Kaipara Harbour Ecological Monitoring Programme:

Report on data collected between October 2009 and February 2012

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Prepared for
Auckland Council

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Executive Summary

In October 2009, the Kaipara Harbour Ecological Monitoring Programme was established to investigate the health of the harbour and to detect changes associated with development in the catchment. In line with other estuarine monitoring programmes run by the Auckland Council (AC), monitoring focuses on intertidal benthic sandflat communities.

Bi-monthly monitoring was conducted at six sites distributed through the main body of the southern section of the harbour; Tapora Bank (TPB), Kakarai Flats (KKF), Omokoiti Flats near the mouth of Haratahi Creek (HCK), Kaipara Flats (KaiF), near the mouth of Ngapuke Creek (NPC) and Kaipara Bank near the mouth of the Kaipara River (KaiB). Similar to monitoring in Manukau Harbour, homogeneous sandflat areas were selected for study, although for the Kaipara, the sites were positioned near to mud/sand transitions to enhance the ability of the programme to detect the spread of muddy sediment. Monitoring methods used were consistent with other established ecological monitoring programmes (i.e., Manukau, Waitemata and Mahurangi Harbours) to facilitate among-harbour comparisons.

Since the initiation of the Kaipara Harbour Monitoring Programme, valuable information has been collected concerning intertidal sediment characteristics and benthic macrofaunal communities in southern Kaipara Harbour. As this programme is still in its early phases, it is not possible to make robust statements regarding temporal trends in the abundance of taxa. However, over 50% of the monitored taxa exhibit seasonality or multi-year patterns or both, which bodes well for the ability of the programme to detect future trends in abundance.

Benthic macrofaunal communities at each site continue to be distinct from one another and little change has occurred over the 2.5 years of monitoring. TPB is dominated by polychaetes, KKF, NPC and KaiB are dominated by a mixture of bivalves and polychaetes, and HCK and KaiF are dominated by bivalves, polychaetes and amphipods.

State of the Environment (SOE) indicators developed for intertidal sites in the Auckland Region (e.g., Benthic Health Model for mud, Benthic Health Model for metals and a complementary Traits-Based functional Index, TBI) suggest that the sites are relatively healthy and little change has occurred since the monitoring programme was started. We recommend that, similar to the other ecological monitoring programmes run by the Auckland Council, bi-monthly monitoring of all sites should continue for the next 2 years. At that time, nearly 5 years of data will have been collected and a robust analysis of the effectiveness of the monitoring programme can be conducted.

1.0 Introduction

Kaipara Harbour is the largest natural harbour in the Auckland region and the second largest in the southern hemisphere with a total surface area of 947 km^2 and a total intertidal area of 409 km^2 (Heath 1975). Formed from a system of drowned river valleys (Hume and Herdendorf 1988), the large inlet, bounded by two large sand spits (South Head and Pouto Point) provides an entrance for high wave action and strong current velocities creating a very dynamic system.

The National Institute of Water and Atmospheric Research (NIWA) was commissioned to establish the Kaipara Ecological Monitoring Programme in October 2009 by the Auckland Regional Council (ARC). It was recognised that there was a lack of detailed knowledge of the spatial and temporal patterns of soft sediment benthic species in Kaipara Harbour (Haggitt et al. 2008). In addition, there was mounting concern surrounding the effects of historical and present day land based activities (i.e., fishing, intensified catchment land use, and sand extraction) on the ecological functioning and health of Kaipara Harbour. This ecological monitoring programme builds on knowledge gained by the comprehensive survey of southern Kaipara Harbour carried out as part of the Tier II monitoring (Hewitt and Funnell 2005).

The methods used to collect and process the samples are consistent with the other established ecological monitoring programmes that the AC undertakes in its harbours (e.g., Manukau (Hailes and Hewitt 2012), Upper Waitemata (Townsend et al. 2012), Central Waitemata (Halliday et al. 2012) and Mahurangi (Halliday and Cummings 2012)). These methods have proven to be successful and standardization enables inter-harbour comparisons.

Macrofauna, sediment grain size, organic matter content and sediment chlorophyll *a* samples are collected at six sites in different parts of the southern Kaipara Harbour. Sampling occurs every two months, and analysis is geared towards determining spatial and temporal patterns within and among sites.

This report presents the results of data collected bi-monthly from monitored sites from the initial sampling in October 2009 until February 2012. With only three years of data, temporal patterns detected are likely to be subsumed within longer-term cycles. Therefore, the primary focus of the report will be intra-site comparisons, seasonal variability and an assessment of health using existing and newly developed indices related to heavy metal concentrations and mud content (Anderson et al. 2006; Hewitt and Ellis 2010; Hewitt et al. 2012; Lohrer and Rodil 2011; van Houte-Howes and Lohrer 2010).

2.0 Methodology

Sites for intertidal monitoring are distributed throughout the main body of the southern section of Kaipara Harbour: Tapora Bank (TPB); Kakarai Flats (KKF); Omokoiti Flats near the mouth of Haratahi Creek (HCK); Kaipara Flats (KaiF); near the mouth of Ngapuke Creek (NPC) and Kaipara Bank near the mouth of the Kaipara River (KaiB) (Figure 1). Sites are 9,000 m^2 and are located in close proximity to major river and creek inputs to reflect the quality of the water discharge into the harbour off the land. The sites chosen for monitoring were sandy, homogeneous, un-vegetated habitats, without excessively dense tube-worm mats, yet they were also in close proximity to sand/mud boundaries. Any future variation away from the sandy, homogeneous habitats (i.e., mud deposition, increased abundance of particular taxa) is likely to be clearly detected.

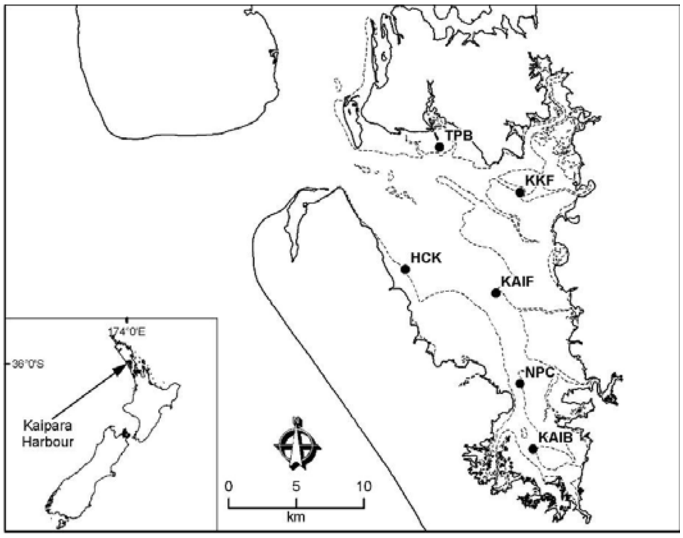


Figure 1: Map of Kaipara Harbour showing the positions of the monitoring sites, Tapora Bank (TPB); Kakarai Flats (KKF); Haratahi Creek (HCK); Kaipara Flats (KaiF); Ngapuke Creek (NPC) and Kaipara River (KaiB)

2.1 Sample Collection and Identification

For this and other intertidal monitoring programmes funded by AC, samples are collected and processed as follows: each 9,000 m^2 site is divided into 12 equal sectors and one macrofauna core sample (13 cm diameter, 15 cm depth) is taken from a random location within each sector. To limit the influence of spatial autocorrelation (Legendre 1993), and preclude any localized modification of populations by previous sampling events, core samples are not positioned within a 5 m radius of each other or of any samples collected in the preceding six months. These samples are sieved over a 500 µm mesh, preserved with 70% isopropyl alcohol and then stained with Rose Bengal, prior to processing. The macrofaunal samples are then sorted; the 28 monitored species (Table 1) identified to the lowest practical taxonomic level, enumerated and stored in 50% isopropyl alcohol.

Table 1. The species monitored in Kaipara Harbour. They are expected to show different types of changes in response to increased sediment or contaminant inputs and are likely to play key roles in influencing the composition of other taxa. For more information each species see Section 6: Recommendations of Hailes et al. (2010).

Amphipoda	*Torridoharpinia hurylei*
	Waitangi brevirostris
Cumacea	*Colorostylis lemurum*
Isopoda	*Exosphaeroma chilensis*
	Exosphaeroma falcatum
Cnidaria	*Anthopleura aueoradiata*
Holothuroidea	*Trochodota dendyi*
Bivalvia	*Austrovenus stutchburyi*
	Macomona liliana
	Musculista senhousia
	Nucula hartvigiana
	Soletellina siliqua
Gastropoda	*Notoacmea scapha*
Polychaeta	*Aglaophamus macroura*
	Aonides trifida
	Aricidea sp.
	Asychis sp.
	Boccardia syrtis
	Cossura consimilis
	Euchone sp.
	Macroclymenella stewartensis
	Magelona dakini
	Nicon aestuariensis
	Orbinia papillosa
	Owenia petersonae
	Prionospio aucklandica
	Scoloplos cylindrifer
	Travisia olens var. NZ

During each bimonthly field trip, attention is paid to the appearance of each site and the surrounding sandflat. In particular, surface sediment characteristics including the presence of sediment ripples, surficial sediment, ray pits, gastropods and macroalgae are noted.

Sediment characteristics (grain size, organic matter and chlorophyll *a* content) are assessed at each site on each sampling occasion. At six random locations within the site, two small sediment cores (2 cm deep, 2 cm diameter) are collected, one to determine grain-size and organic matter content and the other for chlorophyll *a* analysis. Cores from the six locations are pooled and kept frozen in the dark prior to being analysed as described below.

Grain size: Sediment samples are homogenised and a subsample of approximately 5 g of sediment is placed in 9% hydrogen peroxide for organic matter digestion, until bubbling ceases. The sediment sample is then wet sieved through nested 2000 µm, 500 µm, 250 µm and 63 µm mesh sieves. Pipette analysis is used to separate the <63 µm fraction into >3.9 µm and <3.9 µm. All fractions are then dried at 60^{o}C until a constant weight is achieved (fractions are weighed at ~ 40 h and then again at 48 h). The results of the analysis are presented as a percentage weight of gravel/shell hash (>2000 µm), coarse sand (500 – 2000 µm), medium sand (250 – 500 µm), fine sand (62.5 – 250 µm), silt (3.9 – 62.5 µm), and clay (<3.9 µm). Mud content is calculated as the sum of the silt and clay content.

Chlorophyll *a*: Within one month of sampling, the full sediment sample is freeze dried, weighed, then homogenised and a subsample (0.5 g) taken for analysis. Chlorophyll *a* and its degradation product (Phaeophytin) are extracted by boiling the sediment in 90% ethanol. An acidification step is used to remove phaeophytin before reading the extract on a spectrophotometer (measured in µg/g of sediment) (Sartory, 1982).

Organic matter content: Approximately 5 g of sediment is placed in a dry, pre-weighed tray. The sample is then dried at 60^{o}C until a constant weight is achieved (the sample is weighed after ~ 40 h and then again after 48 h). The sample is then combusted for 5.5 h at 400^{o}C and then reweighed.

2.2 Bivalve Size Class Analysis

After identification, bivalves (*Austrovenus stutchburyi*, *Macomona liliana* and *Soletellina siliqua*) were measured (longest shell dimension (mm)) and placed into size classes to enable direct comparison with other long-term monitoring locations (i.e., Manukau, Waitemata and Mahurangi Monitoring Programmes). Individual bivalves were categorized according to size classes of <1 mm; 1-5 mm; 5-10 mm; 10-15 mm; 15-20 mm; 20-30 mm; 30-40 mm; 40-50 mm and > 50 mm.

2.3 Statistical Analyses

The analysis of ecological monitoring data is strongly dependent on the length of the time series (Wolfe et al. 1987). In the initial years, analysis focuses on determination of the degree of variability exhibited within and among sites. With less than 3 years of bi-monthly results from monitored sites, the following analyses were conducted.

1. Variations in the sediment characteristics and densities of monitored species over time at each site were examined graphically and characterised as exhibiting:

   a. Seasonal patterns
   b. Multi-year patterns
   c. Low variability
   d. High unpredictable variability

This analysis was performed because variables need to be relatively predictable in order to differentiate natural and anthropogenic change.

