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Anadara GRAY, 1847 OF KIRIBATI AND FIJI: LENGTH-HEIGHT-BIOMASS RELATIONSHIPS

by

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ABSTRACT

The *Anadara* species from Kiribati and Fiji (Viti Levu) were collected and compared for morphological characteristics using the Multivariate Analysis method with the support of the taxonomic verification provided by Dr. John Stanisic of the Malacology Department of the Queensland Centre for Biodiversity, Queensland Museum, Australia.

The *Anadara* species from Kiribati and Fiji share some morphological characteristics but also differ in others. The two species verified from Kiribati are *Anadara holoserica* and *Anadara uropygmelana.* The former is the living form while the latter is either an extinct form or is in very low densities. Four species of *Anadara* living form identified from the collections made from three sites around Viti Levu (Nasese, Verata and Nadi) are *Anadara antiquata, Anadara maculosa, Anadara anomala* and *Anadara scapha. A. maculosa, A. antiquata* and *A. anomala* are common in the Nasese-Laucala area. *A. scapha* and *A. maculosa* are found in Verata while *A. maculosa* appears to be the only species found in the Nadi area. There may be a half dozen more *Anadara* species in Fiji that are yet to be properly identified.

The correlation coefficient between height and length in all five species (living forms of *Anadara* from Kiribati and Fiji) is positively high ($r > 0.8$) while the coefficient of determination (r^2), whose value ranges from 0.64 to 0.96 in the same species, suggested that between 64% and 96% of variation in height is explained by variation in length. Similarly, r value ranges from 0.8 to 0.9 and r^2 from 0.7 to 0.8 for the BLR, and for the BHR, r value ranges from 0.7 to 0.9 and r^2 from 0.6 to 0.9. These values suggest that there is a high positive correlation between biomass and length and height, and that 60% and 90% of variation in biomass is explained by variation in length and height.

The power growth relationship, for *Anadara holoserica,* between Height and Length (HLR) is $H = 0.9304L^{09267}$; between Biomass and Length (BLR) is $B = 0.0009L^{2.6646}$ and between Biomass and Height (BHR) is $B = 0.0019H^{2.745}$ Height is negatively

allometric with respect to length and biomass is negatively allometric with respect to both shell length and height.

The power growth relationship, for *Anadara anomala,* between Height and Length is $H = 0.961L^{0.913}$; between Biomass Height is $B = 0.002H^{2.7403}$ Height is negatively allometric with respect to length and biomass is negatively allometric with respect to both length and height.

The power growth relationship, for *Anadara antiquata,* between Height and Length is $H = 0.657L^{1.0154}$; between Biomass and Length is $B - 0.0002L^{3.091}$ and between Biomass and Height is $B = 0.001H^{3.091}$ Height is positively allometric with respect to length and biomass is positively allometric with respect to length and height.

The power growth relationship, for *Anadara scapha,* between Height and Length is $H = 1.0373L^{0.8912}$; between Biomass and Length is $B = 0.0036L^{2.3609}$ and between Biomass and Height is $B = 0.009H^{2.3761}$. Height is negatively allometric with respect to length. Biomass is negatively allometric with respect to both shell length and height.

The power growth relationship, for *Anadara maculosa* between Height and Length is $H = 1.7195L^{0.765}$, between Biomass and Length is $B = 0.003L^{2.3609}$ and between Biomass and Height is $B = 0.009H^{2.3761}$ Height is negatively allometric with respect to length and biomass is negatively allometric with respect to length and height.

Anadara antiquata appears to be the only species displaying isometric growth in all three parameters studied. Thus the periostracum (outer shells encapsulating soft parts of animal) increases in both dimensions (height and length) at the same rate; and when either length or height double the biomass will increase in relation to the increase in volume by 8 (or 2^3) These cubic relationships can be represented by the power curve equation, $W = aL^b$ where b is close to 3 in isometric growth and a is a constant determined empirically. *Anadara holoserica,* however, is the second species with values of b very close to 3, $b = 2.6646$ for the BLR and $b = 2.7145$ for the BHR. Therefore, *A.*

holoserica, in this respect, can also be considered as having an isometric growth with respect to the three parameters being investigated.

Voucher specimens of the five living forms, one from Kiribati (Tarawa and Nonouti (Catalog No. 5019) and four from Fiji (Viti Levu, Catalog Nos. 5015 - 5018) are with the Marine Collection of the University of the South Pacific, Suva, Fiji. Middens of old shells of *Anadara uropygmelana* from North Tarawa, Kiribati are also with the Marine Collection (Catalog No. 5020).

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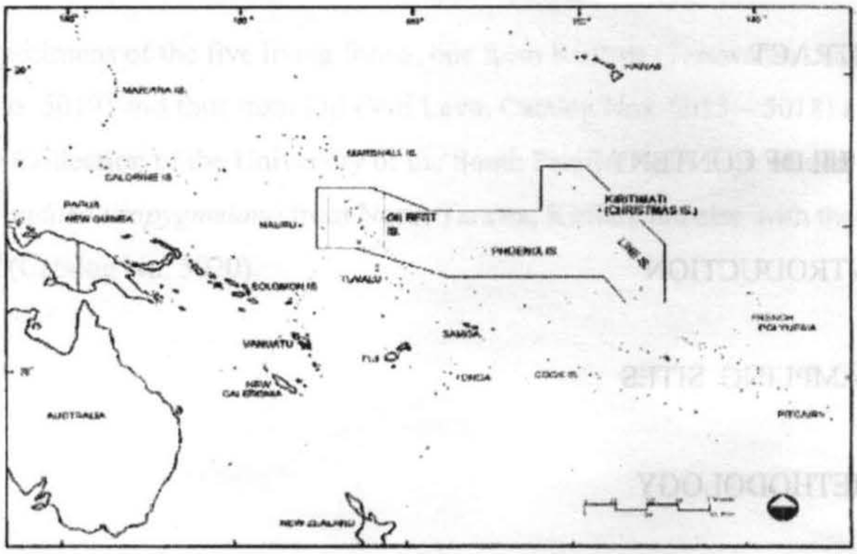
Figure 1a: Map of South and Central Pacific showing the positions of the Republics of Kiribati with the Gilbert group (inserted) and of the Fiji Islands (Fig. 1b below).



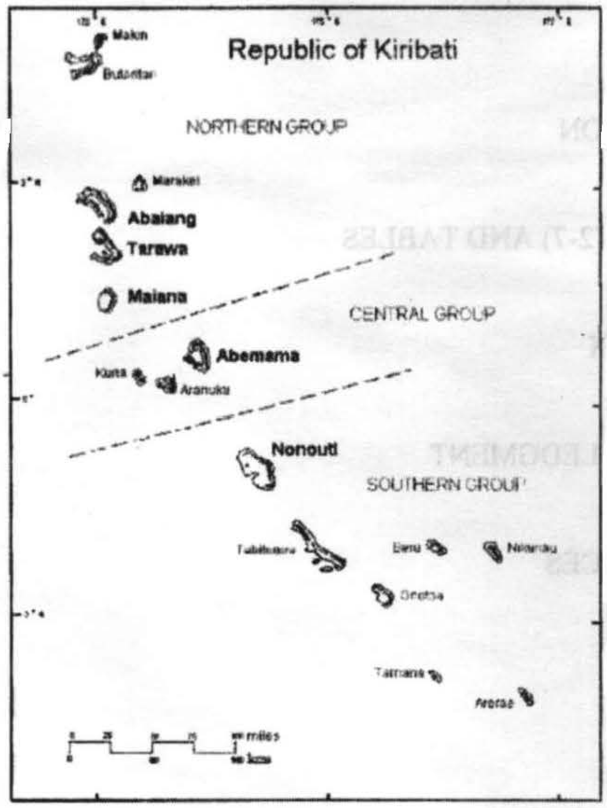
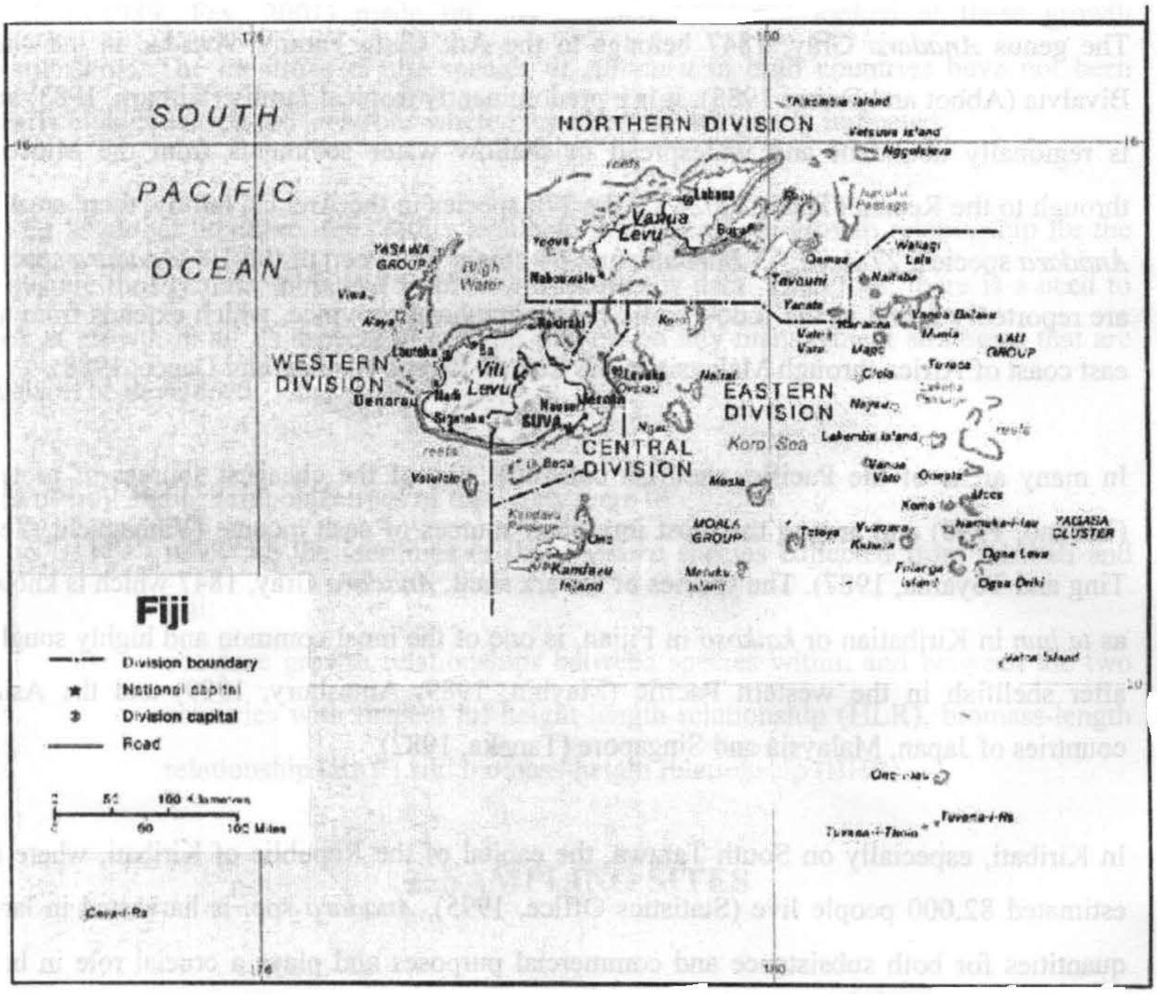


