DISCUSSION

BENTHIC BIOTA

The fringing reefs off Magnetic Island clearly form a complex group, within which there are several striking patterns in the abundances of benthic flora and fauna. Most consistent were the distinctions between reef flats and reef slopes and between reefs in Nelly Bay (including Bright Point and the southern end of Geoffrey Bay) and all other bays. It is also clear, however, that there is considerable variation in these patterns among different groups of organisms. This is particularly the case at finer scales, such as patterns among stations within bays. It is clear that the reefs cannot be considered homogeneous with respect to biotic composition.

At no time in our study, however, was it apparent that the fringing reefs sampled were in any sense biotically unique or unusual, compared to fringing reefs along the coast north of Cape Tribulation for example. They are, however, the nearest fringing reefs to Townsville and they form a suite of habitats that are limited on Magnetic Island to the south east coast. For that reason alone, it is essential that the consequences of any large developments near these reefs are very carefully monitored.

The diversity among the fringing reefs of Magnetic Island has important implications for the assessment of any environmental impacts on them of the Magnetic Quay development. For most corals, the area of certain impact (i.e. the northern end of Nelly Bay) represents a low point in their abundance. Conversely, algae tend to be more abundant there than elsewhere. Given that the corals are of particular interest environmentally, and the algae are very abundant at most stations and form a labile component of the fringing reef communities, the area proposed for development is probably that at which damage to the aggregate of fringing reefs would be least.

It is of interest to note that the fringing reefs of Magnetic Island have been subject to a number of anthropogenic and natural disturbances over at least the past two decades. A particularly strong tropical cyclone (Althea) caused some damage to the reef biota, particularly on reef flats, in December 1971 (Collins, pers. comm). In 1973, there was an active quarrying operation on Bright Point, which would have been likely to increase rates of erosion of terrigenous sediments into the north end of Nelly Bay. Oliver (1985) reported considerable mortality of corals in Nelly and Geoffrey

Bays as a result of bleaching. The cause of bleaching was not known. The status of these reefs in 1988 suggests that they may be reasonably robust to periodic disturbance.

A second implication of the diversity among the fringing reefs on Magnetic island concerns the extent to which the reefs in Arthur, Florence, Picnic and Geoffrey bays reflect the biotic status of reefs in Nelly Bay. In particular, the use of these reefs as control reefs must be considered carefully. On one hand, it is important to note that our grouping of stations according to their geographic and hydrological proximity to the area of development corresponds very closely with the independent classification of stations by biotic similarity. The impact stations tend to form a distinct group from the control stations. This correspondence provides some circumstantial support for the logic we followed in classifying Geoffrey Bay station 4 together with Nelly Bay - *vis* because of the suggested hydrodynamic link between Nelly Bay and the south of Geoffrey Bay by a tidal eddy sweeping north around Bright Point (Parnell & van Woesik, 1988).

On the other hand, comparisons of abundances between impact and control stations for the purpose of impact assessment must be considered in the context of patterns that existed between these groups prior to the commencement of construction. The more complex the relations among stations *a priori*, the more difficult will be the assessment of whether an impact has occurred if that assessment is based on the analysis of patterns in abundances. The situation is exacerbated by the low power expected of tests based on raw abundance data (Box 6).

BOX 6
RESOLVING POWER OF STATISTICAL TESTS

The data from the baseline study were used to examine the statistical power of analyses to detect specified effects (such as differences in abundance or sedimentation between treatments, habitats, or stations). For all analyses of power, we followed the methods of Cohen (1977). Note that we were not examining *a posteriori* the power of the baseline analyses (in which there were many significant results, for which calculation of power has no meaning). Rather, we used estimates of variation from those analyses to predict the power of future analyses to detect specified differences.

In general, the power of analyses to detect differences in abundances of benthic organisms or rates of sedimentation will be poor, except for large effects - such as difference of 50% or 100% of the overall mean abundance (Table 10). This low power reflects the great inherent variability among replicate transects and among sites. Since the 'sites' term in all analyses is the denominator for F-tests of all other terms, and the numbers of levels of other factors is fixed, there are two ways to increase the power of tests for environmental impact. Either we can increase the number of sites sampled in each habitat at each station, or we could pool the variation among sites with the residual variation and test other terms against the pooled residual. The second alternative, however, is only valid if it is reasonably certain that sites do not constitute a significant source of variation (Winer, 1971; Sokal and Rohlf, 1981). This was not the case during the pilot study and is unlikely to change in the future. Hence, in Table 11, we show the numbers of sites that would have to be sampled in order to detect changes in abundances of benthic organisms equal to 25% and 50% of existing levels with equal probabilities of type I and Type II error (0.1).