2. Consistency in sediment characteristics and macrofaunal communities within sites, and the persistence of differences among sites, was assessed:
   a. Sediment data was normalized and analysed by Principle Components Analysis (PCA) to determine similarities between sites.
   b. Data on macrofaunal community composition collected each October, 2009-2011, were summarized with univariate statistics such as number of taxa (total richness), number of individuals (total abundance) and level of diversity (Shannon-Weiner *H*' index). The five most abundant taxa at each site were noted. A multivariate analysis known as non-metric multidimensional scaling (MDS) was then conducted on Bray-Curtis similarities from loge (x+1) transformed data using PRIMER 6 software (Clarke and Gorley 2006).
3. Three State of the Environment (SOE) indicators were calculated using data from October 2010 and 2011. Results were interpreted and compared to results from 2009 (Hailes et al. 2010):
   a. The Benthic Health Model for metals (BHM) is a multivariate model of community structure relative to combined concentrations of total extractable copper, lead and zinc (Anderson et al. 2006). Sediment metal concentration data collected from monitored sites in 2009 was used under the assumption that concentrations have remained relatively unchanged since that time.
   b. A similar Benthic Health Model for mud (BHMmud) has recently been developed to model changes in community structure relative to changes in sediment mud content (Hewitt & Ellis 2010). BHM indices were developed based on 10 replicate samples per site, so a random subset of 10 samples was taken from the 12 replicates collected from each Kaipara site.
   c. A functional diversity index, TBI, has been developed to track the health status of intertidal non-vegetated benthic communities in the Auckland region (Hewitt et al. 2012; Lohrer and Rodil 2011; van Houte-Howes and Lohrer 2010). Index values range between 0 and 1, and indicate the richness of taxa in functional groups shown to be sensitive to both heavy metal contaminants and sediment mud content. Low scores suggest low levels of functional redundancy present in the benthic communities.

3.0 Present Status of Benthic Communities in southern Kaipara Harbour

3.1 General Site Descriptions

Site characteristics, including the appearance and characteristics of the sediment, were observed to provide a context against which changes in macrofauna could be related. Temporal changes to site characteristics, such as the expansion of seagrass (*Zostera muelleri*) or Asian date mussel (*Musculista senhousia*) beds into a monitored area or altered levels of disturbance by eagle rays, are important to observe as they may help explain natural variability (i.e., Townsend 2010). For this reason, a brief description of the appearance and sediment characteristics of each site are given below.

3.1.1 Tapora Bank (TPB)

Located at the top of the southern section of Kaipara Harbour on Tapora Bank, site TPB (36º 23.997'; 174º 18.862'; Figure 1) is characterised by firm sand, low density shell hash and prominent sand ripples (3-5 cm wave length; 1 cm wave height) (Figures 2 and 3) (Hailes et al. 2010). During the winter months (June and August), thick diatom mats are observed and create hummocks on the sediment surface (Figure 4) and thin layers of terrestrial sediment are deposited in the troughs between ripples on the sediment surface. Epifauna are observed throughout the year and include the whelk *Cominella adspersa*, the sand dollar *Fellaster zelandiae* and the cushion star *Patiriella regularis*. In addition, ray feeding pits and small worm tubes (*Macroclymenella stewartensis*) are observed year-round, although they are sparse and usually in low density.

There have been few changes in and around site TPB since last reported by Hailes et al. (2010). Changes that have been observed since 2009 include the variable abundances of gastropods (low-medium density) and the transient nature and density of ray pits. Raised beds of *Musculista* and low density patches of *Zostera* are still present to the north of the site. The *Zostera* shows no sign of movement towards the monitoring site.

Figure 2. **Looking diagonally across site TPB towards the south west.**

Figure 3. The highly rippled sediment surface at TPB with low density tube worms visible.

Figure 4. A portion of the diatom mat binding the surface sediments at TPB in August 2011.

3.1.2 Kakarai Flats (KKF)

Site KKF is located on Kakarai Flats on the north-eastern side of southern Kaipara Harbour (36º 25.733'; 174º 22.919'; Figure 1). The area surrounding the site contains thick meadows of *Zostera*, muddier sediments and large rills and sub-channels (directly to the east of the site). *Musculista* beds have been observed approximately 100 m north of the monitoring site. The monitored area at KKF is generally firm sand with variable sand ripples (3–6 cm wave length, 1–3 cm wave height) (Figures 5 and 6). During sampling in June and August, a muddy surficial sediment layer of less than 2 mm is usually present (Figure 5) and on most other occasions, terrestrial sediment is present in the troughs of ripples. As reported by Hailes et al. (2010), it is still common to observe *Zostera* detritus (single blades) on the sediment surface within the monitored area; however it is not rooted and very sparse in distribution. Old *Musculista* shells (in addition to *Austrovenus stutchburyi* and *Macomona liliana*) are a common constituent of the shell hash that litters the sediment surface at this site. Variable densities (low to high over the course of the year) of *Macomona* feeding tracks are commonly observed on the sediment surface in conjunction with epifauna including the cushion star *Patiriella regularis* and gastropod species *Cominella glandiformis*, *Zeacumanthus lutulentus* and *Diloma subrostrata*. Ephemeral green algae, *Ulva lactuca* (both attached and unattached), is commonly observed at this site, but in greater abundance during the summer months. Black swans, *Cygnus atratus*, have also been observed, often feeding on the *Zostera* patches surrounding the site.

Since February 2010, there has been little change at this site, with the exception of fluctuations in the density of shell hash, surficial sediment and gastropod species on the sediment surface.

Figure 5. Site KKF, looking along the northern 100 m axis towards Pouto Point and the inlet to Kaipara Harbour to the west.

Figure 6. The sediment surface at KKF, displaying medium to high density *Macomona* feeding tracks and unattached *Zostera* detritus.

3.1.3 Haratahi Creek (HCK)

Site HCK is located on the north-western side of southern Kaipara Harbour, on the northern tip of the Omokoiti sandflat, near where the Haratahi Creek meets the main harbour channel (36º 28.909'; 174º 17.313'; Figure 1). The site is characterised by fine firm sand with strong sand ripple features (5–15 cm wave length, 1–3 cm wave height) (Figures 7 and 8). Consistent with Hailes et al. (2010), the site shows minimal evidence of shell hash, gastropods or tube worms and is homogenous across the entire monitored area. Conversely, the raised patch of muddy sand located inshore and west of the site in 2010 has become much firmer and more similar to the sediment characteristics in the monitored area.

Figure 7. Site HCK looking North West diagonally across the monitored area.

Figure 8. The highly undulated rippled surface of the sediment at site HCK.

3.1.4 Kaipara Flats (KaiF)

Site KaiF is located on the eastern side of southern Kaipara Harbour on the Kaipara Flats (the largest sandflat in Kaipara Harbour) (36º 29.835'; 174º 21.824'; Figure 1). The monitored area is on a tapered section of sandflat and is surrounded by water on three of its sides. Beyond the north-western side of the monitored area, there are sparse patches of low to medium density seagrass in raised muddy clumps. The monitored site is firm and sandy (Figure 9) and has strong ripple features (10 cm wave length, 2 cm wave height) (Figure 10) with very fragmented and sparse *Macomona* shell hash. Low density ray feeding pits and sparse low density excavation/faecal mounds are usually present on the sediment surface. Low numbers of epifauna including *Cominella adspersa*, *Cominella glandiformis* and *Zeacumantus lutulentus* are usually evident on the sediment surface.

Between February 2010 and February 2012, there have been fluctuations in worm tubes (ranging from low density/sparse to several high density patches) and shell hash present at this site. In October 2011, approximately 10 live adult scallops (*Pecten novaezealandiae*) were observed. Surficial muddy sediment is not usually evident at this site however, thin deposits of terrestrial sediment have been observed in the troughs of ripples during most sampling trips. In February 2012 a sediment hummock approximately 5-10 cm high, colonised by a small patch of very low density and sparse *Zostera* (approximately 6 × 4 m) was observed in the north-eastern corner of the monitored area (Figure 11). The density and spread of this seagrass will be monitored.

Figure 9. Site KaiF, looking along the northern 90 m side of the monitored area towards the east.

Figure 10. The rippled surface of the sediment at site KaiF, with scattered fragments of shell hash.

Figure 11. A small, sparse patch of *Zostera muelleri* (approximately 6 × 4 m) creating a hummock approximately 5-10 cm in height.

3.1.5 Ngapuke Creek (NPC)

Site NPC is located on the sandflat adjacent to Ngapuke Creek (36º 33.437’; 174º 23.057’; Figure 1). The monitored site is firm sand and has uniform sand ripples (0.5-2 cm wave height; 1-5 cm wave length). Thin layers (<2 mm) of surficial muddy sediment are commonly observed in the troughs of the ripples (Figures 12 and 13). In addition, the sediment surface is marked with high density *Macomona* siphon feeding tracks and a low-medium density of shell hash. Common epifauna observed at this site include low densities of *Cominella glandiformis* and *Diloma* (ranging from 5-10 per m^2). Hailes et al. (2010) reported a large raised muddy area with filamentous red algae, *Gracilaria* sp., approximately 20 m north of the monitored area. There have been no signs of this spreading toward or into the monitored area, although the site marker peg seems to be permanently colonised with the algae (Figure 12).

Between February 2010 and February 2012, sediment and overall site characteristics have remained consistent at NPC, with ray pits and gastropod density remaining low and minimal surficial sediment observed in troughs between ripples.

Figure 12. Site NPC, looking diagonally across the monitored area toward the south east.

Figure 13. The ripple features, *Macomona* feeding tracks and shell hash on the sediment surface at site NPC.

3.1.6 Kaipara River (KaiB)

Site KaiB is the southern-most monitored area and is located on the sandflats where the Kaipara River joins the main body of the harbour (36º 36.044'; 174º 23.768'; Figure 1). This section of the harbour has multiple freshwater inputs, notably the Puharakeke and Parekawa Creeks, and the Kaipara and Kaukapakapa Rivers, which may account for the layer of surficial mud (ranging between 2 mm and 5 cm, in summer and winter, respectively) that is commonly observed. As reported by Hailes et al. (2010), there are still large raised muddy patches just metres outside the monitored area, particularly to the north-west (sink knee deep). These mud patches had extremely high crab and gastropod densities. However, the sediment surface within the monitored area remains firm and sandy (Figures 14 and 15) underneath surficial muddy sediment of varying thicknesses (as mentioned above). Furthermore, the sediment is also characterised by a slightly hummocky appearance and small ripples (generally 1 cm wave height and 5-10 cm wave length) and low density *Macomona* and *Austrovenus* shell hash. Epifauna and infauna at this site are abundant, with a high density of *Hemiplax hirtipes* (especially on the western channel side of the site), *Cominella glandiformis* and *Zeacumantus* and also *Austrovenus* (especially during the warmer months). Bird foraging is common over the entire sandflat (within and beyond the monitoring area).

Between February 2010 and February 2012, site KaiB has remained consistent, despite variable amounts of surficial sediment being deposited on the site.

Figure 14. Site KaiB, looking diagonally across the monitored area towards the south east.

Figure 15. The sediment surface of KaiB taken in December 2010.

3.2 Sediment Characteristics

The bimonthly results for sediment grain size, organic content and chlorophyll *a* for each of the six monitored sites between April 2010 and February 2012 are presented in Appendix 1.

Grain Size

Between October 2009 and February 2012, there were no marked changes in the sediment grain size composition at sites HCK, TPB and KaiF. Consistently, the sediment sand fraction (91.28-99.88%) is the largest constituent of the sediment at these three sites (Figure 16), followed by mud (0.00-8.72%) (Figure 17) and then gravel (0.00-0.44%). Site TPB consistently the greatest amount of medium sand and site NPC has continued to show higher and variable gravel content compared to the other sites, which is a result of the shell hash layer on the sediment surface at this site.

