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Effects of observer swimming speed on sample counts of temperate rocky reef fish assemblages

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ABSTRACT: Effect on estimates of fish abundance of speed at which an observer swims an underwater transect was studied for a temperate rocky reef fish community in eastern Australia. Observer speed had a critical though differential effect upon sample counts. Small or cryptic fishes were severely underestimated at relatively fast observer speeds because not enough time was available to search thoroughly for them. Some highly mobile species, however, were overestimated at slow speeds, due to their movement across the transect during counting periods, or to inadvertent double counting. Rotenone samples confirmed that, regardless of observer speed, highly cryptic species are largely overlooked by visual census. It is suggested that observer speed should be standardized in survey designs. Other suggestions for improving precision and accuracy of visual surveys are discussed.

INTRODUCTION

The application of visual survey methods to quantitatively sample fish on shallow rocky and coral reefs has passed through 3 phases. The first involved the initial development of the technique (Brock 1954), followed by a brief pioneering stage (e.g. Odum & Odum 1955, Bardach 1959). The second phase was characterized by a proliferation over the last 2 decades of studies relying heavily on visual surveys of fish. Limitations of visual surveys were frequently admitted but interpretation of results was generally made without these limitations being kept clearly in mind. Russell et al. (1978) summarized a number of biases that researchers had cited for visual fish surveys and Keast & Harker (1977) used the coefficient of variation (CV) to examine levels of precision for repeat surveys of underwater transects. They arbitrarily set as an acceptable standard for comparison a CV of 0.10. The third phase was initiated by a questioning of the multiplicity of methods (Sale 1980) purporting to be based upon Brock's (1954) method, yet showing little similarity with the original.

Sale's (1980) plea for more critical development of survey methods was responded to in several studies. Sale & Douglas (1981) examined survey methods for patch reefs. Sale & Sharp (1983) studied the effect of transect width on precision and accuracy of estimates of coral reef fishes. Thresher & Gunn (1986) compared transect methods with instantaneous and fixed time interval counts, the latter 2 being adapted from avian studies. Brock (1982) compared fish counts from transects with fish collections from poisoning. Bell et. al. (1985) examined the differences between perceived and actual lengths of fish from visual surveys. Harmelin-Vivien et al. (1985) discussed problems associated with the evaluation of reef fish communities.

This study examines the effect of the speed at which an observer swims on estimates of population abundance. Thresher & Gunn (1986) discussed possible effects of both subject and observer speed in censuses of Carangidae. However, other than as a passing caveat (e.g. Sale & Sharp 1983), the effect of observer speed on sample accuracy has been largely overlooked by reef fish ecologists.

The following questions were addressed by this study: (1) Do sample counts of reef fishes increase as observer speed decreases? (2) If so, are sample counts obtained at slower speeds likely to be confounded by the continuous movement of fishes through the study areas during censusing? (3) How closely do sample counts obtained at slow observer speeds approximate true abundance?

METHODS

All work was carried out along the open coastline fringing Sydney, NSW, Australia (Fig. 1). Experiments 1 and 2 were done off Inscription Point, at the entrance

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to Botany Bay. Experiment 3 was conducted at Barrenjoey Headland, a similar though slightly more protected site at the entrance to Broken Bay, because of prevailing poor weather. The marine fish fauna off Sydney is temperate (McCulloch 1922), with a small presence of juvenile tropical species during summer (pers. obs.). Sublittoral reefs are primarily sandstone. Work was limited to depths of 8 to 12 m. These depths form the approximate limits of a visually distinct microhabitat, topographically complex, consisting of boulder-strewn rock shelves, and characterized by a pervasive covering of encrusting coralline algae (Rhodophyta) and large numbers of sea urchins *Centrostephanus rodgersi*. Preliminary surveys (Lincoln Smith 1985) indicated significantly greater species richness and overall abundance of fish here than on shallower or deeper reefs.

Experiment 1. Comparison of counts made at different observer speeds. Two parallel lines 2 m apart and 150 m long were used to define a belt transect. Attached at 10 m intervals along the line were numbered plastic markers, which divided the reef surveyed into fifteen 10 × 2 m segments. A balanced series of surveys was made along this belt transect in which variable numbers of 10 m segments were sampled depending on the speed of swimming. Care was taken to spread sampling effort along the full length of the transect. Six speeds were selected: 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 m min^{-1}, and the duration of each survey was fixed at 20 min. I regulated speed by gauging distance swum along the transect against the numbered markers and against time elapsed. A diving assistant signalled to me at 4 min intervals during each survey; between signals he stayed 4 to 6 m behind me.

