CHAPTER 7:
Community structure of eastern Australian beaches

7.1 Introduction and aim

Within each of the biogeographic regions of this study, chapters 4, 5 and 6 have shown significant associations between macrofaunal communities and beach morphodynamic state. In particular, species richness and abundance increases with disspativeness of the beach system, apparently regardless of geographic locality. The primary aim of this chapter is to statistically compare the species number, abundance, biomass and diversity (Simpsons Index) results for each of the cool temperate, warm temperate and tropical regions, in anticipation of determining a ubiquitous scheme for eastern Australian beach macrofaunal communities. The degree of influence of latitude on the beach macrofaunal communities is also questioned.

7.2 Materials and Methods

To ascertain whether the regional relationships of species number, abundance, biomass and diversity (Simpsons Index) with Ω and BSI were statistically the same, regressions of the data sets were tested against the null hypothesis that the slopes and intercepts were equal using an analysis of co-variance (as calculated by Minitab Release 9.2, 1993).

Given that Ω and BSI are continua, the data for all the beaches were also pooled for each community parameter, regressed against each beach index and tested for significance as single data sets. In an attempt to further improve upon the relationships and investigate the potential influence of latitude on beach macrofauna, multiple regression analysis was performed for each community parameter against the combination of beach index and latitude (in decimals). Multiple regression expresses the inter-relationship among these variables using an analysis of variance analogous to that in the case of simple regression (Zar, 1984). Because multiple regressions express data relationships in three dimensions, no graphical representation of these analyses has been attempted. As a supplement to this analysis, correlations between independent variables are also investigated.

7.3 Results

7.3.1 Species number

a) Relationships between species number and dimensionless fall velocity (Ω)

Analysis of covariance for the species number versus Ω regressions showed no significant difference in the slope of the three lines ($t_{29}=1.52$, $P=0.118$). However, there was significant difference in the intercepts of the lines ($t31=6.24$, $P<0.001$), indicating that the lines lie at different elevations (i.e. are parallel). This means that no statistically common regression equation can be calculated for species number versus Ω.

b) Relationships between species number and Beach State Index (BSI):

Analysis of covariance for species number/BSI regressions across eastern Australia showed no significant differences in slopes ($t_{29}=1.11$, $P=0.304$) or intercepts ($t_{29}=20.00$, $P=0.947$). The regression lines from each of the study regions thus share the same species number/BSI relationship and can be statistically combined to produce a common regression equation. This common regression shows a very significant increase in species number with BSI across all the beaches studied ($t_{33}=14.90$, $P<0.001$; species number=22.17BSI - 9.04, $R^2=87.1\%$) (Fig. 7.1).

Residual plots for the combined species number data indicate no heterogeneity of variances. Thus, unlike the warm-temperate and tropical regional regressions, a linear equation is the most representative relationship between species number and BSI for eastern Australia overall.