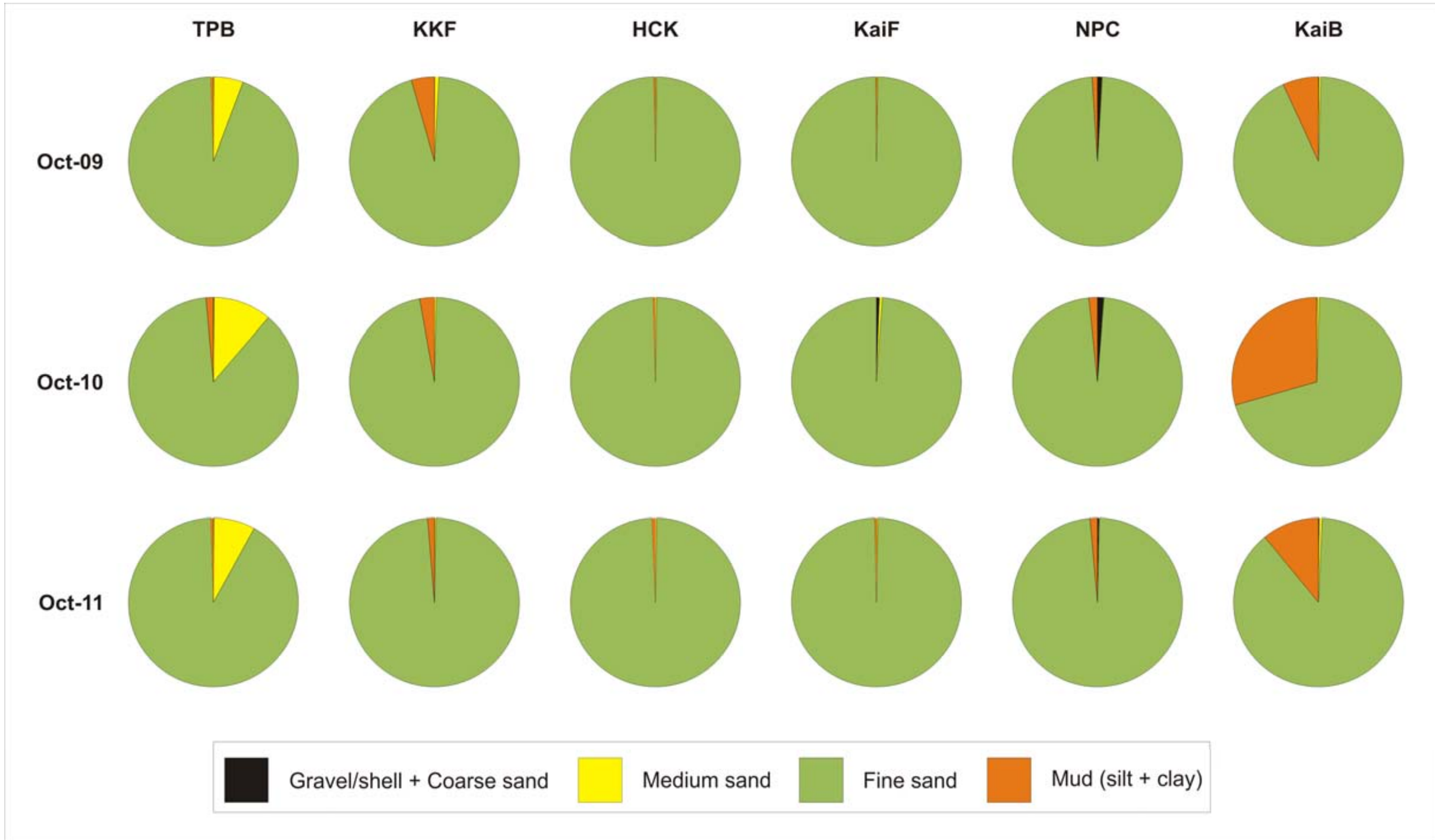


Figure 16. Changes in the proportions of gravel/shell and coarse sand (≥500 µm), medium sand (500-250 µm), fine sand (250-125 µm) and silt/clay (i.e., mud <63 um) at each of the monitored sites over the entire monitoring period (October months only).

The southern-most site, KaiB, had the highest percentage of mud (ranging between 6.82 and 31.15%), followed by KKF (0.70-8.72%). High peaks of mud content were particularly noticeable at site KaiB between April 2010 and April 2011, during which time thicker layers of surficial mud were observed at the site in June 2010, October 2010 and February 2011. Mud was a small component of the sediment at sites TPB, HCK, KaiF or NPC (Figure 17).

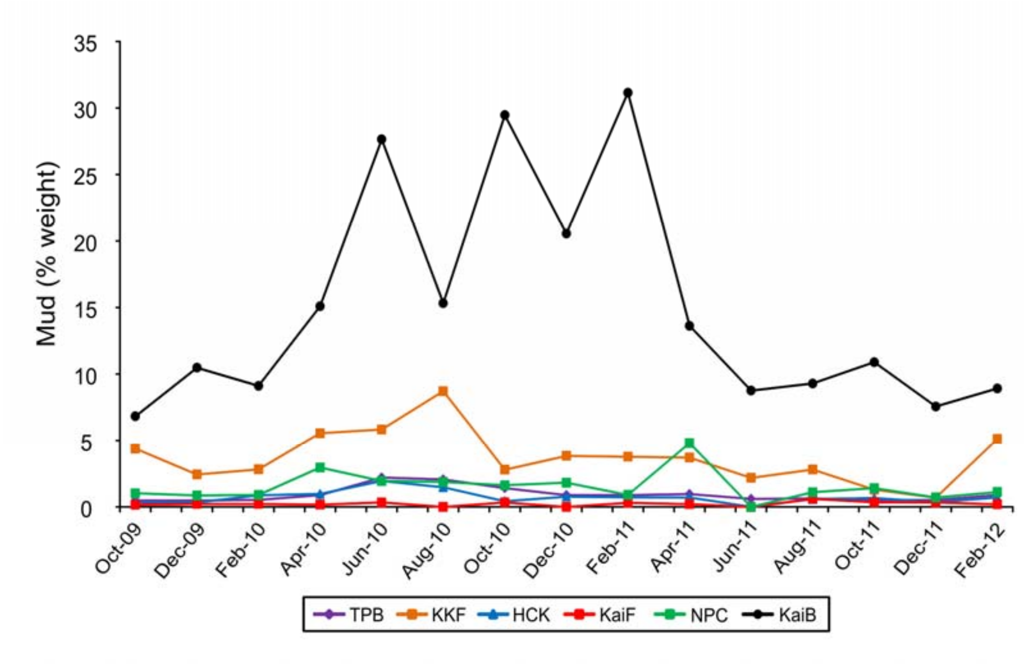


Figure 17. Sediment mud (silt and clay fractions) content (% weight) of sediment collected from monitored sites between October 2009 and February 2012.

Organic Matter Content

Sediment organic matter content at sites TPB, HCK, KaiF and NPC has remained relatively consistent and low (0.14-1.38%; Figure 18; Appendix 1) since the initiation of monitoring in October 2009. The percentage of organic matter in the sediments at site KKF was slightly higher and more annually variable (0.68-1.57%), possibly due to the presence of seagrass detritus at this site. Site KaiB had the highest and most variable organic matter content (0.83-2.46%), particularly observed between June 2010 and October 2011 and probably related to fine sediment deposition events (Figure 16).

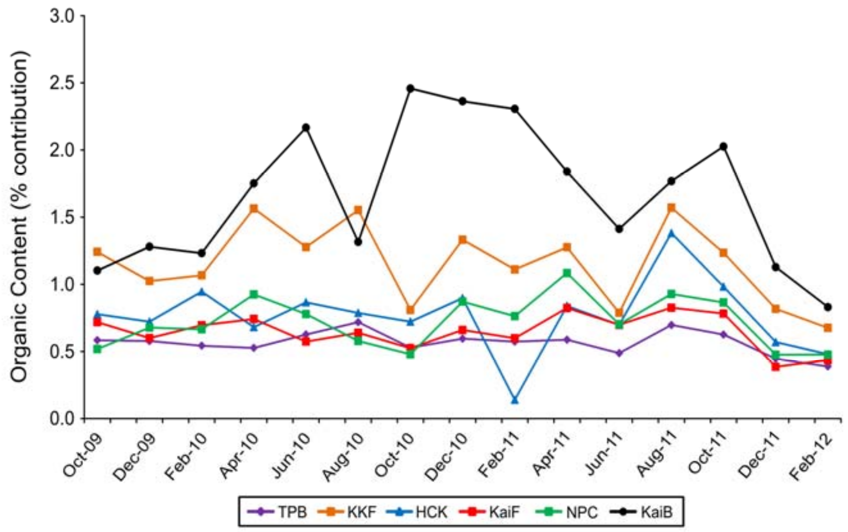


Figure 18. Percentage organic content of sediment collected from monitored sites between October 2009 and February 2012.

Chlorophyll *a*

The chlorophyll *a* (Chl *a)* content of sediment at each site has remained relatively consistent since the monitoring program began in October 2009 (Figure 19; Appendix 1). Interestingly, however, sediment Chl *a* levels increased simultaneously at all sites between December 2011 and February 2012. Generally, the Chl *a* levels were similar across sites (with the exception of HCK in February 2012), although KKF and KaiF typically display higher peaks (i.e. June 2010) and lower values are usually recorded in December (i.e., TPB and KaiF).

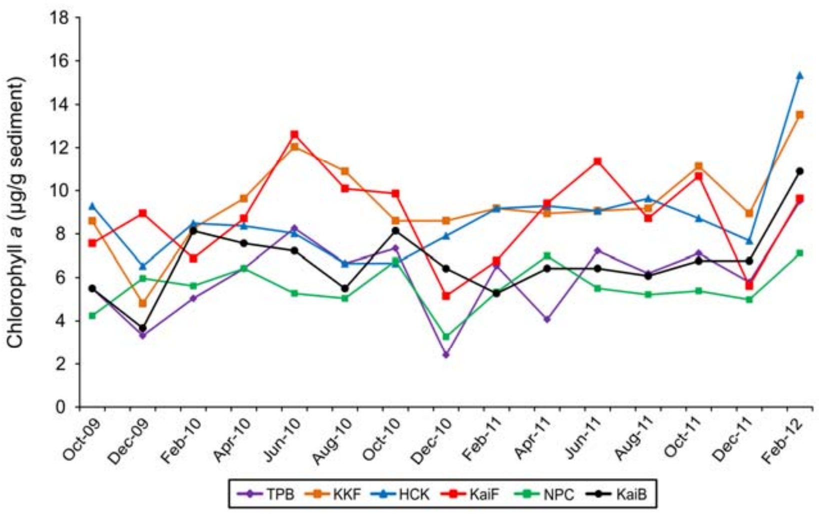


Figure 19. Chlorophyll *a* levels (µm/g sediment) of sediment collected from monitored sites between October 2009 and February 2012.

4.0 Benthic Communities of southern Kaipara Harbour

4.1 Temporal Variability Observed at Sites

The most abundant taxon at each site in October 2009 was found to be the most abundant taxon again in October 2010 (Table 2). The same was true between October 2010 and October 2011, with the exception of sites KKF and KaiB. Rankings among the less abundant taxa displayed greater variability (Table 2), although the top 5 ranked species tended to remain in the top 5 each October.

The abundance of each monitored species from each site was plotted to graphically to detect seasonal patterns, multi-year patterns, and relative stability in abundance versus highly unpredictable variability in abundance over time. Although only a few illustrative plots are included in this report as examples, all of the results of this analysis are summarised in Table 3. Seasonal patterns are generally observed as predictable peaks and troughs in abundance that are similar in timing from year to year. Multi-year patterns can also show seasonality, although variations in the magnitudes of the peaks and troughs create patterns at greater than annual time scales. It is important to note that with less than 3 years of data available, statements regarding seasonal and multi-year patterns should be regarded with caution and a further 2 years of data will enable us to state with more certainty whether patterns in abundance are occurring.

Table 2. The five most abundant taxa from each monitored site in October since the initiation of the monitoring programme in 2009 until 2011. NB: *Heteromastus filiformis*, *Austrovenus stutchburyi* and *Macroclymenella stewartensis* have been abbreviated.