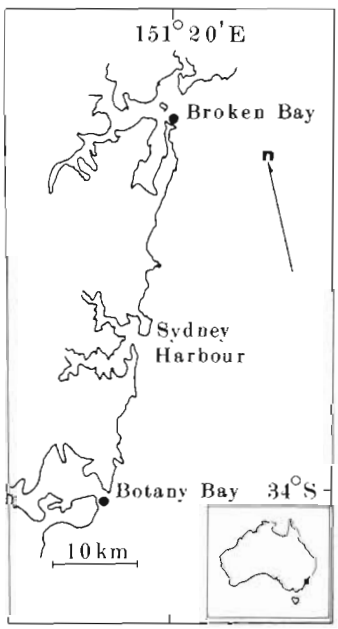

Fig. 1. Location of study sites

Table 1. Classification of rocky reef fish based on relative sightability, with examples from local families

Sightability	Definition
Type 1	Cryptic; small, site-attached; or newly settled juvenile fishes. Difficult to see and to count. E.g. small Serranidae, territorial Pomacentridae
Type 2	Schooling fishes generally occurring in dense aggregations 1 m or more above the substratum. Easy to see, difficult to count. E.g. Kyphosidae, schooling Pomacentridae
Type 3	Fishes encountered singly or in small groups; usually large and/or colourful. Easy to see and to count. E.g. Labridae, Monacanthidae

One survey at each speed was carried out on each of 3 consecutive days, giving a total of 3 samples at each speed. During counting, all crevices and caves were searched as carefully as possible in the time allowed. Thus all reef within the transect segment was searched to the same extent. A deliberate effort was made not to count the same fish twice, or record individuals passing through the transect after counting commenced. Fish were recorded on perspex slates.

Statistical tests were made for number of species (richness), total abundance and counts of the most abundant species or groups of species present on the reef. In addition, the community was divided into 3 categories based on sightability and ease of counting (Table 1). With the exception of richness, all data were converted to densities (number of fish m^{-2} reef). Samples of richness were compared for different 10 × 2 m segments randomly selected from each of the surveys.

A linear regression, partitioned to show deviations from linearity (Sokal & Rohlf 1969), was used to examine the relationship between counts and observer speed. Homoscedacity was tested using Cochran's Test; however, no transformations were made, even where variances were heterogeneous, to prevent altering the relationship between the dependent variable and speed. Where heteroscedacity occurred, the likelihood of a Type 2 error increased (Snedecor & Cochran 1980, Underwood 1981), so significant results were interpreted conservatively.

Experiment 2. Comparison of samples made over different time periods. Here the effect of relative mobility of fishes upon visual survey data was explored. A stationary observer made counts of fishes within or passing through small reef patches. Thus any increases in counts over time would be attributable to the mobility of fish, rather than that of the observer.

A 50 × 2 m transect, divided by markers into five

10×2 m segments, was laid randomly over the reef. Each segment was surveyed 5 times, once for each of the following time periods: 0.5, 1.0, 2.0, 4.0 and 6.0 min, giving a total of 25 samples. The order of surveys was randomized. For each survey I swam to the middle and approximately 1 m to one side of the segment to be surveyed, and after a 1 min adjustment period, recorded all fishes observed within, or moving into the segment.

A partitioned linear regression was used to explore the relationship between the time spent counting and each of total abundance, species richness, and abundance of the most common species present on the reef.

Experiment 3. Comparison of visual surveys of Type 1 fishes with icthyocide collections. Quantitative sampling with rotenone is difficult for active species occurring above the reef substratum (Quast 1968), but it can be very effective for sedentary species (Russell et al. 1978). Hence this experiment sought to compare rotenone collections with visual surveys of Type 1 (cryptic and site-attached) fishes as a way of assessing the accuracy of the latter. On a single day, fish within six 3×3 m randomly laid quadrats were censused over intervals of 0.45, 2.25 or 4.50 min (giving 2 replicates for each duration). These times are equivalent to observer speeds along a 2 m wide transect of 10, 2, and 1 m min^{-1}. After completing the visual surveys, fish in 2 other randomly selected quadrats were collected in dip nets after applying rotenone (200 g dissolved in seawater). These procedures were repeated on 2 subsequent days yielding 6 replicates of each treatment (18 visual and 6 rotenone samples).

