	2.050	0.192	2.040	1.700	2.480	0.714	0.090	0.712	0.531	0.908
2017	0.908	0.095	0.904	0.740	1.110	-0.102	0.100	-0.101	-0.301	0.106
2018	0.834	0.086	0.831	0.680	1.010	-0.187	0.098	-0.185	-0.386	0.015
2019	1.290	0.136	1.280	1.050	1.590	0.248	0.100	0.245	0.049	0.461
2020	1.210	0.112	1.200	0.993	1.450	0.183	0.089	0.180	-0.007	0.370
2021	2.520	0.258	2.500	2.070	3.080	0.921	0.098	0.917	0.725	1.120
2022	1.630	0.152	1.630	1.340	1.920	0.484	0.090	0.486	0.295	0.654
2023	2.070	0.225	2.060	1.670	2.530	0.724	0.103	0.724	0.515	0.929

Table B.7: Final puerulus settlement series by year for Kaikoura ('KAI').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	1.270	1.020	1.050	0.283	3.430	0.023	0.590	0.044	-1.260	1.230
1980	0.920	0.603	0.763	0.241	2.540	-0.268	0.504	-0.270	-1.420	0.930
1981	1.310	0.304	1.260	0.822	2.020	0.240	0.209	0.234	-0.196	0.702
1982	0.107	0.038	0.101	0.050	0.190	-2.300	0.304	-2.290	-3.000	-1.660
1983	0.746	0.139	0.740	0.497	1.020	-0.311	0.171	-0.301	-0.698	0.023
1984	0.258	0.066	0.251	0.150	0.402	-1.390	0.226	-1.380	-1.900	-0.911
1985	0.291	0.076	0.280	0.171	0.474	-1.270	0.233	-1.270	-1.760	-0.747
1986	0.178	0.056	0.171	0.092	0.298	-1.780	0.273	-1.760	-2.380	-1.210
1987	1.000	0.200	0.990	0.671	1.450	-0.017	0.182	-0.010	-0.399	0.368
1988	0.550	0.117	0.540	0.357	0.800	-0.620	0.193	-0.617	-1.030	-0.223
1989	0.917	0.166	0.903	0.642	1.290	-0.103	0.166	-0.102	-0.443	0.251
1990	0.352	0.083	0.346	0.213	0.536	-1.070	0.213	-1.060	-1.550	-0.623
1991	6.170	0.866	6.150	4.640	7.940	1.810	0.131	1.820	1.540	2.070
1992	6.980	0.993	6.900	5.240	8.950	1.930	0.133	1.930	1.660	2.190
1993	2.910	0.422	2.880	2.170	3.840	1.060	0.136	1.060	0.774	1.340
1994	0.966	0.182	0.950	0.659	1.370	-0.052	0.173	-0.051	-0.418	0.316
1995	1.160	0.201	1.140	0.824	1.590	0.134	0.160	0.135	-0.194	0.461
1996	0.819	0.176	0.804	0.535	1.220	-0.223	0.195	-0.218	-0.625	0.198
1997	1.740	0.350	1.710	1.150	2.510	0.536	0.183	0.534	0.140	0.921
1998	2.180	0.439	2.140	1.460	3.110	0.760	0.183	0.760	0.380	1.140
1999	1.600	0.303	1.580	1.080	2.260	0.453	0.173	0.457	0.074	0.817
2000	1.230	0.204	1.210	0.861	1.680	0.194	0.153	0.193	-0.150	0.518
2001	0.488	0.103	0.478	0.313	0.705	-0.739	0.192	-0.738	-1.160	-0.350
2002	1.430	0.252	1.410	0.995	1.960	0.339	0.163	0.340	-0.005	0.675
2003	5.360	0.787	5.270	4.030	7.090	1.670	0.137	1.660	1.390	1.960
2004	1.790	0.280	1.770	1.320	2.380	0.569	0.145	0.571	0.276	0.865
2005	2.250	0.343	2.230	1.690	3.020	0.802	0.142	0.801	0.525	1.110
2006	1.760	0.273	1.740	1.290	2.360	0.552	0.144	0.553	0.254	0.857
2007	1.160	0.178	1.150	0.862	1.530	0.141	0.142	0.141	-0.149	0.425
2008	1.880	0.265	1.860	1.410	2.410	0.623	0.132	0.623	0.345	0.879
2009	0.406	0.077	0.398	0.280	0.575	-0.920	0.175	-0.921	-1.270	-0.554
2010	1.590	0.223	1.570	1.200	2.080	0.454	0.131	0.453	0.182	0.733
2011	0.440	0.085	0.432	0.296	0.635	-0.840	0.176	-0.840	-1.220	-0.455
2012	1.280	0.191	1.270	0.941	1.700	0.236	0.139	0.239	-0.061	0.528
2013	0.714	0.126	0.701	0.509	0.982	-0.352	0.163	-0.355	-0.676	-0.018
2014	0.663	0.113	0.655	0.470	0.907	-0.426	0.158	-0.423	-0.756	-0.097
2015	1.230	0.184	1.230	0.911	1.620	0.196	0.139	0.204	-0.094	0.481
2016	2.050	0.301	2.030	1.550	2.700	0.707	0.137	0.709	0.439	0.995
2017	1.360	0.190	1.340	1.040	1.790	0.298	0.131	0.296	0.041	0.581
2018	0.752	0.113	0.744	0.559	0.982	-0.297	0.140	-0.295	-0.582	-0.019
2019	0.279	0.052	0.275	0.189	0.388	-1.290	0.170	-1.290	-1.660	-0.947
2020	0.589	0.091	0.580	0.431	0.790	-0.541	0.144	-0.544	-0.843	-0.236
2021	1.100	0.172	1.080	0.812	1.470	0.083	0.146	0.078	-0.208	0.383
2022	1.350	0.191	1.330	1.020	1.750	0.290	0.133	0.288	0.019	0.562
2023	2.040	0.284	2.030	1.550	2.630	0.706	0.130	0.708	0.440	0.968

Table B.8: Final puerulus settlement series by year for Moeraki ('MOE').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	3.080	6.390	1.090	0.053	19.700	0.010	1.120	0.082	-2.950	2.980
1980	3.030	5.780	1.100	0.047	19.300	0.030	1.070	0.099	-3.060	2.960
1981	2.680	5.580	0.965	0.060	17.300	-0.048	1.130	-0.035	-2.820	2.850
1982	1.700	2.340	0.957	0.091	7.200	-0.046	0.865	-0.044	-2.400	1.970
1983	9.890	9.030	7.360	1.330	33.700	1.980	0.648	2.000	0.284	3.520
1984	1.010	1.200	0.638	0.074	4.400	-0.480	0.784	-0.449	-2.600	1.480
1985	0.764	1.040	0.417	0.031	3.670	-0.939	0.857	-0.875	-3.490	1.300
1986	0.376	0.402	0.246	0.028	1.400	-1.460	0.727	-1.400	-3.580	0.338
1987	4.220	3.010	3.550	0.798	11.700	1.220	0.539	1.270	-0.226	2.460
1988	0.289	0.296	0.193	0.023	1.090	-1.700	0.705	-1.650	-3.760	0.088
1989	4.120	3.170	3.340	0.675	12.100	1.160	0.571	1.200	-0.393	2.490
1990	1.230	0.960	0.987	0.185	3.710	-0.063	0.578	-0.013	-1.690	1.310
1991	0.445	0.369	0.345	0.060	1.410	-1.110	0.603	-1.070	-2.820	0.342
1992	0.398	0.334	0.310	0.053	1.250	-1.240	0.610	-1.170	-2.950	0.224
1993	0.359	0.297	0.274	0.042	1.190	-1.350	0.603	-1.300	-3.170	0.176
1994	0.318	0.307	0.234	0.037	1.110	-1.500	0.676	-1.450	-3.290	0.105
1995	0.210	0.208	0.158	0.023	0.700	-1.930	0.688	-1.850	-3.780	-0.356
1996	1.180	0.874	0.986	0.189	3.340	-0.070	0.553	-0.014	-1.670	1.210
1997	0.553	0.431	0.446	0.098	1.650	-0.857	0.576	-0.807	-2.330	0.500
1998	0.845	0.637	0.668	0.126	2.530	-0.434	0.562	-0.404	-2.070	0.929
1999	0.315	0.335	0.208	0.029	1.230	-1.580	0.725	-1.570	-3.530	0.208
2000	5.420	3.980	4.330	0.982	15.600	1.450	0.550	1.470	-0.018	2.750
2001	2.690	1.900	2.250	0.478	7.290	0.756	0.534	0.809	-0.738	1.990
2002	1.360	1.040	1.080	0.241	3.990	0.050	0.570	0.080	-1.420	1.380
2003	10.100	6.940	8.300	1.890	28.600	2.090	0.524	2.120	0.637	3.350
2004	0.672	0.489	0.541	0.119	1.960	-0.641	0.547	-0.615	-2.130	0.672
2005	0.169	0.135	0.132	0.025	0.525	-2.060	0.586	-2.020	-3.700	-0.644
2006	0.129	0.119	0.093	0.015	0.406	-2.390	0.654	-2.380	-4.230	-0.901
2007	0.164	0.160	0.111	0.018	0.590	-2.210	0.682	-2.200	-4.000	-0.527
2008	0.155	0.132	0.116	0.021	0.525	-2.180	0.616	-2.150	-3.860	-0.645
2009	0.759	0.606	0.578	0.127	2.360	-0.553	0.587	-0.548	-2.060	0.860
2010	1.900	1.350	1.570	0.324	5.550	0.405	0.537	0.449	-1.130	1.710
2011	1.410	0.967	1.160	0.255	3.870	0.113	0.523	0.145	-1.370	1.350
2012	2.280	1.690	1.860	0.409	6.680	0.580	0.555	0.621	-0.895	1.900
2013	2.060	1.500	1.670	0.362	6.330	0.475	0.548	0.511	-1.020	1.840
2014	0.974	0.789	0.768	0.162	3.090	-0.313	0.593	-0.263	-1.820	1.130
2015	12.600	9.000	10.300	2.310	36.400	2.300	0.538	2.330	0.839	3.590
2016	4.380	3.050	3.640	0.820	12.600	1.250	0.529	1.290	-0.198	2.540
2017	8.960	6.640	7.170	1.500	25.800	1.950	0.555	1.970	0.407	3.250
2018	12.200	9.200	9.580	1.970	37.400	2.250	0.562	2.260	0.679	3.620
2019	3.570	2.710	2.820	0.574	10.500	1.020	0.565	1.040	-0.555	2.350
2020	12.800	9.950	10.100	2.150	39.000	2.300	0.574	2.310	0.763	3.660
2021	3.670	2.860	2.920	0.563	11.400	1.040	0.575	1.070	-0.574	2.430
2022	2.150	1.640	1.680	0.339	6.540	0.502	0.567	0.518	-1.080	1.880
2023	11.900	8.920	9.270	1.900	35.900	2.220	0.561	2.230	0.644	3.580

Table B.9: Final puerulus settlement series by year for Halfmoon Bay ('HMB').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	2.740	4.760	1.070	0.067	17.200	0.057	1.010	0.065	-2.710	2.840
1980	2.380	1.650	1.950	0.477	6.530	0.657	0.526	0.669	-0.740	1.880
1981	11.200	3.350	10.500	6.010	18.400	2.370	0.262	2.360	1.790	2.910
1982	0.684	0.364	0.604	0.205	1.600	-0.515	0.426	-0.503	-1.580	0.469
1983	6.610	1.940	6.410	3.460	11.300	1.850	0.258	1.860	1.240	2.420
1984	0.862	0.498	0.736	0.227	2.100	-0.308	0.456	-0.306	-1.480	0.740
1985	0.216	0.184	0.161	0.020	0.716	-1.880	0.617	-1.820	-3.890	-0.334
1986	0.280	0.162	0.248	0.061	0.692	-1.440	0.456	-1.390	-2.800	-0.368
1987	2.620	0.800	2.530	1.410	4.460	0.919	0.266	0.927	0.345	1.500
1988	0.423	0.200	0.388	0.125	0.883	-0.974	0.387	-0.947	-2.080	-0.125
1989	1.000	0.407	0.945	0.421	2.000	-0.078	0.341	-0.057	-0.864	0.691
1990	0.714	0.267	0.676	0.298	1.330	-0.406	0.318	-0.391	-1.210	0.288
1991	1.590	0.517	1.530	0.797	2.880	0.413	0.282	0.423	-0.227	1.060
1992	0.886	0.315	0.840	0.405	1.600	-0.183	0.305	-0.174	-0.905	0.467
1993	0.079	0.058	0.066	0.010	0.236	-2.800	0.549	-2.720	-4.570	-1.440
1994	1.920	0.547	1.840	1.100	3.140	0.613	0.251	0.611	0.096	1.140
1995	0.607	0.220	0.573	0.256	1.130	-0.565	0.309	-0.556	-1.360	0.120
1996	0.604	0.234	0.563	0.255	1.170	-0.576	0.327	-0.575	-1.360	0.154
1997	0.923	0.297	0.877	0.472	1.650	-0.130	0.279	-0.131	-0.750	0.499
1998	0.554	0.212	0.520	0.246	1.060	-0.662	0.324	-0.654	-1.400	0.061
1999	0.440	0.199	0.404	0.136	0.940	-0.922	0.372	-0.905	-1.990	-0.062
2000	2.130	0.583	2.080	1.230	3.420	0.720	0.242	0.730	0.209	1.230
2001	3.260	0.772	3.160	1.990	4.920	1.150	0.213	1.150	0.687	1.590
2002	2.430	0.660	2.350	1.390	4.070	0.852	0.240	0.854	0.330	1.400
2003	8.220	2.110	7.960	4.870	13.200	2.070	0.228	2.070	1.580	2.580
2004	0.467	0.213	0.430	0.167	0.990	-0.860	0.376	-0.845	-1.790	-0.010
2005	0.166	0.114	0.138	0.033	0.430	-2.010	0.525	-1.980	-3.410	-0.844
2006	0.201	0.098	0.181	0.070	0.446	-1.720	0.397	-1.710	-2.670	-0.807
2007	0.593	0.196	0.563	0.289	1.050	-0.576	0.285	-0.575	-1.240	0.052
2008	0.257	0.155	0.223	0.063	0.652	-1.540	0.472	-1.500	-2.770	-0.428
2009	1.620	0.482	1.550	0.880	2.710	0.438	0.261	0.437	-0.127	0.996
2010	3.110	0.762	3.010	1.920	4.800	1.110	0.219	1.100	0.651	1.570
2011	0.294	0.137	0.263	0.099	0.618	-1.330	0.383	-1.340	-2.310	-0.481
2012	0.359	0.150	0.339	0.138	0.723	-1.110	0.350	-1.080	-1.980	-0.324
2013	1.320	0.417	1.260	0.699	2.360	0.233	0.274	0.232	-0.358	0.859
2014	1.590	0.523	1.520	0.779	2.940	0.410	0.285	0.419	-0.250	1.080
2015	0.961	0.299	0.921	0.516	1.690	-0.086	0.271	-0.082	-0.661	0.525
2016	2.640	0.692	2.560	1.530	4.160	0.937	0.233	0.940	0.424	1.430
2017	3.350	0.816	3.260	2.040	5.160	1.180	0.218	1.180	0.712	1.640
2018	0.964	0.372	0.916	0.413	1.900	-0.110	0.327	-0.087	-0.885	0.643
2019	0.821	0.330	0.786	0.337	1.590	-0.278	0.338	-0.241	-1.090	0.461
2020	1.630	0.457	1.570	0.905	2.710	0.451	0.247	0.454	-0.100	0.995
2021	1.790	0.533	1.720	0.965	3.060	0.539	0.260	0.545	-0.036	1.120
2022	2.320	0.673	2.240	1.280	3.810	0.803	0.254	0.805	0.251	1.340
2023	27.900	7.410	27.100	16.400	45.600	3.290	0.236	3.300	2.800	3.820

Table B.10: Final puerulus settlement series by year for Chalky Inlet ('CHI').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	2.530	4.600	1.020	0.059	16.500	-0.051	1.040	0.020	-2.840	2.800
1980	2.210	3.890	1.010	0.066	12.800	-0.052	1.010	0.014	-2.720	2.550
1981	2.510	4.700	0.982	0.052	16.000	-0.070	1.060	-0.018	-2.950	2.770
1982	2.460	4.990	0.954	0.065	18.900	-0.101	1.110	-0.048	-2.740	2.940
1983	2.390	4.760	0.992	0.060	14.500	-0.059	1.090	-0.008	-2.810	2.680
1984	2.410	4.590	1.010	0.061	14.400	-0.053	1.070	0.012	-2.800	2.670
1985	0.992	0.867	0.727	0.151	3.410	-0.318	0.628	-0.319	-1.890	1.230
1986	0.101	0.046	0.092	0.039	0.224	-2.390	0.372	-2.380	-3.240	-1.500
1987	1.750	0.518	1.680	0.979	3.030	0.521	0.259	0.518	-0.021	1.110
1988	1.020	0.340	0.971	0.502	1.800	-0.034	0.287	-0.030	-0.688	0.589
1989	1.580	0.574	1.470	0.760	3.000	0.399	0.310	0.388	-0.274	1.100
1990	1.980	0.700	1.850	0.949	3.730	0.627	0.302	0.617	-0.052	1.320
1991	0.899	0.318	0.841	0.425	1.640	-0.167	0.303	-0.173	-0.855	0.493
1992	0.562	0.190	0.534	0.294	1.040	-0.628	0.292	-0.627	-1.220	0.042
1993	0.146	0.070	0.130	0.053	0.320	-2.030	0.390	-2.040	-2.950	-1.140
1994	1.850	0.645	1.700	0.952	3.420	0.556	0.300	0.531	-0.049	1.230
1995	0.336	0.131	0.316	0.151	0.634	-1.160	0.330	-1.150	-1.890	-0.455
1996	2.080	0.577	1.990	1.200	3.380	0.694	0.245	0.687	0.180	1.220
1997	1.390	0.430	1.330	0.745	2.400	0.284	0.269	0.282	-0.294	0.873
1998	0.393	0.126	0.371	0.203	0.685	-0.982	0.277	-0.991	-1.600	-0.378
1999	1.340	0.409	1.270	0.737	2.320	0.250	0.266	0.243	-0.305	0.843
2000	1.560	0.508	1.480	0.794	2.800	0.396	0.281	0.393	-0.231	1.030
2001	1.000	0.338	0.941	0.496	1.810	-0.050	0.291	-0.061	-0.700	0.592
2002	0.658	0.250	0.610	0.304	1.230	-0.484	0.323	-0.495	-1.190	0.205
2003	1.990	0.644	1.890	1.020	3.580	0.641	0.280	0.639	0.024	1.280
2004	0.349	0.153	0.319	0.138	0.706	-1.140	0.363	-1.140	-1.980	-0.348
2005	2.410	4.320	0.994	0.067	15.200	-0.015	1.030	-0.006	-2.700	2.720
2006	3.090	6.540	1.060	0.075	19.600	0.062	1.140	0.062	-2.590	2.970
2007	2.690	5.230	1.040	0.082	15.300	0.062	1.080	0.042	-2.500	2.730
2008	2.510	4.860	0.949	0.063	16.000	-0.058	1.080	-0.052	-2.760	2.780
2009	2.720	5.590	1.020	0.065	17.200	-0.005	1.120	0.016	-2.740	2.840
2010	5.680	1.660	5.440	3.080	9.470	1.700	0.256	1.690	1.130	2.250
2011	1.870	0.767	1.740	0.793	3.780	0.548	0.343	0.551	-0.232	1.330
2012	3.920	1.460	3.630	1.950	7.420	1.300	0.315	1.290	0.667	2.000
2013	2.300	4.260	1.000	0.065	13.200	-0.087	1.050	0.004	-2.740	2.580
2014	1.780	1.000	1.530	0.576	4.270	0.445	0.446	0.428	-0.552	1.450
2015	2.480	4.610	0.982	0.064	17.000	-0.056	1.050	-0.019	-2.760	2.830
2016	2.260	3.910	0.938	0.059	14.200	-0.100	1.000	-0.064	-2.830	2.650
2017	2.640	5.100	0.875	0.061	18.500	-0.062	1.080	-0.133	-2.810	2.920
2018	3.400	1.170	3.200	1.740	6.140	1.170	0.297	1.160	0.552	1.810
2019	2.740	2.240	2.050	0.619	8.670	0.766	0.597	0.720	-0.480	2.160
2020	2.510	5.010	0.902	0.059	16.600	-0.105	1.100	-0.103	-2.830	2.810
2021	2.300	3.890	0.978	0.058	14.200	-0.069	0.990	-0.022	-2.850	2.650
2022	2.420	4.350	1.070	0.055	15.200	-0.046	1.030	0.064	-2.890	2.720
2023	2.520	5.890	1.020	0.067	15.800	-0.052	1.210	0.022	-2.710	2.760

Table B.11: Final puerulus settlement series by year for Jackson Bay ('JKB').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	2.570	4.570	1.070	0.076	15.600	0.010	1.020	0.063	-2.570	2.750
1980	2.460	4.220	0.969	0.065	16.000	-0.045	0.998	-0.031	-2.730	2.770
1981	0.224	0.173	0.174	0.029	0.675	-1.770	0.572	-1.750	-3.530	-0.393
1982	1.260	0.455	1.190	0.603	2.350	0.174	0.308	0.177	-0.505	0.855
1983	1.120	0.374	1.060	0.537	2.010	0.063	0.288	0.056	-0.622	0.698
1984	0.916	0.274	0.877	0.492	1.510	-0.131	0.262	-0.132	-0.709	0.410
1985	0.191	0.076	0.178	0.081	0.360	-1.730	0.333	-1.720	-2.510	-1.020
1986	0.280	0.202	0.237	0.051	0.793	-1.500	0.542	-1.440	-2.980	-0.232
1987	2.450	4.300	0.935	0.071	15.100	-0.032	1.010	-0.067	-2.640	2.710
1988	2.650	4.380	1.130	0.064	15.300	0.058	0.976	0.126	-2.750	2.730
1989	2.260	3.760	1.110	0.060	13.900	-0.038	0.981	0.103	-2.810	2.630
1990	2.470	4.260	1.010	0.062	15.300	-0.021	1.000	0.012	-2.780	2.730
1991	2.300	3.980	0.985	0.066	14.100	-0.034	1.000	-0.015	-2.720	2.650
1992	2.190	3.990	0.912	0.068	13.300	-0.122	1.040	-0.093	-2.690	2.590
1993	2.420	4.170	1.090	0.070	15.000	0.010	1.000	0.084	-2.660	2.700
1994	2.390	4.180	0.989	0.076	14.500	-0.043	1.010	-0.011	-2.570	2.670
1995	2.330	4.600	0.986	0.072	14.600	-0.049	1.090	-0.015	-2.630	2.680
1996	2.450	4.370	0.877	0.060	15.400	-0.111	1.020	-0.131	-2.810	2.740
1997	2.650	5.050	1.050	0.073	16.400	0.003	1.070	0.047	-2.610	2.800
1998	2.390	3.940	1.030	0.079	14.200	0.012	0.974	0.026	-2.530	2.650
1999	0.290	0.102	0.275	0.140	0.521	-1.300	0.302	-1.290	-1.970	-0.652
2000	0.487	0.098	0.478	0.322	0.696	-0.739	0.184	-0.737	-1.130	-0.362
2001	0.437	0.081	0.431	0.303	0.611	-0.844	0.169	-0.841	-1.190	-0.493
2002	1.420	0.236	1.390	0.997	1.960	0.334	0.154	0.331	-0.003	0.674
2003	0.735	0.148	0.722	0.483	1.040	-0.329	0.184	-0.326	-0.729	0.038
2004	0.193	0.064	0.184	0.095	0.355	-1.700	0.288	-1.690	-2.350	-1.040
2005	1.700	0.326	1.660	1.160	2.380	0.510	0.176	0.509	0.145	0.868
2006	0.365	0.132	0.345	0.171	0.690	-1.070	0.309	-1.060	-1.770	-0.371
2007	0.235	0.071	0.226	0.122	0.400	-1.490	0.262	-1.490	-2.100	-0.916
2008	0.156	0.059	0.146	0.071	0.300	-1.930	0.322	-1.920	-2.640	-1.200
2009	0.189	0.074	0.175	0.082	0.368	-1.740	0.332	-1.740	-2.500	-1.000
2010	2.020	0.583	1.950	1.150	3.470	0.666	0.253	0.668	0.142	1.240
2011	2.310	0.524	2.230	1.480	3.440	0.812	0.205	0.802	0.391	1.240
2012	6.870	1.330	6.670	4.740	9.870	1.910	0.177	1.900	1.560	2.290
2013	14.500	2.740	14.200	9.960	20.800	2.650	0.173	2.660	2.300	3.030
2014	21.100	4.240	20.600	14.500	29.900	3.030	0.183	3.030	2.670	3.400
2015	11.100	2.230	10.900	7.500	15.800	2.390	0.183	2.390	2.010	2.760
2016	14.900	3.140	14.600	9.920	21.800	2.680	0.190	2.680	2.290	3.080
2017	3.150	0.688	3.070	2.040	4.650	1.120	0.197	1.120	0.715	1.540
2018	3.100	0.586	3.070	2.130	4.380	1.110	0.173	1.120	0.757	1.480
2019	0.632	0.148	0.623	0.384	0.963	-0.486	0.211	-0.473	-0.956	-0.038
2020	1.120	0.252	1.100	0.706	1.670	0.088	0.203	0.092	-0.348	0.515
2021	1.520	0.331	1.480	0.974	2.300	0.400	0.196	0.393	-0.027	0.835
2022	0.853	0.178	0.833	0.560	1.250	-0.180	0.189	-0.183	-0.580	0.225
2023	0.565	0.159	0.542	0.323	0.927	-0.609	0.248	-0.612	-1.130	-0.076

Table B.12: Final puerulus settlement series by year for the Gisborne/Napier grouping ('GIS_NAP').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	1.000	0.187	0.990	0.673	1.410	-0.017	0.172	-0.010	-0.396	0.346
1980	1.170	0.199	1.160	0.827	1.620	0.147	0.157	0.149	-0.190	0.484
1981	1.250	0.199	1.240	0.903	1.660	0.211	0.148	0.215	-0.102	0.509
1982	1.140	0.194	1.130	0.808	1.580	0.120	0.157	0.119	-0.214	0.457
1983	1.030	0.192	1.010	0.713	1.470	0.015	0.171	0.014	-0.339	0.386
1984	0.622	0.127	0.613	0.398	0.908	-0.496	0.186	-0.489	-0.922	-0.096
1985	0.674	0.134	0.664	0.439	0.948	-0.414	0.181	-0.409	-0.823	-0.053
1986	0.860	0.223	0.841	0.528	1.400	-0.182	0.231	-0.174	-0.639	0.335
1987	2.270	0.430	2.220	1.570	3.260	0.802	0.173	0.795	0.453	1.180
1988	1.830	0.299	1.800	1.350	2.500	0.594	0.151	0.589	0.300	0.918
1989	1.100	0.176	1.090	0.777	1.480	0.078	0.149	0.082	-0.253	0.392
1990	0.728	0.120	0.716	0.525	1.020	-0.331	0.153	-0.335	-0.644	0.017
1991	1.890	0.275	1.880	1.410	2.490	0.628	0.136	0.633	0.346	0.910
1992	1.930	0.262	1.910	1.460	2.510	0.648	0.127	0.645	0.377	0.922
1993	2.150	0.303	2.120	1.620	2.840	0.754	0.132	0.751	0.484	1.040
1994	2.360	0.322	2.350	1.790	3.050	0.850	0.128	0.853	0.582	1.110
1995	1.010	0.135	1.010	0.770	1.320	0.003	0.126	0.007	-0.262	0.280
1996	1.410	0.190	1.400	1.070	1.830	0.337	0.126	0.337	0.072	0.604
1997	1.260	0.170	1.250	0.966	1.640	0.224	0.126	0.226	-0.035	0.495
1998	1.480	0.192	1.470	1.150	1.920	0.383	0.122	0.386	0.143	0.651
1999	0.392	0.055	0.388	0.298	0.507	-0.947	0.132	-0.947	-1.210	-0.678
2000	0.901	0.121	0.897	0.691	1.170	-0.113	0.126	-0.109	-0.370	0.160
2001	1.230	0.164	1.220	0.938	1.590	0.202	0.125	0.203	-0.064	0.464
2002	1.250	0.168	1.250	0.956	1.620	0.217	0.126	0.219	-0.045	0.480
2003	1.770	0.245	1.760	1.330	2.310	0.564	0.129	0.568	0.285	0.836
2004	1.000	0.138	0.996	0.761	1.290	-0.010	0.129	-0.004	-0.273	0.254
2005	1.620	0.227	1.610	1.220	2.130	0.475	0.131	0.476	0.199	0.756
2006	0.611	0.091	0.609	0.448	0.803	-0.504	0.138	-0.497	-0.804	-0.219
2007	0.797	0.125	0.788	0.577	1.070	-0.239	0.145	-0.238	-0.549	0.065
2008	0.681	0.102	0.677	0.501	0.896	-0.395	0.140	-0.390	-0.692	-0.110
2009	0.952	0.138	0.944	0.712	1.260	-0.060	0.135	-0.058	-0.339	0.232
2010	1.080	0.156	1.070	0.804	1.410	0.071	0.134	0.072	-0.218	0.344
2011	0.362	0.059	0.357	0.259	0.493	-1.030	0.151	-1.030	-1.350	-0.707
2012	0.791	0.118	0.787	0.592	1.040	-0.245	0.139	-0.240	-0.525	0.035
2013	0.933	0.143	0.919	0.693	1.240	-0.081	0.142	-0.085	-0.367	0.212
2014	0.747	0.122	0.736	0.545	1.030	-0.304	0.152	-0.306	-0.607	0.034
2015	1.310	0.199	1.300	0.960	1.740	0.261	0.141	0.265	-0.041	0.556
2016	1.320	0.205	1.300	0.960	1.760	0.264	0.145	0.262	-0.041	0.567
2017	0.528	0.090	0.518	0.371	0.719	-0.654	0.157	-0.658	-0.992	-0.330
2018	0.510	0.083	0.505	0.366	0.702	-0.687	0.151	-0.682	-1.010	-0.354
2019	0.600	0.094	0.595	0.431	0.799	-0.523	0.146	-0.520	-0.842	-0.224
2020	0.738	0.115	0.725	0.536	0.977	-0.316	0.145	-0.322	-0.623	-0.023
2021	0.839	0.133	0.830	0.605	1.110	-0.189	0.147	-0.186	-0.503	0.109
2022	0.860	0.146	0.855	0.606	1.160	-0.165	0.157	-0.156	-0.500	0.149
2023	1.070	0.191	1.050	0.743	1.510	0.053	0.164	0.052	-0.297	0.410

Table B.13: Final puerulus settlement series by year for the Moeraki/Halfmoon Bay/Chalky Inlet grouping ('MOE_HMB_CHI').