		Most Abundant	→			Less Abundant
Oct-09	TPB	*Euchone* sp.	*Magelona dakini*	*Aricidea* sp.	*Heteromastus*	Syllinae B
	KKF	*Heteromastus*	*Macomona liliana*	*Aricidea* sp.	*Magelona dakini*	*Owenia petersonae*
	HCK	*Aricidea* sp.	*Magelona dakini*	*Heteromastus*	*Colurostylis lemurum*	Nemertea
	KaiF	*Aricidea* sp.	*Methalimedon* sp.	*Magelona dakini*	*Waitangi brevirostris*	*Aglaophamus macoura*
	NPC	*Magelona dakini*	*Heteromastus*	*Soletellina siliqua*	*Anthopleura aueoradiata*	*Macomona liliana*
	KaiB	*Magelona dakini*	*Macomona liliana*	*Austrovenus*	*Cossura consimilis*	Nemertea
Oct-10	TPB	*Euchone* sp.	*Magelona dakini*	*Heteromastus*	*Colurostylis lemurum*	*Macroclymenella*
	KKF	*Heteromastus*	*Magelona dakini*	*Owenia petersonae*	*Macomona liliana*	Nemertea
	HCK	*Aricidea* sp.	*Magelona dakini*	*Soletellina siliqua*	*Waitangi brevirostris*	*Heteromastus*
	KaiF	*Aricidea* sp.	*Soletellina siliqua*	Hessionidae	*Colurostylis lemurum*	*Aglaophamus macoura*
	NPC	*Magelona dakini*	*Heteromastus*	*Soletellina siliqua*	*Macomona liliana*	*Colurostylis lemurum*
	KaiB	*Magelona dakini*	*Heteromastus*	*Macomona liliana*	*Austrovenus*	Nemertea
Oct-11	TPB	*Euchone* sp.	*Magelona dakini*	*Heteromastus*	*Aricidea* sp.	Hessionidae
	KKF	*Macomona liliana*	*Nucula hartvigiana*	Nemertea	*Heteromastus*	*Aricidea* sp.
	HCK	*Aricidea* sp.	*Heteromastus*	*Colurostylis lemurum*	*Aglaophamus macoura*	*Magelona dakini*
	KaiF	*Aricidea* sp.	*Colurostylis lemurum*	Hessionidae	*Soletellina siliqua*	*Aglaophamus macoura*
	NPC	*Magelona dakini*	*Heteromastus*	*Colurostylis lemurum*	*Soletellina siliqua*	*Nicon aestuariensis*
	KaiB	*Austrovenus*	*Macomona liliana*	*Heteromastus*	*Magelona dakini*	*Soletellina siliqua*

Table 3. Monitored species displaying seasonal (S) and multi-year (M) patterns and low (L) and unpredictable high (H) variability in abundance at each site between October 2009 and February 2012. Species rarely or never observed are denoted by - and a blank box, respectively.

	TPB	KKF	HCK	KaiF	NPC	KaiB
Torridoharpinia hurylei	-	L	-	-	-	L
Waitangi brevirostris	S	L	L	L	L	-
Anthopleura aueoradiata	L			-	S	-
Austrovenus stutchburyi	S	S	-	-	L	M
Macomona liliana	H	S	L	-	S	S/M
Musculista senhousia	H	H	L	-	H	L
Nucula hartvigiana	-	H	-	-	-	L
Soletellina siliqua	S	S/M	S/M	S	H	S
Colorostylis lemurum	S	H	S/M	S/M	S/M	S/M
Notoacmea scapha		-		-	L	-
Trochodota dendyi	S/M	H	L	L	L	-
Exosphaeroma chilensis		-			-	
Exosphaeroma falcatum	-	-	-	-	S/M	-
Aglaophamus macroura	S	H	S/M	S/M	S	L
Aonides trifida	-	L	-	-	-	-
Aricidea sp.	H	H	M	S/M	L	H
Asychis sp.	-	H	-		-	L
Boccardia syrtis	S	S	-		L	S
Cossura consimilis		-	-		-	M
Euchone sp.	S/M	-				
Macroclymenella stewartensis	S/M	S/M	-	-	L	-
Magelona dakini	M	S/M	M	L	M	H
Nicon aestuariensis	-	S	H	-	S	H
Orbinia papillosa	-	-	-	-	-	-
Owenia petersonae	S/M	M	-		-	
Prionospio aucklandica	L	M	-	-	-	-
Scoloplos cylindrifer		-		-	-	
Travisia olens var. NZ	L	-	S	S		

4.1.1 Site TPB

Site TPB is polychaete dominated with relatively high abundances of *Euchone* sp., *Magelona dakini*, *Heteromastus filiformis* and *Aricidea* sp. (Table 2). The abundances of *Trochodota dendyi*, *Owenia petersonae*, *Euchone* (Figure 20) and *Macroclymenella stewartensis* appear to be displaying seasonal/multi-year patterns, whilst *Aglaophamus macroura*, *Austrovenus stutchburyi*, *Boccardia syrtis, Waitangi brevirostris*, *Soletellina siliqua* and *Colorostylis lemurum* (Figure 21) are displaying seasonal patterns (Table 3). All other monitored species are displaying low variability in abundance (*Anthopleura aueoradiata*, *Prionospio aucklandica* and *Travisia olens*), high variability in abundance (*Macomona liliana*, *Aricidea* sp. and *Magelona dakini*) or are rarely observed at the site (i.e., *Torridoharpinina hurylei*, *Nucula hartvigiana*, *Orbinia papillosa*). The monitored species *Notoacmea scapha*, *Exosphaeroma chilensis*, *Cossura consimilis* and *Scoloplos cylindrifer* were not found at this site. The spread of nearby *Musculista senhousia* beds (north of the monitored area) into the monitored area is being closely observed and although the abundance of *Musculista* peaked to 53 individuals in June 2010, they are usually rare.

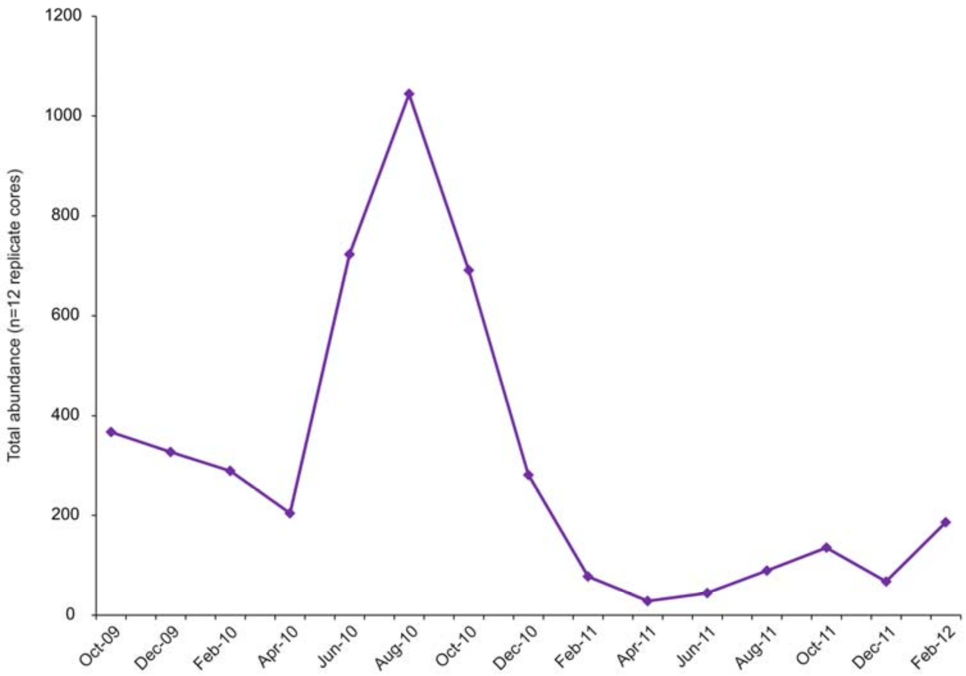


Figure 20. Total abundance (n=12 cores) of *Euchone* displaying a seasonal/multi-year pattern at site TPB between October 2009 and February 2012.

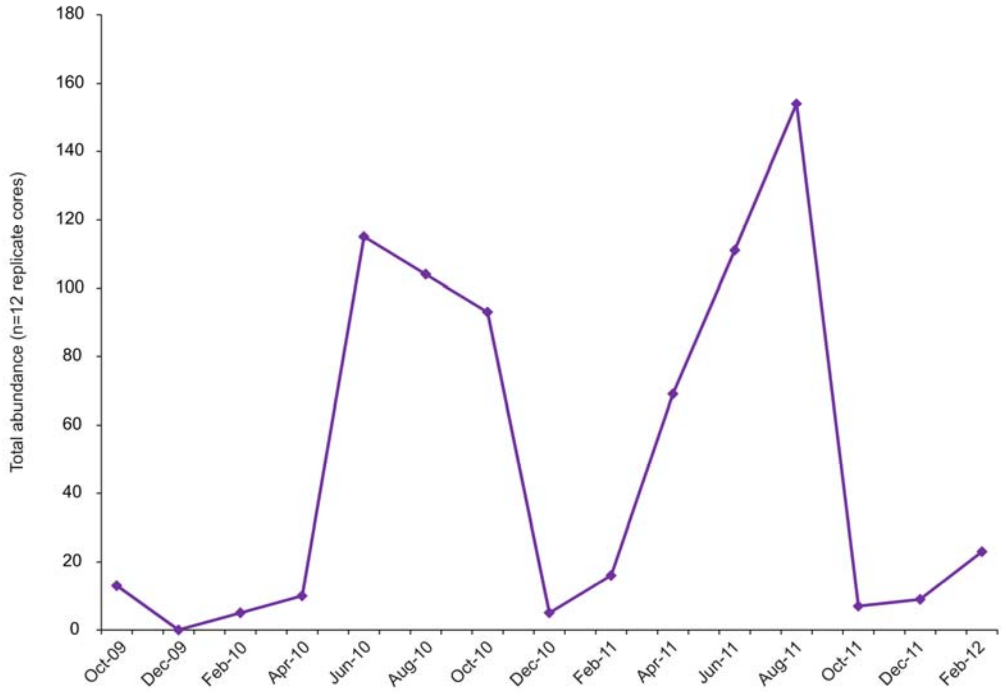


Figure 21. Total abundance (n=12 cores) of *Colorostylis* displaying a seasonal pattern at site TPB between October 2009 and February 2012.

4.1.2 Site KF

Site KKF is both polychaete (i.e., *Heteromastus*, *Aricidea* and *Magelona*) and bivalve (*Macomona* and *Nucula*) dominated (Table 2). In October 2011, bivalves were the numerically dominant organisms at this site, whereas *Heteromastus* had been the most abundant species prior to that in October 2009. Fewer monitored species are displaying multi-year and seasonal patterns at KKF, compared to TPB, which is situated just across the main channel (Figure 1, Table 3). The abundances of *Macroclymenella*, *Soletellina* and *Magelona* (Figure 22) are displaying seasonal/multi-year patterns and *Owenia* and *Prionospio* are displaying multi-year patterns. The abundances of *Austrovenus*, *Boccardia* (Figure 23) and *Nicon aestuariensis* display winter peaks of abundance. *Torridoharpinia*, *Waitangi* and *Aonides trifida* were the only monitored species having low abundances with minimal variability; *Anthopleura* was the only monitored taxon not found at this site. While *Aricidea*, *Asychis*, *Colorostylis* and *Nucula* (among others) have had highly variable abundances, other monitored species including *Cossura*, *Exosphaeroma* spp., *Notoacmea* and *Scoloplos* were rarely present. The shell hash that litters the sediment surface at KKF usually consists of dead *Musculista* shells, and generally it is rare to observe live *Musculista*. However, in June and August 2010, 16 and 15 individuals were found at this site, respectively.

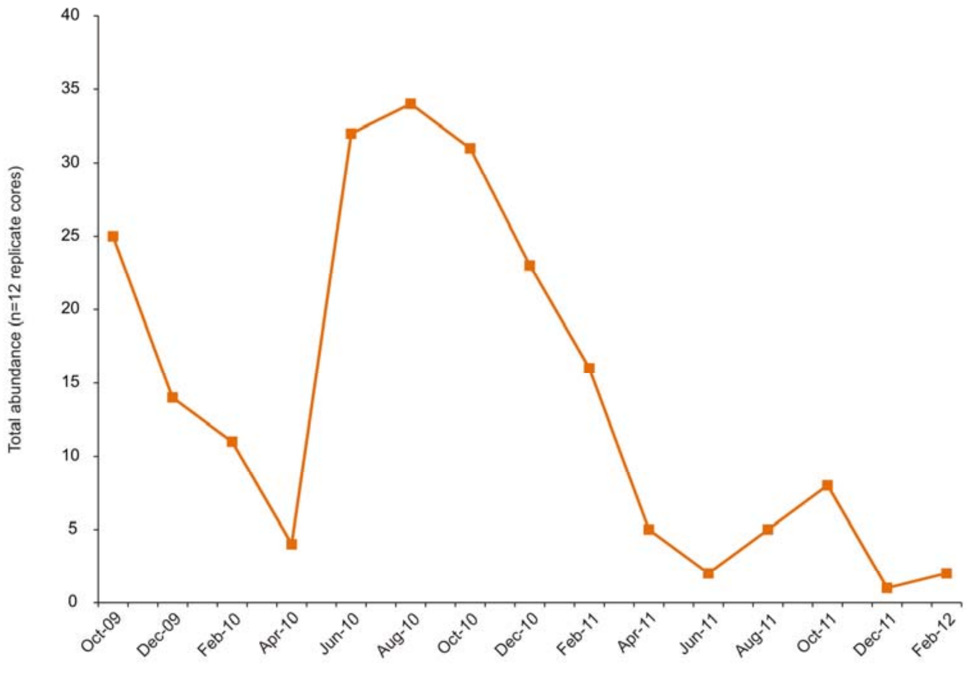


Figure 22. Total abundance (n=12 cores) of *Macroclymenella* displaying a seasonal/multi-year pattern at site KKF between October 2009 and February 2012.