The same quadrat frame was used for visual and rotenone samples. It consisted of a collapsable PVC frame with 1 cm mesh net panels attached to prevent escape of fish. The panels were 3 m deep, and attached to the frame so that a 1 m deep 'skirt' weighted with small leads fell below the frame, and a 2 m high 'curtain' buoyed by small floats was held up around the frame. The frame rested on the reef floor and the skirt was moulded along the uneven substratum. Each poison station was manned by divers for at least 1 h. Any fish fleeing the rotenone cloud were recorded on slates and added to the final count; they accounted for about 5 % of the sample.

Data were analysed using a 2-way analysis of variance (ANOVA), the method of sampling (times or poison) being fixed and the comparison of days random. Where the factor 'days' or the interaction were not significant ($p > 0.25$) pooling was used to strengthen the test of the treatments. A Student-Newman-Keuls analysis (SNK) was used to compare treatment means. In 2 cases partitioned linear regressions were used to examine the relationship between counts and durations of visual censuses.

RESULTS

Experiment 1

Significant effects of observer speed occurred in 13 of the 16 counts tested (Table 2). The regression of richness against observer speed was highly significant, with twice as many species recorded at speeds of 0.5 m min^{-1} as at 5.0 m min^{-1}. The relationship between total abundance and observer speed was also highly significant although variances were heterogeneous. If the assumption that no double counting occurred is valid, then as observer speed tends toward zero total abundance will increase to the point where nearly all fish present on the study reef will be counted. At zero observer speed there was an estimated population density of 11.3 fish m^{-2} of reef (Fig. 2). Conversely, as speed increases, it is highly unlikely that the regression line would cross the x-axis (i.e. record zero density). The line would tend to run parallel with the x-axis, with fishes easily seen always recorded. There was no statistical evidence of curvilinearity, however the data (Fig. 2) suggest a degree of 'flattening out' at speeds beyond 3.0 m min^{-1}.

Ellerkeldia mccullochi Whitley (Serranidae) and the pempherids are diurnally cryptic (Type 1). The significance of the regression for these (Table 2) suggests that if more time is available for searching, higher sample densities will result. *Trachinops taeniatus* Gunther (Plesiopidae) and *Scorpis lineolatus* Kner (Scorpididae) are Type 2 fishes, and both showed a significant

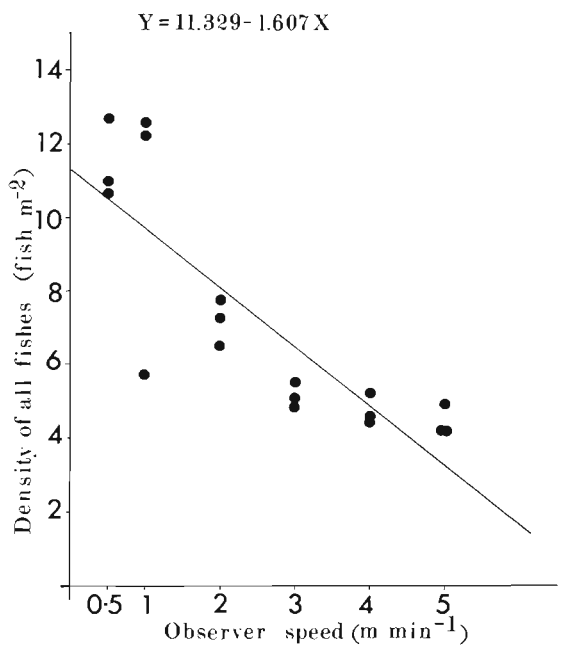

Fig. 2. Sample densities of total abundance against observer speed

dependence of sample density upon observer speed (Table 2). Another Type 2 fish, *Atypichthys strigatus* (Gunther) (Kyphosidae) was very common during the experiment. Its high degree of sightability and ease of counting may account for the lack of dependence of sample densities on observer speed (Table 2).

Whilst sample densities of *Parma microlepis* (Gunther) (Pomacentridae) varied according to observer speed (Fig. 3), analysis showed a significant deviation from linearity (Table 2). This species is territorial (Moran & Sale 1977) and very active over several square metres in and around its territory. Fig. 3 suggests a disproportionately high sample density at 0.5 m min^{-1}. At very slow observer speeds, it is likely that *P. microlepis* from territories adjacent to the transect area are counted as they move in and around the transect. Removal of the 0.5 m min^{-1} data points (Table 2) resulted in a significant linear relationship with non-significant deviations ($p > 0.25$).