	Natural space					Log space				
Year	Mean	SD	Median	5%	95%	Mean	SD	Median	5%	95%
1979	2.500	4.360	1.130	0.057	14.500	0.008	1.010	0.125	-2.860	2.680
1980	2.100	2.040	1.490	0.324	7.000	0.406	0.677	0.401	-1.130	1.950
1981	11.900	9.300	9.550	2.410	35.100	2.240	0.577	2.260	0.882	3.560
1982	0.782	0.602	0.608	0.121	2.380	-0.516	0.571	-0.498	-2.110	0.865
1983	9.900	7.110	8.100	2.020	28.400	2.070	0.541	2.090	0.705	3.340
1984	0.808	0.785	0.598	0.125	2.550	-0.520	0.679	-0.515	-2.080	0.936
1985	0.292	0.263	0.205	0.038	0.987	-1.570	0.642	-1.580	-3.270	-0.013
1986	0.114	0.091	0.089	0.020	0.338	-2.430	0.589	-2.420	-3.890	-1.080
1987	2.350	1.630	1.930	0.547	6.550	0.651	0.527	0.655	-0.603	1.880
1988	0.734	0.526	0.603	0.150	2.100	-0.521	0.540	-0.506	-1.900	0.742
1989	1.530	1.100	1.250	0.339	4.290	0.215	0.544	0.223	-1.080	1.460
1990	1.240	0.867	1.010	0.265	3.460	0.005	0.531	0.009	-1.330	1.240
1991	1.020	0.724	0.843	0.215	2.940	-0.187	0.536	-0.171	-1.540	1.080
1992	0.613	0.451	0.500	0.122	1.730	-0.705	0.552	-0.694	-2.100	0.547
1993	0.124	0.096	0.095	0.023	0.361	-2.340	0.573	-2.350	-3.760	-1.020
1994	1.550	1.080	1.280	0.335	4.380	0.233	0.527	0.246	-1.090	1.480
1995	0.379	0.264	0.313	0.082	1.120	-1.180	0.528	-1.160	-2.500	0.112
1996	1.350	0.921	1.110	0.311	3.760	0.099	0.521	0.106	-1.170	1.320
1997	1.100	0.740	0.911	0.253	2.910	-0.108	0.516	-0.093	-1.370	1.070
1998	0.480	0.339	0.397	0.105	1.320	-0.944	0.535	-0.924	-2.250	0.279
1999	0.812	0.589	0.674	0.161	2.140	-0.421	0.545	-0.395	-1.830	0.761
2000	2.430	1.650	2.030	0.508	6.700	0.692	0.517	0.710	-0.677	1.900
2001	2.310	1.570	1.920	0.530	6.080	0.636	0.518	0.650	-0.636	1.810
2002	1.550	1.060	1.280	0.339	4.360	0.234	0.522	0.247	-1.080	1.470
2003	7.120	4.910	5.820	1.530	19.200	1.760	0.524	1.760	0.426	2.960
2004	0.480	0.348	0.386	0.099	1.430	-0.957	0.544	-0.952	-2.320	0.357
2005	0.132	0.111	0.105	0.022	0.416	-2.300	0.608	-2.250	-3.800	-0.878
2006	0.134	0.108	0.105	0.024	0.417	-2.280	0.591	-2.260	-3.750	-0.874
2007	0.407	0.305	0.337	0.074	1.190	-1.130	0.560	-1.090	-2.610	0.177
2008	0.146	0.113	0.114	0.024	0.417	-2.180	0.574	-2.170	-3.720	-0.875
2009	1.170	0.837	0.929	0.237	3.250	-0.066	0.540	-0.074	-1.440	1.180
2010	3.310	2.260	2.760	0.748	9.160	0.999	0.520	1.010	-0.290	2.210
2011	1.000	0.716	0.841	0.221	2.780	-0.203	0.539	-0.174	-1.510	1.020
2012	1.590	1.140	1.310	0.334	4.640	0.255	0.542	0.269	-1.100	1.540
2013	1.490	1.040	1.250	0.337	4.080	0.188	0.531	0.224	-1.090	1.410
2014	1.320	0.962	1.080	0.290	3.670	0.066	0.547	0.081	-1.240	1.300
2015	4.680	3.220	3.850	1.070	13.000	1.340	0.524	1.350	0.070	2.560
2016	3.090	2.140	2.540	0.642	8.420	0.920	0.527	0.934	-0.443	2.130
2017	4.550	3.220	3.800	0.923	13.200	1.310	0.535	1.330	-0.080	2.580
2018	4.160	2.930	3.430	0.855	11.000	1.220	0.533	1.230	-0.157	2.400
2019	1.690	1.240	1.400	0.369	4.870	0.311	0.551	0.339	-0.998	1.580
2020	4.580	3.110	3.880	1.000	12.100	1.320	0.519	1.360	0.003	2.490
2021	2.070	1.430	1.730	0.456	5.670	0.522	0.525	0.547	-0.785	1.740
2022	1.700	1.190	1.420	0.376	4.780	0.321	0.529	0.347	-0.978	1.570
2023	15.300	10.500	12.700	3.250	40.600	2.530	0.521	2.540	1.180	3.700

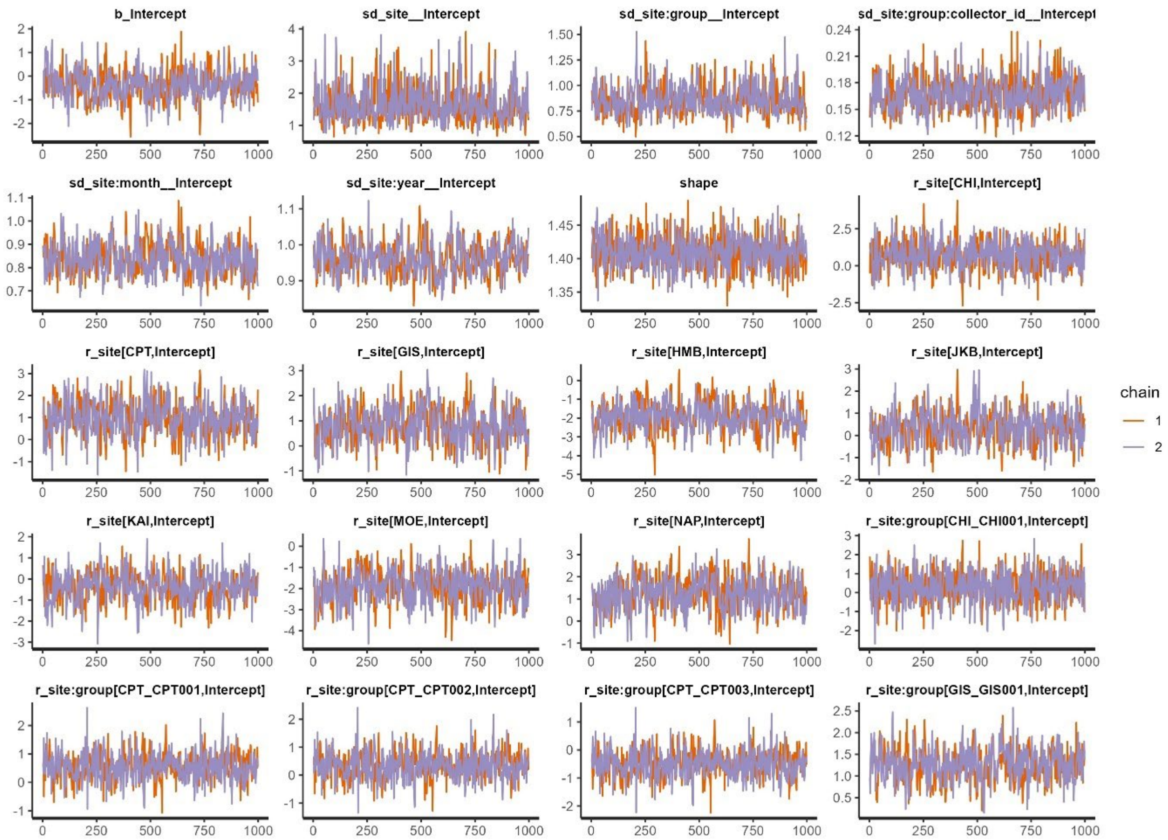

Figure B.1: Trace plots for a sample of estimated model parameters of model run *fit_error_nb*.

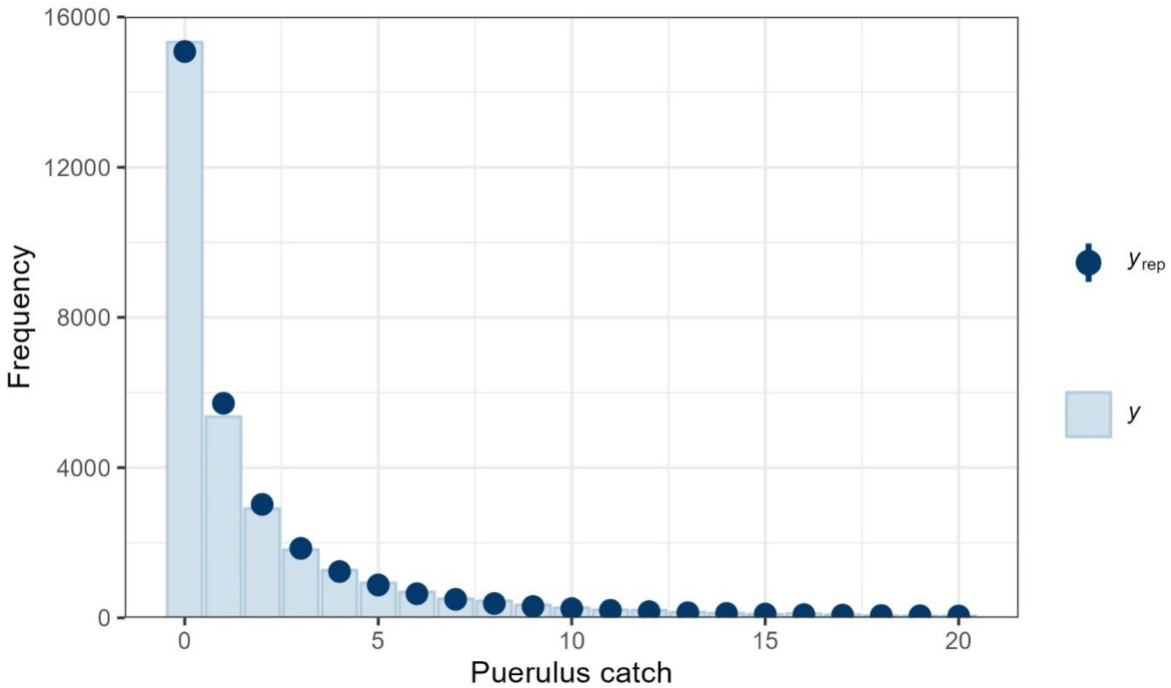

Figure B.2: Posterior predictive check plot for model run *fit_error_nb*. Bars are the observed distribution of puerulus catch and points are the simulated distributions (whiskers represent the 95% credible interval of this distribution but are so small as to not be visible in this plot).

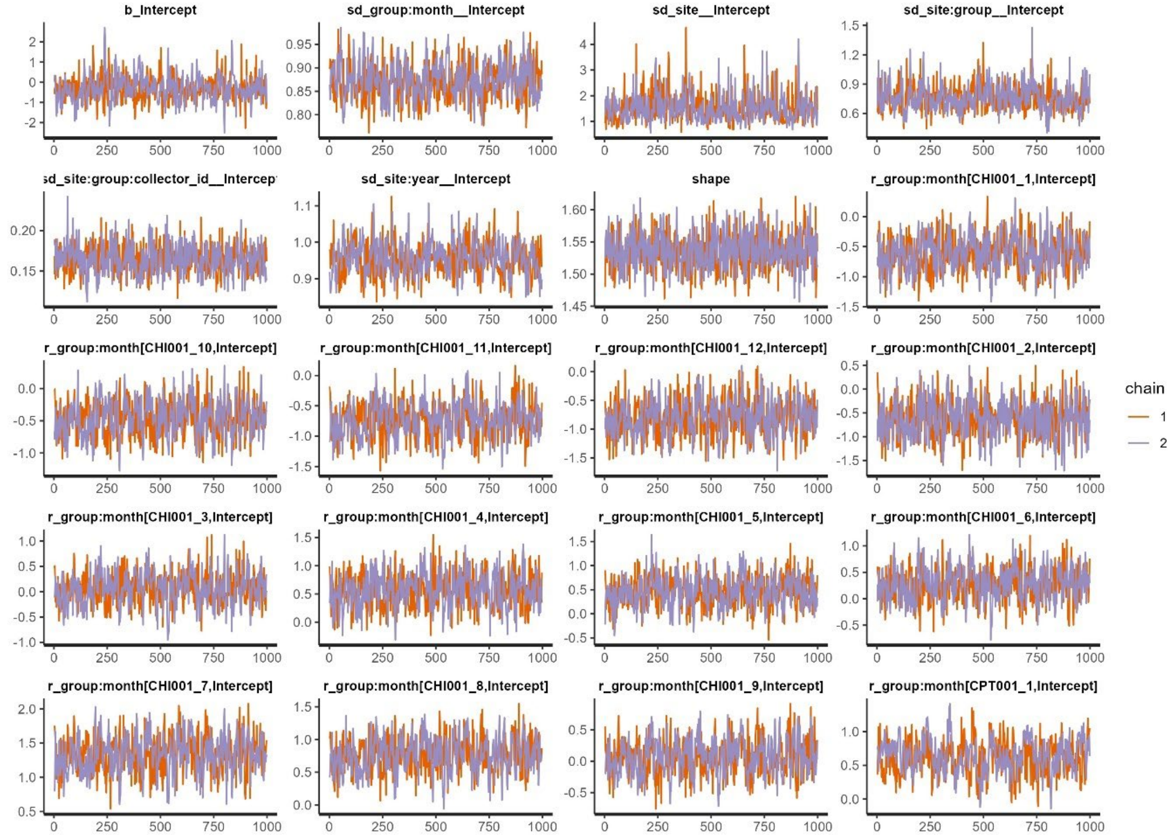

Figure B.3: Trace plots for a sample of estimated model parameters of model run *fit5*.

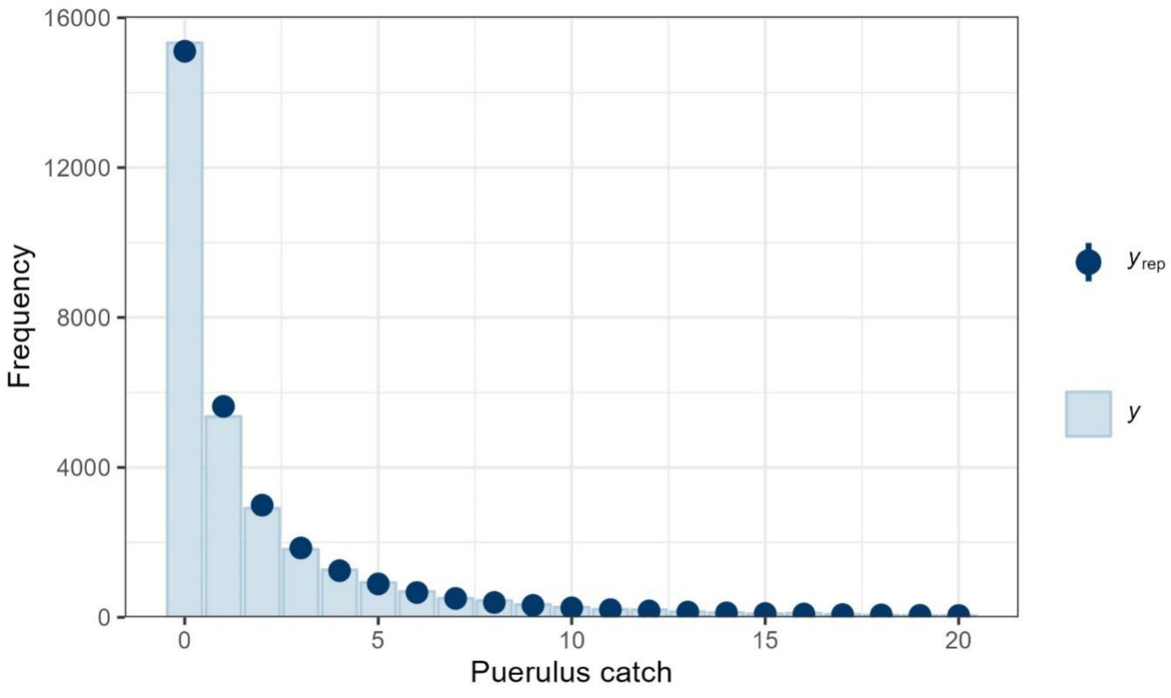

Figure B.4: Posterior predictive check plot for model run *fit5*. Bars are the observed distribution of puerulus catch and points are the simulated distributions (whiskers represent the 95% credible interval of this distribution but are so small as to not be visible in this plot).

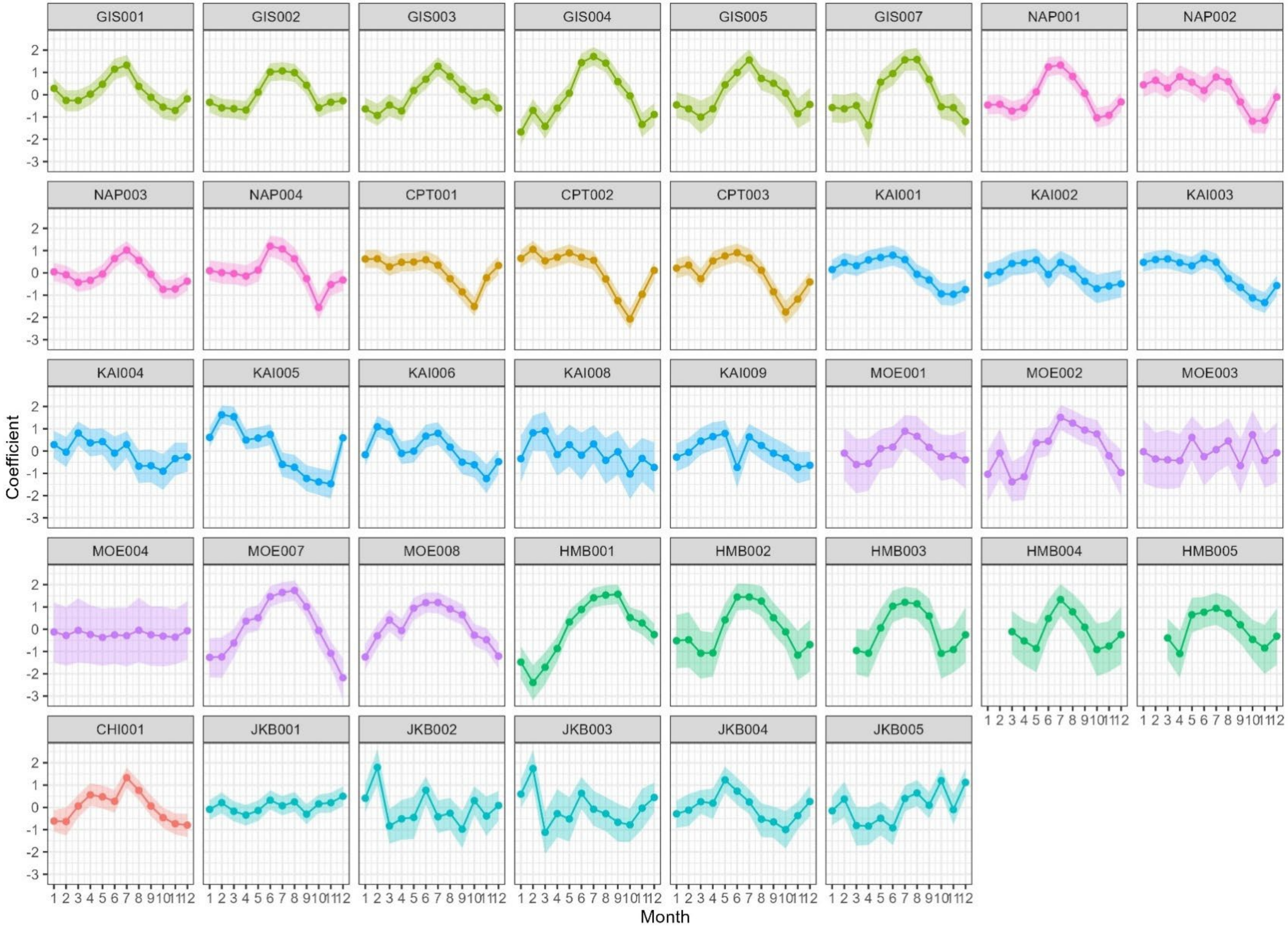

Figure B.5: Plot of puerulus catch coefficients by collector group and month (model run *fit5*), coloured by monitoring site. Lines and points represent the mean predictions. The shaded areas represent the 95% credible intervals. Note that a flat response with wide uncertainty was estimated for collector groups with few observations (e.g., 'MOE004').

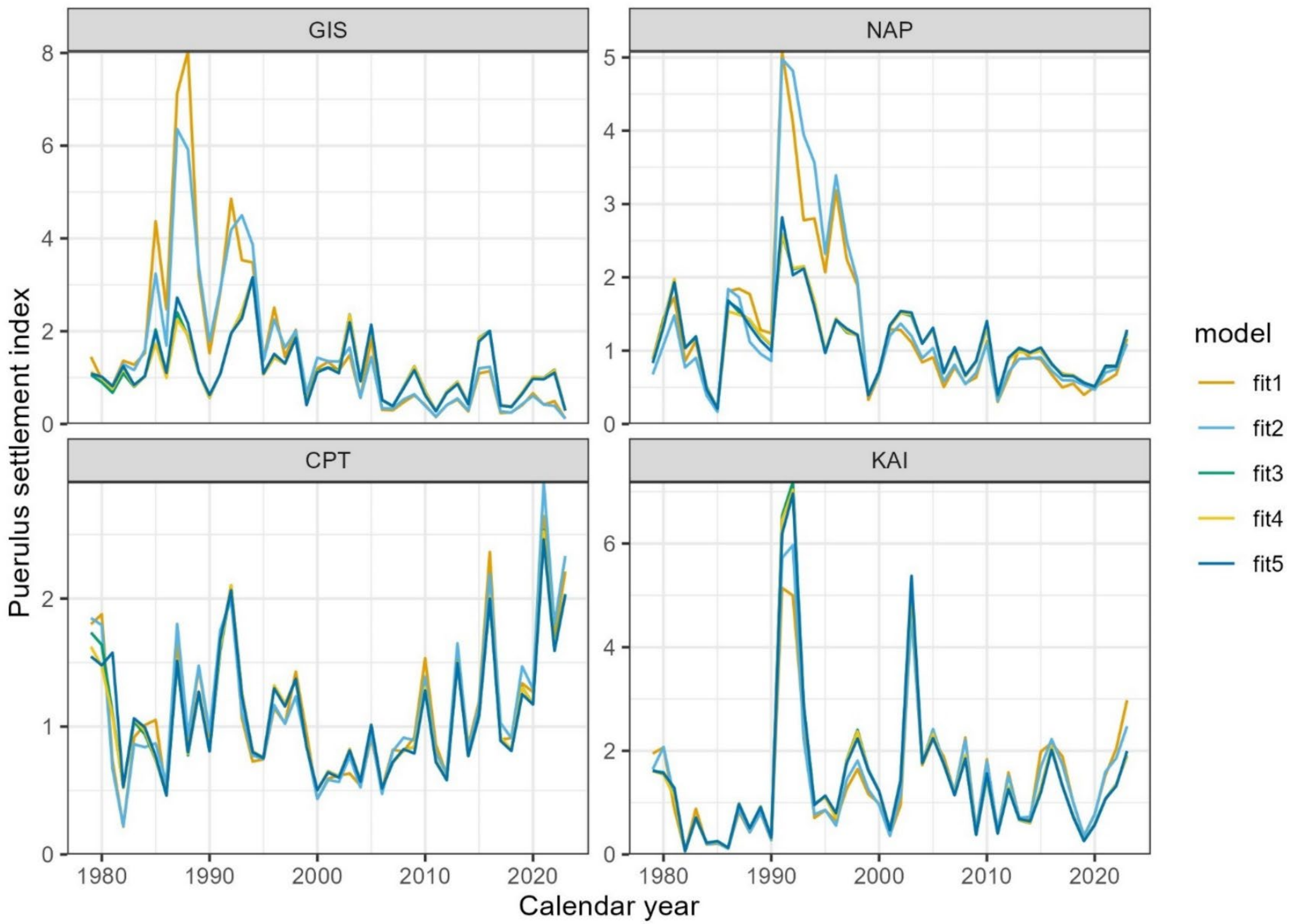

Figure B.6: Progression of model predicted average puerulus settlement series by collector site ('GIS' = Gisborne, 'NAP' = Napier, 'CPT' = Castlepoint, and 'KAI' = Kaikoura) and calendar year, comparing interim models (*fit1* to *fit4*) and the final model (*fit5*).

