GREAT BARRIER REEF
MARINE PARK AUTHORITY

RESEARCH PUBLICATION No. 43

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Reef

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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

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SUMMARY

1. The aim of this project was to explore the value of fish traps and drop-lines for monitoring changes in catch rates of fish species of commercial and recreational importance on the central Great Barrier Reef. Emphasis of the study was on:

   i. Quantifying the catch variability within a single depth zone on two different reefs
   ii. Determining the (statistical) sampling power of the traps to detect changes in catch rates, and
   iii. Determining the extent to which spatially stratifying sampling within the depth zone could increase the power to detect change.

2. Modified North West Shelf fish traps were used to sample reef fishes at two different sites in 40 m depth on each of Rib and Davies Reefs.

3. Over 1000 fish, mostly snappers (Lutjanidae) and emperors (Lethrinidae), were caught during nine days of sampling at each reef.

4. Drop-line sampling, carried out simultaneously with trapping on Davies Reef resulted in very low catch rates. We conclude that this technique has little value for systematic sampling or monitoring of reef fishes.

5. Species-specific differences in catch rates between traps set at night and those set during the day were found, as were differences in catch rates between different habitats within a depth zone.

6. Variability in catch rates at each site was examined, together with an analysis of the effect of sample size on these estimates. Catch rates of traps were characterised by a dominance of zero catches, by low means, high variances and a correlation between mean catch rates and their standard deviations.

7. Estimates of catch rates and their variances were inherently imprecise because of the statistical distribution of the catches. Very large sample sizes would not solve this problem even if logistically possible.

8. The statistical power of 2-sample *t*-tests to detect changes in catch rates of the traps was examined. Power was closely related to the (imprecisely estimated) coefficient of variation (CV = standard deviation/mean) of a sample and to the mean catch rate. The higher the catch rate, the greater the statistical power to detect a change in the sample mean. Mean estimates of CV ranged from 1.2 to 3.8, with over 90% between 1.2 and 2.6. Based on CVs of 1.2 - 2.6 and a logistic limit of 12 traps/set, the following estimates of minimum sampling effort to detect specified changes in mean catch rate were determined:

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

9. The suitability of fish trapping as a tool for monitoring changes in catch rates on the study reefs is limited, particularly if two days or less are available for sampling a site.

10. Spatially stratifying sampling within a depth zone will not increase statistical power to detect change by reducing variance per se but will increase such power if habitats with the highest catch rates can be identified and sampled - assuming these habitats are appropriate to the reason for monitoring in the first place.

11. In the context of the proposed Effects of Fishing Experiment, traps would be an effective monitoring tool only if large amounts of time (approximately > five days) were available to sample each critical habitat on each reef, or if only large (approximately 3-fold or greater) changes in catch rates were of interest.

12. Despite these limitations (10), traps may still be the most effective sampling tool for most snappers, emperors, nocturnal species and others below divable depths [equivalent studies of the effectiveness of line fishing have not yet been carried out]. If this is so, the Great Barrier Reef Marine Park Authority and fish scientists will have to live with these limitations and bear them in mind when designing and interpreting studies of these species.

13. Despite limitations for monitoring, the traps used in this project have proved extremely effective at determining the distribution of the target species below divable depths; determining depth, cross-shelf and within reef distributions and among-reef differences in catch rates, growth rates and age structures of populations.

INTRODUCTION

The structural heterogeneity of coral reefs severely limits the use of traditional sampling gears for the quantitative assessment of stocks of reef fishes. For example, trawl nets cannot be used on reef slopes or rough bottom and gill nets only with great difficulty. Additionally, underwater visual survey methods which have been widely used on coral reefs (e.g. DeMartini and Roberts 1982; Sale and Sharp 1983; Thresher and Gunn 1986) are confined by depth restrictions because of the decompression limits of observers. Further, underwater visual survey methods can only be used diurnally. The quantitative sampling of reef fishes of commercial and recreational importance beyond the effective depth limit of SCUBA diving (20 m) has not yet been successfully developed on the Great Barrier Reef. Potential sampling techniques include demersal longlines, traps and drop-lines. Trials with demersal longlines have demonstrated major problems with hook-ups on rough bottom and subsequent loss of gear, as well as serious problems with sharks taking fish at night (Williams, unpublished data). Demersal longlines also have the problem of sampling necessarily large areas when reef fish are often highly clumped and associated with specific bottom features.

Fish traps are a non-destructive sampling methodology that can be utilised in conditions which prevent the use of other techniques such as visual census, trawls, seines and other nets, and along with drop-lines, handlines and rod and reel, offer the advantage of being essentially point samplers that can be used to target very specific features where fish are expected to aggregate. Additionally, they can be used in almost any kind of habitat. They have been used widely throughout the world as an artisanal or commercial method of fishing (e.g. Prabhu 1954; Kawamura et al. 1970; Smith et al. 1980; Munro 1983; Dalzell and Aini 1987; Desurmont 1989). More recently they have been developed as sampling tools in the quantitative assessment of stocks of reef fishes (Munro 1974, 1983; Wolf and Chislett 1974; Powles and Barans 1980; Stevenson and Stuart-Sharkey 1980; Koslow et al. 1988; Desurmont 1989; Guerin and Cillaurren 1989). They have been used also to assess changes in community composition in response to varying levels of fishing pressure (e.g. Ferry and Kohler 1987; Koslow et al. 1988; Moran and Jenke 1989). A modified North West Shelf 'O' trap design has proved to be an effective methodology for the sampling of species of commercial and recreational fishing significance, such as snappers (Lutjanidae) and emperors (Lethrinidae) on the Great Barrier Reef (Newman and Williams 1995a). These traps have proven more effective for short soak times (< 24 h) than 'Z' traps (cf. Whitelaw et al. 1991).

Trap fishing on the Great Barrier Reef has demonstrated strong day-night, day-to-day and habitat and depth differences in catch rates and species composition (Newman and Williams 1995a, b; Newman et al. 1995a, b). In addition to these sources of variation, high variability in catch occurs among traps set at the same time within a depth stratum. It would be highly desirable to decrease this among 'replicate' variability if traps are to be a statistically powerful tool for monitoring catch rates as an indicator of changes in fish abundance, as will be required, for example, in any Effects of Fishing Experiment. We propose that the variance in catch between 'replicate' trap sets can be reduced, and catch rates increased, by more effective sampling stratification, i.e. by more selective locating of traps within sites.

While our traps have proven effective at catching a range of lutjanid and lethrinid species, catch rates of *Plectropomus* spp. and *Lethrinus miniatus*, which dominate the commercial line fishery, have been relatively low. On the basis of preliminary trials, we believed that these species might be more susceptible to drop-lines than traps and that larger individuals might be more readily caught on lines than in traps.

The aims of this study are to:

1. Quantify the catch variability associated with trap sampling within a depth stratum.
2. Determine the effects of within-depth habitat stratification on this variability.
3. Determine the sampling power (in terms of minimum detectable differences and sample size) of the fish traps in stratified and unstratified sampling designs.
4. Compare the species composition and size of fish caught by traps and drop-lines in the same habitat.

METHODS

Fish traps - design, equipment and procedure

The trap design was based on the O or cylindrical shaped trap which is commonly used in the Western Australian snapper fishery of Shark Bay and the demersal trap fishery of the North West Shelf of Australia (Bowen 1961; Moran and Jenke 1989; Anon. 1990; Whitelaw et al. 1991). The design was modified from that described in Anon. (1990) and Whitelaw et al. (1991). Two funnel entrances were used instead of one (thereby increasing the chance of having one entrance facing away from the prevailing current at any one time), and these funnel entrances were reduced from a vertical slit entrance of 900 mm height to only a 300 mm height × 100 mm wide vertical opening in the centre of the vertical wall of the trap (figure 1.1). The trap entrance had incurving walls which tapered to the opening. The entrances extended approximately 400 mm into the trap (see figure 1.2). The aim of the modified style of entrance funnel was to decrease the egress (escapement) of trapped fish, whilst maintaining the relatively high rates of ingress of fish to the North West Shelf style trap.

The traps were cylindrical with a diameter of 1500 mm, a height of 900 mm, a plan area of approximately 1.8 m^2, and a volume of approximately 1.6 m^3. Frames were constructed of 10 mm diameter steel rod and were covered with galvanised 40 mm hexagonal wire mesh (see Newman and Williams 1995a). Hauling bridles were attached to each individually numbered trap and the bridle was supported above the trap with the aid of a small polystyrene float. The bridles were attached by nylon rope (8 mm) to a surface buoy (25 cm longline float) and then with a leader line to a dan buoy (radar pole). Each trap was individually buoyed to allow ease of recovery. Logistically it was not feasible (with regard to both clearance times and storage space) to fish more than 12 traps at any one time.

Traps were baited with Western Australian pilchards (*Sardinops neopilchardus*), which yielded significantly higher catches than other types of bait in a study on the North West Shelf of Australia (Whitelaw et al. 1991). Each trap was baited with approximately 1 kg of mulched pilchards placed in crab pot style bait canisters. Fresh bait canisters were placed in traps every time that the traps were set. Each bait canister was constructed of 300 mm of 80 mm diameter PVC tubing, in which ten, 30 mm diameter holes were drilled to allow fish access to the bait and to allow the release of a bait plume. The bait canister was capped at each end with a PVC cap and suspended from the top of the trap, so that it hung suspended in the centre of the trap between the funnel openings (see figure 1.2).

The traps were released from the stern of the research vessel, pulled upright when submerged and then allowed to sink to the substratum. Trap lines and floats were always streamed out to decrease the risk of entanglement and hence loss of traps. Hauling or setting a trap took less than three minutes. The catch of each trap was placed in bins of running seawater. Each fish was identified to species according to Allen (1985), Carpenter and Allen (1989) Randall et al. (1990), Randall and Heemstra (1991) and Heemstra and Randall (1993), measured to the nearest millimetre (standard length, length to caudal fork, and body depth), tagged and released or frozen for studies of age and growth.

Traps were set a minimum distance of 100 m apart and ranged up to a several hundred metres apart in order that the capture field of each trap would not overlap (Eggers et al. 1982; Davies 1989). This resulted in less competition (overlap) between the capture fields of adjacent traps.

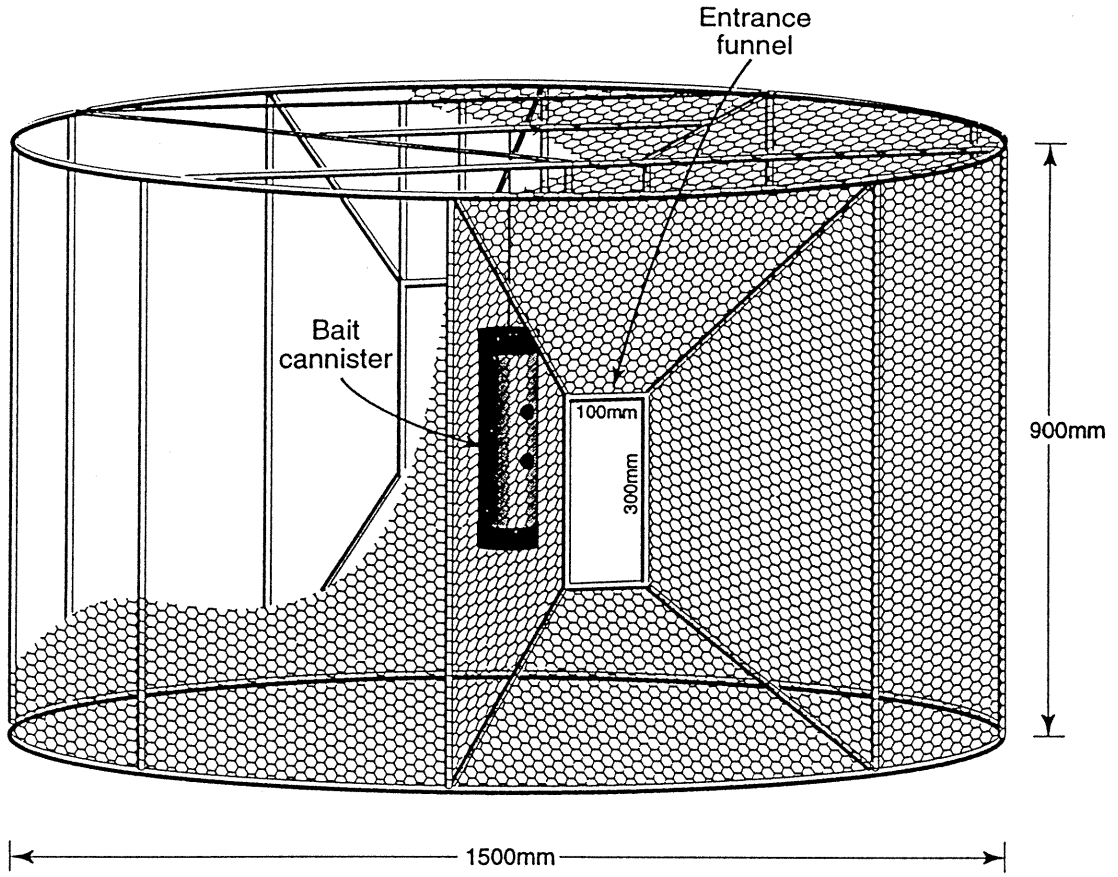


Figure 1.1. Modified 'O' trap design

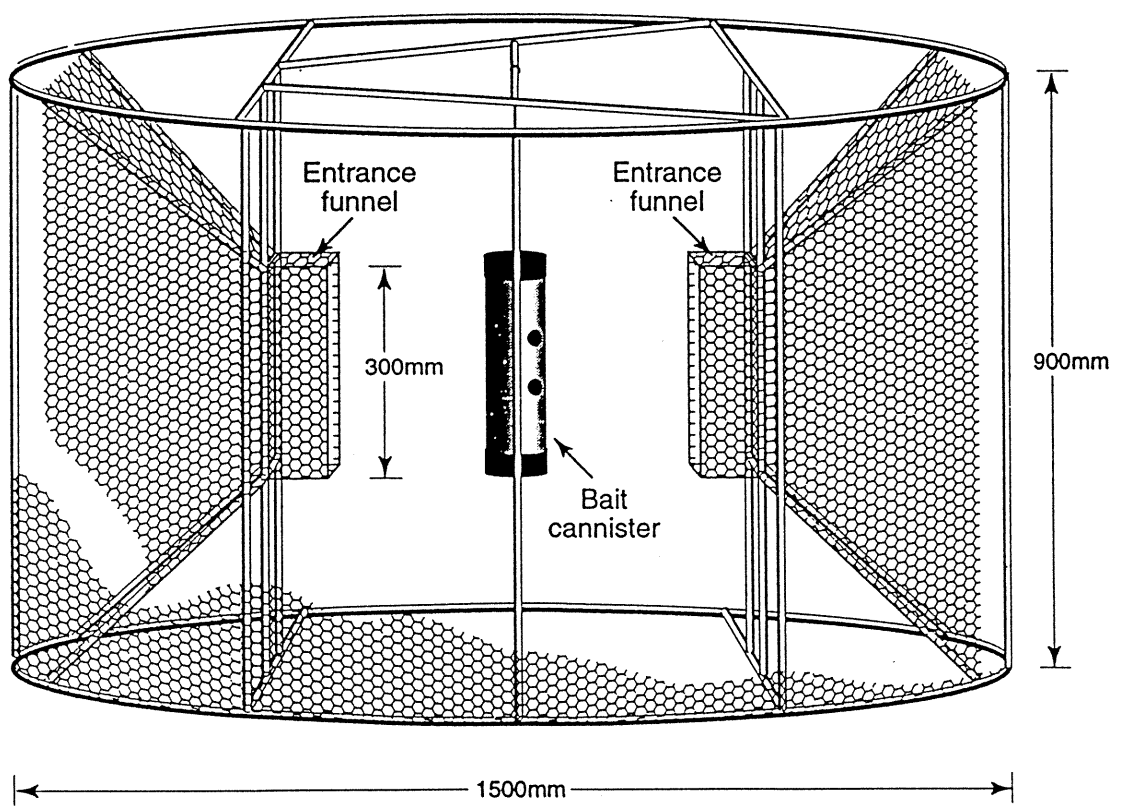


Figure 1.2. Side profile of the modified 'O' trap showing the two incurved funnel entrances and the relative position of the bait canister between the funnel entrances

Setting and hauling of traps was carried out in the early morning and evening. 'Night' set traps were hauled from 0530h, with sorting and processing of trap catches usually completed by 0830h and total soak times (the time between deployment and hauling of the trap) varying from 12 to 14 hours. Usually as each trap was emptied it was refilled with a fresh bait canister and redeployed for a 'Day' set. Alternatively, if traps were being moved to a new habitat, all traps were emptied and kept on board then after steaming to the new location, all were redeployed with fresh bait canisters. 'Day' set traps were hauled from 1630h onwards, with sorting and processing usually completed by 1830h. Soak times during the day varied from 9 to 11 hours. Deployment of 'Night' sets was similar to the deployment of 'Day' sets. The term 'Day-Night' set refers to consecutive 'Day' and 'Night' sets.

Sampling

Catch rates and catch composition of traps and drop-lines were compared within the 40-45 m depth range on two Townsville mid-shelf reefs, Rib and Davies (figure 2). Both these reefs are sites of our ongoing studies on age, growth and distributions of fish species of recreational and commercial interest. The depth stratum for this study was selected on the basis of results from a cruise in January 1992 which indicated that catch rates in 40-45 m depth tended to be higher than those at 20 m and 60 m.

The first 10-day cruise, from 23 April until 1 May, was to Rib Reef. Here a major source of within-habitat variation observed on a previous cruise appeared to be whether or not the trap had been deployed on weed beds or away from them (as evidenced by *Caulerpa* and a thread-like, unidentified alga stuck to the traps on retrieval) and whether or not the traps had been deployed near vertical relief (bommies and ledges). One aim of this cruise was to quantify these effects.

On the first day-night set, 12 traps were set in 40 m (each trap 100-200 m apart), regardless of bottom type or profile, along the northern and north-eastern slopes of Rib Reef (H1 and H2 in figure 2). Echo-sounding profiles (perpendicular to the reef crest) were run from shallow water (< 20 m) through each trap location and out onto the off-reef floor using a paper-recording sounder to give a permanent record of each habitat. The bottom profile, based on the echosounder, was remarkably consistent except that the first six traps (mainly on the northern side of the reef) were set on relatively flat bottom and the second six (mainly on the north-eastern side of the reef) were set on relatively more broken bottom, with significant topographic variation (figure 3). Furthermore, contrary to expectations from the previous trip, little weed came up attached to the traps.

