DISCUSSION

Catch variability and sampling power

Catch rates of traps were characterised by a dominance of zero catches, by low means, high variances and a positive correlation between mean catch rates and their standard deviation.

These data have a great deal in common with those from visual surveys of coral trout (Crimp 1986). Both data sets are not normally distributed, having very long right-hand tails. Distributions of data from the traps are most similar to those from visual census counts in areas with very low densities of fish (e.g. figure 1b in Crimp 1986). In these cases, there is no left-hand tail to the frequency distribution at all, the most common frequency being zero. In trap samples there is a significant linear correlation between the mean of a sample and it's standard deviation. In the visual surveys there is a similar relationship between the mean and it's variance. In both data sets, analyses of low density populations are considerably less powerful than those from high densities. For both kinds of data, relatively high levels of variance occur at all densities of fish and increasing levels of replication (after a certain point) does little to reduce the variance (Ayling and Ayling 1984).

Most, if not all, of these emergent properties are associated with species that have highly clumped distributions (Crimp 1986). Coefficients of variation for visual trout surveys cited by Crimp range from 0.52 - 1.77 [In more recent studies using a single experienced observer, 95% of CVs ranged from 0.31 - 0.63 for mean trout densities of 2.3 - 6.3 trout/1000 m^2. A single CV of 1.13 was associated with a low mean of 0.8 trout/1000 m^2 (calculated from p. 26 of Ayling and Ayling 1989)]. CVs in the present study mostly ranged from 1.2 - 2.6, perhaps as a result of the distributions of fish caught in this study being even more heavily clumped in their distributions than trout are.

Visual observations on SCUBA certainly suggest that lethrinids and lutjanids, which dominated the trap catch, are significantly more highly clumped in their distributions than coral trout (personal observations). One of our reasons for exploring the use of fish traps for sampling lutjanids was that they are so highly clumped during the day that it is difficult to collect abundance data for most species that are amenable to traditional statistics. These fish are primarily nocturnal and we hoped that if we could sample them when they were feeding at night, and presumably more evenly spread across the habitat, we would have a much better chance of getting statistically meaningful results. It is difficult to tell from available data whether this is the case. Visual surveys of lutjanids and lethrinids by Ayling using ten 50 x 20 m transects on Davies, John Brewer and Lodestone Reefs resulted in a range of CVs very similar to those in table 5 [CVs calculated from pp. 50-52 in Ayling and Ayling 1989].

The kinds of statistical distributions discussed above - a dominant frequency in traps of zero and a long right-hand tail - could also possibly arise as an artifact of trap sampling. Anon. (1990) found in their studies of fish traps on the North West shelf that catch rates were not proportional to fish density due to a combination of a bait plume effect and gear saturation. Once a fish went into a trap it's feeding at the bait bag caused an increase in the amount of bait and oil released, which in turn attracted more fish to the trap whose feeding activity further increased the size of the plume. This feedback system results in larger numbers of fish entering the trap than if the catch directly reflected local abundance. Such a process could cause a long right-hand tail to the distribution. If a single fish chanced on a trap, a large catch would result. If it didn't, a zero catch would occur.

We designed our bait containers to minimise this effect. Our containers are PVC tubes with drilled holes through which fish can grab individual baitfish. Each canister contains

approximately one kg of bait. Fish cannot grab hold of the container and shake but must pull individual fish out of the container. Bait bags on the North West shelf are large open-weave bags. Fish can grab these bags and shake them, causing a release of bait - a desired effect when fishing short soak times and trying to maximise the catch. Our traps are necessarily fishing long soak times (overnight) where a more controlled release of bait is desirable.

Gear saturation, in the form of total loss of bait, may limit the upper number of fish in a trap but this will also be very dependent on behavioural interactions between fish and exit rates. Many zero catches could result from long soaks if after all bait were eaten, fish rapidly left the trap. The fact that most of the traps with zero catches in this study have full or nearly full bait canisters, rather than empty ones, suggests that gear saturation is not a major cause of zero catches. The amount of bait left in the canister after the set was recorded for every set during this study. Seventy three percent (73%) of all traps retrieved with no fish in them had full bait canisters. A further 19% of all traps retrieved with no fish in them had canisters full of pilchard skeletons left behind by scavenging amphipods. Of a total of 99 traps retrieved empty of fish, only three had empty bait canisters.

Determining the extent to which the relative abundance of fish in traps reflects local abundance or is an artifact of the sampling technique will require extensive underwater video studies of traps (cf. Anon. 1990) together with visual surveys. In many situations such studies may be logistically impossible or provide unclear evidence. For example, if traps and visual surveys give significantly different answers for fish which are difficult to census visually, how does one decide which is the 'best'? At this stage all we can say is that the degree of clumping suggested by trap catches is not inconsistent with that observed in visual surveys.

