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Assessment of Biogenic Sand Production, Pakiri Embayment

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Cover Illustration: Seabed sandscape showing Biogenic shell lag (May 2014)

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1. INTRODUCTION

1.1 Biogenic Sand

Sands in the Pakiri – Mangawhai embayment are primarily quartzo-feldspathic (Schofield, 1970). The sands also contain varying amounts of carbonate, which is generally of biological origin. Biogenic sand is defined as the fraction of sand formed by dead marine biota, and is mostly composed of molluscs, echinoids, foraminifera and bryozoans (De Falco *et al*., 2017).

In order to provide input into a sand budget model, an assessment of the annual biogenic sand production in the Pakiri – Mangawhai embayment, has been calculated from population estimates of living shellfish in the benthic biota of the bay. The Pakiri – Mangawhai embayment has been defined for the purpose of this study, as from Bream Tail to Goat Island, based on these locations providing barriers, limiting but not excluding sand transport alongshore (Hume, 2005). The barriers are rocky reefs that extend from low tide, to at least 27m below mean sea level. The 25m below chart datum contour, which equates to 27m below mean sea level, was defined as the depth of closure during the previous consenting process in 2005 (Hilton, 1990; Healy, 1996; Hilton and Hesp, 1996) (Figure 1). All depths used henceforth in this report will be in reference to mean sea level.

The depth of closure (DOC) is an important concept used in coastal engineering as it defines the offshore extent of cross-shore sediment transport. The DOC is a theoretical depth along a beach profile where sediment transport is very small or non-existent. Its location is dependent on wave height and period, and occasionally, sediment grain size. More specifically, Kraus (1998) states that the "depth of closure for a given or characteristic time interval is the most landward depth seaward of which there is no significant change in bottom elevation and no significant net sediment transport between the nearshore and the offshore." Since the wave height and period change seasonally and over shorter time periods such as storm events, the DOC will theoretically change, this is supported by Nicholls *et al*. (1998), Dolbeth *et al.* (2007) and Carvalho *et al*. (2012). Therefore, rather than a specific or average depth, the DOC should be expressed as a depth range or transitional zone. The transport of material across this average DOC "boundary" is not precluded as the actual DOC would vary depending on wave conditions. Therefore, the additional area offshore of the 27m average DOC, covering 27 – 32m has been included as a separate area in the calculations of biogenic sand production.

1.2 Previous Studies

Hilton (1990) quantified the carbonate content of surficial sediments south of Te Arai Point. In the fine, very well sorted sands of the upper shoreface, Hilton reported the carbonate was only 2-5% of the total sample in depths less than 27m, however this increased to 20-30% in the area between the 27 – 32m depth contours. Hilton determined that the carbonates consisted mostly of fragments of benthic macrofauna of molluscan origin. Based on the benthic biota data collected in the embayment since 1990 (ASR, 2003, 2006, Bioresearches, 1993, 2011, 2016, 2017, 2019a,b, Grace 1991, 2005) this has not changed with molluscs still dominating the biota.

Hilton (1990), by integrating data from trawls, was able to estimate the total mass of live shell material in the surficial seabed sediments (the top 10-15 cm in this case). He reported an average concentration of shell of 97g/m².

Hilton (1990) assumed that for a shellfish species of a 10-year life expectancy, 10% of the population would die every year and the shell becomes part of the biogenic sand. This assumes a constant population size, and that recruitment and mortality were constant, which they are generally not. It also appears that he assumed all shellfish had a similar life span, which is also not a valid assumption. His assumptions were based on the information available in 1990, greater information on life span is now available but the population size, mortality and recruitment are still not well understood. Based on these assumptions, he calculated that the existing weight of shell material, 5,300 tonnes, would increase to 73,000,000 tonnes after 100 years. This calculation was incorrect. Hilton mistakenly added the dead shell material back to the live shell material each year for a compounding recalculation of dead shell production over the 100-year time frame. This process grossly overestimated the production of dead shell material over time. Based on his assumptions the live shellfish population was not expected to change year to year therefore the production should be the same each year. Even if the shellfish population varied in size between years the expected dead shell production would not approach the tonnage Hilton calculated. Correcting Hiltons dead shell production calculation overtime, results in an annual shell material production of 530 tonnes, translating to 482m³/year assuming shell material has a density of 1.1Mg/m³. Hume *et al.* (1999) suggests these values cover half the bay and should be doubled to a corrected value of 964m³/year, which is considerably less than that Hilton reported in 1990 of 900,000m³/year.

The NIWA sand study (Hume *et al*., 1999) considered Hilton's original shell production value of 900,000m³/year erroneous and suggested biogenic sand production was less than 12,000m³/year based on a sediment budget. Barnett in his 2005 environment court evidence suggested it should be near 90,000m³/year. Neither of the latter estimates of Barnett or NIWA were based on biological science. Hilton's (1990) corrected estimate of 964m³/year is based on actual biological production but was subject to invalid assumptions which could have resulted in greater production. None of the studies have measured annual variation in production or the effects of long-term ecological changes such as species loss on production.

1.3 Current Study

This assessment is based on the fauna abundance data collected as part of the assessment of effects of sand extraction from the McCallum Bros Ltd (MBL) consented areas in, and from areas further offshore in 2019 (Bioresearches, 2019a,b); from the assessment of effects of the Auckland Offshore sand extraction by Kaipara Limited in 2017 (Bioresearches, 2017); and from an intertidal seafood resources survey for Auckland Regional Council in 1993 (Bioresearches, 1994). In addition, growth rate equations were obtained from New Zealand and international literature. This estimation can be added to that of the non-biogenic sand (i.e. from river, shore and cliff) to make the total sediment input to the budget of the bay.

The study is initially based on the previously accepted enclosed embayment model with a DOC at 27m below mean sea level. It excludes the Mangawhai estuary as a biogenic sand source as estuaries are considered to be sediment "sinks" rather than sources. In addition to the predefined DOC embayment area, an area offshore has been added to the assessment for biogenic sand production, as have rocky shore habitats not previous assessed, and the results provided for each individual area.

MBL has a current consent to extract a maximum allowance of 76,000m³/year of sand in consent defined extraction areas as shown in pink in Figure 1 and Figure 2 within a nominal water depth range of 7 to 12m. If the consent is to be renewed, the assessment of biogenic sand production will likely form part of the assessment determining a suitable volume of sand for extraction.

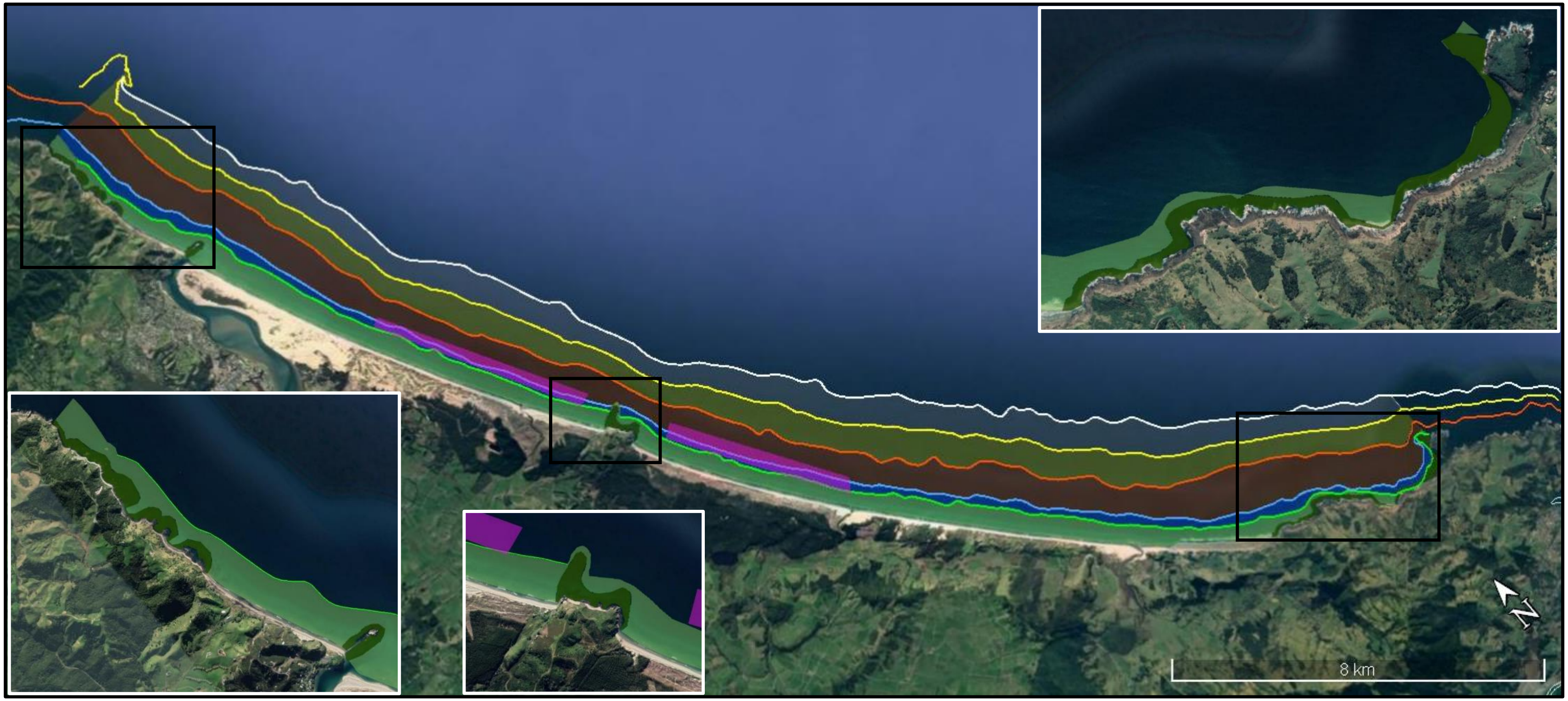

Figure 1 Pakiri – Mangawhai embayment with bathymetry mean sea level contours (light green: 7m; blue: 12m; orange: 22m; yellow: 27m; white 32m), the extent of the areas within these contours, and the extraction areas (in pink). The surface considered for the rocky shore is presented in dark green in the three inserts. Map produced with Google Earth 2019 ©.

2. METHODS

The annual biogenic sand production has been estimated following four major steps:

a) The estimation of densities of benthic biota taxa in number per $100m^2$
b) The estimation of the shell weight in $g/100m^2$
c) The estimation of the annual shell production (growth) in $g/100m^2$ /year
d) The extrapolation of the 3 parameters above for each area and for the whole bay

2.1 Density of benthic biota taxa

The most recent assessment of benthic biota in the Pakiri – Mangawhai embayment, was conducted in early 2019 and used two sampling methods to determine its relative abundance and diversity:

1. **Benthic Infauna:** this involved the collection of 117 samples of benthic biota with a box dredge (18cm wide to a depth of approximately 5-10cm, for a length of approximately 90cm) in a pattern uniformly distributed from the shore to the 27m bathymetric contour on each side of Te Arai point, following a sampling design by Dr Grace. Sample locations are shown in Figure 2 as white squares. Subsamples were screened through a 1mm mesh sieve, and the total sample through a 3.15mm mesh sieve. The 1mm screened samples consisted mostly of polychaetes, amphipods and isopods (Bioresearches 2019a), which are considered a minor source for sand formation. Polychaetes have no calcareous part and small arthropods have a fragile chitin exoskeleton, which would degrade quickly, thus not contributing significantly to biogenic sand production. Therefore, only the 3.15mm screened samples, which contained molluscs and echinoderms, were considered for the biogenic sand production calculation.
2. **Benthic Epifauna:** this involved 33 (65cm wide) variable length dredge tows targeting different depths (white thick lines in Figure 2). The dredge was fitted with a 15mm square mesh bag, thus retained larger biota, the majority of which were molluscs and benthic arthropods, for which the individual lengths were measured.