Figure 1b: Map of the Republic of the Fiji Islands.



1. INTRODUCTION

The genus *Anadara* Gray, 1847 belongs to the Ark Clam Family, Arcidae in the class Bivalvia (Abbot and Dance 1988). It is a predominantly tropical family (Kilburn, 1983) and is regionally abundant and widespread in shallow water sediments from the Miocene through to the Recent (Todd, 2002). Of the 270 species in the Arcidae family, there are 106 *Anadara* species, 27 *Area,* 73 *Barbatia* and 64 others. Eighteen of the 106 *Anadara* species are reportedly found in the Indo-Pacific biogeographical province, which extends from the east coast of Africa through Malaysia to the Central Pacific (Abbott and Dance, 1988).

In many areas of the Pacific, shellfish constitute one of the cheapest sources of protein (Tebano, 1990) and among the most important sources of cash income (Yamaguchi, Yee-Ting and Toyama, 1987). The species of the ark shell, *Anadara* Gray, 1847 which is known as *te bun* in Kiribatian or k*aikoso* in Fijian, is one of the most common and highly sought-after shellfish in the western Pacific (Maybin, 1989; Amesbury, 1999) and the Asian countries of Japan, Malaysia and Singapore (Tanaka, 1982).

In Kiribati, especially on South Tarawa, the capital of the Republic of Kiribati, where an estimated 82,000 people live (Statistics Office, 1995), *Anadara* spp. is harvested in large quantities for both subsistence and commercial purposes and plays a crucial role in both social and economic terms (Boulton, 1982; Biosystems Analysis Inc. 1994). In Fiji, especially on the main and capital island of Viti Levu, where about one quarter of the 844,330 people live (July 2001 est.) the shellfish is also harvested in huge quantities for both subsistence and small scale markets (Fay, 2001)

Because of the critical importance of *Anadara* spp. in the food security of Kiribati and Fiji, and the increasing pressures on marine food resources, as a result of overexploitation and environmental changes, there is a need for in-depth studies on aspects of the biology of these resources. Of interest to this study are the species of *Anadara* present in both countries and their growth relationships in terms of height-length (HLR), biomass-length (BLR) and biomass-height (BHR). Previous studies in Kiribati (for example, Boulton, 1982; Yamaguchi *et al,* 1987; Tebano, 1989, 1990; Fay, 2001), and Fiji (Spennemann, 1987; Maybin, 1989; Fay, 2001) made on this arkshell have not looked at these growth relationships. The identities of the species of *Anadara* in both countries have not been clearly elucidated and the locations where they exist are not clearly indicated.

As far as global literature, the readily available information on growth relationship for the genus are mostly those obtained from length-frequency data. Therefore, there is a need to look at growth in all its aspects to provide support on any management strategies that are likely to be developed.

The overall and general objectives of this study were to:

1) report on the identities of the *Anadara* species collected from Kiribati and Fiji;
2) compare growth relationships between species within and between the two countries with respect to: height-length relationship (HLR), biomass-length relationship (BLR) and biomass-height relationship (BHR).

2. SAMPLING SITES

The Kiribati *Anadara* specimens (for a living form) were collected from the lagoons of Nonouti and Tarawa atolls in the Gilbert group, Kiribati. Middens of old shells (for the second form) were collected from dug-out pits on a remote islet of Tabiteuea in North (Rural) Tarawa (Fig. la). Specimens for Fiji's *Anadara* living forms were collected from the seagrass and mudflat of the following areas: Nasese (Urban Suva District), Verata (Tailevu District) and Denarau (Nadi District) (Fig. 1b)).

The Republic of Kiribati has a total land area of only 822.8 km^2. It consists of thirty three islands in three main groups - the Gilbert Islands, the Phoenix Islands, the Northern and Southern Line Islands plus the single island of Banaba (rock only), 400 km to the west of the Gilbert Islands (Thaman and Tebano, 1992) (Fig. 1). Nonouti Atoll is situated just south of the Equator in the Gilbert Group, approximately 0°35'S latitude and 174°20'E longitude (Pearson, 1999) while Tarawa Atoll is situated north of the Equator in the Central Gilbert Group, between 1°18'N and 1°38*N latitude and 172.0°55'E and 173.0°10'E longitude (Pearson, 1999). South Tarawa is the main administrative center.

The Republic of the Fiji Islands has a total land area of 18,270 km^2 and includes three hundred and thirty two islands of which approximately one hundred and ten are inhabited (The World Factbook, 2002). The total population is around 844,330 (July 2001 estimates). Its geographic coordinates are 18°00'S latitude and 175°00' E longitude (The World Factbook, 2002). Viti Levu is the biggest and main capital island with Vanua Levu in the north as the second largest island.

Nasese is within the Suva City area on the eastern side of Viti Levu and stretches from the Suva Harbor toward the Muanikau area. It is located roughly at 17°51'S latitude and 178°34'E longitude. Verata is a coastal district and comprises of eight villages within the province of Tailevu on the eastern-shore of Viti Levu and is situated at 17°51'S latitude and 178°34'E longitude (Fay, 2001). Denarau Island is on the outskirt of the Nadi Town in western Viti Levu and is located at roughly 17°47'S and 177°29'E longitude.

3. METHODOLOGY

Fresh and middens of old shells from Kiribati were air freighted and brought to the Marine Studies Laboratory, University of the South Pacific, Suva in the second week of March, 2002. The fresh animals were chilled with ice cubes while the old shells were wrapped in soft clean tissue paper. Samples from around Viti Levu, Fiji were collected at different times during the month of March through May, 2002.

The fresh specimens were properly washed with tap water and dried with tissue paper. The wet weight (or biomass) of the animals were taken, the length and height were also taken immediately after weighing (Appendix 1). This is to ensure that the moisture in the animal meat was not lost unnecessarily. Wet weight was recorded in grammes (g) to one decimal point using a digital weighing scale; height and length were recorded in millimeter (mm) to one decimal point using a metrically-calibrated vernier caliper. Middens of old shells were properly dusted and treated similarly as the fresh shellfish.

For the initial comparison of shell morphology the Multivariate analysis using Principal Components Analysis (PCA) was employed (Figs. 2a and b; Tables 1 and 2). Data for all specimens from Nasese, Verata arid Nadi (Fiji) were compared with those from Tarawa and Nonouti (Kiribati). Voucher specimens of the same specimens were sent to the Malacology Department of the Queensland Centre for Biodiversity at the Queensland Museum, Australia for verification (Table 3).

The mean and standard error of each of the 7 variables subjected to the Multivariate Analysis for each specimen were plotted using a histogram to visualize and compare the extent of variability around each mean (Figs. 3a-g; Table 4).

Data for growth relationship (H-L; B-H and B-L) for each species identified was plotted using both the power and regression plots (Figs. 4 - 8). The values for *a* (being the intercept) and *b* (being the slope of a growth curve) are shown in Table 5. Growth equations for each type of relationship are displayed on each respective graph (Figs. 4-8).

The power model was used to investigate relative growth rates of different parts of the body:

$$Y = aX^b$$

where Y is the dimension predicted by the reference dimension, X. The parameters to be estimated can be obtained from the linear form of the power model, derived by taking natural logarithms:

$$\ln Y = a + b \ln X$$

The two parameters can be estimated by using linear regression methods. We are interested in the relationships between the three variables: length, height (width) and biomass. When investigating relative growth, between two linear dimensions, we expect that if the growth rate remains constant, and the value of *b* = 1.0 then growth is said to be isometric. However, if the value of *b* is significantly less than 1.0, growth is said to be negatively allometric and if it is significantly more than 1.0 growth is said to be positively allometric. Allometry measures the degree to which one variable grows faster (or slower) than the other.

The parameters *a* (intercept) and *b* (slope) were estimated for the height-length relationship (HLR), the biomass-length relationship (BLR) and the biomass-height relationship (BHR) by non-linear estimation using Microsoft Excel software (Version 5). Thus the expected value (assuming isometry) of *b* for HLR is 1.0, while the expected values (assuming isometry) for BLR and BHR are 3.0, because in the latter two cases, one variable is a single dimension while the other measures a volume. So in this case negative allometry would be indicated when *b* was significantly less than 3.0 and positive allometry when *b* was significantly more than 3.0. The practical application of these relationships is that you can predict biomass given L or H values.