Analysis of abundance for Type 1 fishes resulted in a significant deviation from linearity (Table 2). Reanalysis excluding *Parma microlepis* from all treatments led to a significant linear relation. At speeds beyond those examined for this experiment, it is likely that the line of best fit for Type 1 fishes would tend to run parallel with the *x*-axis. Unlike total abundance, however, this line may ultimately cross the *x*-axis at a speed where there is not enough time to record any of the Type 1 fishes. The number of Type 1 species recorded per sample showed a linear relation with observer speed. Mean number of species ranged from 1.67 species per 20 m^2 segment at 5.0 m min^{-1} to 5.33 species at 0.5 m min^{-1}. At faster swimming speeds not only does the observer underestimate sample counts of inconspicuous fishes, he also overlooks many species.

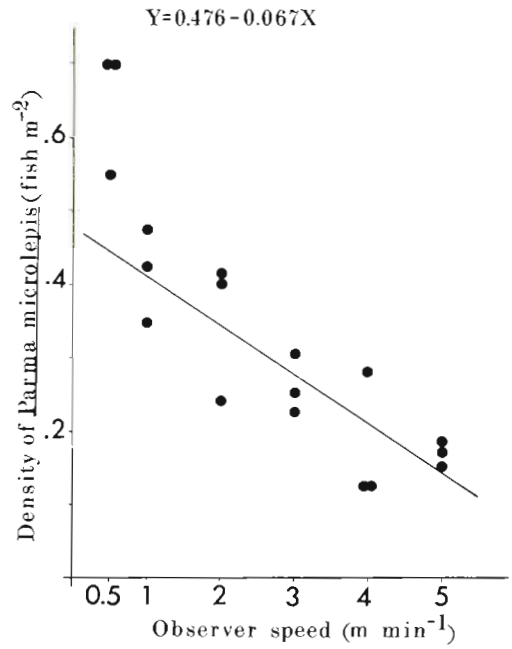

Fig. 3. *Parma microlepis*. Sample density against observer speed (regression based on all data points except for 0.5 m min^{-1} treatment)

Table 2. Summary of linear regressions of fish sample counts on observer speed. Significance of the regression was tested by ANOVA partitioned to show any deviations from linearity

Class tested	Cochran's value	Significance: Linearity	Significance: Deviations	Regression equation
Number of species (20 m^{-2})				
All species	0.222 ns	••	ns	$y = 11.669 - 1.162x$
Type 1 species	0.350 ns	•••	ns	$y = 5.379 - 0.749x$
Type 2 species	0.333 ns	ns	ns	
Type 3 species	0.600 ns	•••	ns	$y = 2.569 - 0.371x$
Abundance (m^{-2})				
Total abundance	0.884•	•••	ns	$y = 11.329 - 1.607x$
Ellerkeldia mccullochi	0.494 ns	•	ns	$y = 0.289 - 0.066x$
Trachinops taeniatus	0.500 ns	•••	ns	$y = 5.247 - 0.675x$
Pempheridae	0.624•	•••	ns	$y = 1.298 - 0.260x$
Atypichthys strigatus	0.559 ns	ns	ns	
Scorpis lineolatus	0.487 ns	••	ns	$y = 0.583 - 0.096x$
Parma microlepis	0.307 ns	–	•	
Parma microleps less 0.5 m min^{-1}	0.401 ns	•••	ns	$y = 0.476 - 0.067x$
Type 1 fishes	0.605 ns	–	••	
Type 1 less *Parma microlepis*	0.589 ns	•••	ns	$y = 1.762 - 0.366x$
Type 2 fishes	0.884•	•••	ns	$y = 8.945 - 1.155x$
Type 3 fishes	0.479 ns	ns	ns	

• $p<0.05$; •• $p<0.01$; ••• $p<0.005$; ns: non-significant ($p>0.05$)

For the Type 2 fishes, sample density decreased with diver speed but the number of species did not (Table 2). These results may not be inconsistent, for while Type 2 species are easily seen, their presence in high densities makes them difficult to count. Because these fish are active, there is also an increased likelihood of overcounting, i.e. incorporating individuals moving into the transect after commencement of counting. This would lead to inflated sample counts at slower observer speeds.