A video camera was towed close to the bottom on transects normal to the depth contours and passing within metres of each trap. Each transect was centred on a trap and was approximately 100 m long, generally running from approximately 35 m depth to 45 m. For most traps, two parallel transects were run either side of the trap. These video transects confirmed that the bottom was relatively uniform, basically sandy with the dominant fauna being a large foram, and that there were no extensive weed beds. The irregularities on the north-eastern side of the reef were found to be isolated bommies approximately 0.5 to 3 m in height. Filming was stopped when an encounter with such a bommie led to severe damage to the protective dome around the camera lens.

These observations led to some changes in the proposed sampling design. The focus changed from small scale variability (< 100 m) to larger scale differences (100s of metres to a kilometre) between habitats within a depth stratum. For the first five days, six traps were fished in each of the 'flat' and 'broken' habitats simultaneously (figure 2). Each 'Day-Night' set, all traps were pulled on deck and redeployed so that identical sites within each habitat were not

fished from one set to the next. The exact positions of deployment of all traps were recorded using GPS. On the last four days all 12 traps were moved into the habitat with the greatest catch rates of the target species ('broken') and fished in the same manner as the first five days.

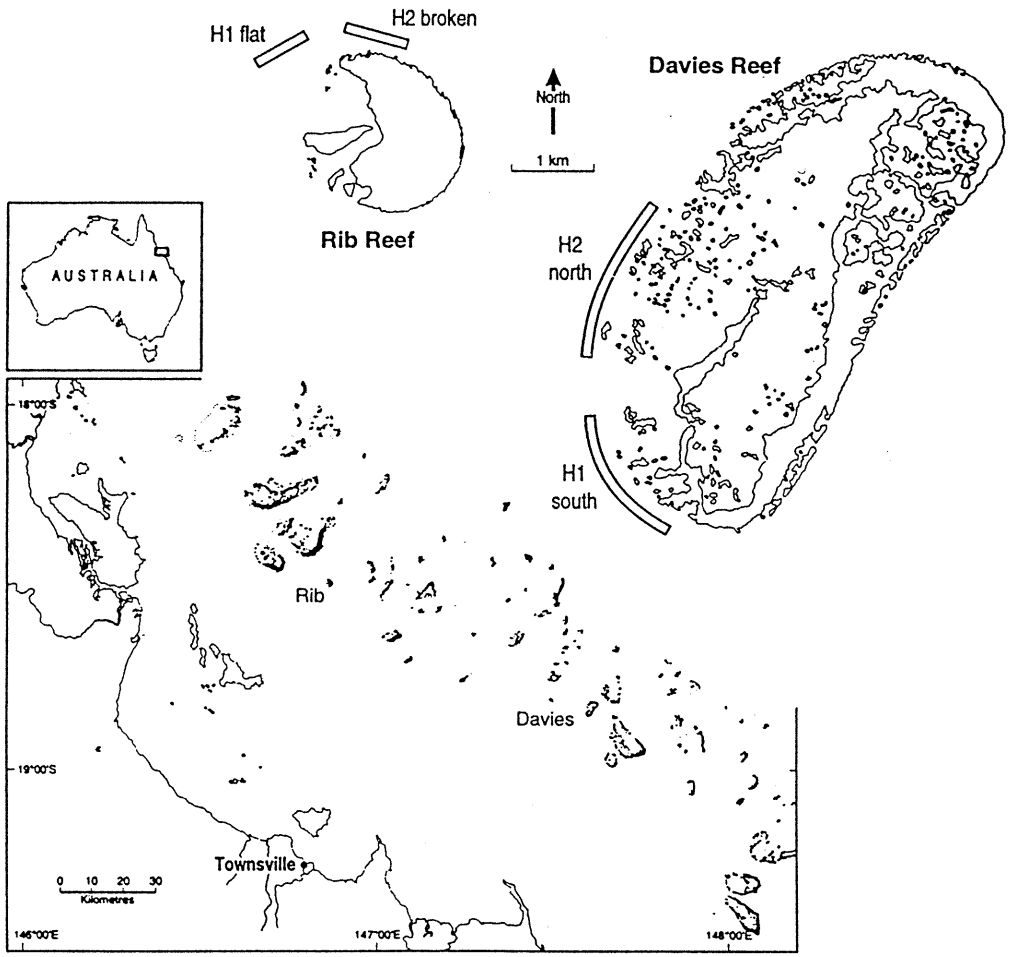
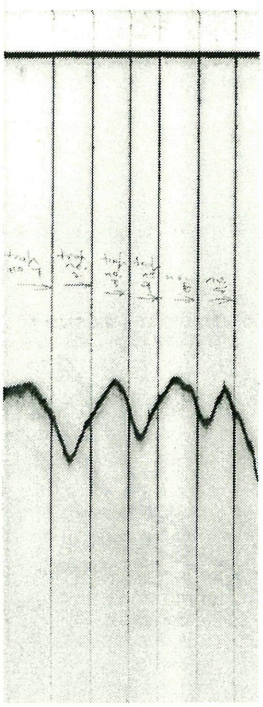


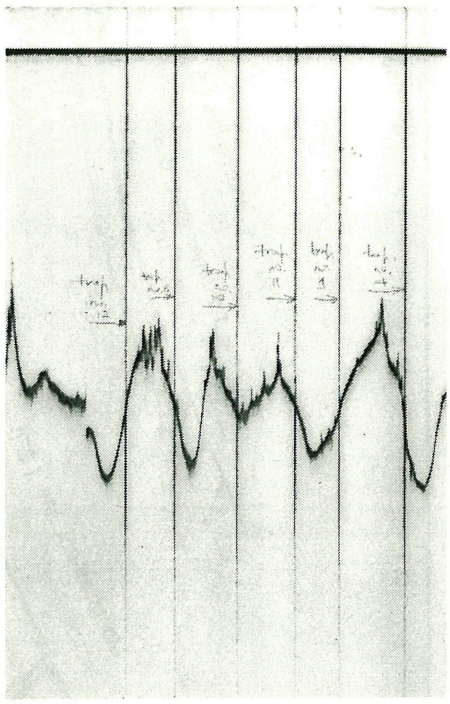
Figure 2. Map of central section of the Great Barrier Reef showing the relative location of Rib and Davies Reefs. Inset shows these reefs at a larger scale, indicating the locations of the 40 m habitats sampled on each reef. There is no specific relationship between the habitats labelled H1 and H2 on the different reefs.

The second cruise, to Davies Reef from 22 May until 30 May, employed a similar design to that of the first cruise. Two habitats of different bottom rugosity were delineated in the back reef at 40 m depth. The differences between these strata were not nearly as great as those between the two habitats on Rib (figure 2). The two habitats on Davies Reef are henceforth referred to as 'north' and 'south' (figure 1).

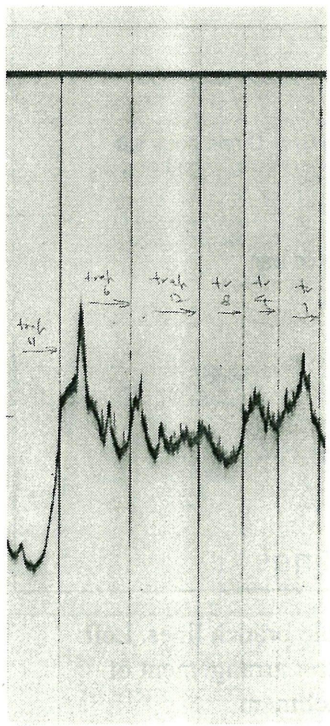
As at Rib, simultaneous comparisons between the two habitats were carried out on five days (n = six traps per habitat) whilst on the remaining four days, all 12 traps were placed in the habitat with the greatest catch rates of the target species only ('north'). In contrast to Rib, however, the timing of these two different series was randomised among days. This was done to avoid the possibility of a consistent change in catchability of fish over the sampling period confounding the results of the two series.



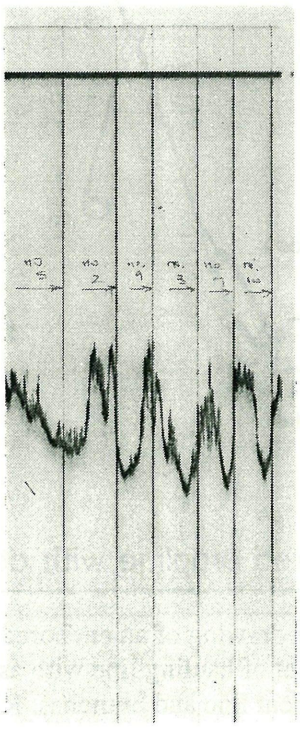
Rib - flat



Rib - broken



Davies - north



Davies - south

Figure 3. Echo-sounding traces recorded on one occasion of deployment of traps with each habitat/reef combination. Lines indicate the point at which each trap was dropped. Zig-zag pattern reflects the track of the boat relative to the 40 m depth contour, whilst the smoothness of the trace reflects substratum rugosity.

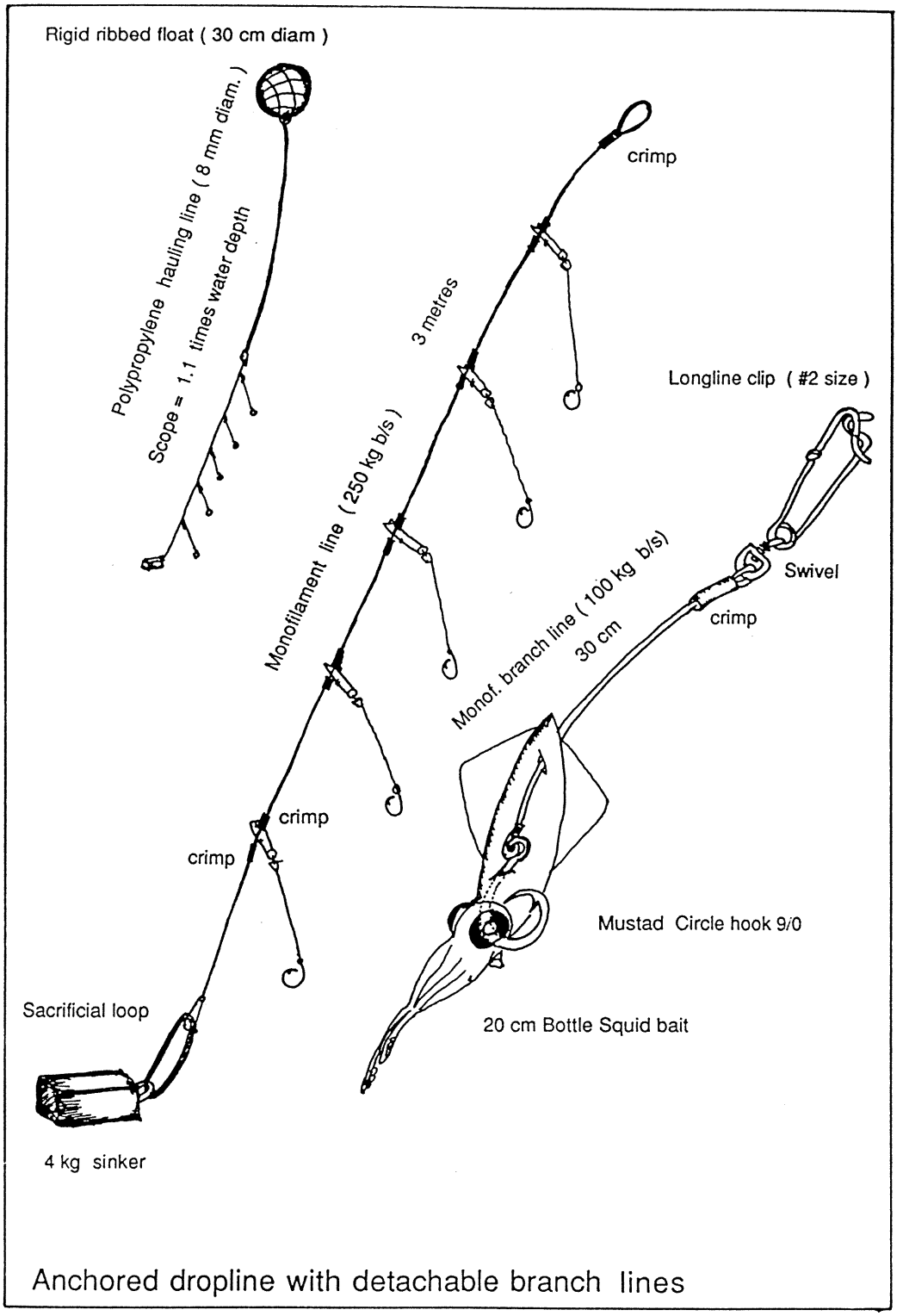


Figure 4. Line drawing of an anchored drop-line with detachable branch lines. Left: arrangement of hauling line with associated branches. Centre: arrangement of monofilament line and branches. Right: method of bait attachment

In addition to the traps at Davies Reef, drop-lines were deployed in the 40 m depth stratum among the traps, on three days. The drop-lines were similar to those developed by a professional line fisherman (Mr Paul Whelan) for catching red snappers (figure 4). Each of the six drop-lines had 5-hooks (medium-sized tuna circle) and were baited with squid. Fishing activity was divided into morning (0800 - 1200h), afternoon (1430 -1700h) and night (2000 - 2330h) sessions. These sampling times were determined by the logistic demands of the concurrent trap sampling. As soon as all six lines had been deployed between the traps, the first

deployed was pulled in, rebaited and redeployed, followed immediately by the redeployment of the second line and so on. Hauling and redeploying was thus a continuous activity for the duration of a fishing session.

Analysis

Because of high taxon-specific differences in catch rates between day and night sets (table 1), day and night sets were analysed separately. Species with a total catch of > 50 individuals in either set on either reef were examined in detail, together with *Lutjanus sebae* on Rib Reef (because of its particular importance to reef fisheries) as well as all species of *Lutjanus* pooled. Thus the following sets and species were examined from Rib Reef: night catches of *Lutjanus adetii*, *L. quinquelineatus*, *L. russelli*, *L. sebae* and all *Lutjanus* spp. pooled; day catches of *Lethrinus* sp. 2 and *Abalistes stellatus*. From Davies Reef, night catches of *L. quinquelineatus*, all *Lutjanus* spp. pooled and both day and night catches of *Lethrinus semicinctus* were examined.

Table 1. Summary of total catches at Rib Reef (23 April - 2 May) and Davies Reef (22 May - 31 May)

	RIB			DAVIES		
	Day	**Night**	**Total**	**Day**	**Night**	**Total**
Lutjanidae:						
Lutjanus adetii	22	541	**563**	-	18	**18**
L. quinquelineatus	1	163	**164**	-	109	**109**
L. russelli	1	65	**66**	5	27	**32**
L. sebae	1	41	**42**	2	17	**19**
L. vitta	4	24	**28**	16	10	**26**
L. fulviflamma	-	2	**2**	-	-	**-**
L. boutton	-	1	**1**	-	-	**-**
L. carponotatus	-	1	**1**	-	-	**-**
L. bohar	-	-	**-**	-	1	**1**
Lethrinidae:						
Lethrinus sp. 2	57	11	**68**	40	15	**55**
L. semicinctus	-	-	**-**	270	142	**412**
L. lentjan	4	6	**10**	7	4	**11**
L. miniatus	2	7	**9**	25	12	**37**
L. nebulosus	2	6	**8**	1	1	**2**
L. ornatus	-	2	**2**	-	-	**-**
Gymnocranius audleyi	41	19	**60**	36	18	**54**
Serranidae:						
Plectropomus leopardus	9	5	**14**	26	14	**40**
Epinephelus areolatus	16	18	**34**	1	-	**1**
Balistidae:						
Abalistes stellatus	76	15	**91**	41	8	**49**
Misc.	72	47	**119**	89	68	**157**
TOTAL	267	955	**1222**	558	464	**1022**

Differences in catch rates between 'flat' vs 'broken' habitats on Rib and 'north' vs 'south' on Davies for five days of each cruise were compared using two-way analysis of variance (ANOVA), with Habitats treated as a fixed factor and Days as random. Because of the apparent log-normal distribution of the data, they were transformed by ln (x + 1) prior to analysis.

In order to determine the effects of sample stratification on sampling variability and power, four habitat/time strata of catch rate data were analysed on each reef:

Data Set	Site		Sample Dates		Traps/day
	Rib	Davies	Rib (April)	Davies (May)	
Habitat 1	flat	south	23 - 27	23,24,26,27,30	6
Habitat 2(t_1)	broken	north	23 - 27	23,24,26,27,30	6
Habitat 2(t_2)	broken	north	28 - 1 May	22,25,28,29	12
Habitat '1 & 2(t_1)'	flat & broken	south & north	23 -27	23,24,26,27,30	12

On each reef, the first two data sets are from different habitats sampled at the same time. Habitat '1 & 2(t_1)' is the pooled data set from the two habitats within each reef. Habitat 2(t_2) represents a resampling of Habitat 2 on each reef. These data sets permit comparisons of catch variability between two different habitats sampled at the same time (H1 vs H2t_1), between 'stratified' and 'unstratified' data (H1 and H2t_1 vs 'H1 & H2t_1') and between the same habitat sampled on different occasions (H2t_1 vs H2t_2).

Catch variability within habitat/time strata was summarised by two different measures of variability: standard deviation (SD) and the coefficient of variation (CV = SD/mean). The effect of sample size (number of days sampled) on estimates of SD and CV was determined by simulation. Separate simulations were run for each taxa for two habitats pooled (H1 and H2(t_1)), and for one of these habitats alone (the habitat with the highest mean catch, i.e. H2(t_1) for all taxa except *Abalistes stellatus* (H1)). The sample population for the simulations was all trap catches within a given habitat/time stratum: thus a sample population of n = 30 for H2(t_1), n = 48 for H2(t_2) and n = 60 for 'H1 & H2(t_1)' on each reef. Each datum (mean CV or SD for a given number of days sampling) was calculated as the mean of 10 draws of 12 'traps' from the appropriate sample population (at random with replacement). The precision of this estimate was examined by a similar simulation with three different numbers of traps per set (6, 12 and 18) for two taxa.

The statistical power to detect changes in catch rates in each of the habitat/time strata was calculated in terms of the sampling effort (number of traps) required to detect a specified percentage change in the sample mean.

The formula used to calculate sample size for a given percentage change was:

$$n = \frac{2.s_p^2 \cdot (t_\alpha + t_\beta)^2}{d^2}$$

where d is the difference between the sample mean and hypothesised new mean (sample mean +/- nominated percentage change); s_p^2 is the pooled variance; n is the sample size; t is the t-test statistic with α the probability of a Type I error, β the probability of a Type II error (Zar 1984). Alpha (α) was set at 0.05, β at 0.1. For one habitat block (2 (t_2)), the same analyses were run with $\beta = 0.25$, for comparison.