Analyses of benthic biota showed little difference in community composition and densities between the area north of Te Arai point and the area south of Te Arai point (Bioresearches 2019a, b), but revealed significant differences between inshore (< 12m depth) areas and deeper ones, highlighting the importance of depth in shaping the benthic community composition. Based on these results, biota samples were separated into three depth defined areas, 7 to 12m, 12 to 22m and 22 to 27m, then used to estimate the production of biogenic sand in each area, and the calculations subsequently combined to assess sand production at the level of the whole Pakiri – Mangawhai embayment.

The current 2019 study did not sample from much less than 7m depth. It is known from historical studies (Bioresearches, 1994, 2016) that this 0 – 7m zone has potentially high numbers of some taxa which are not present in deeper waters, such as the tuatua *Paphies subtriangulata*. In addition, rocky shores are present north and south of the embayment, and at Te Arai Point, with gastropod communities different from the rest of the Bay which is dominated by soft sediment. Therefore, the 0 – 7m depth zone has been included and the historical data used to define densities of taxa present. The first historical study relevant to the surf zone of Pakiri Beach and the rocky shore is the assessment of intertidal seafood resources in 1993 where quantitative sampling of edible seafood was carried out at every kilometre along the beach (Bioresearches, 1994). Sample sites are marked as yellow diamonds in Figure 2. The second historical study is the assessment of the benthic ecology along the Hawaiki submarine cable route project landing on the northern part of the Pakiri – Mangawhai embayment (Bioresearches, 2016). Subtidal benthic biota was assessed by grab sampling and tow sampling at regular depths along the cable route. The grab samples only provided qualitative information on biota (presence, not densities) at regular depths, as there were only up to three samples per bathymetry area, and this was considered insufficient to represent the quantity of clumped-distributed species such as molluscs.

While the DOC of the Pakiri – Mangawhai embayment was defined as the 27m depth contour in the 2005 environment court hearing, this does not totally, preclude transport of material across this depth contour as this theoretical boundary is likely the midpoint of a transitional depth range across which limited on-offshore transport intermittently occurs. Therefore, the biogenic sand production from the 27m – 32m depth contours has also been calculated. The samples collected in this area were from three different methods (Table 1): 20 box dredge samples were collected during the 2019 inshore-midshore survey detailed previously (Bioresearches, 2019b). In addition, 31 grab samples were collected with a Ponar grab sampler (229 x 229 mm), and 8 dredge tow samples were also available from a previous study in 2017 (Bioresearches, 2017) orange squares and lines in Figure 2). Data sets from the three samples methods were combined, and the highest average density from either method was retained for each taxon in each depth-defined area.

The four studies use differing sampling methods and also sampled different faunal populations as represented by the differing composition of biota. Therefore the biogenic sand production calculation was based on a combination of the methods, providing representation of all major contributors of sand production. When the data sets were combined, the highest average density from either method was retained for each taxon in each depth-defined area.

The surface area for each of the five areas (0 to 7m, 7 to 12m, 12 to 22m, 22 to 27m, and 27 to 32m) was calculated by defining a polygon constrained by the bathymetry contours relative to mean sea level defined from the Land information New Zealand chart NZ3000522 in Google Earth. The extent of the bay was constrained in the north, to a line between Bream Tail and McGregor Rock, and in the south to a line north from the northern point of Goat Island. A 27m bathymetry contour was interpolated from the 22 and 32m contours using QGIS software. Table 1 presents the surface of each area and identifies the samples collected in each area. The embayment as described has a total surface area of 55,246,242m² to the 27m contour, or 71,064,438m² to the 32m contour.

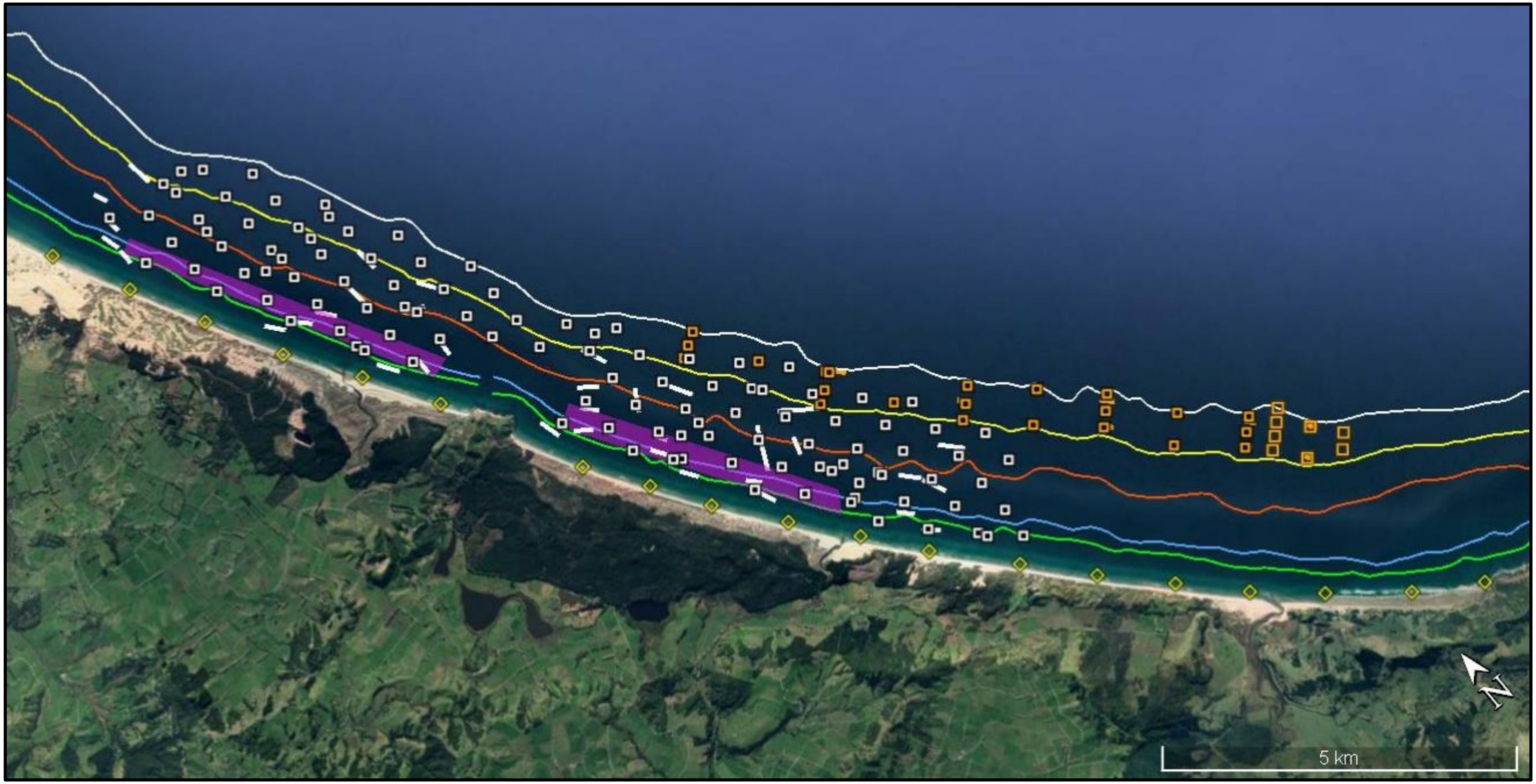

Figure 2 Pakiri – Mangawhai embayment with bathymetry contours, benthic infauna samples and epifauna tows. Map produced with Google Earth 2019 ©.

Key

bathymetry contours (green: 5m; blue: 10m; orange: 20m; yellow: 25m; white: 30m)

benthic infauna samples (white squares: 2019 box dredge samples; Orange squares: 2017 grab samples; yellow diamonds: 1993 quadrats)

epifauna dredge tows (white lines: 2019 samples; orange lines: 2017 samples)

The sand extraction areas are shaded in pink.

Table 1 Benthic samples used to determine the number, weight and growth of biota for biogenic sand calculation.

Area		Rocky shore	0 – 7m depth	7m - 12m depth	12m - 22m depth	22m - 27m depth	27m – 32m depth
Surface (m^2)		1,011,139 m^2	11,549,658 m^2	5,754,054 m^2	20,968,451 m^2	16,558,156 m^2	15,818,196 m^2
Infauna (Box dredge)	**Sample codes (PIB)**	-	-	1, 4, 5, 11, 18, 19, 27, 39, 44, 45, 46, 62, 68, 75, 82, 88, 94, 100, 114	2, 3, 8, 9, 10, 16, 17, 25, 26, 32, 33, 52, 53, 54, 60, 61, 66, 67, 73, 74, 80, 81, 86, 87, 92, 93, 101, 103, 104, 105, 106, 108, 111, 117, 121	6, 7, 13 to 15, 22 to 24, 30, 31, 36 to 38, 42, 43, 50, 51, 57 to 59, 64, 65, 70 to 72, 78, 79, 84, 85, 90, 91, 95, 96, 102, 107, 112, 115, 116, 119, 120	12, 20, 21, 28, 29, 34, 35, 40, 41, 49, 56, 63, 69, 76, 77, 83, 89, 110, 113, 118
	Total (year sampled)	**-**	**-**	**19** (2019)	**35** (2019)	**40** (2019)	**20** (2019)
Infauna (grab sample)	**Sample codes**	-	Extrapolated from historical studies (see text)	-	-	-	TN(W), T0(W, 0, 1), T1(W), T2(W, 0, 1), T3(W), T4(0, 1, 2), T5(W,M), T6(1, 2, 3), T7(W, M), T8(1, 2, 3), T9(1, 2, 3, 4), TC(M, W), T10(1, 2)
	Total (year sampled)	-		**-**	**-**	**-**	**31** (2017)
Epifauna (Tow dredge)	**Tow codes**	-	-	22 to 35	8, 9, 11 to 21	1 to 7, 10	T2A, T4A, T6A, T6B, T8A, T8B, TCA, TCB
	Total (year sampled)	**-**	**-**	**14** (2019)	**13** (2019)	**8** (2019)	**8** (2017)
Intertidal seafood	**Sample codes**	7, 21 to 24	1 to 6, 8 to 20				
	Total (year sampled)	**5** (1993)	**19** (1993)				

The surface area sampled by the infauna box dredge was assumed to be relatively constant between samples and estimated to be 0.162m² based on a width of 0.18m and a tow length of approximately 0.9m. The length of each epifauna dredge tow was more variable and calculated surfaces are displayed in Table A 1. The surface area sampled by the infauna grab sampler was calculated as 0.05m² based on a length of 0.229m either side. The biota data from all sampling methods were tabulated, and abundance standardised to numbers per 100m².

Previous analyses of the 94 infauna box dredge samples (3.15mm size mesh) within the 27m depth contour found a total of 104 taxa (Table A 2). To simplify the calculation of shell growth, the original number of taxa was reduced following two steps:

- The taxa with little or no "shell" component (grey text in Table A 2) were discarded for the shell weight and gross calculation.
- The species with a significant "shell" part but with no information on weight and growth, were combined to a higher taxonomic level for which equations from the international literature existed.

Previous analyses of the 35 epifauna dredge tow samples within the 27m depth contour found a total of 29 taxa (Table A 3). Like the infauna samples, the number of taxa were reduced by eliminating those with little or no "shell" component, and in addition, those taxa for which only one individual over the 35 tows were recorded.

Historical intertidal data at Pakiri found tuatua *P. subtriangulata* to be common all along the beach (Table A 4) (Bioresearches 1994). The average density and size of *P. subtriangulata* were used for the estimation of biogenic sand production in the 0 to 7m area. During the study along the Hawaiki cable route (Bioresearches, 2016), two samples of benthic biota were collected within the 7m depth zone: a benthic grab sample at 4m depth, and a 100m long dredge tow centred on the grab sampling location. The sand dollar *Fellaster zelandiae* was found in both samples, while the paddle crab *Ovalipes catharus* was only present in the tow sample. Densities of these two species for the 0 to 7m zone were extrapolated from the densities calculated from the 7 to 12m area. The wheel shell *Zethalia zelandica* was added to the densities of tuatua, paddle crabs and sand dollars, as its distribution is common in shallow depths of soft-bottomed systems and can have dense beds (Hayward & Morley, 2004). Its distribution is clumped thus the high probability of being missed by the 4m grab sample along the cable route.