c) Multiple regression analyses with species number, beach index and latitude

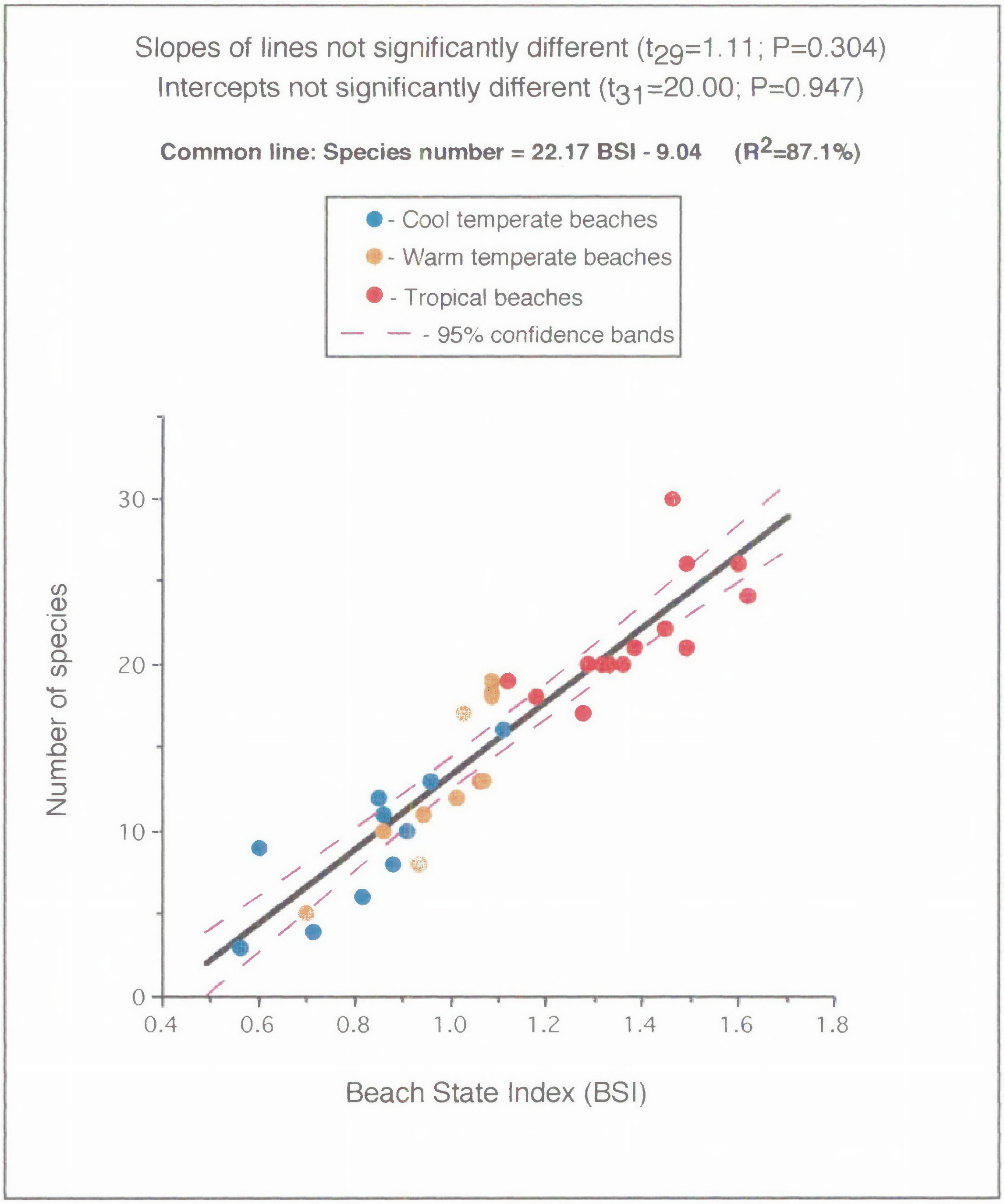
i) Multiple regression of species number against Ω and latitude

A multiple regression of combined species numbers with Ω and latitudinal position yielded a very significant regression (Ω: $t_{32}=6.09$, $P<0.001$; Latitude: $t_{32}=-13.37$, $P<0.001$; species number = 36.4 + 2.34Ω - 1.04Latitude, $R^2=85.3\%$). This relationship shows species numbers significantly ascend with increasing Ω and decreasing latitude.

ii) Multiple regression of species number against BSI and latitude

The multiple regression of combined species numbers with BSI and latitude also produced a significant relationship (BSI: $t_{32}=6.83$, $P<0.001$; Latitude: $t_{32}=-0.27$, $P=0.786$; species number= -7.03 + 21.4BSI - 0.041 Latitude, $R^2=87.1\%$). Although the latitudinal component of the regression is not significant, the adjusted R^2 value is

Figure 7.1: **All beaches: Species number vs BSI**
Showing a significant, statistically common relationship between species number and BSI. This indicates that species number changes with BSI in a similar manner across all eastern Australian beaches, regardless of latitude.



increased above that calculated for the analyses using Ω (above). This indicates that the BSI/latitude combination of independent variables gives a better fit of the data in terms of amount of variation accounted for. However, because BSI and latitude are highly correlated in this study[1] (Table 7.1), the interpretation of the partial regression coefficients becomes questionable (Zar, 1984). This correspondingly affects conclusions regarding the significance of the correlated X values - a problem known as "multi-colinearity". In such cases, discarding of one of the variables and re-analysis is advised (Zar, 1984).