Standard deviations of samples were proportional to means (q.v.) and so the pooled variance was calculated from empirically derived relationships between the standard deviation and the mean for each species (table 6). Observed mean-SD relationships covered the values of the hypothetically decreased means. For some taxa, however, the variance about the regression increased at higher means. In these cases we were not happy using the regression to infer SDs of hypothetically increased means. For analysis of population increases we therefore restricted

ourselves to those taxa in which there was a close empirical relationship between mean and SD throughout the range of observed data (*L. quinquelineatus*, *L. russelli*, *Lethrinus* sp. 2 at Rib Reef, *L. semicinctus* (Day) and *L. semicinctus* (Night) at Davies Reef).

Potential increases and decreases were treated separately, with a view to being able to detect a decrease due to increased fishing pressure or an increase due to reduced fishing pressure, so alpha was taken as one-tailed. Changes in the means corresponding to decreases of 20%, 50% and 75% and increases of 50%, 100% and 200% were examined.

RESULTS

Catch composition

Rib Reef traps

Over nine days, 1222 fish were caught, including 867 snappers (Lutjanidae), 97 emperors (*Lethrinus* spp.) and 91 *Abalistes stellatus* (table 1). Catch rates during this cruise were high compared to previous cruises. For example, the mean catch rate of snappers during the cruise was 8.0 fish/trap/night, compared to 4.5 fish/trap/night in the same habitat on this reef in January. Four species dominated the snapper catch: *Lutjanus adetii* (n = 563), *L. quinquelineatus* (164), *L. russelli* (65) and *L. sebae* (40). The vast majority of all fish were tagged and released. Sixty-nine recaptures of tagged snapper were recorded. Most had been tagged during the course of this trip, but some had been tagged up to six months earlier. Nine *L. adetii* represented multiple recaptures, with individual fish being recaptured up to five times.

Mean catch rates were highly variable from set to set (whether day time or night time) and there was no evidence of co-variability in catch rates among different species or any consistent trend over the nine days (figure 5a). Highest catch rates for all snappers were during night sets, whilst those for *Lethrinus* sp. 2 and *A. stellatus* were during daylight hours (table 1). Further discussions of these species refer only to night sets for snappers and day sets for *Lethrinus* sp. 2 and *A. stellatus*. Numbers of fish/trap were highly variable within habitat/time strata. The most common catch of each species was no fish/trap, whilst the most common catch for all snapper species combined was one fish/trap (figure 6). The maximum number of fish in any trap for each species was 117 *L. adetii,* 11 *L. quinquelineatus,* 5 *L. russelli,* 5 *L. sebae*, 11 *Lethrinus* sp. 2 and 8 *Abalistes* (figure 6).

Catch rates of each species of snapper were consistently higher in the 'broken' habitat than the 'flat' habitat (figure 5a). This difference was significant at $P<0.05$ for two of the species and all species pooled (two-way ANOVA). Catch rates of *Lethrinus* sp. 2 were also significantly higher in the 'broken' habitat, whilst those of *A. stellatus* were significantly higher in the 'flat' habitat. A significant day-to-day variability in catch rates was detected only for *L. sebae* (table 2).

Davies Reef traps

A total of 1022 fish were caught in traps over nine days at Davies Reef, including 204 snappers, 517 *Lethrinus* spp., 49 *A. stellatus* and 40 *Plectropomus leopardus.* The catch was dominated by *Lethrinus semicinctus* (412 fish) which we have never caught at Rib Reef.

As for Rib Reef, mean catch rates were highly variable from day to day and there was no evidence of co-variability in catch rates among different species or any consistent trend over the nine days (figure 5b). Species that were more numerous in night sets at Rib were also more numerous in night sets at Davies. *Lethrinus* sp. 2 was more numerous in day sets at both reefs. Highest catch rates of *L. semicinctus* occurred during the day but good catches were also taken at night (table 1). Further discussions and analyses refer to the night time snapper catches and daytime *Lethrinus* sp. 2 catches. Both day and night catches of *L. semicinctus* are analysed separately. Numbers of fish/trap were again highly variable. The most common catch of each species was no fish/trap (figure 6d). Maximum catches in any one trap were 12 *L. quinquelineatus* and 28 *L. semicinctus*.

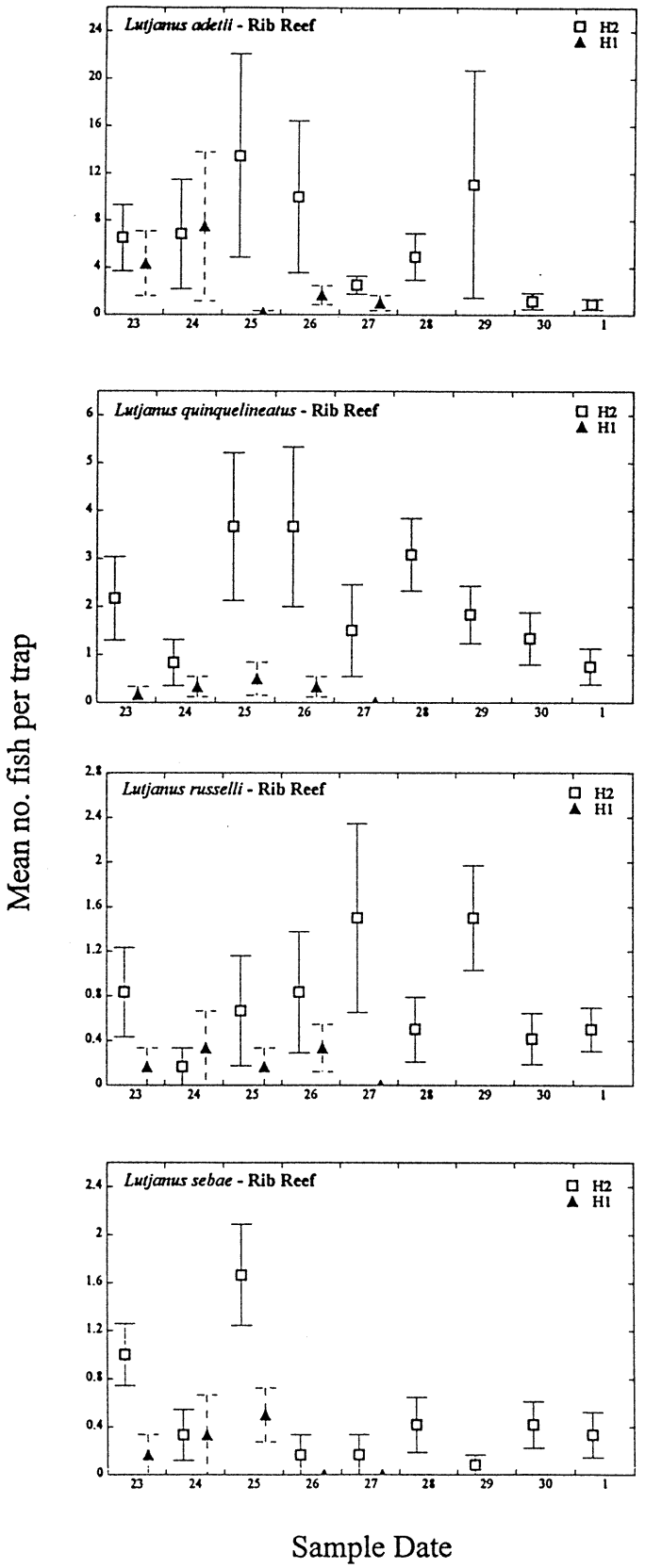


Figure 5a. Mean catch rate per day (+/- standard errors) for each habitat sampled at Rib Reef (H1 = flat; H2 = broken)

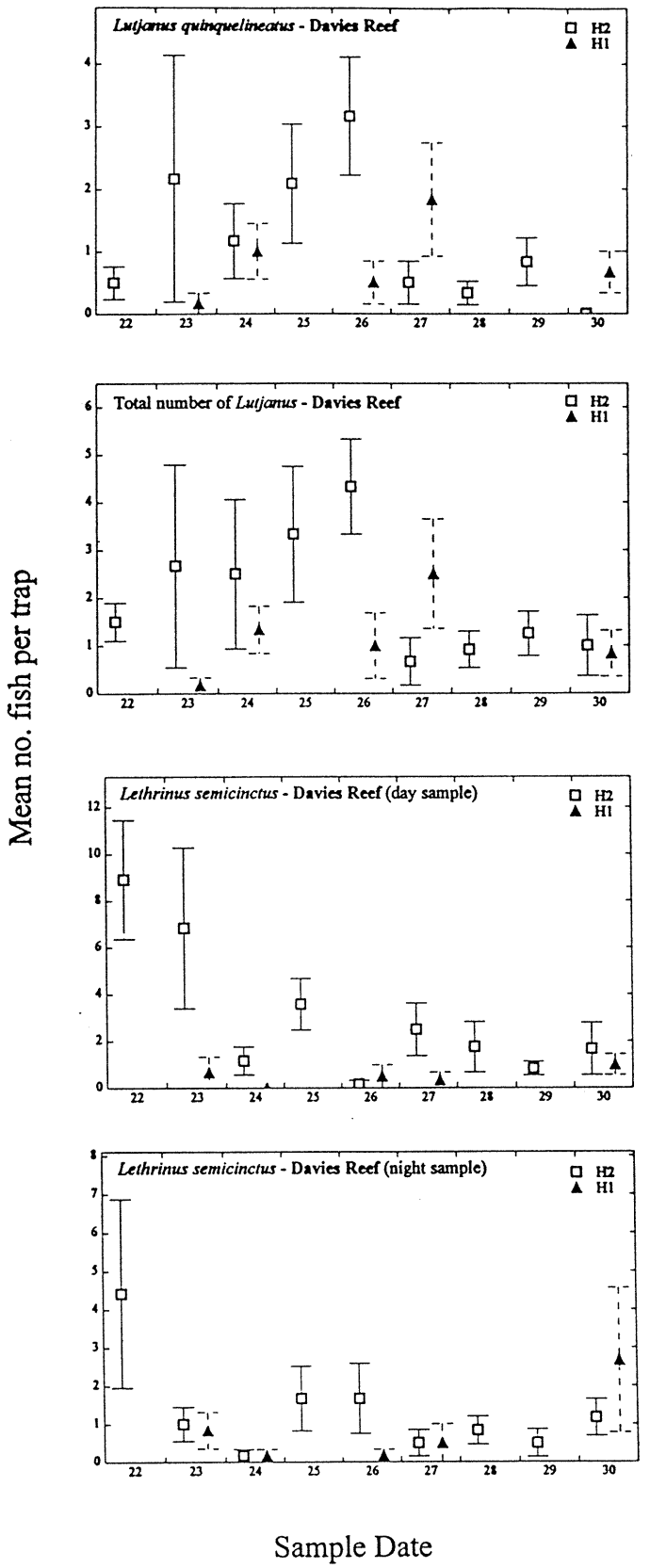


Figure 5b. Mean catch rate per day (+/- standard errors) for each habitat sampled at Davies Reef (H1 = south; H2 = north)

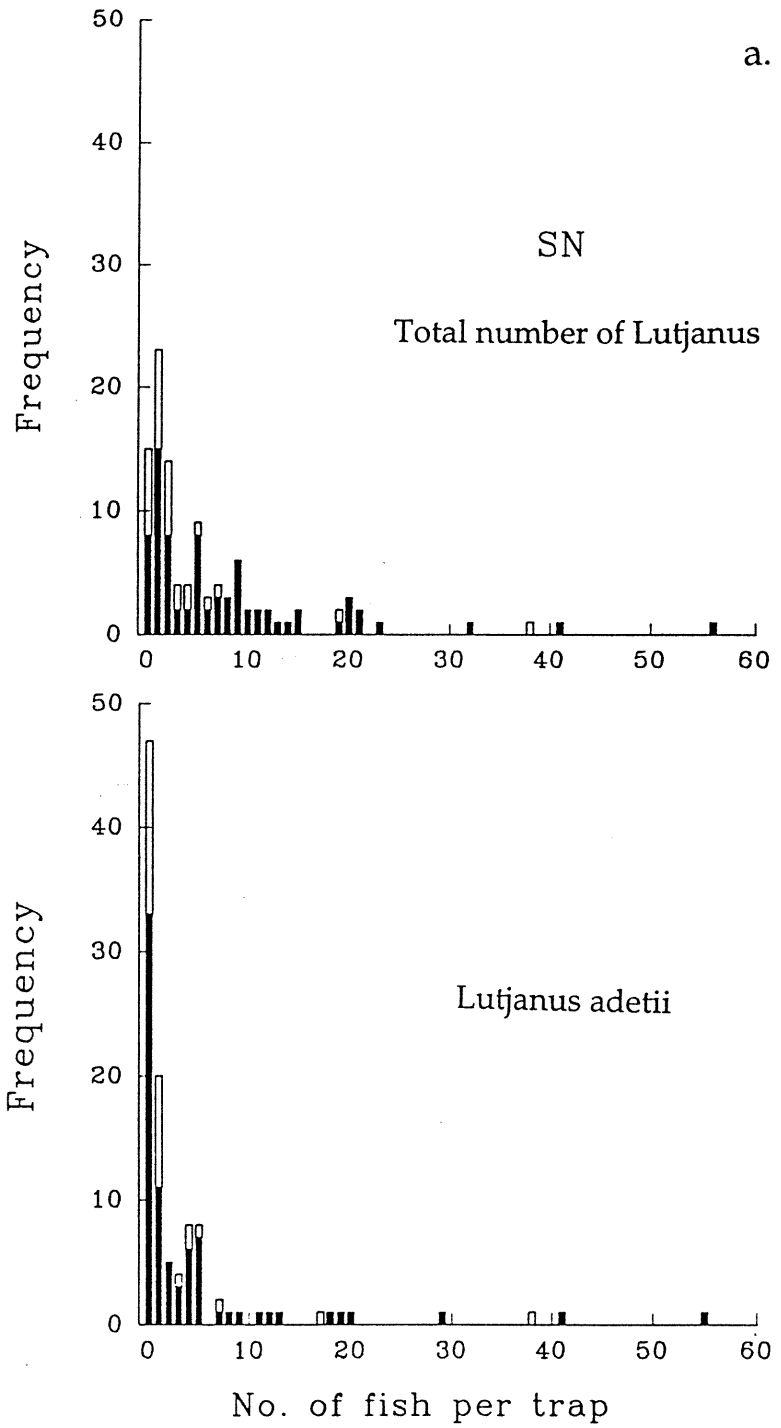


Figure 6. Frequency distributions of catch rates per trap. Unshaded bars = H1, shaded bars = H2. (a) Rib Reef - night samples. Figure for total snapper excludes one value of 131, that for *L. adetii* excludes one of 117; (b) Rib Reef - night samples; (c) Rib Reef - day samples; (d) Davies Reef - night samples except where indicated

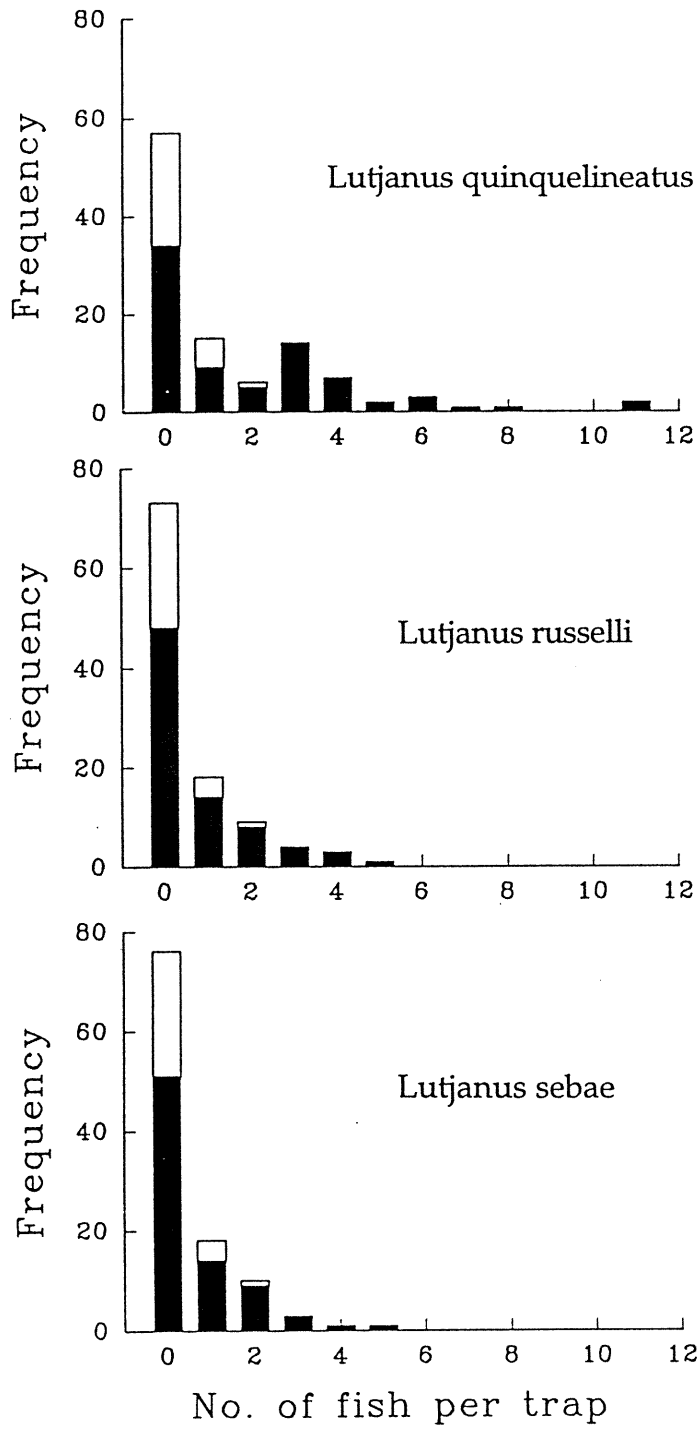
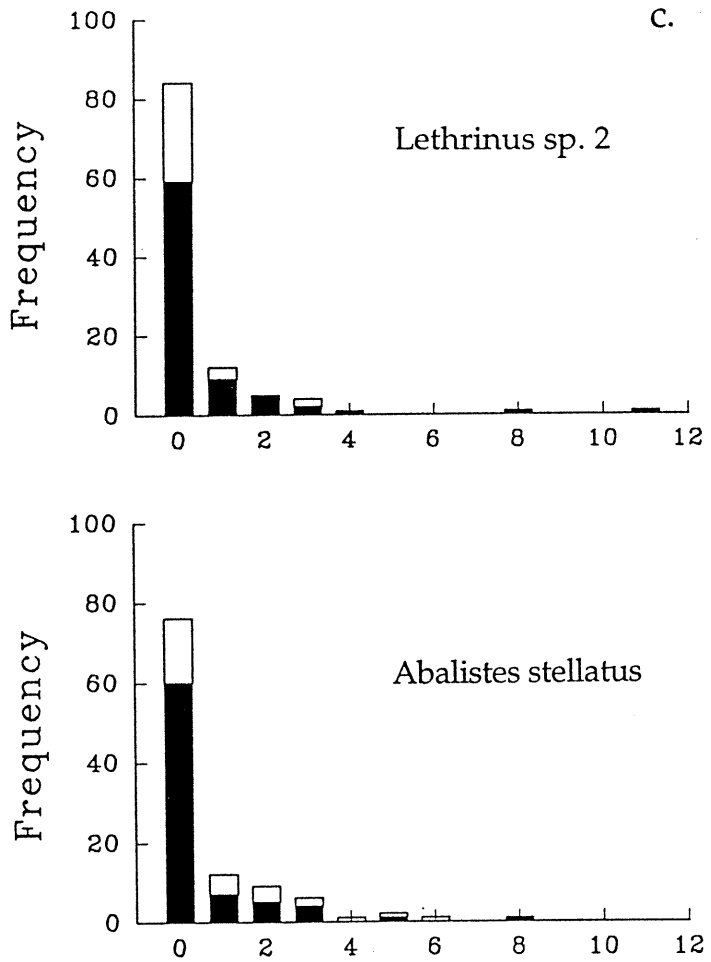


