The effect of a minimum length specification on visual estimates of density and biomass of coral reef fishes

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Abstract. The effects of fish length on visual estimates of fish abundance and biomass are assessed based on analyses of size frequency distributions. A 2 cm change in the specified minimum size of fish surveyed produced a calculated change of 14.5 to 126% in numerical estimates. A change of 28.4 to 411% was calculated for a 4 cm change. The extent of the change in the numerical estimate varies with the family considered but, in all cases, was most marked if the specified minimum size was decreased. The effects upon biomass estimates are less marked. In the Scaridae, for example, there is a calculated change of 4.1 to 7.4% for a 2 cm change in the minimum specified size. The changes in the estimates are discussed in relation to the use of visual survey techniques for assessing reef fish standing stocks.

Introduction

There are two basic methods of estimating the abundance of fishes on coral reefs: destructive and non-destructive. Destructive methods, including ichthyocides (e.g. Randall 1963) and explosives (e.g. Goldman and Talbot 1976; Williams and Hatcher 1983), are rarely used because of logistical difficulties and their destructive nature although the latter method, in particular, is an accurate quantitative method of determining both the numbers and biomass of species present with little selectivity (Williams and Hatcher 1983).

The most frequently used non-destructive technique for estimating reef fish populations is the visual survey. It enables specific species or groups to be selected for study, usually requires only one worker, and is relatively rapid and inexpensive.

A large range of visual survey methods have been employed. These methods vary, depending on the aims of the investigation. For a general overview of fish popula-

tions, fish numbers may be estimated on a log scale (e.g. Williams 1982, 1983; Russ 1984a, b). The use of log abundance categories allows one to describe numerical patterns or detect changes of 2, 3, or 4-fold etc. depending on the log value used. For more detailed surveys of specific groups, individual counts are often used (e.g. Bouchon-Navaro and Harmelin-Vivien 1981; Choat and Bellwood 1985). Individual counts address more specific questions such as habitat related differences and the influence of scale on abundance patterns. For specific species of particular importance, numbers and individual lengths are estimated (e.g. Craik 1981; Bell et al. 1985; Russ 1985).

There is also a range of methods available for determining the area surveyed. For general surveys, timed transects are often used, with the observer swimming either a straight or zig-zagged course (e.g. Williams 1982, 1983; Russ 1984a, b). Alternatively, a measured area may be used (e.g. Russ 1985) or in the case of highly mobile species, point-based census methods (e.g. Tresher and Gunn 1986). In more detailed studies, a single linear transect is often used (e.g. Bouchon-Navaro and Harmelin-Vivien 1981; Choat and Bellwood 1985).

Each of these visual survey techniques has its own advantages and limitations in terms of accuracy, sample size, potential diver effect on fish behaviour and the nature of the data obtained. Only a few studies, for example, have estimated standing stocks in terms of weight (e.g. Harmelin-Vivien and Bouchon-Navaro 1981; Russ 1985).

Visual surveys have been used extensively for assessing fish community structures and the relative abundances of various groups. In recent years, the need to determine standing stocks of reef fishes has been recognized and as a result, visual survey techniques have been used, for example, to assess management policies (Craik 1981; Russ 1985) and for comparison with fish yields (Savina et al. 1986). However, the accuracy of many of these observations may be questioned as there is little information on the systematic errors associated with the various vi-

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sual survey techniques. Only recently have studies begun to address this question (e.g. Brock 1982; Sale and Sharp 1983; Thresher and Gunn 1986; Fowler 1987; H. P. A. Sweatman personal communication).

If visual techniques are to be used to estimate standing stocks of reef fishes, the size of the fish is one major factor which must be considered. Because few authors specify the minimum size of individuals surveyed, there is an ever-present possibility that the various workers are counting or describing different portions of the available size distribution of the species present, an inconsistency which may have profound effects on visual estimates and invalidate comparisons between study sites or between studies.