4. RESULTS

The coefficients of linear combinations of variables (SP1 biomass, SP1 length, SP1 Width (Height), SPlThickness, SPlBeak distance, SP1No. Teeth and Ribs) make up Principal Components (PCs 1-5) (Tables 1 and 2) and the same variable combinations shown in Table 4 present a general trend that the number of teeth and ribs and the distance of a beak from a hingeline seem to be poor indicators of species differences compared to other variables, such as biomass, shell length, width (height) and thickness (Figs. 3a - g). Plots of variables compared and contrasted, using the assumption that there are two different *Anadara* species (one each from Kiribati and Fiji) (Figure la) and then assuming only a single species (Figure 2b) show that there are 3 potential species, one for Kiribati and two for Fiji. In addition, there are three outliers and that the single Kiribati outlier falls between one of each of the other potential species from Fiji and Kiribati. Of the Fiji's outliers, one falls between two of its [Fiji] potential species. The second outlier appears to be related only to one of the potential species (Fiji). These suggest that there are four species in Fiji, two of which resemble the other two distinct species and can be easily confused (Fig. 2a). For Kiribati there are two possibilities, 1) there is only one species that shares some characteristics with those of Fiji's species or 2) there are two distinct species and one of them is closely related to one of Fiji's distinct species (Fig. 2a). The second analysis based on the single species (Figure 2b) clearly shows five potential species with two of the Fiji species, Nadi (F3) and Nasese (F1) are closely related while Tarawa (Kl), Nonouti (K2) (Nonouti) and Verata (F2) are quite far apart. Both analyses suggest that Kiribati could possibly have 1 or 2 forms and Fiji 3 or 4. Overall, the *Anadara* species from Kiribati and Fiji share some morphological characteristics but differ in others.

When these results are compared with those provided by the Queensland Museum, it is clear that Fiji (Viti Levu only) has 4 distinct species, *Anadara maculosa,* (Reeve, 1843), *A. antiquata* (Linnaeus, 1758), *A. scapha* (Linnaeus, 1758) and *A. anomala* (Reeve, 1843) (Table 3). Using PCA only 2 species with 2 outliers were initially detected from Fiji (Fig 2a), but on the PCI axis one of these groups was more variable and it may be that this group actually contains two species that PCA cannot detect.

For Kiribati, the identified living form is *A. holoserica* (Reeve, 1843) and a presumed extinct form (midden of old shells) or with very low density is *A. uropygmelana* (Bory de St. Veincent, 1824). The Tarawa and Nonouti forms both belong to *A. holoserica* and there is a possibility that some characteristics of *A. uropygmelana* is shared by *A. holoserica* and one of Fiji's species as shown by the 2-species PCA analysis (Fig. 2a).

For Fiji, the identified living forms of *Anadara* are *A. anomala* (Nasese and Laucala Bay), *A. antiquata* (Nasese), *A. scapha* (Verata) and *A. maculosa* (Nasese-Laucala area, Verata and Nadi).

Table 5 displays the values of *a* (point of intercept) and *b* (slope of curve) for the relative growth relationships between height and length (HLR), biomass and length (BLR) and biomass and height (BHR). The coefficient of determination (r2) and correlation coefficient, r, are also displayed in Table 5. Table 6 lists the power and regression curve equations for the five species.

All species of *Anadara* from the two countries show high coefficients of determination with regards to HLR, r^2 = 0.64 - 0.96, suggesting that between 64% and 96% of the variation in height is explained in the variation in length. The correlation coefficient, r = 0.810 - 0.982 suggests a very strong positive correlation between the two parameters, and were significant at pO.OO1. A similar pattern is also exhibited in the BLR where r = 0.710 - 0.822 and r = 0.843 - 0.907 suggesting that between 70% and 80% variation in biomass is explained in variation in length, and that the two parameters are strongly and positively correlated. The BHR also shows a similar pattern with r = 0.616 — 0.911 and r =0.785 - 0.954.

When comparing all three relationships for the five species (Table 5), it is clear that all are negatively allometric in the HLR because the value of *b* (instantaneous growth increment or slope of curve) is less than 1, except A *antiquata* with *b* = 1.015. Since this value is > 1 it an isometric growth, that is, the periostracum increases at the same rate in both dimensions. In the BLR and BHR, all relationships are also negatively allometric except *A. antiquata* with *b* > 3.091 and 3.019, respectively. Taking the value of *b* to one decimal point, these relationships can be treated as isometric growth suggesting that when the animals double in length or height, their biomass will increase in relation to the increase in volume; that is, by 8 (or 2^3) times. Thus there is a cubic relationship between length (L) and biomass (B) and height (H) and biomass (B), which can be represented by the cubic or power curve equation, $W = aL^b$ or $B = aL^b$ where *b* is close to 3 in isometric growth, and *a* is a constant determined empirically. The values of *b* in the power relation in the BLR and BHR for *A. holoserica* are 2.665 and 2.725, respectively. Taking into account of the closeness of these values to 3, *A. holoserica* may also be considered as having an isometric growth with respect to the relationship in between the three parameters.

The regression plot for HLR shows that both parameters intersect at H = 0 when L = -0.16 Other species intersect at H = 0 when L is between 2-3 with the highest value for L of 8.95 for *A. maculosa* (Table 6). The regression plots for the BLR and BHR shows the biomass intersects length and height at negative values (ranging from -19.97 to - 104.92) for all species except for *A. scapha* whose biomass intersects height at 3.28 (Table 5). These results suggest that height is negligibly too small when length is physically measurable.

5. DISCUSSION

The identification of animals and plants to the species level is no easy task. This is often the result of inadequate original descriptions and regional variation not having been encapsulated. Even with the increasing availability of sophisticated analytical techniques, such as DNA comparison and electrophoretic analysis, and their use in the recognition of sub-generic divisions, including the genus *Anadara*, identification results vary greatly from author to author (Sasaki, 1990; Todd, 2002).

Gray (1847) defined the Arcidae family primarily on the basis of shell morphometric characteristics most distinct to the complex (Dodge, 1952). Shell shape and relative size of the left and right valves are important but there is high level of variation. Consequently there has been much dispute about the identity of many species. In his revision of *Anadara* Gray, 1847 Kilburn (1983) noted, in reference to the systematics and nomenclature of African species of *Anadara*, "that there may exist a gradual transformation sequence between the inaequivalve and equivalve states within the genus". In Africa Kilburn (1983) recognized *A. uropygmelana* (Bory de St. Vincent, 1824), which can be confused with *A. holoserica.* During the course of the present study I collected living specimens of what was initially presumed to be *A. uropygmelana* but subsequently these were identified at the Queensland Museum as being *A. holoserica* (Table 3).

The comparison of the two Kiribati and three Fiji *Anadara* populations showed that there are phenotypic variations within and between sites with a possibility that Kiribati has two forms while Fiji may have at least three forms. The examination of morphological characteristics showed that *A. scapha* has been identified from Fiji (see also Koven, 1997).

The identity of the Kiribatian living form, which has been wrongly named as *A. maculosa* by Boulton (1982) and Tebano (1983), is now *A. holoserica.* The second form, *A. uropygmelana,* that Paulay (pers. comm., 1993) assumed to be the living form of *Anadara* in Kiribati is either extinct or in very low densities.

The identity of the *Anadara* empty shells from Fiji sent to the Queensland Museum, showed that the Fiji forms include *A. scapha, A. antiquata, A. anomala* and *A. maculosa* with the latter two names considered to be more accurate than those used by Maybin (1989). Three of these are found in the Suva area (Nasese- Laucala Bay and Kinoya mudfiat and seagrass beds). They are *A. maculosa, A. antiquata,* and *A. anomala.* The two forms that exist in Verata are *A. maculosa* and *A. scapha. Anadara maculosa* appears to be the only species found in the Nadi area.

Maybin (1989) identified three species of *Anadara* from four South Pacific countries, Fiji, Tonga, Samoa and Vanuatu. These include *A. antiquata* (found in all four countries) while *A. inaequivalvis* (Bruguiere, 1789) and *A. subcrenata* (Lischke, 1869) are found in Fiji only. The Fiji's forms previously presumed to be *A. subcrenata* and *A. ineaquivalvis* are yet to be confirmed. However, these would probably fit in with *A. maculosa* and *A. anomala*, respectively, according to the latest verification by the Queensland Museum. This study agrees with the presence of *A. antiquata, per se,* but the absence of deposits of the specimens makes accurate comparison impossible. Maybin (1989) included *A. ineaquivalvis* in her listing but this name probably should have been *A. anomala* if the description refers to unequal sizes of the valves which is distinct to *A. anomala.* The *A. subcrenata* should probably be *A. maculosa. Anadara scapha* was never mentioned because probably it was misidentified as *A. antiquata.* Both *A. anomala* and *A. antiquata* look identical when single valves are examined. One of the two specimens obtained from Samoa appears to be morphologically identical to the Fijian *A. maculosa* while the other is identical to *A. antiquate* (Table 3).

Studies available on growth of various species of *Anadara* are mostly based on length-frequency data from which L., and K values were derived. These include studies by Pathansali and Soong (1958) and Broom (1982) on *A. granosa,* Yoo and Park

(1978) and Kwon and Cho (1986) on *A. broughtonii,* and Kayombo and Manoya (1987) on *A. antiquata.*

The findings of Yoo and Park (1978) show that growth in the animal they studied is non-linear and that instantaneous growth fits most growth patterns. This takes into account not only growth increment per unit time but also other factors that affect growth in one way or another.