Type 3 fishes are relatively uncommon, but easily seen and counted. A significant increase in number of species occurred at slow speeds, perhaps because of incorrect inclusion of fish which entered the transect (Table 2). However, abundance of Type 3 fish was unaffected by observer speed (Table 2).

Experiment 2

A significant increase in sample counts over time was found for 8 of the 12 counts tested (Table 3). Insufficient data were available to analyse the number of species for each sightability type. Total species richness had a significant deviation from linearity (Fig. 4), indicating that as time passes, the number of new species recorded begins to level off. It took from 1 to 2 min to record all species within the patches at the commencement of the surveys. Beyond 2 min, additions were made principally because Type 3 species moved through the survey patches. Sample counts of total abundance showed a significant increase through time with no levelling off (Fig. 5). There is clearly a great deal of activity occurring among fishes even over the short time scales of this experiment.

Pempheris compressa (Shaw) (Pempheridae), *Trachinops taeniatus* and *Schuettea scalaripinnis* Steindachner (Monodactylidae) showed no significant relation between sample abundance and the time spent counting. This result supports the observation that these species remain relatively stationary over the short periods required for surveying. *Atypichthys strigatus* and *Scorpis lineolatus*, however, are more active about the reef, and sample counts of these showed a marked increase with time (Table 3). In Experiment 1, I had obtained counts of *A. strigatus* which were independent of observer speed, but counts of *S. lineolatus* that were significantly affected by

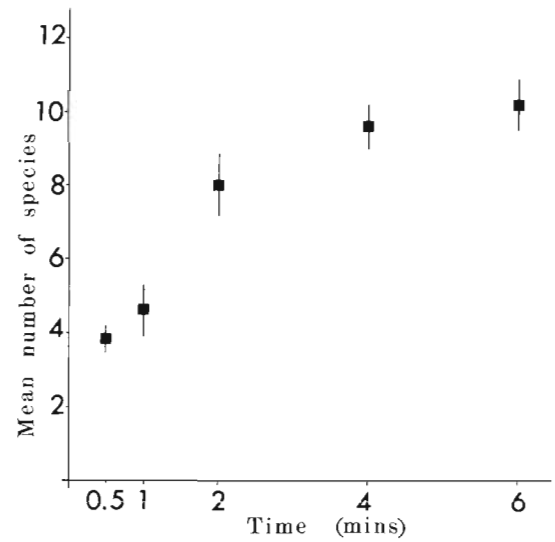

Fig. 4. Increase in mean species richness on 20 m^2 reef patches through time recorded from a stationary position (± 1 SE)

Table 3. Summary of linear regressions of fish sample counts on time spent counting. Significance of the regression was tested by ANOVA partitioned to show any deviations from linearity

Class tested	Cochran's value	Significance: Linearity	Significance: Deviations	Regression equation
Species richness				
All species	0.333 ns	·	·	
Abundance				
Total abundance	0.451 ns	•••	ns	$y = 10.63 + 26.10x$
Pempheris compressa	0.424 ns	ns	ns	
Trachinops taeniatus	0.364 ns	ns	ns	
Schuettea scalaripinnis	0.289 ns	ns	ns	
Atypichthys strigatus	0.387 ns	•••	ns	$y = 4.74 + 14.16x$
Scorpis lineolatus	0.559·	•••	ns	$y = 0.01 + 1.65x$
Parma microlepis	0.317 ns	·	ns	$y = 0.91 + 0.46x$
Type 1 fishes	0.394 ns	••	ns	$y = 1.88 + 1.64x$
Type 2 fishes	0.402 ns	•••	ns	$y = 6.20 + 23.94x$
Type 3 fishes	0.817·	•••	ns	$y = 0.76 + 0.87x$
Type 1 fishes less *Parma microlepis*	0.444 ns	ns	ns	

· $p<0.05$, •• $p<0.01$, ••• $p<0.005$, ns: non significant ($p>0.05$)

speed. Thus the difference between them in Experiment 1 probably occurred because I was more able to track and correct for movements of *A. strigatus*. The dependence of abundance of *Parma microlepis* on time (Table 3) supports my earlier assertion that neighbouring individuals moved through the transect area after commencement of counting.

Abundance of Type 1 fishes showed a significant relation with time only when *Parma microlepis* was included. In contrast, the effect of time proved highly significant for Type 2 and Type 3 fishes (Table 3).