Many authors have recorded the number of fish present in an area but they do not define what an individual represents. Do counts refer to adult individuals only or do they include all post-recruitment individuals from 1 cm upwards? There is often no specific mention of the inclusion or exclusion of small individuals, even though the survey techniques used incorporate wide transects which make the inclusion of small individuals totally impracticable.

This study investigates the potential effects of differences in the minimum size of species recorded upon numerical and biomass estimates, and compares the applicability of numerical and biomass estimates in assessing fish standing stocks.

Materials and methods

Surveys were undertaken in the marine reserve on the southwestern side of Apo Island, Central Visayas, Philippines (9°4′ N, 123°16′ E), between March 15 and April 25, 1986. At the time of the survey, the area had been under limited protection for 8 years and closed to all fishing for approximately 2 years. The fish populations therefore were not severely disturbed by fishing. All surveys were carried out using SCUBA with notes recorded on underwater paper.

Fish were surveyed using measured linear transects. Transects measuring 50 × 2 m were used to survey individuals under 10 cm total length, whilst 50 × 6 m transects were used to survey individuals over 10 cm total length. [The total length (TL) is the distance from the tip of the snout to the posterior tip of the caudal fin, not including any lunate extensions or filaments.] The width of the transect was measured at the beginning of each transect, then visually estimated during the transect

Table 1. Regression equations used in the estimation of fish weights based on estimated lengths

Species	n	Equation[a]	r^2
S. tricolor	57	logWT = 3.413 logTL − 2.321	0.884
S. niger	37	logWT = 3.032 logTL − 1.750	0.952
S. bleekeri	19	logWT = 3.088 logTL − 1.890	0.987
S. dimidiatus	18	logWT = 3.003 logTL − 1.775	0.975
S. prasiognathos	8	logWT = 3.232 logTL − 2.246	0.999
S. gibbus	6	logWT = 3.353 logTL − 2.246	0.995

[a] Weight (WT) is calculated in grams and total length (TL) in centimetres. The weights of other species were based on the above equations following the groupings of Bellwood (1986). These were as follows: On *S. tricolor*: *S. chameleon*, *S. flavipectoralis* and *S. psittacus;* on *S. niger*: *S. rivulatus* and *Calotomus carolinus;* on *S. bleekeri*: *S. sordidus;* on *S. dimidiatus*: *S. spinus*

swim. Five replicate transects were made at each of three depths, 2–3 m, 6–8 m and 15 m, corresponding with the reef flat, crest and slope, respectively.

The TL of each individual within each transect was estimated to the nearest 1 cm (rounded down) by comparison with a graduated scale which was carried at all times. The estimated weight of each individual was subsequently calculated based on a Log10 transformed length-weight regression for each species, or using that of a closely related species (Table 1). The accuracy of the weight estimate was determined by comparing the estimated weight of individuals based on visual estimates of their length in the field, with the actual weight when collected. These specimens were either speared using a modified hawaiian sling or caught using a small mesh (14 mm) barrier net and hand-net. The surveys were restricted to three fish families, the Scaridae (13 species), Labridae (32 species) and Acanthuridae (16 species), although only the Scaridae will be considered in detail in this study. Linear regressions were calculated using an ABSTAT statistical program. All other statistical analyses follow Zar (1974).

