

# CRC REEF RESEARCH

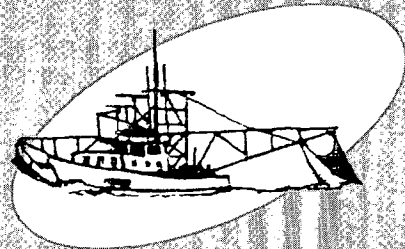
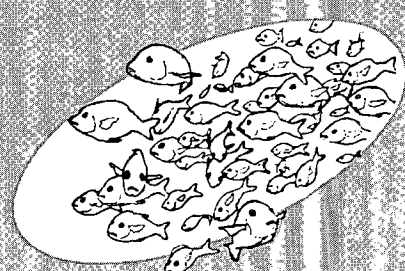
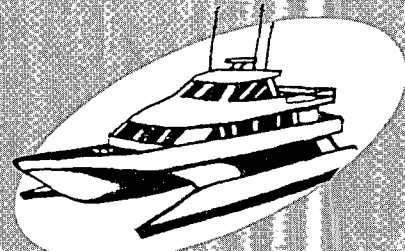
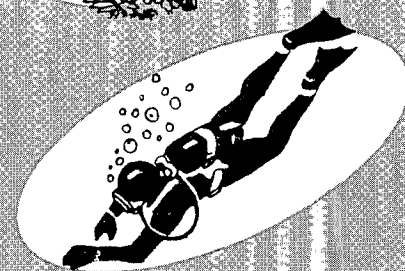
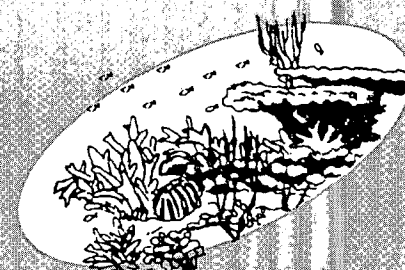
## TECHNICAL REPORT

### Evaluation of sampling methods for reef fish populations of commercial and recreational interest

**Michael Cappo & Ian W. Brown**

Australian Institute of Marine Science

Southern Fisheries Research Centre,  
Queensland Department of Primary Industries



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**EVALUATION OF SAMPLING  
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OF COMMERCIAL AND  
RECREATIONAL INTEREST**

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## 1. SUMMARY

Information on the number of fish in a population is necessary to determine the effects of fishing and distinguish them from natural changes. The more accurate this information is, the more easily changes in the populations can be detected. The power of statistical tests to detect changes in population size depends on the accuracy and precision of population estimates. *Accuracy* is the closeness of an estimate to the true population size; *precision* is the closeness of repeated estimates of the population size. Systematic *bias* in the counting or sampling of fish can cause very precise estimates to be inaccurate and most methods of fish sampling have some sources of characteristic bias. This review aims to evaluate the accuracy, precision and biases of the sampling techniques most useful for surveying fish populations in Great Barrier Reef waters.

Tropical fish populations associated with coral reefs are among the most difficult groups of fish to survey accurately, partly because of the variety of their behavioural patterns and partly because of the topography of their habitat. The landed value of individual species is generally low and has not attracted the expenditure on surveys of their numbers that have been justified for the industrial fisheries of temperate zones. However, the need to develop systems for reliably assessing populations of target groups (coral trout, sweetlip emperors and the sea perches in particular) is becoming more urgent, as recreational and commercial fishing effort on the Great Barrier Reef intensifies.

In shallow waters within the limits of safe SCUBA diving (about 20 m depth) underwater visual survey along strips (transects) of known width have been clearly demonstrated to be a precise way of obtaining relatively accurate estimates of coral trout density that are useful in routine monitoring of their populations. This has not been the case for the sweetlip emperors and the schooling sea perches. These fish are seen so rarely in counts along transects, or school up in such clumped numbers, that there are many zeroes in visual surveys with occasional large numbers when schools are seen. This type of data is so imprecise that only very large changes in population size would be detectable. If a technology can be developed that measures the area covered by a SCUBA diver then large scale searches of reefs within fixed time intervals may be a way of counting these sweetlips and sea perches.

Many of the other popular reef fishes such as red emperor, scarlet and saddle-tail sea perch, spangled emperor and red-throat sweetlip spend most, or all, of their time in deeper waters

between reefs where underwater visual surveys are not possible. There is presently little knowledge about the types of habitat and sea floor cover (sponges, corals, sea fans) that these fishes aggregate around, but once this is determined there are a variety of sampling methods that will be useful to estimate their abundance.

Underwater visual surveys could be carried out from submersible vehicles, from which a human observer counts fish, or remotely-operated vehicles or ROVs, from which video recordings are made for later interpretation and analysis. Submersibles and ROVs generally can operate over a very great depth range and both would be very useful in determining the habitat requirements of the fish between reefs. They are not suitable for routine monitoring of fish populations as submersibles are extremely expensive, and presently unavailable in Australia, and ROVs have a field of view that is too narrow and shallow to match the human eye.

Hydroacoustic techniques operate in the same way as an echosounder by transmitting pulses of sound down to the seabed and analysing the echoes returned from fish and other objects in their path. These techniques have the potential advantage of speed and ease of operation, in that they do not require deployment of gear or divers. Sonar and other forms of acoustic echolocation have been used in estimating school size of pelagic fish stocks for many years, but the technique's application to coral reef stocks has not progressed very far, primarily because of lack of interest and difficulties associated with species recognition. Unlike the situation with large schools of pelagic fish (which tend to be of one species), reef fish populations comprise a high diversity of species, many of which have visual similarities and undoubtedly sonic 'fingerprints' that are almost indistinguishable.

Most other 'capture' methods for sampling reef fish follow the line fishing, trapping and trawling that form the basis of commercial fisheries. These methods offer the advantages of deployment at all times or depths, and of providing specimens for studies of age and reproduction or for tagging and release. The catch-per-unit-of-fishing-effort (CPUE) in the sampling gear is assumed to be an index of population density. Most of the bias and problems with use of these gears concern the way CPUE relates to fish abundance. Fish can avoid trawls and escape from traps, and mesh or hook size can select for or against capture of certain sizes of fish, so that CPUE is uncoupled from fish abundance. Similar effects are caused by changes in the vulnerability or 'catchability' of fish. The use of underwater videos to study the way these



gears catch fish, and comparison with visual surveys or other gear types, has allowed calibration of CPUE as an index of abundance.

The use of baited, wire-mesh fish traps is the best known of these capture methods for reef fish. Selectivities caused by entrance and mesh size, trap volume, bait type, soak time and fish behaviour are some of the factors shown to affect trap CPUE, but the real constraints on their use as a sampling tool relate to the characteristics of the data collected. Like the visual surveys, catches of small emperors and sea perches reflect their clumped distribution with many empty traps and some large catches when schools enter. Recent studies have also shown that fish will readily leave traps once the bait is finished. As a consequence, traps may be a useful monitoring tool only if large amounts of time are spent sampling in each critical habitat on a reef, or only if very large (3-fold or greater) changes in CPUE were of interest. Underwater videos can be attached to monitor the visits, entrance and escape of fish from these traps to reduce some of the biases and perhaps increase the efficiency and sampling power of trapping.