ASSESSMENT OF IMPACT ON CORALS

The focus of interest in assessing the environmental impact on fringing reefs of the development of Magnetic Quay will be whether the development causes any noticeable decline in abundances of benthic biota, particularly hard corals. An impact of development would be signalled by decreases in the abundances of some or all corals at impact stations whilst abundances of those corals had not changed, or had changed in a different direction or by smaller amounts, at control stations. If no impact occurred, we would expect that changes in abundances would be the same, on average, at all sites, and unrelated to the patterns in absolute abundance among sites, stations etc. on any given occasion. The important point to note here is that it is the comparison of changes in abundance from one time to the next that is important.

The choice of fixed as opposed to random transects for this study provides a convenient solution to the problems of great variability in absolute abundance and low power of tests based on absolute abundance data. Fixed transects allow us to measure changes in abundances independently of patterns in absolute abundance, and to eliminate the effects of great spatial variability in abundance on analytical power. Since the same transects (and hence the same individual colonies) at each site will be surveyed on each occasion, changes in abundance can be measured with little error, certainly with far less error than had random transects been used. This is possible only because the corals are sessile and long lived relative to the intervals between repeated surveys.

Under these conditions, identification of changes in the corals attributable to an impact of development can be based on the measurement of changes in abundances of particular corals between resurveys of the same site. There are three sources of variation involved in this procedure. Firstly, there is the real, biological change in abundance resulting from processes such as growth, fragmentation, settlement, and death of corals. This is what we wish to measure and use to assess whether an impact has occurred. Secondly, there is variation attributable to errors in the measurement of abundance at any given time. Perceived changes in corals along a particular transect will reflect both these things. Variation due to errors of measurement, however, can be estimated by remeasuring the same transects at very short intervals, during which the corals along that transect would not have changed.

Finally, there is likely to be stochastic variation among transects, sites, etc. in the natural processes that cause change. This will result in real differences among transects or sites in the amount of change in corals that will occur over longer periods. Estimates of change in abundance at scales larger than transects (such as sites, stations, or groups of stations) will contain components of all three sources of variation. An impact would occur if the Magnetic Quay (or other) development systematically influenced the natural changes in abundance at the impact stations.

Following the resurvey of all transects during the construction and operational phases of Magnetic Quay, the differences between those data and the baseline data can be calculated. These differences will be the above estimates of the changes in abundances of corals along each transect. They will be independent of the patterns in absolute abundances among transects, sites, etc. If these 'difference data' are then divided by the abundances present during the baseline, the changes in abundance will be expressed as proportional change and will then also be independent of the abundance at each site.

Hypotheses about environmental impact (e.g. the specification of effect sizes) can now be conveniently stated and tested in terms of proportional change in abundance. For example, if it was stated that a decline in abundance of 20% that could be attributed to the development would be cause for management action, that criterion could be tested directly by comparison of proportional changes in abundance between impact and control stations. These tests are likely to have considerably greater power to detect environmental impacts than analyses of absolute abundances (Box 7).

If proportional change data were analysed, the sampling design that we used during the baseline would be sufficiently sensitive to detect relatively slight effects of the Magnetic Quay development at most scales. The detection of a 'critical' impact of, say, 20% change in abundance with 90% certainty would be a realistic proposition for most taxa (Table 12). Such changes would be very costly and difficult to detect with reasonable certainty, however, using absolute abundance data (Table 11). The analysis of differences is likely to provide a powerful method for detecting anthropogenic impacts on organisms such as corals.

The main constraint of analysing proportional changes in abundance is that change over only a single time interval can be analysed at once. In the assessment of environmental impact, however, this is acceptable since each 'treatment' condition (i.e. each survey during construction and operation of Magnetic Quay) should be compared to the single control - *vis* abundances present during the baseline. The questions of interest are 'has an impact occurred after six months of construction?', 'has an impact occurred after 12 months of construction?', etc. These questions constitute a series of separate paired before-after comparisons, appropriate to the analyses we have suggested.

BOX 7
POWER OF ANALYSES OF PROPORTIONAL CHANGE IN ABUNDANCE

We resurveyed transects at two sites at Nelly Bay station 5 (one on the reef slope and one on the reef flat) shortly after the completion of field work for the baseline study to estimate the error of measurements inherent in repeated surveys of the same carefully marked transects. The repeated surveys were only four weeks apart, and it was considered unlikely that there would have been significant real changes in abundances of corals. Consequently, variation in estimates of cover for each transect between the two surveys would be attributable to only observer error and slight variation in the placement of the measuring tape. Using these estimates of within and between site variation in repeated measures of the same transects, we calculated the power-effect size characteristics of analysing proportional differences in abundances between two times when biological change was small (Table 12).