Results

The effects of fish length on numerical estimates

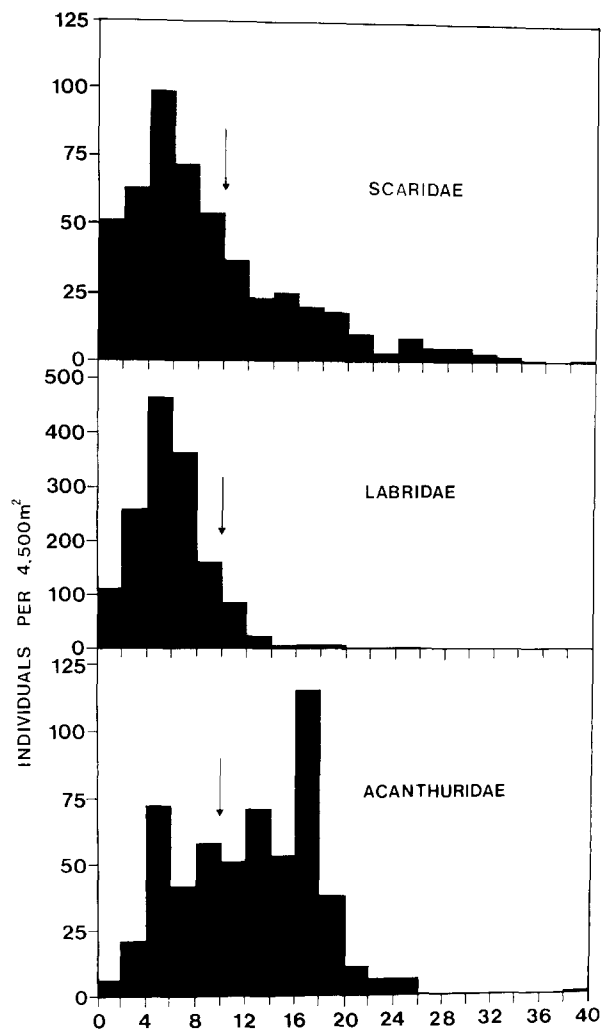The size frequency distributions of the scarids, labrids and acanthurids surveyed in the study area are summa-

Fig. 1. The length frequency distributions of scarids, labrids and acanthurids based on visual underwater estimates. These data represent pooled totals from 30 transects; 15 for individuals under 10 cm TL and 15 for individuals over 10 cm TL. The 10 cm cut-off point is indicated (arrow)

rized in Fig. 1. The numbers of individuals below 10 cm TL have been multiplied by three to compensate for the dissimilar transect sizes used to estimate the number of individuals above and below 10 cm TL. It is apparent from this figure that any change in the minimum size of the individuals recorded in the transects will have a profound influence on the total numbers recorded, especially if the minimum size is decreased.

The effects of changing the minimum size below which individuals are not included in the survey are summarized in Fig. 2. A 2 cm change in the specified minimum size of fish surveyed produced a calculated change of 14.5 to 126% in numerical estimates, whilst a change of 28.4 to 411% was calculated for a 4 cm change. The extent of the changes in the numerical estimates differs markedly between families, with the Labridae being particularly sensitive, the Scaridae less so, and the Acanthuridae least of all.

The effect of fish length on estimates of the biomass of standing stocks

In this study, biomass analyses were restricted to the Scaridae since adequate length-weight data were unavailable for many of the species in the other two families. The standing stock of scarids in the study area, based on pooled values from all transects, was 56.2 kg ha^{-1} (50.7 kg ha^{-1} for fish over 10 cm TL). Changes in the minimum size of individuals recorded have a relatively small effect on the estimated biomass when compared to the changes in numerical estimates (Fig. 2). The contribution of each size class to the total biomass is summarized in Fig. 3. The smaller size classes contribute little to the overall biomass. When compared to their relative abun-