The use of bait to attract fish is also fundamental to the use of line fishing as a sampling tool. A variety of factors will alter the responsiveness of fish to bait in traps and on hooks, and hence their 'catchability', so that CPUE does not always reflect their density on a reef. Tidal state and spawning season have been identified as causes of consistent increases in the catchability of coral trout on handlines, but there is a need for more experimental fishing to refine our knowledge of the times and places where handline fishing would best be used as an index of abundance. This technique is rapid, relatively cheap, and can cover all habitats and depths on a reef. Catch rates can be high if professional fishermen are used, but effort is labor intensive and notoriously difficult to standardise. The coefficient of variation in handline fishing operations on the GBR ('tinny' fishing) is similar to that for trapping in the same habitats. With a thorough analysis of the precision and sampling power of the technique, including existing datasets, we believe handline fishing will be useful in monitoring coral trout populations. Visual surveys and spearfishing in the same areas before, after and perhaps during line-fishing would allow better understanding of the biases associated with handline fishing.

The similarities in precision between trapping and line-fishing indicate that extensive sampling will be required to use these techniques. In itself, this sampling will cause major population declines of some species independent of any natural change or effects of fishing, unless the catch is released unharmed. There is an urgent need to assess the short-term and long-term survival of fish released from sampling with traps and lines - especially when those gears are

being used in the 20-40 m depths around reefs. Only anecdotal observations and tag recovery data from shallow water (<10 m) fishing is available to infer the mortality of these fish.

For this reason, and failure of most of the assumptions relating recapture rates of tagged fish to total population numbers, we believe that mark-release-recapture experiments will not be a practical way of estimating reef fish population sizes in deeper waters around reefs.

Semi-pelagic trawls, traps and line-fishing have all been successful in catching the inter-reef sea perches and emperors in northern Australia, but the precision and sampling power of these gears has not been analysed for these species. A key requirement for developing sampling techniques in the inter-reef waters of the GBR will be much better knowledge of the type and extent of habitat favoured by these species here. The performance of traps and handlines in a sampling role in deep inter-reef waters has not been fully analysed, but both could be deployed with pin point accuracy on habitat features and in aggregations or schools of fish. There may be a role for hydroacoustic surveys of these schools if traps, lines or trawls can be used to determine the species composition of them. Much progress has recently been made in developing semi-pelagic fish trawls that can efficiently operate at 0.4-1 m above the seabed to avoid hookups and reduce bycatch and destruction of seabed fauna and habitats. These will not be useful on rough shoals and pinnacles and virtually all the catch is killed, but trawls offer advantages elsewhere of very large areas sampled in all sea conditions and some ability to target aggregations found with hydroacoustics. They also completely avoid the biases and selectivities of different responsiveness of fish to baits that hamper trap and line fishing. The effective area fished by trawls is not yet fully understood and the catch tells nothing about the nature of schooling or clumping of species along the trawl path. Cameras and hydroacoustics (netsonde) mounted on trawl headropes could provide this information as fish enter the net.

There is no single method currently available which will satisfy all the requirements for population assessment of commercially and recreationally important fish species on the Great Barrier Reef. Each method has characteristic advantages and disadvantages, and the selection of an appropriate suite of methods will clearly depend upon the objective of the assessment and the need for biological data in addition to the simple counts of fish numbers. This conclusion is essentially the same as those from past comparative studies of reef fish assessment methods, and indicates that the advances in sampling methodology within the past few years have not clearly identified a particular technique as being of general applicability to the tropical reef

fisheries. It also indicates that promising leads in the use of side-scan sonar and baited stations with video cameras have not been developed since they were first suggested.

However, protocols relating to underwater visual surveys and trapping have been well defined, tested and improved. There remains a need to extend this to other non-destructive methods (particularly baited video stations and hydroacoustics) and generally to the capture methods in inter-reef waters. There is also a need for development of subsidiary techniques to identify and categorise habitat type, particularly in depths greater than the SCUBA diving limit, as knowledge of these variables will have a profound effect on allocation of sampling effort and subsequent power of statistical tests.

The Great Barrier Reef has been host to these advances in the development of underwater visual census techniques, which have been shown to be adequate for monitoring the abundance of coral trout in shallow water habitats, and which will probably play an increasingly important role if the live-fish trade expands into the exploitation of species other than coral trout. However we believe that alternative techniques must be developed and tested for the emperors and sea perches, as well as for inter-reef populations of coral trout. Among these we would recommend traps, handlining operations and baited video stations as immediate solutions, with the possibility of side-scan sonar and semi-pelagic trawls in the longer term.

## **2. OBJECTIVES AND CONTEXT**

The objective of this study is to review the international scientific literature in order to:

- (i) determine the most appropriate and cost-effective methods for sampling fish populations on and around coral reefs, and
- (ii) identify unresolved issues and the tactical research needed to address them effectively.

The review is confined to enumeration methods, intentionally excluding reference to stock assessment methods involving the use of fishery-dependent catch and effort data. The focus of the review is the demersal fish fauna of the GBR that have some commercial and recreational value in harvest fisheries and, in terms of their habitats, we define 'coral reef' to include hard substrata ranging to the bottom of the reef slope, as well as inter-reef shoals and pinnacles.

Particular emphasis is given to the relatively few studies in which different sampling techniques are compared, and to reports on novel techniques that may offer some potential for use in the GBR. In comparing different methods and the results of different studies using similar methods we have, where possible, made use of the mean catch rate and associated coefficient of variation as the most useful comparative statistics.

### 3. INTRODUCTION

The demersal GBR fishes of major commercial and recreational interest comprise members of the Serranidae (coral trouts and cods), Lethrinidae (emperors) and Lutjanidae (sea perches or tropical snappers). Much, if not most, of the fishery for the latter two families occurs below the 20 metre depth contour, below the range to which scientific SCUBA diving on the GBR is generally restricted (Williams and Russ 1994).

These fishes are generally large (>1 kg), mobile, and may school on an obligate or facultative basis. The coral trouts are active only during the day, but at some places and times the lethrinids and lutjanids show diurnal, nocturnal and seasonal changes in activity.

In terms of their habitats, we define 'coral reef' to include hard substrata ranging to the bottom of the reef slope, as well as inter-reef shoals and pinnacles. Habitats between reefs and dominated by sponge and gorgonian epibenthos are referred to as 'near-reef', 'off-reef', or 'inter-reef'.

With some important exceptions, comparisons of reef fish sampling techniques have generally been carried out in Caribbean and Bermudan reef systems in waters less than 20 m deep. Following Parrish (1982), the subjects of those studies comprise mainly small Type A and B species. Type A (reef-restricted) families (pomacentrids, chaetodontids, serranids and scarids) briefly, if ever, leave the reef substratum. Type B (reef-related) families, such as the holocentrids and haemulids, leave the reef at dusk to forage in 'off-reef' areas, and return to shelter in the reef complex during the day. 'Reef-indifferent pelagics' (Type C) and 'non-reef demersal' (Type D) are represented there by carangids and sparids.

Fishes of major commercial and recreational interest on the GBR fall into all four of these categories: Type A (coral trout *Plectropomus* spp.), Type B (lethrinids and small lutjanids), Type C (Spanish mackerel *Scomberomorus commerson*) and Type D (red emperors and sea perches). However lethrinids are not represented in the Caribbean and Bermudan fauna, nor are there ecological equivalents in the Sparidae or Haemulidae in those seas that approach the diversity, size and abundance of the GBR lethrinid fauna. The large 'reds' (*Lutjanus sebae*, *L. malabaricus* and *L. erythropterus*) arguably fall into both categories B and D because of their abundance in off-reef areas dominated by sponge and gorgonian epibenthos. The eteline

snappers *Pristipomoides*, *Etelis* and *Wattsia* comprising the small GBR deepwater handline fishery (Kramer *et al.* 1994) can be considered reef-related.