Experiment 3

The results of ANOVAs testing effects of method and day on magnitude of counts are summarised in Table 4. For all counts tested except number of species, the samples × days interaction and comparison of days were non-significant (Table 4). The SNK test for number of species indicated that the poison samples taken on Days 1 and 2 were statistically equivalent and greater than for all other treatments and days. The 3 short surveys yielded lowest counts, but there was considerable overlap among the other treatments and days.

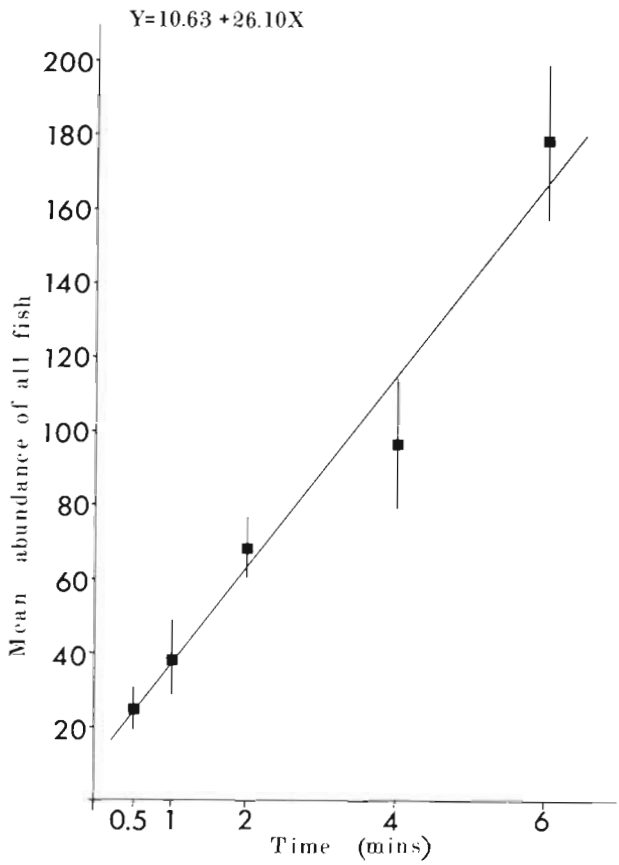

Fig. 5. Increase in mean total abundance on 20 m^2 reef patches through time recorded from a stationary position (± 1 SE)

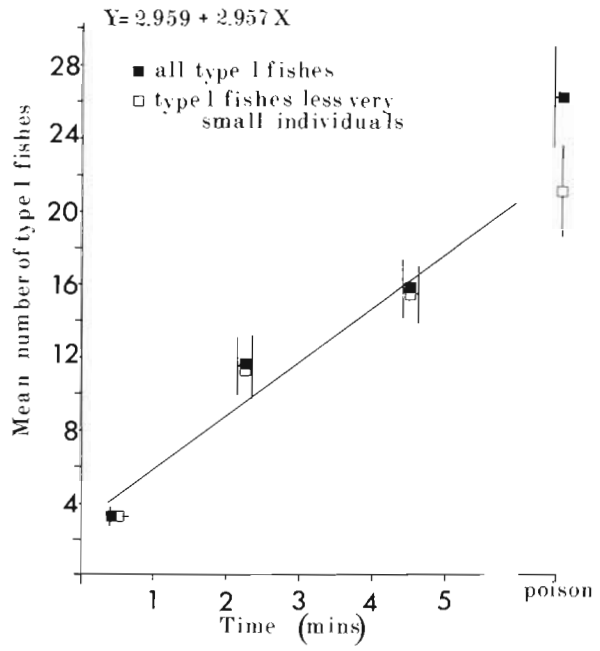

Fig. 6. Mean number of individuals, and mean number of individuals less fish < 5 cm sampled visually for varying time periods and by rotenone (± 1 SE). The line of best fit and regression equation were calculated from individuals less fish < 5 cm against time

The other counts all indicate that visual surveys fall short of the rotenone collections. Analysis of total abundance showed a large difference between the rotenone and visual samples (Fig. 6). An analysis of total abundance of fish > 5 cm (i.e. excluding small fish likely to be overlooked) was carried out. The ANOVA and SNK tests gave the same result (Table 4). However, whilst mean abundance for visual samples was only slightly affected by removal of the very small fishes, mean abundance for the rotenone samples was reduced by about 20 % (Fig. 6). The regression of abundance of fish > 5 cm against time (data only for visual samples) was significant (ANOVA: Linearity, $p < 0.005$; Deviations, $p > 0.25$). Whilst care should be taken in extrapolation, the line of best fit from the visual samples reaches the rotenone samples after 6.10 min, equal to an observer speed of 0.70 m min^{-1}.