For the area 27m to 32m with three different types of samples, reduction of taxa followed the same steps as above (removal of taxa with little or "no shell" component and grouping of taxa with one individual only for the whole dataset). The original taxa are presented in Table A 5 (grab samples), Table A 6 (tow samples) and Table A 7 (box samples).

2.2 Shell weight

Of those taxa identified as present in sufficient density, estimates of shell weight /100m² were calculated from individual green weights[1] for each retained taxon. Individual green weights were estimated from the average length measured from tow samples using length-weight equations from the literature (Table A 8). The paddle crab *O. catharus*, the bivalves *Dosinia subrosea*, *Perna canaliculus* and *P. subtriangulata*, and the urchin *Evechinus chloroticus* were the only species with specific information from New Zealand. The green weights of other species found in the Pakiri – Mangawhai embayment samples were estimated from

[1] The weight of fish, aquatic life, or seaweed before any processing commences and before any part is removed.

equations of related species from same genera or families (Table A 8). When taxa had no measured length associated (*i.e.* only collected in box dredge samples), the maximum length found in the literature was used.

2.3 Annual Growth rate shell production

The production of green weight per year was estimated by using taxa specific growth curves from the literature. In most cases, the growth curves correlate age (year) with length (mm), not weight. Therefore, individual lengths at different ages were first calculated with growth equations, then converted to green weight using length-weight equations. Individual growth rates (weight gained per year) were calculated by subtracting the green weights between two consecutive ages. They were averaged to make an average individual green weight growth.

The estimated individual green weight growth was then converted to an individual shell weight growth by applying an estimated percentage of shell weight to green weight (see note 3 in Table A 8). The term “shell” here is not limited to the shell calcium carbonate of molluscs but is also used as a general term for the chitin of arthropods, the test of echinoderms, and the notochord of cephalochordates.

Finally, the individual shell weight growth was multiplied by the number of individuals per 100m^2 to calculate annual shell weight growth in g /100m^2 per year for each taxon.

The methodology presented above uses the average length of each taxon to calculate weight, and the average growth rate over the life span of the animal. However, growth rate can change significantly through life with a rapid growth in the first years and a slow growth when animals reach maturity. Here, the average length of each taxon was used as one age cohort only. Ideally, age-specific growth rates would be used on an age distribution, but for most taxa, growth-specific information was not available. Therefore, the estimation of biogenic production from non-specific averaged growth rates has uncertainties which could not be quantified. In order to check the magnitude of the calculated biogenic production, another method was used by using maximum biomass and maximum age for each taxon and is described below.

2.4 Population mortality shell production

An alternative methodology employed in part by Hilton in 1990, relies on a percentage of the population, based on the maximum age of each taxon, dying each year. This method assumes that recruitment will be the same each year, and that mortality will only occur at maximum age. Both of these assumptions are not likely to be met as such population data is not generally available for the taxon included in this study. However, if these assumptions were true then the production can be given by the equation below, where *p*= annual shell production; w_i = the weight of the maximum length for the i^{th} taxon (calculated using the length-weight equations from the literature); d_i = the population density (No./100m^2) for the i^{th} taxon; a_i = the maximum age for the i^{th} taxon; and *N* = the total number of taxa in the sample.

$$p = \sum_{i=1}^{i=N} \frac{(w_i \times d_i)}{a_i}$$

If the assumption of zero juvenile mortality is not met, then this method would overestimate the shell production as fewer individuals will reach maximum size. If the assumption of equal recruitment is not met, then the production will vary between years leading to both over and underestimations. If more detailed information were available on size specific mortality, then the calculation could be modified to reflect this. Similarly, if the variation in recruitment were known then production could be expressed as a range. The method also assumes no variation in growth rates between individuals. Growth rates do vary between individuals as commonly shown by population size frequency plots, in which older age cohorts tend to have a wider size range spread, than younger age cohorts.

The maximum age of a taxon is required for this calculation method, and this basic information is not currently known for many species. Hilton assumed that all biota lived to 10 years of age, which is now known not to be valid. Thus, if taxon were shorter lived than 10 years his method underestimated mortality biomass production. Hilton also used the average population size rather than maximum size in his calculation of the mortality biomass. Again, this will have underestimated the mortality biomass production. This study has used more taxa specific maximum age and size estimates than employed in Hilton (1990) and is therefore a better reflection of actual production.

2.5 Shell production for the Pakiri – Mangawhai embayment

To determine the annual shell production for depth defined areas the equation below was used. Here, P = total production of shell per year (Mg) for the embayment as defined to the 27m depth contour; G_i = the annual shell weight growth (g/100m²/yr) for the i^{th} taxon; SA = the surface area of the depth-defined area; and N = the total number of taxa in the area. The production from the adjacent deeper 27 - 32m area has also been calculated separately to allow its inclusion if it is determined as relevant based on the wave climate.

$$P = \sum_{i=1}^{i=N} \frac{(G_i \times SA)}{100}$$

To convert shell production from weight to volume (m³) the density of the shell material is required. The literature suggests compacted shell density ranges between about 1.1Mg/m³ and 1.4Mg/m³ depending on the species (Eziefula *et al*., 2018, Mo *et al.*, 2018). A previous study by NIWA on sand budget in the bay assumed a shell density of 1.6Mg/m³ (Hume *et al*., 1999), however this was not substantiated. A range of values between 1.1 to 1.4Mg/m³ has been used to provide estimates of the likely range in the volume of biogenic sand produced.

3. RESULTS

3.1 Density of benthic biota taxa

Table A 2 to Table A 7 in the appendices, summarise the original number of taxa and individuals found in the soft sediment, and on the rocky shore. After the reduction of taxa to those likely to produce carbonate shell content, numbers were converted to densities per $100m^2$. The data from the infauna and epifauna surveys were then pooled and separated into habitat type and depth-defined areas. Table 2 to Table 7 provide summaries of data divided by habitat and depth range.

For taxa appearing in both the infauna and epifauna surveys, the data from the survey with the highest density was retained. This was always the box dredge infauna method. However, the epifauna method recorded some taxa not found in the infauna survey, and similarly the reverse also occurred.

Each of these tables consists of two parts: the first, defined by white heading text, is based on the annual growth rate calculations. The second, defined by yellow heading text, is based on the population mortality calculation method.

3.2 Weight and shell production

For the annual growth rate part (blue heading white text) of Table 2 to Table 7, each table is divided by thicker lines into three sections across the table;

a) Left: This covers population density and average length.
b) Middle: This uses formula to estimate green weight based on length, then applies an estimate of percentage shell and density to calculate shell weight per area.
c) Right: This summarises the results of calculations for annual shell growth

The length-weight equations and growth rate equations used for each taxon are listed in Table A 8.

For the mortality part (blue heading yellow text) of Table 2 to Table 7, each table is divided by thicker lines into three sections across the table;

a) Left: This covers population density and maximum size.
b) Middle: This uses formula to estimate green weight based on maximum length, then applies an estimate of percentage shell and density to calculate shell weight of maximum-sized individual per area.
c) Right: This presents a maximum age per taxa and calculates annual weight of shell released by mortality.

Table 8 presents the area of each habitat and depth area and summarises the shell production data from both methods. A total weight of shell production from each method for the entire Pakiri – Mangawhai embayment to the predefined 27m below mean sea level DOC, is presented as bold red numbers. The bold italic red numbers show the range of total volume produced per year by each method. The row of blue numbers at the bottom represent the area 27m – 32m depth, located just offshore of the DOC to the embayment.

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Table 2 Weight and growth estimated for the rocky shore area 0m – 7m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(g/y)	(g/y)	(g/100m²/y)
Gastropods	*Nerita melanotragus*	10680	quadrat	16	0.4	85	0.34	3631	0.94	0.80	8533
	Cellana ornate	5567	quadrat	18	0.4	70	0.28	1559	0.94	0.66	3663
	Cellana radians	3240	quadrat	26	0.7	70	0.49	1588	0.94	0.66	2132
	Lepsiella scobina	42625	quadrat	15	0.4	85	0.34	14493	3.69	3.14	133693
	Melagraphia aethiops	4767	quadrat	15	3.0	85	2.55	12155	0.94	0.80	3809
	Turbo smaragdus	4400	quadrat	26	4.0	85	3.40	14960	0.94	0.80	3516
	Cookia sulcata	1450	quadrat	58	14.0	85	11.90	17255	0.94	0.80	1159
	Haustrum haustorium	550	quadrat	41	5.3	85	4.51	2478	10.00	8.50	4675
	Thais orbita	3750	quadrat	41	5.3	85	4.51	16894	20.00	17.00	63750
Bivalves	*Perna canaliculus*	3100	quadrat	69	32.0	65	20.80	64480	10.00	6.50	20150
Echinoderms	*Evechinus chloroticus*	3125	quadrat	60	65.0	20	13.00	40625	9.00	1.80	5625
Arthropods	*Leptograpsus variegatus*	1800	quadrat	-	5.0	20	1.00	1800	0.50	0.10	180
Total		**85054**						**191919**			**250885**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(y)	(g/100m²/y)
Gastropods	*Nerita melanotragus*	10680	quadrat	30	1.1	85	0.94	9986	6	1664
	Cellana ornate	5567	quadrat	50	2.0	70	1.40	7793	6	1299
	Cellana radians	3240	quadrat	50	2.0	70	1.40	4536	6	756
	Lepsiella scobina	42625	quadrat	34	7.8	85	6.63	282604	9	31400
	Melagraphia aethiops	4767	quadrat	30	7.1	85	6.04	28767	6	4794
	Turbo smaragdus	4400	quadrat	91	100.0	85	85.00	374000	8	46750
	Cookia sulcata	1450	quadrat	119	117.0	85	99.45	144203	8	18025
	Haustrum haustorium	550	quadrat	65	30.4	85	25.84	14212	8	1777
	Thais orbita	3750	quadrat	110	200.0	85	170.00	637500	8	79688
Bivalves	*Perna canaliculus*	3100	quadrat	160	110.0	65	71.50	221650	4	55413
Echinoderms	*Evechinus chloroticus*	3125	quadrat	160	230.0	20	46.00	143750	15	9583
Arthropods	*Leptograpsus variegatus*	1800	quadrat	50	10.0	20	2.00	3600	4	900
Total		**85054**						**1872604**	**7 (mean max. age)**	**252050**

Table 3 Weight and growth estimated for the Sandy area 0m – 7m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(g/y)	(g/y)	(g/100m²/y)
Arthropods	*Ovalipes catharus*	130	Box	37	11.4	20	2.28	296	69.00	13.80	1794
Gastropods	*Zethalia zelandica*	9617	Box	10	2.0	80	1.60	15387	0.94	0.75	7232
Bivalves	*Paphies subtriangulata*	1244	quadrat	28	15.0	65	9.75	12129	0.20	0.13	162
Echinoderms	*Fellaster zelandiae*	422	Box	47	10.0	90	9.00	3798	3.10	2.79	1177
Total		**11413**						**31610**			**10365**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(y)	(g/100m²/y)
Arthropods	*Ovalipes catharus*	130	Box	130	378.0	20	75.60	9825	4	2456
Gastropods	*Zethalia zelandica*	9617	Box	26	6.0	80	4.80	46162	6	7694
Bivalves	*Paphies subtriangulata*	1244	quadrat	80	74.0	65	48.10	59836	5	11967
Echinoderms	*Fellaster zelandiae*	422	Box	100	18.0	90	16.20	6836	10	684
Total		**11413**						**122659**	**6 (mean max. age)**	**22801**