In terms of fauna and habitat, few overseas studies are directly applicable to evaluation of different enumeration strategies for the major GBR fisheries. Perhaps the closest are the snapper and grouper studies of the North Atlantic (Barans 1982; Gutherz 1982), the lagoonal studies in New Caledonia (Kulbicki 1988a, 1988b), the deepwater snapper studies in Hawaii and the Marianas (Ralston *et al.* 1986; Polovina 1987), and the Gulf of Mexico red snapper sampling trials (Haynes 1988). The general paucity of information on stock enumeration contrasts with the worldwide importance of tropical fisheries based on snappers and groupers, and reflects the difficulties experienced at all levels in assessing patchily distributed fishes within a topographically complex region of patchy habitats.

In this review we examine enumeration methods which have been described in the literature (both main-line and 'grey') and which may have application on the GBR. The methods fall generally into two major categories - observational and capture methods - and we have divided our review accordingly.

Non-destructive, observational methods are of relatively recent origin and are considered 'environmentally friendly' because they involve observation rather than capture, and do not disturb the substratum. Such methods include an array of underwater visual census (UVC) techniques carried out by divers, usually using SCUBA, or from submersibles; remotely-operated underwater vehicles (ROVs) equipped with video systems; static or sled-mounted video cameras; and hydroacoustic (echolocation) systems.

Capture methods reflect techniques which have been used historically in commercial, recreational, and artisanal fisheries throughout the tropics and subtropics, and include trapping, hook-and-line fishing, trawling, spearfishing, netting, poisoning and the use of explosives. Capture methods are not always destructive, as fish can sometimes be released unharmed from traps and hooks, but some of them cause undesirable levels of habitat disturbance and/or kill all captives. These methods have an important advantage through provision of specimens; for identification; measurement; collection of biological material for age determination and reproductive studies; and (in some cases) for mark-release experiments.

In the final section we review the studies that have compared observational and capture techniques to calibrate each other.

#### **4. OBSERVATIONAL METHODS**

##### **4.1. Visual Estimation**

A large body of literature exists on the visual estimation of reef fish abundance (see Thresher and Gunn 1986; Samoilys and Carlos 1992; Mapstone and Ayling 1993 for reviews), and it is our purpose here only to evaluate these techniques in context of the commercially and recreationally important serranids, lutjanids and lethrinids. Most of the major sources of bias and logistical difficulties reviewed from the literature on SCUBA-based visual surveys are also applicable to techniques that employ observation from submersibles (Ralston *et al.* 1986; Uzmann *et al.* 1977; Richards and Schnute 1986) and remotely operated video recordings or camera sleds (Gutherz and Pellegrin 1988; Uzmann *et al.* 1977).

Strip or belt transects are the most commonly used visual survey technique (Mapstone and Ayling 1993; McCormick and Choat 1987), followed by point counts (Bohnsack and Bannerot 1986; Samoilys and Carlos 1992). Although widely used in terrestrial mammal and avian ecological studies, line transects (Kulbicki 1988a) and spot mapping (McCormick and Choat 1987) have not been used widely by reef fish ecologists (Thresher and Gunn 1986).

When accuracy and bias have been evaluated in comparisons of visual censuses by destructive use of ichthyocides and explosives, it is generally found that observers underestimate the numbers of abundant, shy or cryptic species (Stone *et al.* 1979; Brock 1982).

The five most important criteria in selecting a visual census technique are considered by Thresher and Gunn (1986) to be:

- extent and rate of individual mobility,
- abundance and patchiness (and hence size of sampling area required),
- effects of observers on local abundance,
- the detection probability function, and
- cost/efficiency factors.

The relative performance of the main UVC techniques for some serranids, lutjanids and lethrinids are discussed here in a review of the sampling characteristics of each technique.

#### **4.1.1. Strip transects**

Strip (or Belt) transects have been widely used to estimate the abundance of fishes on coral reefs (Mapstone and Ayling 1993), temperate reefs (McCormick and Choat 1987) and artificial reefs (Buckley and Hueckel 1989). Measuring tapes, lines or fixed stakes are laid out to mark the length and width of the lanes in which counts are made, or the path width is estimated visually or gauged with a hand-held ruler in the case of narrow lanes. Divers move along the lanes recording the number, size, and sometimes position and activity of fish, at a speed that aims to reduce disturbance and the possibility of recounting individuals.

Of all sampling methods for reef fishes, the use of strip transects has received the most intensive analysis of precision, accuracy, efficiency and data attributes. Much of this work has been done on the GBR and with the coral trout as a major focus (Mapstone and Ayling 1993), but temperate studies in mapped populations of known size have also refined development of the method (McCormick and Choat 1987).

For strip transects, density estimates are converted to 'true' densities by (i) analysis of strip transect data for populations of known size, (ii) determination by regression of effects of strip width and other variables on perceived density, or (iii) empirical analysis of the effect of increased strip width on the probability of detecting a subject. For example, stratifying sampling by reef habitat type and allocating strip transects randomly within strata has been demonstrated to produce precise density estimates of the morwong *Cheilodactylus spectabilis* in a mapped population of known size, after optimal transect dimensions were determined empirically (McCormick and Choat 1987).

Mapstone and Ayling (1993) have presented an extensive analysis of factors affecting bias and precision associated with strip transects, including analysis or consideration of effects of:

- site and pass choice,
- transect length and width,
- migration of fish across transect borders,
- variations in counting times,



- depths of transects, and
- time of day.

Most importantly, the data obtained for most taxa from transects of all sizes were not consistent with the assumptions underpinning most parametric statistical procedures - and this factor should be carefully considered in evaluation of visual sampling techniques.

The effects of transect size on estimated density were not caused by observers failing to count or double count fishes which migrated into or out of the transects whilst they were being surveyed. Nor was the variation attributable to trends in abundance related to the depth surveyed or the time of day when counts were taken. Rather, Mapstone and Ayling (1993) consider that changes in bias with transect size are caused by systematic variation in the intensity (time taken per unit area) with which transects were searched. As a consequence, fishes are more likely to be overlooked in large transects than in small transects.

Estimated densities differed systematically between two observers, and thorough training and periodic recalibration of observers will be essential for utility of data from an ongoing monitoring program. This need reinforces earlier perceptions by Bell *et al.* (1985) of observer bias in estimating coral trout lengths during visual surveys.

Mapstone and Ayling (1993) concluded that strip transects are useful methods for estimating population densities of coral trout (*Plectropomus* spp.), but they could not be recommended as primary methods of survey for all the lutjanids and lethrins, which were at such low abundances, distributed so patchily, or sufficiently wary of divers that there would not be reasonable expectation of encountering individuals in most transects - even those as large as 100 m x 20 m.

#### **4.1.2. Line transects**

In a brief comparison of terrestrial and avian surveys of abundance with those of reef fish ecology, Thresher and Gunn (1986) noted that in almost all terrestrial studies strip transects have been replaced by line transects because of the problems with density inferences when subject detectability is unknown.

When traversing a line transect, the observer records individually the subjects seen with information on the sighting angle and distance from the observer. This allows calculation of the perpendicular distance between the subject and the line. Unlike a strip transect, a line transect has length as its only dimension.

Any reduction in the number of individuals seen, with increasing distance ( $x$ ), reflects a decline in the probability of a subject being detected.  $G(x)$  is described as the probability function of subject detection, the shape of which can be derived from the line transect data, and depends on the size, conspicuousness and behaviour of subjects, as well as topographic relief of the survey area, observer biases and conditions of visibility. The most important working assumptions of the line transect method are that:

- subjects on the line are never missed ie.  $g(0) = 1$ ,
- subjects are fixed in their position, not attracted to or scared from the line and not counted twice,
- distances and angles are measured exactly, and
- $g(x)$  is monotonically decreasing.