Table 7.1: Correlations between independent variables.
A perfect correlation exists at values of 1.0 (+ or -), with low correlation existing at values close to 0. This table shows BSI and latitude are negatively correlated to a large extent.

	BSI	**Ω**
Ω	0.198	-
Latitude	-0.877	0.266

Nevertheless, and temporarily disregarding the existence of multi-colinearity, the multiple regression of species numbers/BSI/latitude shows no improvement upon the simple regression of species numbers/BSI (in terms of adjusted R^2 values). Thus the simple linear relationship of species numbers with BSI is considered the most representative for combined eastern Australian beaches.

7.3.2 Abundance

a) Relationships between log abundance and dimensionless fall velocity (Ω)

Analysis of covariance for the log abundance versus Ω regressions showed no significant difference in the slope of the three lines (t_{29}=1.13, P=0.118). However, the elevations of the lines were significantly different (t_{31}=9.82, P<0.001), indicating that the lines lie parallel. Therefore, no statistically common regression equation can be calculated for log abundance versus Ω.

b) Relationships between log abundance and Beach State Index (BSI)

Analysis of covariance for log abundance and BSI showed these lines to also lie parallel to one another (slopes not significantly different: t_{29}=0.529, P=0.756; intercepts

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[1] i.e. the beaches in this study increased in BSI value as they decreased in latitude

significantly different: t_{31}=4.09, P<0.001). Thus, although there again appears to be less difference in the intercepts using BSI, statistically there is no common regression equation. Figure 7.2 indicates that beaches of the warm temperate area have higher abundances relative to Beach State Index than tropical beaches, which are higher in abundance magnitude than cool temperate beaches.

However, if the BSI is considered a continuum and the combined log abundance data a single set, the regression shows log abundance to significantly increase with BSI (t_{33}=10.25, P<0.001; log abundance = 3.09 BSI + 0.03, R^2=76.1%)(Fig. 7.2). The combined log abundance/Ω regression is scattered and not significant.

c) Multiple regression analyses of abundance, beach index and latitude

i) Multiple regression of abundance against Ω and latitude

A multiple regression of combined log abundance values with Ω and latitudinal position yielded a very significant regression (Ω: t_{32}=3.92, P<0.001; latitude: t32=-12.44, P<0.001; log abundance = 7.22 + 2.42Ω - 1.55Latitude, R^2=82.9%).

ii) Multiple regression of abundance against BSI and latitude

Log abundance with BSI and latitude also produced a very significant relationship (BSI: t_{32}=3.04, P<0.005; latitude: t32=-2.64, P=0.013; species number= 3.86 + 1.75BSI - 0.071 Latitude, R^2=80.4%). This relationship does not improve upon the multiple regression of log abundance/Ω/latitude and, again, holds problems in multi-colinearity due to the large correlation between BSI and latitude in this study.

Alternatively, dimensionless fall velocity values (Ω) and latitude are correlated to a lesser extent (at 26.6%; Table 7.1). Because multi-colinearity is at a much lower magnitude in this case, it can be ignored and the multiple regression equation more confidently assumed to reflect the dependencies of macrofaunal abundance on Ω and latitude (section 2.3.2$c_{(i)}$). Thus, it is discerned that the most representative relationship for log abundance on eastern Australian beaches is a multiple regression against Ω and latitude (expressed in decimals).