Figure 6 cont. Frequency distributions of catch rates per trap. Unshaded bars = H1, shaded bars = H2. (a) Rib Reef - night samples. Figure for total snapper excludes one value of 131, that for *L. adetii* excludes one of 117; (b) Rib Reef - night samples; (c) Rib Reef - day samples; (d) Davies Reef - night samples except where indicated



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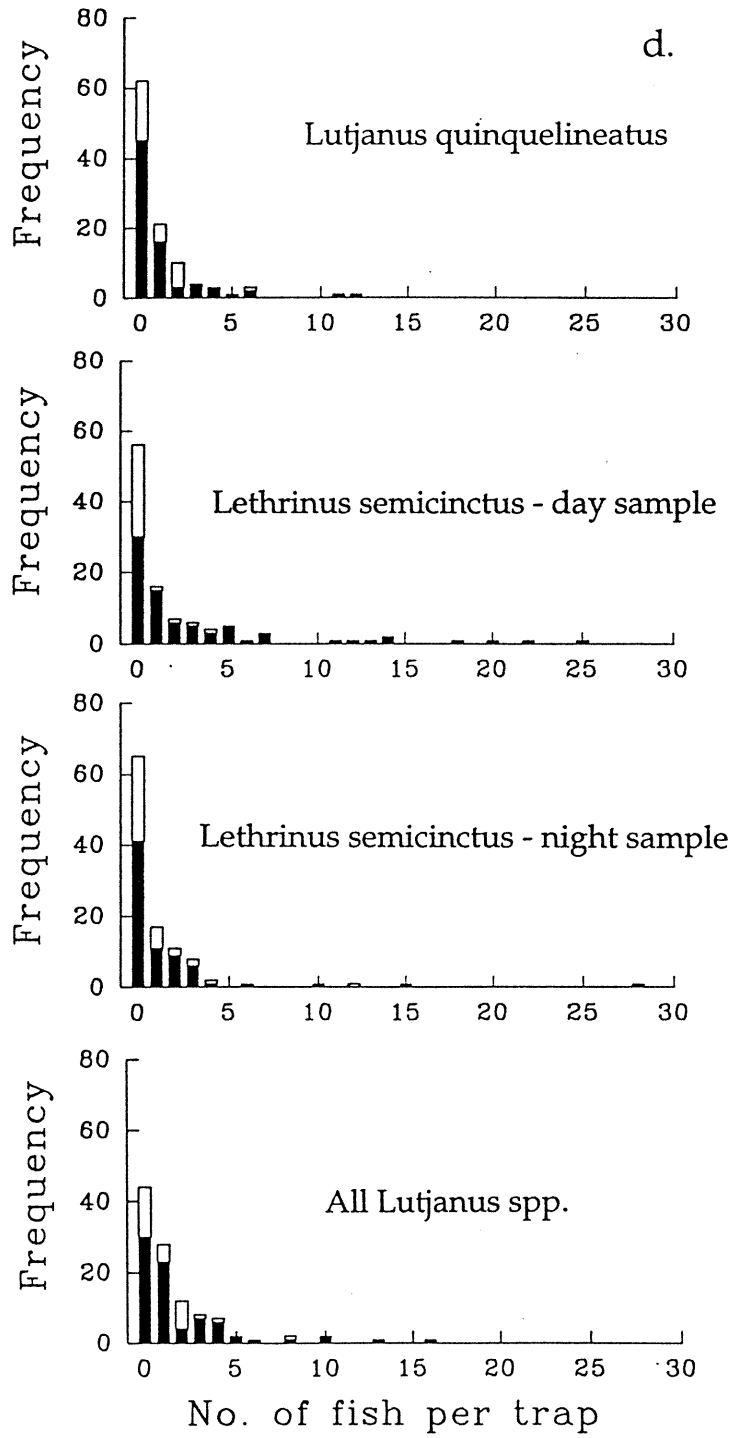


Figure 6 cont. Frequency distributions of catch rates per trap. Unshaded bars = H1, shaded bars = H2. (a) Rib Reef - night samples. Figure for total snapper excludes one value of 131, that for *L. adetii* excludes one of 117; (b) Rib Reef - night samples; (c) Rib Reef - day samples; (d) Davies Reef - night samples except where indicated

Table 2. Summary of within-reef ANOVAs testing for differences in catch rates between habitats and among days (2 habitats, 5 days): Probabilities of F-ratios for Day, Habitat and Day x Habitat (D x H) interactions. *, $P < 0.05$

Samples	Days	Habitats	D x H
Rib Reef:			
Lutjanus adetii	0.735	**0.035***	0.602
L. quinquelineatus	0.199	**0.007***	0.516
L. russelli	0.878	0.081	0.465
L. sebae	**0.000***	0.069	0.169
All *Lutjanus* spp.	0.447	**0.025***	0.280
Lethrinus sp. 2	0.489	**0.034***	0.904
Abalistes stellatus	0.595	**0.011***	0.918
Davies Reef:			
L. quinquelineatus	0.133	0.704	**0.015***
L. semicinctus (D)	0.103	0.110	0.128
L. semicinctus (N)	0.092	0.442	0.993
All *Lutjanus* spp.	0.216	0.474	**0.038***

The differences in catch rates between different habitats at Davies were less than at Rib and none was statistically significant (table 2). There was a significant interaction between habitat and day of sampling for *L. quinquelineatus* which also affected the analysis for all snappers pooled because this was the dominant snapper in the catch.

Davies Reef drop-line

Catch rates on the drop-lines were very low, particularly during the morning session. In no single session was the average catch rate greater than one fish per hour (table 3). A total of 42 fish were caught comprising 15 *Lethrinus miniatus,* two *L. nebulosus,* two *L. lentjan,* one *Gymnocranius grandoculis,* three *Lutjanus russelli,* two *L. malabaricus,* one *L. sebae,* one *L. vitta,* one *Aprion virescens,* one *Symphorus nematophorus,* three *Plectropomus leopardus,* one *Epinephelus malabaricus,* one *E. fuscoguttatus,* two *Carangoides fulvoguttatus,* one *C. gymnostethus,* one *Abalistes stellatus,* one *Nemipterus peronii,* one *Nebrius ferrugineus* and one *Triaenodon obesus.*

Table 3. Summary of drop-line catch data from Davies Reef. Each set consisted of six lines with five hooks

Date	Session	# Sets	Line hrs	# Fish	Line hrs/ Fish
25/5	AM	5	19.5	3	6.5
26/5	AM	2	8.5	1	8.5
27/5	AM	5	22.5	3	7.5
25/5	PM	4	10.5	3	3.5
26/5	PM	3	13.5	11	1.2
27/5	PM	3	11.0	9	1.2
25/5	Night	3	8.5	4	2.1
27/5	Night	3	7.5	4	1.9

A comparison of the size frequency of the trap and drop-line catches of *Lethrinus miniatus* on Davies Reef suggests, contrary to expectations, that the drop-lines caught smaller fish than the

traps but not larger ones (figure 7). The small total numbers of fish caught on the drop-lines does not, however, warrant further statistical analysis.

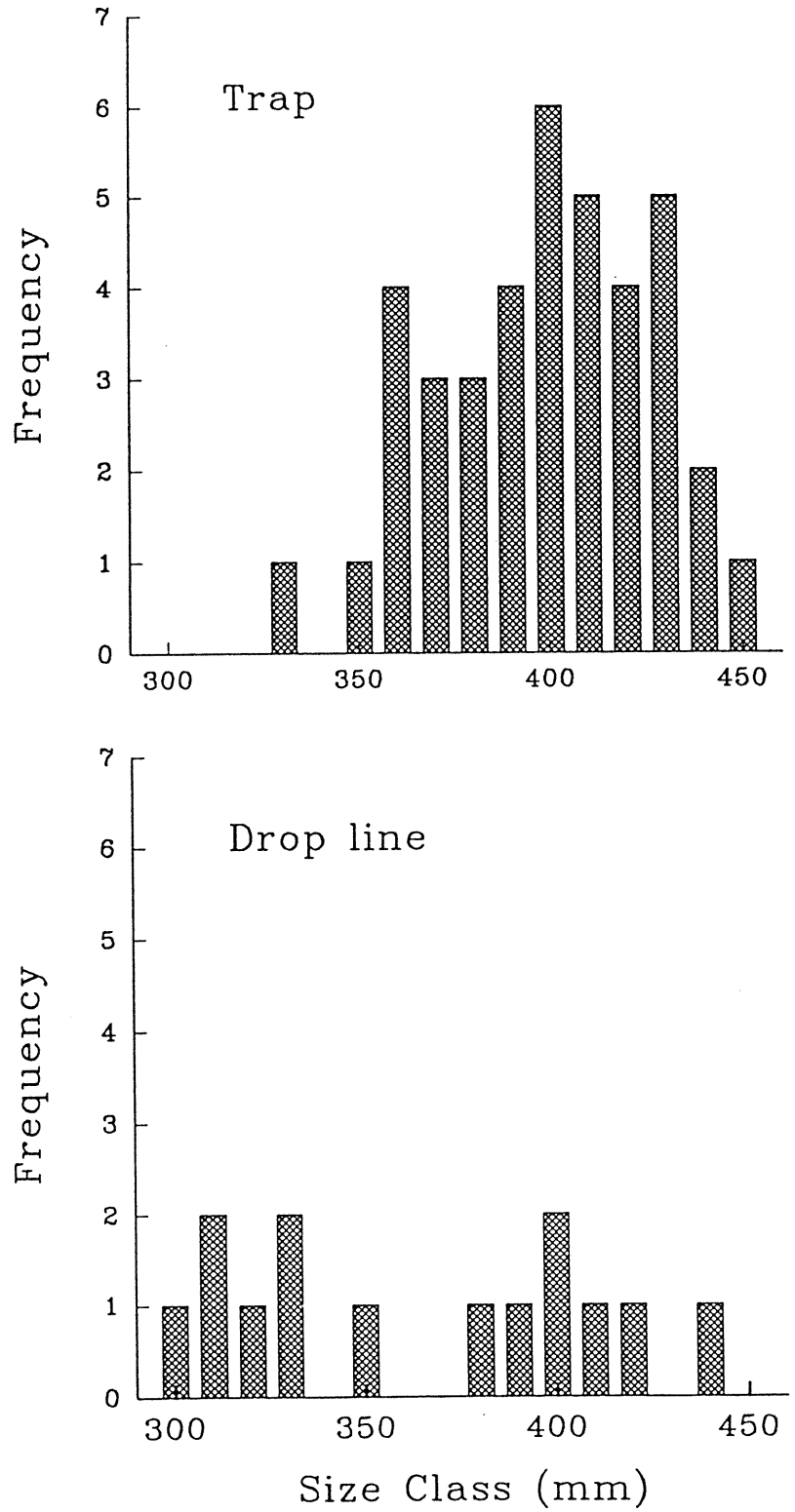


Figure 7. Size-frequency distributions (length to caudal fork) for catches of *Lethrinus miniatus* in traps and on drop-lines at Davies Reef

Catch variability

The high day-to-day variability in mean catches of all taxa has already been referred to above and is well demonstrated in figure 5. Variability in catch among traps within any day was, however, also very high, accounting for the lack of any significant day effect in the ANOVAs (except for *L. sebae,* table 2). A major cause of this variability was that, even when one or two traps had good catches, most had zero or very low catches (figure 6). The result is generally low mean catch rates (often <1 fish/trap) and high variances (relative to the mean) about these means (table 4). These variances are not independent of the means but clearly increase with them: for each species there is a highly significant linear correlation between mean daily catch rates and their standard deviation (table 6).

Table 4a. Means (standard deviations) of catch rates by habitat and taxon on Rib Reef

Habitat:	**H1**	**H2(t_1)**	**H2(t_2)**	**H1 + H2(t_1)**
Sample size:	30	30	48	60
Taxon:				
L .adetii	2.93 (7.60)	7.87 (12.86)	4.52 (17.06)	5.40 (10.76)
L. quinquelineatus	0.27 (0.52)	2.37 (2.94)	1.75 (2.14)	1.32 (2.34)
L. russelli	0.20 (0.48)	0.80 (1.30)	0.73 (1.14)	0.50 (1.02)
L. sebae	0.20 (0.48)	0.67 (0.84)	0.31 (0.62)	0.43 (0.72)
All *Lutjanus* spp.	3.70 (7.66)	11.97 (13.22)	7.63 (18.77)	7.83 (11.50)
Lethrinus sp. 2	0.30 (0.79)	1.00 (2.21)	0.38 (1.21)	0.65 (1.69)
A. stellatus	1.13 (1.63)	0.47 (1.50)	0.58 (1.16)	0.80 (1.59)

Table 4b. Means (standard deviations) of catch rates by habitat and taxon on Davies Reef

Habitat:	**H1**	**H2(t_1)**	**H2(t_2)**	**H1 + H2(t_1)**
Sample size:	30	30	48	60
Taxon:				
L. quinquelineatus	0.83 (1.29)	1.40 (2.61)	0.94 (1.94)	1.12 (2.06)
L. semicinctus (D)	0.50 (1.08)	2.47 (4.55)	3.77 (5.92)	1.48 (3.43)
L. semicinctus (N)	0.90 (1.32)	0.87 (2.27)	1.85 (4.71)	0.88 (1.44)
All *Lutjanus* spp.	1.17 (1.72)	2.23 (3.27)	1.75 (2.84)	1.70 (2.64)

The inherent between and within days variability in mean catch rates of taxa within habitat/time strata is indicated by the coefficient of variation for catch rates of each species within each habitat/time strata (table 5). The 44 CVs (11 taxa x 4 habitat/time strata) range in value from 1.10 to 3.77, with over 90% (40/44) between 1.2 and 2.6. There are no clear reef- or taxon-dependent patterns in the CVs (table 5).

There was also considerable temporal variability in estimates of CVs. The broken habitat at Rib was sampled over two successive time periods. In some cases, estimates of CV varied little between H2(t_1) and H2(t_2) (*L. quinquelineatus, L. russelli*). In others, the CV increased markedly from the first to the second sample (*L. adetii, L. sebae, Lethrinus* sp. 2) and in one case, *A. stellatus*, it decreased markedly. Two separate estimates of means, SDs and CVs are available for the north habitat at Davies [H2(t_1) and H2(t_2) in tables 4 and 5]. In one of the four examples, *L. semicinctus* (night), the CV varies from 1.47 in one sample to 2.55 in the next. This change could not be attributed to some environmental or behavioural change between sampling periods, as the Rib data might be, because the days on which samples were taken were randomly mixed.

Table 5. Coefficients of variation of catch rates by reef, habitat and taxon

	Rib				Davies			
Habitat:	H1	$H2t_1$	$H2t_2$	H1&$H2t_1$	H1	$H2t_1$	$H2t_2$	H1&$H2t_1$
Taxon:								
L. adetii	2.59	1.63	3.77	1.99	-	-	-	-
L. quinquelineatus	1.93	1.24	1.22	1.77	1.55	1.86	2.06	1.84
L. russelli	2.40	1.63	1.56	2.04	-	-	-	-
L. sebae	2.40	1.25	2.00	1.67	-	-	-	-
All *Lutjanus* spp.	2.07	1.10	2.46	1.47	1.47	1.47	1.62	1.55
Abalistes	1.44	3.19	2.00	1.99	-	-	-	-
Lethrinus sp. 2	2.63	2.21	3.18	2.60	-	-	-	-
L .semicinctus (D)	-	-	-	-	2.16	1.84	1.60	2.32
L. semicinctus (N)	-	-	-	-	2.61	1.47	2.55	2.09

Table 6. Results from regression analyses relating daily sample means and SDs. These regressions were used to infer SDs around hypothetical means. Based on daily measurements of means and SDs within H1, $H2(t_1)$ and $H2(t_2)$. SD = **a**, Mean = **b**, n = sample size, r^2 = regression coefficient

Taxon	**n**	**a**	**b**	**r^2**
Rib Reef:				
L. adetii	13	1.62	-0.36	0.97
	14	2.02	-1.30	0.90
L. quinquelineatus	14	0.94	0.33	0.97
L. russelli	14	1.12	0.24	0.95
L. sebae	9	1.45	0.10	0.88
All *Lutjanus* spp.	13	1.32	-0.45	0.81
	14	0.49	0.32	0.74
Lethrinus sp. 2	14	1.88	0.02	0.98
Abalistes stellatus	14	1.39	0.24	0.81
Davies Reef:				
L .quinquelineatus	14	1.14	0.29	0.81
L. semicinctus (Day)	14	1.01	0.54	0.97
L. semicinctus (Night)	14	1.84	-0.17	0.98
All *Lutjanus* spp.	14	0.93	0.59	0.74

Sample size and precision of variability estimates

The effect of sample size, in terms of numbers of days sampled, on estimates of variability was examined for two habitats pooled, H1 & $H2(t_1)$, and for a single habitat, $H2(t_1)$. Mean daily values of SD and CV based on sampling 12 traps for 2-18 days were simulated for the most abundant taxa (figure 8). Some general patterns did come out of these simulations. Estimates of SD and CV showed no clear trends with numbers of days sampled but were highly variable even at the largest sample sizes. At the smaller sample sizes estimates were sometimes more variable than at larger sample sizes but the CV was as likely to be over-estimated as under-estimated (figure 8).