Table 4 Weight and growth estimated for the Sandy area 7m – 12m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m^2		(mm)	(g)	%	(g)	(g/100m^2)	(g/y)	(g/y)	(g/100m^2/y)
Arthropods	*Pagurus setosus*	65	box	9	0.2	20	0.04	3	0.30	0.06	4
	Ovalipes catharus	130	box	24	3.4	20	0.68	88	69.0	13.80	1793
	other arthropods	487	box	10	0.3	20	0.06	29	0.30	0.06	29
Gastropods	*Cominella adspersa*	3	tow	35	5.3	80	4.24	11	3.69	2.95	8
	Zethalia zelandica	9617	box	10	2.0	80	1.60	15387	0.94	0.75	7232
	Amalda australis	227	box	30	3.3	80	2.64	600	3.69	2.95	671
	other gastropod	97	box	25	2.0	80	1.60	156	2.77	2.22	216
Bivalves	*Myadora* spp.	162	box	28	9.0	50	4.50	731	3.50	1.75	284
	Dosinia subrosea	227	box	40	30.0	65	19.50	4435	7.00	4.55	1035
Echinoderms	*Fellaster zelandiae*	422	box	47	8.0	90	7.20	3041	3.10	2.79	1178
	Amphiura sp.	2	tow	80	5.0	90	4.50	7	1.50	1.35	2
	Astropecten polyacanthus	6	tow	130	16.0	90	14.40	82	3.10	2.79	16
Chordates	*Epigonichthys hectori*	422	box	40	0.3	20	0.06	25	0.20	0.04	17
Total		**11867**						**24595**			**12485**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m^2		(mm)	(g)	%	(g)	(g/100m^2)	(y)	(g/100m^2/y)
Arthropods	*Pagurus setosus*	65	box	15	10.0	20	2.00	130	4	32
	Ovalipes catharus	130	box	130	378.0	20	75.60	9825	4	2456
	other arthropods	487	box	15	10.0	20	2.00	975	4	244
Gastropods	*Cominella adspersa*	3	tow	65	32.0	80	25.60	67	9	8
	Zethalia zelandica	9617	box	26	6.0	80	4.80	46160	6	7693
	Amalda australis	227	box	40	7.8	80	6.24	1419	9	142
	other gastropod	97	box	44	15.0	80	12.21	1190	8	149
Bivalves	*Myadora* spp.	162	box	42	30.0	50	15.00	2437	11	244
	Dosinia subrosea	227	box	57	68.0	65	44.20	10052	11	1005
Echinoderms	*Fellaster zelandiae*	422	box	100	18.0	90	16.20	6842	10	684
	Amphiura sp.	2	tow	80	5.0	90	4.50	7	15	0
	Astropecten polyacanthus	6	tow	200	20.0	90	18.00	103	15	7
Chordates	*Epigonichthys hectori*	422	box	80	1.0	20	0.20	84	8	11
Total		**11867**						**79291**	**9 (mean max. age)**	**12578**

Table 5 Weight and growth estimated for the Sandy area 12m – 22m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(g/y)	(g/y)	(g/100m²/y)
Arthropods	*Pagurus setosus*	194	box	16	0.8	20	0.15	29	0.30	0.06	12
	Crabs other than *Ovalipes*	282	box	15	0.9	20	0.18	51	1.00	0.20	56
	other arthropods	317	box	10	0.3	20	0.06	19	0.30	0.06	19
Gastropods	*Zethalia zelandica*	53	box	10	2.0	80	1.60	85	0.94	0.75	40
	Sigapatella tenuis	247	box	5	0.01	50	0.005	1	0.10	0.05	12
	Austrofusus glans	1	tow	33	4.4	80	3.54	4	3.69	2.95	3
	Cominella adspersa	176	box	29	3.0	80	2.42	426	3.69	2.95	521
	Amalda spp.	141	box	25	2.0	80	1.56	220	3.69	2.95	417
	Struthiolaria papulosa	2	tow	60	25.9	80	20.70	34	3.69	2.95	5
	other gastropods	229	box	37	6.2	80	4.96	1137	3.69	2.95	677
Bivalves	*Myadora* spp.	1728	box	23	5.0	50	2.50	4321	3.50	1.75	3025
	Dosinia subrosea	88	box	25	10.0	65	6.50	573	7.00	4.55	401
	Nucula nitidula	494	box	13	0.2	50	0.10	49	0.10	0.05	25
	Glycymeris modesta	35	box	26	6.3	65	4.11	145	1.44	0.94	33
	Atrina zelandica	1	tow	45	8.7	65	5.68	4	12.60	8.19	6
	Gari convexa	459	box	25	0.5	65	0.33	152	1.43	0.93	426
Echinoderms	*Fellaster zelandiae*	212	box	47	8.0	90	7.20	1524	3.10	2.79	590
	Astropecten polyacanthus	9	tow	125	16.0	90	14.40	136	3.10	2.79	26
Total		**4668**						**8910**			**6294**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m²		(mm)	(g)	%	(g)	(g/100m²)	(y)	(g/100m²/y)
Arthropods	*Pagurus setosus*	194	box	15	10.0	20	2.00	388	4	97
	Crabs other than *Ovalipes*	282	box	100	200.0	20	40.00	11287	4	2822
	other arthropods	317	box	15	10.0	20	2.00	635	4	159
Gastropods	*Zethalia zelandica*	53	box	26	6.0	80	4.80	254	6	42
	Sigapatella tenuis	247	box	5	0.0	50	0.01	1	6	0
	Austrofusus glans	1	tow	65	32.0	80	25.60	26	9	3
	Cominella adspersa	176	box	65	32.0	80	25.60	4515	9	502
	Amalda spp.	141	box	40	7.8	80	6.24	880	9	98
	Struthiolaria papulosa	2	tow	65	32.0	80	25.60	42	9	5
	other gastropods	229	box	52	22.0	80	17.57	4028	9	448
Bivalves	*Myadora* spp.	1728	box	42	30.0	50	15.00	25926	11	2357
	Dosinia subrosea	88	box	57	68.0	65	44.20	3898	11	354
	Nucula nitidula	494	box	13	0.2	50	0.10	49	8	6
	Glycymeris modesta	35	box	26	5.0	65	3.25	115	10	11
	Atrina zelandica	1	tow	300	88.0	65	57.20	40	15	3
	Gari convexa	459	box	58	4.0	65	2.60	1192	8	149
Echinoderms	*Fellaster zelandiae*	212	box	100	18.0	90	16.20	3429	10	343
	Astropecten polyacanthus	9	tow	200	20.0	90	18.00	170	15	11
Total		**4668**						**56875**	**9 (mean max. age)**	**7411**

Table 6 Weight and growth estimated for the area Sandy 22m – 27m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Individual growth	Individual shell growth	Shell growth
		No. /100m^2		(mm)	(g)	%	(g)	(g/100m^2)	(g/y)	(g/y)	(g/100m^2/y)
Arthropods	*Pagurus setosus*	633	box	13	0.6	20	0.12	76	0.30	0.06	38
	Crabs other than *Ovalipes*	201	box	15	0.9	20	0.18	37	1.00	0.20	40
	other arthropods	340	box	10	0.3	20	0.06	20	0.30	0.06	20
Polyplacophora	*Leptochiton* sp.	93	box	10	0.1	50	0.05	5	0.30	0.15	14
Gastropods	*Stiracolpus pagoda*	170	box	24	0.5	80	0.40	68	1.00	0.80	136
	Sigapatella tenuis	293	box	5	0.01	50	0.003	1	0.10	0.05	15
	Cominella quoyana	355	box	21	1.16	80	0.93	329	3.69	2.95	1048
	Amalda spp.	154	box	25	2.0	80	1.56	241	3.69	2.95	456
	other gastropods	556	box	28	2.7	80	2.18	1209	0.20	0.16	89
Bivalves	*Myadora* spp.	401	box	23	5.0	50	2.50	1003	3.50	1.75	702
	Dosinia subrosea	247	box	25	10.0	65	6.50	1605	7.00	4.55	1123
	Nucula nitidula	509	box	13	0.2	50	0.10	204	0.10	0.05	25
	Glycymeris modesta	31	box	26	6.3	65	4.11	127	1.44	0.94	29
	Gari convexa	340	box	25	0.5	65	0.33	113	1.43	0.93	316
Echinoderms	*Amphiura* sp.	123	box	80	5.0	90	4.50	556	1.50	1.35	167
Chordates	*Epigonichthys hectori*	201	box	40	0.3	20	0.06	12	0.20	0.04	8
Total		**4647**						**6322**			**4226**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m^2		(mm)	(g)	%	(g)	(g/100m^2)	(y)	(g/100m^2/y)
Arthropods	*Pagurus setosus*	633	box	15	10.0	20	2.00	1265	4	316
	Crabs other than *Ovalipes*	201	box	100	200.0	20	40.00	8025	4	2006
	other arthropods	340	box	15	10.0	20	2.00	679	4	170
Polyplacophora	*Leptochiton* sp.	93	box	30	4.0	50	2.00	185	15	12
Gastropods	*Stiracolpus pagoda*	170	box	24	0.5	80	0.40	68	3	23
	Sigapatella tenuis	293	box	5	0.01	50	0.01	1	6	0
	Cominella quoyana	355	box	21	1.2	80	0.96	341	9	38
	Amalda spp.	154	box	40	7.8	80	6.24	963	9	107
	other gastropods	556	box	43	13.4	80	10.75	5970	7	853
Bivalves	*Myadora* spp.	401	box	42	30.0	50	15.00	6019	11	547
	Dosinia maoriana	247	box	57	68.0	65	44.20	10914	11	992
	Nucula nitidula	509	box	13	0.2	50	0.10	51	8	6
	Glycymeris modesta	31	box	26	5.0	65	3.25	100	10	10
	Gari convexa	340	box	58	4.0	65	2.60	883	8	110
Echinoderms	*Amphiura* sp.	123	box	80	5.0	90	4.50	556	15	37
Chordates	*Epigonichthys hectori*	201	box	80	1.0	20	0.20	40	8	5
Total		**4647**						**31497**	**8 (mean max. age)**	**4580**

Table 7 Weight and growth estimated for the Sandy area 27m – 32m deep following two methodologies

Taxonomic group	Taxa	Density	Survey method	Average length	Actual Weight				Annual growth		
		No. /100m²		(mm)	Individual Green weight (g)	Percentage Shell %	Individual shell weight (g)	Shell weight (g/100m²)	Individual growth (g/y)	Individual shell growth (g/y)	Shell growth (g/100m²/y)
Arthropods	*Pagurus setosus*	22467	grab	13	0.6	20	0.12	2696	0.30	0.06	1348
	Crabs other than *Ovalipes*	1400	grab	15	0.9	20	0.18	252	1.00	0.20	280
Polyplacophora	*Leptochiton* sp.	1200	grab	10	0.1	50	0.05	60	0.30	0.15	180
Gastropods	*Epitonium* sp.	200	grab	14	0.2	80	0.16	32	1.00	0.80	160
	Turritellidae	2067	grab	24	0.5	80	0.40	827	1.00	0.80	1653
	Rissoina fictor	154	box	5	0.1	80	0.04	6	1.00	0.80	123
	Sigapatella sp.	2667	grab	5	0.0	50	0.01	13	0.10	0.05	133
	Amalda sp.	1067	grab	25	2.0	80	1.60	1707	3.69	2.95	3149
	Austrofusus glans	133	grab	33	4.4	80	3.54	471	3.69	2.95	394
	Cominella quoyana	988	box	20	1.0	80	0.80	790	3.69	2.95	2916
	Antimelatoma buchanani	62	box	20	1.0	80	0.80	49	3.69	2.95	182
	Zeatrophon ambiguus	200	grab	30	3.3	80	2.67	534	3.69	2.95	590
	Xymenella pusilla	62	box	25	2.0	80	1.56	96	3.69	2.95	182
	Cantharidus sp.	133	grab	10	2.0	80	1.60	213	0.94	0.75	100
	Antisolarium egenum	401	box	5	0.7	80	0.59	238	0.94	0.75	302
	Roseaplagis rufozona	93	box	10	2.0	80	1.60	148	0.94	0.75	70
	Solariella tryphenensis	93	box	5	0.7	80	0.59	55	0.94	0.75	70
	Other gastropods	1600	grab	10	2.0	80	1.60	2560	2.22	1.78	2846
Bivalves	*Hunkydora* & *Myadora*	400	grab	23	5.0	50	2.50	1000	3.50	1.75	700
	Corbula zelandica	401	box	12	5.0	50	2.50	1003	3.50	1.75	702
	Glycymeris modesta	216	box	26	6.3	65	4.10	885	1.44	0.94	202
	Pratulum pulchellum	400	grab	25	5.6	65	3.61	1446	1.44	0.94	374
	Gari & *Hiatula*	2933	grab	25	0.5	65	0.33	953	1.43	0.93	2727
	Pleuromeris sp.	467	grab	8	5.6	65	3.61	1687	1.44	0.94	437
	Purpurocardia purpurata	123	box	26	6.3	65	4.10	506	1.44	0.94	116
	Limatula maoria	333	grab	8	0.0	50	0.01	2	0.10	0.05	17
	Nucula nitidula	3533	grab	8	0.0	50	0.01	18	0.10	0.05	177
	Atrina zelandica	333	grab	45	8.7	65	5.68	1894	12.60	8.19	2730
	Dosinia sp.	267	grab	25	10.0	65	6.50	1733	7.00	4.55	1213
	Tawera sp.	1267	grab	24	10.0	65	6.50	8233	7.00	4.55	5763
	Zemysina globus	62	box	25	10.0	65	6.50	401	7.00	4.55	281
	Lasaeidae	1333	grab	1	0.0	50	0.01	7	0.10	0.05	67
	Pecten novaezelandiae	15	tow	84	55.7	65	36.19	550	50.00	32.50	494
	Other bivalves	667	grab	23	10.0	65	6.50	4333	5.00	3.25	2167
Echinoderms	*Echinocardium* sp.	1733	grab	30	10.0	20	2.00	3467	10.00	2.00	3467
	Astropecten polycanthus	4	tow	114	14.0	90	12.60	53	3.10	2.79	12
	Amphiura sp.	533	grab	80	5.0	90	4.50	2400	1.50	1.35	720
Chordates	*Epigonichthys hectori*	5467	grab	40	0.3	20	0.06	328	0.20	0.04	219
Total		**55474**						**41646**			**37263**