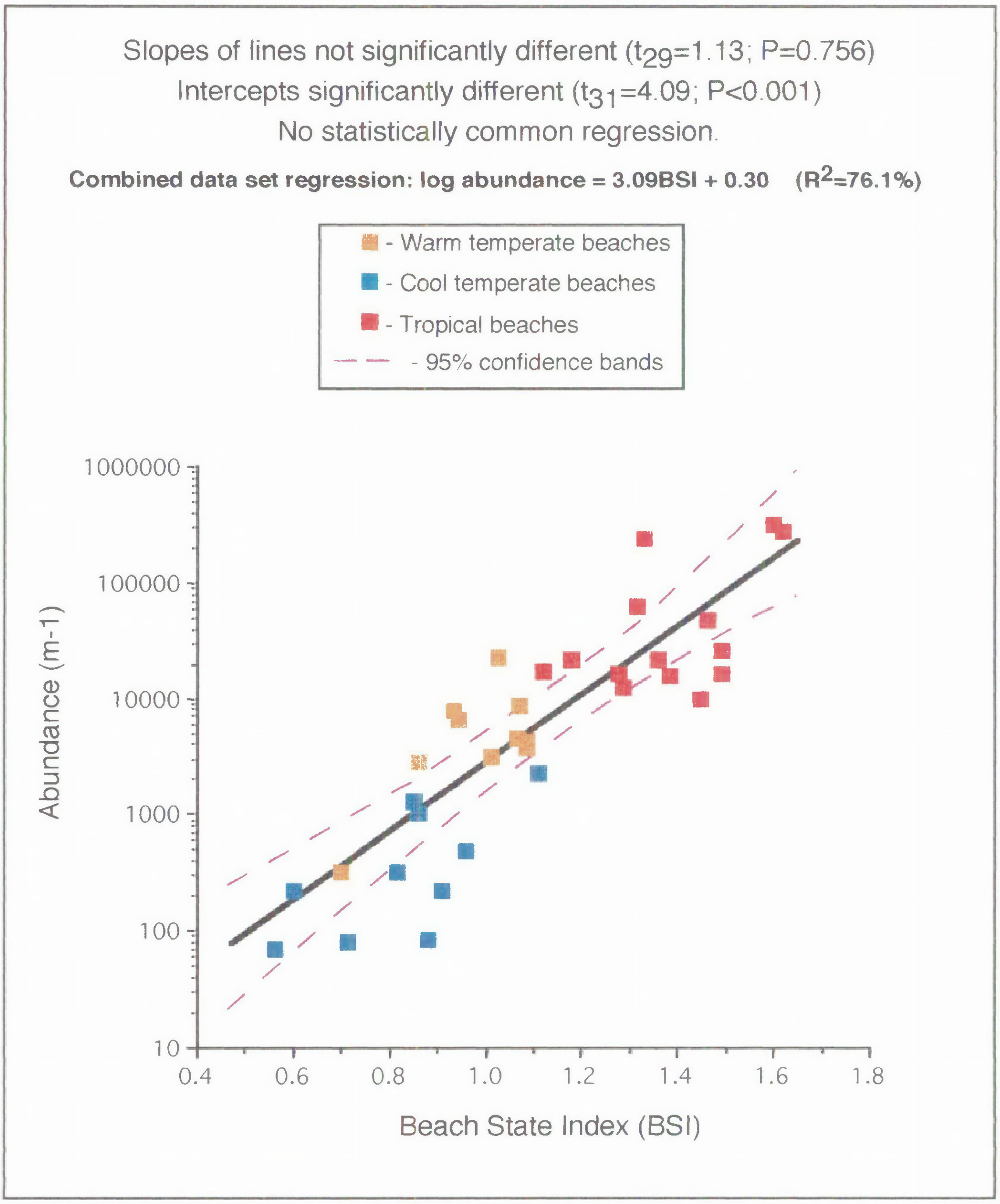
7.3.3 Biomass

a) Relationships between log biomass and dimensionless fall velocity (Ω)

Like the abundance regressions, analysis of covariance showed the three regional Ω/biomass lines to lie parallel (slopes: t_{29}=0.33, P=0.895; intercepts: t_{29}=4.739, P<0.001). There is thus no statistically common regression equation.

Figure 7.2: All beaches: Abundance vs BSI

Although the regional lines lie at significantly different elevations, this figure shows a significant relationship between the combined log abundance data and Beach State Index (BSI). However, an even stronger relationship is obtained for log abundance against Ω and latitude (not presented graphically - see section 7.3.2c)..



Slopes of lines not significantly different (t_{29}=1.13; P=0.756)

Intercepts significantly different (t_{31}=4.09; P<0.001)

No statistically common regression.

Combined data set regression: log abundance = 3.09BSI + 0.30 (R^2=76.1%)

b) Relationships between log biomass and Beach State Index (BSI)

The log biomass/BSI regional regressions also lie parallel to each other (slope: $t_{29}=0.94$, $P=0.423$; intercepts: $t_{31}=4.26$, $P<0.001$). Thus, although the difference in elevations is less than for the biomass/Ω regressions, no statistically common regression equation can be calculated.