Contrary to our initial expectations, standard deviations tended to be greater for samples from the single ('stratified') habitat than from the pooled ('unstratified') sample. In contrast, CVs tended to be lower for the single habitat than the pooled sample.

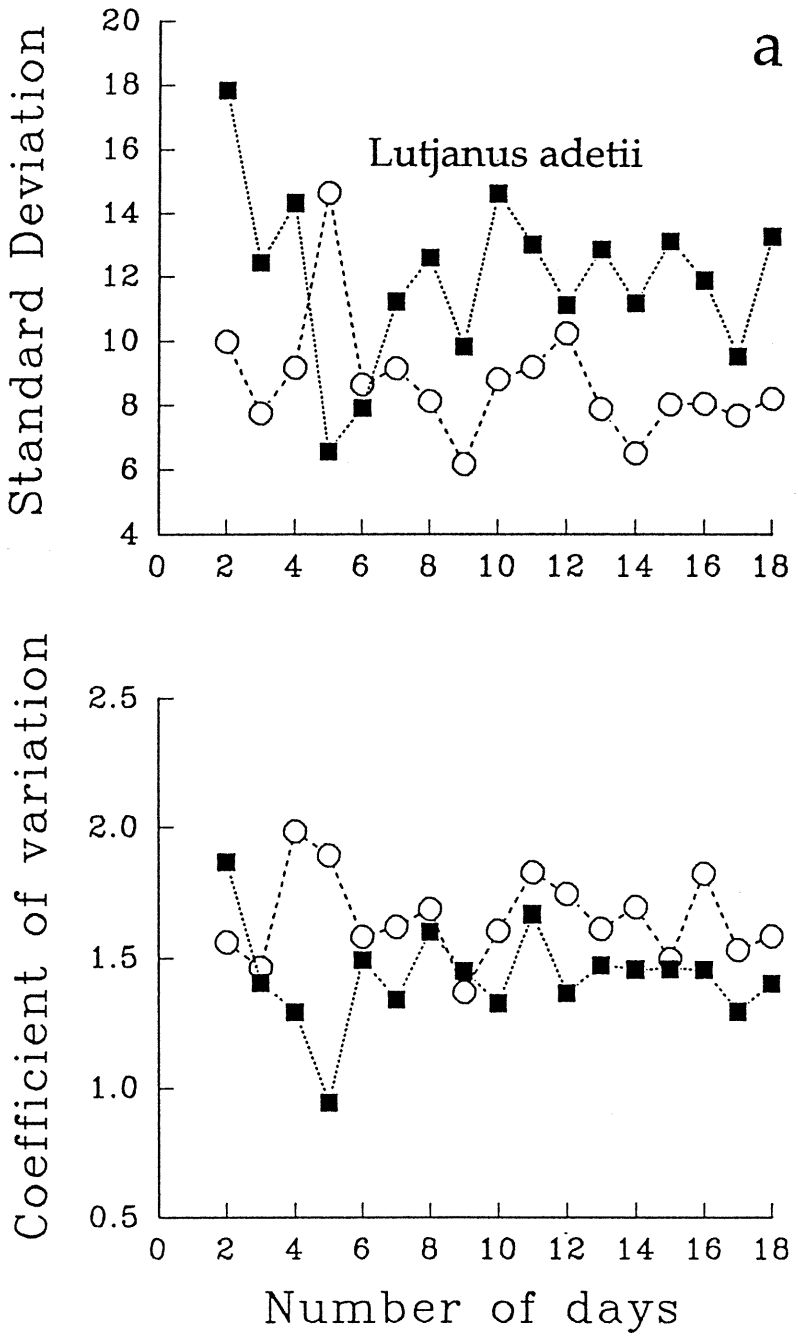


Figure 8. Variation in SD and CV as a function of the number of sets (= days sampling). Determined by simulation, randomly selecting traps from the total data set. Data presented are the mean values calculated for 12 traps/set. O = unstratified habitat (H1+H2(t_1)]. ■ = stratified habitat with maximum catch rate [H1 for *Abalistes stellatus*, H2(t_1) for all other taxa]

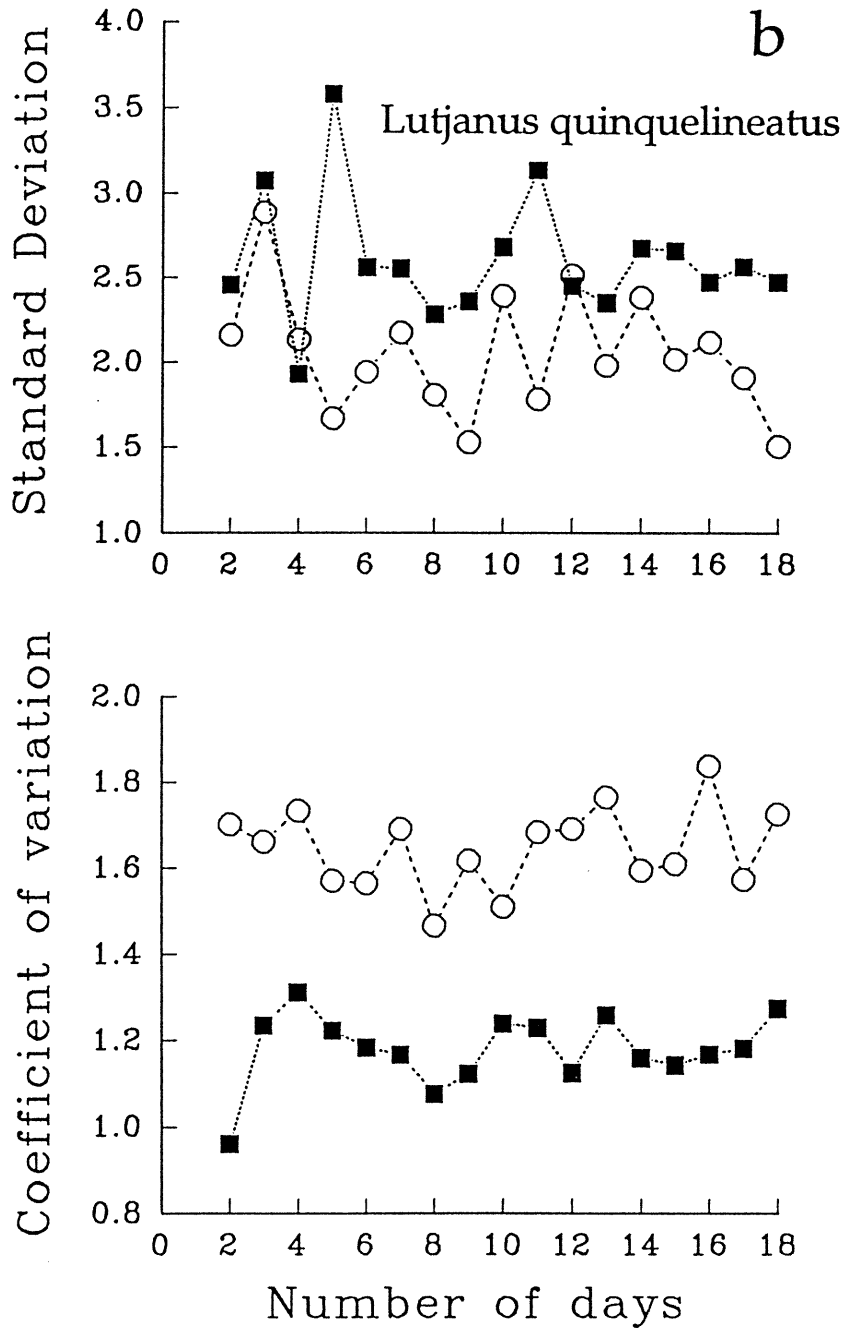
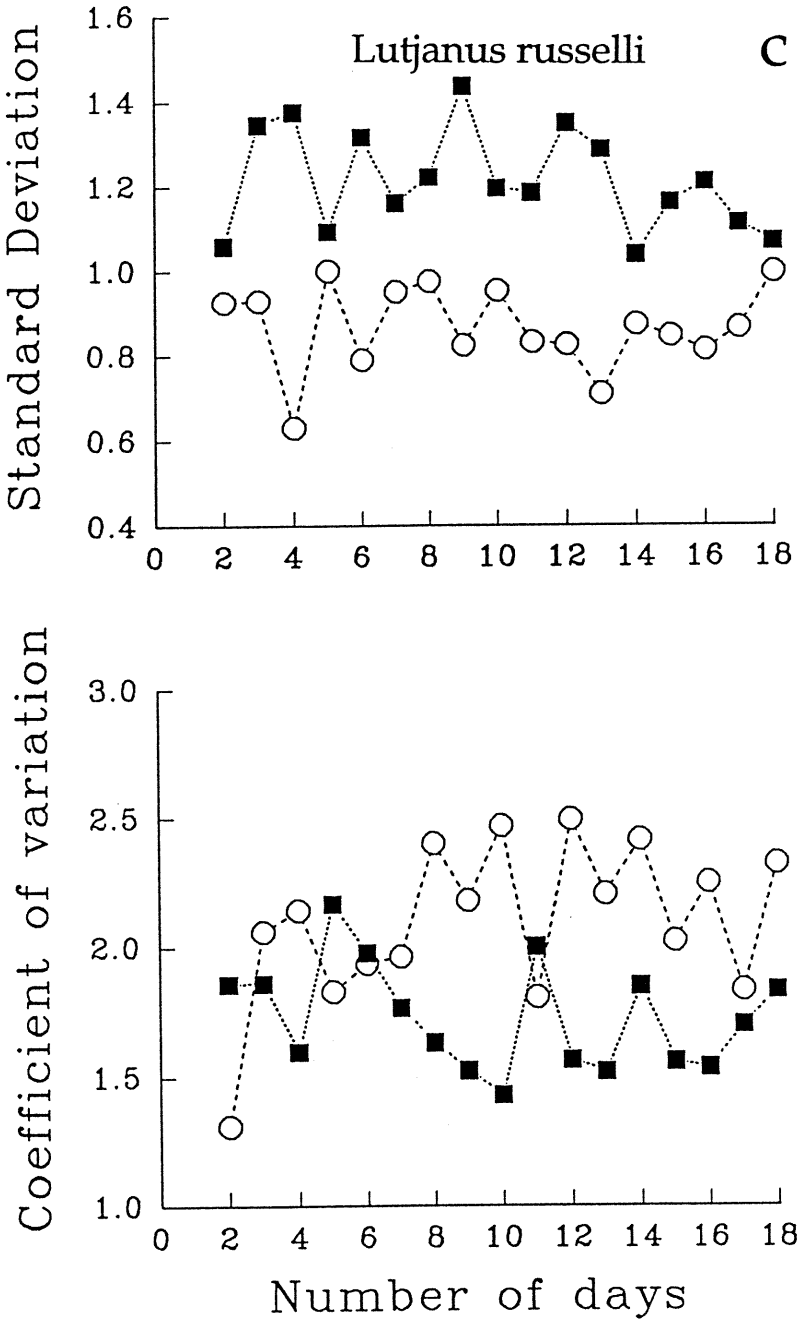


Figure 8 cont. Variation in SD and CV as a function of the number of sets (= days sampling). Determined by simulation, randomly selecting traps from the total data set. Data presented are the mean values calculated for 12 traps/set. O = unstratified habitat (H1+H2(t_1)]. ■ = stratified habitat with maximum catch rate [H1 for *Abalistes stellatus*, H2(t_1) for all other taxa]



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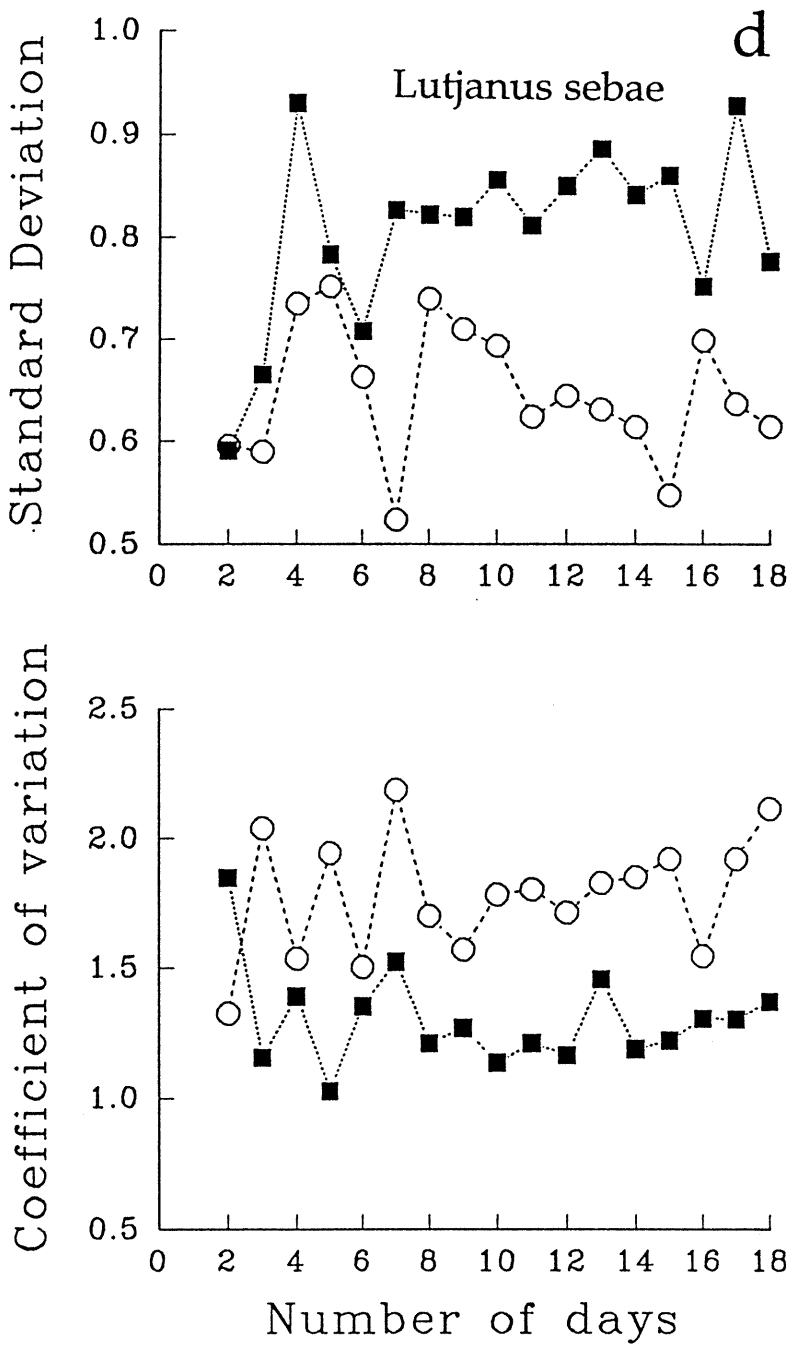

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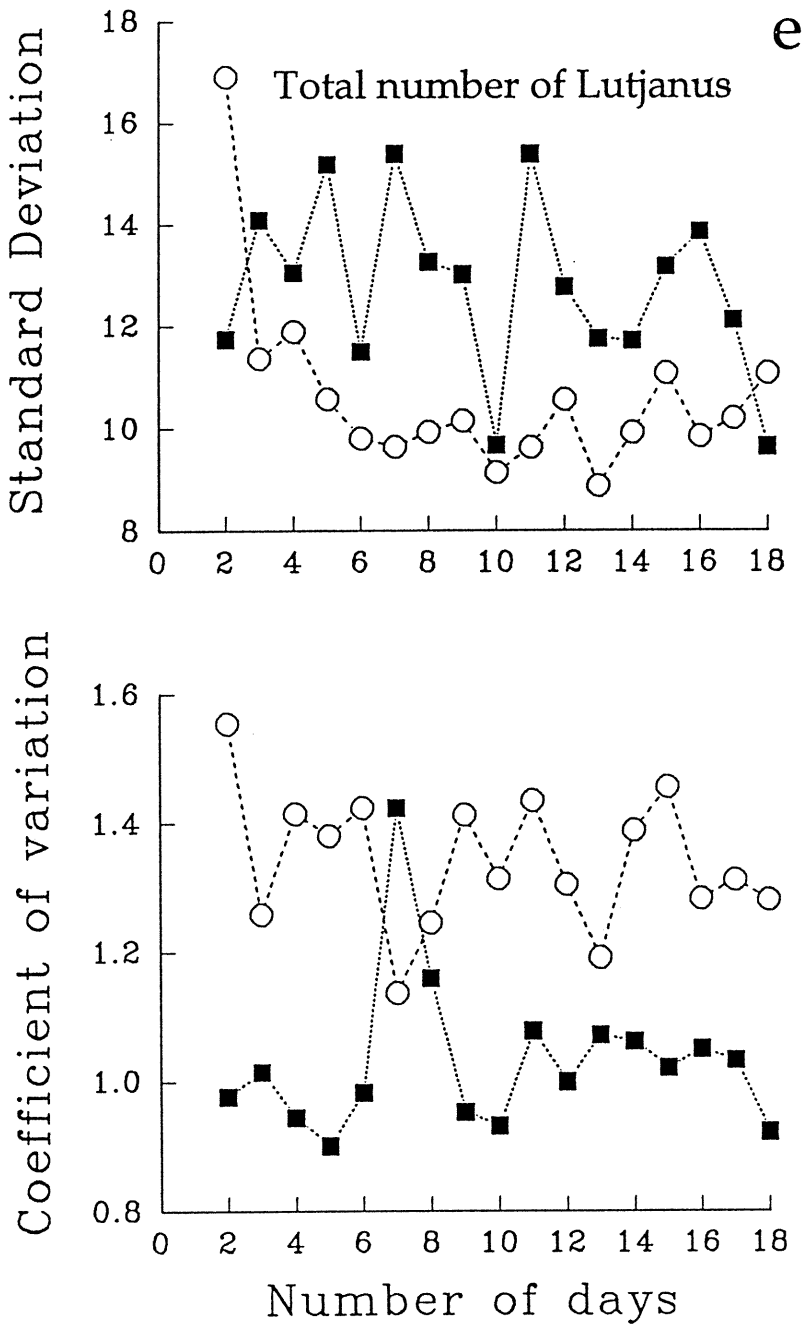
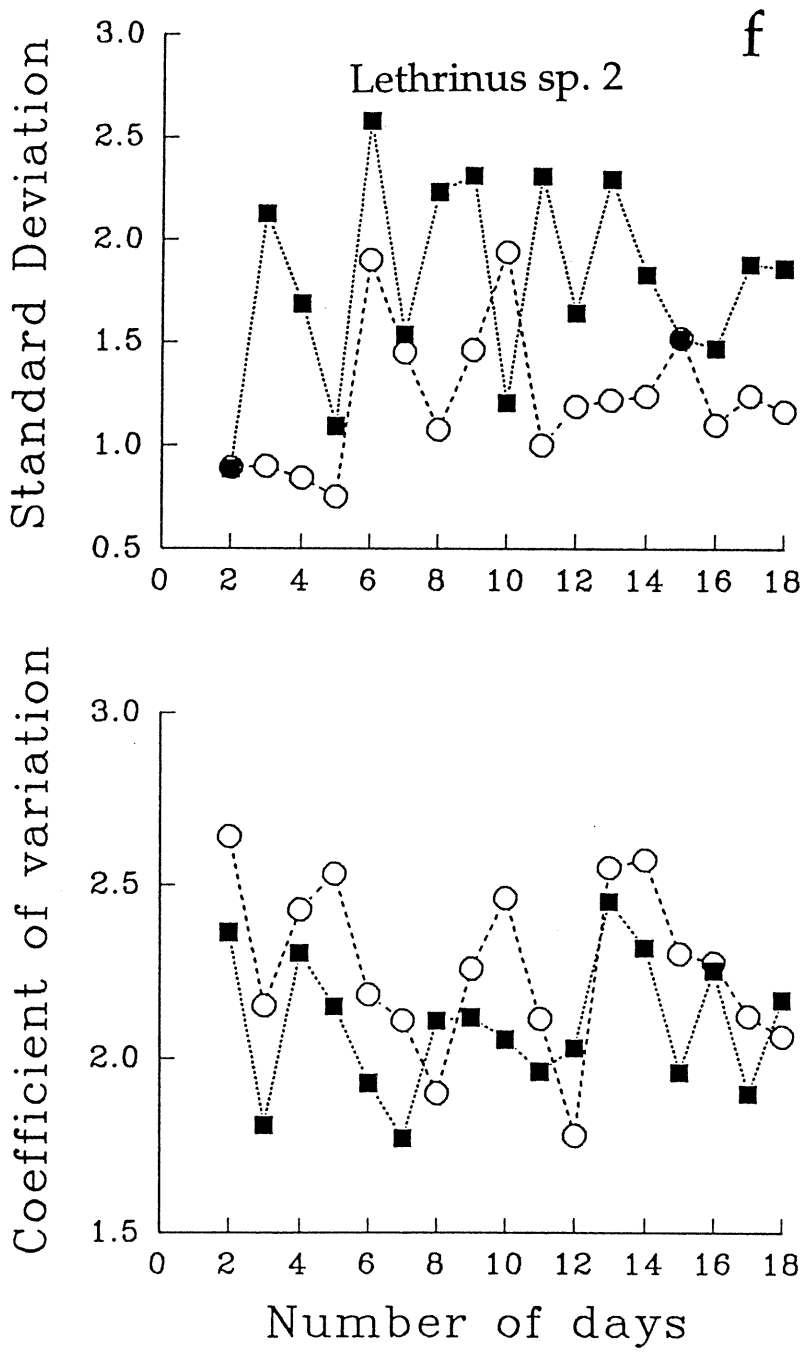