Taxonomic group	Taxa	Density	Survey method	Maximum length	Maximum Weight				Annual Mortality	
					Individual Green weight	Percentage Shell	Individual shell weight	Shell weight	Maximum age	Shell mortality
		No. /100m^2		(mm)	(g)	%	(g)	(g/100m^2)	(y)	(g/100m^2/y)
Arthropods	*Pagurus setosus*	22467	grab	15	10.0	20	2.00	44933	4	11233
	Crabs other than *Ovalipes*	1400	grab	100	200.0	20	40.00	56000	4	14000
Polyplacophora	*Leptochiton* sp.	1200	grab	30	4.0	50	2.00	2400	15	160
Gastropods	*Epitonium* sp.	200	grab	14	0.2	80	0.16	32	3	11
	Turritellidae	2067	grab	24	0.5	80	0.40	827	3	276
	Rissoina fictor	154	box	5	0.1	80	0.04	6	3	2
	Sigapatella sp.	2667	grab	8	0.2	50	0.10	267	2	134
	Amalda sp.	1067	grab	40	7.8	80	6.24	6656	10	666
	Austrofusus glans	133	grab	65	32.0	80	25.60	3413	8	427
	Cominella quoyana	988	box	20	1.0	80	0.80	790	8	99
	Antimelatoma buchanani	62	box	20	1.0	80	0.80	49	8	6
	Zeatrophon ambiguus	200	grab	30	3.3	80	2.67	534	8	67
	Xymenella pusilla	62	box	25	2.0	80	1.56	96	8	12
	Cantharidus sp.	133	grab	26	6.0	80	4.80	640	6	107
	Antisolarium egenum	401	box	7	0.8	80	0.64	257	6	43
	Roseaplagis rufozona	93	box	26	6.0	80	4.80	444	6	74
	Solariella tryphenensis	93	box	5	0.7	80	0.59	55	6	9
	Other gastropods	1600	grab	10	2.0	80	1.60	2560	6	401
Bivalves	*Hunkydora* & *Myadora*	400	grab	42	10.0	50	5.00	2000	10	200
	Corbula zelandica	401	box	12	5.0	50	2.50	1003	10	100
	Glycymeris modesta	216	box	26	5.0	65	3.25	702	5	140
	Pratulum pulchellum	400	grab	26	5.0	65	3.25	1300	5	260
	Gari & *Hiatula*	2933	grab	58	11.0	65	7.15	20973	10	2097
	Pleuromeris sp.	467	grab	8	5.6	65	3.64	1699	5	340
	Purpurocardia purpurata	123	box	35	5.0	65	3.25	401	5	80
	Limatula maoria	333	grab	8	0.2	50	0.10	33	2	17
	Nucula nitidula	3533	grab	8	0.2	50	0.10	353	2	177
	Atrina zelandica	333	grab	300	88.0	65	57.20	19067	15	1271
	Dosinia sp.	267	grab	52	40.0	65	26.00	6933	10	693
	Tawera sp.	1267	grab	24	10.0	65	6.50	8233	10	823
	Zemysina globus	62	box	24	10.0	65	6.50	401	10	40
	Lasaeidae	1333	grab	2	0.2	50	0.10	133	2	67
	Pecten novaezelandiae	15	tow	116	128.0	65	83.20	1265	10	127
	Other bivalves	667	grab	30	10.0	65	6.50	4333	9	495
Echinoderms	*Echinocardium* sp.	1733	grab	30	10.0	20	2.00	3467	10	347
	Astropecten polycanthus	4	tow	200	20.0	90	18.00	76	15	5
	Amphiura sp.	533	grab	80	5.0	90	4.50	2400	15	160
Chordates	*Epigonichthys hectori*	5467	grab	80	1.0	20	0.20	1093	8	137
Total		**55474**						**195824**	**7 (mean max. age)**	**35303**

Table 8 Summary of shell production by area in the Pakiri – Mangawhai embayment.

Area	Surface Area	Dominant sampling method	Average density	Actual Shell weight		Annual Shell Growth				Annual Shell Morality			
						Weight		Volume		Weight		Volume	
				Average	Total	Average	Total	Lower	Upper	Average	Total	Lower	Upper
	(m^2)		No./100m²	g/100m²	Mg	g/100m²/y	Mg/y	m³/y	m³/y	g/100m²/y	Mg/y	m³/y	m³/y
Rocky shore 0m – 7m	1,011,139	quadrat	85,054	191,919	1,941	250,885	2,537	1,812	2,306	252,050	2,549	1,821	2,317
Shoreline 0m – 7m	11,119,839	box	11,413	31,610	3,515	10,365	1,153	823	1,048	22,802	2,536	1,811	2,305
Shallow 7m - 12m	5,701,399	box	11,867	24,595	1,402	12,485	712	508	647	12,578	717	512	652
Mid 12m - 22m	20,855,709	box	4,668	8,910	1,858	6,294	1,313	938	1,193	7,411	1,600	1,143	1,455
Deep 22m - 27m	16,558,156	box	4,647	5,606	928	4,226	700	500	636	4,580	1,059	757	963
Pakiri – Mangawhai embayment within depth of Closure	55,246,242	box	8,234*	17,457*	9,645	11,609*	**6,414**	***4,581***	***5,831***	14,671*	**8,106**	***5,790***	***7,369***
Offshore 27m – 32m	15,818,196	grab	41,646	56,231	8,895	37,263	**5,894**	***4,210***	***5,358***	35,303	**5,584**	***3,989***	***5,076***

Note:

A range of densities was used for the shell volume with upper defined as 1.1 Mg/m³ and lower as 1.4 Mg/m³ (see text).

It was not possible to estimate errors with the methodologies used.

* area weighted average

4. DISCUSSION

4.1 Shell weight annual production

The majority of the calculations of growth rates of taxa present were not based on taxa specific equations as no such equations have been developed for most New Zealand species. Therefore, similar local or international taxa growth rate equations were substituted. The use of non-specific equations and extrapolations provides an estimate of the production albeit with an increased measure of uncertainty. The present estimation assumed a single cohort per taxa (no size distribution of biota available for box dredge) with no migration in or out the system. Until more data on the biology of the biota become available (population dynamics), building more complex growth models of current biota is pointless.

The annual shell production in the Pakiri – Mangawhai embayment (0m – 27m) was estimated to be around 7,200 tonnes depending on the methodology used (by growth rate 6,414 tonnes or by mortality 8,106 tonnes). This was equivalent to a range in volume of 4,600 – 5,800m^3 by growth rate or between 5,800 – 7,400m^3 by mortality, depending on different crushed shell densities of 1.1 - 1.4 Mg/m^3 used (Eziefula *et al.*, 2018). Given the number of estimations, assumptions and substitutions it was not possible to provide an estimation of the error associated with the results produced by either method.

In general, subtidal marine invertebrate communities can support a high diversity of species with different ecological and life history traits. Species with different adaptations, occupy different niches along a depth gradient, which among other factors, varies with sediment texture and with their ability to cope with the physical environment (Dolbeth *et al.,* 2007). The environmental severity conditioning the fauna is determined by the bottom disturbance, which in turn potentially affects sediment texture, food availability and biotic interactions. Both wave climate and morphological parameters showed that the higher the energy to which the community is subjected, the lower the species number and density in the inhabited area (Dolbeth *et al.,* 2007). The DOC reflects differences in hydrodynamics, with lower energy conditions on the seabed, seawards of this boundary. Therefore, both increased food availability and reduced disturbance may allow for the existence of richer and denser assemblages beyond the DOC (Carvalho *et al*., 2012).

The benthic biota data collected in the Pakiri embayment for both the McCallum Brothers Limited and Kaipara Limited consents and in the past (Hilton, 1990, Bioresearches, 2016) show variations in the species composition and abundance with increased depth. The current data shows the inshore areas (0-12m) are dominated by biota adapted to high wave energy such as wheel shells and sand dollar, both of which can occur in high densities. Further offshore between 12 and 27m depth the biota was diverse, but low in abundance. Here, communities were dominated by a few species of polychaete worms and contained moderate numbers of amphipods, hermit crabs, the bivalves *Nucula* and *Myadora* and the Lancelet, *Epigonichthys hectori*. Beyond the predefined 27m DOC, the biota was still diverse with similar species to those present in the mid shore (12 – 27m) but numbers of individuals, particularly bivalves, were greater beyond the 27m depth.

Table 8 shows the average biomass of biota per 100m^2 decreased with increasing depth to the 27m depth contour. The highest numbers were recorded in the rocky shore areas. The higher numbers recorded in the shallow sandy environments were mostly due to the high abundances of the wheel shells and sand dollars. The decreasing numbers were the result of fewer biota present and their smaller sizes. Beyond the 27m depth contour, the biomass increased again due to increased numbers of bivalves and echinoderms (Table 7).

As there are uncertainties on the amount of sediment and shell material moving to and from the Pakiri – Mangawhai embayment (0m – 27m) across the predefined 27m DOC, the calculation of annual shell production in the 27m – 32m area is also presented. The production in the 27m – 32m area alone (4,000 - 5,400m³ depending on the methodology) is marginally lower but comparable to that of the whole Pakiri – Mangawhai embayment (0m – 27m) (4,600 – 7,400m³ depending on the methodology). Thus, the inclusion of the 27m – 32m area in the biogenic sand budget of the Pakiri – Mangawhai embayment (0m – 32m) gives figures of approximately 8,800 to 12,400m³ of annual biogenic sand production.

Based on the data included in this study the different sampling methods; grab sampler, box dredge, quadrat and dredge tow, appear to produce different densities of biota. The grab sampler samples the smallest area, but the area sampled is standardised. The box dredge samples a similar volume, but a larger area and the area sample varies depending on how well the dredge operates in the sediment. The quadrat again samples a standardised area. The dredge tow samples are very different to the other two samplers in that the area sampled is much greater and is selective for the larger biota only.