Some caveats are necessary, however. Firstly, we cannot be certain of the accuracy of our estimates of total variation in repeated survey among transects and sites. Our estimates of variation are likely to be predominantly comprised of variation due to errors of measurement. We have almost certainly underestimated the variations among sites and transects in natural changes in abundances that would occur over periods longer than one month. This would mean that the analyses of changes in abundance would be less powerful than predicted.

Counterbalancing this, is the fact that our errors of measurement were likely to be larger than normal for several reasons. Firstly, the transects were resurveyed in relatively rough, turbid conditions; rougher conditions than those in which transects would normally be surveyed. The considerable movement of the transect lines, and difficulty for divers to stay in one place above the lines during surveys, would have increased considerably the variation between original and repeated estimates of abundances. This effect would be important particularly for species with low abundances, such as the *Turbinaria* sp. and sponges at the sites we re-sampled. Secondly, we estimated within and between site variation from data from only two sites. It might be expected that these estimates would be considerably larger than those derived from averaging within and between site variation over all sites sampled, as would be the case when the complete set of transects was resurveyed. Finally, the two sites re-sampled were in different habitats. Our estimate of between site variation measurement error, therefore, would have included a component of between habitat variation in repeatability of surveys. This may have inflated the estimate of between site variance we used to calculate power.

If abundances of corals at adjacent sites change in fairly similar ways over the relatively short construction phase (18 months) of Magnetic Quay, we expect that we will be able to detect effect sizes at least as small than those given in Table 12 with the same power (0.9). Preliminary analysis of data from Cape Tribulation suggest that this is likely. It is possible, however, that natural change in abundances or any effects of development might be patchy at small scales, with corals in some transects or sites changing much more than others at adjacent transects or sites. This would have the effect of increasing variability in repeated measures within and/or among sites. Consequently, we would be not be able to detect differences in proportional change as small as those in Table 12 with power held at 0.9. We therefore suggest that the 'detectable effect sizes' in Table 12 form the basis for specifying initial criteria for management action and any improvement in sensitivity of our sampling be seen as an opportunity to review those criteria.

ASSESSMENT OF IMPACT ON ALGAE

Algae on the fringing reefs of Magnetic Island have been shown to have a strong seasonal component of growth and abundance (Vakamoce, 1987). Large changes in abundance and distribution of algae at most scales are expected over short periods. The plants present during the baseline, therefore, may not be present on all, or even most, subsequent sampling occasions. Even during the four weeks between the initial and repeated surveys of the sites in Nelly Bay, abundances of algae declined significantly. The rate of decline varied greatly between and within sites, however, indicating that the detection of moderate differences in changes in abundance between, say, impact and control stations would be difficult for these organisms (Table 12). Consequently, the analysis of differences proposed for the assessment of impact on corals may not be a powerful or appropriate method for analysis of impacts on algae.

Because many of the algae, in particular the *Sargassum* sp., are known to grow rapidly, it might be expected that variation in growth would be the most sensitive indicator of any effects on them of environmental perturbation over short periods (particularly changes in nutrient levels). We suggest, therefore, that during the construction and operation of Magnetic Quay, the growth (stipe elongation) of individually tagged *Sargassum* plants be recorded at regular intervals. These growth data would be amenable to analysis by analysis of variance similar to those used already, and would be likely to provide powerful tests of hypotheses about the effects of Magnetic Quay on the benthic algae.

It may also be necessary to monitor the status of adventitious turfing and filamentous algae that have the potential to over-grow live corals (Potts, 1977). Data on percentage cover by algae would be collected as a matter of course when the fixed line transects were being re-surveyed, and would be analysed to assess any gross changes in the patterns in abundances of algae from those described here. Biomass of algae should also be assessed, for the reasons outlined previously (materials and methods).

SEDIMENTATION

It was clear even during the limited period of the baseline study that the fringing reefs around Magnetic Island are subject to a relatively turbid, high sediment environment. Rates of sedimentation during only moderately rough seas were high compared to those measured at offshore reefs and fringing reefs in other parts of the world (Pastorok & Bilyard, 1985; but see Cortes and Risk, 1985 for

the water column. Such a programme would allow the calculation of an average difference in rates of sedimentation between the slopes of Nelly Bay and other Bays based on a greater range of seasonal and local whether conditions. The difference would be indexed to the average rates of sedimentation in the control bays so that data from both calm and rough periods could be sensibly and separately averaged. With these data in hand, a significant effect of the development would be deemed to have occurred if, during construction, sedimentation in the vicinity of Magnetic Quay or in Nelly Bay generally was greater than at the control stations by an amount greater than the 90% confidence limits of the mean difference prior to construction. On the basis of the results of the baseline study, we also recommend the ammendment of the programme of sampling sediments (Table 13).