Figure 8 cont. Variation in SD and CV as a function of the number of sets (= days sampling). Determined by simulation, randomly selecting traps from the total data set. Data presented are the mean values calculated for 12 traps/set. O = unstratified habitat (H1+H2(t_i)]. ■ = stratified habitat with maximum catch rate [H1 for *Abalistes stellatus*, H2(t_i) for all other taxa]



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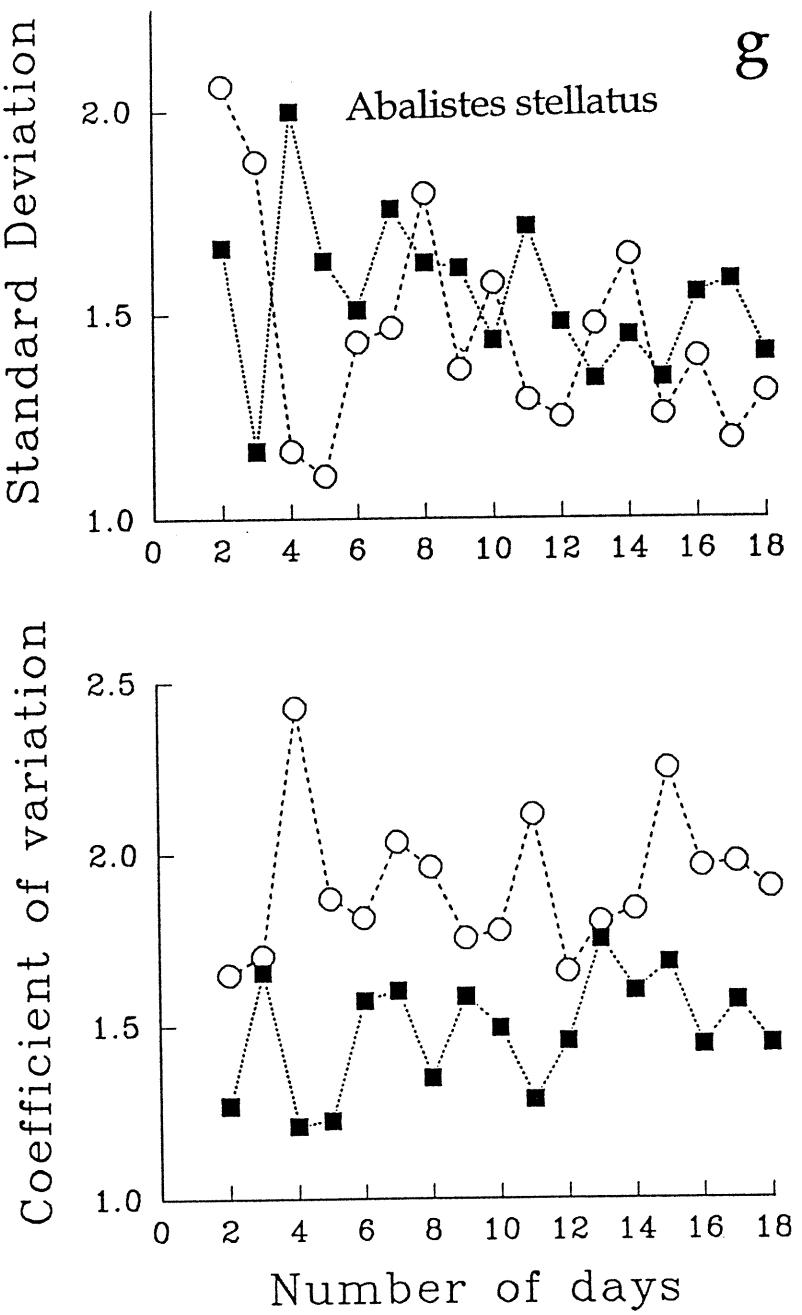

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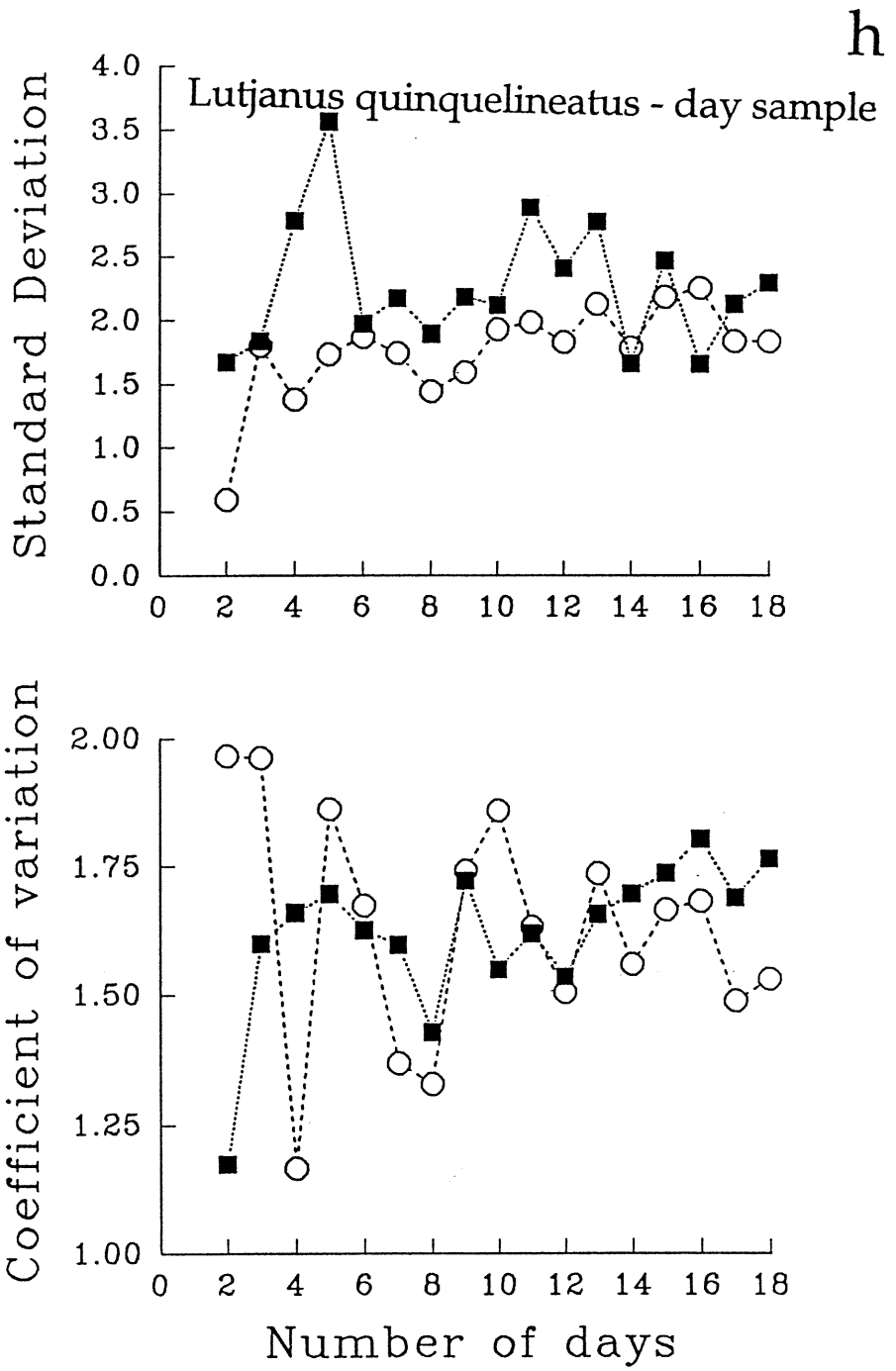

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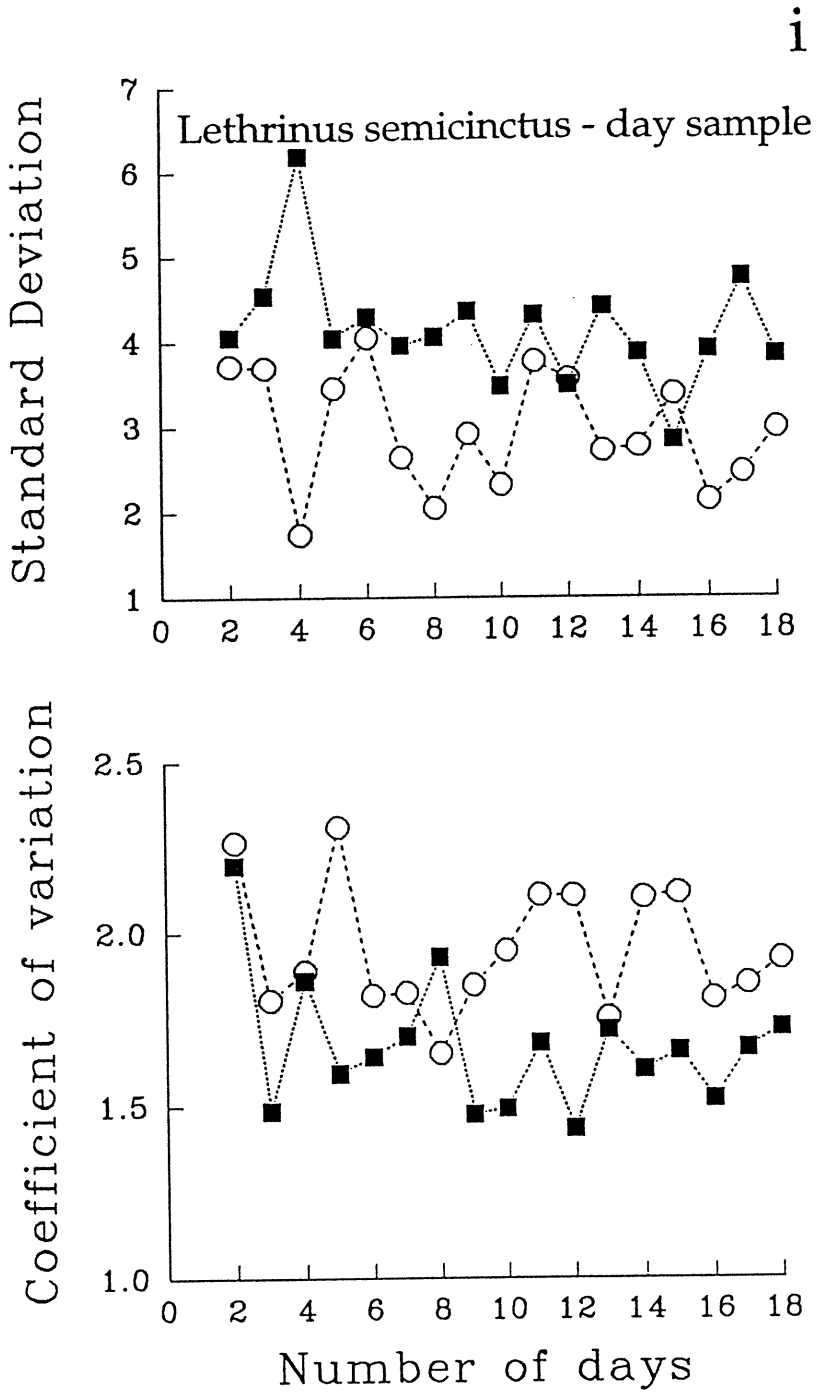

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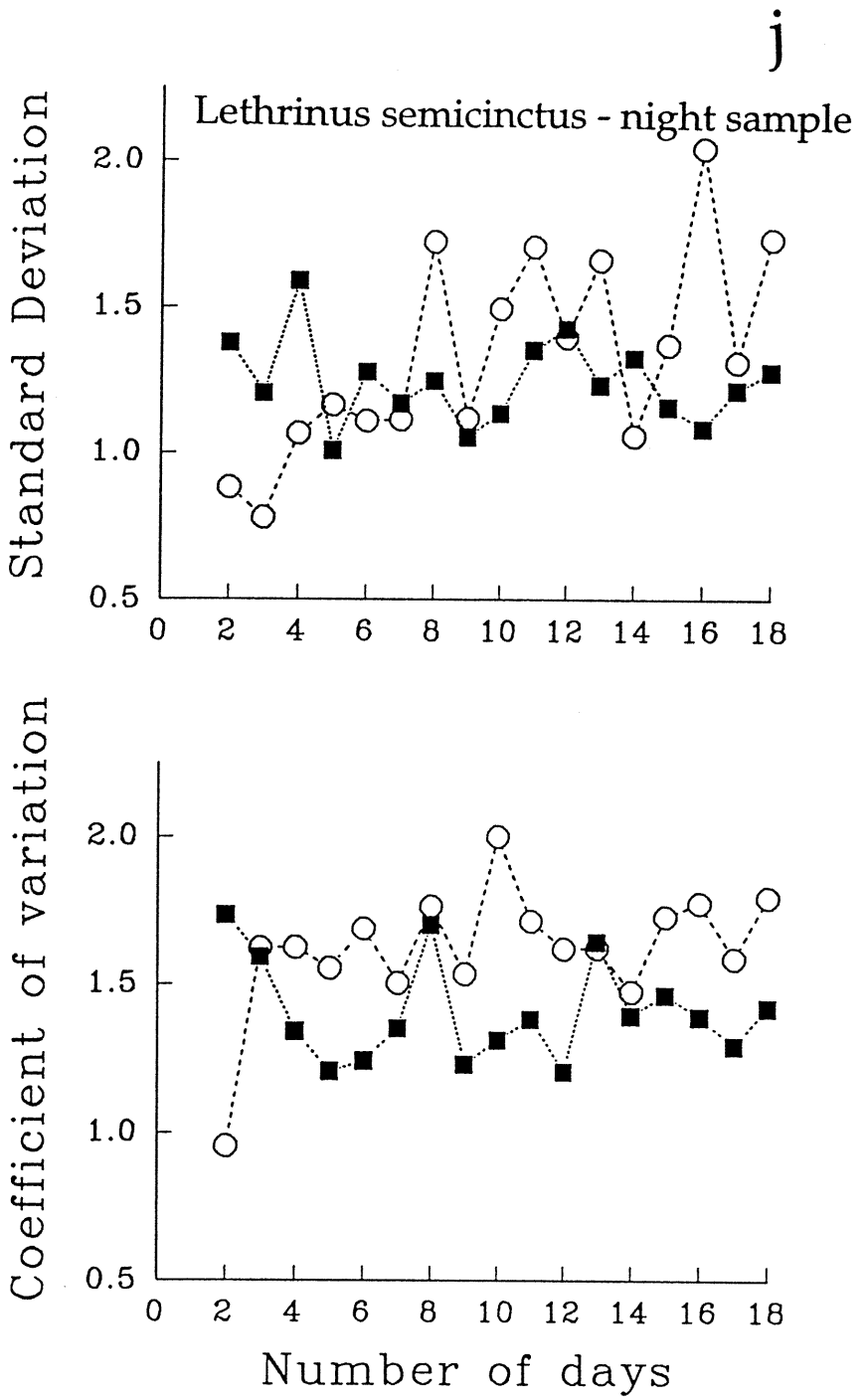