Of the six defined areas sampled, only the 27m -32m area was sampled with the grab sampling method and this method systematically produced greater densities in comparison with box dredge or tow dredge samples in the same area. Nonetheless, the higher densities recorded beyond the 27m depth contour are not solely a bias of sampling methodology. Seabed images recorded in four transects in 2019 reported in Bioresearches (2019b) showed increased proportions of shell fragments on the seabed in areas beyond 25m depth (as recorded at the time of sampling), and corroborates the increased biota recorded in the samples. In the absence of data to directly compare the different sampling methods it has been assumed neither sampling method has any greater bias.

4.2 Comparison with previous estimated numbers

Sands in the Pakiri-Mangawhai embayment are primarily quartzo-feldspathic (Schofield, 1970). They also contain varying amounts of carbonate, as sand material.

Based on the 2019 soft shore calciferous biota densities the estimated average concentration of shell is 142g/m², ranging between 56 and 316g/m², which is comparable with Hilton's estimate or 97g/m², albeit for slightly different areas. Hilton's transect areas extended beyond the 27m depth contour and did not include the rocky shore biota, making direct comparison with the current study problematic. When rocky shore biota was included the average concentration of shell increased to 175g/m², due the estimated rocky shore shell biomass of 1920g/m².

Hilton (1990) assumed that for a shellfish species of a 10-year life expectancy, 10% of the population would die every year and the shell becomes part of the biogenic sand. This assumes a constant population size, and that recruitment and mortality were constant, which they are generally not. It also appears that he assumed all shellfish had a similar life span, which is also not a valid assumption. We now know biota range in lifespan from 3 to 15 years. Longer lived species would contribute a lesser percentage of the population per year than a short-lived species. His assumptions were based on the information available in 1990, greater information on life span is now available but the population size, mortality and recruitment are still not well understood. We do know from monitoring data (Grace, 1991, 2005, Bioresearches 2019) that the populations of wheel shell and several other species have varied between years which suggested either mortality or more likely recruitment are not constant.

Based on Hilton's assumptions, he calculated that the existing weight of shell material 5,300 tonnes would increase to 73,000,000 tonnes after 100 years. This calculation was incorrect. Hilton mistakenly added the dead shell material back to the live shell material each year for a compounding recalculation of dead shell production over the 100-year time frame. This process grossly overestimated the production of dead shell material over time. One of the major assumptions is that the live shellfish population does not change year to year therefore the production should be the same each year. To quantify any changes year to year or between seasons would require repeated surveys of taxa abundance and sizes, which is beyond the scope needed for this project. Given that mortality and recruitment vary between years and between species the live shellfish population will vary over time. However even if the shellfish population varied in size between years the expected dead shell production would not approach the tonnage Hilton calculated. Correcting Hiltons dead shell production calculation overtime, results in an annual shell material production of 530 tonnes, translating to 482m³/year assuming shell material has a density of 1.1Mg/m³. Hume *et al.* (1999) suggests these values cover half the bay and should be doubled to a corrected value of 964m³/year, which is considerably less than that Hilton reported in 1990 of 900,000m³/year.

The NIWA sand study (Hume *et al*., 1999) considered Hilton's original shell production value of 900,000 m³/year erroneous and suggested the biogenic sand product was less than 12,000 m³/year based on a sediment budget. Barnett in his 2005 environment court evidence suggested it should be near 90,000 m³/year, neither of the latter estimates were based on biological science.

Of these estimates only the Hilton (1990) corrected estimate of 964m³/year is based on actual biological production, but it was based on invalid assumptions and missing significant sources.

In an ideal world with data on distribution and abundance, growth curves, population structure, recruitment and mortality variability available on each of the specific taxa the total shell production could be refined as the sum of each component taxa per area. The estimate produced in this report has attempted to further refine Hilton's assessment by segregating the seabed into five zones based on species composition and abundance and defined by depth. In addition, rather than assuming that all shellfish grow in the same way, taxa specific growth has been applied to each taxon within each zone. Species-specific growth data, age, population structure, recruitment etc, do not generally exist for the species recorded. Therefore, data from similar taxa have been used as estimates for growth and age. Detailed population structure data was generally not available for any of the taxa recorded, therefore the annual growth of the average known size for each taxon was used to provide one estimate of growth. A second estimate of growth was based on the similar method to Hilton of the annual population mortality as estimated by the reciprocal of maximum age. Variability in recruitment and mortality were not available for in the production estimate. Nonetheless, the similarity of the two estimates produced for the rocky and soft shore environments of the Pakiri-Mangawhai embayment to the 27m depth contour (annual growth 4,581 – 5,831 m³/year, and population mortality 5,790 – 7,369 m³/year), provides some confidence in the calculations, and fits within the 12,000m³ net shoreward transport of material proposed by Hume *et al* (1999).

Addition of the results of biogenic sand production from the 27-32 m contour (Table 8), would increase the production by a further 4,200 – 5,400 m³/year under the annual growth methodology, and 4,000 – 5,000 m³/year under the population mortality methodology.

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6. APPENDICES

Table A 1 Surface area calculated for each tow. The width of the dredge was 650mm for the tows up to a depth of 25m, and 600mm for the tows in the 25 – 30m depth area.

Tow Code	Depth area	Distance (m)	Surface (m^2)
1	20 – 25m	383	248.95
2	20 – 25m	595	386.75
3	20 – 25m	514	334.1
4	20 – 25m	387	251.55
5	20 – 25m	284	184.6
6	20 – 25m	334	217.1
7	20 – 25m	392	254.8
8	10 – 20m	205	133.25
9	10 – 20m	289	187.85
10	20 – 25m	322	209.3
11	10 – 20m	301	195.65
12	10 – 20m	347	225.55
13	10 – 20m	255	165.75
14	10 – 20m	357	232.05
15	10 – 20m	317	206.05
16	10 – 20m	655	425.75
17	10 – 20m	275	178.75
18	10 – 20m	157	102.05
19	10 – 20m	233	151.45
20	10 – 20m	315	204.75
21	10 – 20m	258	167.7
22	5 – 10m	281	182.65
23	5 – 10m	277	180.05
24	5 – 10m	233	151.45
25	5 – 10m	272	176.8
26	5 – 10m	279	181.35
27	5 – 10m	228	148.2
28	5 – 10m	254	165.1
29	5 – 10m	274	178.1
30	5 – 10m	296	192.4
31	5 – 10m	270	175.5
32	5 – 10m	319	207.35
33	5 – 10m	336	218.4
34	5 – 10m	315	204.75
35	5 – 10m	234	152.1
T2 A	25 – 30m	100	60
T4 A	25 – 30m	125	75
T6 A	25 – 30m	100	60
T6 B	25 – 30m	100	60
T8 A	25 – 30m	100	60
T8 B	25 – 30m	99	59.4
TC A	25 – 30m	100	60
TC B	25 – 30m	100	60

Table A 2 Infauna taxa found in the 94 box dredge samples (3.15mm mesh size) collected within 0 to 27m depth (Bioresearches, 2019a,b).

Taxa	Total No.
Polychaeta: *Hydroides* sp.	7
Polychaeta: Spionidae	2
Polychaeta: *Paraprionospio pinnata*	7
Polychaeta: Terebellida	11
Polychaeta: Ampharetidae	19
Polychaeta: ?*Lanice* sp.	2
Polychaeta: Cirratulidae	14
Polychaeta: Eunicidae	3
Polychaeta: Lumbrineries sp.	8
Polychaeta: Onuphidae	4
Polychaeta: Goniadidae	1
Polychaeta: Nephtyidae	6
Polychaeta: ?*Aglaophamus/Nephtys*	6
Polychaeta: Nereididae	1
Polychaeta: Phyllodocidae	10
Polychaeta: Polynoidae	4
Polychaeta: Sigalionidae	21
Polychaeta: *Magelona* cf. *dakini*	3
Polychaeta: Capitellidae	26
Polychaeta: *Armandia maculata*	2
Polychaeta: Maldanidae	525
Polychaeta: *Travisia olens*	1
other polychaeta	59
Nemertea	9
Calanoida	2
Cyclopoida	3
Amphipoda: Gammaridea undet.	9
Amphipoda: Gammaridea sp. 2	3
Amphipoda: Gammaridea sp. 3	22
Amphipoda: Gammaridea sp. 5	1
Amphipoda: Lysianassidae	2
Amphipoda: Phoxocephalidae sp. 1	23
Amphipoda: Phoxocephalidae sp. 2	2
Amphipoda: Phoxocephalidae sp. 3	2
Amphipoda: Haustoriidae	1

Taxa	Total No.
Amphipoda: Liljeborgiidae	2
Amphipoda: *Ampelisca chiltoni*	3
Cumacea: *Cyclaspis*	7
Cumacea: *Diastylopsis thileniusi*	2
Decapoda: *Periclimenes yaldwyni*	2
Decapoda: *Ogyrides delli*	2
Decapoda: *Liocarcinus corrugatus*	4
Decapoda: *Ovalipes catharus*	**2**
Decapoda: *Ebalia laevis*	5
Decapoda: Anomura	11
Decapoda: *Pagurus setosus*	**58**
other decapods	3
Arthropoda: Isopods	20
Arthropoda: Mysidae	10
Arthropoda: Pariliacantha	7
Arthropoda: Tanaidacea	1
Arthropoda: Pycnogonida	1
Arthropoda: Coleoptera undet.	2
Polyplacophora: *Leptochiton inquinatus*	**7**
Gastropoda: *Zethalia zelandica*	**300**
Gastropoda: *Antisolarium egenum*	10
Gastropoda: *Maoricolpus roseus*	2
Gastropoda: *Stiracolpus pagoda*	**11**
Gastropoda: *Sigapatella tenuis*	**33**
Gastropoda: *Trichosirius inornatus*	2
Gastropoda: *Cominella adspersa*	**6**
Gastropoda: *Cominella quoyana*	**28**
Gastropoda: Austrofusus glans	1
Gastropoda: *Amalda australis*	**10**
Gastropoda: *Amalda depressa*	**2**
Gastropoda: *Amalda novaezelandiae*	**13**
Gastropoda: Borsoniidae	3
Gastropoda: *Euterebra tristis*	5
Gastropoda: *Pupa affinis*	20
Gastropoda: *Cylichna thetidis*	3

Taxa	Total No.
other gastropods	4
Bivalvia: *Nucula nitidula*	**61**
Bivalvia: *Glycymeris modesta*	**3**
Bivalvia: *Purpurocardia purpurata*	1
Bivalvia: Galeommatidae	3
Bivalvia: *Scalpomactra scalpellum*	2
Bivalvia: *Gari convexa*	**5**
Bivalvia: *Gari lineolata*	**3**
Bivalvia: *Gari stangeri*	**4**
Bivalvia: *Hiatula nitida*	4
Bivalvia: *Zemysina globus*	6
Bivalvia: *Tawera spissa*	8
Bivalvia: *Dosinia lambata*	**2**
Bivalvia: *Dosinia maoriana*	**5**
Bivalvia: *Dosinia subrosea*	**18**
Bivalvia: *Corbula zelandica*	10
Bivalvia: *Myadora boltoni*	**71**
Bivalvia: *Myadora striata*	**45**
Bivalvia: Myadora subrostrata	**13**
Bivalvia: *Hunkydora novozelandica*	2
other Bivalvia	4
Echinodermata: *Amphiura aster*	**15**
Echinodermata: *Fellaster zelandiae*	**16**
other echinoderms	2
Nematoda	8
Foraminifera	7
Bryozoa: *Selenaria concinna*	68
Porifera	11
Leptothecata	2
Actiniaria	1
Epigonichthys hectori	**67**
Limnichthys polyactis	6
TOTAL	**1896**

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature. The other highlighted taxa were combined into a higher taxonomic level.

Table A 3 Epifauna taxa found in the 35 dredge tow samples collected within 0 to 27m depth (Bioresearches, 2019a,b).