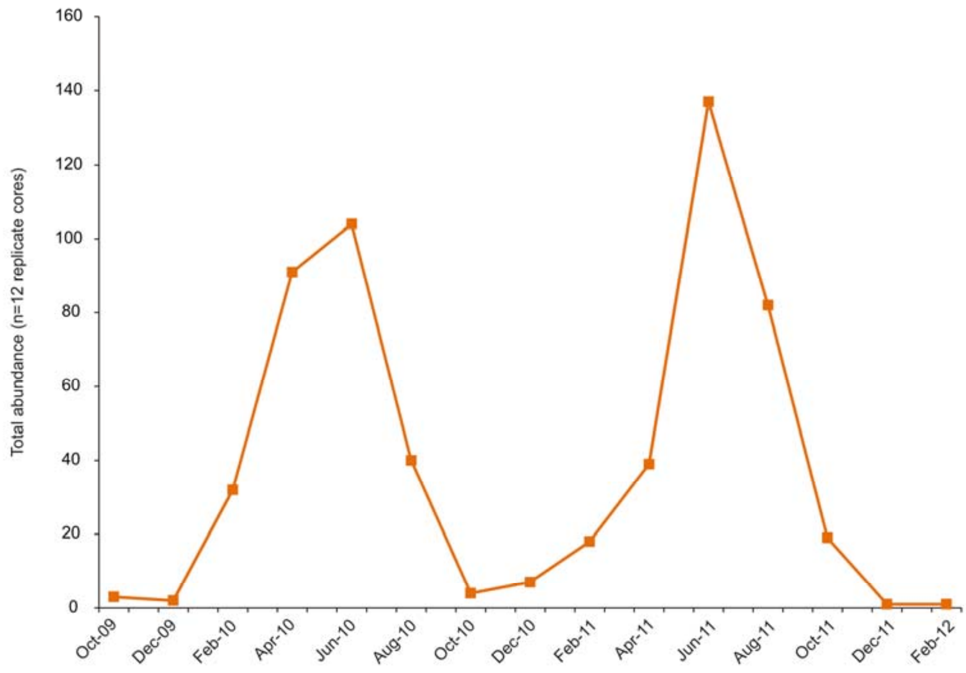
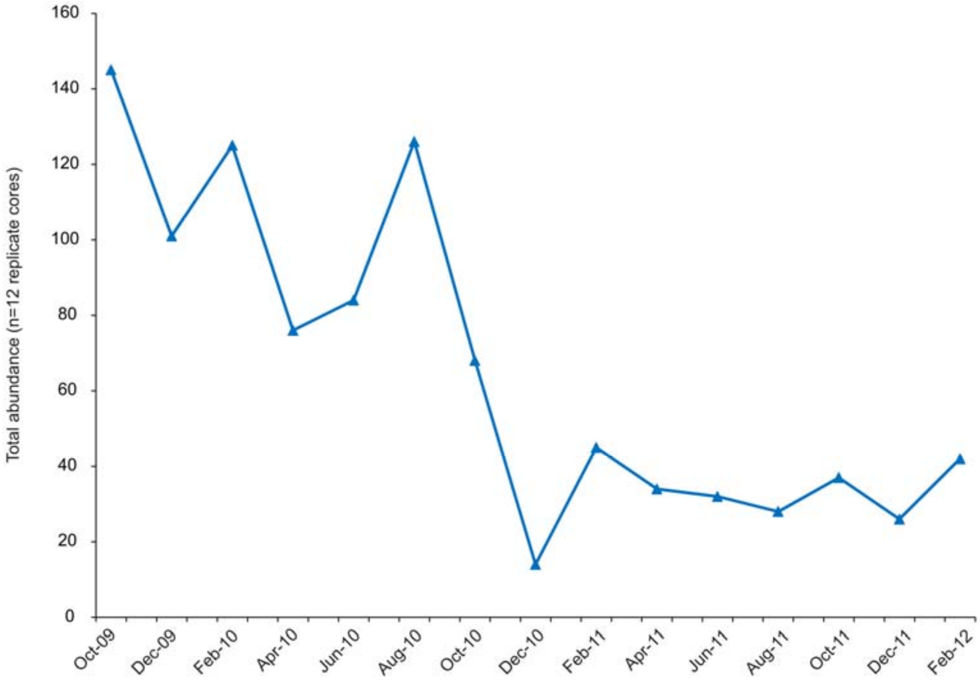


Figure 23. Total abundance (n=12 cores) of *Boccardia* displaying a seasonal pattern at site KKF between October 2009 and February 2012.

4.1.3 Site HCK

HCK is dominated by a mixture of polychaetes (*Aricidea, Heteromastus* and *Magelona*) and the cumacean *Colorostylis* (Table 2), although the abundances of most of these species are low. Monitored species *Aricidea* (Figure 24) and *Magelona* are displaying multi-year patterns, *Colorostylis*, *Soletellina* and *Aglaophamus* are displaying seasonal/multi-year patterns and *Travisia* (Figure 25) is displaying a seasonal pattern in abundance (Table 3). *Waitangi*, *Macomona*, *Musculista* and *Trochodota* all have low abundances with minimal variability and *Nicon* is the only monitored species at this site with variable unpredictable abundance over time. All other monitored species were either rarely observed (i.e., *Torridoharpinia*, *Austrovenus*, *Exosphaeroma falcatum* and *Prionospio*) or have never been found at HCK (*Notoacmea*, *Exosphaeroma chilensis*, *Euchone* and *Scoloplos*).

Figure 24. Total abundance (n=12 cores) of *Aricidea* displaying a multi-year pattern at site HCKbetween October 2009 and February 2012.



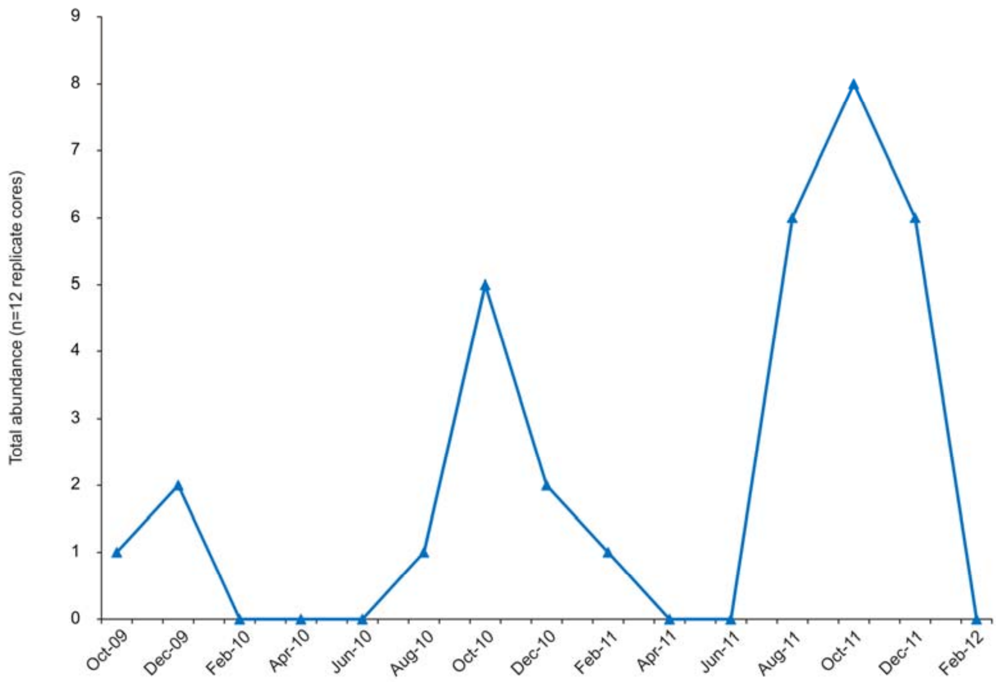


Figure 25.Total abundance (n=12 cores) of *Travisia* displaying a seasonal pattern at site HCK between October 2009 and February 2012.

4.1.4 Site KaiF

Site KaiF has consistently been dominated since October 2009 by the polychaete *Aricidea* (Figure 26) which is displaying a seasonal/multi-year pattern of abundance (Table 2). KaiF is also dominated by amphipods (namely *Methalimedon* and *Waitangi*), the cumacean *Colorostylis* and the bivalve *Soletellina.* In addition to *Aricidea, Corostylis* and *Aglaophamus* also appear to have abundances displaying seasonal/multi-year patterns (Table 3). Furthermore, *Soletellina* (Figure 27) and *Travisia* are both displaying seasonal patterns. No species at KaiF are displaying high variability. To the contrary, *Waitangi, Trochodota* and *Magelona* all have low abundances and minimal variability. Many of the monitored species are rarely observed at this site (i.e., *Anthopleura*, *Aonides*, *Nucula*, *Prionospio* and *Torridoharpinia*) or have not been observed at all (i.e., *Asychis*, *Boccardia*, *Cossura, Euchone* and *Owenia petersonae*). *Musculista* is also usually rarely observed at this site. However; in April 2011 there was a single peak of 40 individuals (over 12 replicate cores).

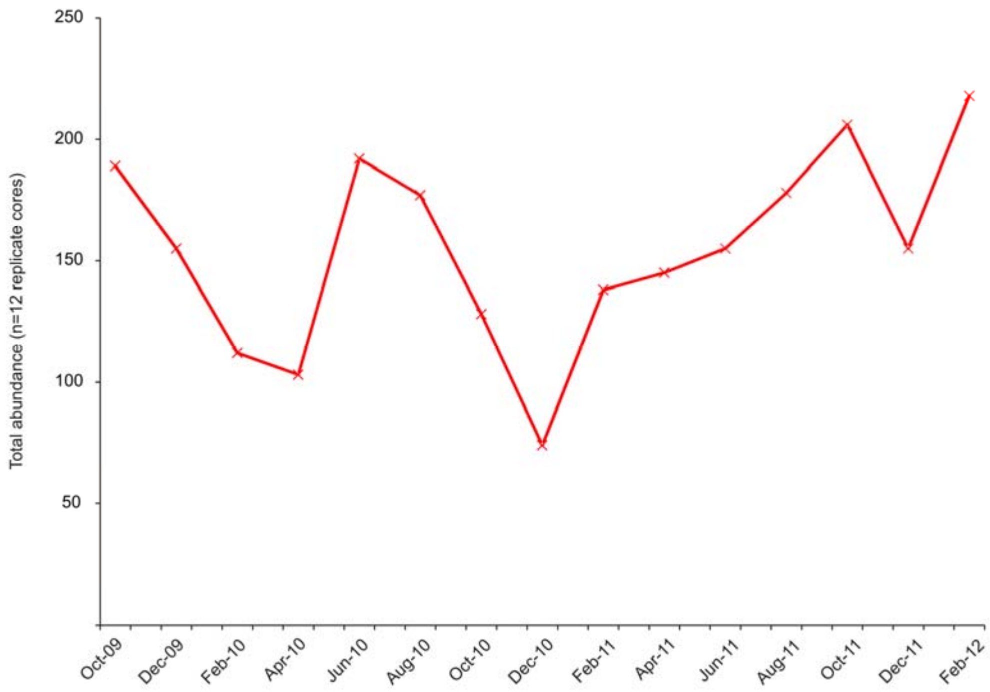


Figure 26. Total abundance (n=12 cores) of *Aricidea* displaying a seasonal/multi-year pattern of abundance at site KaiF between October 2009 and February 2012.