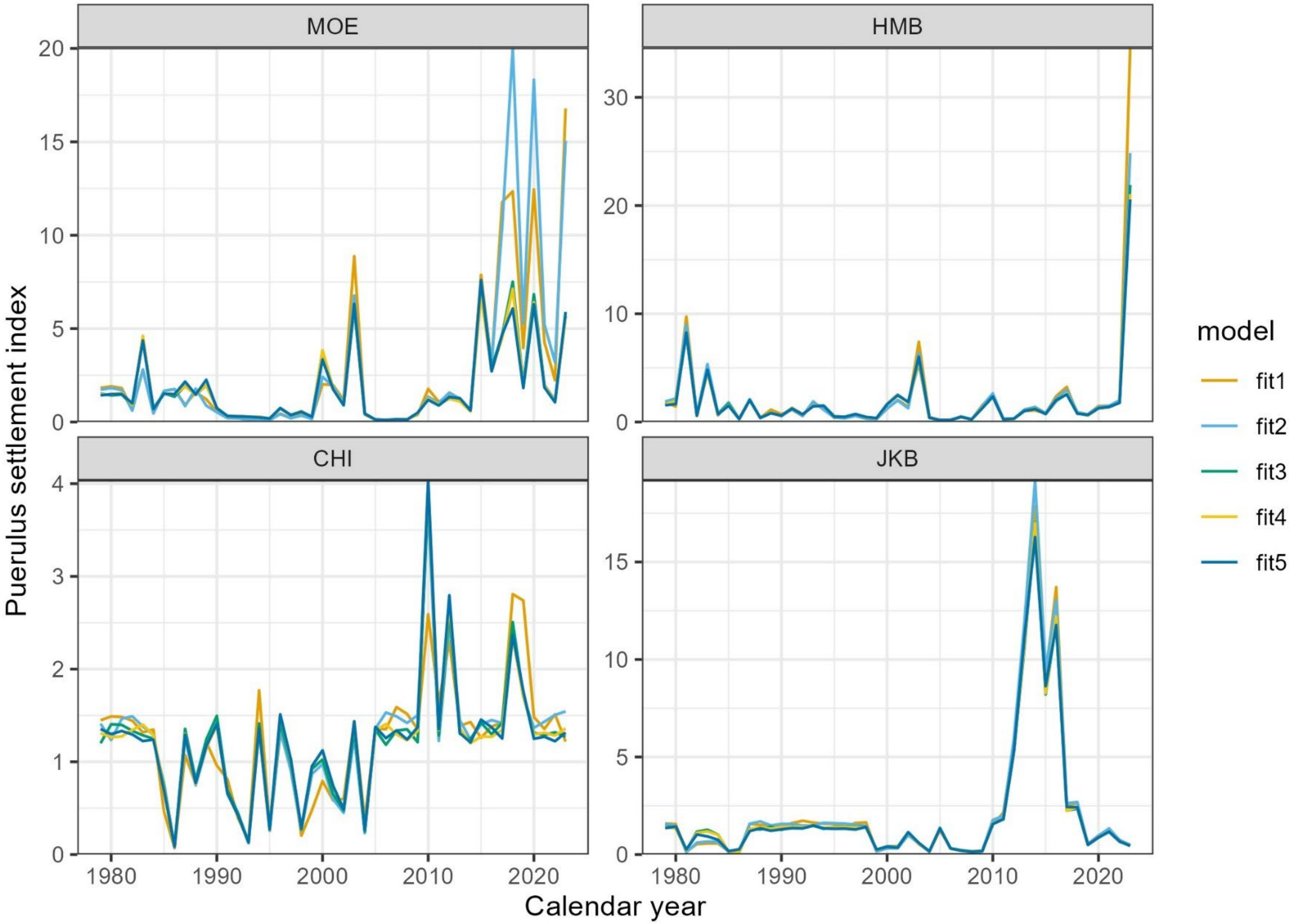

Figure B.7: Progression of model predicted average puerulus settlement series by collector site ('MOE' = Moeraki, 'HMB' = Halfmoon Bay, 'CHI' = Chalky Inlet, and 'JKB' = Jackson Bay) and calendar year, comparing interim models (*fit1* to *fit4*) and the final model (*fit5*).

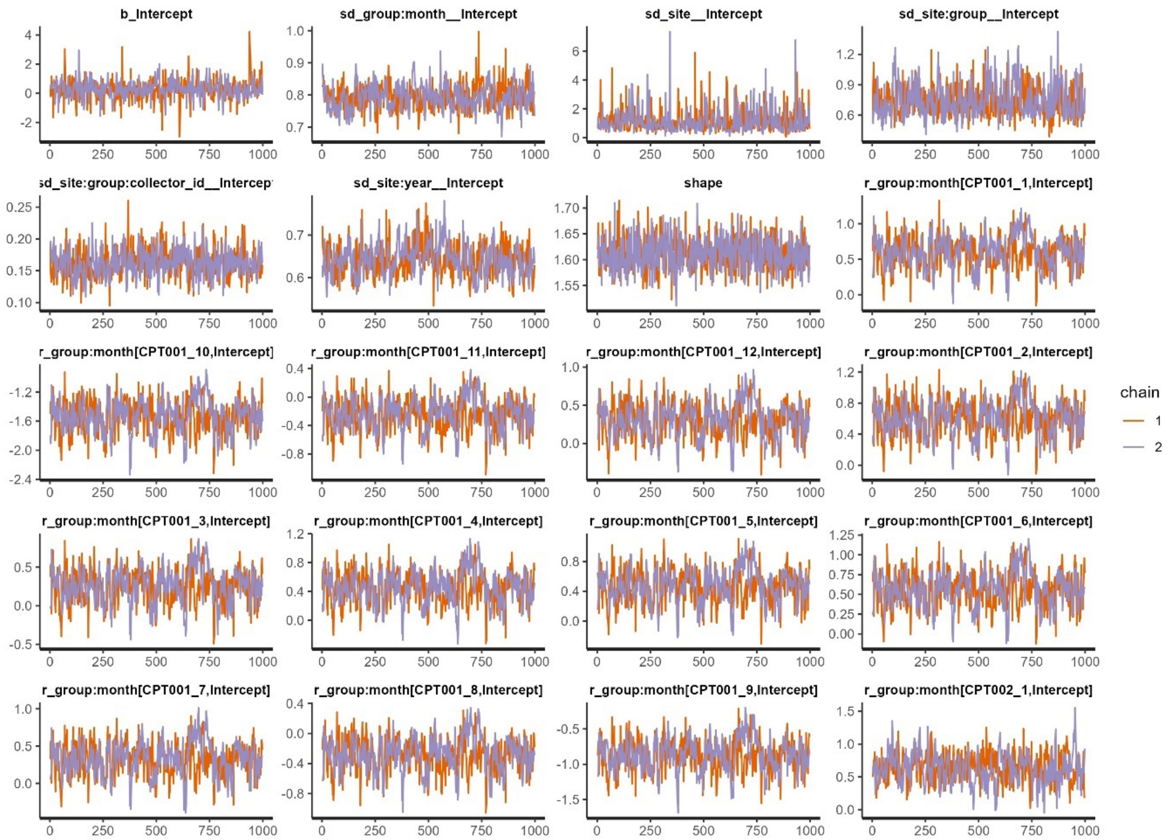

Figure B.8: Example trace plots from model run *fit5_north*.

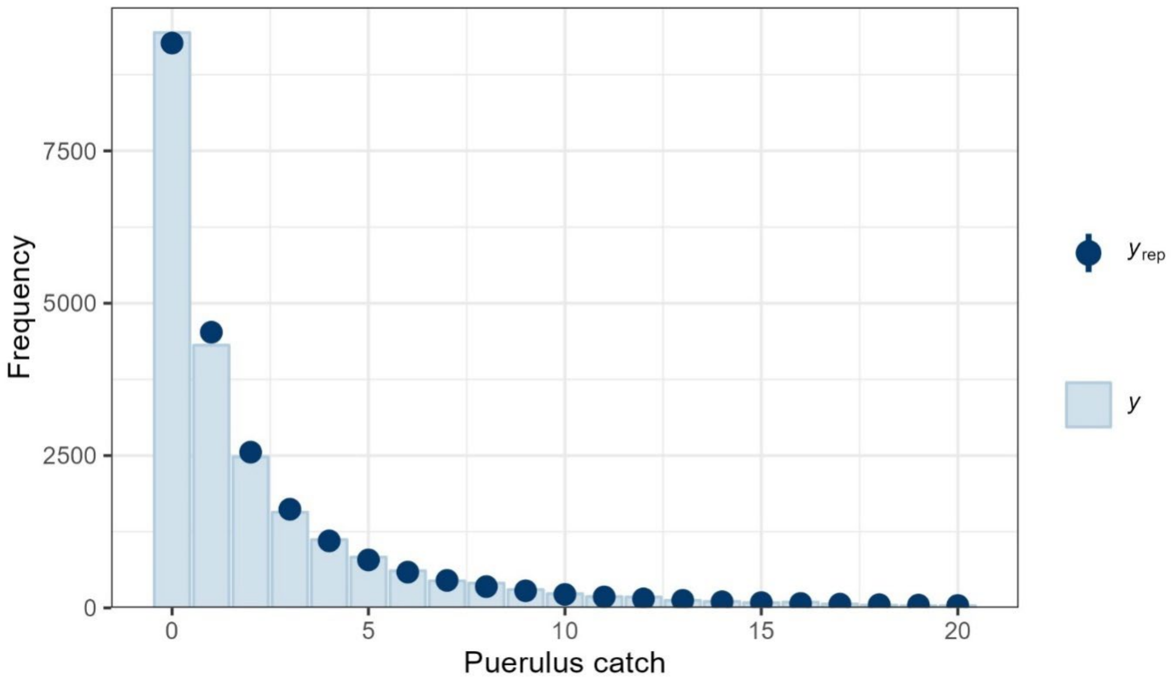

Figure B.9: Posterior predictive check plot for model run *fit5_north*. Bars are the observed distribution of puerulus catch and points and the simulated distribution (whiskers represent the 95% credible interval of this distribution but are so small as to not be visible in this plot).

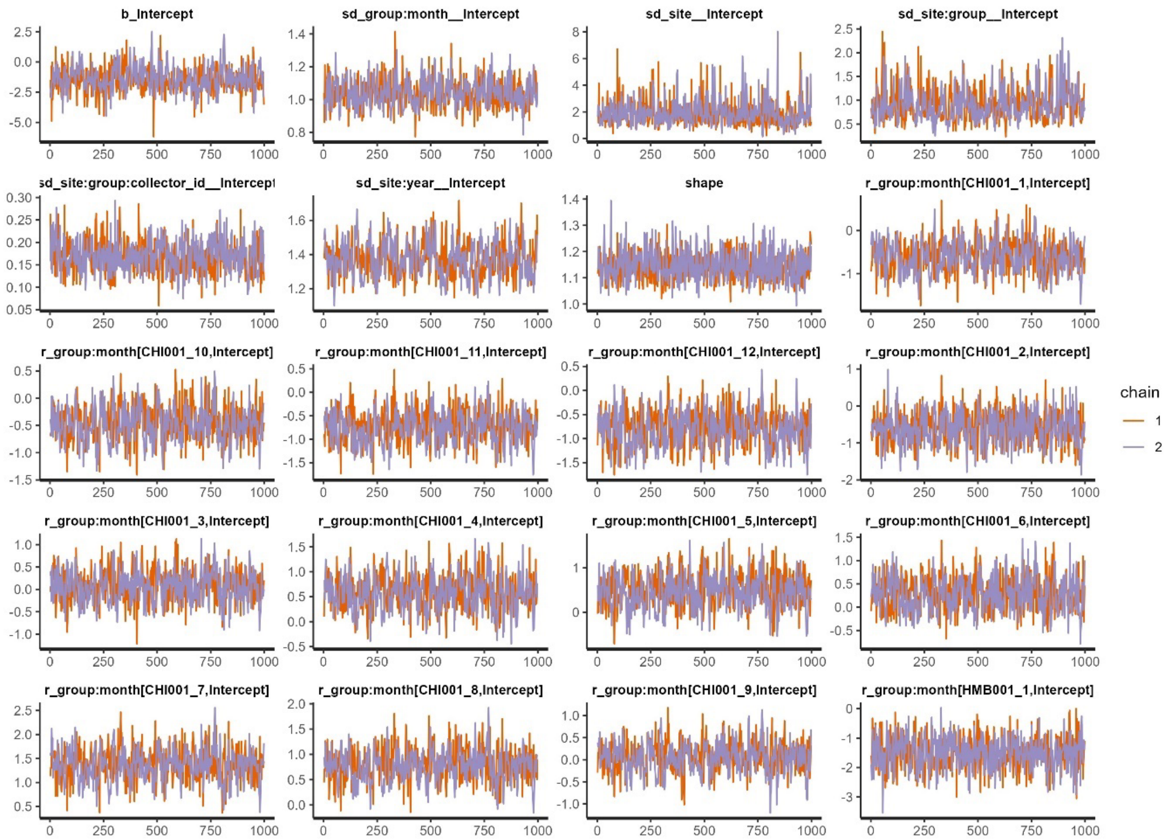

Figure B.10: Example trace plots from model run *fit5_south.*

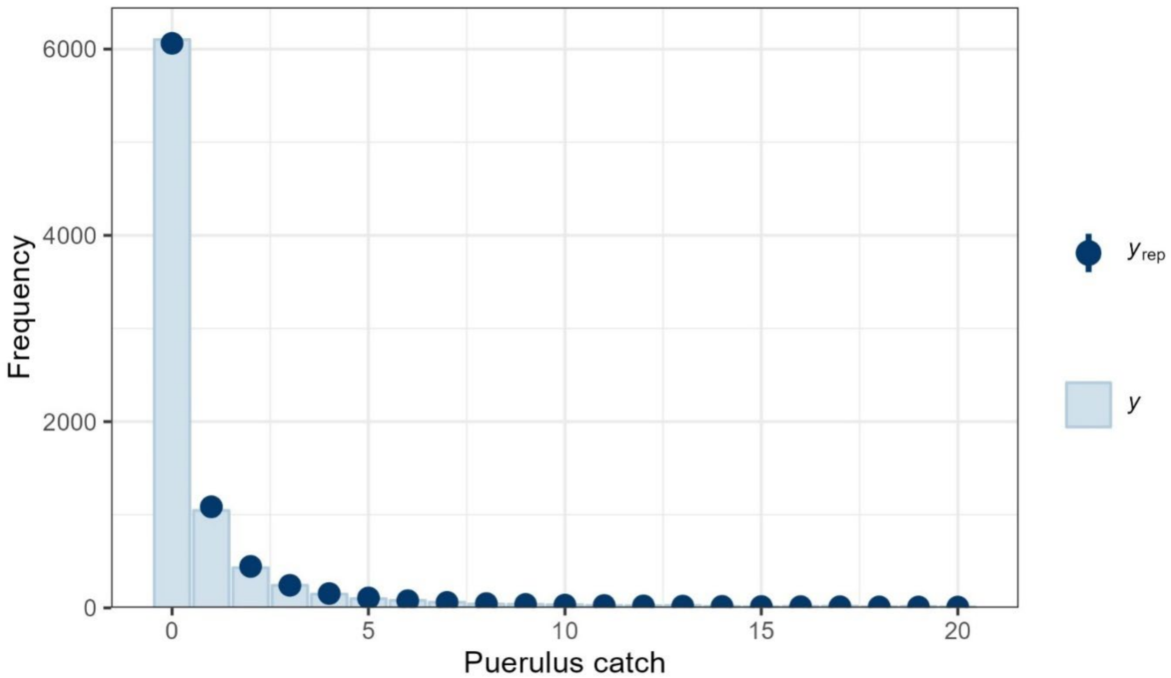

Figure B.11: Posterior predictive check plot for model run *fit5_south*. Bars are the observed distribution of puerulus catch and points and the simulated distribution (whiskers represent the 95% credible interval of this distribution but are so small as to not be visible in this plot).

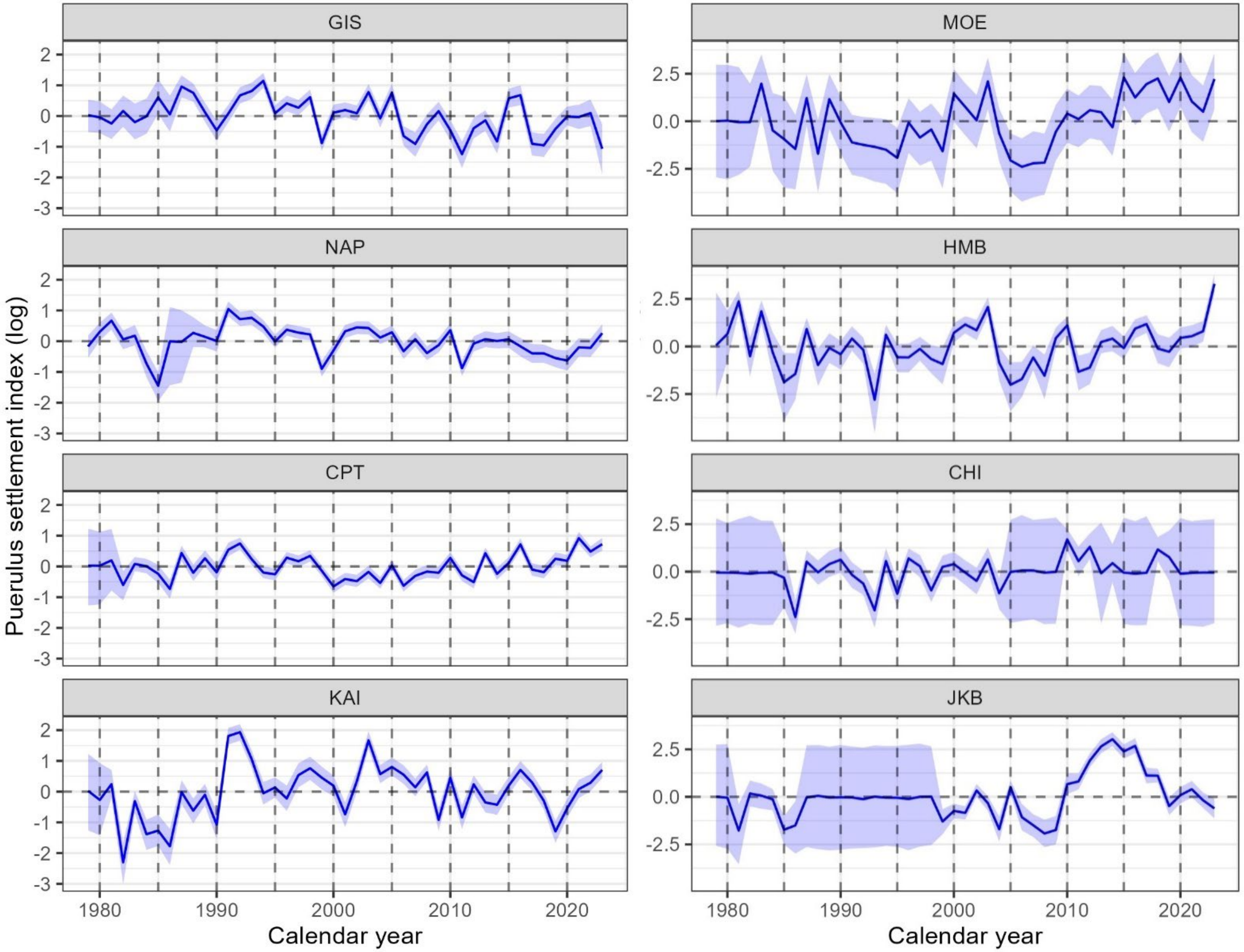

Figure B.12: The final <u>log-transformed</u> standardised puerulus settlement series by calendar year and collector site, scaled to respective geometric means. Blue points and lines are the average predictions, blue shaded areas are 95% credible intervals. Predictions generated from model runs *fit5_north* and *fit5_south.*

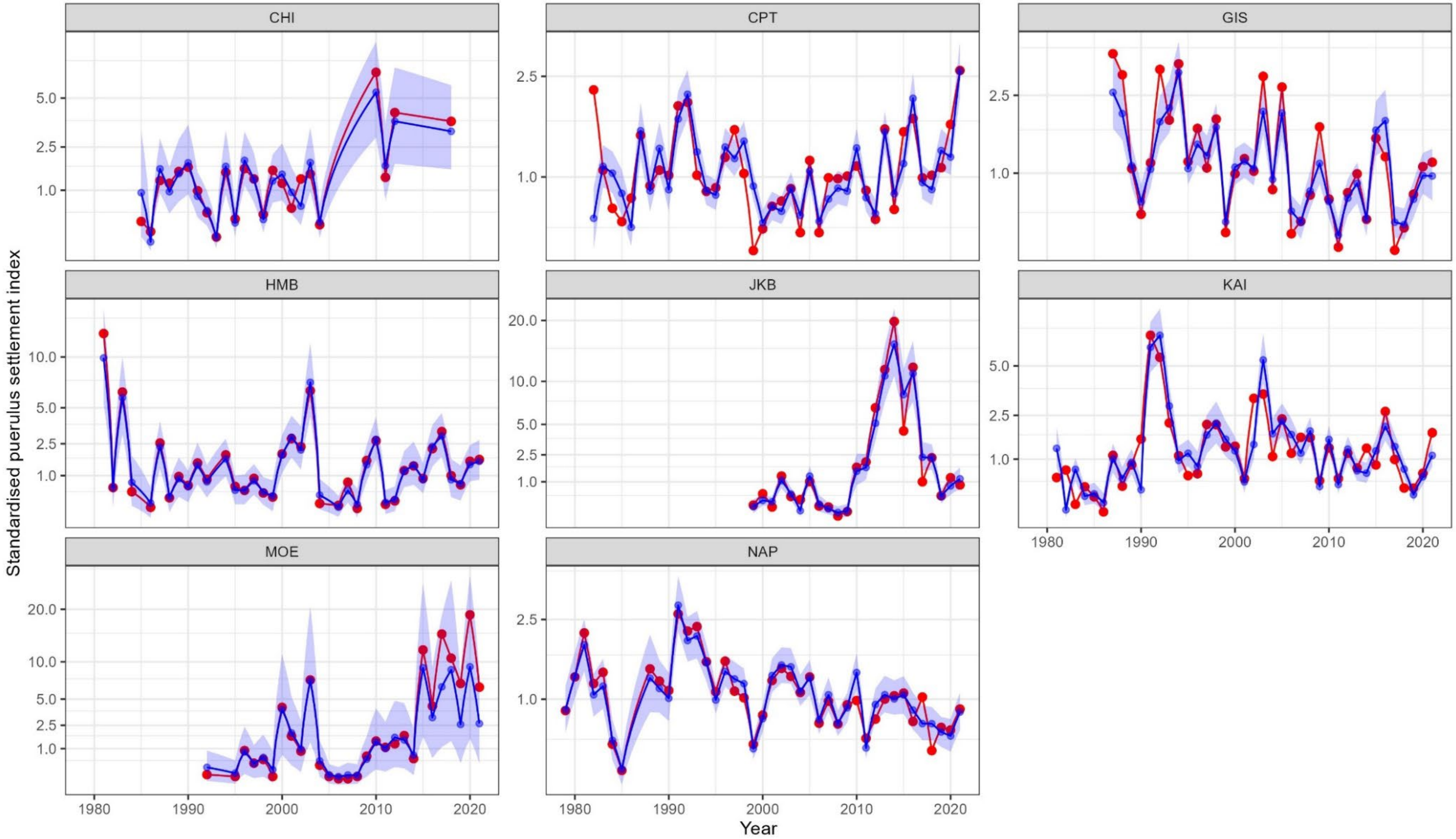

Figure B.13: Model predicted settlement series of puerulus catch rate by year and collector sites from model runs *fit5_north* and *fit5_south*. Blue points and lines are the average predictions, blue shaded areas are 95% credible intervals, and red points and lines are the average predictions of Forman et al. (2023), all scaled to the geometric mean. Note that the current analysis was by calendar years, whereas the Forman et al. (2023) analysis was by fishing year. Only years for which both analyses made predictions for a respective collector site were included in these plots.

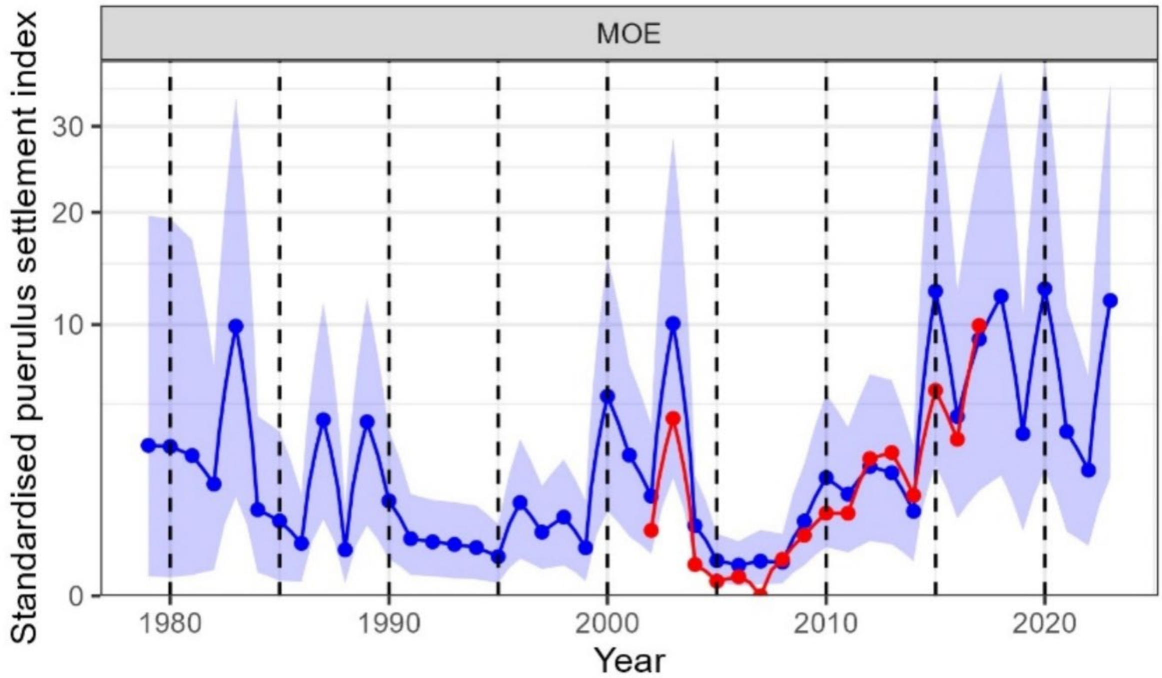

Figure B.14: Model predicted settlement series of puerulus catch rate for the Moeraki collector site by year fit5_south, compared with mean counts from mesh collectors at Moeraki Wharf (constrained to peak settlement months from June to September), all scaled to the geometric mean. Blue points and lines are the average predictions, blue shaded areas are 95% credible intervals, and red points and lines are the average predictions from the crevice collectors at Moeraki Wharf (Bob Street and Lucy Coyle, unpublished data).