There is clear evidence that the last two assumptions are the least robust in use of line transects to estimate reef fish abundances. Kulbicki (1988a) found that there was a 'heaping' phenomenon in line transect data from New Caledonia lagoon surveys where serranids (2-5 m), *Diagramma pictum* (4-6 m) and lethrinids (0-1 and 4 m) were most often recorded at particular distances from the line, rather than on it. The larger commercially important taxa were shy of both the divers and the line, and tended to stay further away, producing a depression in sightings at distance 0. Using Fourier series (Burnham *et al.* 1980), these data distributions were used to produce probability density function estimates at distance 0 ( $f(0)$ ). Kulbicki (1988a) then used  $f(0)$  estimates (serranids = 0.1403, lethrinids = 0.2995, lutjanids = 0.1740) to construct density estimates for each species  $i$  along transect line length  $L$ :

$$D_i = \frac{n_i (f(0)_i)}{2L}$$

Thresher and Gunn (1986) recommended the use of Burnham's *et al.* (1980) TRANSECT program to model the detection probability function  $f(x)$  by seeking a best fit between the empirically determined distribution of perpendicular sighting distances and a series of parametric and non-parametric distributions. To determine density,  $f(x)$  is integrated with the length of the search line and the number of fish seen.

This process is particularly sensitive to errors in estimation of distance between observer and fish subjects, and such observer bias was a major source of error in Thresher and Gunn's (1986) comparison of techniques for counting mobile carangids. Discrepancies in distance estimates were surprisingly high and consistent between two experienced observers.

#### **4.1.3. Stationary point counts**

The other most common form of underwater visual census is the stationary point count, in which a diver counts fish within a cylindrical space of radius 7.5 - 10 m at randomly selected, stationary points for a duration of 5-10 minutes (Bohnsack and Bannerot 1986; Samoilys 1992). Working assumptions for this method are that biases (due to subject crypsis) are consistent and apply to all samples, and that the effect of an observer on fish behaviour is minimal or at least constant among samples.

Samoilys (1992) refined the technique to enable divers to rapidly count occupant (of the census cylinder) individuals during their descent, with shy species first, and then identify incoming fish during the remainder of the count as well as new occupant individuals which emerge from crypsis.

To overcome the problem of mobility of incoming fish, a logical extension of this technique is the instantaneous variable distance point count. In this method a point is rapidly (almost instantaneously) surveyed at fixed or random intervals of sufficient duration to ensure that counts are independent (Thresher and Gunn 1986). Perpendicular distances are calculated, and the error and parameterization methods to account for detectability are the same as for line transects.

The data distributions from Samoilys' (1992) study demonstrate how the behavioural patterns of the target species or groups affect the utility of this technique (Table 1). Data from both strip transects and point counts in Samoilys' (1992) comparisons generally had low means and

very wide confidence limits. Some high counts of 'sedentary' lutjanids may reflect the fact that these fish clump in daytime aggregations between off-reef feeding bouts at night. The classification of 'incoming' fish in the point count technique has no theoretical basis yet for application to density estimation, but peer review of transect/point count comparisons was unable to specifically identify significant advantages of one method over the other in Samoilys' study. However, as the area of a circle is proportional to the square of its radius, errors in distance estimation defining the point count technique may be important.

**Table 1.** Estimates of mean density (number of fish 1000 m<sup>-2</sup>) and 95% confidence intervals (bold type) for log<sub>10</sub> data from UVC using four transect dimensions and a stationary point count. From Table C.2.3.3 in Samoilys and Carlos (1992).

Species Group \ UVC method	50 x 5 m (c)	75 x 5 m (c)	75 x 5 m (b)	75 x 10 m (b)	Point Count
lethrinids	6.04 <b>0.76-27.15</b>	2.88 <b>0.61-8.39</b>	1.65 <b>0.0-7.54</b>	3.55 <b>0.72-11.04</b>	8.12 <b>1.9-27.84</b>
Roving lutjanids	1.131 <b>0.0-4.39</b>	0.176 <b>0.0-0.73</b>	0 -	0.373 <b>0.0-0.98</b>	0.41 <b>0.0-2.67</b>
Sedentary lutjanids	0.88 <b>0.0-4.02</b>	0 -	0 -	0 -	0.42 <b>0.0-1.35</b>
Small serranids	1.59 <b>0.08-5.19</b>	6.86 <b>4.69-9.85</b>	2.25 <b>0.71-5.2</b>	1.89 <b>0.5-4.55</b>	2.82 <b>1.01-6.26</b>
Roving serranids	0.32 <b>0.0-1.52</b>	0.0	0.18 <b>0.0-2.31</b>	0.24 <b>0.0-0.71</b>	0

b = survey speed of 50 m<sup>2</sup> per minute.

c = survey speed of 33 m<sup>2</sup> per minute.

#### 4.1.4. Interval counts

More recently, interval counts (timed SCUBA swims) over larger areas have been used to assess relative abundance of lutjanids and lethrinids on the central GBR (Table 2). Since 1989 Williams (unpublished) has included counts of individual coral trout, lethrinids and lutjanids in 45 minute surveys. These surveys were part of a long-term series of censuses on the outer

**Table 2.** Coefficients of variation and means for lutjanids, large lethrinids and *Pletropomus leopardus* using three UVC methods on three central GBR reefs. Ayling - ten 50 x 20 m transects in 3-20 m depth; Williams - five 45 minute swims in 1-12 m depth x approx. 150 m long; Newman - three 45 minute swims in 1-12 m depth x approx. 400 m long. Lodest. = Lodestone reef.