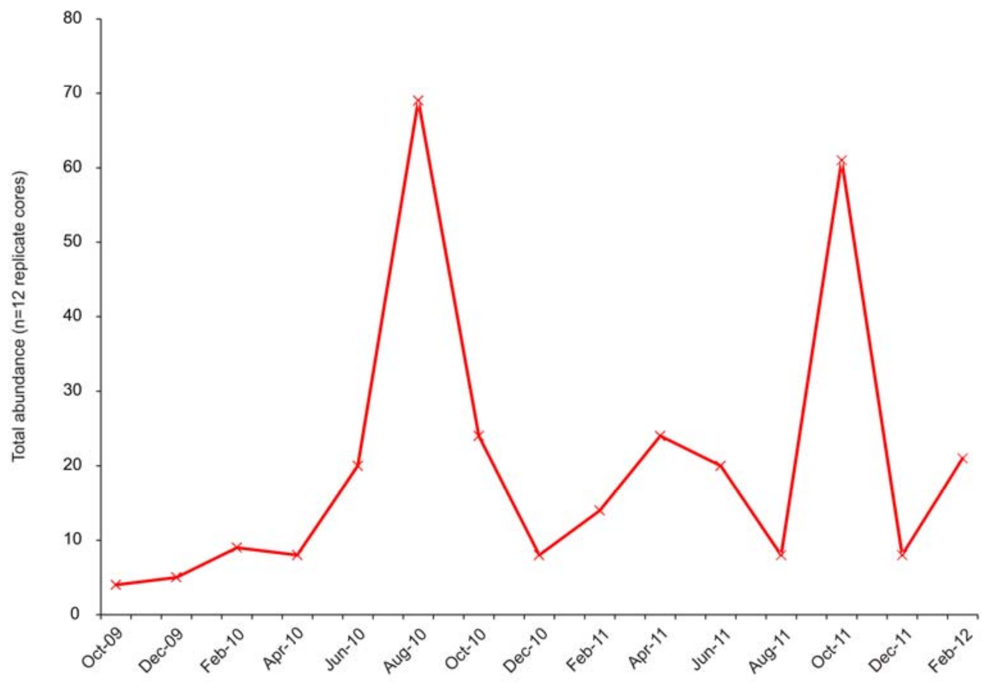


Figure 27. Total abundance (n=12 cores) of *Soletellina* displaying a seasonal pattern at site KaiF between October 2009 and February 2012.

4.1.5 Site NPC

Site NPC is dominated by both polychaetes *Magelona* and *Heteromastus* and the bivalve *Soletellina.* The rank abundance of the dominant species has not changed significantly at this site since initial sampling in 2009 (Table 2). The monitored species *Magelona* (multi-year), *Colorostylis* (Figure 28) and *Exosphaeroma falcatum* (seasonal/multi-year) all displayed temporal patterns of abundance. *Anthopleura*, *Macomona*, *Nicon* and *Aglaophamus* (Figure 29) are displaying seasonal patterns of abundance (Table 3). *Musculista* and *Soletellina* both have highly variable abundances and species including *Waitangi*, *Austrovenus*, *Boccardia* and *Macroclymenella* are all displaying low abundances with minimal variation over time. Monitored species *Asychis*, *Cossura*, *Orbinia*, *Prionospio* and *Torridoharpinia* are rarely present, while *Euchone* and *Travisia* are the only monitored species that have not been observed at this site.

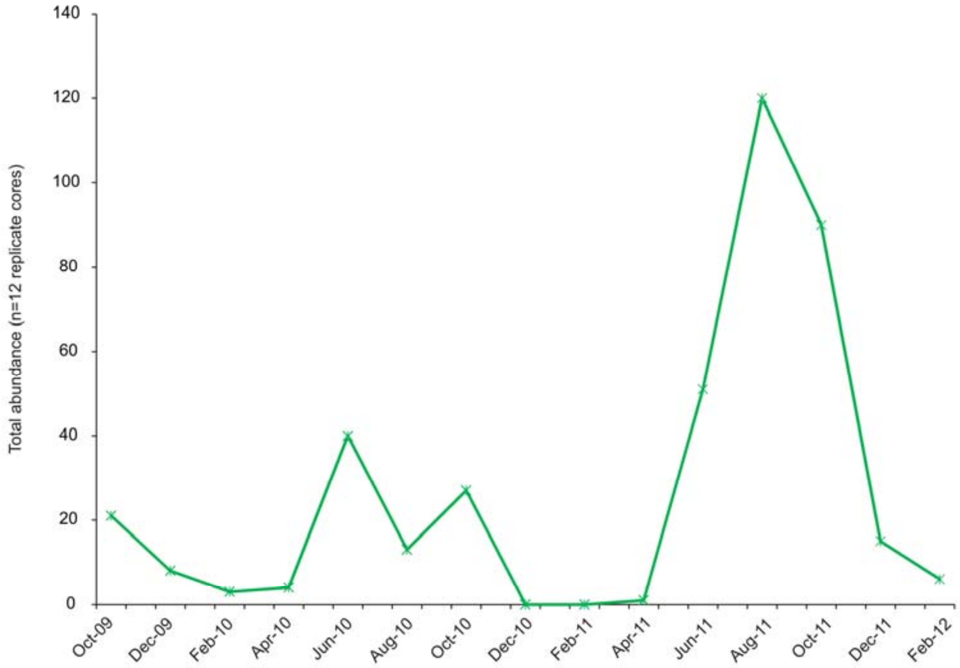


Figure 28. Total abundance (n=12 cores) of *Colorostylis* displaying a seasonal/multi-year pattern at site NPC between October 2009 and February 2012.

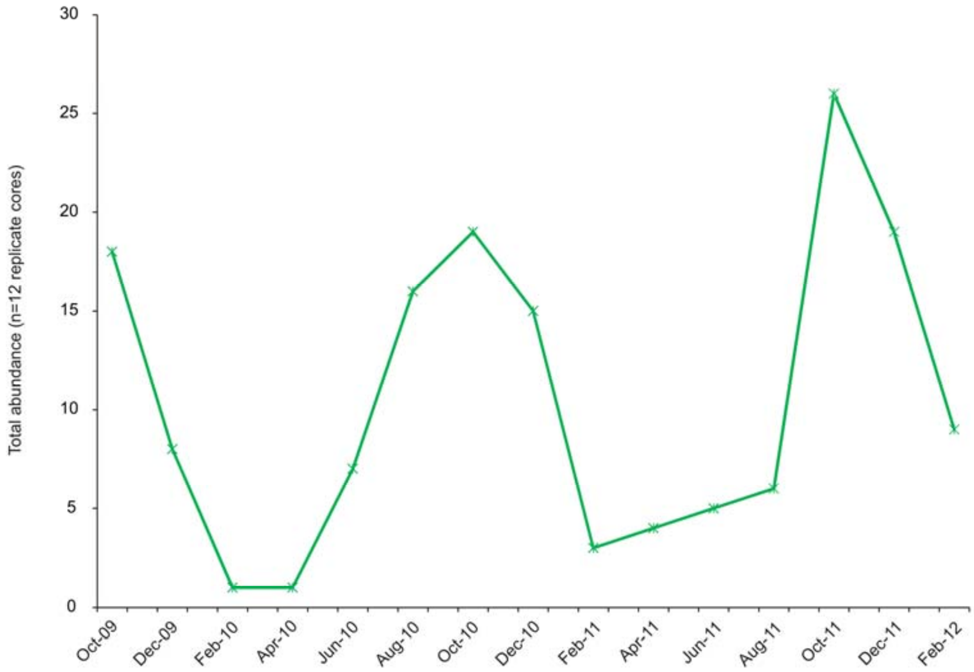


Figure 29.Total abundance (n=12 cores) of *Aglaophamus* displaying a seasonal pattern at site NPC between October 2009 and February 2012.

4.1.6 Site KaiB

KaiB has been continually dominated by a mixture of polychaetes and bivalves since monitoring was initiated in 2009. In October 2009 and 2010, the dominant taxa was *Magelona*, however in October 2011, *Austrovenus* became the most numerically dominant (Table 2). Monitored species *Austrovenus* and *Cossura* (Figure 30) are displaying abundances that could potentially be part of multi-year patterns, *Colorostylis* (Figure 31) and *Macomona* look to be displaying seasonal/multi-year patterns and the abundance of *Boccardia* and *Soletellina* appears to peak in June of 2010 and 2011 (Table 3). Abundances of *Aricidea*, *Magelona* and *Nicon* appear to be highly variable over time, while other species including *Torridoharpinia*, *Nucula* and *Aglaophamus* have consistently low abundances with minimal variation. In April 2010, the abundance of *Musculista* peaked at 70 (total abundance across 12 replicate cores). However, following this, numbers have remained low (< 10) with minimal variation. Many of the monitored species are rarely observed at KaiB and *Exosphaeroma chilensis*, *Euchone*, *Owenia*, *Scoloplos* and *Travisia* have never been observed at this site.

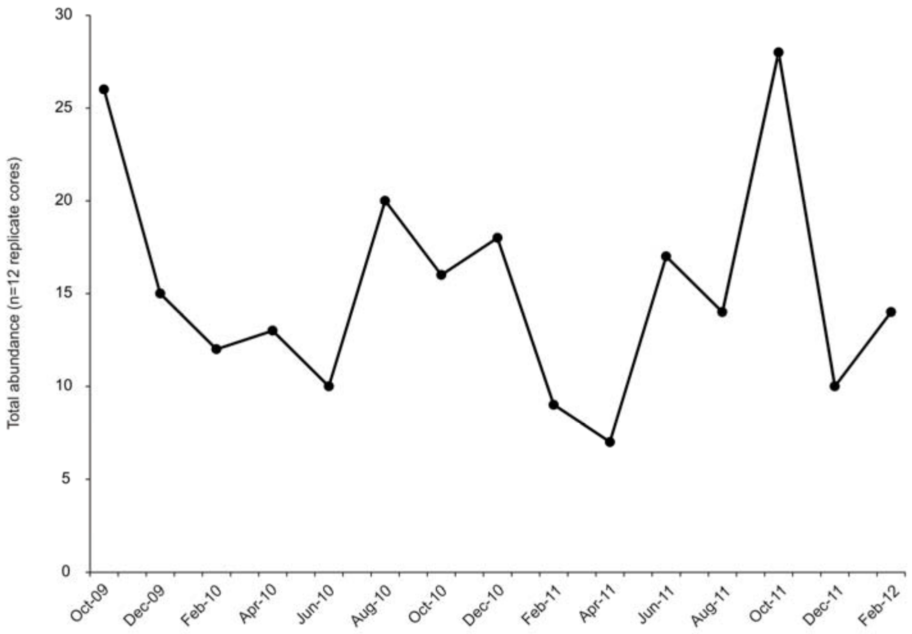


Figure 30. Total abundance (n=12 cores) of *Cossura* displaying what could potentially be part of a multi-year pattern at site KaiB between October 2009 and February 2012.

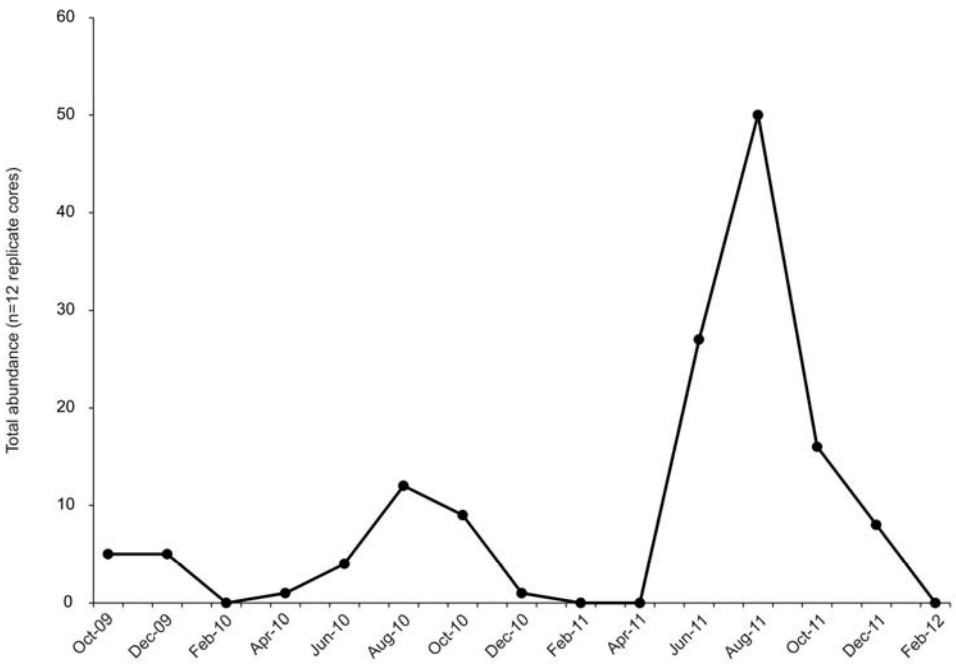


Figure 31. Total abundance (n=12 cores) of *Colorostylis* displaying a seasonal/multi-year pattern at site KaiB between October 2009 and February 2012.