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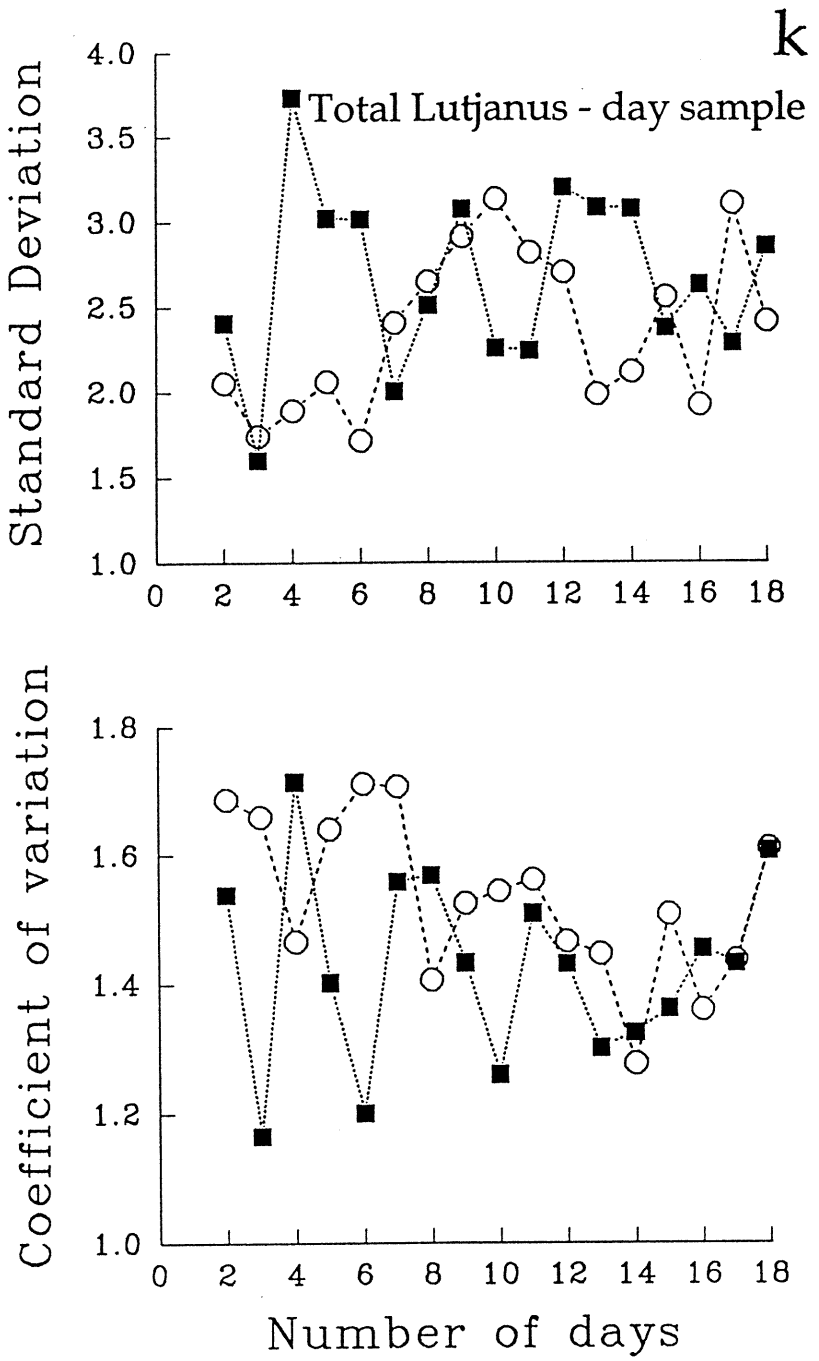

Figure 8 cont. Variation in SD and CV as a function of the number of sets (= days sampling). Determined by simulation, randomly selecting traps from the total data set. Data presented are the mean values calculated for 12 traps/set. O = unstratified habitat (H1+H2(t_1)]. ■ = stratified habitat with maximum catch rate [H1 for *Abalistes stellatus*, H2(t_1) for all other taxa]

Although at moderately large sample sizes, the CV generally fluctuates around a mean value, the lack of consistency in the CVs summarised in table 5 led us to some concern for the precision of our sample estimates of this parameter. The means, SDs and CVs in tables 4 and 5 are based on relatively large sample sizes (n = 30-60) and are the best estimates we have, but because they are based on total samples, we have no direct estimate of their precision. This problem is critical because, as we will show below, the statistical power associated with our two-sample tests is related to the square of the value of CV.

To estimate the precision of our sample estimates of CV, we ran a second series of simulations for two taxa: *L. quinquelineatus* from Rib and *L. semicinctus* (Day samples) from Davies. The second series of simulations was similar to the first but in addition we compared results for three different sample sizes (number of traps/day) and calculated 95% confidence limits around the mean estimate of CV.

Whether 6, 12 or 18 traps/day were 'sampled', the effect on confidence limits of the CV was small compared to the effect of number of days sampling, particularly up to 5 to 10 days (figure 9). After 5 to 10 days, estimates were still variable but showed only very small decreases in the 95% confidence limits for large increases in effort.

Although the confidence intervals around the estimates of the mean CV would not look bad to most reef fish ecologists, they encompass a sufficient range in CV to cover a significant proportion of the total observed range of CV estimates. This converts to a very large range in statistical power (see below). Given these relatively large confidence limits in our estimates of CV, it is not surprising that we had difficulties in trying to discern any habitat- or taxon-specific patterns in CV. We are limited to concluding that the CV for the majority of habitat/time substrata lies within the range of 1.2 - 2.6, and that within a taxon, samples from habitats where catch rates are low will tend to have higher CVs than those from habitats with higher catch rates.

Power tests

Minimum sample sizes required to detect 20%, 50% and 75% decreases and 50%, 100% and 200% increases in catch rates for each species in each time/strata are given in tables 7-9. Observation of these tables highlights the very steep rise in number of traps required to detect progressively smaller changes in catch rates and a strong relationship between the CV and number of traps required. The relationship between number of traps required to detect different effect sizes and the CV is plotted in figure 10.

Based on the present studies we can say that CVs of catch rates in traps are most likely to vary between 1.2 and 2.6 (table 5). Figure 10 indicates that sample populations with CVs in this range will require a minimum number of between approximately 25 and 100 traps set to detect a 200% **increase** in the population mean and between approximately 50 and 200 traps to detect a 100% increase in population density. Detection of a 50% increase will require a minimum of more than 120 traps and as many as 500. The number of traps required to detect **decreases** in the population mean are, not surprisingly, no less daunting. Detection of a 50% decline requires a minimum number ranging from approximately 80 traps to 300. A 75% reduction in the mean would require between approximately 25 and 120 traps. A 20% reduction would require between approximately 500 and 2000 traps.

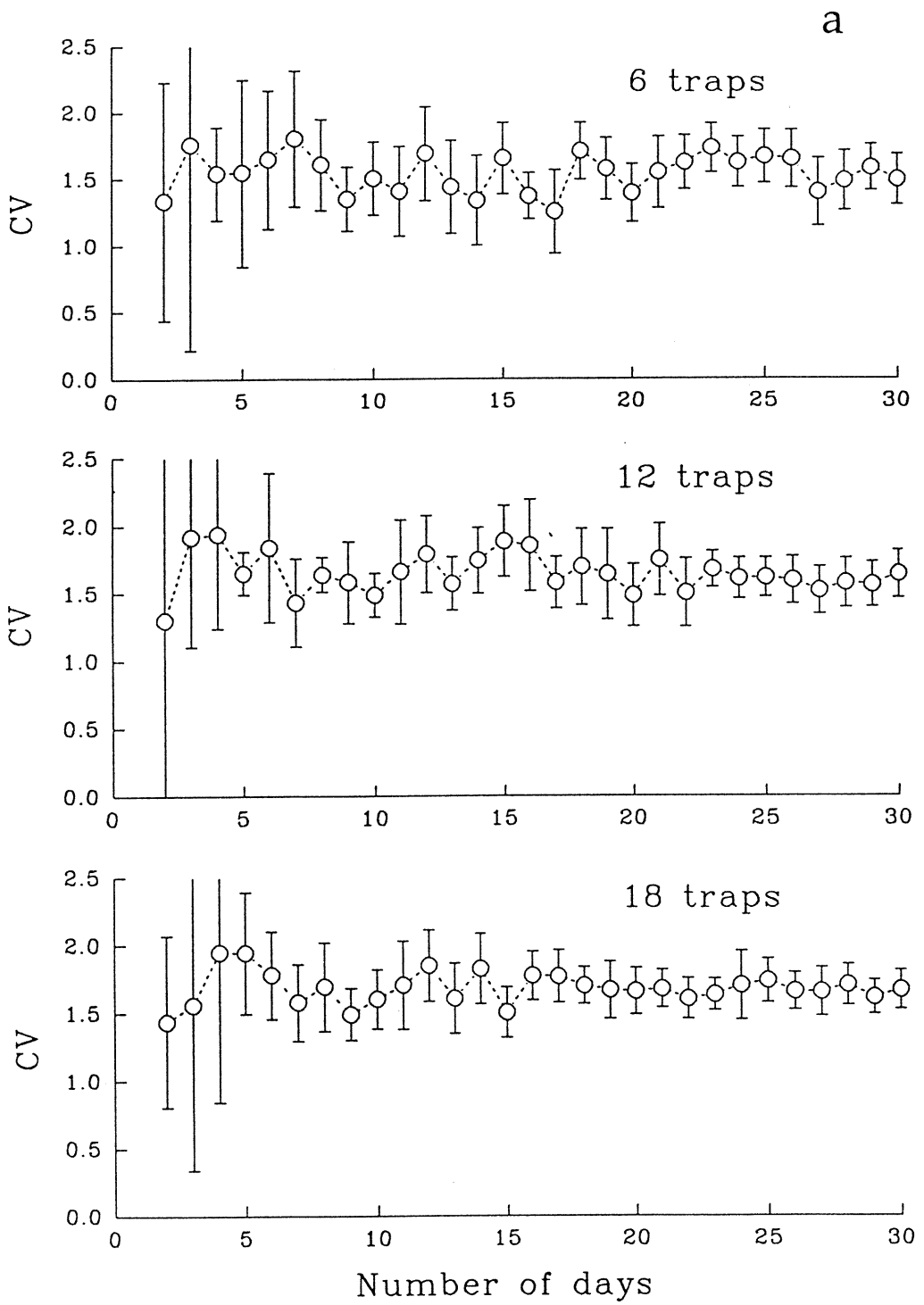

Figure 9. Variation in the CV as a function of the number of sets (= days sampling). Determined by simulation, randomly selecting traps from the total data set: means and 95% confidence limits for 6, 12 and 18 traps/set. a, b. Rib Reef, *Lutjanus quinquelineatus*. c, d. Davies Reef, *Lethrinus semicinctus* - day samples

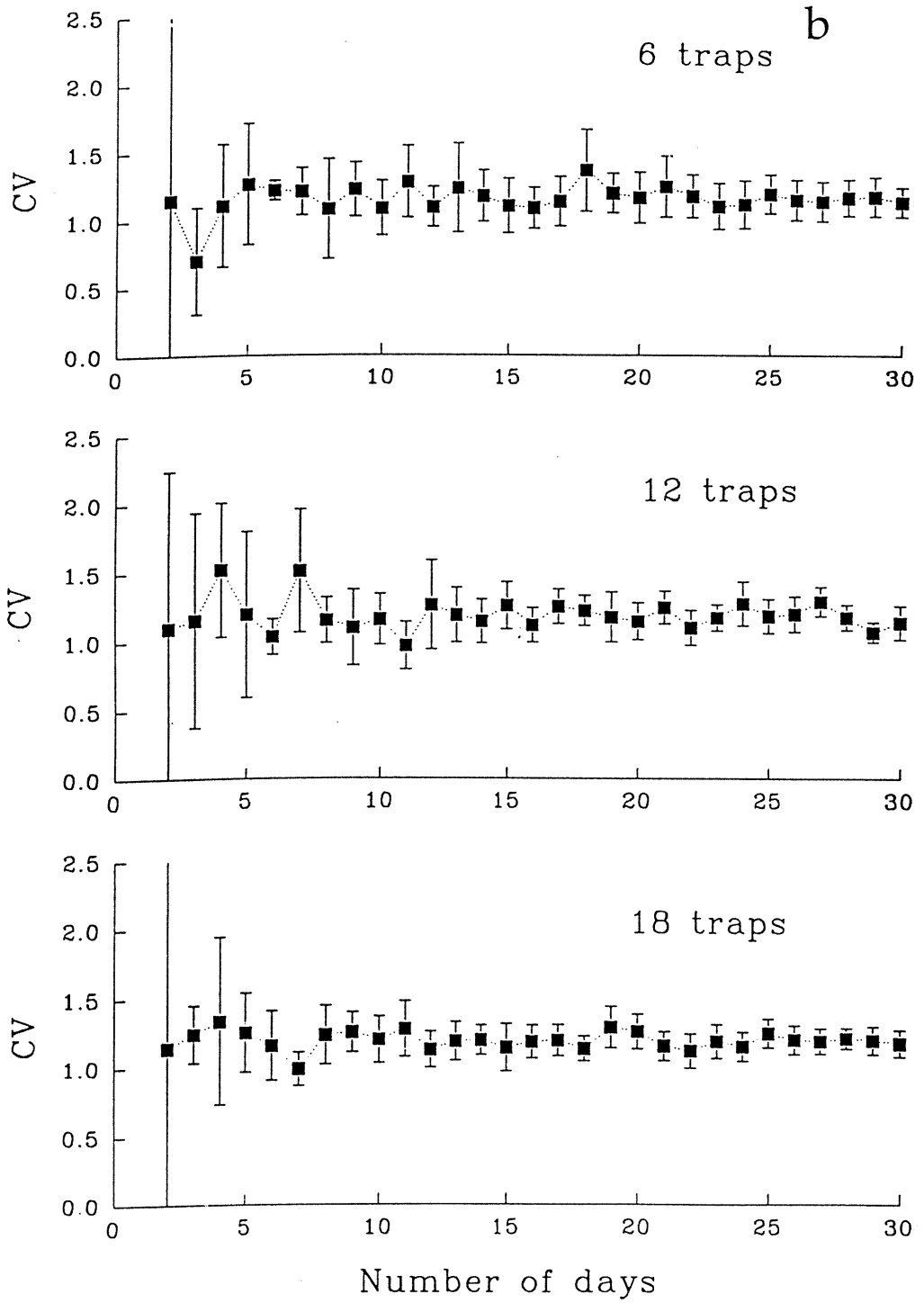

Figure 9 cont. Variation in the CV as a function of the number of sets (= days sampling). Determined by simulation, randomly selecting traps from the total data set: means and 95% confidence limits for 6, 12 and 18 traps/set. a, b. Rib Reef, *Lutjanus quinquelineatus*. c, d. Davies Reef, *Lethrinus semicinctus* - day samples

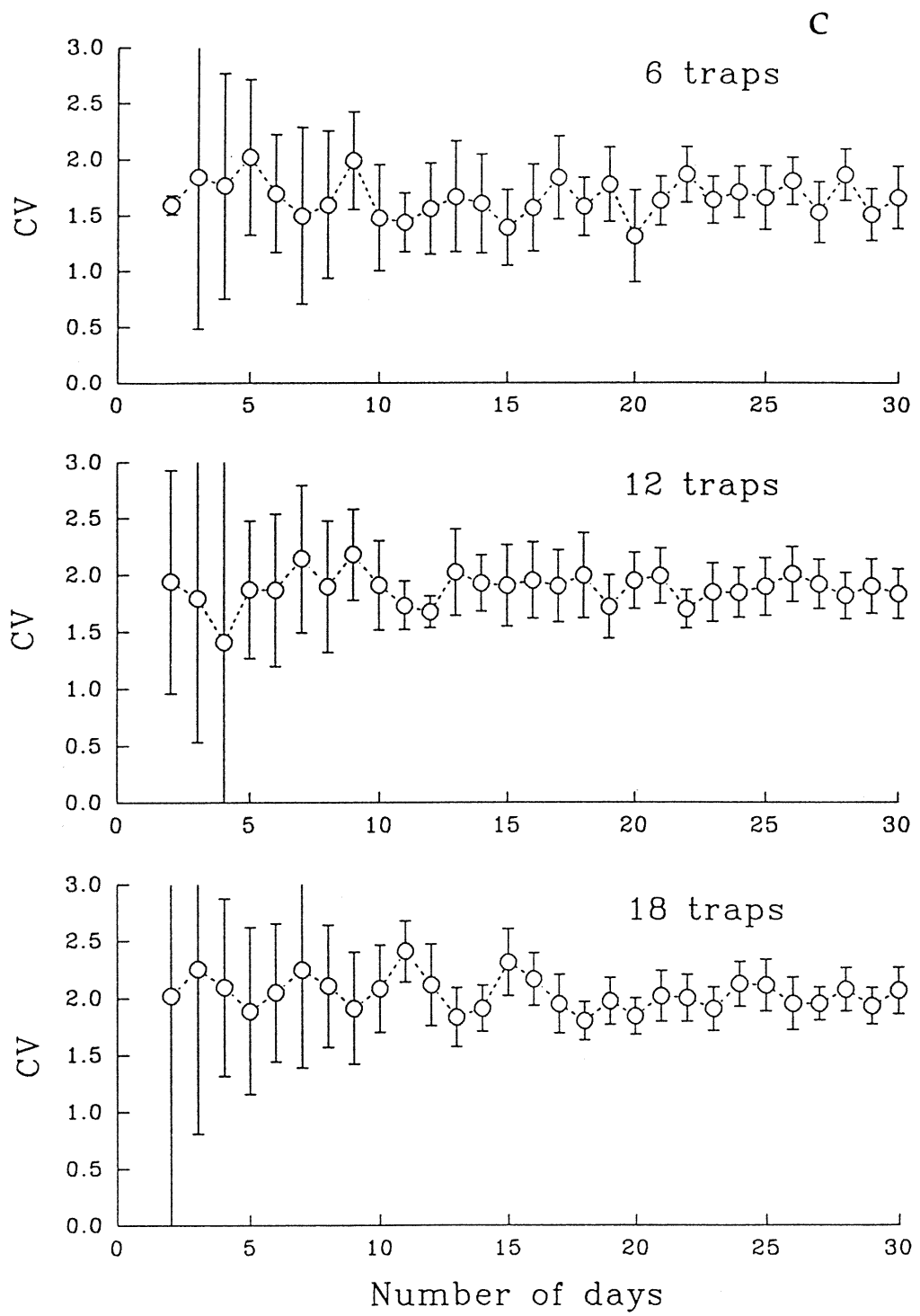

Figure 9 cont. Variation in the CV as a function of the number of sets (= days sampling). Determined by simulation, randomly selecting traps from the total data set: means and 95% confidence limits for 6, 12 and 18 traps/set. a, b. Rib Reef, *Lutjanus quinquelineatus*. c, d. Davies Reef, *Lethrinus semicinctus* - day samples