Taxa	Total No.
Polychaete	21
Amphipods	7
Nemertea	3
Isopod	2
Bryozoa	4
Porifera	6
Decapoda: Paguridae	122
Decapoda: *Ovalipes catharus*	**7**
Decapoda: *other than Ovalipes*	9
Gastropoda: Zethalia zelandica	**7**

Taxa	Total No.
Gastropoda: Dicathais orbita	1
Gastropoda: Cominella adspersa	**32**
Gastropoda: Sigapatella tenuis	1
Gastropoda: Ranella australasia	1
Gastropoda: Austrofusus glans	2
Gastropoda: Amalda australis	**5**
Gastropoda: *Zeatrophon mortenseni*	1
Gastropoda: *Struthiolaria papulosa*	4
Bivalvia: *Atrina zelandica*	**3**
Bivalvia: *Pecten novaezealandiae*	**12**

Taxa	Total No.
Bivalvia: *Tawera spissa*	1
Bivalvia: *Dosinia subrosea*	**9**
Bivalvia: *Myadora striata*	**5**
Bivalvia: *Purpurocardia purpurata*	1
Bivalvia: *Ostrea chilensis*	1
Bivalvia: *Gari convexa*	1
Echinodermata: *Fellaster zelandiae*	**38**
Echinodermata: *Amphiura sp.*	**3**
Echinodermata: *Astropecten polyacanthus*	30
Total	**339**

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The taxa with only 1 individual were also excluded before combination of the results with infauna as they would have minimal contribution to sand formation. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature.

Table A 4 Shellfish collected in the intertidal zone along the Pakiri Beach in 1993 (Bioresearches, 1994)

Transect	Station	Species	Number/m²	Average length (mm)
1	70	*Paphies subtriangulata*	4	41.3
2	80	*Paphies subtriangulata*	22	48.1
3	90	*Paphies subtriangulata*	25	51.3
4	100	*Paphies subtriangulata*	25	49.0
5	160	*Paphies subtriangulata*	11	49.8
6	120	*Paphies subtriangulata*	5.3	41.3
7	10	*Nerita melanotragus*	21	22.9
7	20	*Cellana ornata*	43	19.9
7	20	*Leptograpsus variegatus*	18	
7	30	*Cellana radians*	35	32.6
7	30	*Lepsiella scobina*	587	15.3
7	30	*Melagraphia aethiops*	45	16.2
7	30	*Turbo smaragdus*	17	39.4
7	50	*Haustrum haustorium*	4	44.3
7	50	*Thais orbita*	16	43.0
8	120	*Paphies subtriangulata*	11	43.8
9	100	*Paphies subtriangulata*	10	42.4
10	100	*Paphies subtriangulata*	6	46.4
11	100	*Paphies subtriangulata*	16	44.9
13	60	*Paphies subtriangulata*	15	50.5
14	65	*Paphies subtriangulata*	19	44.2
15	50	*Paphies subtriangulata*	13	44.5
16	60	*Paphies subtriangulata*	13	46.7
17	60	*Paphies subtriangulata*	12	45.5
18	150	*Paphies subtriangulata*	5	48.5
19	60	*Paphies subtriangulata*	6	46.1
19	70	*Paphies subtriangulata*	13	51.8
20	90	*Paphies subtriangulata*	5	51.7
		Average *Paphies*	**12**	**46.7**

Note: Transect 7 (grey shaded) was at a rock area at Te Arai Point and was not considered for the 0-5m biota of the biogenic study as the species sampled in 7 are representative of a rock substrate, not of a sand system.

Table A 5 *Infauna taxa found in the 31 grab samples collected within 27 to 32m depth (Bioresearches, 2017).*

Taxa	Total No.
Polychaeta: *Euchone pallida*	46
Polychaeta: Sabellidae	12
Polychaeta: *Hydroides sp.*	1
Polychaeta: *Serpula sp.*	5
Polychaeta: *Phyllochaetopterus*	5
Polychaeta: *Boccardia sp.*	1
Polychaeta: *Paraprionospio*	14
Polychaeta: *Prionospio sp.*	661
Polychaeta: *Spio sp.*	13
Polychaeta: *Spiophanes kroyeri*	34
Polychaeta: *Spiophanes modestus*	1634
Polychaeta: Ampharetidae	109
Polychaeta: Cirratulidae	49
Polychaeta: *Lagis australis*	3
Polychaeta: Terebellidae	91
Polychaeta: Dorvilleidae	6
Polychaeta: Lumbrineridae	15
Polychaeta: *Nothria sp.*	122
Polychaeta: *Onuphis*	4
Polychaeta: Onuphidae	3
Polychaeta: Glyceridae	9
Polychaeta: Goniadidae	61
Polychaeta: Hesionidae	17
Polychaeta: Aglaophamus sp.	11
Polychaeta: Phyllodocidae	87
Polychaeta: Polynoidae	1
Polychaeta: Sigalionidae	64
Polychaeta: *Sphaerosyllis sp.*	39
Polychaeta: Syllidae	63
Polychaeta: *Magelona dakini*	11
Polychaeta: *Barantolla lepte*	9
Polychaeta: *Capitella capitata*	1
Polychaeta: *Notomastus*	8
Polychaeta: *Armandia maculata*	116
Polychaeta: *Leodamas cylindrifer*	2
Polychaeta: *Orbinia papillosa*	6
Polychaeta: Maldanidae	194
Polychaeta: *Aricidea sp.*	8

Taxa	Total No.
Polychaeta: Paraonidae	9
Polychaeta: *Travisia sp.*	21
Hemichordata	7
Phoronida (*Phoronis* sp.)	23
Nemertea	20
Copepoda	12
Amphipoda: Caprellidae	20
Amphipoda: Haustoriidae	96
Amphipoda: Lysianassidae	248
Amphipoda: Oedicerotidae	2
Amphipoda: Phoxocephalidae	506
Amphipoda: Talitridae	2
other amphipods	4526
Cumacea	502
Decapoda: *Pagurus sp.*	337
Decapoda: shrimps	4
Decapoda: crabs other than Ovalipes	21
Isopoda	98
Mysida	19
Podocopida	465
Tanaidacea	43
Ostracoda	660
Polyplacophora: *Ischnochiton maorianus*	18
Gastropoda: *Epitonium sp.*	3
Gastropoda: *Maoricolpus roseus*	30
Gastropoda: *Zeacolpus sp.*	1
Gastropoda: *Philine sp.*	1
Gastropoda: *Relichna aupouria*	2
Gastropoda: *Caecum digitulum*	1
Gastropoda: *Sigapatella tenuis*	**38**
Gastropoda: *Sigapatella sp.*	**2**
Gastropoda: *Tanea sp.*	1
Gastropoda: Rissoidae	4
Gastropoda: *Struthiolaria pap.*	1
Gastropoda: *Tonna sp.*	1
Gastropoda: *Amalda northlandica*	**13**
Gastropoda: *Amalda sp.*	**3**
Gastropoda: *Austrofusus glans*	2

Taxa	Total No.
Gastropoda: *Cominella quoyana*	**2**
Gastropoda: *Cominella virgata*	**9**
Gastropoda: Marginellidae	1
Gastropoda: *Zeatrophon ambiguus*	3
Gastropoda: *Cantharidus sp.*	2
Gastropoda: *Adelphotectonica reevei*	3
Gastropoda Unid. Juv.	9
Bivalvia: *Hunkydora novozelandica*	1
Bivalvia: *Myadora antipodum*	**3**
Bivalvia: *Myadora striata*	**2**
Bivalvia: *Glycymeris modesta*	**1**
Bivalvia: *Glycymeris sp.*	**2**
Bivalvia: *Pratulum pulchellum*	6
Bivalvia: *Gari lineolata*	**4**
Bivalvia: *Hiatula sp.*	40
Bivalvia: *Pleuromeris zelandica*	5
Bivalvia: *Pleuromeris sp.*	2
Bivalvia: *Limatula maoria*	5
Bivalvia: *Corbula zelandica*	3
Bivalvia: *Nucula nitidula*	**53**
Bivalvia: *Atrina zelandica*	**5**
Bivalvia: *Dosinia subrosea*	**2**
Bivalvia: *Dosinia sp.*	**2**
Bivalvia: *Notocallista multistriata*	1
Bivalvia: *Tawera spissa*	1
Bivalvia: *Tawera sp.*	17
Bivalvia: *Myllita vivens*	1
Bivalvia: *Mysella sp.*	19
Bivalvia: *Scalpomactra scalpellum*	2
Bivalvia: *Diplodonta zelandica*	2
Bivalvia Unid. (juv)	3
Echinodermata: *Echinocardium sp.*	26
Echinodermata: *Amphiura sp.*	8
Epigonichthys hectori	82
TOTAL	11634

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature.

Table A 6 *Epifauna taxa found in the 8 dredge tow samples collected within 27 to 32m depth (Bioresearches, 2017).*

Taxa	Total No.
Ascidian	38
Octopus	1
Decapoda: Paguridae	8
Decapoda: *Ovalipes catharus*	**1**
Polyplacophora	2
Gastropod: Cominella adspersa	**1**

Taxa	Total No.
Gastropoda: Struthiolaria sp.	2
Gastropoda: Monoplex parthenopeus	1
Gastropoda: Maoricolpus roseus	1
Gastropoda: Murexsul espinosus	2
Bivalvia: Pecten novaezelandiae	**73**
Bivalvia: Irus reflexus	1

Taxa	Total No.
Bivalvia: Zemysina striatula	2
Bivalvia: Mesopeplum convexum	1
Echinodermata: Astropecten polycanthus	20
TOTAL	154

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature.

Table A 7 Infauna taxa found in the 20 box dredge samples (3.15mm mesh size) collected within 27 to 32m depth (Bioresearches, 2019).

Taxa	Total No.
Polychaeta: *Euchone* sp.	3
Polychaeta: *Hydroides* sp.	17
Polychaeta: *Paraprionospio pin.*	2
Polychaeta: *Malacoceros*	3
Polychaeta: Terebellida	19
Polychaeta: Ampharetidae	24
Polychaeta: Cirratulidae	8
Polychaeta: *Lagis australis*	2
Polychaeta: Eunicidae	3
Polychaeta: Onuphidae	1
Polychaeta: Goniadidae	1
Polychaeta: Nephtyidae	1
Polychaeta: *Aglaophamus*	1
Polychaeta: Nereididae	1
Polychaeta: Phyllodocidae	3
Polychaeta: Polynoidae	3
Polychaeta: Sigalionidae	14
Polychaeta: Syllidae	5
Polychaeta: *Magelona dakini*	5
Polychaeta: Capitellidae	18
Polychaeta: Cossuridae	4
Polychaeta: Maldanidae	93
Polychaeta: *Travisia olens*	4
other polychaeta	52
Nemertea	7
Cyclopoida	1
Amphipoda: Gammaridea	64
Amphipoda: Phoxocephalidae	13

Taxa	Total No.
Amphipoda: Haustoriidae	2
Amphipoda: Liljeborgiidae	9
Cumacea: *Cyclaspis*	2
Decapoda: *Liocarcinus corrugatus*	9
Decapoda: *Ebalia laevis*	7
Decapoda: *Notomithrax minor*	2
Decapoda: Anomura	4
Decapoda: Paguridae	55
Isopods	17
Mysidae	1
Tanaidacea	1
Myodocopida	12
Pycnogonida	1
Echinodermata: *Leptochiton inquinatus*	35
Gastropod: *Antisolarium egenum*	13
Gastropod: *Roseaplagis rufozona*	3
Gastropod: *Solariella tryphenensis*	3
Gastropod: *Maoricolpus roseus*	3
Gastropod: *Striacolpus pagoda*	**28**
Gastropod: *Rissoina fictor*	8
Gastropod: *Pisinna semisulcata*	3
Gastropod: *Sigapatella tenuis*	24
Gastropod: *Seila cincta*	2
Gastropod: *Cominella quoyana*	**37**
Gastropod: *Austrofusus glans*	1
Gastropod: *Xymenella pusilla*	2
Gastropod: *Amalda novaezelandiae*	**3**
Gastropod: *Antimelatoma buchanani*	3

Taxa	Total No.
Gastropod: *Cylichna thetidis*	3
other gastropods	3
Bivalvia: *Nucula nitidula*	**55**
Bivalvia: *Glycymeris modesta*	**7**
Bivalvia: *Pleuromeris* sp.	11
Bivalvia: *Purpurocardia purpurata*	8
Bivalvia: Galeommatidae	1
Bivalvia: *Scalpomactra scalpellum*	1
Bivalvia: *Gari stangeri*	**14**
Bivalvia: *Hiatula nitida*	3
Bivalvia: *Zemysina globus*	2
Bivalvia: *Tawera spissa*	2
Bivalvia: *Dosinia maoriana*	**5**
Bivalvia: *Dosinia subrosea*	**1**
Bivalvia: *Corbula zelandica*	17
Bivalvia: *Myadora subrostrata*	**6**
Bivalvia: *Hunkydora novozelandica*	1
other bivalvia	6
Echinodermata: *Amphiura aster*	6
Echinodermata: Ophiuroidea	2
other echinoderms	2
Nematoda	18
Foraminifera	41
Bryozoa	45
Porifera	35
Ascidiacea	4
Epigonichthys hectori	41
TOTAL	**1005**

Note: The grey text taxa were considered to have no or little "shell" component and were not included into the calculation of shell weight and growth. The highlighted taxa in bold are the species for which information on individual weight and growth at a family level was available in the literature.