Power analysis

A positive consequence of the correlation between means and SDs of catch rates was a simple relationship between the CV of a sample and the statistical power to detect hypothetical changes in the sample mean.

Green (1989) has demonstrated that when the sample standard deviation is directly proportional to the mean, equation (1) can be re-arranged, using Taylor's Power Law, to:

$$n = 2(t + t)^2 (CV/f)^2$$

where f is the effect size expressed as a fraction of the mean (e.g. a fishing impact causing an f = 0.33, or 33%, decrease in abundance). Thus for a given effect size, the number of traps required will be proportional to the square of the coefficient of variation. The variance in the relationship between CV and number of traps required in figure 10 is due to the different, empirically determined, relationships between the mean catch rate and its SD for each species on each reef (table 6).

The CV of a sample can be easily measured and the relationship is applicable to all samples. Although the CV of a sample is easy to calculate, our simulations suggests that at least six traps/day/strata are required to avoid an underestimate of its size which would lead to an overestimate of statistical power (simulation not included here).

They also suggest that estimates of the CV will be unavoidably imprecise, even when, as in the simulations, the population is constant (which is unlikely in reality). This is doubly important because relatively small changes in the estimate of the CV can lead to large changes in statistical power. In the results section we give the example of samples of *L. quinquelineatus* from Rib (H2). Although these samples are among our best in terms of consistently low CVs,

the 95% confidence limits for the mean CV are 1.1 to 2.2 which not only covers much of the observed range of CVs but also encompasses a 4-fold change in statistical power.

The two-sample power tests used here are based on Student's *t* and assume that the data is normally distributed and the variances homogeneous. The catch rates are very clearly not normally distributed (figure 6) and the true variances are unlikely to be homogeneous. The effects of these departures from the main assumptions of parametric analysis on our power tests are unknown to us. Simulation studies will probably be required to determine their significance.

It seems unlikely that any other standard statistical tests would have been more powerful in analysing our data than a two-sample *t* test. Crimp (1986) compared the relative power of two-sample *t* tests, three-sample one-way ANOVA and the non-parametric Kruskal-Wallis test to detect simulated changes in coral trout populations. The *t* test proved more sensitive in detecting change than the other two tests, although the ANOVA was better 'behaved', producing more consistent results (P.J. Doherty, pers. comm.).

Given the nature of the data, an appropriate log transformation would usually be applied to help normalise the data and reduce heterogeneity of the variances. We did not do this before carrying out the power tests for two reasons. The first is that we wished to examine the power of the sampling to detect readily comprehended changes in the mean, such as a halving or doubling in the catch rate. This would have been much more difficult to do if we had transformed the data. The second was concern that with the high frequency of zero counts in our data, standard transformations such as $\ln(x + 1)$ may introduce unknown biases into the results of the analyses (McArdle et al. 1990; Mapstone and Ayling 1993). This is a general problem with such data (e.g. Underwood 1981) and we have no ready solution here (even though we earlier applied a $\ln(x + 1)$ transform to carry out the Habitat/Day ANOVAs!).

Relevance of results for the Effects of Fishing experiment

Quite apart from the problem of the extent to which trap catches reflect the abundance of fish (see, for example, Anon. 1990), this study highlights two other difficulties in using catch rates of fish in traps to monitor changes in fish populations. The first is the apparent lack of precision in estimates of mean catch rates and their variance. The second is the low statistical power associated with these estimates, even if SDs and CVs could be estimated precisely.

We do not at this stage see any feasible means of increasing the precision in estimates of catch rates using traps. Our simulations suggest that maximising the trapping effort could improve the estimate but only to a limited extent. There are, however, a number of logistic constraints on the number of traps that can be deployed at any one time.

These include:

1. The number of traps that can be carried on a vessel,
2. Deployment and turn-around times (restricted to a couple of hours because of diel variability in fish behaviour: all traps need to be picked up and re-deployed in early morning and late afternoon - early evening), and
3. The amount of suitable habitat on a reef and the need to place traps a minimum distance apart (nominally 100 m) to avoid interference between traps and to allow room for the research vessel to manoeuvre around the traps.

The first two factors effectively limit the number of traps that can be fished by three people even on a large research vessel to 12. Based on this number, the minimum number of traps required to detect a specified change in the population mean, based on CVs ranging from 1.2 to 2.6 (p. 16), can be converted to number of days sampling required:

Change in Mean	Min. # of Traps	Min. # of Days
+200%	25 - 100	2 - 8
+100%	50 - 200	4 - 16
+50%	120 - 500	10 - 40
-20%	500 - 2000	40 - 165
-50%	80 - 300	7 - 25
-75%	25 - 120	2 - 10

By stratifying sampling to maximise catch rates and hence minimise the CV, the minimum number of days would fall towards the lower end of the range. On the down side it must also be born in mind that these figures represent maximum trapping effort concentrated in one habitat in one depth strata. Monitoring more than one restricted habitat would correspondingly increase the required effort. These figures are also relatively conservative. They do not allow, for example, overestimates of power through underestimation of the CV due to too small a sample.

