Part D

Summary, conclusions, references and publications

Fishermen at Goolwa beach, South Australia
[Photo: N. Hacking]

Chapter 13
Summary, conclusions and directions for future research

13.1 Summary and conclusions

Sandy beach ecology is a relatively young science and, as such, still requires much future research in order to fully understand the biological beach system. Ecological science can be considered to involve four main components:

a) description of patterns;
b) philosophy on the causes of patterns;
c) predictions; and
d) environmental management.

With respect to the above, this study has approached "half-way" in terms of the description of inter-tidal macrofaunal patterns and the relation of these to the physical environment of the eastern Australian coastline. This provides, at the very least, some broad scale knowledge on the biological workings of these beach systems.

With respect to the original aims (outlined in chapter 1.5), the main conclusions from the present research are summarised as follows:

Aim #1: To investigate trends in species number, abundance, biomass and Simpsons Index of diversity for a morphodynamic series of sandy beaches.

The present study shows that macrofaunal species number, abundance and biomass each significantly increase from a reflective to ultra-dissipative beach state. Within region regressions were not always statistically significant; however, this appears to be an artefact of the small range of morphodynamic states available for sampling within the limited area. When all data for the full range of beach states are combined, regressions with BSI are very significant with over 65% of the variation in the data points accounted for by beach state. Species number/beach state regressions were especially significant, suggesting that macrofaunal communities of eastern Australia are largely determined by physical beach processes.

Warm temperate and tropical regressions of species number and beach state were best described by a logarithmic model. Conversely, combined species number data were best related to morphodynamics using a linear model. It is likely that, in nature, the combined beaches also show a logarithmic increase in species number towards ultra-dissipative conditions. This trend was probably not discerned owing to under-sampling of the present dissipative shores.

Simpsons Index of diversity was unrelated to beach morphodynamics in all cases; proportional abundance of animals were obviously not shaped by physical parameters expressed as Ω or BSI. Diversity indices have been favoured in ecological studies in the past owing to the convenient summarisation of community data in to one value. However, many types of variation are also compounded into the indices, limiting their discriminatory power and making comparisons between sites unreliable. Diversity simply expressed as "species richness" (species number) is more easily linked with the physical environment of sandy shores in eastern Australia.

Aim #2: To compare beach state/faunal relationships between the different biogeographic regions afforded by the eastern Australian coastline.

Cluster and ordination analysis showed the three regions of the present study to be distinct in over 75% of their species. Nevertheless, number of species in the intertidal beach shows the same relationship with BSI across all the regions sampled. With nearly 90% of the variation explained by this index, it can be said that species richness of eastern Australian beaches is fundamentally physically controlled and is related to physical beach processes regardless of latitude.

Abundance and biomass also showed similarities in response to BSI, though at different levels of magnitude. Ultimately, variation in the data was best accounted for by a multiple regression against Ω and latitude, suggesting that surf-zone processes and climatic factors are more responsible for animal numbers and weight on a given beach. This can possibly be related to generation and distribution of primary nutrients with increased wave activity (surf-scaling parameters) and intensity of sunlight. Nevertheless, it is difficult to form absolute conclusions on these realtionships as tidal range and latitude in this study are highly correlated.

Aim #3: To investigate the macrofaunal communities of ultra-dissipative/tidal flat beaches and compare the results with those for other beach types.

Macro-tidal beach communities differ from micro-tidal communities in that slower-moving animals and those which inhabit more permanent burrows can utilise the intertidal area. However, although the tide has taken over as the primary force behind water movement across the inter-tidal beach, tide-dominated shores increase in species number (relative to BSI) in exactly the same way as their wave-dominated counterparts. These results support the swash exclusion hypothesis of McArdle and McLachlan (1992), with species richness continuing to increase as intertidal conditions become more and more benign.

Abundance and biomass data were of a similar slope, though lower in magnitude than micro-tidal warm temperate beaches. This suggests that dominance of waves plays a role in determining these community features. As summarised above, it appears that the combination of surf-zone/wave processes and degree of sunlight (and perhaps warmth) are the major determinants of abundance and biomass for beaches of eastern Australia.

Aim #4: To investigate how physical beach face processes associated with each of the beach types influence the intertidal distribution of the species of macrofauna present (within and between provinces).