The work of Pathansali and Soong (1958) and Broom (1982) showed that the animals grew from a range of 4-10 mm to 18-32 mm in 8 months (roughly 2 mm/mo) on the natural beds, and that density and exposure (height on the shore) were the major factors exerting an influence on growth rate, resulting in poor growth of approximately 0.10 mm mo" respectively. In addition extreme salinity fluctuations may be important in marginal populations (Broom, 1981). Oon (1986) and Yulianda (1995) stressed that factors that could seriously affect growth in the animals are salinity, turbidity, substrate composition and human exploitation.

The most striking factor that must have affected growth and density of the Kiribati *A. holoserica* is human exploitation. This is reflected in the sizes of the animals that rarely exceeded 60+ mm (Tebano, 2002 in progress). He also observed that growth could have resulted from the combined effect of recruitment and human over-exploitation of the larger animals. These factors and others could substantially cause errors in the estimation of growth parameters. The small sizes of *kaikoso {Anadara)* sold in the Suva and Nadi markets indicate a decline in the amount of large animals. This can drastically affect the viability of the stocks in terms of recruitment and population rejuvenation.

Growth in terms of height and biomass can be valuable where length measurements are cumbersome to take (Everhart, *et al,* 1953). These parameters can easily be converted into length data if growth relationships between these parameters are known. In most aquaculture ventures where tonnage is talked about and not length or height, the biomass of a product is very important (e.g., for bivalves and even in finfish) (Everhart *et al,* 1953). If the growth relationship between length and height is isometric then growth factors can be easily calculated provided one of the parameters is known and other terms defined. It is clear in this study that *Anadara antiquata* is the only species whose growth is isometric both in the HLR, BLR and BHR. This can be interpreted as having more meat content per unit volume than the other four species. This fits in with literature that it is one of the most studied *Anadara* species in the areas of growth and culture for commercial purposes (Kastoro, 1978; Broom, 1985; Kayombo and Mainoya, 1987; Kasigwa and Mahika, 1991; Yulianda, 1995).

Biomass can provide a vital cue in mortality determination. A population which is subject to increased mortality will respond by increasing in biomass, that is, by increasing growth, reproduction, and survival; whereas a population at its highest levels of biomass will experience increasing mortality, decreasing growth and reproduction (King, 1995; Everhart *et al*, *19*53). This idea forms the basis of various fisheries recruitment and yield models.

A body of literature on the various growth parameters on the genus *Anadara,* particularly the species in this study, is still growing. So far the results obtained from this work and similar studies have provided first hand and useful information required for more informed management of these important resources. These information need to be seriously studied by fisheries planners and interested stakeholders to determine how these resources respond to over-harvesting and other factors. There is also a need to extend the study on *Anadara* to other related shellfish of economic importance to the neighboring islands in the region of the University of the South Pacific.

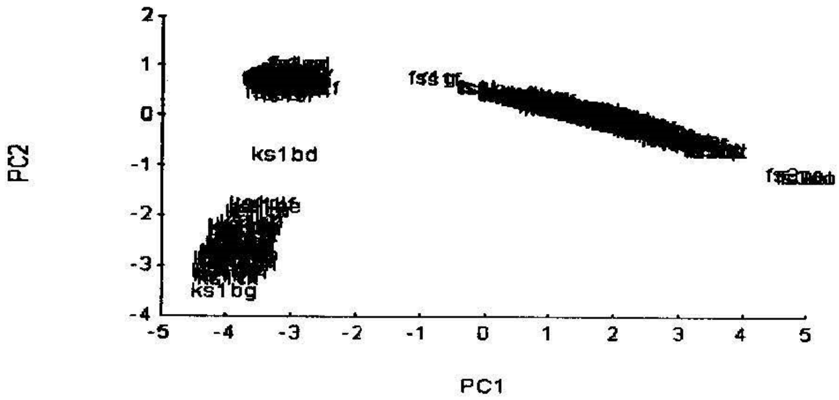
6. FIGURES AND TABLES

Figure 2a: A plot of a Multivariate Analysis comparing morphological characteristics of *Anadara* species from Kiribati and Fiji using the Principle Component Analysis (PCA) assuming 2 species.
(See Appendix i-a for raw data).

Figure 2b: A plot of a Multivariate Analysis using PCA and grouping study sites from Kiribati and Fiji under one species,
(see Appendix i-b for raw data).

Figure 2:

a)



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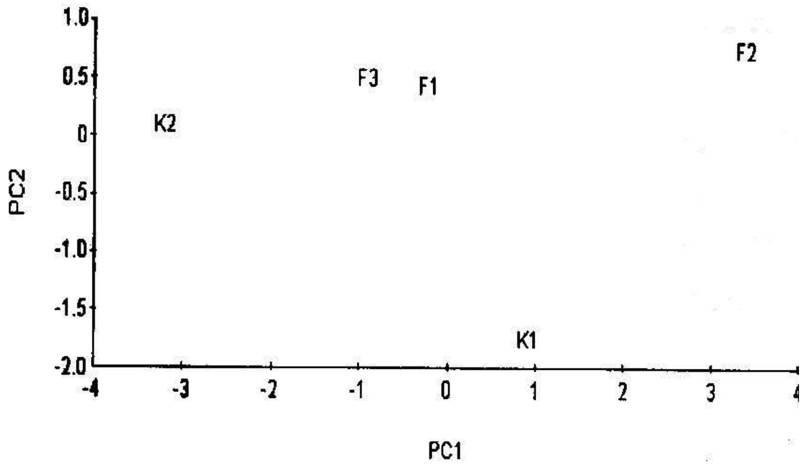


Figure 3a: A plot of mean biomass for *Anadara holoserica* of Kiribati and of Fiji species with SE bars showing the variation of the mean biomass of specimens (around overall mean) from Tarawa - Kirl **(1),** Nonouti-Kir2 (2), Nasese - Fjl (3), Verata - Fj2 **(4)** and Nadi - Fj3 (5).

Figure 3b: A plot of mean shell length (SL) *for A. holoserica* of Kiribati and of Fiji species with SE bars showing the variation of the mean SL of specimens (around overall mean) from the same study sites above.

Figure 3c: A plot of mean width (height) for *A. holoserica* of Kiribati and of Fiji species with SE bars showing the variation of the mean height of specimens (around overall mean) from same study sites above.

Figure3d: A plot of mean fatness (thickness) for *A. holoserica* of Kiribati and of Fiji species with SE bars showing the variation of the mean fatness of specimens (around overall mean) from study sites shown above.

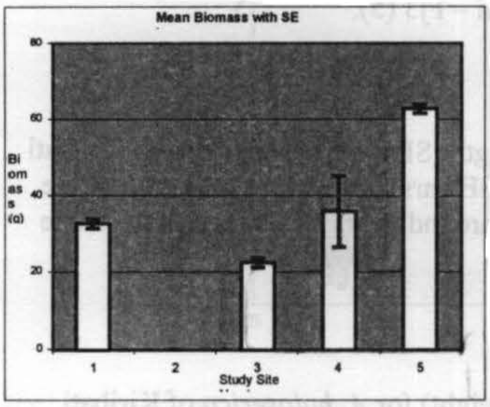
Figure 3e: A plot of mean beak distance from hingeline for *A. holoserica* of Kiribati and of Fiji species with SE bars showing the variation of the mean distance of beak of specimens (around overall mean) from same study sites shown above.

Figure 3f: A plot of mean number of teeth for *A. holoserica* of Kiribati and of Fiji species with SE bars showing the variation of the mean number of teeth of specimens (around overall mean) from same study sites shown above.

Figure 3g: A plot of mean number of ribs for *A. holoserica* of Kiribati and of Fiji species with SE bars showing the variation of the mean of ribs of specimens (around overall mean) from the same study sites explained in Figure 2a.

Figure 3: Plots of means of variables (biomass, length, height, thickness, beak distance from hingeline, number of teeth and number of ribs) for *Anadara* specimens from Kiribati and Fiji.

a



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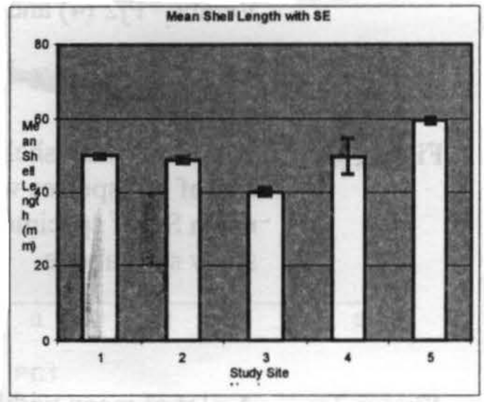

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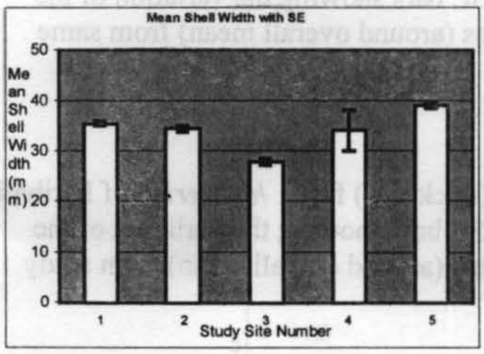

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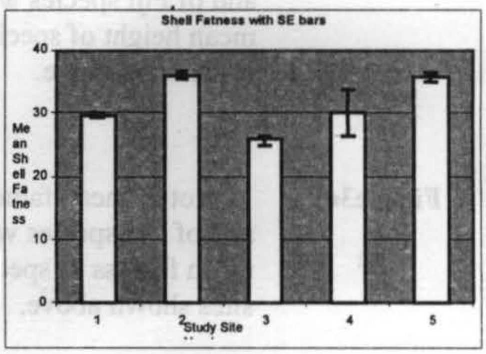