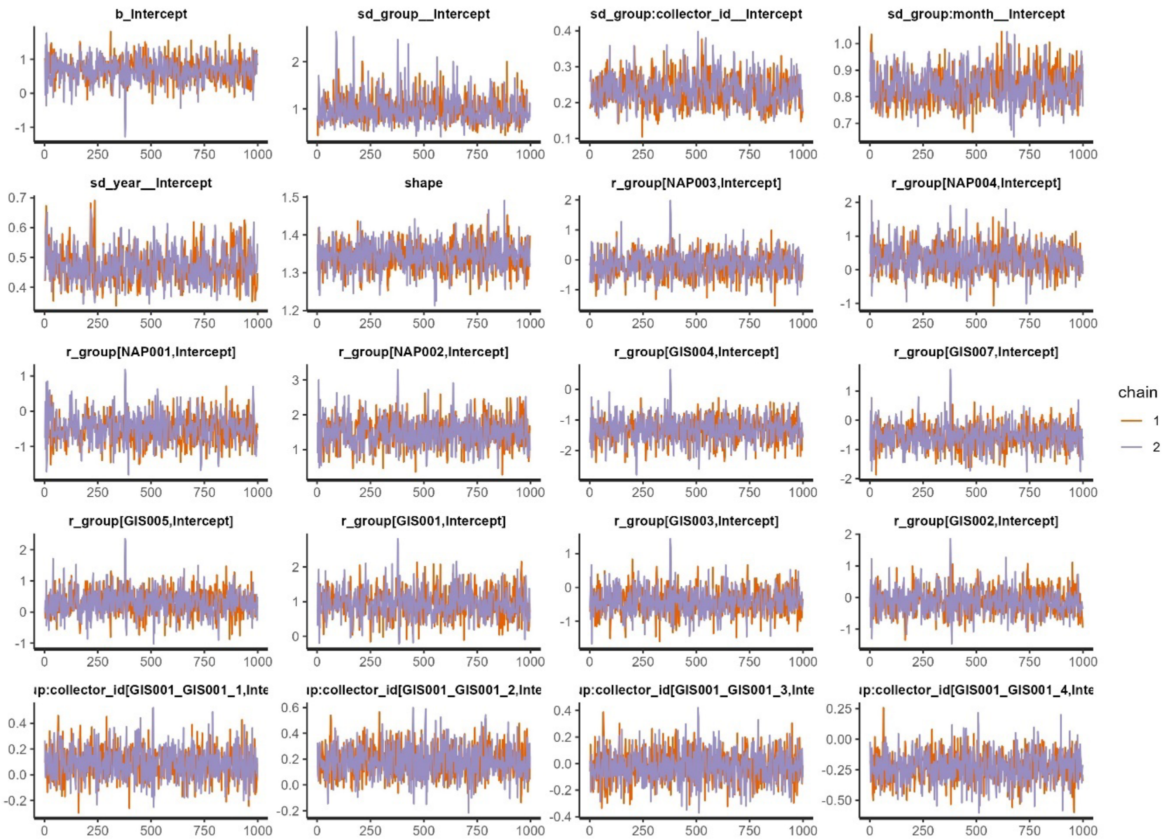

Figure B.15: Example trace plots from model run *fit5_gisnap*.

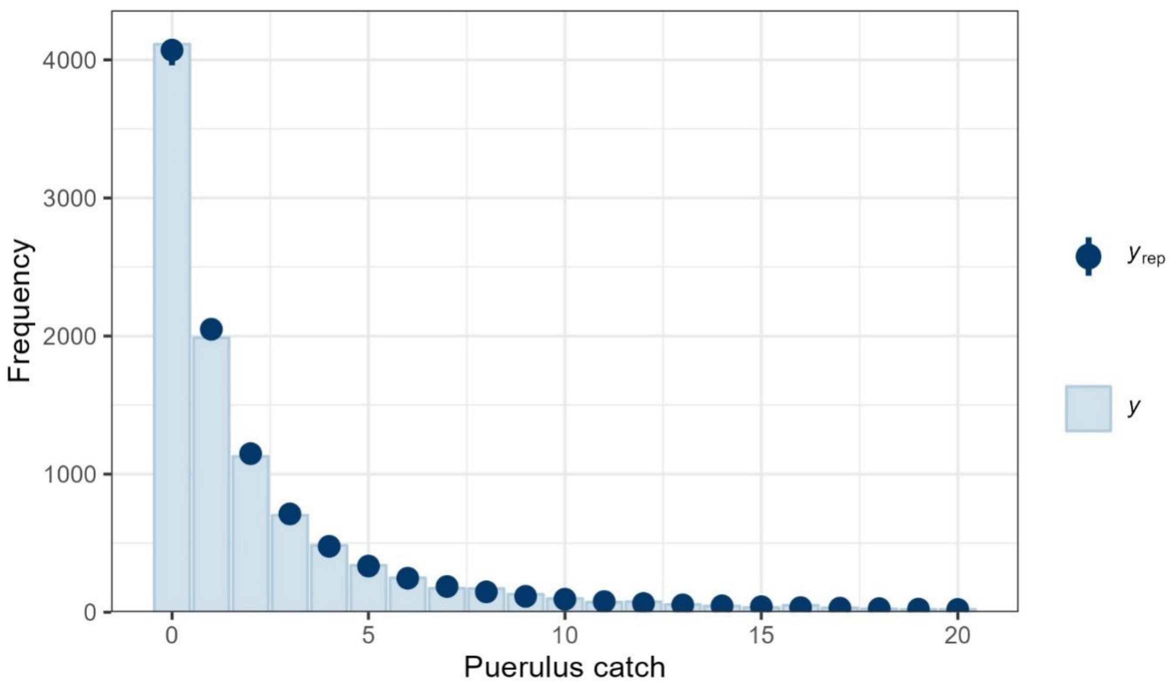

Figure B.16: Posterior predictive check plot for model run *fit5_gisnap*. Bars are the observed distribution of puerulus catch and points and the simulated distribution (whiskers represent the 95% credible interval of this distribution but are so small as to not be visible in this plot).

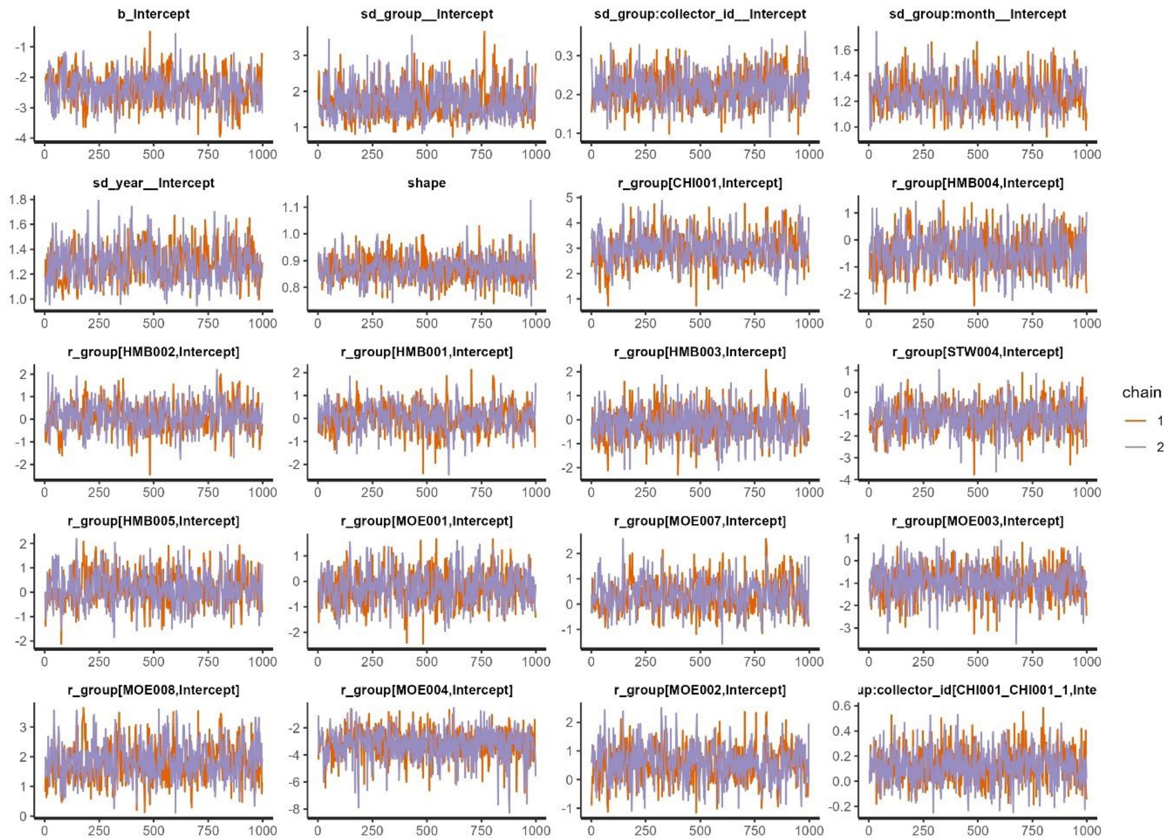

Figure B.17: Example trace plots from model run *fit5_moehmbchi.*

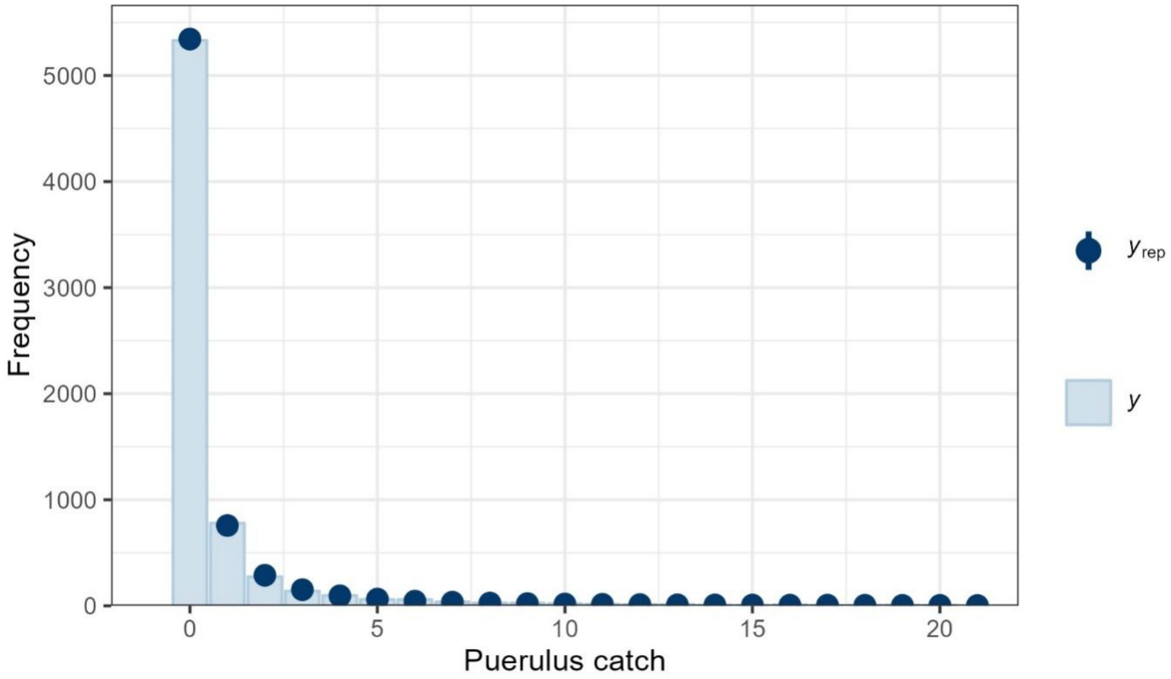

Figure B.18: Posterior predictive check plot for model run *fit5_moehmbchi*. Bars are the observed distribution of puerulus catch and points and the simulated distribution (whiskers represent the 95% credible interval of this distribution but are so small as to not be visible in this plot).

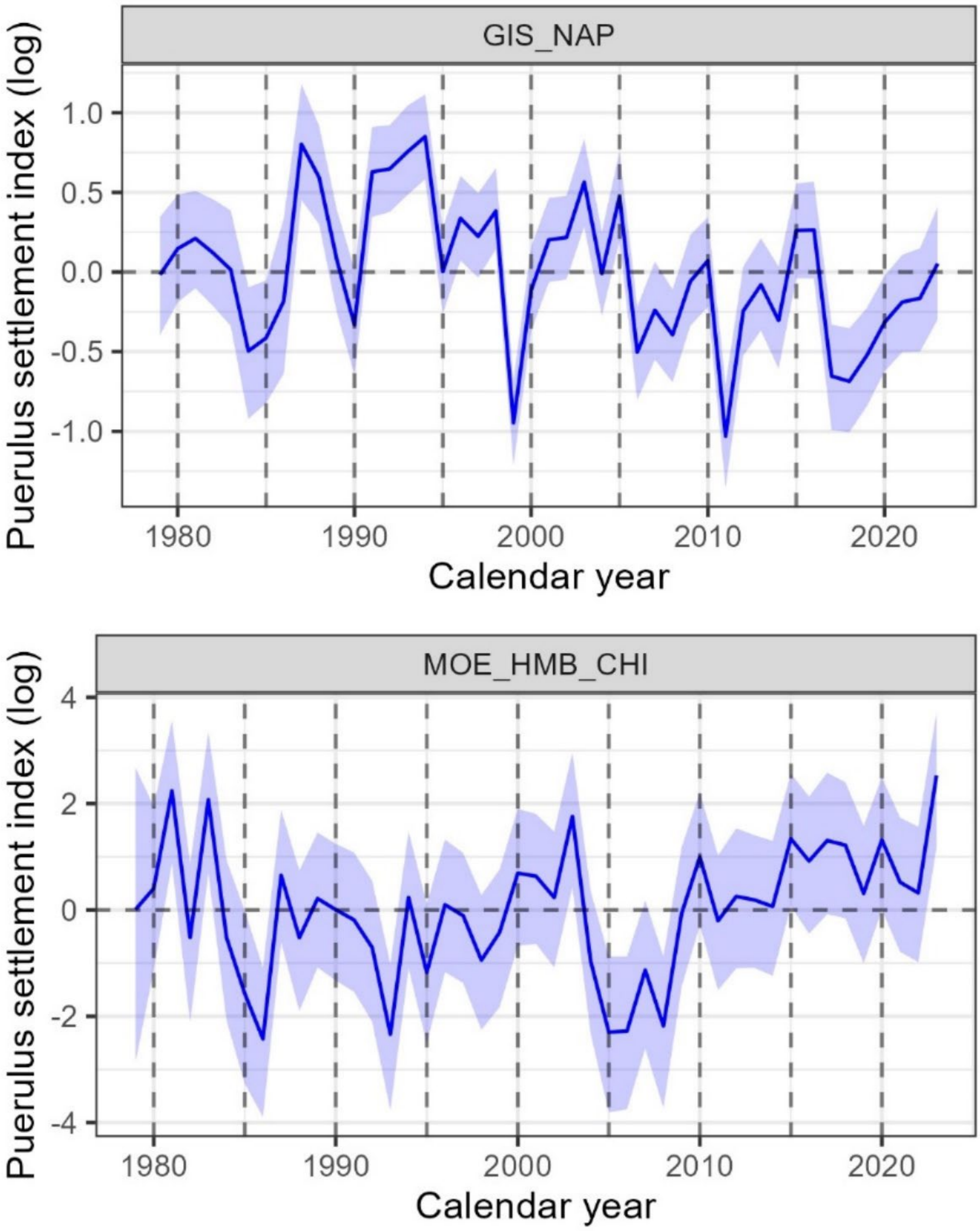

Figure B.19: The final <u>log-transformed</u> standardised puerulus settlement series by calendar year and collector site grouping ('GIS_NAP' = the Gisborne/Napier index series, and 'MOE_HMB_CHI' = the Moeraki/Halfmoon Bay/Chalky Inlet index series), scaled to respective geometric means. Blue points and lines are the average predictions, blue shaded areas are 95% credible intervals. Predictions generated from model runs *fit5_gisnap* and *fit5_moehmbchi.*

Appendix C. Additional figures and plots from climate predictors of puerulus settlement analysis

Table C.1: Summary of candidate climate series for predicting puerulus catch rate.

Climate index series label	Description	Source
sst_lag0	Mean SST in the year of the puerulus catch data.	ERA5 monthly averaged data (Hersbach et al. 2023).
wind_u_lag0	Mean westerly wind velocity (m/sec) in the year of the puerulus catch data.	
wind_u_lag1	Mean westerly wind velocity (m/sec) in the year before the puerulus catch data.	
wind_u_lag2	Mean westerly wind velocity (m/sec) two years before the puerulus catch data.	
wind_v_lag0	Mean southerly wind velocity (m/sec) in the year of the puerulus catch data.	
wind_v_lag1	Mean southerly wind velocity (m/sec) in the year before the puerulus catch data.	
wind_v_lag2	Mean southerly wind velocity (m/sec) two years before the puerulus catch data.	
soi_lag0	Mean SOI index series in the year of the puerulus catch data.	NOAA (2023).
soi_lag1	Mean SOI index series in the year before the puerulus catch data.	
soi_lag2	Mean SOI index series two years before the puerulus catch data.	
m1_lag0	Mean M1 Trenberth Index series in the year of the puerulus catch rate data.	Unpublished update to this index series provided by Andrew Lorrey (NIWA).

Table C.2: Comparison of models including climatic predictors to predict puerulus settlement rate. The shaded models were within 4 SE of the optimal model in terms of ELPD, so were not differentiated on this basis.

Model label	Climatic predictors included in the model	Bayesian R-squared (95% credible interval)	δ-ELPD	SE δ-ELPD	δ-LOO IC	SE LOO IC
fit_cli_7	wind_u_lag1:site + wind_v_lag1:site	0.368 (0.343 – 0.394)	0.0	0.0	0.0	501.4
fit_cli_1	soi_lag0:site	0.398 (0.372 – 0.425)	-35.2	38.2	70.3	500.6
fit_cli_4	wind_u_lag0:site + wind_v_lag0:site	0.382 (0.356 – 0.409)	-107.9	42.0	215.7	504.7
fit_cli_5	soi_lag1:site	0.373 (0.347 – 0.400)	-157.2	27.0	314.4	501
fit_cli_2	sst_lag0:site	0.385 (0.361 – 0.411)	-177.6	33.6	355.3	501
fit_cli_8	wind_u_lag2:site + wind_v_lag2:site	0.387 (0.361 – 0.413)	-188.2	37.1	376.3	498.8
fit_cli_3	m1_lag0:site	0.374 (0.346 – 0.403)	-243.9	39.1	487.8	504.6
fit_cli_6	soi_lag2:site	0.395 (0.370 – 0.420)	-296.0	37.1	592.0	503.8
fit_cli_0	None	0.378 (0.352 – 0.402)	-401.4	34.5	802.9	506.2

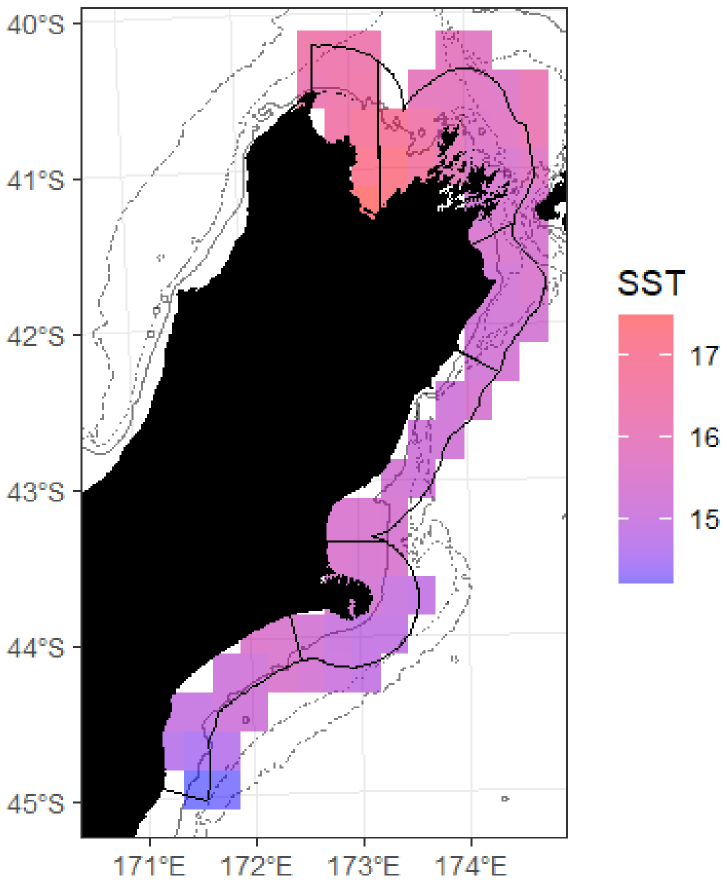

Figure C.1: Example sea surface temperature (SST) layer, which was used to derive the SST for the CRA 5 domain in January 1980. The black lines are the fisheries statistical areas that comprise CRA 5 and that were used to clip the SST data.

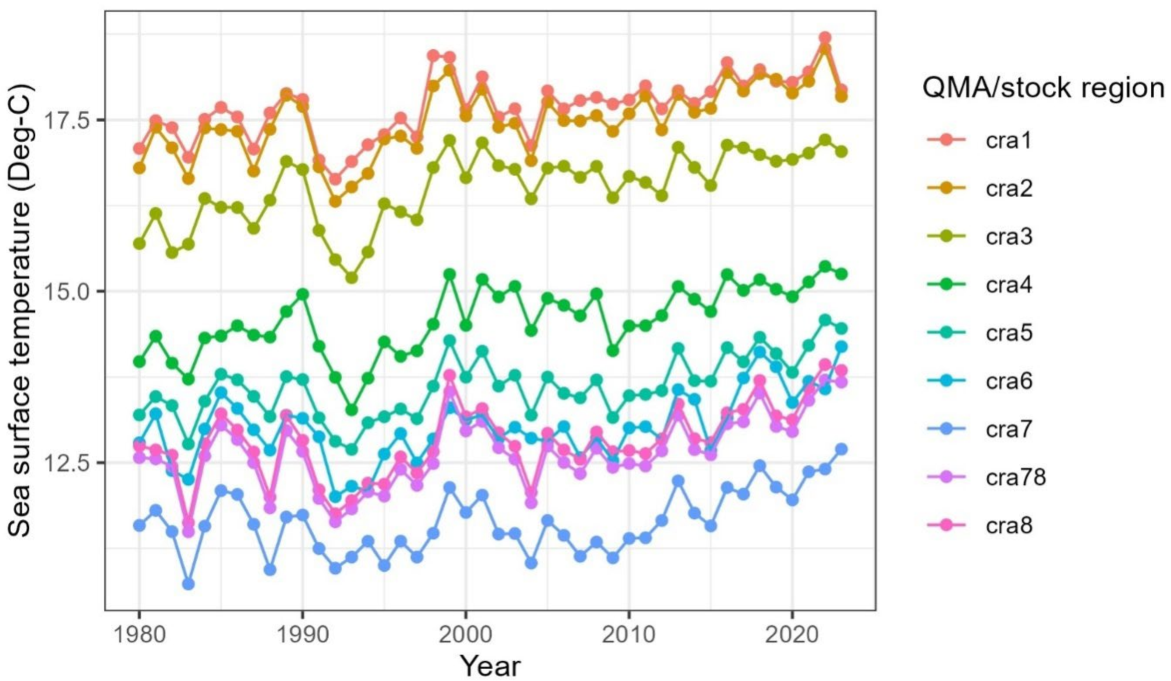

Figure C.2: Mean sea surface temperature (degree Celsius) by QMA and calendar year.

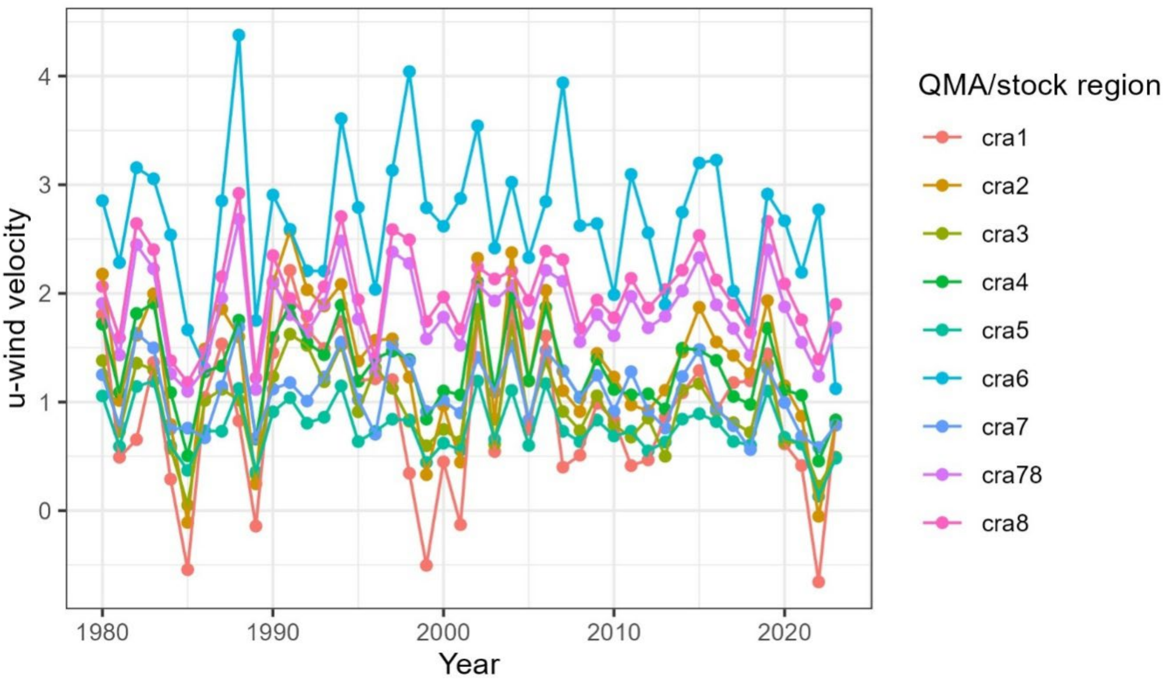

Figure C.3: Mean u-wind velocity by QMA and calendar year.