However, if BSI is again considered a continuum and the pooled data a single set, the regression shows log biomass to significantly increase with BSI ($t_{33}=7.84$, $P<0.001$; log biomass = 2.74BSI-1.41, $R^2=65.1\%$)(Fig. 7.3). The pooled log biomass/Ω regression is not significant.

c) Multiple regression analyses of biomass, beach index and latitude

i) Multiple regression of biomass against Ω and latitude

Multiple regression of log biomass against Ω and latitude showed a very significant relationship with both independent variables (Ω: $t_{32}=3.50$, $P=0.001$; Latitude: $t_{32}=-9.49$, $P<0.001$; log biomass=4.64+0.256Ω-0.140Latitude, $R^2=74.0\%$). Like the abundance results, this shows biomass to significantly rise with increasing Ω and decreasing latitude. This regression strengthens the relationship of the abundance data over a simple combined linear regression against Ω (which is not significant).

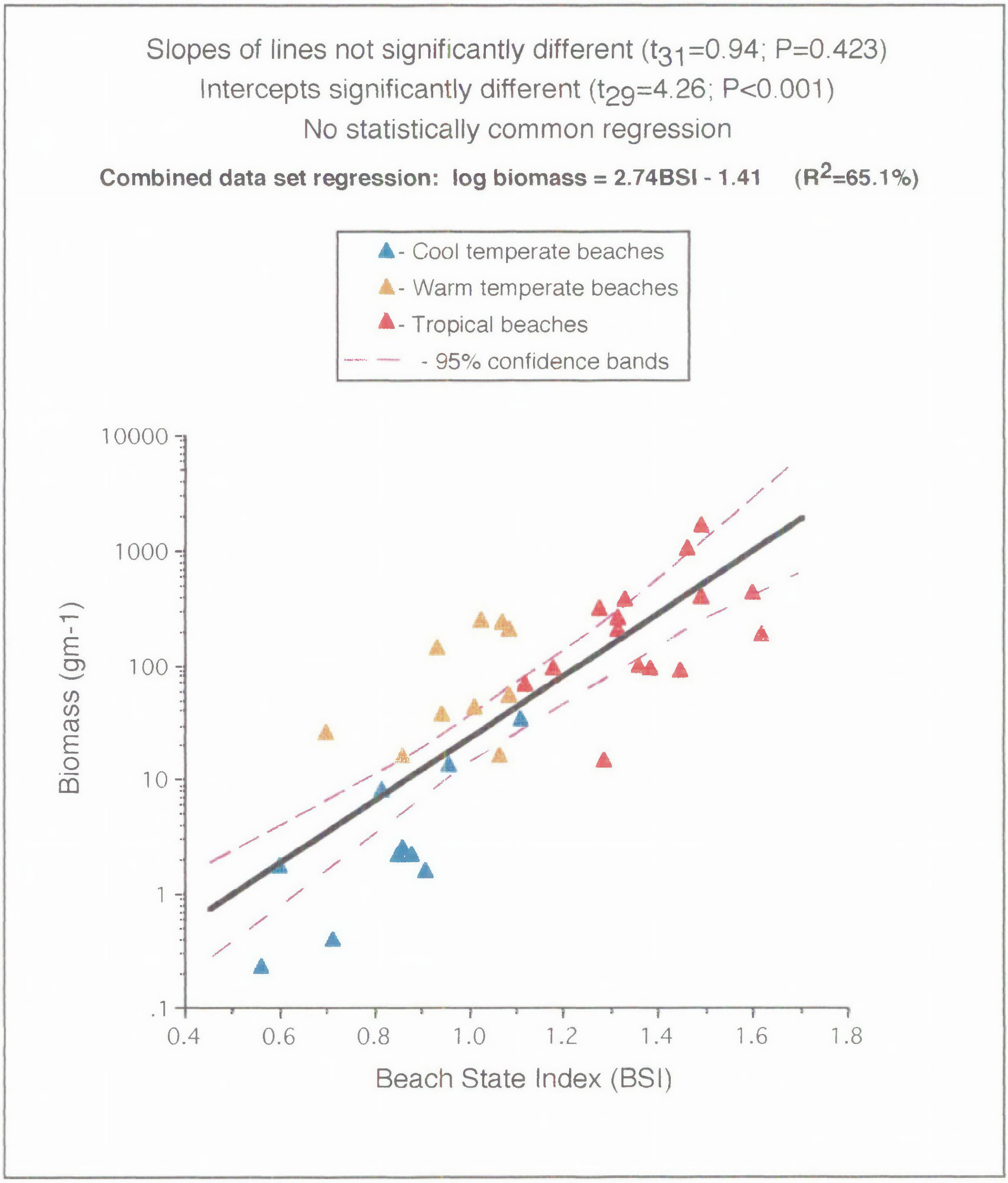
ii) Multiple regression of biomass against BSI and latitude