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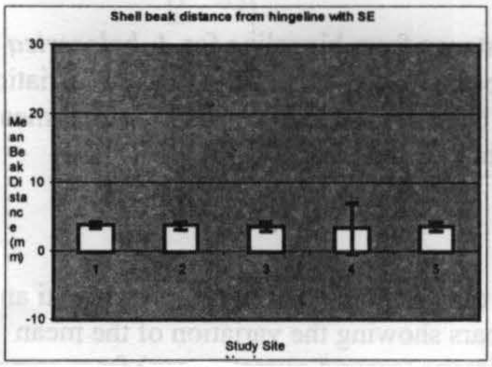

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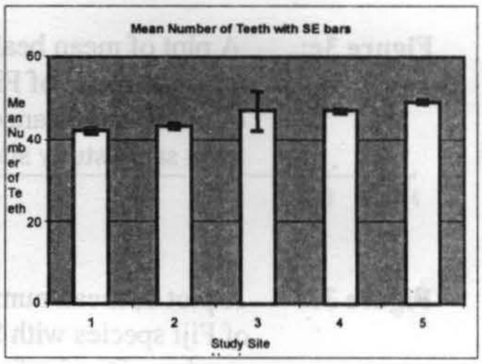
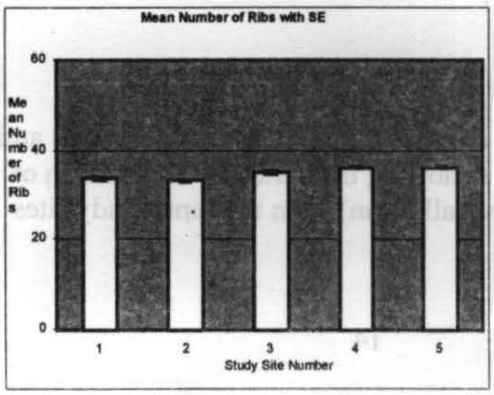


g



Growth Correlation plots of *Anadara holoserica* between:

a) Height and Length (power curve)

b) Height and Length (linear curve)

c) Biomass versus Length (dark squares) and Height (dark triangles) (power curves)

d) Biomass versus Length (dark squares) and Height (dark triangles) (regression curves)

Figure 4:

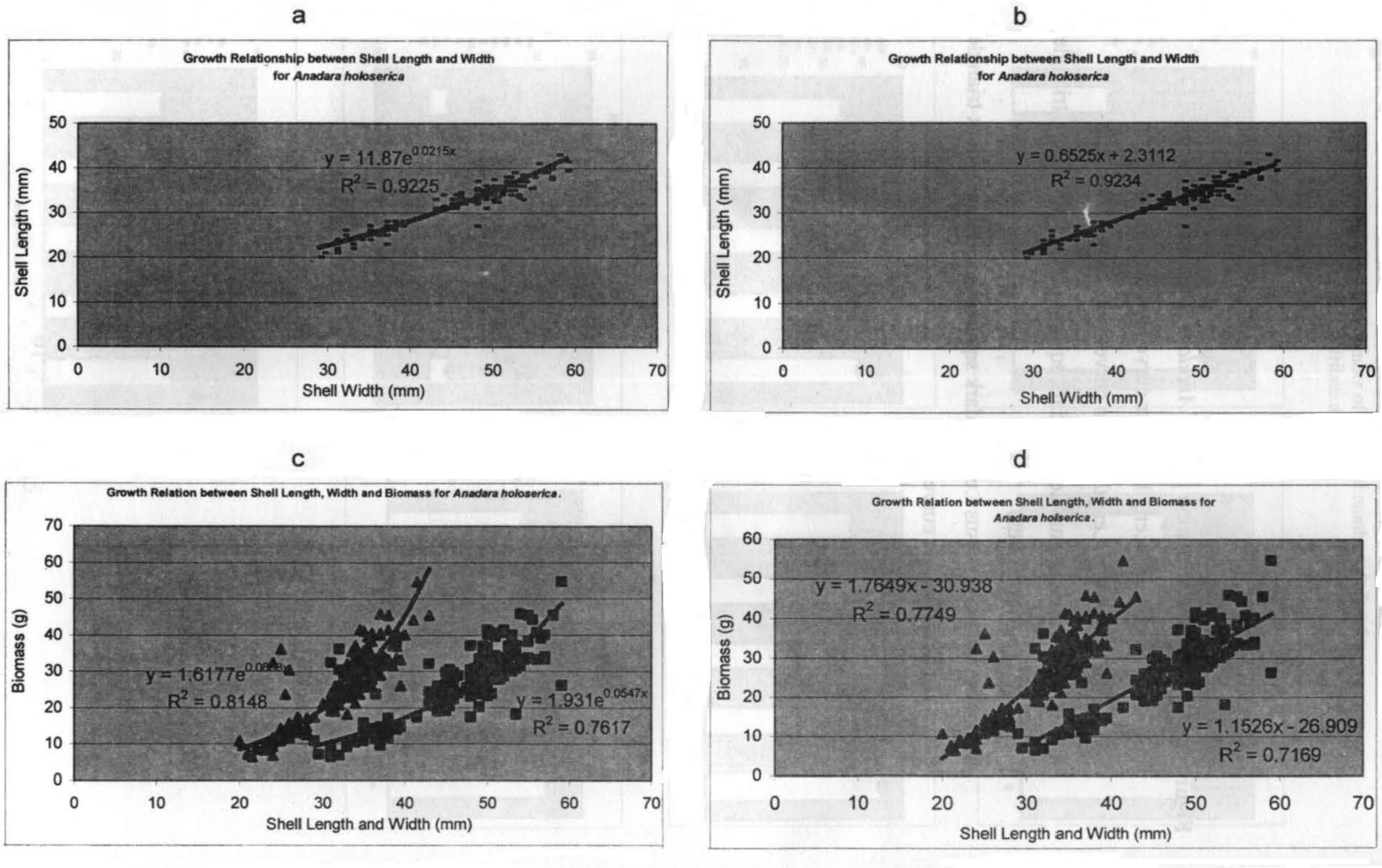

a
Growth Relationship between Shell Length and Width for Anadara holoserica
y = 11.87e^0.0215x
R² = 0.9225
Shell Length (mm)
Shell Width (mm)
b
Growth Relationship between Shell Length and Width for Anadara holoserica
y = 0.6525x + 2.3112
R² = 0.9234
Shell Length (mm)
Shell Width (mm)
c
Growth Relation between Shell Length, Width and Biomass for Anadara holoserica.
y = 1.6177e
R² = 0.8148
y = 1.931e^0.0547x
R² = 0.7617
Biomass (g)
Shell Length and Width (mm)
d
Growth Relation between Shell Length, Width and Biomass for Anadara holserica.
y = 1.7649x - 30.938
R² = 0.7749
y = 1.1526x - 26.909
R² = 0.7169
Biomass (g)
Shell Length and Width (mm)

Figure 5: Growth Correlation plots of *Anadara anomala* between:

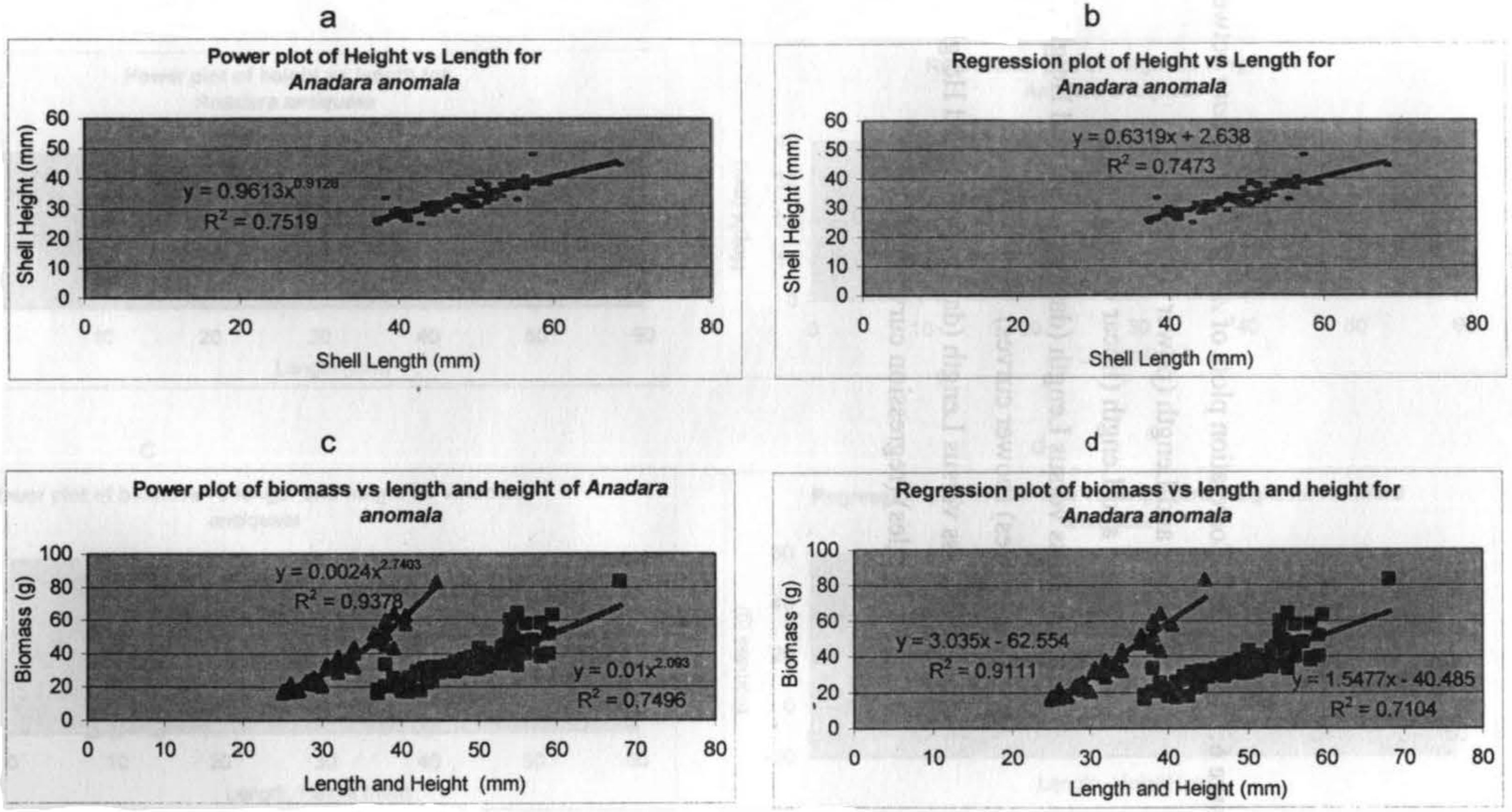
a) Height and Length (power curve)

b) Height and Length (linear curve)

c) Biomass versus Length (dark squares) and Height (dark triangles) (power curves)

d) Biomass versus Length (dark squares) and Height (dark triangles) (regression curves)