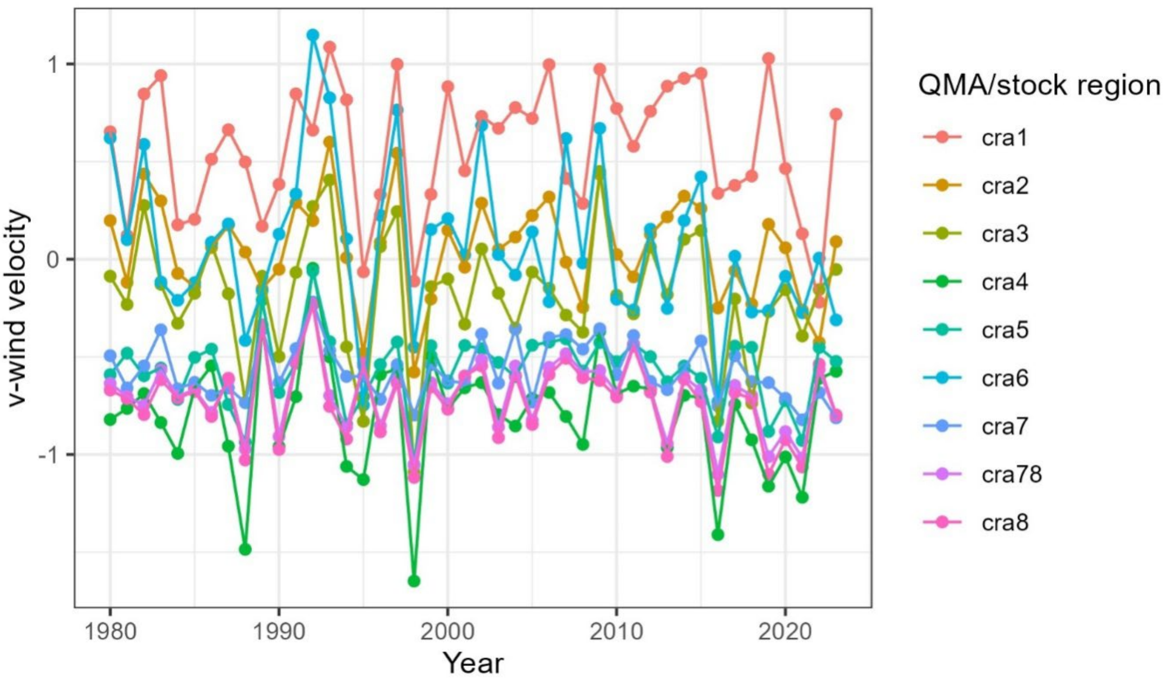

Figure C.4: Mean v-wind velocity by QMA and calendar year.

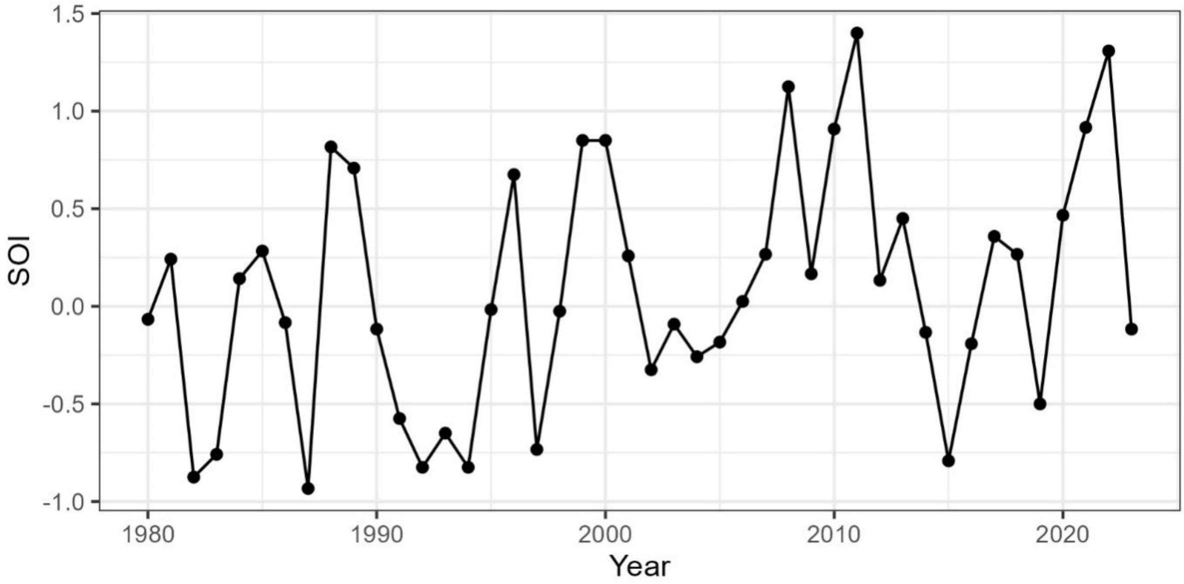

Figure C.5: Southern Oscillation Index (SOI) by calendar year.

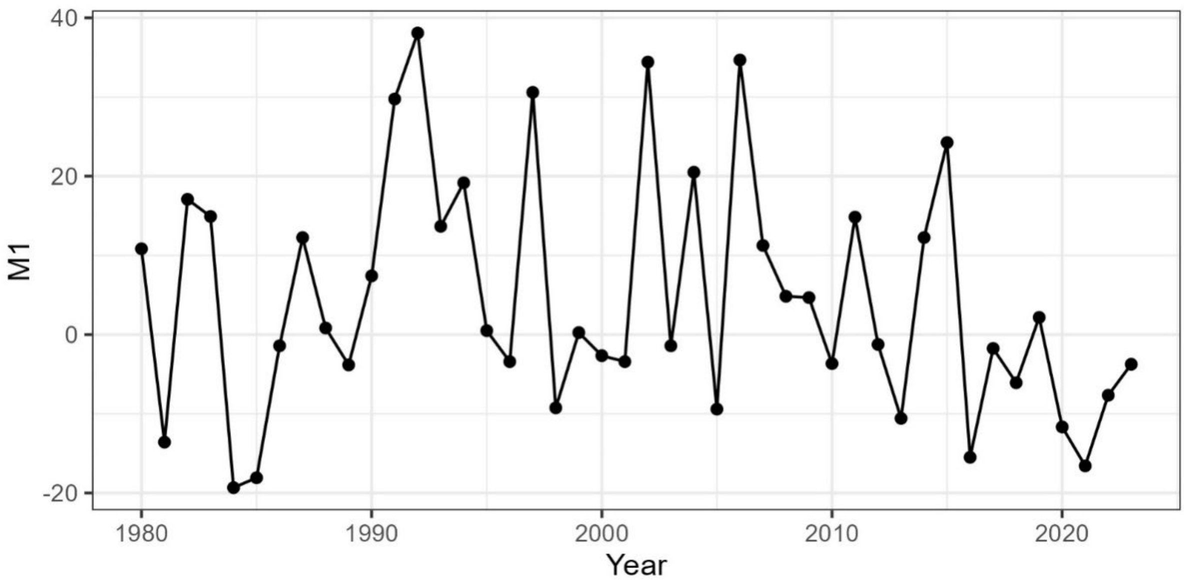

Figure C.6: M1 Trenberth Index series (M1) by calendar year.

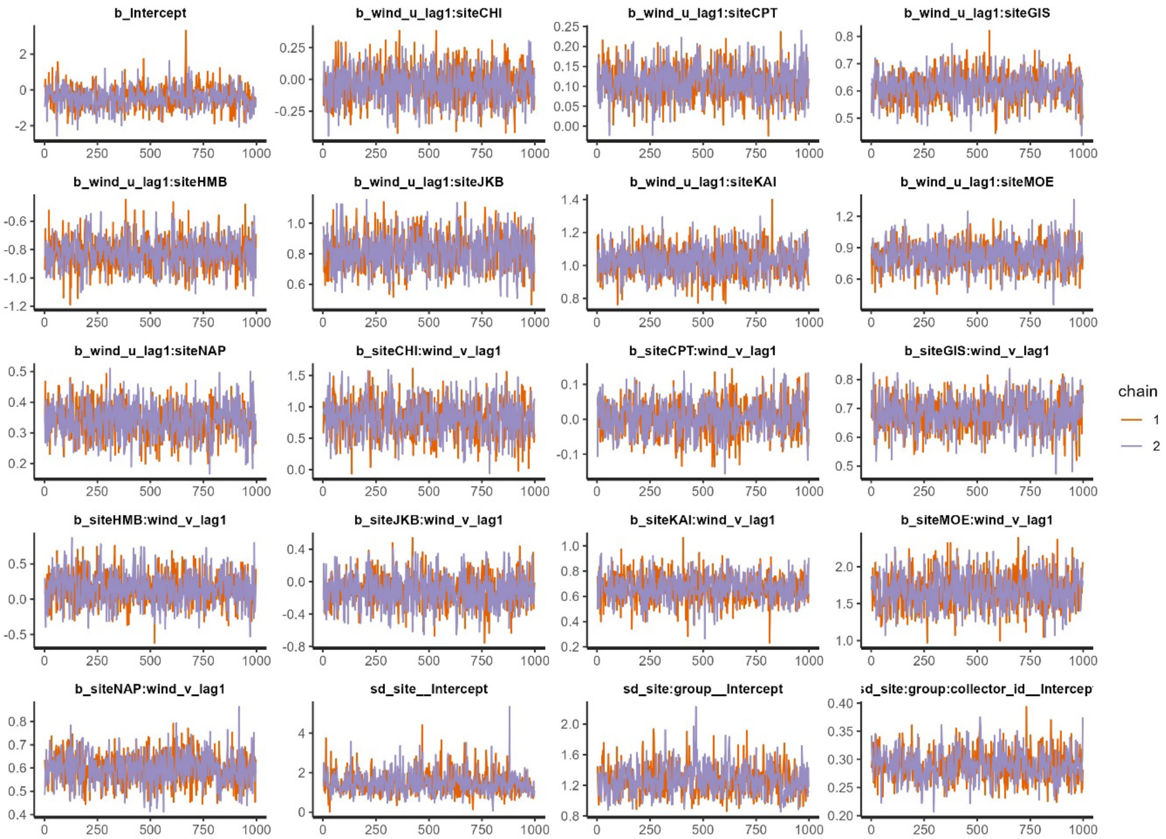

Figure C.7: Example trace plots from model run *fit_cli_7*.

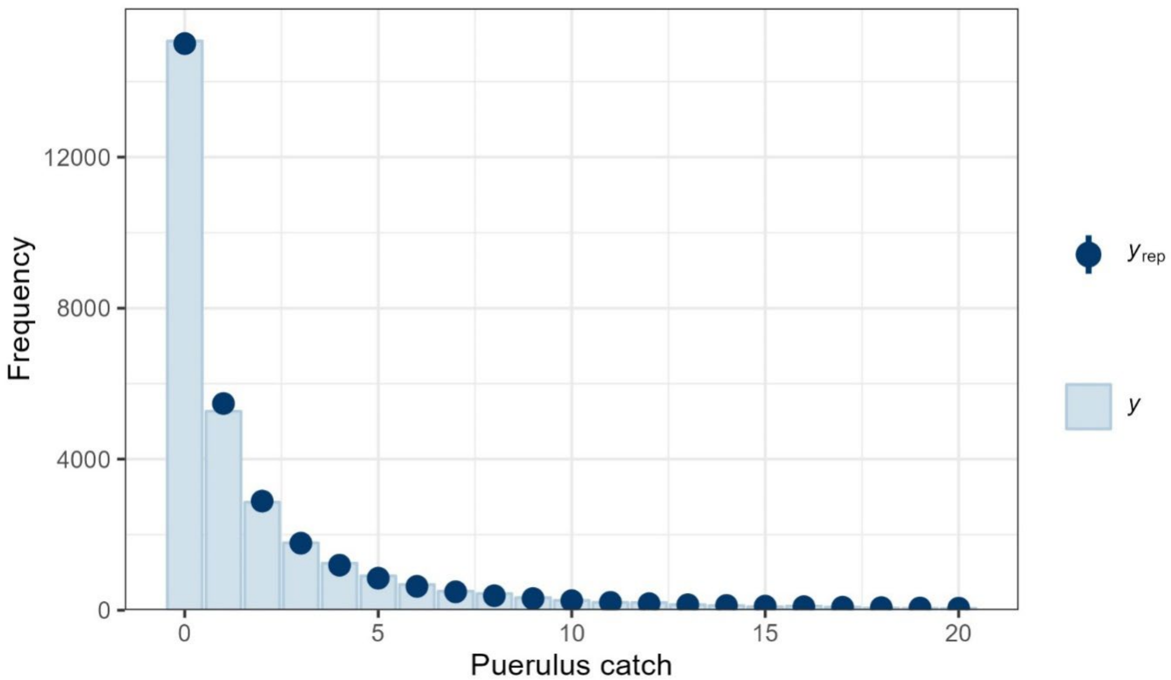

Figure C.8: Posterior predictive check plot for model run *fit_cli_7*. Bars are the observed distribution of puerulus catch and points and the simulated distribution (whiskers represent the 95% credible interval of this distribution but are so small as to not be visible in this plot).

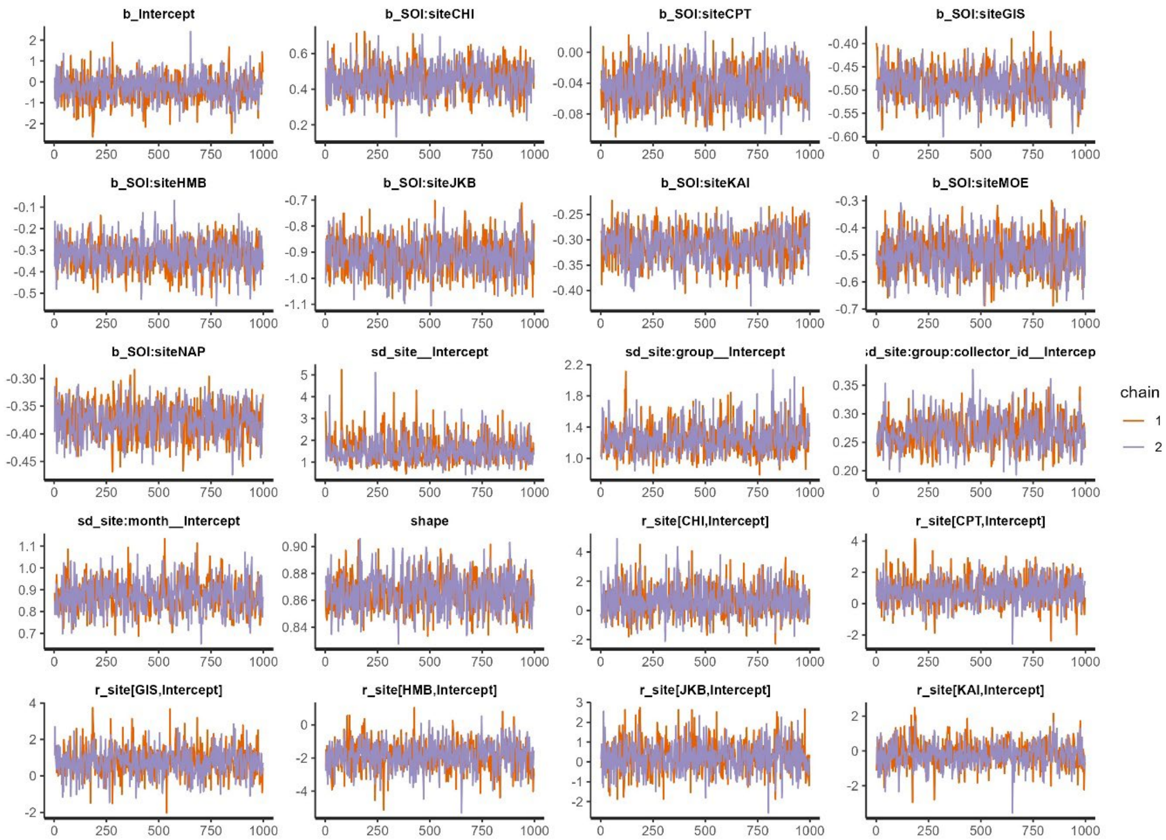

Figure C.9: Example trace plots from model run *fit_cli_1*.

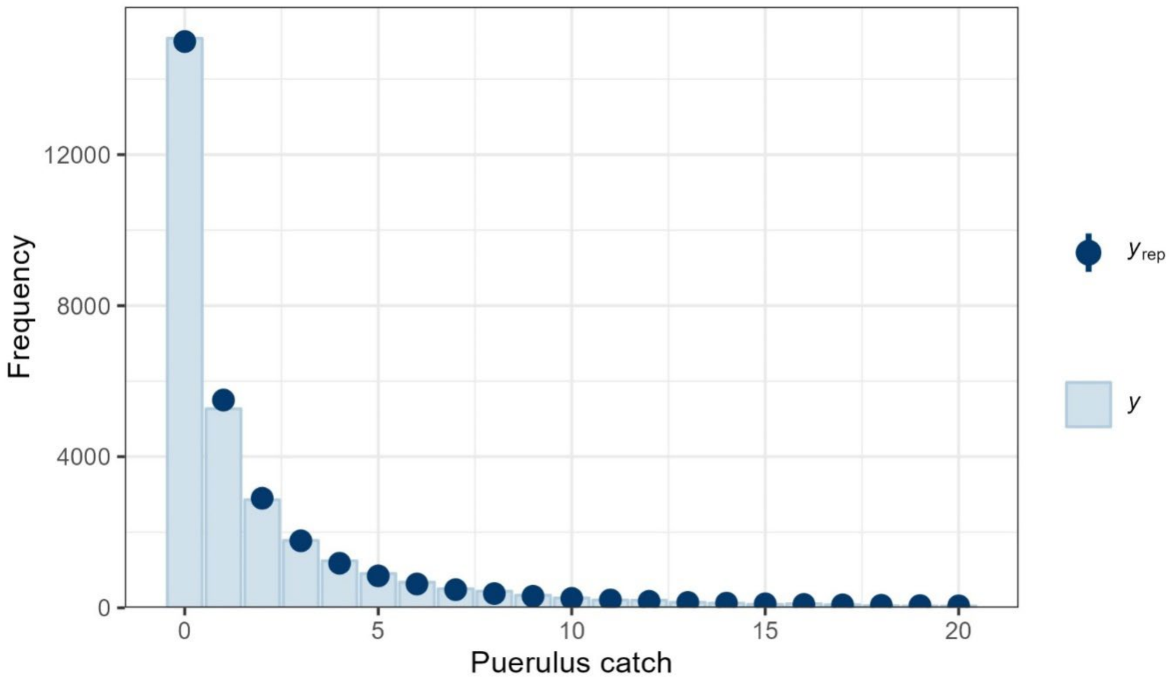

Figure C.10: Posterior predictive check plot for model run *fit_cli_1*. Bars are the observed distribution of puerulus catch and points and the simulated distribution (whiskers represent the 95% credible interval of this distribution but are so small as to not be visible in this plot).

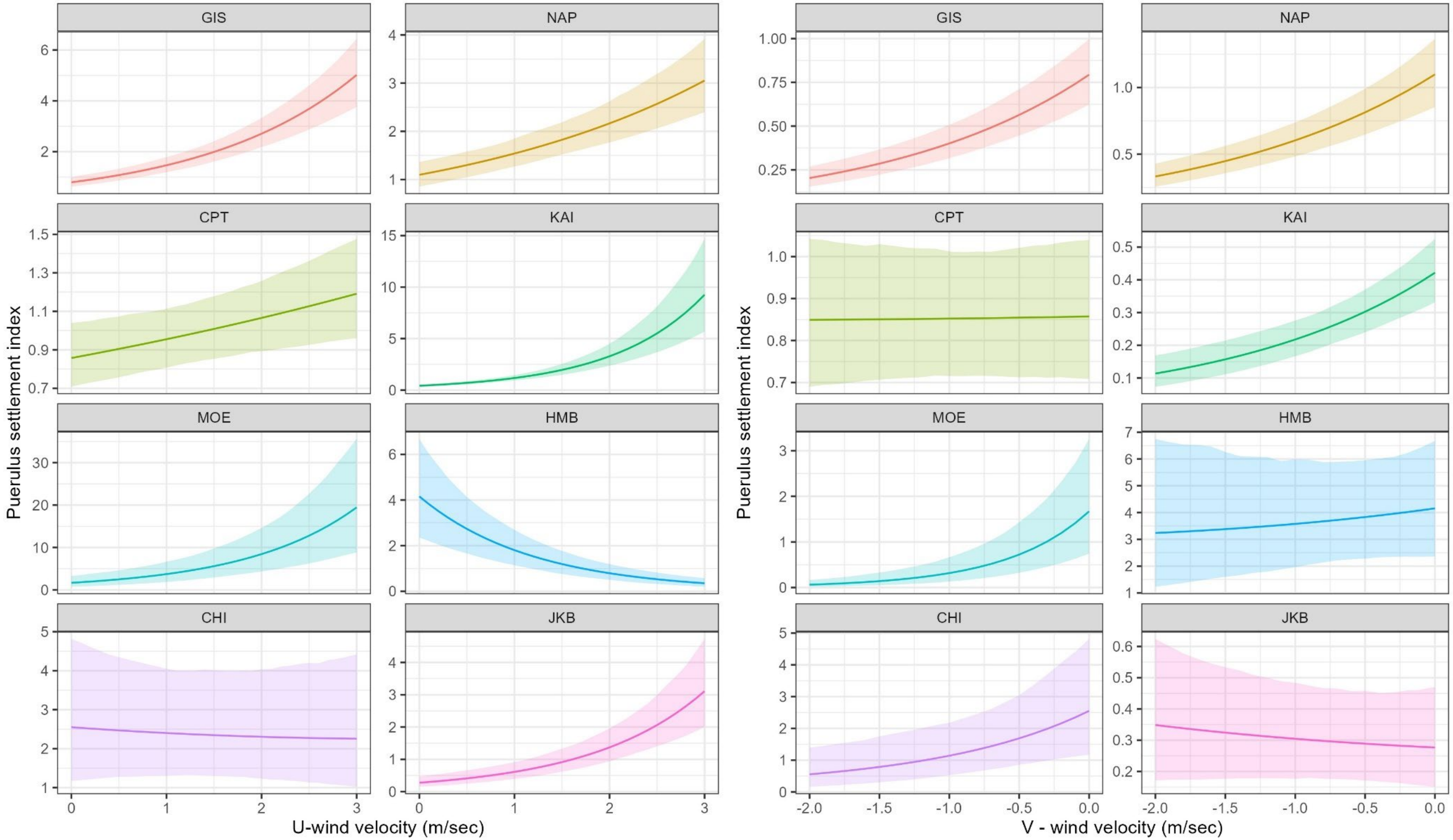

Figure C.11: Predicted puerulus settlement rate in response to u- and v-wind velocity by puerulus monitoring site (model *fit_cli_7*).

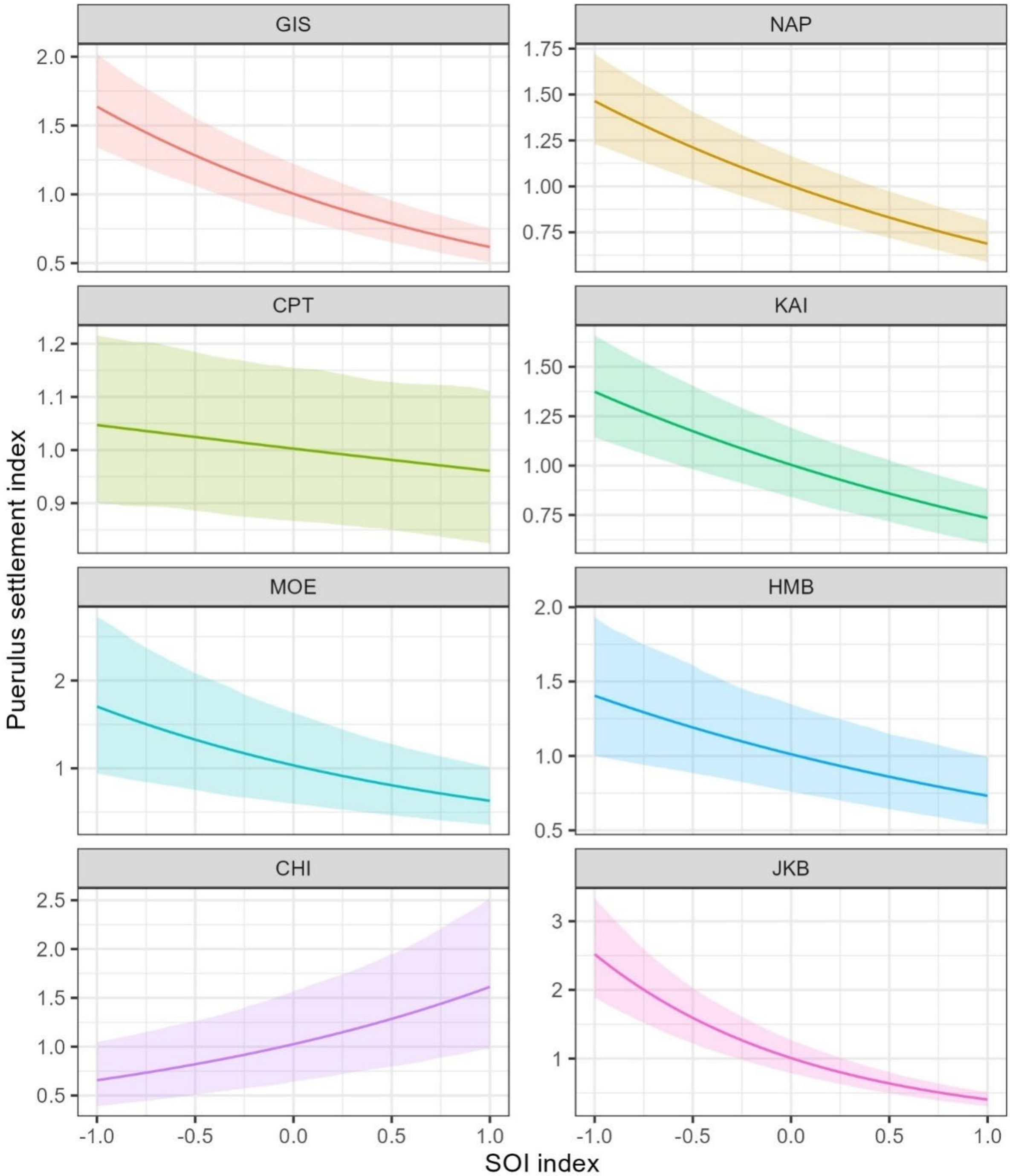

Figure C.12: Predicted puerulus settlement rate in response to SOI index series by puerulus monitoring site (model *fit_cli_1*).