The multiple regression of log biomass against BSI and latitude also holds some significance (BSI: $t_{32}=2.21$, $P=0.034$; Latitude: $t_{32}=1.96$, $P=0.059$; log biomass= 1.69 + 1.54BSI - 0.063Latitude, $R_2=68.8\%$). However, this relationship shows no improvement over the biomass/Ω/latitude regression and is multi-colinear. Thus macrofaunal biomass is best described by the combination of Ω and latitude for eastern Australian beaches overall.

7.3.4 Simpson's Index of diversity

The within-region data sets of Simpson's Index were not significantly related to beach state in any case. These data are also significantly different in slopes and elevations for both Ω and BSI and did not reveal any relationship as a combined regression (Fig. 7.4). Thus, there is no further analysis of this parameter.

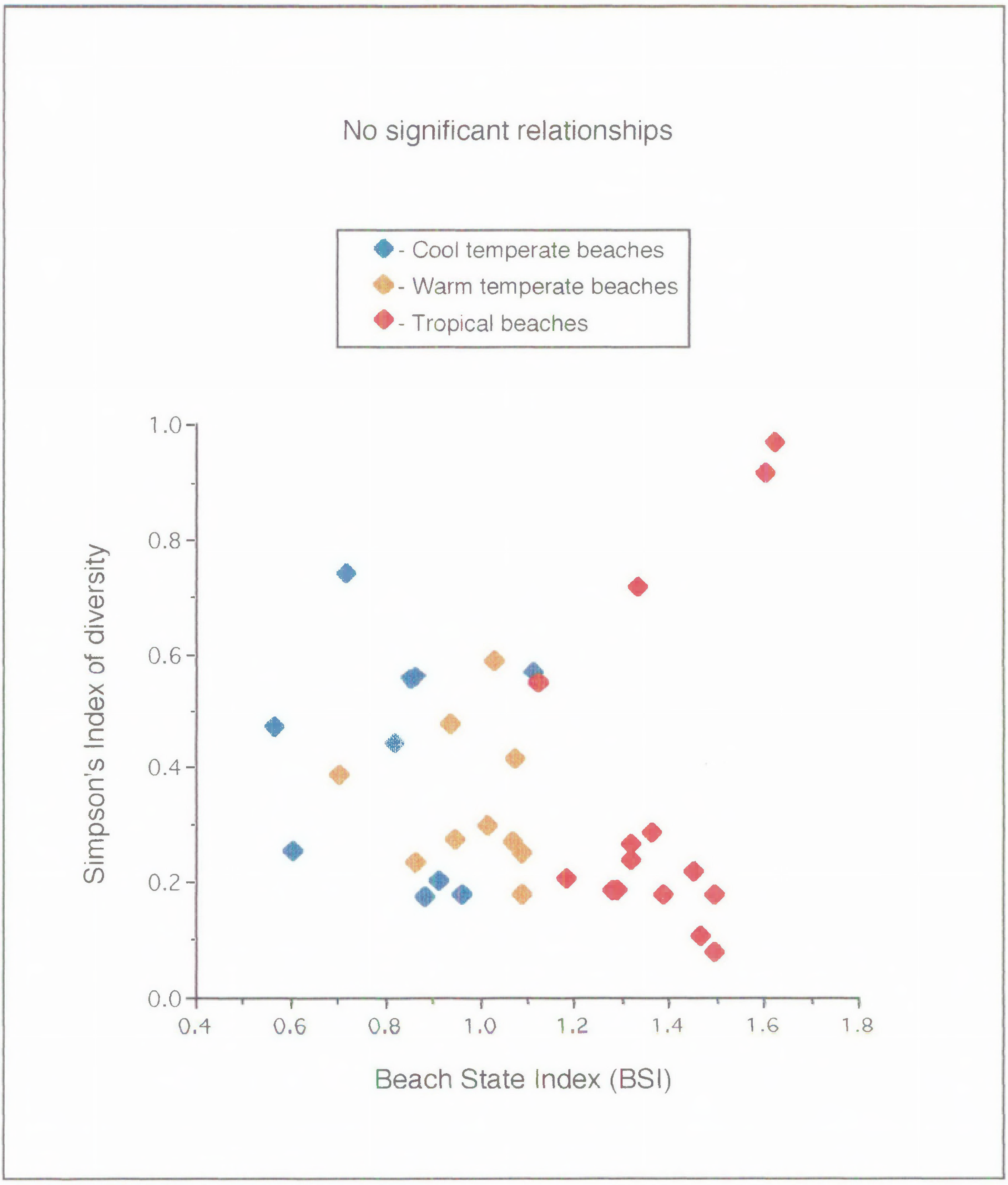
Figure 7.3: All beaches: Biomass vs BSI
Although the regional lines lie at significantly different elevations, this figure shows a significant relationship between the combined log biomass data and Beach State Index (BSI). However, an even stronger relationship is obtained for log biomass against Ω and latitude (not presented graphically - see section 7.3.3c)