		AYLING <sup>1</sup> 1989 (Jun)						WILLIAMS <sup>2</sup> 1991 (Nov)				NEWMAN <sup>3</sup> 1992 (Nov)		
		Front			Back			Front				Back		
		Brewer	Lodest.	Davies	Brewer	Lodest.	Davies	Brewer	Lodest.	Davies	Rib	Brewer	Lodest.	Rib
Lutjanidae														
<i>L. sebae</i>	CV	-	-	-	-	-	2.17	-	-	-	-	-	-	2.24
	mean	-	-	-	-	-	0.6	-	-	-	-	-	-	0.16
<i>L. carponotatus</i>	CV	1.83	2.00	3.00	0.93	1.40	1.33	0.99	1.20	0.56	1.05	0.65	0.86	0.38
	mean	0.6	0.4	0.1	1.4	0.5	0.6	2.2	1.8	0.8	0.8	9.2	5.8	3.7
<i>L. fulviflamma</i>	CV	3.00	-	2.17	-	-	2.38	0.96	2.09	0.39	1.09	0.5	0.77	1.1
	mean	0.2	-	2.3	-	-	2.1	10.6	3.8	9.0	3.6	41.3	10.3	3.0
<i>L. bohar</i>	CV	-	-	-	3.00	-	3.00	2.24	1.23	1.09	1.41	1.2	0.92	2.2
	mean	-	-	-	0.1	-	1.0	0.20	1.0	1.2	1.0	11.6	1.2	0.16
<i>L. quinquelineata</i>	CV	1.60	-	3.00	1.47	2.79	1.55	2.24	2.24	-	1.39	0.45	0.7	0.46
	mean	0.5	-	0.1	1.5	2.9	1.1	0.20	0.4	-	1.4	14.5	6.7	3.7
<i>L. russelli</i>	CV	-	1.75	-	-	2.33	2.55	-	-	-	1.37	1.2	1.55	1.05
	mean	-	0.4	-	-	0.3	1.1	-	-	-	0.4	7.7	3.7	2.8
Total <i>Lutjanus</i>	CV	1.23	1.63	1.96	1.20	2.43	1.66	0.75	1.19	0.36	0.61	0.11	0.47	0.53
	mean	1.3	0.8	2.5	3.0	3.7	5.6	11.0	7.4	10.6	9.6	93.2	29.1	14.2
Lethrinidae														
<i>L. nebulosus</i>	CV	-	2.20	-	-	3.00	1.56	1.55	-	1.31	-	1.3	0.54	1.27
	mean	-	0.5	-	-	0.3	1.6	4.4	-	3.40	-	106.8	8.3	1.33
<i>L. atkinsoni</i>	CV	3.00	-	2.33	-	-	-	0.96	1.49	1.39	0.39	1.15	1.53	1.2
	mean	0.1	-	0.3	-	-	-	1.4	0.6	1.40	4.2	4.0	0.5	1.0
<i>L. miniatus</i>	CV	1.00	1.40	2.00	1.83	1.11	1.25	0.95	1.05	1.49	0.71	1.2	0.84	1.4
	mean	1.3	0.5	0.5	0.6	0.9	0.8	1.6	0.8	0.60	1.0	5.0	1.5	0.3
Serranidae														
<i>P. leopardus</i>	CV	0.45	0.38	0.34	0.31	0.48	0.42	0.48	0.64	1.09	0.35	0.20	0.43	0.29
	mean	3.3	2.6	3.5	3.5	2.7	5.0	5.20	2.8	2.40	5.0	9.5	6.8	10.0

Sources: <sup>1</sup> Ayling and Ayling (1992); <sup>2</sup> D.McB. Williams (unpublished); <sup>3</sup> S.J. Newman (unpublished).

slopes of reefs, using a log<sub>5</sub> scale, of about 150 species from a wide diversity of trophic groups. Newman (1995) carried out 45 minute swims in a range of reef habitats, but searched for lutjanids, lethrinids and serranids only. These counts, particularly those of Newman, which covered larger areas than Williams', have tended to give much higher mean counts per swim and considerably lower variance:mean ratios than strip transects (50 m x 20 m) in similar areas, albeit at different times (Table 2). They have provided very useful information on the distributions of these species (Newman *et al.*, submitted a).

Large scale interval counts hold potential for monitoring lutjanids and lethrinids. The development of such techniques, however, is well behind that of strip transects or even traps. Further development and testing is worth pursuing particularly on precision, area standardisation and cost efficiency, where cost efficiency is the comparative cost or time taken to sample sufficient transects or swims to achieve a standard level of precision (Mapstone and Ayling 1993). Timed swims are logistically much simpler than strip transects, and can cover large areas and any kind of habitat. The most difficult problem is to correct counts for different areas surveyed. Dive computers are already available that can record a diver's depth profile. If a technology can be developed for divers to carry that can measure the area covered during a swim, interval counts may become a preferred sampling technique for reef fishes, particularly those that are patchily distributed like lethrinids and lutjanids.

#### **4.1.5. Baited stations and UVC**

Combining the use of baits with local or remote observation has much potential for development as an enumeration technique, despite having received little attention in the literature.

Gotshall (1987) described a variation on counts made at stationary points (section 4.1.3) involving the use of bait to attract fish into the observation zone to assess temporal and spatial changes in fish populations. It was hoped that the method would reduce some of the variability associated with other visual methods such as crypsis of fish subjects, disturbance by divers and the effects of visibility and surge on the diver's performance in censuses.

SCUBA divers counted fish at 317 'stations' in four localities on rocky substrata in depths ranging from 9 to 21 m. Each station consisted of a vertical cylindrical space 2 m in diameter to a height of 1 m above the sea-floor, baited with sea urchin viscera. During the 10-min

enumeration period, two divers counted and recorded the numbers of fish of each species that entered the observation zone. The technique was likened to a trap with no impediment to ingress or egress, and it therefore exhibits some of the advantages (and disadvantages) of both trapping and UVC methods. Gotshall (1987) was able to demonstrate significant seasonal differences in the sightings of four of the five commercially and recreationally important species tested, and concluded that the baited station provides a standardised, controlled and repeatable method of obtaining data on relative abundance. Unfortunately the study did not include a comparison with the results of other UVC methods and concluded that more work is needed to quantify the variance associated with the technique itself and the allocation of sampling effort in time and space. Biases associated with the use of bait to attract fish, including the 'berley effect', bait plume and fish behaviour, are reviewed in Section 5.1.

We strongly believe that the recent technological developments in video cameras and infra-red light sources offer great potential for use in monitoring such baited stations in depths below the limits of SCUBA. Charge coupling device (CCD) video cameras, underwater housings and light sources have generally become miniaturised and less expensive and further innovation has occurred in low-light hardware and software for image intensification. These low-light video cameras are far more sensitive than the human eye and have been used from submersibles to monitor grouper spawning aggregations in deep Florida waters under conditions of very low ambient light (C. Grimes NOAA/NMFS pers. comm.).

Video sampling units could be designed by attaching a CCD camera to an upright pole above, and focussing around, a large (>4 kg) mesh bag of oily baitfish, such as pilchards, attached to a stable base. This would ensure an upright stature when deployed on rough terrain and a standard field of view. These video/bait stations could be set to record visits of fish for standard periods of time in replicate strings with pinpoint accuracy in selected habitats. Stereoscopic camera arrangements would also allow for size estimation of the fish attracted to the bait stations. This sampling unit offers the potential advantages of powerful replication in any depth and seabed terrain and identification of microhabitat types and fish behaviour for each set, as well as completely avoiding the need to capture fish. It avoids many of the biases associated with UVC by SCUBA divers, submersibles and ROVs and permanent records of video images can be archived for preliminary mechanical screening to reduce the human workload in analysing images. These units will be expensive but would take up far less deck space than even modest fleets of standard fish traps in use now. This would allow greater

replication of sampling effort with reduced expense in charter of smaller carrier vessels for shorter periods at sea.

A video camera with capabilities for sensing red light at low levels was used to observe a bait placed on the seabed to identify benthic scavengers of trawl discards as part of studies on the effects of prawn trawling in the GBR (Blaber *et al.* 1994, 1995). The numbers and species of fish sighted during 28 sets of 30 minutes duration was encouraging, especially given the fact that the sets were made at random, in smooth areas with sparse cover of large epibenthos, on commercial prawn grounds or adjacent areas closed to trawling. The small lethrinid *Lethrinus genivittatus* was seen in 25 % of sets and the snappers *Lutjanus sebae* (11%), *L. russelli* (4%) and *L. vittus* (4%) also visited the bait. Other unidentified lethrinids comprised 7% of the scavengers sighted and were seen in 7% of the camera sets. The most abundant visitor to the bait was *Nemipterus furcosus*, which was also one of the major species caught in trawls in the area. There is clearly a need to develop this technique and test it on habitats known to support lethrinids, lutjanids and serranids.

#### **4.1.6. Submersibles and ROVs**

Submersibles can be used to directly observe and count fish in deep habitats, using a variety of UVC techniques but introducing further bias into enumeration (Ralston *et al.* 1986; Richards 1987). Once underwater, submersibles can operate in strong currents, in poor visibility, and at night and it is the need for relatively calm conditions for retrieval at the surface that enforces logistical limits on their activities, as well as high cost.