Fig. 3. The contribution of various size classes to the total number and biomass of scarids in Apo Island marine reserve
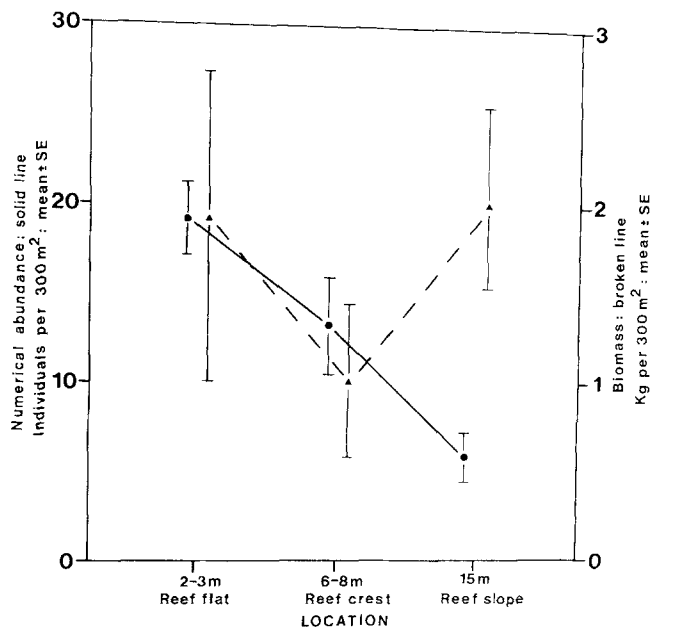
Fig. 4. The numerical abundance (continuous line) and biomass (broken line) of scarids at three depths in Apo Island marine reserve

dance it is the larger size classes that are most important (Fig. 3).

The average degree of error for fish length estimates was 4.6% of the TL (± 1.1 95% CI; $n=21$), whilst the average degree of error for total weight estimates was 17.3% of the total weight (± 7.4 95% CI; $n=18$). These errors represent the mean difference between the field estimated lengths and subsequently calculated weights and the actual lengths and weights of the specimens when collected.

A comparison between numerical and biomass estimates

Numerical and weight-based estimates of fish stocks both indicate the relative size of the standing stock but there are important differences in their application. This is clearly demonstrated if the relative abundance and biomass of scarids are quantified at the three depth strata considered in this study. These data are summarized in Fig. 4. The number of individuals on the reef slope was
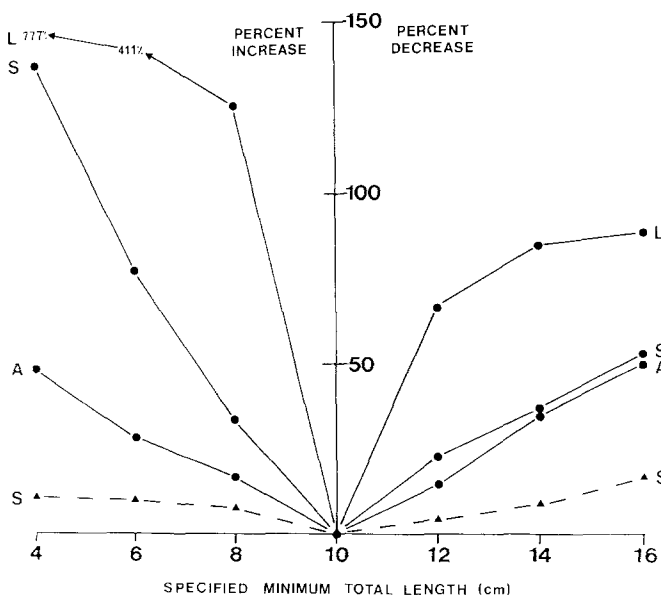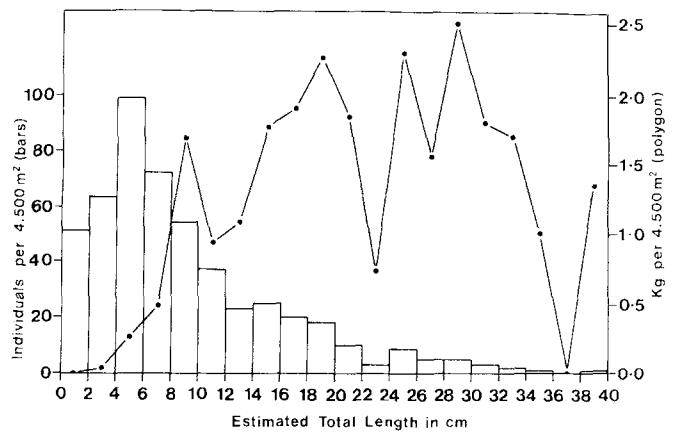