Slopes of lines not significantly different ($t_{31}=0.94$; $P=0.423$)
Intercepts significantly different ($t_{29}=4.26$; $P<0.001$)
No statistically common regression

Combined data set regression: log biomass = 2.74BSI - 1.41 (R^2=65.1%)

Figure 7.4: **All beaches: Simpson's Index vs BSI**
Showing no significant regressions or relationships between Simpson's Index of diversity and Beach State Index (BSI).



7.4 Discussion

7.4.1: Species number

Although there was little overlap between the tropical and temperate regressions of species number and beach index, regressions with BSI were not significantly different in slope or elevation and have a statistically common regression equation. This means that species richness changes with beach type in a similar manner across all the regions, regardless of latitude. The common regression coefficient of determination (R^2) was 87.1% - showing that only 12.9% ($1-R^2$) of the variation in species number between beaches could not be attributed to BSI. This is a very strong association between species number and beach state and it can thus be said that species richness of eastern Australian beach macrofaunal communities is primarily physically controlled.

Lack of effect of geography is also implied by the multiple regression with BSI and latitude. Within this relationship, latitude was not significant and the equation showed no improvement over the single regression with BSI. This suggests that latitudinal locality acts as only a minor influence (if at all) on the number of macrofaunal species found in a given beach. It is difficult to further ascertain any effect of latitude on species number of sandy beaches because of the high negative correlation with BSI.

Alternatively, the relationship between species number and Ω was greatly enhanced for the combined data set when latitude was added to the regression (R^2=85.3). Although latitude was a significant component of this regression, it seems likely that this is a consequence of a high correlation between tidal magnitude and latitudinal locality. With tide included in its formula, BSI alone provided the closest fit of the data overall.

In terms of species richness, these results refute the proposal by Dexter (1992) that tropical beaches harbour less diverse macrofaunal communities than their temperate counterparts. Rather it seems that any beach type at any latitude will exhibit a macrofaunal species number related to its BSI at the time of sampling. This conclusion could be further solidified in future research via inclusion and similar analysis of beach types not available on the east coast of Australia (for example, micro-tidal tropical beaches and/or macro-tidal temperate beaches).

The existence and strength of the common equation for species number and BSI forms useful information applicable to further studies on eastern Australian beaches. Because the data were all collected from beaches that were unpolluted and free of large amounts of stranded kelp, the results can be used to determine the degree of influence of such input on a natural beach system. The regression equation can also be used to make predictions about the species richness of any given beach; for example, according the common regression equation, a beach in eastern Australia with a BSI value of 0.407 or less could be expected to be devoid of macrofaunal species.