Richards (1987) considered some of the main sampling limitations to the use of submersibles in the reef environment to be related to bias in visual counts, due to the behaviour and visibility of small, cryptic or schooling species in a complex habitat, and to attraction or repulsion of the fish by the presence of the vehicle itself. The field of vision is narrow from submersibles and they are relatively slow to move between replicates and sites. The costs of operation are proportional to the levels of replication, and more replication is needed to overcome the sources of variability and bias mentioned above.

Application of UVC theory to the use of submersibles involves assumptions regarding observer effects which may be particularly weak. Ralston *et al.* (1986) made observations from a submersible port into an artificially lit area of 30 m<sup>2</sup> (a 'quadrat') and performed sets of 4



counts every 15 seconds. Eteline snappers and *Pristipomoides* spp. were clearly repelled by the submersible and its lights, while carangids appeared to be attracted, and actually followed the submersible. Their best attempt to compensate for this observer-induced error was to pool fish counts across taxa to average the errors (biases) due to attraction and repulsion of different species. High (1980) observed sculpins forming large aggregations around a stationary submersible.

Richards and Schnute (1986) used a submersible to count rockfish (*Sebastes* spp.) along a sight line perpendicular to the port and reported that schooling, small and cryptic species were not amenable to such UVC and, even for exposed species, underestimates arose from inability to search cracks and crevices. Parker and Ross (1986), however, considered that submersibles did have an advantage over SCUBA observers for counting larger, less abundant species as greater areas could be covered in a census. This advantage may have been overstated, as the use of a single submersible cannot match the simultaneous deployment of several SCUBA teams at different sites, and the relative ease with which SCUBA teams can move between sites at larger scales. In the depths within which SCUBA can operate safely it would appear that UVC from submersibles would have worse problems of translating local counts to regional scales that are inherent in stock enumeration.

The most useful role of submersibles and ROVs in stock enumeration will be the provision of data on habitat structure and for close study of the operation and efficiency of other gears and sampling techniques. Knowledge of the extent and nature of habitat for serranids, lethrinids, lutjanids and other species of commercial and recreational interest around and between the reefs of the GBR is poor, yet will be essential to allocate expensive sampling effort to sensible strata.

Studies on tilefish habitat and behaviour in relation to longline fishing gear exemplify some of the best uses of submersibles for fisheries research. Able *et al.* (1993) used observations and collections made from a submersible to map the spatial and temporal variation of tilefish (*Lopholatilus chamaeleonticeps*) habitat requirements in terms of sediment type and texture, temperature and depth range. Relatively warm seabed temperatures and the availability of shelter or malleable, clay sediments were found to be critical characteristics of the species distribution after earlier work from submersibles had discovered tilefish of the genera *Caulolatilus* and *Lopholatilus* dig burrows in the seafloor (Grimes *et al.* 1986; Able *et al.* 1987). A complementary study by Grimes *et al.* (1982) directly observed the performance of

longline fishing gear to determine optimal soak times from bait loss, attraction of fish to the longline and loss of hooked fish. A surprisingly high catch loss (17%) occurred when the longline was retrieved and hooks pulled free of fish in burrows. The length frequency of hooked fish could be compared with the lengths of fish seen by the submersible to evaluate gear selectivity and hence infer the reliability of mortality estimates based on relative abundance of age classes in the commercial fishery. Matlock *et al.* (1991) also report the advantages of submersibles for assessing deployment, efficiency, bait predation and potential catch loss from fishing gear such as longlines, and the insights gained by direct observation of fish behaviour.

It could be concluded from this series of studies that an ideal approach to tilefish stock enumeration would involve survey of the seabed configuration and fish abundance at regional scales in preferred depth ranges to allocate sampling effort to strata, followed by UVC of tilefish burrows from a submersible to estimate tilefish density. Matlock *et al.* (1991) adopted this approach to estimate the abundance of tilefish (*L. chamaeleonticeps*) and yellowedge grouper (*Epinephelus flavolimbatus*) off Texas to contrast the Leslie depletion method using longlines with UVC from a small submersible.

This study is discussed in detail in Section 7.3, but the major findings were that longline estimates were cheaper (US\$5000) than the submersible (US\$8000) to obtain each day, and were probably more accurate because errors in area estimation and double counting were evident in the UVC data.

Uzmann *et al.* (1977) compared submersible, towed camera sled and otter trawl sampling techniques to estimate density of megafauna on trawl grounds. They found that herring, mackerel and butterfish were caught only in trawls, perhaps because they were the least constrained to the seabed of all taxa surveyed, but also because they were photonegative and shied away from the lights. The camera sled was the least effective device for surveying mobile megafauna.

Important logistical considerations in selection of a submersible platform for UVC relate to the requirements of support vessel and specialist staff, weather limitations and cost effectiveness. The overriding limits on their use as a survey tool to estimate absolute abundance may, however, be the unknown biases due to behavioural differences between fish of different species with respect to the presence of the survey vehicle, especially when lights are used to illuminate the observation area.

The small size of remotely operated video cameras (ROVs), their ease of operation, depth capability and potential for providing permanent video survey recordings for subsequent analysis are factors which would seem to be of great advantage in counting reef fish. Major disadvantages include the narrow field of view, shallow depth of field and inability to change focus to identify fish passing rapidly through the field of view. There have been few studies of the performance of the technique. Bergstedt (1990) evaluated UVC using line transects from a sled-mounted video camera to determine whether video records could be used to estimate the extent of mortality on lake trout by sea lampreys. The trials involved estimating a known density of house-bricks distributed over the lake-floor. The final (pooled) density estimate was not significantly different from the actual density, and the authors concluded that the method is appropriate to count dead lake trout.

In perhaps a more relevant study, Okamoto (1989) compared the results obtained from a small ROV with those from diving around an artificial reef, and concluded that (on the basis of species counts) 20 min of observation by divers was superior to 360 min of observation by ROV. Despite the ROV's advantages (depth capability to 200 m, night-time operation as well as day-time) the author pointed out a major logistical problem associated with snagging the umbilical cable on the reef, and concluded that the results from ROVs are not suitable for quantitative analysis.

Perhaps the greatest potential use of ROVs in reef fish enumeration will be in habitat mapping. Development of the technique is underway to study the effects of prawn trawling in the far northern section of the GBR (Blaber *et al.* 1994, 1995). In that study the use of differential GPS allows research vessels to deploy the ROV within 5 metres of a single point. A tracking transponder and side-scan sonar are mounted on the ROV and this enables the remote operator to 'home in' on habitat features once a GPS point is revisited. This has enabled researchers to revisit strip transects for UVC using the ROV and even individual sponges to assess temporal changes. The video, side-scan and transponder data are recorded together with ship's heading and echosounder data on tape, and the operator overlays a running numerical commentary by keying in microhabitat codes in real time. This allows later quantitative analysis of habitat data using relational databases and retrieval of most relevant sectors of the tape. Problems with the umbilical have been largely avoided by deploying the ROV on a leash from a large dump-weight suspended near the bottom from the research vessel. The ROV (Hyball 'Offshore') has a wide angle lens and low-light camera with laser pointers that allow accurate measurement of

organisms within the entire depth of field (pers. comm. R. Pitcher CSIRO Division of Fisheries).