Morphodynamic beach state appears to have no influence on the "zonation" of eastern Australian beach macrofauna. Indeed, discrete "zones" were difficult to distinguish in the present beaches with the present sampling procedure. Generally the results support the ideas of (Dahl, 1952) in terms of the types of crustacean fauna present and their locations across the shore. However, as a total community, a "regional seriation" appears to be the only consistent means of categorising across-shore distribution. It describes a loose contiguity of regional species where they are most likely to be found across the shore at low tide. Remembering that species presence on a given beach is largely determined by morphodynamics, this series may also compress or expand at any point or for individual populations depending on small-scale intertidal factors or events of weather (such as storms). The idea of a "regional seriation" of beach macrofauna directly supports the *autecological hypothesis* of Noy-Meir (1979): that sandy beach animals are physically structured in their distribution, with each species responding independently to changing conditions on the intertidal beach.

13.2 Problems with this study and recommendations for future research.

Although this study has produced some interesting and useful results, many problems in sandy beach research are also highlighted with much "fine-tuning" still to be done. Besides the inability to ascertain the animals present before sampling, one of the main reasons so little research has been attempted in sandy beach ecology is that the animals are difficult to quantitatively remove from the sand. This is especially the case in community studies where temporal effects within the sample are not desired and field-work must be completed within one low tide. Many statisticians have little faith in pseudo-replicated results, especially where within sample (beach) variation is greater than that between samples (beaches). "Noise" is a major feature of all ecosystems and studies should attempt to account for it, even if it can't be overcome. Thus, sandy beach sampling must, somehow, be technically improved in the future to allow larger sampling areas and perhaps multiple transects per morphodynamic state. It may be that the only solution to this is simply a larger labour force and increased effort in this field of study. It would be extremely interesting to see how results obtained by averaging multiple transects per beach compare with the "snap-shot" surveys of the present study.

Another major problem, especially in determining world-wide patterns in beach ecology, is that researchers have used different sampling procedures (sample size, sample depth, mesh size for extraction, number of levels of the beach). In order for sandy beach research to become unified around the world, a standardised beach sampling program which can be applied on a global scale is necessary. This would allow more confident comparisons of world-wide beach communities - especially in studies involving collations of "snap-shot" data. Broad scale latitudinal effects on beach fauna, as well as effects of nearby coastal proecesses (e.g. upwelling) and season could then also be better investigated. With all such variables accounted for, ecologists could then form a ubiquitous model for beach macrofaunal communities world-wide and, following, turn to investigations of the effects of biological interactions on these inter-tidal communities.

13.2.1 Future applied research

This study has provided an underlying understanding of the nature of un-perturbed, wrack-free sandy beach communities in eastern Australia. This knowledge can be utilised in applied studies - especially of an environmental concern. Ocean pollution is particularly topical in Australia, especially with much of our sewage disposal in the form of ocean outfalls. Sediments in general are pollution traps (or at least filters) and, unlike other marine environments such as rocky shores which may begin to recover as soon as perturbation ceases, sandy shores may retain a pollutant for some time.

In a review of effects of organic pollution on benthic invertebrates, Pearson and Rosenberg (1978), Read *et al.* (1978) and Emmerson *et al.* (1983) have shown organic enrichment to superimpose a gradient on the environment and thus influence the distribution of organisms. In highly perturbed situations, there may be an obvious gradient of community change away from a discharge point, adjacent to which the sediments may be devoid of macrofaunal life or inhabited by only a few opportunistic species. With further understanding of the natural fluctuations in beach communities, macrofauna may prove to be efficient biological monitors for organic and other pollution problems.

As a primarily coastal population, much of the Australian life-style is concentrated at the beach. Although mechanical disturbance by humans (on foot) has not been shown to affect beach macrofaunal communities (Jaramillo *et al.*, 1996), there has been little investigation into the effects of off-road vehicles and bait-collecting in this country. Many local councils also remove stranded kelp from the beach face for aesthetic purposes with little regard as to its place in the biological beach system. Thus, although naturally occurring disruptions by waves appear to more significantly affect beach macrofaunal communities than recreational beach-goers, some information on the effects of larger human disturbances (such as the above) would be beneficial in managing our beaches as a recreational and biological resource.

13.3 Final comments

With acknowledgment to the limitations on the results in investigating the posed hypotheses, this study provides the first broad scale ecological and descriptive account of sandy beach macrofauna in Australia. Although the time and labour available have dictated that the results might be somewhat superficial (in terms of pseudo-replication of transects), trends in the composition of beach macrofaunal communities with beach type are distinct and repeatable. This provides important base-line information for future reference. The results also compare favourably with other work, despite the differences in sampling methods between researchers. It is hoped that research will continue and expand in this fascinating field.