Within the warm-temperate and tropical regions (chapters 5 and 6), species numbers were best expressed against beach state when log transformed. This indicates an acceleration in the rate of species increase towards higher BSI values within these localities. Conversely, combined beach species data was best related to BSI using untransformed species numbers. The reason for this may lie in the sampling method. Jaramillo *et al.* (1996) have demonstrated that the total area needing to be sampled in beach macrofauna surveys for species richness depends on beach type and tide range. They show that beaches containing the highest number of species (ie. the most dissipative) need to be sampled more extensively in order to collect each representative; suggesting a minimum area of 3-4 m^2 for micro-tidal beaches increasing to above $5m^2$ in macro-tidal areas. Sampling area for beaches in the present study was constant across the beach types at $3m^2$. This means that a high proportion of existing species was probably collected at the more reflective sites, whilst there was a tendency to under-sample species richness in dissipative conditions. Especially many species may have been missed on the tropical beaches in this study which, according to Jaramillo *et al.* (1996), require nearly twice the present sampling area in order to approach all species. Thus it is likely that the present species number estimates for macro-tidal beaches are much lower than their actual values. As a result, the combined species number/BSI relationship appears to increase linearly across the combined range of beaches, when in reality the increase more likely logarithmic.

In any case it appears that the macrofaunal species numbers on eastern Australian beaches are commonly and greatly related to physical parameters expressed as BSI. This seems, by coincidence, correlated with latitude in this study.

7.4.2 Abundance

The regional regressions with beach index for log abundance were not statistically similar; the lines positioned parallel to each other. This suggests that macrofaunal abundance of eastern Australian beaches increases with beach dissipativeness at a similar rate among regions, though at different levels of magnitude. For BSI, Figure 7.2 suggests that warm temperate beaches contain the highest order of abundance followed by beaches in the tropics. Reise (1991) has also described a similar phenomenon in comparisons between warm temperate and tropical tidal flats.

Although combined log abundance data were significantly related to BSI, a stronger association was obtained when related to the combination of Ω and latitude. This implies that macrofaunal abundance on eastern Australian beaches is influenced more by surf-zone dissipativeness and geographic climate than by combinations of surf-zone processes and tidal range (BSI producing a significant regression because of the connection between tidal magnitude and geographic locality). It thus seems likely that abundance of eastern Australian beach macrofauna is largely determined by input of primary production (as a function of dissipativeness of the surf-zone and increasing hours of sunlight as beaches become more tropical). As mentioned in section 5.4, wave energy (as a major determinant of surf-zone dissipativeness) plays a large role in generating nutrients and distributing such organics through the sand habitat (McLachlan, 1990). Because primary production is reliant on sunlight to a large degree, it might be expected that available nutrients are higher relative to beach type towards the equator. If BSI is used as a beach index, surf-zone dissipativeness is considered without climate. Consequently, because the warm temperate beaches have higher surf-scaling parameters than the tropical beaches, they appear to have a higher macrofaunal abundance with beach type. However, differences in abundance magnitude appear to be accounted for by inclusion of latitude in the describing equation.

Again, further studies containing a wider variety of beach types within a small latitudinal spectrum are needed in order to fully determine macrofaunal abundance trends with beach state.

7.4.3 Biomass

Biomass results were similar to those for abundance in that, although BSI produced a significant regression, the relationship between biomass, Ω and latitude provided the strongest relationship for the data overall. This again suggests that biomass is related to the higher generation of primary production by a dissipative surf-zone which is, in turn, enhanced at latitudes close to the equator. It thus appears that abundance and biomass of beach macrofauna are both related to nutrient input, the degree of their association with each other requiring investigations into body size/density patterns.

7.4.4. Simpsons Index of diversity

Simpsons Index of diversity, is unrelated to beach morphodynamic state and/or latitude across eastern Australian beaches. This additionally refutes the proposal by Dexter (1979) that tropical beaches are less diverse than temperate beaches. Rather, macrofaunal diversity, as a measure of proportional species abundance in the community, does not appear related to geographic locality or physical beach processes. As out lined in chapter 4.4, however, a number of factors can influence the values of diversity indices and confound any trend that might exist.

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Because of the high correlation between BSI and latitude in this study, it is difficult to fully differentiate the degree of influence of these variables on the beach macrofaunal communities. In chapter 8, results for the present beaches are compared with similar data for beaches world-wide in an effort to resolve this matter.