For *Ellerkeldia mccullochi* there was no significant difference between samples obtained for long and medium times and the rotenone samples, indicating that surveys conducted at low observer speeds provide a reasonably close approximation to the true abundance of this species. On the other hand, SNK tests for *Lotella callarias* Gunther (Moridae) and fishes < 5 cm alone show far greater sample sizes for the rotenone

collections than for even the longest visual surveys. The visual surveys over longer durations appeared to provide a good approximation of larger *L. callarias*, but grossly underestimated small juveniles.

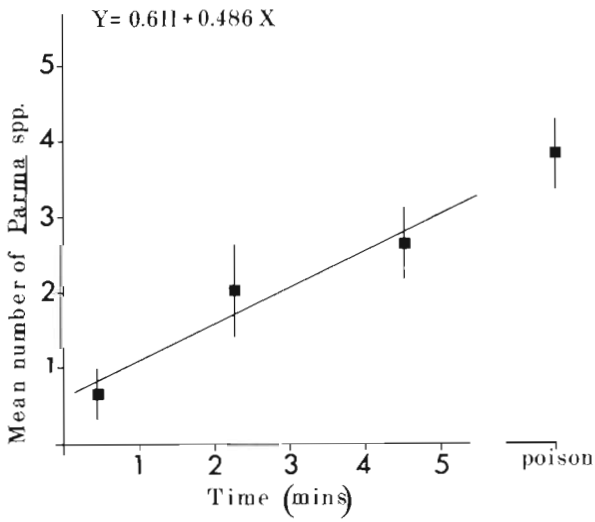

Fig. 7 *Parma microlepis* plus *P. unifasciata*. Mean number, sampled visually for varying time periods and by rotenone (± 1 SE). The regression analysis includes only data from visual surveys

Data for *Parma microlepis* and *Parma unifasciata* (Steindachner) were combined to increase sample size (Fig. 7). The SNK test differentiated the poison samples from the visual surveys conducted over short and medium duration, but not from surveys of longer duration (Table 4). The regression of sample size against time (ANOVA: Linearity, $p < 0.025$; Deviations, $p > 0.25$) reached the mean rotenone collection after 6.63 min, equal to an observer speed of 0.68 m min^{-1}.

DISCUSSION

The relationship between sample counts and observer speed has important consequences for reef fish surveys, regardless of the question of which observer speed yields counts closest to the true density in the community. As justification for many survey procedures in fish ecology, researchers often claim strict standardization as a valid means of allowing close comparisons between sets of survey data. A further factor requiring standardisation is observer speed, preferably using the lowest practical swimming speed.

The above assertions are rather simplistic, however, since the dependence on observer speed of sample counts of all fishes combined arises because of close

Table 4. Summary of 2-way ANOVAs comparing visual counts over different time period with rotenone collections for Type 1 fishes

Class tested	Factors	Probability	SNK test* (alpha = 0.05) (increasing mean size: L to R)
Number of species	Samples	–	S1, 2, 3 M2 L2 M1, 3 L1 P3 L3 P2, 1
	Days	–	
	S × D	< 0.05	
Abundance of Type 1 fishes	Samples	< 0.005	S < M = L < P
	Days	> 0.05	
	S × D	> 0.25	
Ellerkeldia mccullochi	Samples	< 0.005	S < M = L = P
	Days	> 0.25	
	S × D	> 0.25	
Lotella callarias	Samples	< 0.005	S = M = L < P
	Days	> 0.10	
	S × D	> 0.25	
Parma microlepis & *P. unifasciata*	Samples	< 0.005	S M L P
	Days	> 0.10	
	S × D	> 0.25	
Fish < 5 cm	Samples	< 0.005	S = M = L < P
	Days	> 0.25	
	S × D	> 0.25	
Type 1 fishes less fish < 5 cm	Samples	< 0.005	S < M = L < P
	Days	> 0.05	
	S × D	> 0.25	

* S: surveys conducted over 0.45 min; M: surveys over 2.25 min; L: surveys over 4.50 min; P: poison samples. For species richness, letters with a number indicate treatment means for a particular day (e.g. S1 is short survey, Day 1)

approximation to true density in counts for some species (cf. Type 1 fishes) and overestimation for others (Types 2 and 3 fishes). Furthermore, as Caughley (1979) asserts for aerial surveys of mammals in Africa, when the number of species counted at any one time increases, counts of individuals go down, due to the fact that 'search images' are switching all the time. I found this notion applicable when trying to count Type 1 fishes at the same time as Types 2 and 3. Shifting vision from one to the other required adjusting from light to dark, and whilst looking downward into crevices and caves, more mobile fish are likely to have passed into and out of the transect without being seen. It is therefore unlikely that any single method can be used to provide an unbiased sample of all community constituents.