4.2 Consistency between Sites

Characteristics of benthic macrofaunal communities, including Shannon-Weiner diversity and the mean number of species and individuals, are displayed for all sites for the three consecutive October samplings, 2009-2011 (Figure 32). Communities sampled from sites KKF and HCK consistently display higher and lower numbers of species and individuals, respectively. Since monitoring was established in October 2009, the number of species sampled at all sites other than TPB and KKF has increased, as has the number of individuals found (except at HCK). In contrast, the number of species and individuals sampled from TPB and KKF has decreased, though generally mean abundance remains higher than at the other sites. Shannon-Weiner diversity has remained similar at all sites except for HCK, KaiF and NPC, where diversity has increased.

Austrovenus, *Macomona* and *Soletellina* are present at all sites, but in varying abundances and size class structure (Figure 33). *Austrovenus* at sites HCK and KaiF and *Macomona* at KaiF are only rarely present; mainly as juveniles (< 5 mm maximum shell length). Adult *Austrovenus* (>20 mm maximum shell length) have not been consistently present at any of the sites over time, although their abundance at site KKF has increased over time. Adult *Macomona* are highest in abundance at site KaiB, and then site KKF, although they do also occur in low numbers at sites HCK and NPC. *Soletellina* sized > 20 mm are not found at any sites, and juvenile abundances show strong fluctuations, with some similarities in the timing of fluctuations at sites TPB, KaiF and KaiB. Juvenile recruitment of *Macomona* and *Austrovenus* is also variable, although there are similarities for *Austrovenus* between sites KaiF and TPB with peaks occurring in April, and at sites NPC and KKF with peaks occurring later in the year.

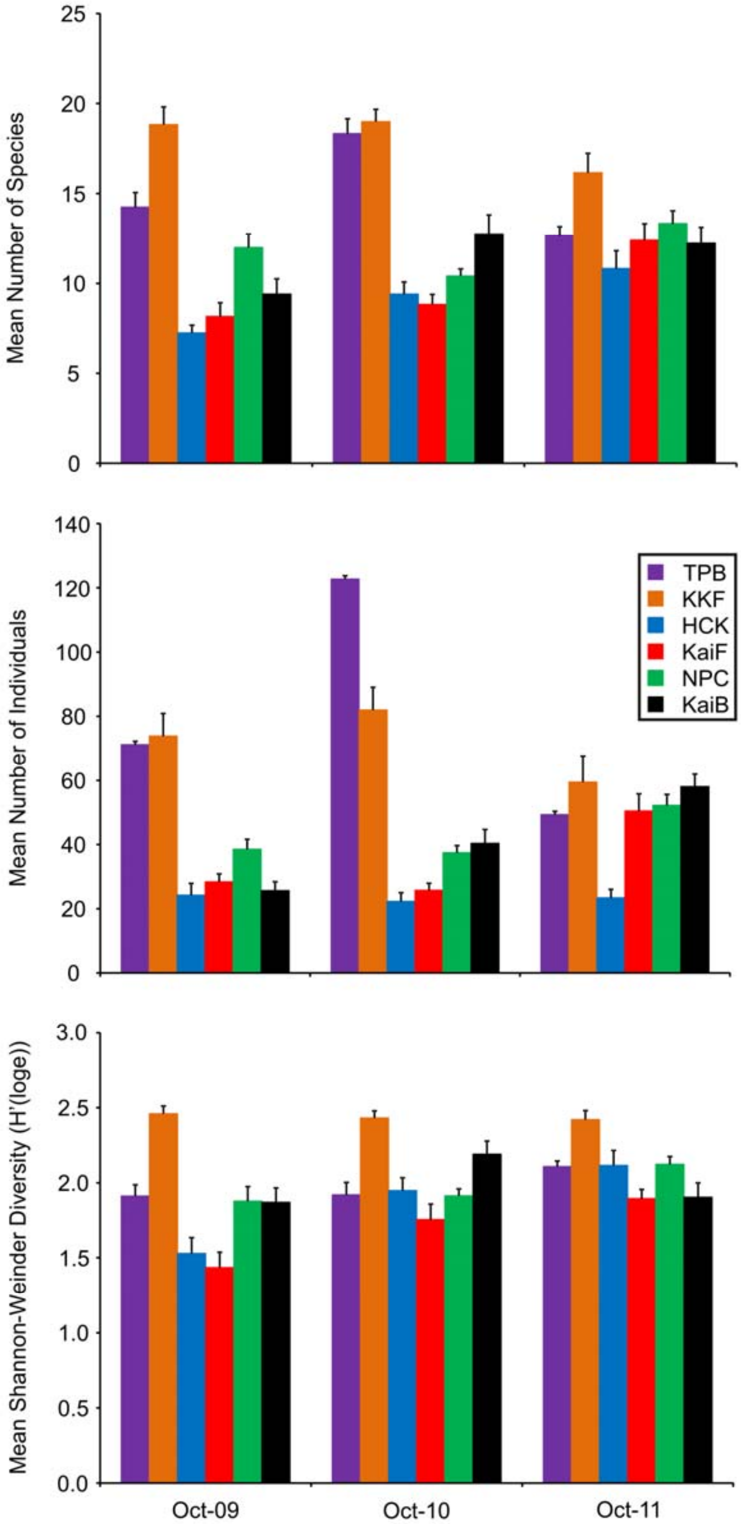


Figure 32. Mean number of species, individuals and Shannon-Weiner diversity of macrofaunal communities at monitored sites in October 2009, 2010 and 2011 (+SE).

Figure 33. Size class structure of the dominant bivalves *Austrovenus stutchburyi*, *Macomona liliana* and *Soletellina siliqua* at monitored sites (sum of 12 cores) from October 2009 until February 2012.

Figure 33. (cont.) Size class structure of the dominant bivalves *Austrovenus stutchburyi*, *Macomona liliana* and *Soletellina siliqua* at monitored sites (sum of 12 cores) from October 2009 until February 2012.

Within-site variability of macrofaunal communities is similar to that reported by Hailes et al. (2010). In October 2009 within-site variability ranged between 52 and 60% similarity and macrofauna collected in 12 replicates clustered together in distinct groups. SIMPER results for October 2011 macrofaunal data indicated that site homogeneity is still strong, with within-site similarity ranging between 51% (HCK) and 66% (TPB and KaiB).

Non-metric multidimensional ordination of macrofaunal community data collected in October 2009, 2010 and 2011 indicated that communities have remained relatively distinct (Figure 34).

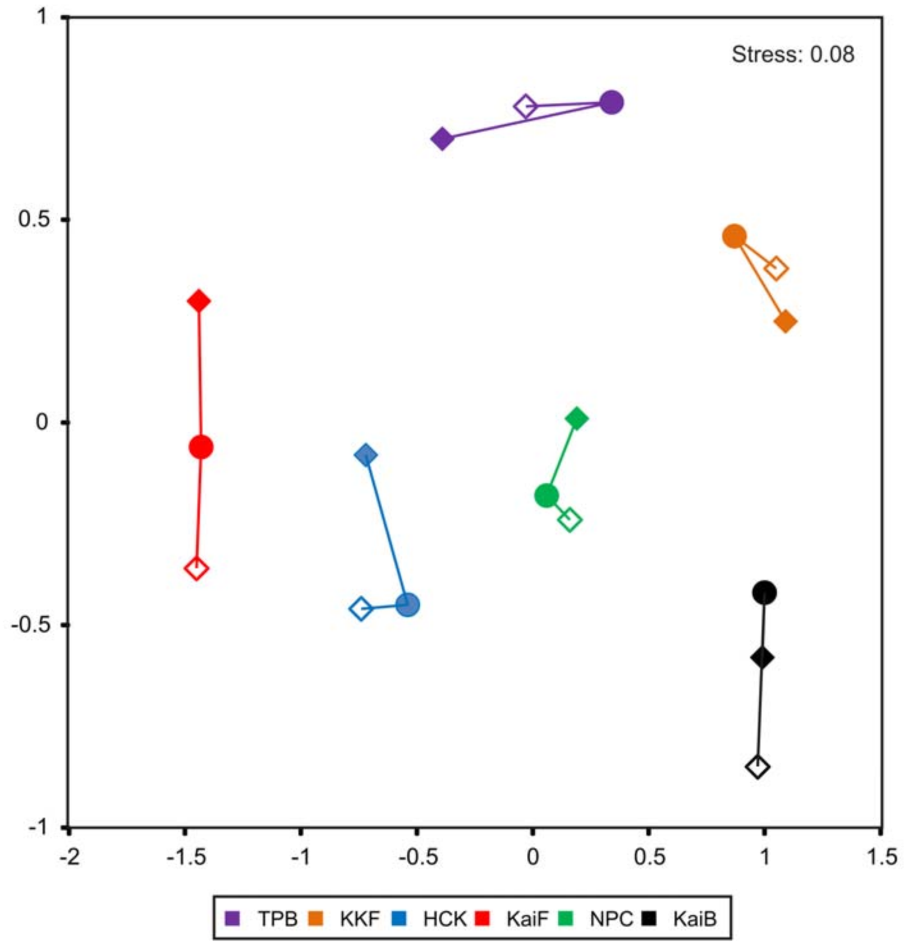


Figure 34. Multi-dimensional scaling plot (MDS) indicating the dissimilarity of macrofauna communities over time: 2009 (open diamonds), 2010 (closed circles) and 2011 (closed diamonds) from each site: TPB (purple); KKF (orange); HCK (blue); KaiF (red); NPC (green) and KaiB (black). The data is log-transformed and the plot stress is acceptable at 0.08. The closer points are in ordination space, the more similar the community composition is.

4.3 State of the Environment Indicators

There was no consistent change in the community composition associated with mud found at site KKF (Table 4, Figure 35). However, CAPmud scores at sites TPB, HCK, KaiF, NPC and KaiB all increased between 2009 and 2011 (negative values increased closer to zero), with the largest change observed at site KaiB (56.1%). Nevertheless, the placements of the Kaipara sites in the BHMmud model all continue to indicate good health with all sites attaining a BH score of 2 (Hewitt et al. 2012).

Table 4. CAPmud scores for all sites over time, together with whether there is a consistent direction of change (Direction: Yes or No) and the % change relative to the model range is given. In addition, the BH scores of communities (1 =very healthy, 2=good health) are also displayed in brackets.