Our power tests covered two analytical options that could potentially reduce the required sampling effort to detect a specified change in the mean. The first is to reduce the probability level of making a type II error, i.e. accept a lower-powered test. Throughout most tests we used $b = 0.1$, a power of 90%. For habitat H2(t_2) we also calculated MDDs and sample sizes for $b = 0.25$, a power of 75% (tables 7-9). Accepting the lower power reduces MDDs by approximately 20% and minimum required sample sizes by 35%. While significant, this 'improvement' does not make major inroads into the size of the sampling problem.

The second option is to monitor catch rates of all species of, say, a given genus pooled. We examined this for all *Lutjanus* pooled. Our expectation was that this would have little positive effect on power because it would increase the variance considerably. However, because the pooling increases the mean relative to that of the individual species, pooling does considerably increase the statistical power of the test in the present case. While this makes pooling of taxa an attractive analytical option from a monitoring stand point, great care is required in interpreting the results. If a significant overall increase or decrease occurs one could further examine the data to see which species were tending to increase or decrease. If no change is detected in the pooled data, however, it is possible that some species are increasing while others are decreasing. A useful interpretation of the analysis of the pooled data cannot be made without also examining trends in the individual species.

One is forced to conclude that, at the level of catch rates observed in this study, the suitability of fish trapping as a monitoring tool is limited, particularly if two days or less are available for sampling each habitat.

Why use traps at all?

Given our demonstration of the relatively large sample sizes required to detect change using catch rates from our fish traps, many readers may ask 'why persevere with fish traps as a sampling tool?'. There are a number of strong reasons.

While sampling with traps may have limited power to detect small differences in catch rates, it does have sufficient power to make major advances in our understanding of the ecology of species, including lethrinids and snappers, about which we presently know little. For example, five days sampling at Rib Reef with 12 traps was adequate to detect differences in catch rates between adjacent habitats at the same depth for all seven taxa tested at $P < 0.1$ (table 2). These comparisons are a lot more subtle than other basic comparisons about which we know little,

such as depth distributions and differences between reefs. Studies running concurrently with this one have proven traps to be extremely useful in determining depth distributions and among reef differences in distributions (cross-shelf and within shelf locations) of lutjanids, lethrinids and serranids below divable depths. They have also proved extremely useful in among reef comparisons of growth rates, mortality rates and age structures of these species (Newman and Williams 1995a, b; Newman et al. 1995a, b).

For quantitatively sampling reef species below divable depths and sampling at night, the only viable alternative to traps at present would appear to be line fishing or perhaps bait stations and infra-red photography (M. Cappo, pers. comm.) Catch per unit effort of coral trout, in particular, is likely to be greater for experienced fishermen using handlines or rods than for traps. This does not necessarily mean it is a more effective sampling tool for monitoring or for examining distributions. In the first place, linefishing is much harder to standardise than trapping due to variability in skills of individual fishermen. Secondly, it is man-power intensive compared to traps. Thirdly, extensive tests of the statistical power of line-fished samples have not yet been carried out.

We proposed to examine drop-lining as a sampling technique because we were concerned about relatively low catch rates of coral trout and *L. miniatus* in the traps. In retrospect these low catch rates probably reflect the relatively low abundances of these species on the study reefs. Interestingly, the catch rates of trout and *L. miniatus* in traps at Rib and Davies closely reflected perceptions of relative densities of the two species on these reefs based on linefishing on many research cruises. (Total catch of trout over 10 days at Rib was 9+5 (day + night) and at Davies 26 + 14. Total catch of *L. miniatus* was 2 + 7 at Rib and 25 + 12 at Davies). On a July-August cruise after field sampling for this project was completed, we sampled two outer shelf reefs protected by Great Barrier Reef Marine Park Authority zoning from fishing (Rib and Davies are not). Two days and nights were spent at each reef. The same depth and habitat was sampled as at Davies and Rib but only nine traps were used instead of 12. Day/night catches of *L. miniatus* on two days at Dip reef were 23/10 and 21/9. Almost identical catch rates occurred at Bowl. Catch rates at Davies were approximately 4X those at Rib. Our catch rates of *L. miniatus* at Dip and Bowl were about 12X those at Davies. Most interesting was that the CV for catch rates of *L. miniatus* on Dip during the day was 0.71 (CV = 1.23 at night). This CV was much lower than any we had for any taxa on Rib and Davies, suggesting potentially greater statistical power. Perhaps the relatively low catch rates of sweetlip and trout that concerned us were only a reflection of their low relative abundance on the reefs we'd been fishing earlier.

We have deliberately not dealt with the problem of the extent to which catch rates of traps reflect the true relative abundances of the catch species. As indicated by Anon. (1990), it is a complex problem and one that applies equally to line fishing. It is a problem that requires considerable future research.