Fig. 2. Changes in the estimated total numbers (continuous line) or biomass (broken line) of scarids (S), labrids (L) and acanthurids (A) as a result of changes in the minimum specified total length, below which fish are not recorded during transects. These are estimated changes based on the data in Fig. 1

significantly lower than on the reef crest or reef flat (1-way ANOVA, F = 9.433, 2,12 *df,* Student-Newman-Keuls analysis, *P* < 0.05, flat = crest > slope; Cochrans' C = 0.506, *P* > 0.05). Despite this difference, there was no significant difference in the estimated biomass of scarids at the three depths (1-way ANOVA, F = 0.99703, 2,12 *df,* *P* > 0.05; Cochrans' C = 0.232, *P* > 0.05). Indeed, the largest mean biomass was recorded on the reef slope which had the lowest number of individuals. Thus in terms of the potential yield of scarids from the three depths, standing stock estimates based on numerical analyses may give misleading results, as the maximum potential yield in terms of Kg per unit area of individuals over 10 cm did not differ significantly between the three depths and appeared to be highest in the area with fewest individuals.

Discussion

Despite the widespread use of visual surveys and critical appraisals of the technique (reviewed briefly by Thresher and Gunn 1986) several potential sources of error have not been considered. In the present study, analyses of the effects of differences in the minimum size of individuals included in surveys have shown that such differences may have a major effect upon numerical estimates. Thus, differences in the size frequency distribution of populations in various areas may mask other differences or may show trends in numerical abundances which have little relation to the biomass or ecological impact of that group in the area.

It is noteworthy that most workers using visual census techniques do not specify the minimum size of individuals included in the census. The few that do refer to a minimum size, refer only to a minimum size range which is species-dependent (e.g. Russ 1985). Because of possible differences between workers in the minimum size of specimens recorded in censuses, comparisons between the data of various workers are not possible with any degree of confidence.

The choice of a suitable minimum size varies with the family, species, location and nature of the study. In the present study, for example, 10 cm was chosen as it was a relatively easy unit to estimate by comparison with the 10 cm graduations on the measuring rod and it approximated the minimum size at which species in the three familes studied entered the local reef fish fishery (Bellwood unpublished data). It was to some extent a fortuitous choice as it was also near the point of overlap between the dominant size classes, for scarids, in terms of numbers or weight (Fig. 3) and therefore did not particularly favour estimates based on either of the two parameters. Although there is no optimum minimum size, in order to facilitate comparisons between surveys a standard specified minimum size may be desirable. Because of the ease of estimation, by comparison with graduated rods, a 10 cm minimum is recommended.

Although the potential effects of differences in the minimum size are great, the actual effect remains to be determined. In addition to an increase in the number of fish included in the census, a reduction in the minimum size also increases the size range of fish censused. The inclusion of small fish, whilst maintaining a large transect width, may result in errors because of the difficulty in detecting small individuals when censusing large areas. The size specificity therefore, of various transect sizes needs to be determined. In the present study, for example, 50 × 2 m transects were used to ensure an adequate ability to locate small individuals which would probably be overlooked in larger transects. Fowler (1987) has assessed the efficiency of various transect sizes for estimating chaetodontid densities. Comparable studies assessing the interaction between transect size, size frequency distributions, habitat structure and fish behaviour are required for other families.

In the present study, the problems of numerical and biomass estimates are contrasted so that with an understanding of the strengths and limitations of the estimating techniques, each may be applied in the most appropriate situations.