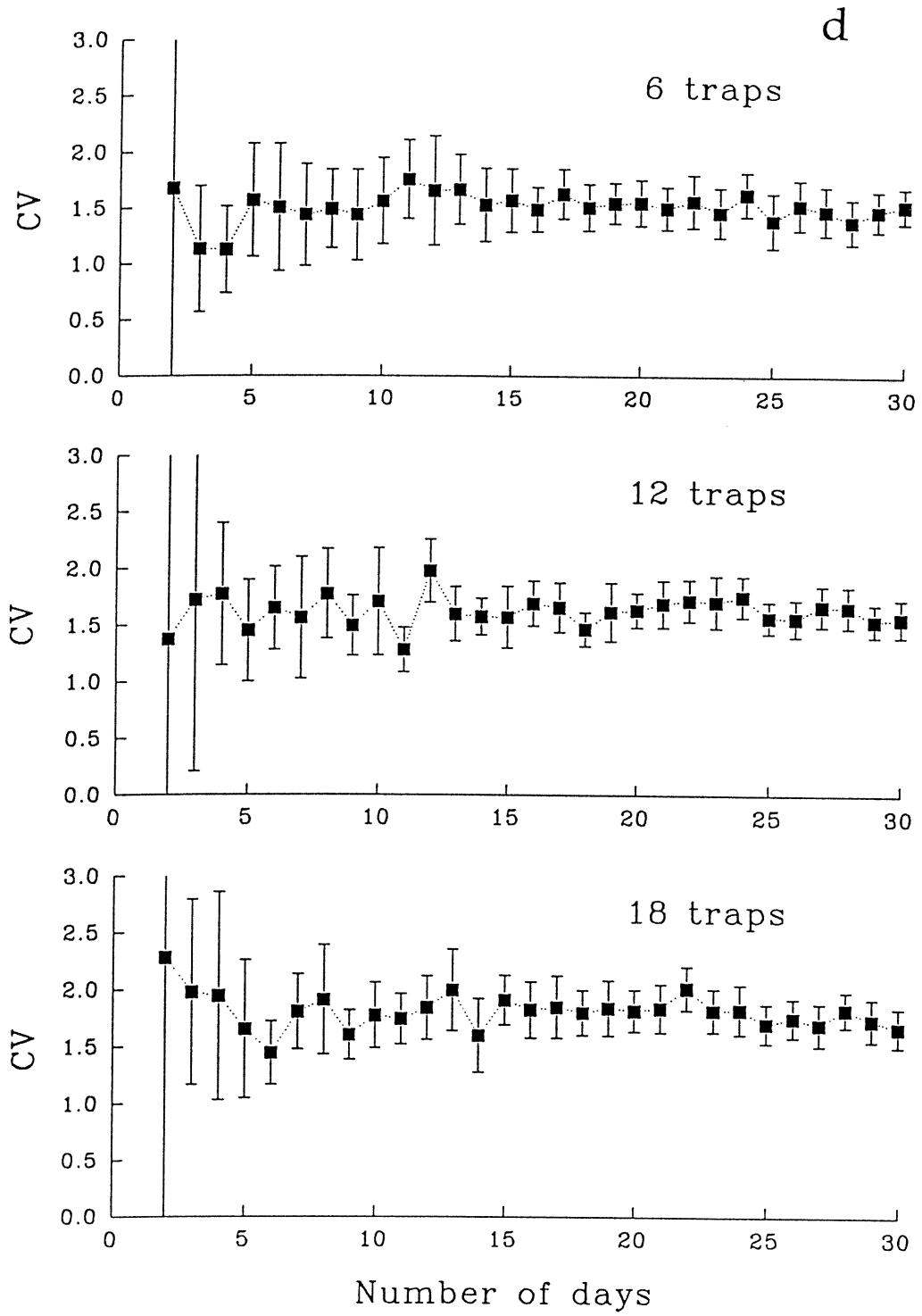

Figure 9 cont. Variation in the CV as a function of the number of sets (= days sampling). Determined by simulation, randomly selecting traps from the total data set: means and 95% confidence limits for 6, 12 and 18 traps/set. a, b. Rib Reef, *Lutjanus quinquelineatus*. c, d. Davies Reef, *Lethrinus semicinctus* - day samples

Table 7.1. *Lutjanus adetii* Rib Reef. Predicted sample size (number of traps fished) required to detect the nominated change in sample size (MDD). MDD is expressed as a percentage of the sample mean. See text for explanation of habitat types. SD = standard deviation, CV = coefficient of variation of sample mean based on sample size of N. * B = 0.25

Habitat	N	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2(t_1)	60	5.40	10.76	1.99	63	155	1174
Habitat 1	30	2.93	7.60	2.59	104	249	1713
Habitat 2 (t_1)	30	7.87	12.86	1.63	43	112	912
Habitat 2 (t_2)	48	4.52	17.06	3.77	218	506	3458
Habitat 2 (t_2)*	48	4.52	17.06	3.77	137	318	2173

Table 7.2. *Lutjanus quinquelineatus* Rib Reef. As table 7.1

Habitat	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2 (t_1)	1.32	2.34	1.77	52	126	915
Habitat 1	0.27	0.52	1.93	93	245	1926
Habitat 2 (t_1)	2.37	2.94	1.24	26	68	508
Habitat 2 (t_2)	1.75	2.14	1.22	26	67	511
Habitat 2 (t_2)*	1.75	2.14	1.22	17	43	321

Table 7.3. *Lutjanus russelli* Rib Reef. As table 7.1

Habitat	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2(t_1)	0.50	1.02	2.04	66	180	1299
Habitat 1	0.20	0.48	2.40	122	303	2178
Habitat 2 (t_1)	0.80	1.30	1.63	46	116	874
Habitat 2 (t_2)	0.73	1.14	1.56	43	114	797
Habitat 2 (t_2)*	0.73	1.14	1.56	27	72	501

Table 7.4. *Lutjanus sebae* Rib Reef. As table 7.1

Habitat	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2(t_1)	0.43	0.72	1.67	50	135	917
Habitat 1	0.20	0.48	2.40	99	251	1817
Habitat 2 (t_1)	0.67	0.84	1.25	29	83	750
Habitat 2 (t_2)	0.31	0.62	2.00	70	186	1418
Habitat 2 (t_2)*	0.31	0.62	2.00	44	117	891

Table 7.5. All *Lutjanus* spp. Rib Reef. As table 7.1

Habitat	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2 (t_1)	7.83	11.50	1.47	35	87	672
Habitat 1	3.70	7.66	2.07	67	157	1105
Habitat 2 (t_1)	11.97	13.22	1.10	20	56	485
Habitat 2 (t_2)	7.63	18.77	2.46	93	211	1329
Habitat 2 (t_2)*	7.63	18.77	2.46	59	133	835

Table 7.6. *Lethrinus* sp. 2 Rib Reef. As table 7.1

Habitat	Mean	SD	CV	-75%	-50%	-25%
Habitats 1 & 2 (t_1)	0.65	1.69	2.60	106	273	1955
Habitat 1	0.30	0.79	2.63	115	272	2011
Habitat 2 (t_1)	1.00	2.21	2.21	79	199	1541
Habitat 2 (t_2)	0.38	1.21	3.18	165	382	2425
Habitat 2 (t_2)*	0.38	1.21	3.18	104	240	1524

Table 7.7. *Abalistes stellatus* Rib Reef. As table 7.1

Habitat	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2 (t_1)	0.80	1.59	1.99	67	170	1273
Habitat 1	1.13	1.63	1.44	37	102	790
Habitat 2 (t_1)	0.47	1.50	3.19	169	417	2990
Habitat 2 (t_2)	0.58	1.16	2.00	72	179	1261
Habitat 2 (t_2)*	0.58	1.16	2.00	45	113	793

Effect of stratification

Our expectation was that the samples stratified for habitat within depth strata would give a more powerful test of variation in mean catch rates than those that were not, because the sample variability would be minimised relative to samples which ignored the habitats. This was only partly realised (tables 7-9). If the mean catch rates differed significantly between the habitats (H1 and H2), the sample from the habitat with the greatest mean catch rate almost invariably gave the most powerful test. In such cases the unstratified sample, with an intermediate mean catch rate, usually also had intermediate power (e.g. *L. quinquelineatus* (Rib), *L. russelli, L. adetii, L. sebae* but see also *L. quinquelineatus* (Davies) and *L. semicinctus* (Day)). In the one instance where mean catch rates of a species in two habitats were virtually identical, power of the sample was inversely related to the size of the standard deviation of the sample (*L. semicinctus* (Night)).

Our initial expectation had been that better site selection within depth strata should improve the statistical power of tests on catch rates by reducing the variance (and hence SD) around the estimate of catch rate. Because of the relationship between mean and SD estimates, sampling in habitats with maximum catch rates did tend to significantly improve statistical power but by decreasing the SD/mean ratio rather than decreasing variance per se. This is vividly illustrated in figure. 8. For each taxon of snapper the stratified sample (and habitat of maximum catch rate) clearly has a **higher** SD than the unstratified sample but a significantly **lower** CV (hence greater associated power).

Drop-lines vs traps

Results of the drop-line sampling were extremely disappointing, albeit a significant improvement on earlier trials during the January 1992 cruise. Catch rates were very low with no fishing session yielding better than one fish/line hour. Major differences in catch composition of drop-lines compared to the traps were a relatively high proportion (10% of total catch) of carangids on the lines, the capture of two sharks and the absence of *L. semicinctus* which dominated the traps.

Table 8.1. *Lutjanus quinquelineatus* Davies Reef. Predicted sample size (number of traps fished) required to detect the nominated change in sample size (MDD). MDD is expressed as a percentage of the sample mean. See text for explanation of habitat types. SD = standard deviation, CV = coefficient of variation of sample mean based on sample size of N. * B = 0.25

Habitat	N	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2 (t_1)	60	1.12	2.06	1.84	57	140	1055
Habitat 1	30	0.83	1.29	1.55	44	115	820
Habitat 2 (t_1)	30	1.40	2.61	1.86	57	140	1014
Habitat 2 (t_2)	48	0.94	1.94	2.06	72	173	1207
Habitat 2 (t_2)*	48	0.94	1.94	2.06	45	109	759

Table 8.2. *Lethrinus semicinctus* (Day catch) Rib Reef. As table 8.1

Habitat	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2 (t_1)	1.48	3.43	2.32	85	211	1402
Habitat 1	0.50	1.08	2.16	102	246	1756
Habitat 2 (t_1)	2.47	4.55	1.84	56	136	969
Habitat 2 (t_2)	3.77	5.92	1.60	40	100	730
Habitat 2 (t_2)*	3.77	5.92	1.60	26	63	459

Table 8.3. *Lethrinus semicinctus* (Night catch) Rib Reef. As table 8.1

Habitat	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2 (t_1)	0.88	1.84	2.09	68	168	1233
Habitat 1	0.87	2.27	2.61	106	258	1893
Habitat 2 (t_1)	0.90	1.32	1.47	35	93	811
Habitat 2 (t_2)	1.85	4.71	2.55	101	249	1795
Habitat 2 (t_2)*	1.85	4.71	2.55	64	157	1128

Table 8.4. All *Lutjanus* spp. pooled, Davies Reef. As table 8.1

Habitat	Mean	SD	CV	-75%	-50%	-20%
Habitats 1 & 2 (t_1)	1.70	2.64	1.55	43	106	770
Habitat 1	1.17	1.72	1.47	41	108	825
Habitat 2 (t_1)	2.23	3.27	1.47	37	93	667
Habitat 2 (t_2)	1.75	2.84	1.62	46	114	814
Habitat 2 (t_2)*	1.75	2.84	1.62	29	72	512

Contrary to expectations, drop-lines did not catch larger *L. miniatus* than were caught in the traps. They did catch smaller *L. miniatus* than caught in traps on this occasion but similar small fish have been caught in the traps on other cruises. Given this and the very small numbers involved, it seems most unlikely that the apparent difference in size frequencies between the gear types in figure 7 is a persistent one. Insufficient numbers of coral trout were caught to make any size comparison with those caught in traps.

Table 9.1. *Lutjanus quinquelineatus* Rib Reef. Predicted sample size (number of traps fished) required to detect the nominated change in sample size (MDD). MDD is expressed as a percentage of the sample mean. See text for explanation of habitat types. SD = standard deviation, CV = coefficient of variation of sample mean based on sample size of N. * B = 0.25

Habitat	Mean	SD	CV	+200%	+100%	+50%
Habitats 1 & 2 (t_1)	1.32	2.34	1.77	27	66	202
Habitat 1	0.27	0.52	1.93	43	115	339
Habitat 2 (t_1)	2.37	2.94	1.24	23	49	134
Habitat 2 (t_2)	1.75	2.14	1.22	23	50	138
Habitat 2 (t_2)*	1.75	2.14	1.22	15	32	87

Table 9.2. *Lutjanus russelli* Rib Reef. As table 9.1

Habitat	Mean	SD	CV	+200%	+100%	+50%
Habitats 1 & 2 (t_1)	0.50	1.02	2.04	41	100	303
Habitat 1	0.20	0.48	2.40	57	152	486
Habitat 2 (t_1)	0.80	1.30	1.63	35	78	225
Habitat 2 (t_2)	0.73	1.14	1.56	35	78	217
Habitat 2 (t_2)*	0.73	1.14	1.56	22	49	137

Table 9.3. *Lethrinus* sp. 2 Rib Reef. As table 9.1

Habitat	Mean	SD	CV	+200%	+100%	+50%
Habitats 1 & 2 (t_1)	0.65	1.69	2.60	84	181	494
Habitat 1	0.30	0.79	2.63	85	181	526
Habitat 2 (t_1)	1.00	2.21	2.21	80	165	456
Habitat 2 (t_2)	0.38	1.21	3.18	91	212	630
Habitat 2 (t_2)*	0.38	1.21	3.18	58	134	396

Table 9.4. *Lethrinus semicinctus* (Day catch) Davies Reef. As table 9.1

Habitat	Mean	SD	CV	+200%	+100%	+50%
Habitats 1 & 2 (t_1)	1.48	3.43	2.32	37	95	305
Habitat 1	0.50	1.08	2.16	47	123	392
Habitat 2 (t_1)	2.47	4.55	1.84	30	73	212
Habitat 2 (t_2)	3.77	5.92	1.60	27	62	178
Habitat 2 (t_2)*	3.77	5.92	1.60	18	39	112

Table 9.5. *Lethrinus semicinctus* (Night catch) Davies Reef. As table 9.1

Habitat	Mean	SD	CV	+200%	+100%	+50%
Habitats 1 & 2 (t_1)	0.88	1.84	2.09	71	142	376
Habitat 1	0.87	2.27	2.61	76	163	448
Habitat 2 (t_1)	0.90	1.32	1.47	66	123	300
Habitat 2 (t_2)	1.85	4.71	2.55	77	166	462
Habitat 2 (t_2)*	1.85	4.71	2.55	49	105	290

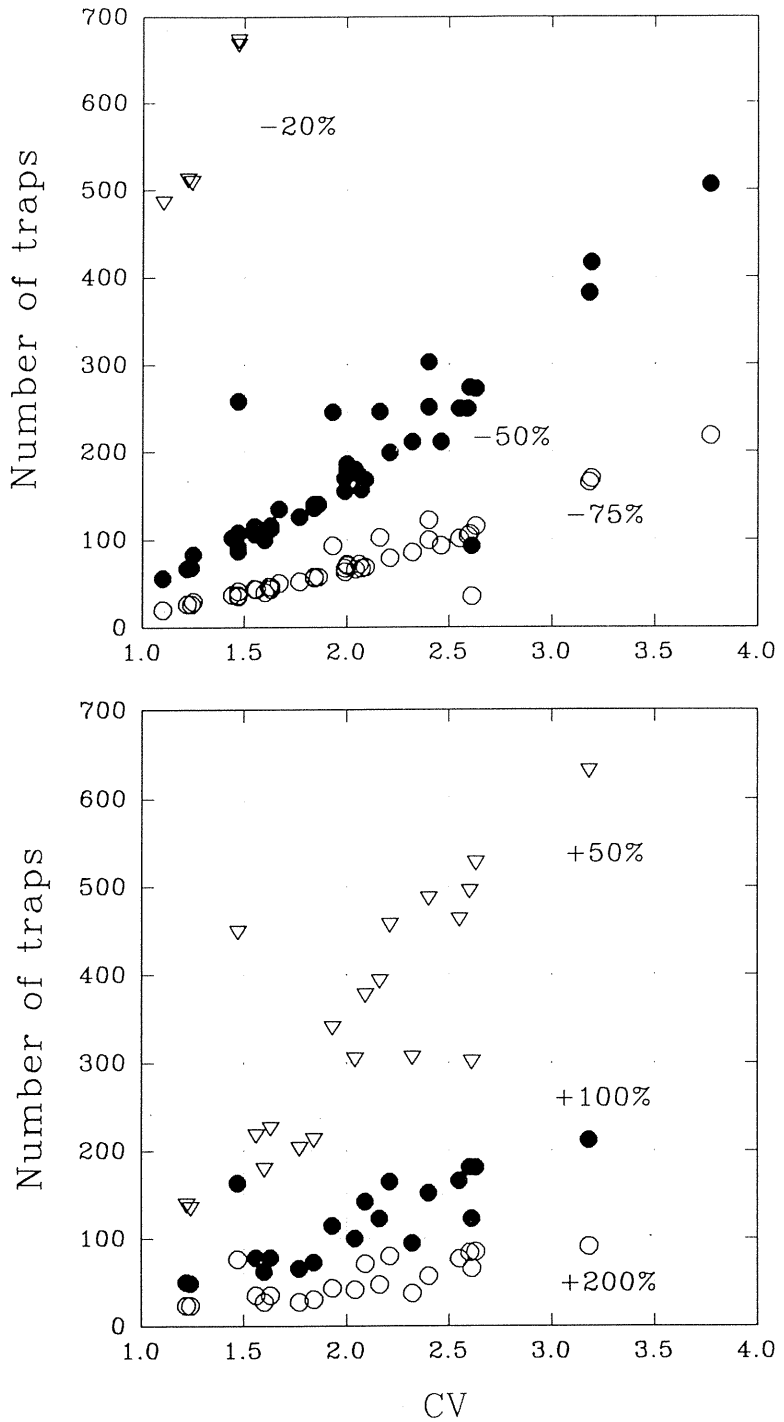

Figure 10. Minimum number of traps required to detect a nominated percentage change in the sample mean for observed sample CVs. Top: ∇ = 20% decrease in the sample mean; ● = 50% decrease; O = 75% decrease in sample mean. Bottom: ∇ = 50% increase in the mean; ● = 100% increase; O = 200% increase in the mean

While no *L. semicinctus* were caught on the drop-lines, we suspect that they may have been the primary 'bait-stealers'. Perhaps one of the greatest limitations of the drop-lines was that the baits, although relatively tough (squid), were quickly removed from the hook, usually without the culprits being caught. This may place a severe limit on the usefulness of this gear in the reef environment where there are potentially many small bait-stealers. The drop-line operations were supervised by a commercial line fisherman within the specified habitat. We see little value in pursuing the usefulness of drop-lines as a sampling technique in the immediate reef environment. They may be more useful in inter-reefal areas if the densities of 'pickers' are lower in these areas.

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.

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