	2009	2010	2011	Direction	% Change
TPB	-0.130 (1)	-0.104 (2)	-0.066 (2)	Y	15.95
KKF	-0.101 (2)	-0.108 (2)	-0.087 (2)	N	
HCK	-0.135 (1)	-0.110 (2)	-0.066 (2)	Y	17.21
KaiF	-0.096 (2)	-0.101 (2)	-0.062 (2)	N	
NPC	-0.108 (2)	-0.110 (2)	-0.068 (2)	N	
KaiB	-0.109 (2)	-0.088 (2)	-0.048 (2)	Y	15.34

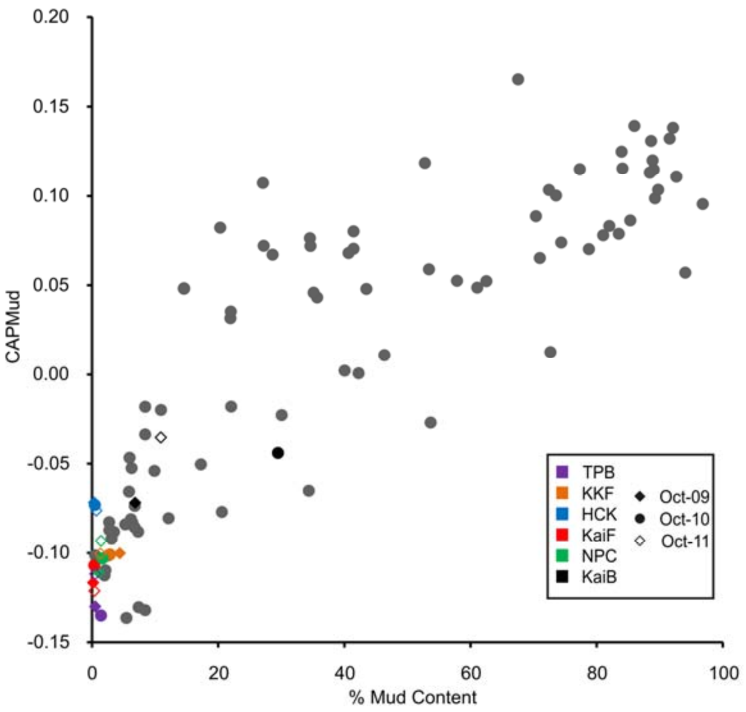


Figure 35. Plot of the relationship between % mud content of the sediment and community composition related to mud (CAPmud). Sites used to derive the BH model are grey circles; data collected in October 2009, 2010 and 2011 are denoted by a closed triangle, closed circle and open triangle, respectively. Kaipara sites TPB, KKF, HCK, KaiF, NPC and KaiB are colored purple, orange, blue, red, green and black, respectively.

No consistent changes in community composition were found to be associated with contaminants at five of the six Kaipara sites (Table 5). At KaiB, CAPmetal scores increased slightly (negative values increased closer to zero), resulting in a decline in BH score (Hewitt et al. 2012) between 2009 and 2011, but continued to remain in a healthy state.

Table 5. CAPmetal scores for all sites over time, together with whether there is a consistent direction of change (Direction: Yes or No) and the % change relative to the model range is given. In addition, the BH scores of communities (1 = very healthy, 2 =good health) are also displayed in brackets.

	2009	2010	2011	Direction	% Change
TPB	-0.217 (1)	-0.104 (2)	-0.175 (1)	N	
KKF	-0.184 (1)	-0.203 (1)	-0.127 (2)	N	
HCK	-0.221 (1)	-0.132 (2)	-0.174 (1)	N	
KaiF	-0.168 (1)	-0.219 (1)	-0.105 (2)	N	
NPC	-0.204 (1)	-0.129 (2)	-0.188 (1)	N	
KaiB	-0.187 (1)	-0.182 (1)	-0.109 (2)	Y	15.67

TBI scores were calculated at all sites in October 2009-2011 using all available monitored and non-monitored taxa (Table 6; Hewitt et al. 2012; van Houte-Howes and Lohrer 2010; Lohrer and Rodil, 2011).

The index is based upon the richness of taxa in seven functional groups that are sensitive to increased levels of sediment mud and heavy metal contamination. Index values range between 0 and 1, with values close to 1 indicating pristine sites with high functional redundancy and good health. Communities with high functional redundancy (i.e., many species present in each functional trait group) will tend to have higher inherent resistance and resilience in the face of environmental changes, as the higher numbers of species per functional group provide "insurance" for stochastic or stress-induced losses of particular species. As a guide, TBI scores >0.4 indicate intermediate-to-good health, whereas scores <0.3 have intermediate-to-poor health.

TBI scores were relatively high across the sites (>0.4 in most cases, suggesting intermediate-to-good health). KaiB, the muddiest of the six sites, had slightly lower TBI scores (0.33 to 0.37). HCK had the lowest scores of all (0.25 to 0.29), though this is likely a reflection of the low overall richness at this site resulting from high rates of physical disturbance by wind waves (rather than a negative response to mud or metals).

Table 6. TBI scores for monitored communities sampled in October 2009-2011.

	2009	2010	2011
TPB	0.49	0.60	0.48
KKF	0.62	0.65	0.59
HCK	0.25	0.29	0.29
KaiF	0.38	0.37	0.45
NPC	0.40	0.35	0.43
KaiB	0.37	0.37	0.34

5.0 Recommendations

Since the initiation of the Kaipara Harbour Monitoring Programme, valuable information has been collected concerning intertidal sediment characteristics and benthic macrofaunal communities in southern Kaipara Harbour. As this programme is still in its early phases, it is not possible to make robust statements regarding temporal trends in the abundance of taxa. However, the majority of monitored populations do not show unpredictable patterns over the monitored period (Average 16%, Table 7). Over 50% of the monitored taxa across sites demonstrate seasonality or multi-year patterns or both. This bodes well for the ability of the programme to detect future trends in abundance.

Table 7. Summary of patterns in taxon abundances observed at Kaipara Harbour monitoring sites. S = seasonal, M = multi-year, L = low abundances, H = high unpredictable variation, total = number of monitored species found at each site.

	TPB	KKF	HCK	KAIF	NPC	KAIB	Average
S	35	21	9	25	25	14	22
M	6	11	18	0	6	14	9
S/M	24	16	27	38	13	14	22
L	18	16	36	38	44	36	31
H	18	37	9	0	13	21	16
Total	16	18	10	7	15	13	

Interestingly, there were strong differences between sites in the number of taxa with unpredictable variation (0–37%). Sites with high variability may prove not to be appropriate to retain within a long-term monitoring programme. However, with only 2.5 years of monitoring, it is possible that this unpredictable variation will be resolved in the future, particularly as among-site differences in community composition have been maintained.

Therefore, we recommend that, similar to the other ecological monitoring programmes run by Auckland Council, bi-monthly monitoring of all sites continues for at least the next 2 years. After that time, 5 years of data will have been collected and a robust analysis of the effectiveness of the monitoring programme can be conducted.

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8.0 Appendix 1

% sediment grain size (Gravel (G), coarse sand (CS), medium sand (MS), fine sand (FS) and mud (silt+clay)), % sediment organic content (OC) and chlorophyll *a* content at monitored sites between April 2010 and February 2012.

		% G	% CS	% MS	% FS	% Mud	% OC	Chlorophyll *a* (µg/g sediment)
TPB	Apr-10	0.10	0.05	8.02	90.94	0.89	0.53	6.42
	Jun-10	0.00	0.06	7.27	90.45	2.21	0.63	8.26
	Aug-10	0.00	0.04	6.90	90.98	2.07	0.72	6.65
	Oct-10	0.00	0.12	11.09	87.38	1.41	0.53	7.34
	Dec-10	0.02	0.09	26.52	72.48	0.89	0.60	2.41
	Feb-11	0.00	0.03	10.91	88.17	0.89	0.57	6.54
	Apr-11	0.05	0.12	7.67	91.20	0.97	0.59	4.07
	Jun-11	0.00	0.04	10.69	88.66	0.61	0.49	7.22
	Aug-11	0.00	0.07	8.12	91.17	0.63	0.70	6.19
	Oct-11	0.02	0.07	7.88	91.54	0.50	0.63	7.11
	Dec-11	0.00	0.05	8.74	90.69	0.52	0.45	5.79
	Feb-12	0.00	0.09	7.27	91.74	0.90	0.39	9.52
KKF	Apr-10	0.00	0.07	0.42	93.97	5.55	1.56	9.63
	Jun-10	0.00	0.04	0.47	93.66	5.83	1.28	12.04
	Aug-10	0.00	0.07	0.51	90.70	8.72	1.55	10.89
	Oct-10	0.00	0.01	0.33	96.86	2.80	0.81	8.60
	Dec-10	0.00	0.06	0.33	95.77	3.84	1.33	8.60
	Feb-11	0.00	0.05	0.37	95.81	3.77	1.11	9.17
	Apr-11	0.01	0.13	0.33	95.82	3.71	1.28	8.94
	Jun-11	0.00	0.03	0.29	97.50	2.18	0.79	9.06
	Aug-11	0.00	0.00	0.22	96.97	2.81	1.57	9.17
	Oct-11	0.03	0.07	0.21	98.40	1.29	1.23	11.12
	Dec-11	0.09	0.02	0.19	99.00	0.70	0.82	8.94
	Feb-12	0.40	0.13	0.34	94.01	5.12	0.68	13.53
HCK	Apr-10	0.00	0.01	0.70	98.32	0.98	0.68	8.37
	Jun-10	0.00	0.25	0.58	97.23	1.95	0.87	8.02
	Aug-10	0.00	0.07	0.56	97.89	1.48	0.79	6.65
	Oct-10	0.00	0.01	0.18	99.39	0.43	0.72	6.65
	Dec-10	0.01	0.04	0.39	98.79	0.78	0.90	7.91
	Feb-11	0.03	0.01	0.40	98.84	0.72	0.14	9.17
	Apr-11	0.02	0.12	0.49	98.66	0.71	0.84	9.29
	Jun-11	0.00	0.07	0.37	98.93	0.00	0.70	9.06
	Aug-11	0.00	0.05	0.17	99.19	0.59	1.38	9.63
	Oct-11	0.01	0.04	0.17	99.11	0.67	0.98	8.71
	Dec-11	0.00	0.01	0.49	99.14	0.37	0.57	7.68

		% G	% CS	% MS	% FS	% Mud	% OC	Chlorophyll *a* (µg/g sediment)
	Feb-12	0.00	0.01	0.45	98.84	0.71	0.48	15.36
KaiF	Apr-10	0.00	0.02	0.10	99.70	0.17	0.74	8.71
	Jun-10	0.00	0.06	0.71	98.89	0.33	0.57	12.61
	Aug-10	0.00	0.20	1.48	97.96	0.00	0.64	10.09
	Oct-10	0.00	0.06	0.64	98.97	0.34	0.52	9.86
	Dec-10	0.44	0.16	0.50	98.62	0.00	0.66	5.16
	Feb-11	0.00	0.05	0.14	99.51	0.31	0.60	6.76
	Apr-11	0.09	0.23	0.39	99.16	0.21	0.82	9.40
	Jun-11	0.00	0.03	1.24	98.61	0.00	0.70	11.35
	Aug-11	0.06	0.18	0.44	98.72	0.61	0.83	8.71
	Oct-11	0.00	0.11	0.21	99.33	0.35	0.78	10.66
	Dec-11	0.12	0.45	2.55	96.54	0.34	0.39	5.62
	Feb-12	0.00	0.11	0.30	99.38	0.20	0.44	9.63
NPC	Apr-10	1.10	0.10	0.08	95.76	2.96	0.92	6.42
	Jun-10	0.00	0.03	0.11	97.90	1.95	0.78	5.27
	Aug-10	0.72	0.00	0.03	97.37	1.88	0.58	5.04
	Oct-10	1.14	0.03	0.05	97.14	1.63	0.48	6.77
	Dec-10	0.25	0.02	0.01	97.89	1.82	0.87	3.27
	Feb-11	0.28	0.01	0.15	98.66	0.90	0.76	5.33
	Apr-11	0.13	0.07	0.10	94.90	4.81	1.08	6.99
	Jun-11	0.13	0.04	0.06	98.79	0.00	0.70	5.50
	Aug-11	0.00	0.00	0.06	98.84	1.10	0.93	5.22
	Oct-11	0.20	0.10	0.06	98.23	1.41	0.86	5.39
	Dec-11	0.92	0.01	0.02	98.35	0.71	0.48	4.99
	Feb-12	0.82	0.01	0.08	97.96	1.12	0.48	7.11
KaiB	Apr-10	0.00	0.10	0.28	84.53	15.09	1.75	7.56
	Jun-10	0.17	0.10	0.58	71.51	27.64	2.17	7.22
	Aug-10	0.00	0.01	0.53	84.13	15.33	1.32	5.50
	Oct-10	0.06	0.06	0.37	70.04	29.47	2.46	8.14
	Dec-10	0.00	0.06	0.49	78.90	20.55	2.36	6.42
	Feb-11	0.00	0.02	0.34	68.48	31.15	2.31	5.27
	Apr-11	0.34	0.14	0.41	85.49	13.62	1.84	6.42
	Jun-11	0.07	0.05	0.31	90.81	8.76	1.41	6.42
	Aug-11	0.95	0.11	0.46	89.19	9.29	1.77	6.08
	Oct-11	0.08	0.11	0.49	88.43	10.89	2.03	6.76
	Dec-11	0.68	0.03	0.63	91.10	7.56	1.13	6.76
	Feb-12	1.25	0.13	0.58	89.13	8.92	0.83	10.89