Figure 5:


a
Power plot of Height vs Length for Anadara anomala
y = 0.9613x^0.9128
R² = 0.7519
Shell Height (mm)
Shell Length (mm)
b
Regression plot of Height vs Length for Anadara anomala
y = 0.6319x + 2.638
R² = 0.7473
Shell Height (mm)
Shell Length (mm)
c
Power plot of biomass vs length and height of Anadara anomala
y = 0.0024x^2.7403
R² = 0.9378
y = 0.01x^2.093
R² = 0.7496
Biomass (g)
Length and Height (mm)
d
Regression plot of biomass vs length and height for Anadara anomala
y = 3.035x - 62.554
R² = 0.9111
y = 1.5477x - 40.485
R² = 0.7104
Biomass (g)
Length and Height (mm)

Growth Correlation plots of *Anadara antiquata* between:

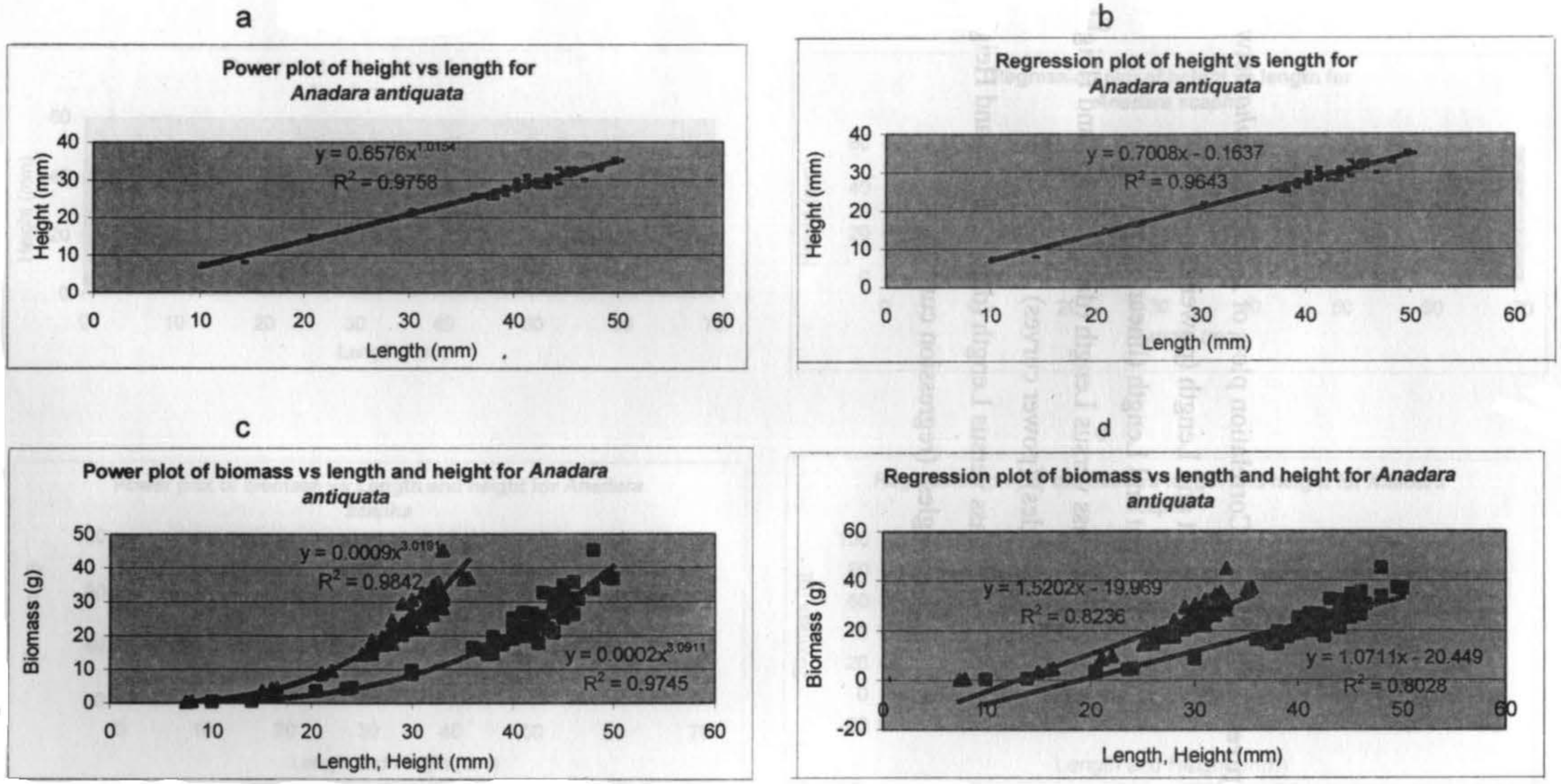
a) Height and Length (power curve)

b) Height and Length (linear curve)

c) Biomass versus Length (dark squares) and Height (dark triangles) (power curves)

d) Biomass versus Length (dark squares) and Height (dark triangles) (regression curves)

Figure 6:



a
Power plot of height vs length for *Anadara antiquata*
y = 0.6576x^1.0154
R² = 0.9758
Height (mm)
Length (mm)
b
Regression plot of height vs length for *Anadara antiquata*
y = 0.7008x - 0.1637
R² = 0.9643
Height (mm)
Length (mm)
c
Power plot of biomass vs length and height for *Anadara antiquata*
y = 0.0009x^3.0191
R² = 0.9842
y = 0.0002x^3.0911
R² = 0.9745
Biomass (g)
Length, Height (mm)
d
Regression plot of biomass vs length and height for *Anadara antiquata*
y = 1.5202x - 19.969
R² = 0.8236
y = 1.0711x - 20.449
R² = 0.8028
Biomass (g)
Length, Height (mm)

Figure 7: Growth Correlation plots of *Anadara scapha* between:

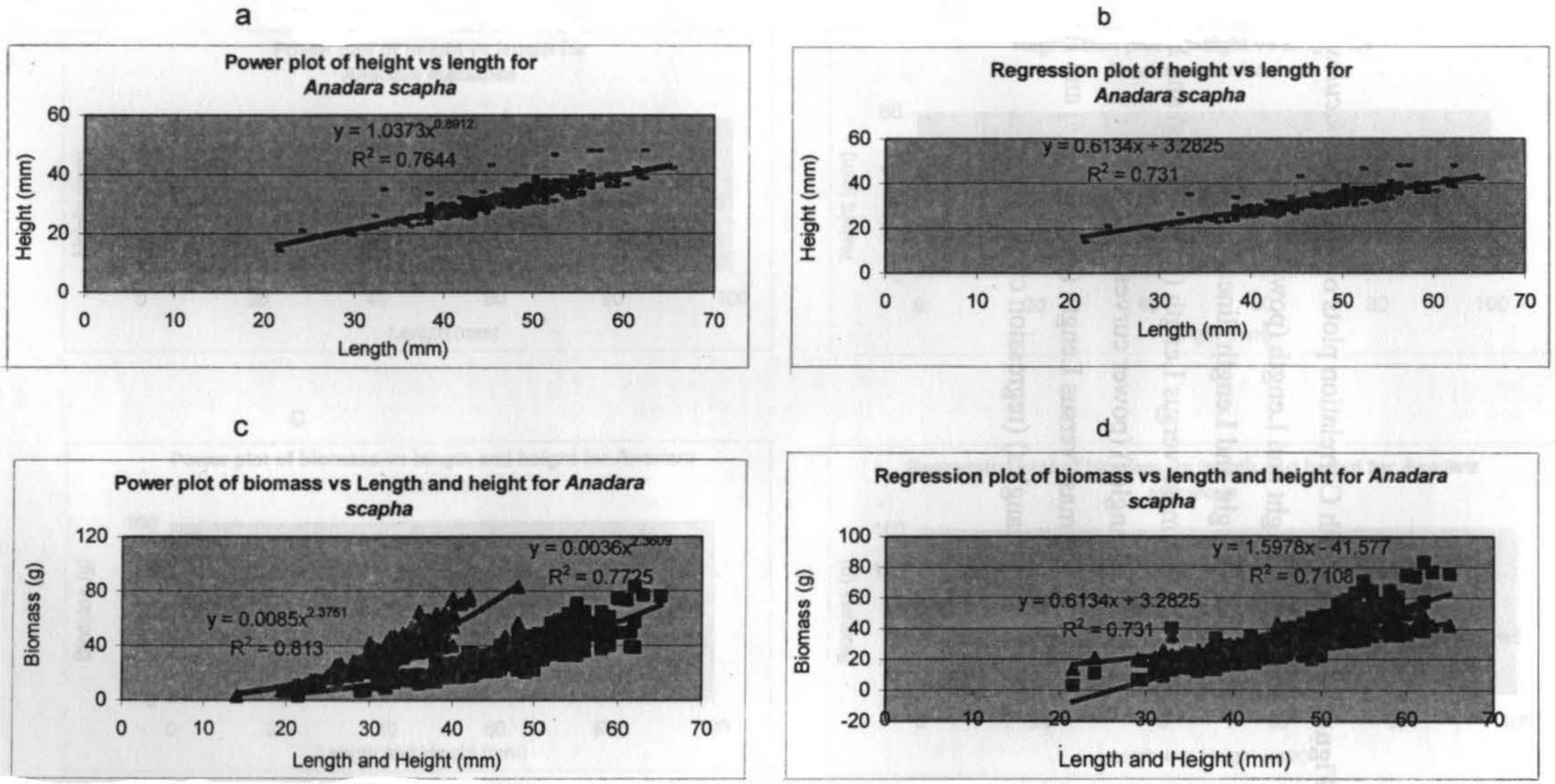
a) Height and Length (power curve)

b) Height and Length (linear curve)

c) Biomass versus Length (dark squares) and Height (dark triangles) (power curves)

d) Biomass versus Length (dark squares) and Height (dark triangles) (regression curves)