Appendix D. Additional figures and plots from predictors of stock assessment recruitment analysis

Table D.1: Stock assessment model estimated recruitment deviates for CRA 1 by fishing year (in log-space)

	Recruitment deviates				
Fishing year	Mean	SD	Median	5%	95%
1975	0.045	0.406	0.046	-0.610	0.711
1976	0.084	0.402	0.073	-0.563	0.743
1977	0.175	0.374	0.191	-0.461	0.770
1978	0.219	0.374	0.259	-0.421	0.791
1979	0.356	0.389	0.395	-0.339	0.952
1980	0.244	0.369	0.273	-0.404	0.791
1981	0.070	0.329	0.089	-0.507	0.580
1982	0.040	0.360	0.085	-0.604	0.598
1983	0.102	0.329	0.114	-0.444	0.608
1984	-0.024	0.339	-0.018	-0.623	0.491
1985	-0.150	0.345	-0.130	-0.762	0.380
1986	-0.267	0.337	-0.252	-0.841	0.289
1987	-0.244	0.341	-0.236	-0.816	0.273
1988	-0.276	0.302	-0.255	-0.796	0.180
1989	-0.418	0.280	-0.412	-0.910	0.020
1990	-0.278	0.306	-0.249	-0.836	0.192
1991	0.215	0.353	0.229	-0.383	0.763
1992	0.871	0.287	0.918	0.324	1.250
1993	0.260	0.352	0.267	-0.342	0.832
1994	0.011	0.321	0.026	-0.536	0.503
1995	0.004	0.286	0.020	-0.523	0.433
1996	-0.046	0.278	-0.031	-0.523	0.398
1997	0.040	0.300	0.070	-0.488	0.500
1998	0.170	0.278	0.186	-0.317	0.585
1999	0.049	0.292	0.066	-0.467	0.493
2000	-0.143	0.297	-0.123	-0.669	0.316
2001	-0.081	0.294	-0.057	-0.597	0.362
2002	-0.009	0.290	0.015	-0.518	0.408
2003	0.149	0.300	0.180	-0.369	0.615
2004	0.493	0.280	0.516	0.018	0.914
2005	0.204	0.326	0.241	-0.368	0.687
2006	-0.149	0.311	-0.137	-0.685	0.315
2007	-0.333	0.307	-0.313	-0.857	0.155
2008	-0.124	0.288	-0.098	-0.626	0.319
2009	0.270	0.251	0.287	-0.184	0.654
2010	0.082	0.299	0.092	-0.452	0.539
2011	0.197	0.274	0.213	-0.293	0.626
2012	-0.016	0.280	0.009	-0.519	0.394
2013	0.159	0.240	0.183	-0.280	0.510
2014	0.101	0.257	0.111	-0.349	0.482
2015	0.190	0.244	0.208	-0.230	0.546
2016	0.072	0.237	0.089	-0.333	0.425
2017	-0.215	0.278	-0.202	-0.701	0.222
2018	0.038	0.237	0.049	-0.353	0.401
2019	-0.156	0.251	-0.149	-0.593	0.242
2020	-0.192	0.243	-0.191	-0.606	0.204

Table D.2: Stock assessment model estimated recruitment deviates for CRA 2 by fishing year (in log-space)

	Recruitment deviates				
Fishing year	Mean	SD	Median	5%	95%
1975	0.334	0.323	0.365	-0.240	0.804
1976	0.110	0.339	0.131	-0.464	0.629
1977	0.237	0.369	0.260	-0.399	0.777
1978	0.320	0.357	0.337	-0.315	0.882
1979	0.128	0.347	0.149	-0.479	0.637
1980	0.017	0.320	0.034	-0.520	0.523
1981	-0.074	0.338	-0.051	-0.638	0.443
1982	-0.245	0.337	-0.232	-0.851	0.295
1983	-0.251	0.300	-0.244	-0.759	0.200
1984	-0.207	0.286	-0.186	-0.686	0.220
1985	-0.167	0.291	-0.149	-0.697	0.268
1986	0.137	0.278	0.163	-0.323	0.552
1987	0.520	0.221	0.536	0.141	0.856
1988	0.759	0.206	0.773	0.399	1.070
1989	0.567	0.219	0.578	0.171	0.896
1990	0.178	0.248	0.200	-0.262	0.552
1991	-0.191	0.256	-0.168	-0.644	0.187
1992	-0.523	0.236	-0.519	-0.924	-0.145
1993	-0.483	0.222	-0.470	-0.866	-0.144
1994	-0.409	0.207	-0.398	-0.769	-0.078
1995	-0.569	0.243	-0.549	-1.010	-0.207
1996	-0.164	0.211	-0.148	-0.560	0.141
1997	-0.073	0.213	-0.056	-0.452	0.253
1998	-0.214	0.236	-0.192	-0.642	0.141
1999	0.304	0.178	0.318	-0.021	0.563
2000	-0.020	0.237	0.001	-0.451	0.341
2001	-0.187	0.227	-0.172	-0.600	0.151
2002	-0.097	0.200	-0.086	-0.442	0.203
2003	-0.157	0.200	-0.142	-0.497	0.135
2004	-0.430	0.250	-0.421	-0.873	-0.058
2005	0.141	0.184	0.143	-0.154	0.420
2006	-0.022	0.199	-0.017	-0.366	0.285
2007	-0.453	0.228	-0.440	-0.879	-0.109
2008	-0.523	0.208	-0.512	-0.888	-0.202
2009	-0.494	0.204	-0.486	-0.852	-0.176
2010	-0.424	0.224	-0.402	-0.819	-0.085
2011	0.250	0.171	0.252	-0.038	0.505
2012	-0.066	0.242	-0.049	-0.504	0.301
2013	-0.468	0.251	-0.464	-0.889	-0.079
2014	-0.398	0.243	-0.386	-0.825	-0.032
2015	0.080	0.195	0.084	-0.238	0.398
2016	0.334	0.323	0.365	-0.240	0.804
2017	0.110	0.339	0.131	-0.464	0.629
2018	0.237	0.369	0.260	-0.399	0.777
2019	0.320	0.357	0.337	-0.315	0.882

Table D.3: Stock assessment model estimated recruitment deviates for CRA 3 region 1 by fishing year (in log-space) (*r1_qdrift* model run).

	Recruitment deviates				
Fishing year	Mean	SD	Median	5%	95%
1975	0.562	0.535	0.555	-0.302	1.460
1976	1.470	0.540	1.650	0.327	2.060
1977	0.812	0.614	0.802	-0.181	1.810
1978	0.456	0.442	0.452	-0.303	1.170
1979	0.454	0.443	0.475	-0.287	1.160
1980	0.484	0.401	0.512	-0.241	1.090
1981	0.264	0.391	0.291	-0.476	0.846
1982	-0.108	0.345	-0.090	-0.693	0.421
1983	-0.333	0.308	-0.323	-0.850	0.151
1984	-0.341	0.297	-0.339	-0.850	0.131
1985	-0.290	0.304	-0.269	-0.830	0.180
1986	-0.381	0.291	-0.352	-0.891	0.086
1987	-0.493	0.285	-0.481	-0.971	-0.054
1988	-0.316	0.307	-0.306	-0.830	0.165
1989	0.329	0.327	0.356	-0.238	0.794
1990	0.721	0.281	0.753	0.193	1.110
1991	0.151	0.346	0.161	-0.452	0.678
1992	0.193	0.316	0.220	-0.360	0.673
1993	0.155	0.350	0.189	-0.479	0.679
1994	0.302	0.325	0.320	-0.267	0.802
1995	-0.043	0.319	-0.029	-0.586	0.461
1996	-0.350	0.308	-0.333	-0.889	0.141
1997	-0.489	0.282	-0.478	-0.996	-0.044
1998	-0.430	0.258	-0.412	-0.852	-0.022
1999	-0.427	0.263	-0.402	-0.887	-0.018
2000	-0.455	0.268	-0.446	-0.894	-0.030
2001	-0.376	0.307	-0.363	-0.933	0.094
2002	-0.046	0.302	-0.019	-0.544	0.416
2003	0.287	0.298	0.313	-0.247	0.719
2004	0.027	0.335	0.057	-0.531	0.511
2005	-0.158	0.321	-0.137	-0.741	0.329
2006	0.057	0.323	0.068	-0.499	0.560
2007	0.382	0.300	0.420	-0.173	0.813
2008	0.098	0.334	0.125	-0.488	0.584
2009	0.067	0.308	0.083	-0.454	0.528
2010	0.008	0.336	0.042	-0.579	0.506
2011	0.093	0.318	0.112	-0.462	0.584
2012	0.003	0.285	0.023	-0.526	0.429
2013	-0.467	0.287	-0.449	-0.957	-0.042
2014	-0.806	0.257	-0.798	-1.240	-0.411
2015	-0.882	0.268	-0.871	-1.330	-0.446
2016	-0.728	0.268	-0.728	-1.180	-0.289
2017	-0.324	0.304	-0.308	-0.831	0.151
2018	0.528	0.356	0.534	-0.073	1.090
2019	0.872	0.423	0.875	0.155	1.500
2020	0.230	0.399	0.234	-0.471	0.864

Table D.4: Stock assessment model estimated recruitment deviates for CRA 3 region 2 by fishing year (in log-space) (*r1_qdrift* model run).

	Recruitment deviates				
Fishing year	Mean	SD	Median	5%	95%
1975	0.574	0.518	0.576	-0.288	1.420
1976	1.140	0.563	1.240	0.077	1.890
1977	0.893	0.594	0.901	-0.084	1.790
1978	0.635	0.510	0.646	-0.227	1.430
1979	0.459	0.484	0.477	-0.383	1.210
1980	0.202	0.391	0.226	-0.479	0.796
1981	-0.039	0.359	-0.039	-0.634	0.529
1982	-0.184	0.326	-0.185	-0.717	0.351
1983	-0.267	0.335	-0.249	-0.849	0.282
1984	-0.374	0.330	-0.365	-0.955	0.166
1985	-0.430	0.321	-0.415	-0.957	0.064
1986	-0.309	0.324	-0.289	-0.840	0.215
1987	0.010	0.347	0.011	-0.554	0.562
1988	0.540	0.364	0.587	-0.120	1.040
1989	0.460	0.390	0.489	-0.217	1.060
1990	0.137	0.351	0.153	-0.484	0.686
1991	0.121	0.317	0.141	-0.417	0.602
1992	-0.038	0.322	-0.017	-0.588	0.472
1993	-0.283	0.310	-0.271	-0.807	0.192
1994	-0.366	0.317	-0.354	-0.908	0.124
1995	-0.278	0.318	-0.264	-0.818	0.227
1996	-0.241	0.318	-0.228	-0.794	0.262
1997	-0.257	0.302	-0.237	-0.802	0.208
1998	-0.368	0.321	-0.354	-0.897	0.115
1999	-0.427	0.296	-0.426	-0.928	0.023
2000	-0.279	0.298	-0.257	-0.805	0.172
2001	-0.047	0.305	-0.008	-0.584	0.387
2002	-0.063	0.313	-0.046	-0.622	0.424
2003	-0.005	0.354	0.005	-0.595	0.545
2004	0.440	0.398	0.472	-0.272	1.050
2005	0.871	0.345	0.921	0.223	1.350
2006	0.210	0.396	0.224	-0.444	0.850
2007	-0.132	0.345	-0.111	-0.710	0.424
2008	-0.221	0.348	-0.195	-0.812	0.331
2009	-0.097	0.337	-0.086	-0.680	0.426
2010	0.108	0.331	0.136	-0.481	0.594
2011	0.098	0.313	0.109	-0.453	0.564
2012	-0.129	0.314	-0.115	-0.660	0.367
2013	-0.215	0.308	-0.200	-0.761	0.265
2014	-0.212	0.298	-0.186	-0.742	0.246
2015	-0.168	0.296	-0.156	-0.675	0.296
2016	-0.172	0.311	-0.154	-0.728	0.306
2017	-0.135	0.319	-0.124	-0.673	0.366
2018	0.109	0.360	0.120	-0.509	0.685
2019	0.439	0.429	0.457	-0.287	1.100
2020	1.070	0.368	1.090	0.441	1.650

Table D.5: Stock assessment model estimated recruitment deviates for CRA 4 by fishing year (in log-space)

	Recruitment deviates				
Fishing year	Mean	SD	Median	5%	95%
1975	0.194	0.407	0.201	-0.508	0.814
1976	0.389	0.400	0.402	-0.307	1.040
1977	0.622	0.410	0.656	-0.115	1.220
1978	0.527	0.408	0.571	-0.174	1.160
1979	0.287	0.391	0.314	-0.375	0.891
1980	0.230	0.389	0.255	-0.416	0.834
1981	0.467	0.393	0.483	-0.223	1.060
1982	0.714	0.362	0.763	0.063	1.210
1983	0.365	0.390	0.387	-0.318	0.944
1984	0.093	0.370	0.115	-0.492	0.687
1985	-0.139	0.329	-0.123	-0.709	0.385
1986	-0.194	0.304	-0.181	-0.745	0.276
1987	-0.101	0.317	-0.077	-0.663	0.390
1988	0.166	0.298	0.193	-0.341	0.607
1989	0.295	0.315	0.326	-0.283	0.751
1990	0.385	0.407	0.416	-0.330	0.978
1991	0.981	0.337	1.040	0.323	1.440
1992	0.441	0.408	0.467	-0.266	1.080
1993	0.104	0.371	0.130	-0.546	0.671
1994	0.031	0.333	0.034	-0.484	0.568
1995	0.068	0.342	0.083	-0.506	0.610
1996	0.262	0.338	0.300	-0.376	0.753
1997	0.203	0.322	0.224	-0.356	0.687
1998	-0.068	0.316	-0.046	-0.618	0.408
1999	-0.329	0.283	-0.326	-0.827	0.124
2000	-0.396	0.277	-0.390	-0.876	0.049
2001	-0.494	0.256	-0.483	-0.937	-0.091
2002	-0.596	0.270	-0.589	-1.040	-0.173
2003	-0.480	0.279	-0.464	-0.956	-0.033
2004	-0.071	0.333	-0.035	-0.657	0.439
2005	0.421	0.339	0.476	-0.182	0.897
2006	0.426	0.318	0.455	-0.133	0.898
2007	-0.047	0.339	-0.032	-0.637	0.463
2008	-0.459	0.313	-0.456	-0.999	0.030
2009	-0.675	0.277	-0.663	-1.160	-0.240
2010	-0.629	0.262	-0.619	-1.090	-0.209
2011	-0.436	0.279	-0.419	-0.921	-0.029
2012	-0.106	0.263	-0.078	-0.556	0.302
2013	-0.076	0.255	-0.062	-0.512	0.313
2014	-0.391	0.270	-0.398	-0.845	0.046
2015	-0.447	0.270	-0.432	-0.901	-0.002
2016	-0.343	0.276	-0.324	-0.821	0.079
2017	-0.190	0.291	-0.188	-0.671	0.288
2018	-0.110	0.309	-0.098	-0.617	0.390
2019	0.016	0.358	0.031	-0.594	0.555
2020	0.192	0.345	0.212	-0.413	0.745

Table D.6: Stock assessment model estimated recruitment deviates for CRA 5 Region 1 by fishing year (in log-space)

	Recruitment deviates				
Fishing year	Mean	SD	Median	5%	95%
1975	-0.086	0.342	-0.088	-0.622	0.487
1976	-0.091	0.353	-0.090	-0.676	0.467
1977	-0.073	0.334	-0.071	-0.615	0.470
1978	-0.027	0.362	0.005	-0.653	0.537
1979	0.040	0.356	0.052	-0.560	0.624
1980	0.057	0.356	0.067	-0.557	0.650
1981	-0.053	0.343	-0.041	-0.625	0.490
1982	-0.286	0.329	-0.279	-0.820	0.236
1983	-0.585	0.315	-0.576	-1.120	-0.091
1984	-0.794	0.296	-0.783	-1.310	-0.319
1985	-0.905	0.282	-0.907	-1.360	-0.417
1986	-0.874	0.270	-0.869	-1.320	-0.453
1987	-0.686	0.284	-0.674	-1.180	-0.260
1988	-0.247	0.275	-0.230	-0.750	0.165
1989	-0.256	0.272	-0.244	-0.718	0.167
1990	-0.407	0.302	-0.385	-0.904	0.032
1991	-0.094	0.332	-0.090	-0.660	0.421
1992	0.733	0.294	0.760	0.204	1.140
1993	0.390	0.364	0.411	-0.265	0.936
1994	-0.046	0.346	-0.028	-0.636	0.503
1995	-0.026	0.353	-0.022	-0.623	0.518
1996	0.232	0.364	0.244	-0.381	0.807
1997	0.433	0.358	0.447	-0.225	0.952
1998	0.267	0.389	0.278	-0.409	0.864
1999	0.190	0.371	0.205	-0.464	0.785
2000	0.256	0.394	0.259	-0.379	0.897
2001	0.388	0.420	0.414	-0.338	1.080
2002	0.799	0.504	0.836	-0.067	1.560
2003	1.110	0.506	1.180	0.177	1.790
2004	0.600	0.494	0.634	-0.242	1.340
2005	0.479	0.425	0.506	-0.252	1.130
2006	0.389	0.390	0.400	-0.271	1.030
2007	0.284	0.386	0.301	-0.403	0.897
2008	0.263	0.384	0.278	-0.418	0.845
2009	0.234	0.364	0.266	-0.409	0.791
2010	0.309	0.358	0.328	-0.306	0.844
2011	0.012	0.352	0.038	-0.610	0.558
2012	-0.244	0.317	-0.237	-0.750	0.263
2013	-0.368	0.310	-0.357	-0.869	0.121
2014	-0.407	0.293	-0.397	-0.914	0.050
2015	-0.314	0.301	-0.308	-0.804	0.181
2016	-0.088	0.308	-0.082	-0.628	0.379
2017	-0.104	0.326	-0.091	-0.676	0.405
2018	-0.212	0.348	-0.208	-0.791	0.344
2019	-0.267	0.326	-0.249	-0.826	0.248
2020	-0.203	0.341	-0.211	-0.748	0.366

Table D.7: Stock assessment model estimated recruitment deviates for CRA 5 Region 2 by fishing year (in log-space)

	Recruitment deviates				
Fishing year	Mean	SD	Median	5%	95%
1975	0.013	0.359	0.031	-0.599	0.590
1976	0.000	0.346	0.022	-0.593	0.521
1977	0.163	0.348	0.187	-0.434	0.689
1978	0.292	0.344	0.319	-0.300	0.790
1979	0.072	0.348	0.082	-0.524	0.622
1980	-0.204	0.302	-0.192	-0.723	0.270
1981	-0.369	0.292	-0.350	-0.904	0.088
1982	-0.349	0.286	-0.337	-0.831	0.096
1983	-0.376	0.260	-0.368	-0.807	0.022
1984	-0.579	0.277	-0.579	-1.030	-0.156
1985	-0.693	0.284	-0.679	-1.170	-0.253
1986	-0.742	0.289	-0.732	-1.230	-0.282
1987	-0.658	0.270	-0.643	-1.110	-0.251
1988	-0.438	0.276	-0.437	-0.908	-0.015
1989	-0.245	0.299	-0.228	-0.778	0.198
1990	-0.039	0.330	-0.024	-0.615	0.456
1991	0.350	0.389	0.380	-0.353	0.931
1992	0.999	0.398	1.050	0.211	1.520
1993	0.716	0.447	0.757	-0.081	1.400
1994	0.532	0.432	0.548	-0.225	1.200
1995	0.375	0.403	0.381	-0.342	0.998
1996	0.243	0.396	0.264	-0.421	0.841
1997	0.323	0.371	0.338	-0.345	0.881
1998	0.302	0.394	0.337	-0.384	0.886
1999	0.197	0.358	0.224	-0.440	0.743
2000	0.180	0.350	0.200	-0.435	0.713
2001	0.200	0.328	0.230	-0.387	0.716
2002	0.182	0.326	0.212	-0.385	0.664
2003	0.178	0.318	0.200	-0.377	0.662
2004	0.210	0.310	0.231	-0.348	0.697
2005	0.145	0.321	0.170	-0.423	0.655
2006	0.067	0.329	0.093	-0.495	0.553
2007	-0.245	0.300	-0.247	-0.742	0.233
2008	-0.412	0.288	-0.401	-0.902	0.025
2009	-0.514	0.287	-0.502	-1.010	-0.050
2010	-0.499	0.307	-0.493	-1.010	-0.022
2011	-0.437	0.300	-0.424	-0.940	0.030
2012	-0.206	0.302	-0.205	-0.697	0.264
2013	-0.094	0.311	-0.065	-0.621	0.374
2014	-0.321	0.302	-0.304	-0.817	0.160
2015	-0.233	0.353	-0.226	-0.816	0.348
2016	-0.071	0.328	-0.065	-0.623	0.469
2017	0.005	0.412	0.011	-0.699	0.675
2018	0.037	0.386	0.037	-0.625	0.681
2019	-0.013	0.361	-0.003	-0.602	0.562
2020	-0.062	0.413	-0.040	-0.764	0.588

Table D.8: Stock assessment model estimated recruitment deviates for CRA 6 by fishing year (in log-space)

	Recruitment deviates				
Fishing year	Mean	SD	Median	5%	95%
1975	0.015	0.386	0.023	-0.624	0.646
1976	-0.030	0.375	-0.016	-0.676	0.574
1977	-0.111	0.359	-0.099	-0.686	0.470
1978	-0.160	0.350	-0.146	-0.772	0.376
1979	-0.177	0.347	-0.155	-0.770	0.369
1980	-0.205	0.324	-0.189	-0.765	0.307
1981	-0.280	0.334	-0.260	-0.868	0.250
1982	-0.410	0.304	-0.391	-0.919	0.075
1983	-0.514	0.286	-0.507	-1.010	-0.042
1984	-0.525	0.290	-0.513	-0.999	-0.075
1985	-0.505	0.284	-0.494	-0.995	-0.062
1986	-0.491	0.291	-0.482	-0.979	-0.048
1987	-0.510	0.282	-0.500	-0.996	-0.095
1988	-0.463	0.281	-0.438	-0.966	-0.045
1989	-0.402	0.270	-0.388	-0.838	0.012
1990	-0.335	0.257	-0.317	-0.778	0.063
1991	-0.247	0.264	-0.236	-0.692	0.166
1992	-0.061	0.259	-0.044	-0.515	0.316
1993	-0.185	0.271	-0.165	-0.638	0.238
1994	-0.159	0.300	-0.153	-0.705	0.308
1995	0.102	0.333	0.113	-0.472	0.607
1996	0.072	0.368	0.070	-0.520	0.625
1997	0.084	0.358	0.107	-0.531	0.637
1998	0.003	0.358	0.007	-0.570	0.561
1999	-0.090	0.351	-0.081	-0.665	0.460
2000	-0.081	0.327	-0.061	-0.659	0.409
2001	-0.090	0.337	-0.082	-0.657	0.436
2002	-0.185	0.334	-0.169	-0.772	0.313
2003	-0.361	0.309	-0.360	-0.909	0.119
2004	-0.465	0.309	-0.460	-0.983	0.011
2005	-0.443	0.289	-0.442	-0.924	0.038
2006	-0.346	0.301	-0.339	-0.860	0.115
2007	-0.220	0.309	-0.217	-0.743	0.282
2008	-0.091	0.300	-0.088	-0.605	0.381
2009	0.039	0.304	0.060	-0.477	0.491
2010	0.144	0.301	0.156	-0.382	0.595
2011	0.110	0.294	0.132	-0.433	0.569
2012	0.260	0.301	0.293	-0.282	0.706
2013	0.482	0.266	0.495	0.026	0.877
2014	0.319	0.302	0.352	-0.242	0.759
2015	0.173	0.311	0.206	-0.368	0.659
2016	0.351	0.313	0.380	-0.232	0.812
2017	0.616	0.286	0.647	0.059	1.010
2018	0.375	0.313	0.399	-0.170	0.859
2019	0.498	0.251	0.506	0.063	0.876

Table D.9: Stock assessment model estimated recruitment deviates for CRA 7&8 Region 1 by fishing year (in log-space)

	Recruitment deviates				
Fishing year	Mean	SD	Median	5%	95%
1975	0.530	0.439	0.541	-0.211	1.210
1976	0.126	0.355	0.138	-0.482	0.658
1977	-0.132	0.317	-0.125	-0.679	0.367
1978	-0.212	0.304	-0.213	-0.681	0.296
1979	0.040	0.346	0.044	-0.559	0.592
1980	0.579	0.362	0.636	-0.064	1.090
1981	0.772	0.367	0.842	0.096	1.240
1982	0.360	0.374	0.375	-0.270	0.952
1983	0.044	0.300	0.070	-0.490	0.507
1984	-0.041	0.283	-0.033	-0.508	0.416
1985	-0.105	0.261	-0.094	-0.556	0.332
1986	-0.286	0.285	-0.273	-0.751	0.157
1987	-0.305	0.257	-0.292	-0.735	0.095
1988	0.055	0.177	0.058	-0.253	0.321
1989	-0.444	0.224	-0.443	-0.822	-0.102
1990	-0.862	0.217	-0.864	-1.230	-0.518
1991	-1.050	0.212	-1.040	-1.410	-0.732
1992	-1.070	0.196	-1.070	-1.370	-0.737
1993	-1.160	0.221	-1.130	-1.550	-0.834
1994	-1.190	0.223	-1.180	-1.590	-0.836
1995	-0.823	0.218	-0.811	-1.200	-0.491
1996	-0.554	0.211	-0.543	-0.923	-0.227
1997	-0.458	0.237	-0.440	-0.873	-0.100
1998	-0.491	0.233	-0.489	-0.881	-0.130
1999	-0.540	0.259	-0.523	-0.975	-0.144
2000	-0.530	0.244	-0.516	-0.958	-0.158
2001	-0.604	0.267	-0.590	-1.060	-0.180
2002	-0.626	0.269	-0.598	-1.120	-0.242
2003	-0.643	0.258	-0.630	-1.090	-0.222
2004	-0.628	0.258	-0.619	-1.080	-0.212
2005	-0.658	0.251	-0.644	-1.090	-0.273
2006	-0.797	0.275	-0.795	-1.260	-0.374
2007	-0.749	0.303	-0.723	-1.290	-0.301
2008	-0.547	0.283	-0.542	-1.010	-0.113
2009	-0.513	0.301	-0.499	-1.060	-0.047
2010	-0.437	0.300	-0.422	-0.971	0.032
2011	-0.307	0.293	-0.297	-0.802	0.145
2012	-0.277	0.340	-0.255	-0.868	0.233
2013	-0.100	0.325	-0.098	-0.675	0.412
2014	-0.147	0.347	-0.115	-0.764	0.375
2015	-0.036	0.343	-0.025	-0.598	0.512
2016	0.096	0.366	0.123	-0.555	0.670
2017	0.196	0.363	0.186	-0.367	0.821
2018	0.155	0.396	0.160	-0.525	0.808
2019	-0.038	0.391	-0.065	-0.660	0.615
2020	-0.059	0.358	-0.047	-0.640	0.499

Table D.10: Stock assessment model estimated recruitment deviates for CRA 7&8 Region 2 by fishing year (in log-space)

Fishing year	Recruitment deviates Mean	SD	Median	5%	95%
1975	-0.217	0.309	-0.202	-0.762	0.256
1976	-0.321	0.307	-0.317	-0.838	0.147
1977	-0.464	0.309	-0.451	-0.936	0.011
1978	-0.391	0.320	-0.379	-0.945	0.104
1979	0.002	0.325	0.018	-0.540	0.484
1980	0.677	0.258	0.702	0.211	1.040
1981	0.195	0.338	0.227	-0.406	0.687
1982	-0.074	0.331	-0.038	-0.658	0.403
1983	-0.156	0.281	-0.133	-0.675	0.262
1984	-0.341	0.285	-0.322	-0.875	0.097
1985	-0.378	0.264	-0.369	-0.812	0.028
1986	-0.374	0.251	-0.365	-0.796	0.017
1987	-0.144	0.261	-0.123	-0.606	0.256
1988	0.082	0.240	0.104	-0.341	0.410
1989	-0.130	0.238	-0.113	-0.557	0.228
1990	-0.340	0.240	-0.317	-0.783	0.010
1991	-0.348	0.210	-0.341	-0.700	-0.035
1992	-0.624	0.237	-0.613	-1.040	-0.257
1993	-0.645	0.259	-0.612	-1.110	-0.287
1994	-0.213	0.227	-0.208	-0.596	0.153
1995	0.018	0.206	0.029	-0.330	0.336
1996	-0.095	0.244	-0.065	-0.529	0.277
1997	-0.136	0.288	-0.118	-0.634	0.311
1998	0.255	0.258	0.289	-0.225	0.620
1999	0.360	0.264	0.390	-0.106	0.751
2000	0.237	0.294	0.255	-0.267	0.695
2001	0.481	0.309	0.513	-0.085	0.923
2002	0.572	0.329	0.592	-0.030	1.070
2003	0.360	0.333	0.405	-0.272	0.842
2004	0.044	0.314	0.055	-0.475	0.518
2005	-0.238	0.299	-0.221	-0.747	0.209
2006	-0.215	0.289	-0.203	-0.705	0.221
2007	-0.088	0.269	-0.069	-0.563	0.328
2008	-0.029	0.296	0.002	-0.541	0.414
2009	0.044	0.308	0.081	-0.479	0.479
2010	0.225	0.320	0.257	-0.333	0.703
2011	0.561	0.327	0.608	-0.056	1.030
2012	0.612	0.387	0.671	-0.132	1.140
2013	0.604	0.407	0.661	-0.094	1.160
2014	0.495	0.426	0.534	-0.239	1.120
2015	0.873	0.409	0.926	0.082	1.440
2016	1.010	0.383	1.060	0.294	1.570
2017	0.378	0.400	0.408	-0.310	1.010
2018	0.196	0.365	0.203	-0.412	0.775
2019	0.033	0.382	0.041	-0.604	0.661
2020	-0.041	0.398	-0.032	-0.698	0.590

Table D.11: Comparison of models for predicting stock assessment recruitment deviates, when assuming a two-year lag period between the puerulus series and recruitment, a one-year lag period for sea surface temperature, and no measurement error in the puerulus index series. The shaded models were within 4 SE of the optimal model in terms of ELPD, so were not differentiated on this basis.