We have been asked by the GBRMPA to provide recommended 'critical' rates of sedimentation on the reefs of Magnetic Island. In theory, these would be rates of sedimentation near the upper limits of the tolerance of the corals, and equal to or greater than rates that occur naturally. If these figures were exceeded because of construction activities, the GBRMPA would halt proceedings pending further investigation of the enhanced rates of sedimentation and their biological consequences. Such 'critical' levels, however, should not be the sole criterion for management action. The logical steps that should be followed in deciding whether the development has indeed had an impact are discussed in Box 8.

In view of the naturally greater rates of sedimentation in Nelly Bay, we have also recommended further sampling to better establish what can be considered the natural limits of such differences. At this time, we would suggest that an impact would be indicated if sedimentation on the reef flats of impact stations were significantly different from those on reef flats at control stations. Sedimentation on the reef slopes in Nelly Bay, however, was on average 2.6 times greater than that on reef slopes at the control sites. Because this relation was very variable, and we were able to sample for only four weeks, the (one-tailed) 90% confidence interval for the relation is 1.4. This would indicate that sedimentation on the slopes of Nelly Bay would have to be more than 4 times greater than that on the slopes of control stations before an effect of development could be inferred with reasonable certainty. This figure seems high, and we therefore reiterate the need for further sampling before construction operations are fully implemented.

If, on the basis of these criteria, it is decided that an impact has occurred (Box 8), the question of whether the enhanced sedimentation in Nelly Bay has exceeded critical levels must be answered. The answer will clearly be weather dependent. On the basis of rates of sedimentation recorded during the baseline, we suggest that in moderate to rough conditions (winds > 25 knots), sedimentation on the reef flat should not exceed 95mg/cm^2/day. On the reef slope, an upper limit of average sedimentation at a station of 254mg/cm^2/day would be cause for concern, although rates of sedimentation at single sites are likely to exceed this figure.

We stress that these figures are at best 'guestimates' because there is insufficient knowledge of the effects of specific rates of sedimentation on the health and survivorship of corals on Australian fringing reefs to provide definitive statements about critical thresholds. Suggestions from elsewhere of maximum rates of sedimentation that can be tolerated by corals range from 10mg/cm^2/day (Pastorok & Bilyard, 1985) to well over 500mg/cm^2/day (Cortes & Risk, 1985). These disparate figures highlight the likely dependence of tolerances of corals to sedimentation on local conditions, species, and acclimation of the corals to local conditions.

Instantaneous Measurements of Sedimentation

Except in rough weather, when sedimentation will be great, sediment traps will not adequately measure sediment deposition over short periods (1-2 days). Inferring average rates of sedimentation from instantaneous measures of other variables, however, is also unlikely to provide adequate estimates of sedimentation. We have shown that there are several difficulties with attempting to relate data from sediment traps to those from secchi depth and suspended solids. Sediment traps sample sediment deposition over 7-10 days, whereas turbidity measures are instantaneous. The sediment trap measurements are affected by varying weather conditions on days preceding and following those on which turbidity was measured. Clearly, more experimental work is necessary to establish whether there are short-term relations between turbidity and sedimentation. We therefore suggest that extreme caution is necessary if management decisions are to be based on inferences of rates of sedimentation from rapid, on site measurements of variables such as water clarity and turbidity.

SUMMARY

We have described the characteristics of the benthic biota on the fringing reefs along the south-east coast of Magnetic Island. The reefs are variable in structure at a variety of scales. Of particular interest with respect to the proposed development of Magnetic Quay, is the relatively clear distinction, on biological grounds, between Nelly Bay and the reefs Geoffrey, Arthur, Florence, and Picnic Bays, particular for reef slope biota. Although several taxa differ in abundance among the bays, reefs in Nelly Bay in general, and the northern end of Nelly Bay in particular, generally support a similar taxonomic assemblage of corals and algae as reefs in the other bays. It is unlikely, therefore, that ecologically significant features will be lost through excavation at the north end of Nelly Bay.

Several difficulties are likely to be encountered in the assessing of environmental impacts of the development of Magnetic Quay. These difficulties are not unique to this development, but their solution has not often been addressed. We devote considerable text to the discussion of possible