The results of Experiment 3 have 2 important consequences for visual surveys of reef fishes. Firstly, no matter how slowly the observer swims, his speed is unlikely to be slow enough to determine true abundance, except where the seafloor is of such low relief that all crevices can be thoroughly searched. Secondly, certain small, highly cryptic species apparently can never be adequately sampled by visual census. Exceptions apply with certain species – slower visual estimates of *Ellerkeldia mccullochi* and *Parma microlepis* plus *P. unifasciata* were not significantly different from the rotenone collections. This generally supports the results of Brock's (1982) study, where large differences in estimated abundance occurred between visual counts and a rotenone collection.

The use of ichthyocides or anaesthetics could have 2 functions in reef fish surveys. The first is as a quantitative collecting tool for small, highly cryptic species, as suggested by Smith (1973) and Russell et al. (1978). A parallel approach would then be to use rotenone samples to 'calibrate' visual surveys of concealed though less cryptic fishes conducted at different observer speeds. This would provide an estimate of total abundance against which the line of best fit of observer speed against visual sample counts can be compared. This second approach may be useful in pilot experiments for large-scale projects in order to determine optimum observer speed, and to minimize the use of destructive collections.

Data are available for observer swimming speeds in a number of fish surveys. Quast (1968) reports observer speeds of 16.58 and 18.6 m min^{-1} for 100 and 120 m long transects in California kelp beds; Jones & Chase (1975) swam at 5.0 m min^{-1} over coral reefs; De Martini & Roberts (1982) swam at an average of 8.20 m min^{-1} on Californian rocky reefs; and Bell (1983) swam at 6.0 m min^{-1} on Mediterranean rocky reefs. Burchmore et al. (1985) swam at 9.7 m min^{-1} on rocky reefs at Inscription Point, the main site for the present study.

In work prior to this study (Lincoln Smith 1985), I recorded unregulated swimming speeds of 2.18 to 2.97 m min^{-1}. Assuming that the above researchers (with the exception of Burchmore et al. 1985) were also surveying at unregulated speeds, then it is possible that the highly complex nature of the seabed on the reefs studied here requires a far greater degree of searching than the reefs surveyed by other researchers. The speed fixed by Burchmore et al. (1985) is very high compared with speeds in my study, suggesting a severe underestimation of Type 1 fishes. Fish in that study were also surveyed to the limits of water visibility, leading to a far greater reef area being surveyed in the time available. In that study, however, fish were not counted, but placed in abundance classes, possibly allowing more time for searching out Type 1 fishes.

Burchmore et al. (1985) surveyed a course of about 290 m over reef in 30 min, thus fixing the observer speed. In the other studies which reported observer speed, researchers fixed either the distance or time, but not both. So in these cases observer speed was unregulated, presumably being determined by the observer's natural swimming speed, or by environmental factors such as topographic complexity or abundance of fish present. If more time is required for searching, a time-based method will lead to shorter distances being covered in the time allocated; but a distance-based method may require more time to cover the distance set. Such differences may bias estimates of certain species, especially those distributed unevenly in space or time.

Whilst this study addressed the effect of observer speed on sample counts, an implicit assumption is made that sample counts can also be affected by the speed of the fishes surveyed. This assumption partly forms the basis of fish classification according to sightability types. Thresher & Gunn (1986) discuss the effects of both observer and subject speed in relation to surveys of carangid populations along a coral reef front but there are considerable difficulties associated with determining subject speed. For example, Thresher & Gunn determined subject speed for only one individual of one species, which was then applied to all individuals of all other carangid species present. Assuming a constant patrol speed, carangids should be amongst the easiest of families for which subject speed could be determined. Most of the species on the reefs surveyed for the present study showed intraspecifically variable degrees of mobility as well as apparently random movements over the reef. Clearly, the relationship between observer and subject speed should be an area of future research in the development of methodology for visual assessment of reef fishes.

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