Model label	Model structure	Bayesian R-squared (95% credible interval)	δ-ELPD	SE δ-ELPD	δ-LOO IC	SE LOO IC
fit_puer2yr_4	recdev | se(recdev) ~ puer * qma_region + s(sst, k = 4, bs = "cs")	0.234 (0.164 – 0.301)	0.0	0.0	0.0	26.6
fit_puer2yr_3	recdev | se(recdev) ~ puer * qma_region + sst	0.208 (0.142 – 0.275)	-4.3	3.3	8.6	25.9
fit_puer2yr_2	recdev | se(recdev) ~ puer * qma_region	0.204 (0.140 – 0.266)	-4.8	3.9	9.6	25.8
fit_puer2yr_1	recdev | se(recdev) ~ puer	0.044 (0.020 – 0.094)	-17.3	8.7	34.5	25.1
fit_puer2yr_0	recdev | se(recdev) ~ 1	0.000 (0.000 – 0.000)	-22.3	9.4	44.5	24.8

Table D.12: Comparison of models for predicting stock assessment recruitment deviates, when assuming no lag period between the puerulus series and recruitment, a one-year lag period for sea surface temperature, and no measurement error in the puerulus index series. The shaded models were within 4 SE of the optimal model in terms of ELPD, so were not differentiated on this basis.

Model label	Model structure	Bayesian R-squared (95% credible interval)	δ-ELPD	SE δ-ELPD	δ-LOO IC	SE LOO IC
fit_puer0yr_4	recdev | se(recdev) ~ puer * qma_region + s(sst, k = 4, bs = "cs")	0.310 (0.234 – 0.380)	0.0	0.0	0.0	23.3
fit_puer0yr_2	recdev | se(recdev) ~ puer * qma_region	0.307 (0.233 – 0.372)	0.0	1.8	0.1	22.9
fit_puer0yr_3	recdev | se(recdev) ~ puer * qma_region + sst	0.301 (0.227 – 0.366)	-0.1	1.2	0.2	23.1
fit_puer0yr_1	recdev | se(recdev) ~ puer	0.143 (0.076 – 0.216)	-15.1	7.9	30.2	25
fit_puer0yr_0	recdev | se(recdev) ~ 1	0.000 (0.000 – 0.000)	-35.3	9.5	70.6	24.7

Table D.13: Comparison of models for predicting stock assessment recruitment deviates, when assuming a two-year lag period between the puerulus series and recruitment, and a one-year lag period for sea surface temperature, and measurement error in the puerulus index series. The shaded models were within 4 SE of the optimal model in terms of ELPD, so were not differentiated on this basis.

Model label	Model structure	Bayesian R-squared (95% credible interval)	δ-ELPD	SE δ-ELPD	δ-LOO IC	SE LOO IC
fit_puer2yr_0_me	recdev | se(recdev) ~ 1	0.000 (0.000 – 0.000)	0.0	0.0	0.0	24.9
fit_puer2yr_4_me	recdev | se(recdev) ~ me(puer, puer_sd) * qma_region + s(sst, k = 4, bs = "cs")	0.269 (0.195 – 0.343)	-6.6	18.6	13.1	42.0
fit_puer2yr_1_me	recdev | se(recdev) ~ me(puer, puer_sd)	0.107 (0.025 – 0.200)	-7.2	6.0	14.5	28.1
fit_puer2yr_3_me	recdev | se(recdev) ~ me(puer, puer_sd) * qma_region + sst	0.246 (0.170 – 0.325)	-11.4	17.5	22.7	40.4
fit_puer2yr_2_me	recdev | se(recdev) ~ me(puer, puer_sd) * qma_region	0.238 (0.158 – 0.319)	-13.4	19.5	26.8	44.1

Table D.14: Comparison of models for predicting stock assessment recruitment deviates, when assuming no lag period between the puerulus series and recruitment, and a one-year lag period for sea surface temperature, and measurement error in the puerulus index series. The shaded models were within 4 SE of the optimal model in terms of ELPD, so were not differentiated on this basis.

Model label	Model structure	Bayesian R-squared (95% credible interval)	δ-ELPD	SE δ-ELPD	δ-LOO IC	SE LOO IC
fit_puer0yr_0_me	recdev | se(recdev) ~ 1	0.000 (0.000 - 0.000)	0.0	0.0	0.0	24.7
fit_puer0yr_1_me	recdev | se(recdev) ~ me(puer, puer_sd)	0.254 (0.147 – 0.343)	-9.6	11.2	19.3	32.6
fit_puer0yr_4_me	recdev | se(recdev) ~ me(puer, puer_sd) * qma_region + s(sst, k = 4, bs = "cs")	0.376 (0.292 – 0.451)	-31.6	18.7	63.2	41.1
fit_puer0yr_2_me	recdev | se(recdev) ~ me(puer, puer_sd) * qma_region	0.381 (0.295 – 0.453)	-46.7	21.5	93.5	46.4
fit_puer0yr_3_me	recdev | se(recdev) ~ me(puer, puer_sd) * qma_region + sst	0.376 (0.230 – 0.450)	-49.6	21.5	99.2	47.3

Table D.15: Comparison of models for predicting stock assessment recruitment deviates when assuming a one-year lag period for sea surface temperature (no puerulus index series). The shaded models were within 4 SE of the optimal model in terms of ELPD, so were not differentiated on this basis.

Model label	Model structure	Bayesian R-squared (95% credible interval)	δ-ELPD	SE δ-ELPD	δ-LOO IC	SE LOO IC
fit_sst_3	recdev | se(recdev) ~ s(sst, k = 4, bs = "cs") + qma_region	0.183 (0.122 – 0.245)	0.0	0.0	0.0	25.0
fit_sst_2	recdev | se(recdev) ~ s(sst, k = 4, bs = "cs")	0.045 (0.010 – 0.093)	-17.5	7.0	35.0	25.1
fit_sst_1	recdev | se(recdev) ~ sst	0.019 (0.001 – 0.050)	-21.2	8.2	42.3	26.1
fit_sst_0	recdev | se(recdev) ~ 1	0.000 (0.000 – 0.000)	-23.4	8.9	46.9	26.7

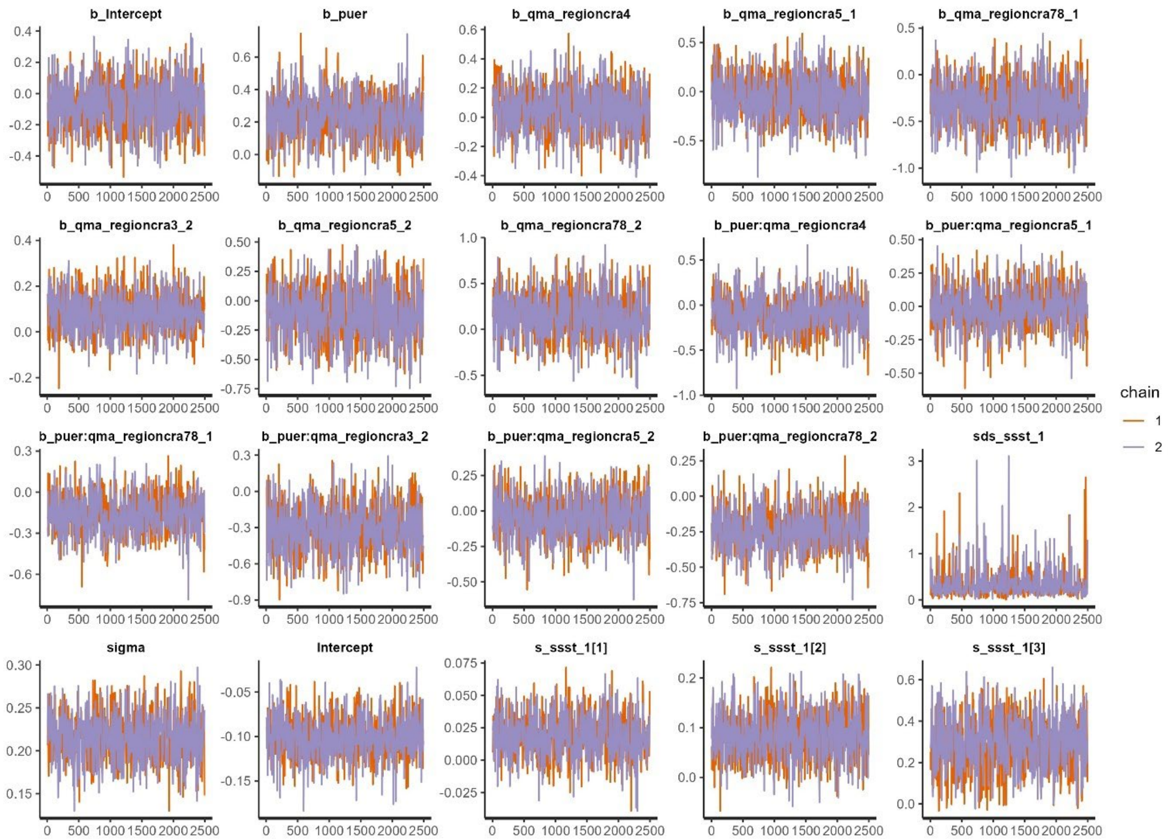

Figure D.1: Example trace plots from model run *fit_puer2yr_4*.

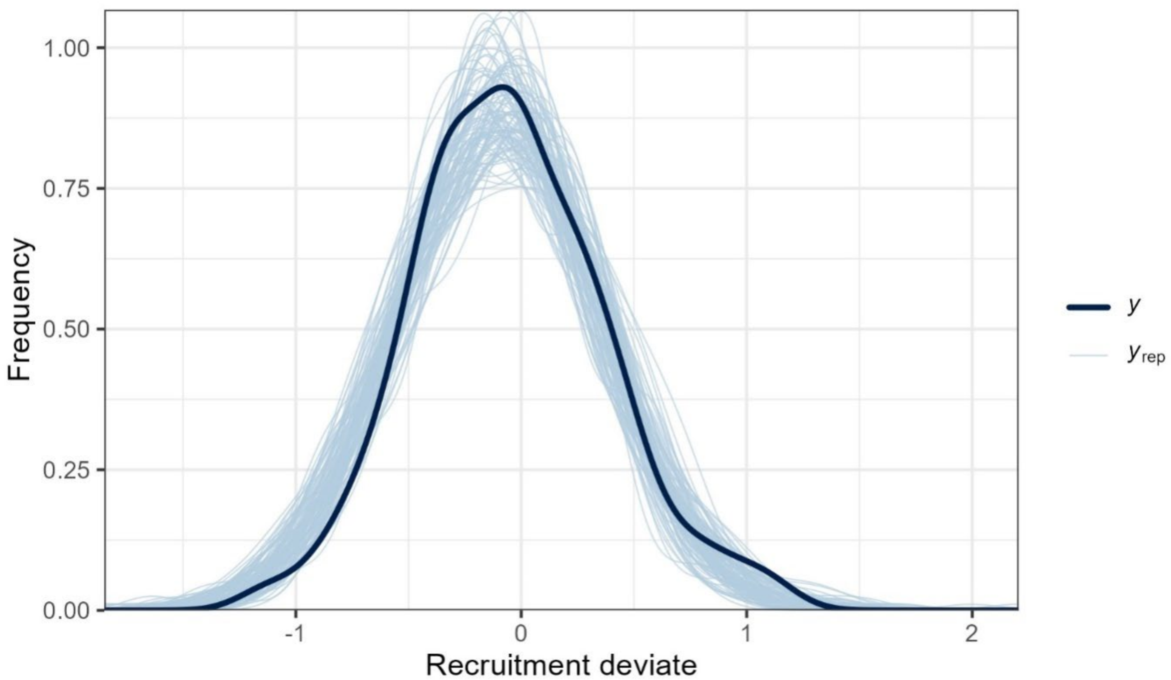

Figure D.2: Posterior predictive check plot for model run *fit_puer2yr_4*. The dark blue line is the observed distribution of the recruitment deviates and the pale blue lines are the simulated distributions.

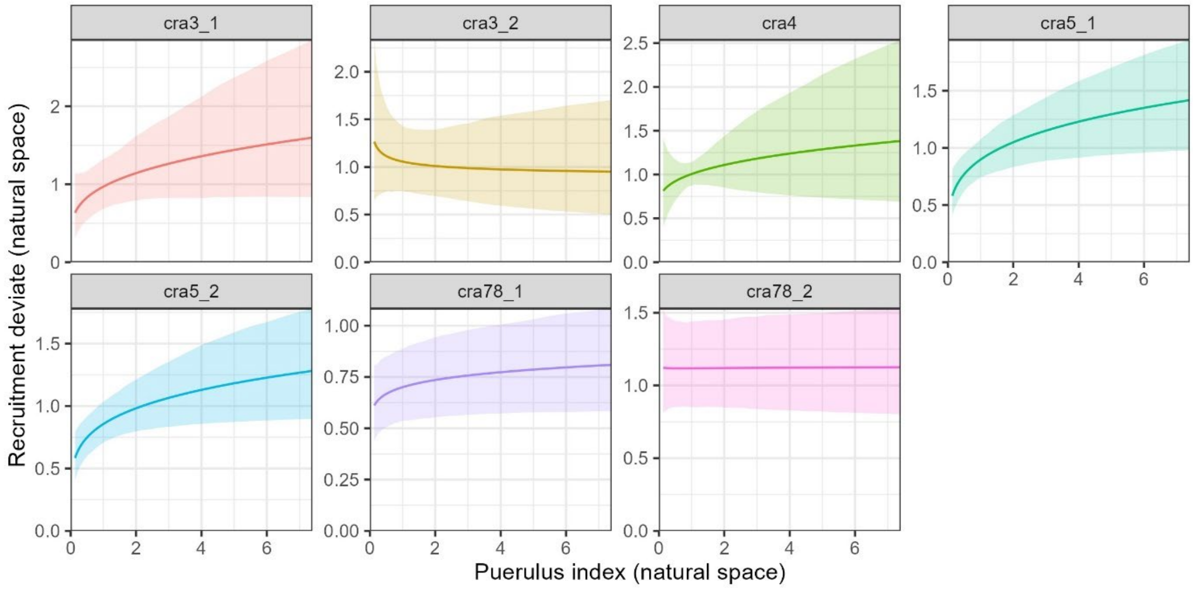

Figure D.3: Predicted recruitment deviates (natural space) in response to puerulus index series (also in natural space) by stock-region, from model run *fit_puer2yr_4*.

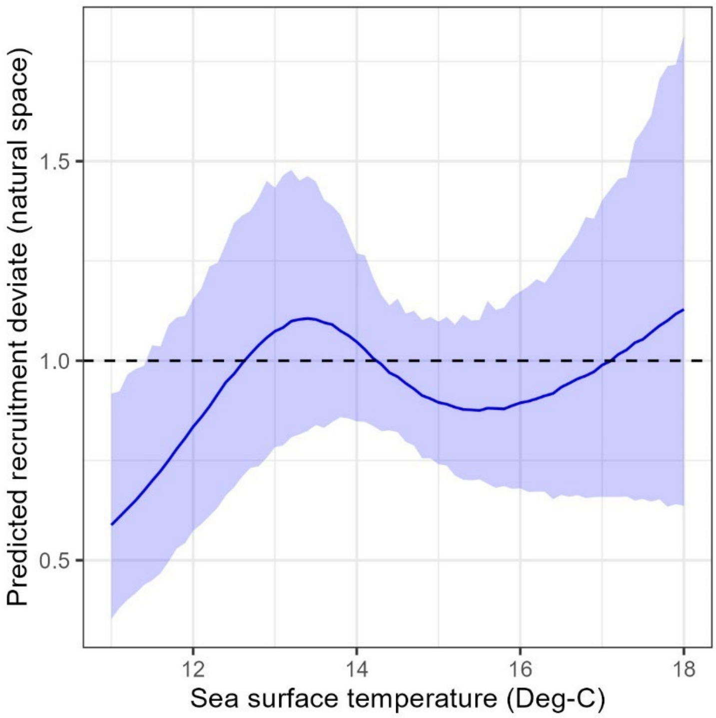

Figure D.4: Predicted recruitment deviates (natural space) in response to sea surface temperature by stock-region, from model run *fit_puer2yr_4*.

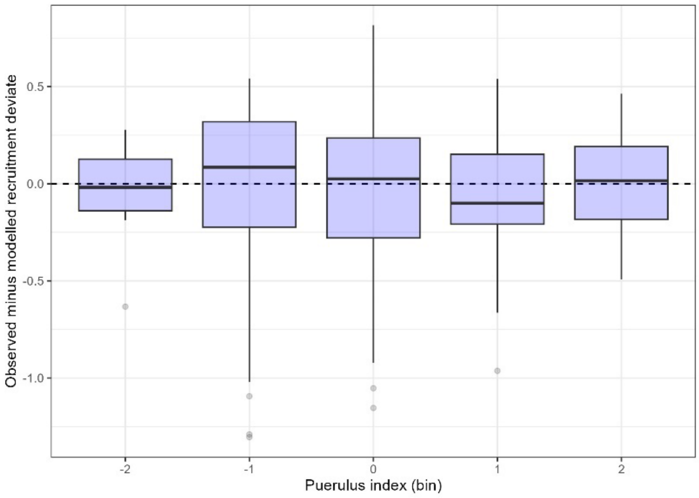

Figure D.5: Residual plot of observed minus expected recruitment deviates in response to puerulus settlement index series bin, from model run *fit_puer2yr_4*.

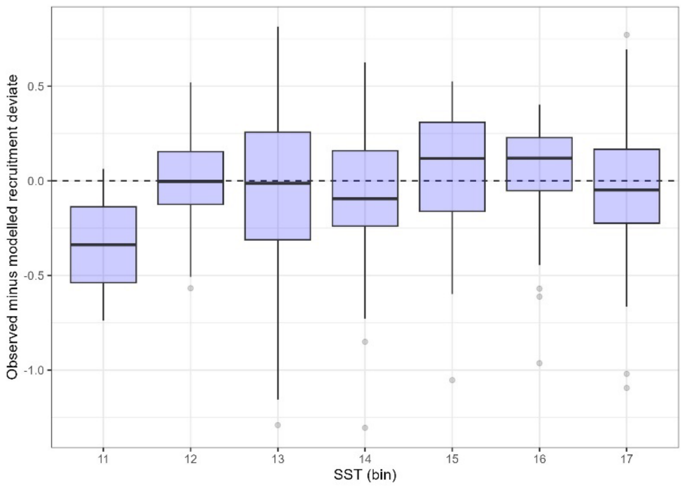

Figure D.6: Residual plot of observed minus expected recruitment deviates in response to sea surface temperature bin, from model run *fit_puer2yr_4*.

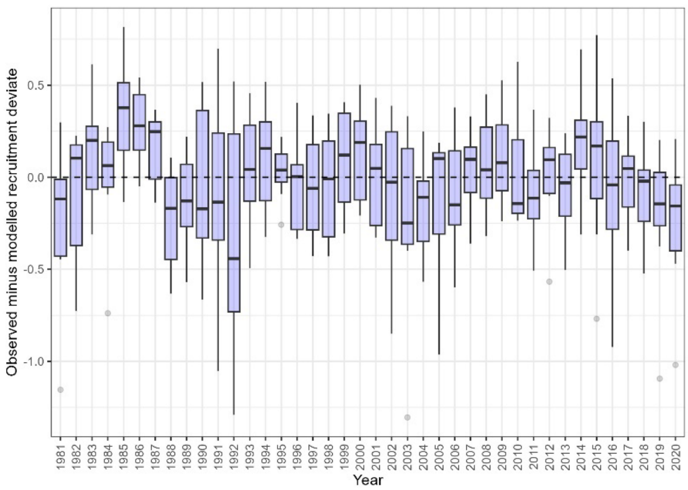

Figure D.7: Residual plot of observed minus expected recruitment deviates in response to year, from model run *fit_puer2yr_4*.

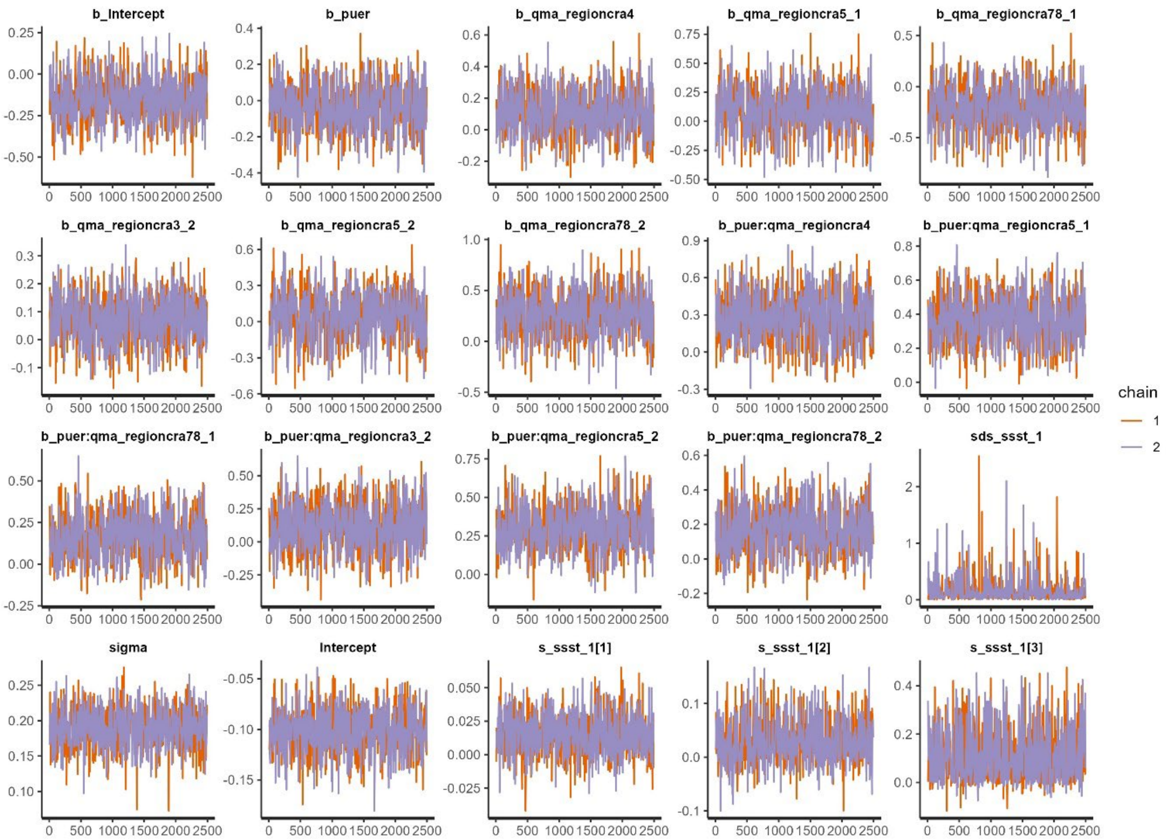

Figure D.8: Example trace plots from model run *fit_puer0yr_4*.

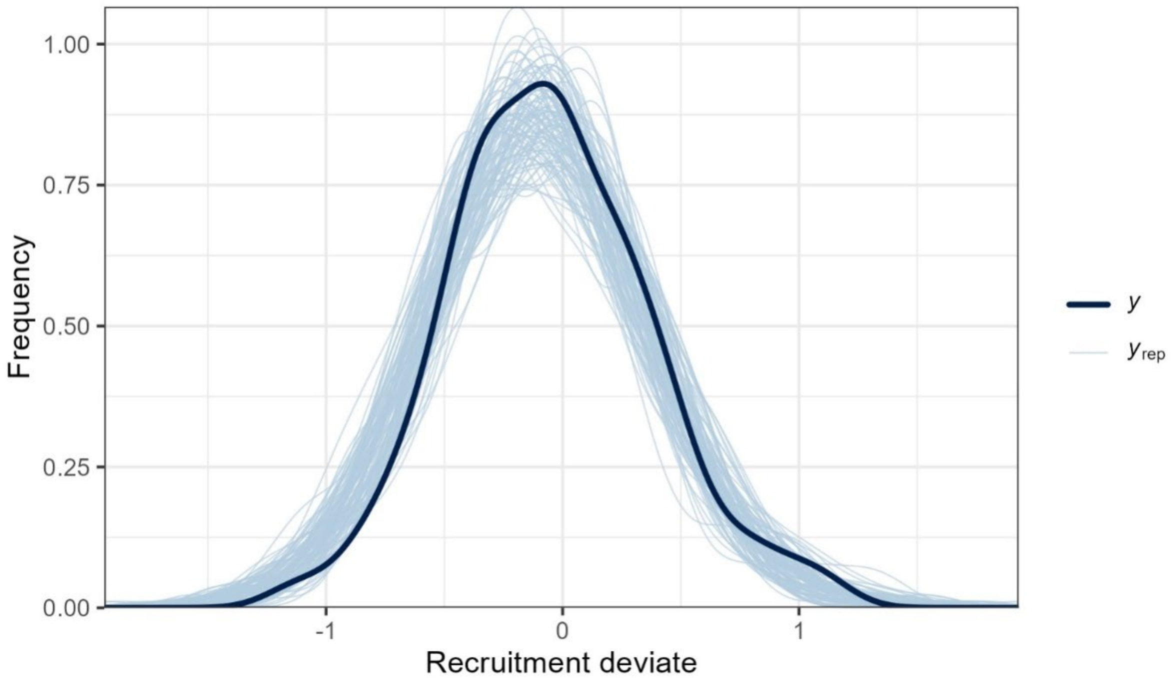

Figure D.9: Posterior predictive check plot for model run *fit_puer0yr_4*. The dark blue line is the observed distribution of the recruitment deviates and the pale blue lines are the simulated distributions.

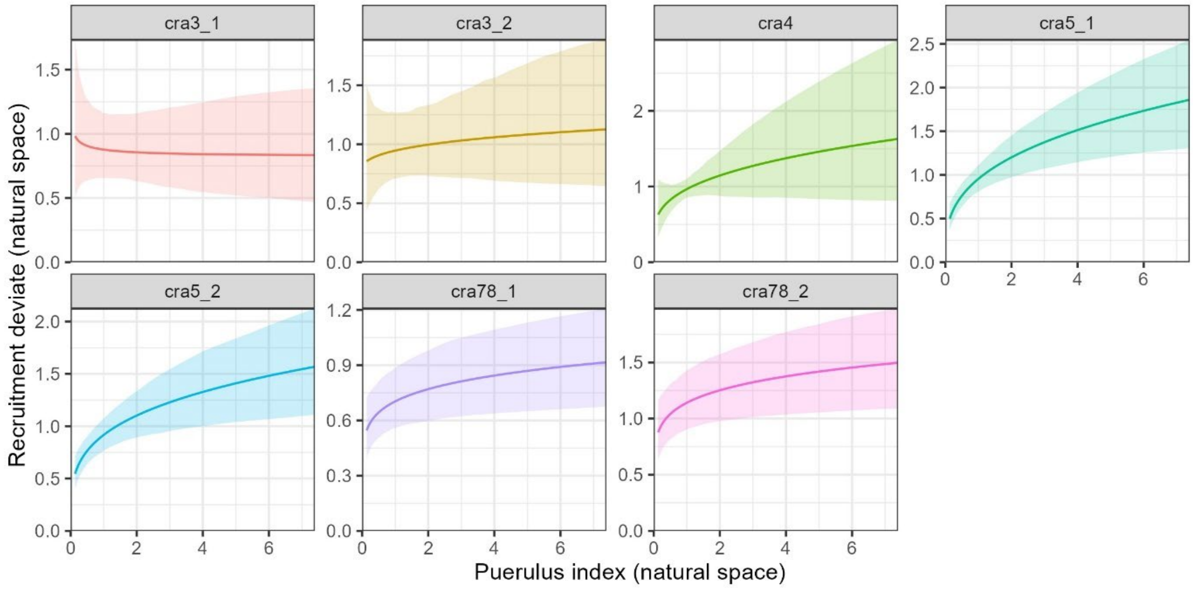

Figure D.10: Predicted recruitment deviates (natural space) in response to puerulus index series (also in natural space) by stock-region, from model run *fit_puer0yr_4*.