Figure 7:



a
Power plot of height vs length for
Anadara scapha
y = 1.0373x^0.8912
R² = 0.7644
Height (mm)
Length (mm)
b
Regression plot of height vs length for
Anadara scapha
y = 0.6134x + 3.2825
R² = 0.731
Height (mm)
Length (mm)
c
Power plot of biomass vs Length and height for Anadara scapha
y = 0.0085x^2.3761
R² = 0.813
R² = 0.7725
Biomass (g)
Length and Height (mm)
d
Regression plot of biomass vs length and height for Anadara scapha
y = 1.5978x - 41.577
R² = 0.7108
y = 0.6134x + 3.2825
R² = 0.731
Biomass (g)
Length and Height (mm)

Figure 8: Growth Correlation plots of *Anadara maculosa* between:

a) Height and Length (power curve)

b) Height and Length (linear curve)

c) Biomass versus Length (dark squares) and Height (dark triangles) (power curves)

d) Biomass versus Length (dark squares) and Height (dark triangles) (regression curves)

Figure 8:

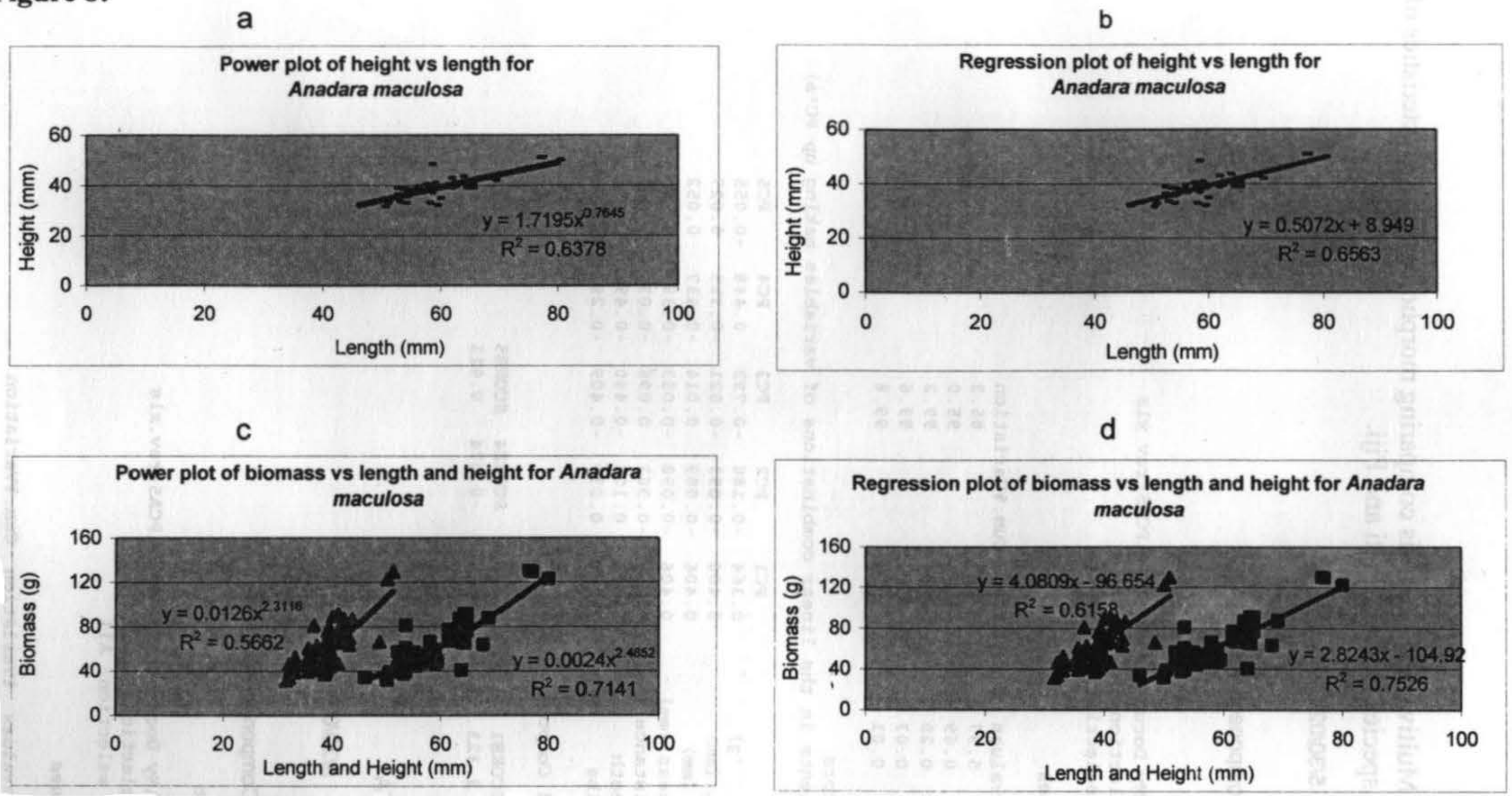

a
Power plot of height vs length for *Anadara maculosa*
Height (mm)
Length (mm)
y = 1.7195x^0.7645
R² = 0.6378
b
Regression plot of height vs length for *Anadara maculosa*
Height (mm)
Length (mm)
y = 0.5072x + 8.949
R² = 0.6563
c
Power plot of biomass vs length and height for *Anadara maculosa*
Biomass (g)
Length and Height (mm)
y = 0.0126x^2.3116
R² = 0.5662
y = 0.0024x^2.4852
R² = 0.7141
d
Regression plot of biomass vs length and height for *Anadara maculosa*
Biomass (g)
Length and Height (mm)
y = 4.0809x - 96.654
R² = 0.6158
y = 2.8243x - 104.92
R² = 0.7526

Table 1: Multivariate Analysis comparing morphological characteristics of *Anadara* species from Kiribati and Fiji.

PRIMER 5/30/02

PCA

Principal Component Analysis

Worksheet

File: C:\My Documents\Temakei\PCA5-rev.xls
Sample selection: All
Variable selection: All

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	5.97	85.2	85 .2
2	0.69	9.8	95.0
3	0.29	4 .1	99 .2
4	0.03	0.4	99.6
5	0.01	0.2	99.8

Eigenvectors
(Coefficients in the linear combinations of variables making up PC's)

Variable	PCI	PC2	PC3	PC4	PC5
SPlBiomass (g)	0 364	-0 186	-0 792	0 448	-0 055
SPllength (mm)	0 406	-0 093	-0 021	-0 355	0 027
SPlwidth (mm)	0 406	-0 089	0 014	-0 437	0 052
SPlthickness (mm)	0 406	-0 098	-0 053	-0 393	0 083
SPlbeakdistance (mm)	-0 246	-0 963	0 096	-0 036	-0 041
SPlNo. teeth	-0 394	0 102	-0 440	-0 492	-0 632
SP1No. ribs	-0 397	0 039	-0 409	-0 291	0 766

Principal Component Scores

Sample	SCORE 1	SCORE2	SCORE3	SCORE4	SCORE 5
ksla	2.323	-0.1200	-0.385	-0.074	0.011

FULL DATA

PRIMER 5/30/02

PCA

Principal Component Analysis

Worksheet

File: C:\My Documents\Temakei\PCA5-rev.xls
Sample selection: All
Variable selection: All

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	5.97	85.2	85.2
2	0.69	9.8	95.0
3	0.29	4.1	99.2
4	0.03	0.4	99.6
5	0.01	0.2	99.8

Eigenvectors
(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
SP1Biomass (g)	0.364	-0.186	-0.792	0.448	-0.055
SP1length (mm)	0.406	-0.093	-0.021	-0.355	0.027
SP1width (mm)	0.406	-0.089	0.014	-0.437	0.052
SP1thickness (mm)	0.406	-0.098	-0.053	-0.393	0.083
SP1beakdistance (mm)	-0.246	-0.963	0.096	-0.036	-0.041
SP1No. teeth	-0.394	0.102	-0.440	-0.492	-0.632
SP1No. ribs	-0.397	0.039	-0.409	-0.291	0.766

Principal Component Scores

Sample	SCORE1	SCORE2	SCORE3	SCORE4	SCORE5
ks1a	2.323	-0.200	-0.385	-0.074	0.011
ks1b	1.981	-0.054	0.141	-0.271	0.035
ks1c	1.272	0.162	0.578	0.006	-0.008
ks1d	1.773	0.010	0.278	-0.193	0.020
ks1e	1.762	-0.007	0.131	-0.051	0.018
ks1f	1.784	0.010	0.290	-0.219	0.023
ks1g	2.145	-0.138	-0.218	-0.065	0.007
ks1h	1.323	0.160	0.650	-0.121	0.009
ks1i	1.590	0.048	0.254	0.015	-0.006
ks1j	1.564	0.074	0.403	-0.103	0.000
ks1k	1.911	-0.038	0.145	-0.202	0.025
ks1l	1.286	0.099	0.129	0.426	-0.036
ks1m	1.288	0.161	0.598	-0.032	-0.003
ks1n	0.845	0.287	0.801	0.208	-0.035
ks1o	1.983	-0.063	0.080	-0.207	0.025

(See Appendix) for complete scores.