#### **4.2. Hydroacoustics**

Remote acoustic sensing of the seafloor and fish aggregations are routinely used in commercial and recreational fisheries to find fish, and form the basis of stock assessments for a variety of pelagic and demersal temperate fish (Thorne 1983). Acoustic techniques are probably the most effective and widespread sampling method for fishery-independent stock enumeration in temperate waters, but have received almost negligible attention in reef fisheries. This may be due to the ease of identification of temperate species in monospecific schools and the flat topography of the banks or plateaus where they are found. Tropical reef fisheries are generally based on many different species, most of which are thought to aggregate in relatively small numbers in multi-specific schools or do not form schools at all, and the aggregations often occur in close proximity to topographically complex reef structures.

However, Barans (1982) and Barans and Holliday (1983) have shown that remote acoustic sensing, when used with complementary ground-truthing methods, has the potential for obtaining rapid synoptic estimates of the size of snapper and grouper populations. A side-scan sonar with a 50 microsecond pulse length enabled Barans and Holliday (1983) to distinguish individual echoes separated by less than 4 cm along the sonar beam axis. An aggregation of large fish was insonified and the general body shape of individuals was determined from an enlarged record. This demonstration determined a length of 87 cm for one fish at an altitude of 8.7 m above the seabed. Image enhancement, data recording and automated counting and sizing calculations were considered by the authors to be software and hardware additions readily adapted to the basic system. The tested system showed a field resolution of fish 20 cm in length and at a distance of 20 cm between fish and the seabed or between individuals in the school.

In a recent review of developments in fisheries acoustics, Karp (1987) stressed that very large differences in target strength can arise from fish length, aspect, tilt angle and position in the sound field. Species identification from acoustic signals is at an early stage of development, and biases arise even in simple estimation of abundance in monospecific schools. For example, above a certain fish length other organs besides the swimbladder affect backscatter from insonified fish, and the swimbladder itself changes shape and volume (and presumably also reflectivity) during vertical movements by fish.

However the advantages of wide area coverage, reduced effects on fish behaviour and operation over high or low relief without gear damage offer great potential for development if research is directed toward overcoming some of the present limitations, the most important of which Barans (1982) considers to be:

- analyst bias in echogram interpretation,
- need for species identifications, and
- acoustic resolution of fish close together or near the seabed.

Attitudes and opinions regarding development of an acoustic assessment technique present further limitations, and Barans (1982) suggested that many biologists who have been 'browbeaten into communications with statisticians' would like to avoid similar interactions with electricians and engineers.

A theme of our review has been the importance of studying the distribution of 'characteristic' habitat types where serranids, lutjanids and lethrinids are likely to be found below the limits of SCUBA. The large scales at which habitats can be mapped quickly with side-scan sonar means that this technique will have great potential for identifying the extent of coral cover in waters 20-50 m deep between the coral reefs recognised on the GBR, and for locating pinnacles, shoals and other features in inter-reef waters. For example, Able *et al.* (1987) used sidescan sonar to map the distribution of tilefish burrows and boulders. This enables stratification of sampling effort and also helps in choice of sampling gear types to avoid hook-ups with the substrata. Early verification of sonographs with observations from submersibles or ROVs was considered essential for identification of important habitat types.

Another important technique in development for use in the effects of prawn trawling program (Blaber *et al.* 1994, 1995) is sonar processing of the full envelope of echoes received by echosounders. Indices of 'roughness' and 'hardness' can be obtained from the side lobes and second echoes returned to the sounder (but not normally used) by using the 'ROXANN' processor (Marine Microsystems Pty Ltd) and developing appropriate algorithms. This has enabled the separation of macrobenthos such as sponges from the signature of rubble and hard substrata (pers comm. R. Pitcher CSIRO Division of Fisheries).

## 5. CAPTURE METHODS

The catch-per-unit-of fishing effort, or CPUE, has long been used as an indicator of relative stock abundance of capture fisheries. The relationship between CPUE and stock abundance is influenced by the vulnerability or 'catchability' coefficient  $q$ , which defines the proportion of the stock captured by each unit of effort. Many factors can affect vulnerability (eg. schooling, gear saturation, gear selectivity, learned gear avoidance), and departures from the assumption of linearity between CPUE and stock abundance have been well documented (eg. Cooke and Beddington 1984; Beinssen 1989; Richards and Schnute 1986; Richards 1987). This is perhaps one of the most serious and difficult issues to deal with when assessing the relative merits of population estimation techniques based on capture methods.

### 5.1. Trapping

Traps are used throughout the world in tropical and sub-tropical fisheries for reef-restricted, reef-related and non-reef, demersal fishes. While varying widely in design, construction material and deployment strategy, the fundamental concept of operation of fish traps is universal - fish enter an enclosed structure through one or more entrance funnels, and are inhibited from escaping by a constriction at the inner end of the funnel (Munro 1974). Bait of various types may be used to help attract fish into the trap, but many trap fisheries do not use bait.

Until recently (Anon. 1990) the theory of how traps operate was poorly understood because of a lack of non-intrusive, objective, in situ observations. Munro's (1974) model for unbaited traps proposed that the rate of ingress of fish into a trap was largely a function of stock density within the area in which the trap is set. Fish enter a trap at a constant rate throughout the soak period and escape at a rate proportional to the number of fish in the trap. According to this model, the catch is maximised after a period of time specific to the design of the trap (eg. 7-10 days for Antillean 'Z' traps). Subsequently an equilibrium is reached between ingress and escapement (egress). As a corollary it would be expected that the average size of captives would increase with increasing soak-time (Hartsuiker and Nicholson 1981), as larger fish would have greater difficulty escaping than smaller ones. The effect of bait was considered simply as an enhancement of initial ingress rate; when the bait was exhausted the 'unbaited model' would apply. This model has been reinforced by studies on capture dynamics based upon either:

- (i) numerous sets lifted after a range of soak times (eg. Hartsuijker and Nicholson 1981; Dalzell and Aini 1987), or
- (ii) observation of traps by SCUBA divers making successive counts of captives (eg. Munro 1974; Recksieck *et al.* 1991).

Anon. (1990) argued that these approaches to studies of trap dynamics suffer from the infrequent scale at which observations are made: 1 to 5 days between successive visits by divers to traps (average 2.3 days) in Munro's (1974) study; 1 to 5, 6 to 10 and 11 to 15 days soak time between hauls in Dalzell and Aini's (1987) trapping trials. The problems with such observations - made at a frequency less than once per day - are that:

- the number of trap-sets must be large to make statistically significant comparisons,
- it is possible to have high turnover of fish with a relatively constant number remaining in the trap,
- fish may leave the area when the trap is set, may be eaten in the trap, or may be replaced by conspecifics indistinguishable to divers from earlier captives,
- data are rarely obtained to justify assumptions that the presence of a SCUBA diver has no effect on the pool of fishes available to the traps,
- bait is depleted at a scale of minutes to hours, and
- trap saturation can occur within as short a period as one hour.

In the CSIRO North West Shelf study, video observations at 2-minute intervals were used to model the dynamics of trap operation (Anon. 1990), partly on the basis of the above considerations, and partly because substantial catches could be achieved with soak times as short as 1 hr (Table 3). Video camera units were mounted above standard and experimental design 'O' traps to provide direct observations of the separate processes involved with fish capture. These were: arrival of fish at the trap site; fish ingress; use of the bait; and fish egress.