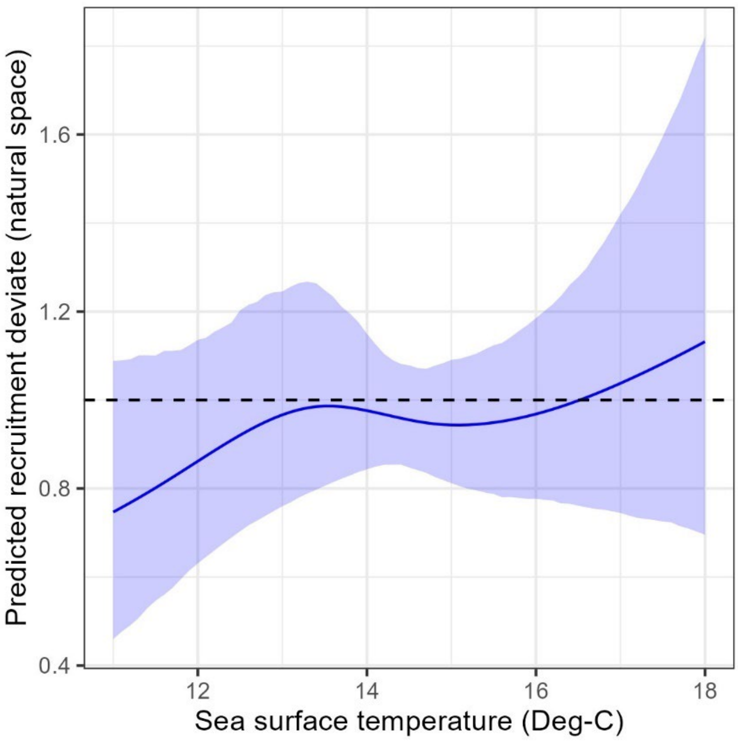

Figure D.11: Predicted recruitment deviates (natural space) in response to sea surface temperature by stock-region, from model run *fit_puer0yr_4*.

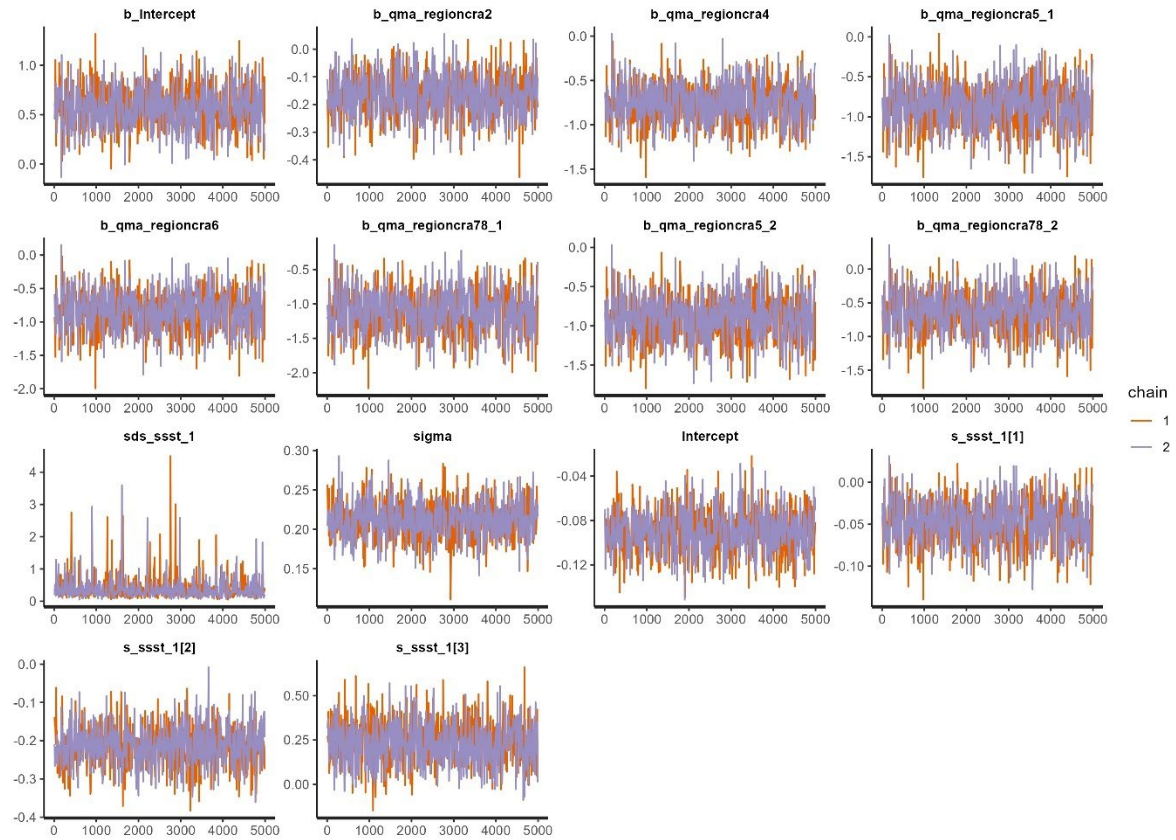

Figure D.12: Example trace plots from model run *fit_sst_3*.

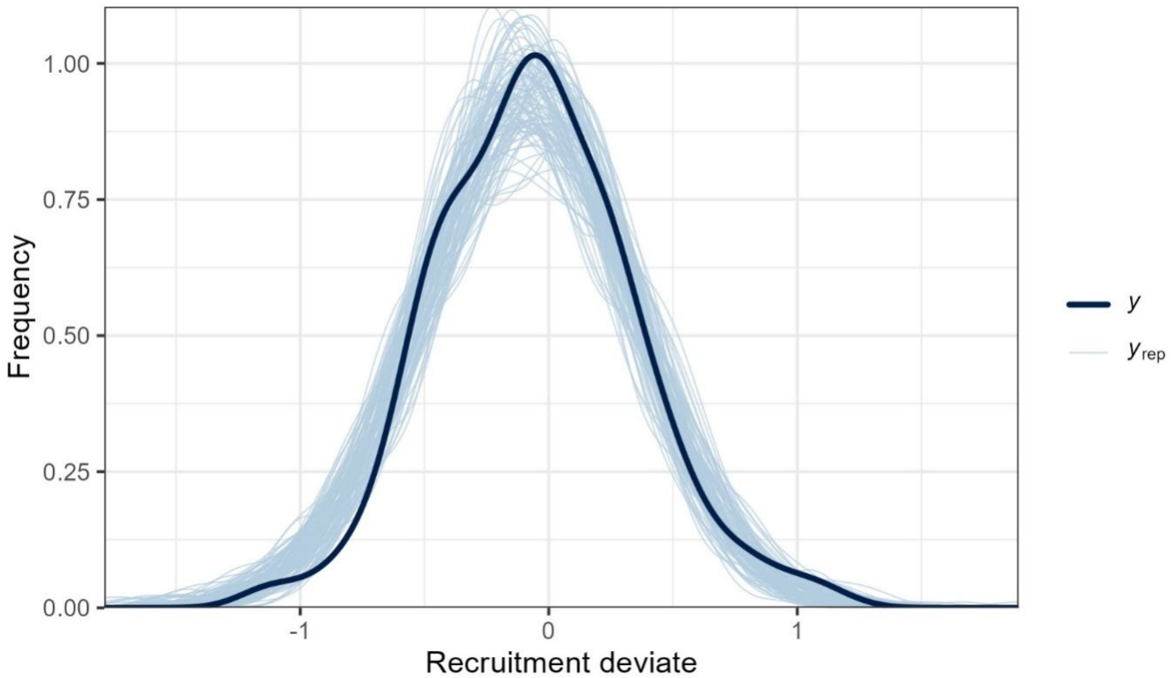

Figure D.13: Posterior predictive check plot for model run *fit_sst_3*. The dark blue line is the observed distribution of the recruitment deviates and the pale blue lines are the simulated distributions.

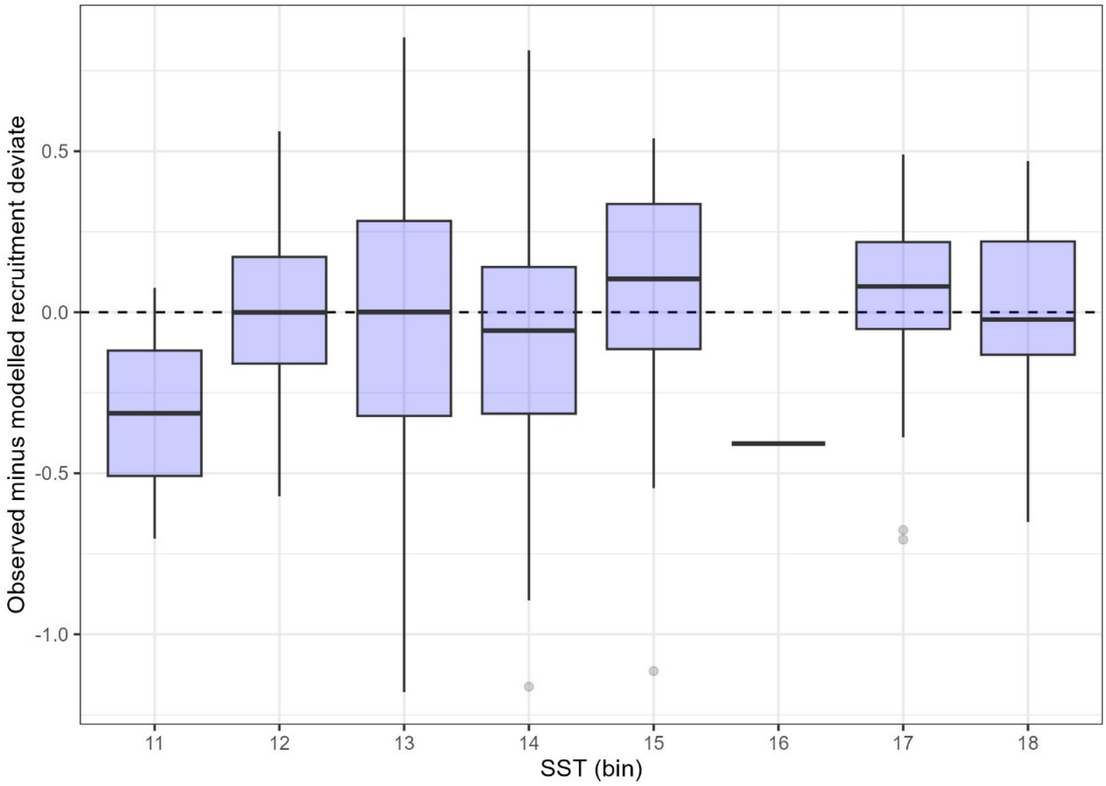

Figure D.14: Residual plot of observed minus expected recruitment deviates in response to sea surface temperature bin, from model run *fit_sst_3*.

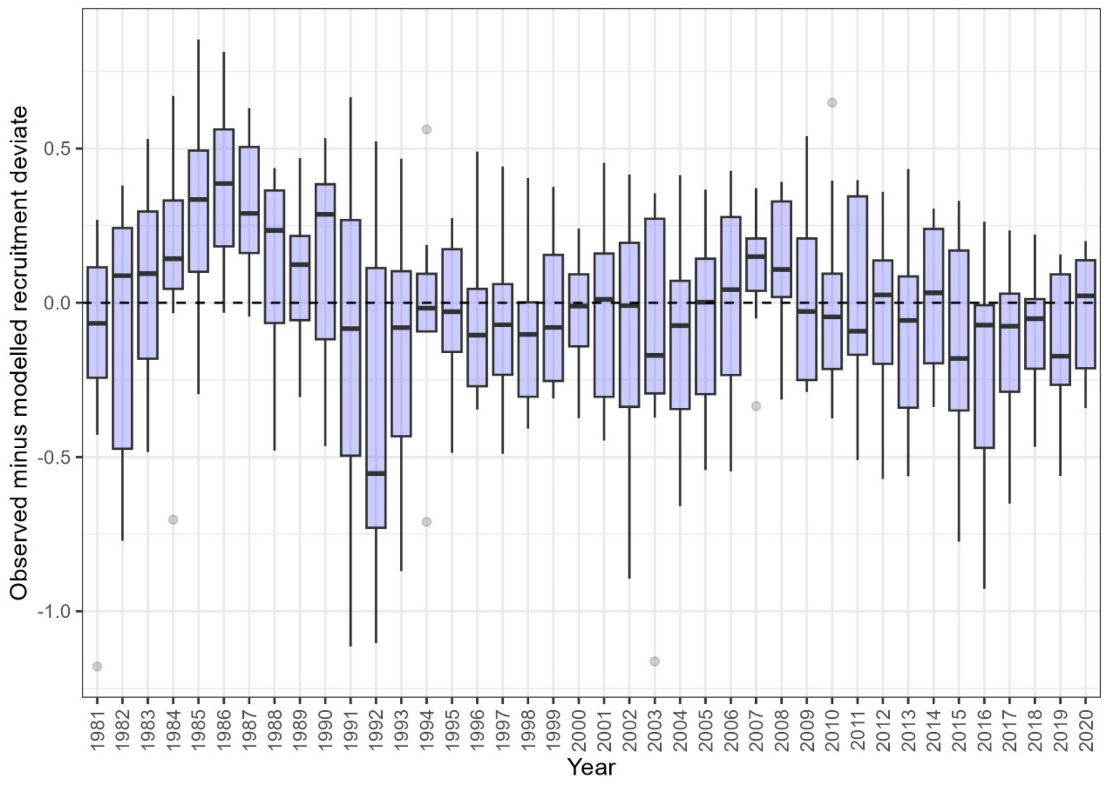

Figure D.15: Residual plot of observed minus expected recruitment deviates in response to year, from model run *fit_sst_3*.

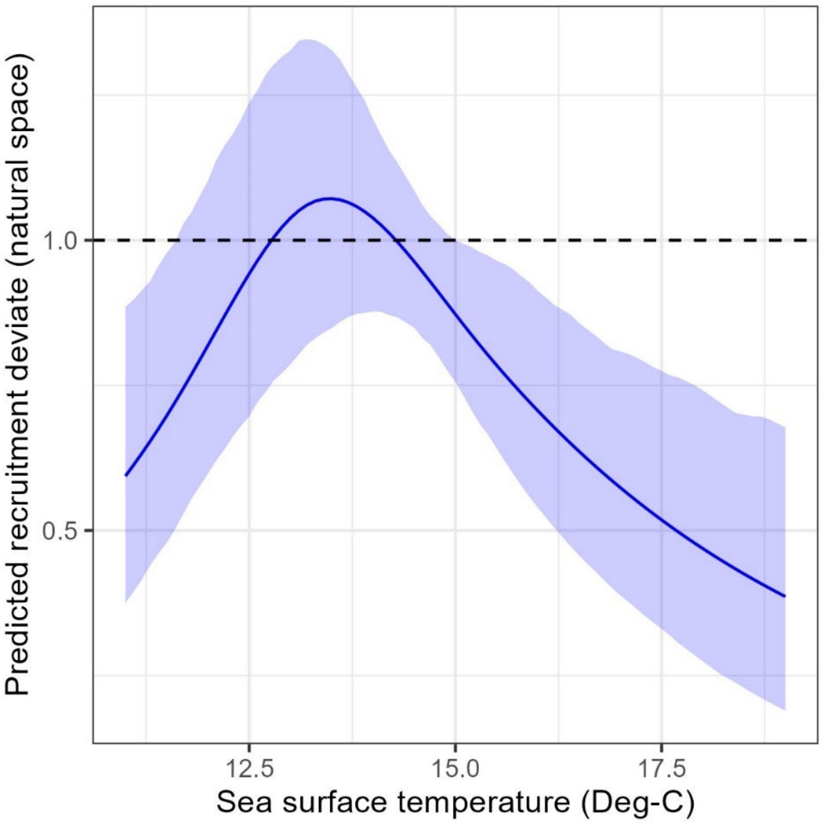

Figure D.16: Predicted recruitment deviates (natural space) in response to sea surface temperature by stock-region, from model run *fit_sst_3*.

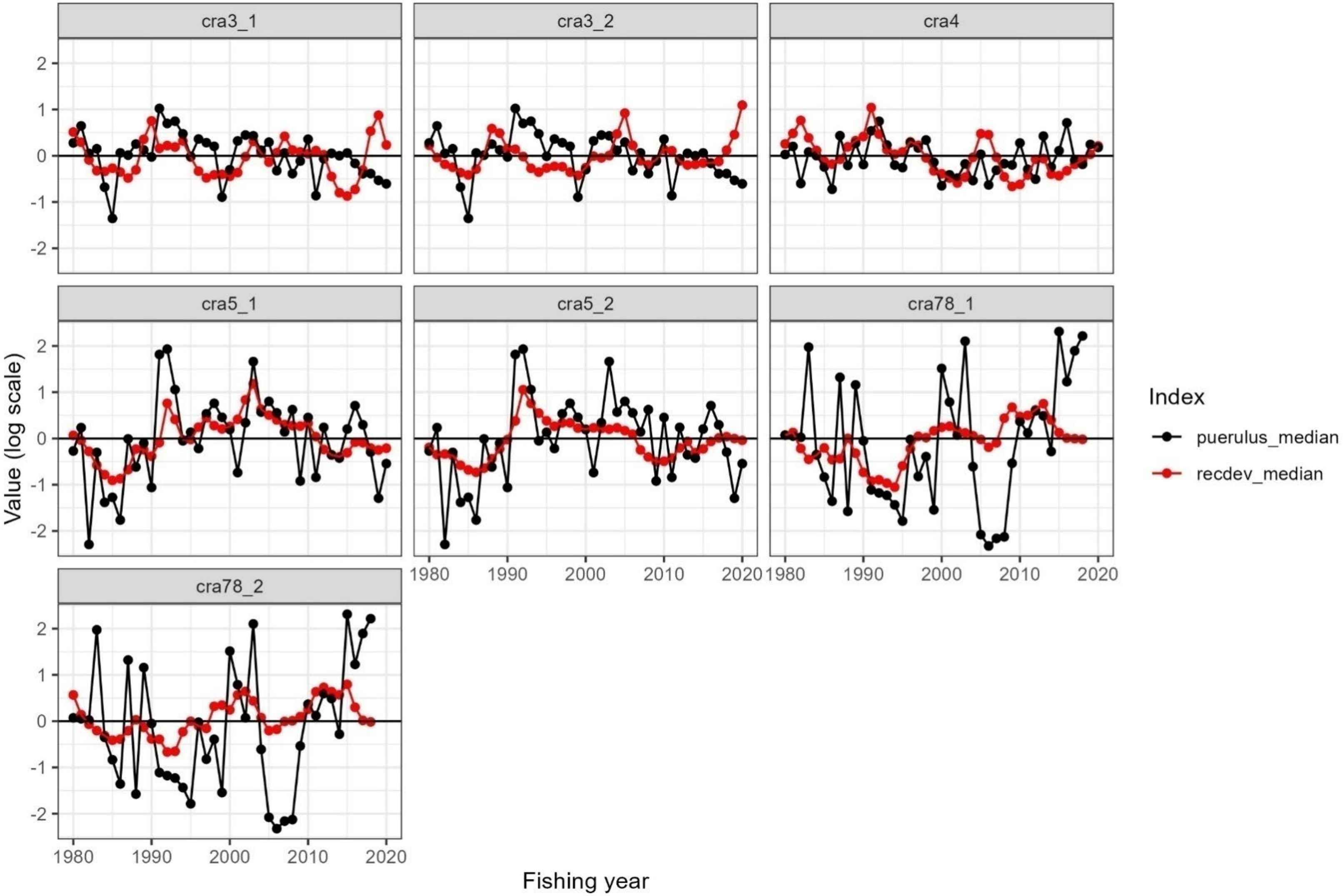

Figure D.17: Comparison of recruitment deviates by QMA and the respective puerulus settlement series, both log-transformed. In this plot the puerulus settlement series were not shifted in time (i.e., no lag).

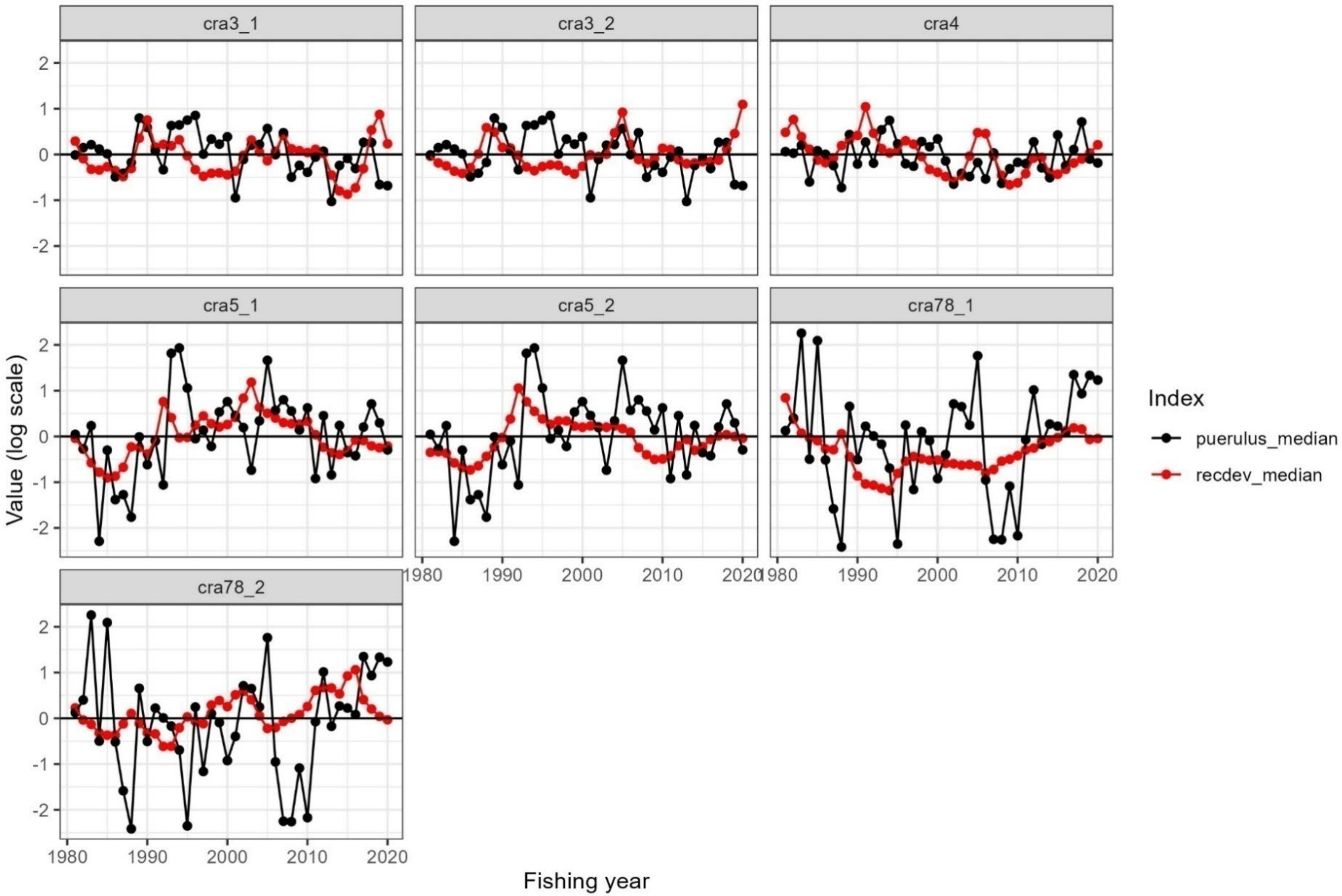

Figure D.18: Comparison of recruitment deviates by QMA and the respective puerulus settlement series, both log-transformed. In this plot the puerulus settlement series were shifted two years in to the future (i.e., a two-year lag period).

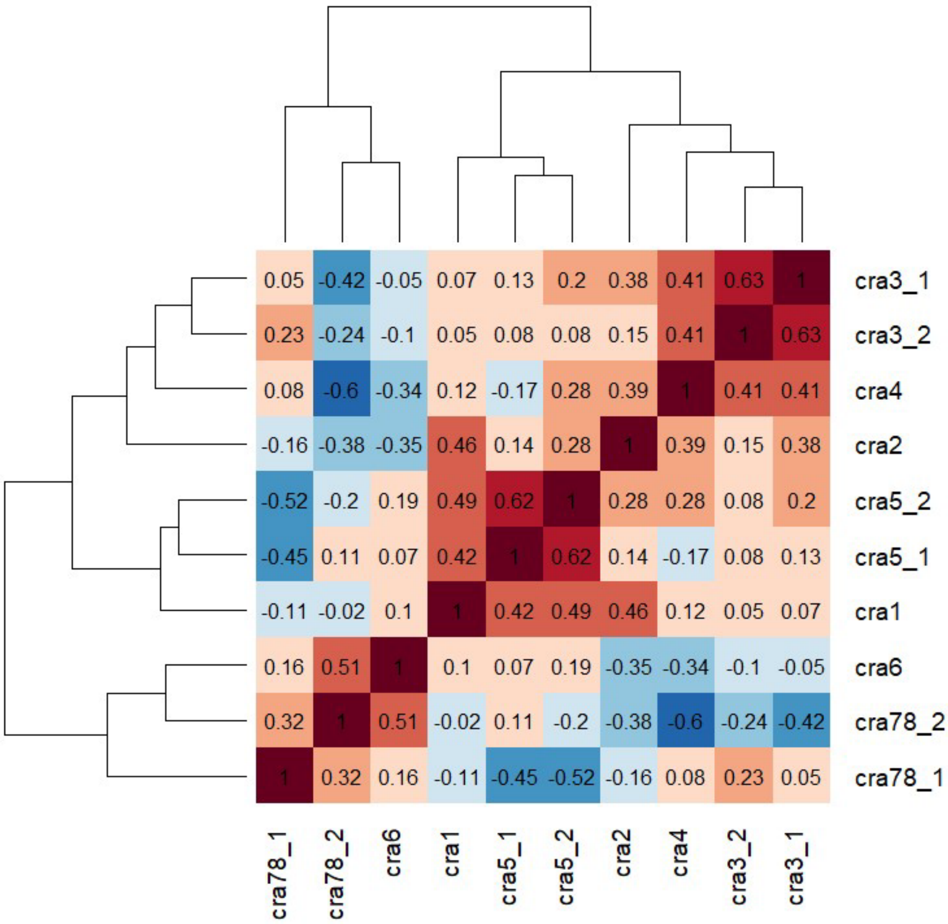

Figure D.19: Pearson product moment correlation coefficients of pairings of annual stock assessment recruitment deviates by QMA/stock assessment region. The dendrogram above the correlation matrix represents the results of hierarchical clustering analysis based on the recruitment deviates.