Output Plot (Figure 1a) above.

Table 2: Multivariate Analysis grouping study sites from Kiribati and Fiji under one species.

AVERAGE P PCA5

PRIMER 5/30/02

Average
Means over factor and indicator levels

Worksheet

File: C:\My Documents\Temakei\PCA5-rev.xls
Sample selection: All
Variable selection: All

Outputs

Worksheet: Sheet2

PCA
Principal Component Analysis

Worksheet

File: Sheet2
Sample selection: All
Variable selection: All

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	5.85	83.6	83.6
2	1.01	14.4	98.0
3	0.14	2.0	100.0
4	0.00	0.0	100.0
5	0.00	0.0	100.0

Eigenvectors
(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
SP1Biomass (g)	0.390	0.176	-0.756	0.085	0.211
SP1length (mm)	0.413	-0.045	-0.091	-0.078	0.018
SP1width (mm)	0.413	-0.066	-0.038	-0.074	-0.882
SP1thickness (mm)	0.413	-0.027	-0.020	0.250	0.287
SP1beakdistance (mm)	-0.101	-0.962	-0.241	0.073	0.031
SP1No. teeth	-0.405	0.158	-0.305	0.751	-0.289
SP1No. ribs	-0.403	0.111	-0.517	-0.591	-0.103

Principal Component Scores

Sample	SCORE1	SCORE2	SCORE3	SCORE4	SCORE5
K1	0.930	-1.750	-0.034	0.005	0.000
K2	-3.202	0.100	0.098	-0.069	0.000
F1	-0.205	0.423	0.497	0.066	0.000
F2	3.379	0.734	-0.014	-0.050	0.000
F3	-0.902	0.493	-0.547	0.048	0.000

Output Plot (Figure 1b) above.

Table 3: Voucher specimen numbers at the Queensland Museum (Australia) and the Marine Studies Program Marine Collection (Fiji).

Species name	Queensland Museum Call Number	Marine Collection Accession Number
Anadara anomala	B1, B2	5018
A. antiquata	C1, C2, D1, D2	5015
A. maculosa	A2, D2	5016
A. scapha	A1	5017
A. holoserica	F, G	5019
A. uropigmelana	E1, E2	5020

Table 4: Table for Plot of Mean and Standard Error, for Kiribati and Fiji *Anadara* specimens.

		Biomass (g)	Length (mm)	Height (mm)	Thickness (mm)	Beak dist. (mm)	# teeth	#ribs
Kirl	Mean (SE)	32.530 (1.153)	49.919 (0.7312)	35.275 (0.5195)	29.664 (0.451)	3.829 (0.122)	42.065 (0.803)	33.581 (0.226)
Kir2	Mean (SE)	0 (0)	48.716 (0.663)	34.318 (0.489)	36.070 (0.581)	3.7614 (0.060)	43.273 (0.646)	33.136 (0.194)
Fjl	Mean (SE)	22.393 (1.143)	40 (0.956)	27.867 (0.682)	25.648 (0.743)	3.638 (0.137)	46.950 (4.767)	34.8 (0.341)
Fj2	Mean (SE)	35.893 (9.356)	49.758 (4.878)	33.988 (3.971)	30.019 (3.790)	3.335 (0.889)	46.901 (0.615)	36.07 (0.225)
Fj3	Mean (SE)	62.719 (1.143)	59.358 (0.956)	39.054 (0.682)	35.714 (0.743)	3.667 (0.137)	49.074) (0.625)	36.074 (0.152)

Table 5: Summary of the Relative Growth Relationships for *Anadara* species from Kiribati and Fiji, 2002.

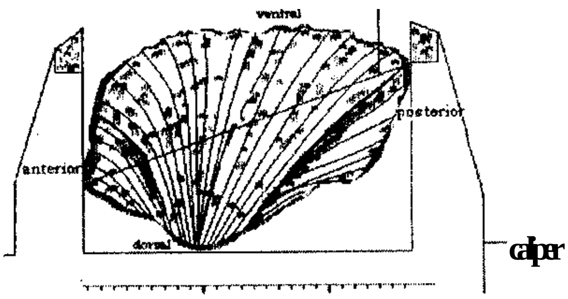
Species

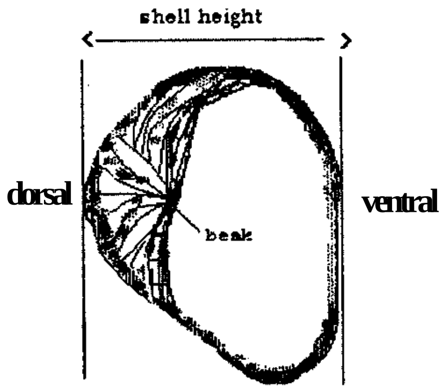
			A. holoserica	*A. anomala*	*A. antiquata*	*A. scapha*	*A. maculosa*
Relationship	HLR	a	0.930	0.961	0.658	1.037	1.720
		b	0.927	0.913	1.015	0.891	0.765
Growth relative to L			-ve allometry	-ve allometry	+ve allometry	-ve allometry	-ve allometry
		r^2	0.923	0.747	0.964	0.731	0.656
		r	0.961	0.864	0.982	0.855	0.810
Relationship	BLR	a	0.0009	0.658	0.0002	0.004	0.002
		b	2.665	1.015	3.091	2.361	2.485
Growth relative to L			-ve allometry	-ve allometry	+ve allometry	-ve allomtery	-ve allometry
		r^2	0.822	0.710	0.803	0.711	0.753
		r	0.907	0.843	0.896	0.843	0.868
Relationship	BHR	a	0.002	0.002	0.0009	0.009	0.013
		b	2.715	2.740	3.019	2.376	2.312
Growth relative to L			-ve allometry	-ve allometry	+ve allometry	-ve allometry	-ve allometry
		r^2	0.852	0.911	0.824	0.731	0.616
		r	0.923	0.954	0.908	0.855	0.785

Table 6: Growth equations for all *Anadara* species sampled.

Growth equation	*A. holoserica*	*A. anomala*	*A. antiquata*	*A. scapha*	*A. maculosa*
Power (HLR)	$H = 0.304L^{0.927}$	$H = 0.961L^{.0.913}$	$H = 0.657L^{1.0154}$	$H = 1.0373L^{0.8912}$	$H = 1.7195L^{0.7645}$
Regress. (HLR)	$H = 0.6525L + 2.3112$	$H = 0.6319L + 2.638$	$H = 0.7008L - 0.1637$	$H = 0.6134L + 3.2825$	$H = 0.5072L + 8.949$
Power (BLR)	$B = 0.0019L^{2.665}$	$B = 0.01L^{2.093}$	$B = 0.0002L^{3.091}$	$B = 0.0036L^{2.3609}$	$B = 0.002L^{2.4852}$
Regress. (BLR)	$B = 1.266L - 32.553$	$B = 1.5477L - 40.485$	$B = 1.0711L - 20.449$	$B = 1.5978L - 41.577$	$B = 2.824H - 104.92$
Power (BHR)	$B = 0.002H^{2.715}$	$B = 0.002H^{2.7403}$	$B = 0.001H^{3.0191}$	$B = 0.009H^{2.3761}$	$B = 0.0126H^{2.3116}$
Regress. (BHR)	$B = 1.879H - 34.993$	$B = 3.035H - 62.554$	$B = 1.5202H - 19.969$	$B = 0.6134H + 3.2825$	$B = 4.081H - 96.654$

7. APPENDIX


ventral
posterior
anterior
dorsal
caliper


shell height
dorsal
ventral
beak

8. ACKNOWLEDGMENT

I wish to thank Dr. John Stanisic and Ms Thora of the Malacology Department of the Queensland Centre for Biodiversity, Queensland Museum, Brisbane, Autralia for the tremendous support they have given in the verification of the identities of the voucher materials of *Anadara* from Kiribati and Fiji, without which the identities of the animals under study will never be elucidated. Their voluntary service is highly commendable and their names will remain with the specimens that are now with the Marine Collection of the University of the South Pacific, Suva, Fiji.

My special thanks also go to Mwakei Teewai and Tamoa Ruateki for the collection and sending of the *Anadara* specimens from Kiribati. I also owe the following for their various assistance in the data collection and write-up of this report: Ms Taina Temakei and Mr Teinai Temakei (my children), Biribo Tekanene (Thokalal Pharmacy, Lautoka, Fiji), Samasoni and Lilian Sauni (Noumea, New Caledonia), Marson Lilopez, James Teri and Juney Ward (students in the Marine Studies Program, University of the South Pacific (USP), Suva campus, Fiji), the Fisheries Department of Samoa, and TNT Fiji. Not forgetting others who have contributed in one way or another.

I also thank Mr. Johnson Seeto, Lecturer in Marine Science the Marine Studies, USP for editing the initial draft. Not forgetting Laboratory Technician, Shiv Sharma for lending me lab equipment required for this project. Thank you all, Kam rabwa, Vinaka vakalevu and Dhanyavaad.

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