Although numerical estimates give an indication of the distribution and abundance of a species or family and its relative numerical importance, they are of limited value in terms of assessing an area's fishery potential or status with regards to fishing impact. As fish yields and catch per unit effort data are almost invariably measured in kg per unit area or time, weight or biomass estimates are therefore needed to assess standing stocks. An estimate of the biomass is also of considerable value when considering fish distributions and/or their ecological impact as it will give a more precise indication of the magnitude of a population in terms of its spatial or trophic requirements.

The technique used for estimating the biomass of scarids in the present study has some limitations which must be noted. Nevertheless, it does enable comparisons to be made in terms of kg per unit area. The greatest limitation is that it does not allow for errors in the estimating techniques. The standard errors in Fig. 4 refer to the variance of the estimates between replicate transects. These do not allow for systematic errors in the estimation of fish abundances within a transect, the estimation of fish lengths or the conversion of lengths to weight. While the present method of estimating fish biomass is useful for preliminary estimates, conclusions drawn from these analyses must remain tentative until the effects of the various sources of variation are fully understood.

The high variability in the estimated standing stocks of scarids in the present study appeared to be primarily a result of the schooling behaviour and clumped nature of larger individuals. *S. gibbus* Ruppell and *S. bleekeri* (de Beaufort) formed small harems, whilst *S. dimidiatus* Bleeker and *S. sordidus* Forsskal frequently joined mixed schools. The main advantages of the present biomass estimating technique is that it yields data in terms of kg per unit area which can be compared directly with fish yields and catch per unit effort data. It will also give a clearer

picture of a species distribution, especially if used in conjunction with numerical estimates. It must be noted that the estimated weights are relatively insensitive to changes in the minimum size of individuals surveyed.

A comparison between numerical and weight estimates is important as it affects investigations of both the fisheries potential and ecological role of a species or family. In the present study, the discrepancy between numerical and weight estimates was primarily the result of the presence of only a few large individuals in the deep survey area, particularly large *S. gibbus* which were found almost exclusively in the deep area, and to a lesser extent, large *S. bleekeri* and *S. niger* Forsskal.

As a result of the present study, the following recommendations are proposed for estimating the standing stocks of reef fishes using visual surveys:

A. That a minimum size must be specified, below which individuals are not to be included in the census. The size should be stated and adhered to. This enables comparisons to be made within the study and between studies.

B. If possible, express the abundance of fish in terms of the numbers and weight of fish per unit area (the former is invariably collected to derive the latter). For fisheries comparisons, only the weight estimate is of direct applicability, although the limitations of the technique must be taken into consideration.

C. Because of the insensitivity of biomass estimates to changes in the minimum size limit, the high variability of biomass estimates, the relatively low abundance of large individuals and the strong negative reaction of many species to divers in many fished areas (personal observation) the following guidelines are recommended for visually surveying standing stocks of reef fishes. A large sample area is preferable, with at least 5 replicates. An undulating transect within a measured area (e.g. Russ 1985) is not recommended as each part of the transect is bordered by an area which is either (a) due to be censused or (b) already censused. This increases the chance of diver-mediated effects (e.g. diver aversion) and the chances of recounting the same individual. Single linear transects or timed transects, with the area back calculated, are preferable as they reduce the potential for diver mediated effects. As small specimens need not be surveyed, a relatively large minimum size limit of at least 10 cm is recommended. A larger minimum limit enables larger transects to be used. A minimum limit of 15 cm and a transect of 10 m width will probably suffice for most large reef species, whilst 10 cm and 6 m are probably reasonable if smaller species are to be included. These fish sizes would include most specimens available for capture by artisanal reef fishermen, whilst the transect widths are wide enough to locate, identify, and estimate the size of target specimens. Smaller transects reduce the number of individuals censused and may decrease precision (cf. Fowler 1987), whilst larger transects make species identifications and length estimations increasingly difficult and may result in some peripheral specimens be-

ing overlooked (personal observation). The number of species recorded and the time needed to record the data should also be considered when chosing an appropriate transect width.

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