Table A 8 List of equations used for weight and growth.

Taxa			Allometric equations			Growth equations		
Taxonomic group	**Family**	**Species**	**Species used for weight estimation**	**Equation length –weight (mm - g)**	**Source**	**Species used for growth estimation**	**Equation age –length (y - mm)**	**Source**
Arthropods	Paguridae	*Pagurus setosus*	*Ovalipes catharus*	log(W)=3.32+2.79log(L)	Fisheries NZ 2018, vol 2, p467	*Pagurus* sp.	curve in Fig. 5	Mc Lay, 1985
Arthropods	Portunidae	*Ovalipes catharus*	*Ovalipes catharus*	log(W)=3.32+2.79log(L)	Fisheries NZ 2018, vol 2, p467	*Ovalipes catharus*	from info in text	Fisheries NZ 2018, vol 2, p467
Arthropods	Grapsidae	*Leptograpsus variegatus*	*Ovalipes catharus*	log(W)=3.32+2.79log(L)	Fisheries NZ 2018, vol 2, p467	*Ovalipes catharus*	from info in text	Fisheries NZ 2018, vol 2, p467
Arthropods		Crabs other than *Ovalipes*	*Ovalipes catharus*	log(W)=3.32+2.79log(L)	Fisheries NZ 2018, vol 2, p467	*Ovalipes catharus*	from info in text	Fisheries NZ 2018, vol 2, p467
Polyplacophora	Leptochitonidae	*Leptochiton* spp.	*Chiton albolineatus*	$W = 0.0002L^{2.7097}$	Flores-Campana *et al.*, 2012	Estimated from other molluscs		
Gastropods	Trochidae	*Zethalia, Antisolarium, Roseaplagis, Melagraphia*	*Monodonta turbinata*	W = 0.5099(L/2)-0.5392	Boucetta *et al.*, 2010	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Solariellidae	*Solariella tryphenensis*	*Monodonta turbinata*	W = 0.5099(L/2)-0.5392	Boucetta *et al.*, 2010	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Neritidae	*Nerita melanotragus*	*Nerita crepidularia*	curve	Jaiswar & Kulkarni 2002	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Nacellidae	*Cellana* spp.	*Patella nigra*	from info in text	Echem 2017	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Turbinidae	*Turbo, Cookia*	*Turbo bruneus*	$W = 0.00017L^{3.091}$	Saleky *et al.*, 2016	*Phorcus sauciatus*	$L = 31.9 (1-e^{-0.31(age)})$	Sousa *et al.* 2019
Gastropods	Buccinidae	*Cominella, Austrofusus*	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Muricidae (large)	*Haustrum, Thais*	*Hexaplex nigritus*	$W = 0.000004L^{3.7956}$	Escamilla-Montes *et al.*, 2018	*Concholepas concholepas*	$W = 461.37 (1-e^{-0.55(age)})^3$	Rabi & Maravi, 1997
Gastropods	Muricidae (small)	*Lepsiella, Xymenella, Zeatrophon*	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Pseudomelatonidae	*Antimelatoma*	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Olividae	*Amalda* spp.	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Struthiolaridae	*Struthiolaria papulosa*	*Buccinum undatum*	$W = 0.000144L^{2.955}$	Heude-Berthelin *et al.*, 2011	*Buccinum undatum*	$L = 73 (1-e^{-0.221(age)})$	Heude-Berthelin *et al.*, 2011
Gastropods	Turritellidae	*Stiracolpus pagoda*	*Turritella communis*	Curve p179	Allmon, 2011	assumption of 1g/y from gastropod data of same size		
Gastropods	Epitoniidae	*Epitonium* spp.	*Turritella communis*	Curve p179	Allmon, 2011	assumption of 1g/y from gastropod data of same size		
Gastropods	Rissoniidae	*Rissoina fictor*	*Turritella communis*	Curve p179	Allmon, 2011	assumption of 1g/y from gastropod data of same size		
Gastropods	Calyptraeidae	*Sigapatella tenuis*	assumption of 0.005g			assumption of 0.10g / y		
Bivalves	Myochamidae	*Myadora* spp.	1/2 of *Dosinia subrosea*	curve p80 /2	Aljadani, 2013	*Dosinia* spp.	$L = 58.7 (1-e^{-0.13(age)})$	Fisheries NZ 2018, vol 3, p342
Bivalves	Veneridae	*Dosinia, Tawera*	*Dosinia subrosea*	curve p80	Aljadani, 2013	*Dosinia* spp.	$L = 58.7 (1-e^{-0.13(age)})$	Fisheries NZ 2018, vol 3, p342
Bivalves	Ungulinidae	*Zemysina globus*	*Dosinia subrosea*	curve p80	Aljadani, 2013	*Dosinia* spp.	$L = 58.7 (1-e^{-0.13(age)})$	Fisheries NZ 2018, vol 3, p342
Bivalves	Corbulidae	*Corbula zelandica*	½ of *Dosinia subrosea*	curve p80 /2	Aljadani, 2013	*Dosinia* spp.	$L = 58.7 (1-e^{-0.13(age)})$	Fisheries NZ 2018, vol 3, p342
Bivalves	Nuculidae	*Nucula nitidula*	*Nucula* spp.	from info in text	Allen 1954	*Nucula* spp.	from info in text	Allen 1954

Taxa			Allometric equations			Growth equations		
Taxonomic group	Family	Species	Species used for weight estimation	Equation length –weight (mm - g)	Source	Species used for growth estimation	Equation age –length (y - mm)	Source
Bivalves	Limidae	*Limatula maoria*	*Nucula* spp.	from info in text	Allen 1954	*Nucula* spp.	from info in text	Allen 1954
Bivalves	Lasaeidae	Lasaeidae	*Nucula* spp.	from info in text	Allen 1954	*Nucula* spp.	from info in text	Allen 1954
Bivalves	Glycymeridae	*Glycymeris modesta*	*Austrovenus stutchburyi*	$W = 0.00014L^{3.29}$	Fisheries NZ 2018, vol 1, p235	*Austrovenus stutchburyi*	$L = 35\ (1-e^{-0.26(age)})$	Fisheries NZ 2018, vol 1, p235
Bivalves	Carditidae	*Purpurocardia, Pleuromeris*	*Austrovenus stutchburyi*	$W = 0.00014L^{3.29}$	Fisheries NZ 2018, vol 1, p235	*Austrovenus stutchburyi*	$L = 35\ (1-e^{-0.26(age)})$	Fisheries NZ 2018, vol 1, p235
Bivalves	Cardiidae	*Pratulum pulchellum*	*Austrovenus stutchburyi*	$W = 0.00014L^{3.29}$	Fisheries NZ 2018, vol 1, p235	*Austrovenus stutchburyi*	$L = 35\ (1-e^{-0.26(age)})$	Fisheries NZ 2018, vol 1, p235
Bivalves	Pinnidae	*Atrina zelandica*	*Pinna bicolor*	W = 3.111Lcm-5.397	Idris *et al.*, 2012	*Pinna bicolor*	$Lcm = 34.66\ (1-e^{-0.8(age)})$	Idris *et al.*, 2012
Bivalves	Psammobiidae	*Gari convexa*	*Gari solida* (Jan 1992)	logW=-4.32+2.792log(L)	Urban & Campos, 1994	*Gari solida* (Jan 1992)	$L = 89.6\ (1-e^{-0.307(age-0.354)})$	Urban & Campos, 1994
Bivalves	Pectenidae	*Pecten novaezelandiae*	*Pecten novaezelandiae*	$W = 0.00042L^{2.662}$	Fisheries NZ 2014	*Pecten novaezelandiae*	$L = 115.9\ (1-e^{-1.2(age)})$	Fisheries NZ 2014
Bivalves	Mytilidae	*Perna canaliculus*	*Perna canaliculus*	From info in text	Fisheries NZ 2018, vol 1, p479	*Perna canaliculus*	From info in text	Fisheries NZ 2018, vol 1, p479
Bivalves	Psammobiidae	*Paphies subtriangulata*	*Paphies subtriangulata*	$W = 0.0002L^{2.927}$	Fisheries NZ 2018, vol 3, p581	*Paphies subtriangulata*	from info in text	Fisheries NZ 2018, vol 3, p581
Echinoderms	Arachnoididae	*Fellaster zelandiae*	*Echinarachnius*	from info in text p56	Lohavanijaya, 1964	*Echinarachnius*	from info in text p56	Lohavanijaya, 1964
Echinoderms	Loveniidae	*Echinocardium* sp.	*Echinocardium cordatum*	log(W)= -3.449 +3.011log(L)	Robinson *et al.*, 2010	*Evechinus chloroticus*	from info in text p657	Fisheries NZ 2018, vol 2, p651
Echinoderms	Echinometridae	*Evechinus chloroticus*	*Evechinus chloroticus*	$W = 0.000627L^{2.88}$	Fisheries NZ 2018, vol 2, p651	*Evechinus chloroticus*	from info in text p657	Fisheries NZ 2018, vol 2, p651
Echinoderms	Amphiuridae	Amphiura sp.	Assumption of ½ Astropecten			Assumption of ½ Astropecten		
Echinoderms	Astropectinidae	*Astropecten polyacanthus*	Echinodermata species	from info in text	Ventura *et al.*, 1995	*Astropecten aranciacus*	$L = 136.75\ (1-e^{-0.44(age-0.017)})$	Baeta *et al.*, 2016
Cephalochordates	Brachiostomidae	*Epigonichthys hectori*	*Branchiostoma belcheri*	range 0.2 to 0.3g at 30 to 40mm	Henmi & Yamaguchi, 2003	Assumption of 0.2g / y		

Note1: Many species have no specific information, and equations from species of the same taxonomic group were used. Calculated growth and weight have numerous biases from these approximations. All results were checked for unreasonable weight ranges and readjusted with other equations if not appropriate.

Note 2: *Amalda* spp includes three species (A. *australis*, A. *depressa* and A. *novaezelandiae*). *Cominella* spp includes two species (C. *adspersa* and C. *quoyana*). *Myadora* spp includes two species (M. *boltoni* and M. *striata*). *Dosinia* spp includes 2 species (D. *subrosea* and D. *maoriana*).

Note 3: The percentage shell weight to green weight was estimated for the thick bivalves (*Glycymeris*, *Gari*, and *Dosinia*) from *Dosinia* values (65%) in Aljadani (2013). The percentage shell weight for other taxonomic groups are estimates based on the "shell" volume, thickness and form. 20% was used for the arthropods and Cephalochordates, considering their thin chitin and volume of notochord. 80% was used for the gastropods considering their general thick shell, except for *Sigapatella*. 50% was used for the thin bivalves such as *Myadora*, *Nucula*, and for *Sigapatella*. 90% was used for echinoderms considering the volume of their test relative to their whole body.