A positive feedback mechanism was found between trap catch, size of the bait attracting plume, and the number of new arrivals at the trap (Anon. 1990). Soluble proteins from the bait disperse down current in a plume that contains concentration maxima caused by fish feeding at the bait canister (the 'berley effect'). When a single fish enters and commences eating, it disturbs the bait and increases the bait flux, resulting in increased ingress of other fish. When the trap becomes saturated there is a decrease in ingress rates, and when bait is depleted there is an increase in the egress rate, and an abrupt decline in new arrivals of fish at the trap. This process varied somewhat for serranids, which entered the traps to feed on the captives and

Table 3. Comparative trap catch rates by region, trap design and target taxa.

Region	Trap Type, entrance funnel size (cm)	Depth (m)	Bait	Average Catch		Average Soak (hours)	Catch Rate		Family, genus or species
				kg haul <sup>-1</sup>	no. haul <sup>-1</sup>		kg trap <sup>-1</sup> hr <sup>-1</sup>	no. trap <sup>-1</sup> hr <sup>-1</sup>	
<b>Jamaica (a)</b>									
Leeward Is Banks	O	40-200	Scombridae	15.8	10.3	15.4 (O/N)	1.03	0.67	{ <i>Lutjanus</i> (58.2%)
	Z	40-200	Decapterus	29.9	37.3	15.4 (O/N)	1.94	2.42	{ <i>Epinephelus</i> (25.7%)
	D	40-200		24.1	17.6	15.4 (O/N)	1.56	1.14	{ <i>Carangids</i> (3.7%)
									{ Other 'reef' spp. (10.9%)
<b>Vanuatu (b)</b>									
Undine Bay	Z	50-430	Scombridae	0.2		24	0.008		<i>Etelis carbunculus</i> (5.8%)
Undine Bay	Z	50-430	Scombridae	0.5		24	0.021		<i>Pristipomoides</i> spp. (16.5%)
Undine Bay	Z	50-430	Scombridae	0.2		24	0.008		<i>Lutjanus malabaricus</i> (7.0%)
Undine Bay	Z	50-430	Scombridae	1.0		24	0.042		<i>Epinephelus</i> spp. (31.1%)
Nguna	Z	100-215	Scombridae	1.8		24	0.075		<i>Pristipomoides</i> (23.7%)
Nguna	Z	100-215	Scombridae	2.1		24	0.088		<i>L. malabaricus</i> (27.8%)
<b>North West Australia (c)</b>	0 (90 x 90 cm)	20	Pilchards	7.91		1	9.9		{ All lutjanids (1.0 - 5.3%)
	0 (90 x 90 cm)	20	Pilchards	12.19		2	2.58		{ <i>Lutjanus sebae</i> "
	0 (90 x 90 cm)	20	Pilchards	13.89	≈15	3			{ <i>L. vitta</i> "
	0 (90 x 90 cm)	20	Pilchards	13.18	≈15	6	2.72		{ <i>L. carponotatus</i> "
	0 (90 x 90 cm)	20	Pilchards	16.61	≈15	9			{ <i>S. nematophorus</i> "
	0 (90 x 90 cm)	20	Pilchards	7.01	≈8	24	0.40		All lethrinids (50.7 - 67.4%)
	0 (90 x 90 cm)	20	Pilchards	5.16		2	2.58		{ <i>Lethrinus nebulosus</i> "
	0 (90 x 90 cm)	20	Pilchards	7.00		4	1.75		{ <i>L. choerorhynchus</i> "
	0 (90 x 90 cm)	20	Pilchards	16.34		6	2.72		{ <i>L. mahsena</i> "
	Z (14 x 15 cm)	20	Pilchards	4.17		2	2.09		{ <i>L. fraenatus</i> "
	Z (14 x 15 cm)	20	Pilchards	6.79		4	1.70		All serranids (10.5 - 25%)
	Z (14 x 15 cm)	20	Pilchards	11.28		6	1.88		{ <i>Plectropomus maculatus</i> "
	S (90 x 15 cm)	20	Pilchards	5.99		2	3.00		{ <i>Epinephelus areolatus</i> "
	S (90 x 15 cm)	20	Pilchards	3.71		4	0.93		{ <i>E. multinotatus</i> "
	S (90 x 15 cm)	20	Pilchards	9.30		6	1.55		{ <i>E. microdon</i> "



Table 3 (continued)

Region	Trap Type, entrance funnel size (cm)	Depth (m)	Bait	Average Catch		Average Soak (hours)	Catch Rate		Family, genus or species
				kg haul <sup>-1</sup>	no. haul <sup>-1</sup>		kg trap <sup>-1</sup> hr <sup>-1</sup>	no.trap <sup>-1</sup> hr <sup>-1</sup>	
<b>GBR (d)</b>									
Rib Reef (flat)	O (25 x 10)	40-45	Pilchards		3.7	12		0.308	All <i>Lutjanus</i> spp.
Rib Reef (broken)	O (25 x 10)	40-45	Pilchards		11.97	12		0.164	All <i>Lutjanus</i> spp.
Davies Reef (flat)	O (25 x 10)	40-45	Pilchards		1.17	12		0.098	All <i>Lutjanus</i> spp.
Davies Reef (broken)	O (25 x 10)	40-45	Pilchards		2.23	12		0.186	All <i>Lutjanus</i> spp.
<b>GBR (e)</b>									
Capricorn-Bunker Group	Box (24 x 10)	25-30	Mullet		3.95	23.3		0.17	All species
	Box (24 x 10)	30-45	Mullet		1.67	24.4		0.07	All species
	Box (36 x 11)	25-30	Mullet		3.76	23.2		0.16	All species
	Box (36 x 11)	30-45	Mullet		0.00	24.4		0.00	All species
Capricorn-Bunker Group	Box (36 x 11)		Mullet		3.62	47.4		0.07	All species
	Box (36 x 11)		Mullet		9.75	94.8		0.10	All species
Swains (Sweetlip Reef)	Box (36 x 11)	30	Mullet		13.67	25.8		0.53	All species
	Soft (24 x 10)	30	Mullet		3.45	22.3		0.15	All species
	Box (36 x 11)	30	Mullet		7.27	23.3		0.31	All species
	Soft (24 x 10)	30	Mullet		2.55	23.7		0.11	All species
	Box (36 x 11)	30	Mullet		3.70	25.0		0.15	All species
	Soft (24 x 10)	30	Mullet		0.78	22.5		0.03	All species
Swains (Pike/Banana/ Snake/Long Reefs)	Box (36 x 11)	35	Mullet		18.91	21.0		0.90	All species
	Soft (24 x 10)	35	Mullet		5.58	22.3		0.25	All species
	Box (36 x 11)	35	Mullet		14.33	24.9		0.58	All species
	Soft (24 x 10)	35	Mullet		5.73	24.6		0.23	All species

(a) Wolf and Chislett (1975) [Table 5];

(b) Blanc (1986);

(c) Anon. (1990);

(d) Williams et al. (1995);

(e) Brown (unpublished)

ignored the bait. They also observed a significantly lower mean time of first arrival at the trap (6.6 min. versus 9.9 min.) in instances when small fish ('pickers') initially fed on the bait, causing a berley effect.

The berley effect results in highly variable catches of traps set in the same way at the same location and with similar soak times. For this reason, it has been argued (Anon. 1990) that CPUE from baited traps may not provide a proportional measure of fish density, even if standardised for soak time. Similar factors also influence the catch rates of large decapods in baited traps and hence do not give a proportional measure of density (see Miller 1975; 1979; 1981; 1983; 1989; Kennelly and Craig 1989).

Anon. (1990) included an estimation procedure for a density index in a 4 step process model with ingress and egress processes preceded by the loss and dispersal of the bait and the arrival and retention of fish around the trap. Instead of relying upon several hundred observations of catch vs. soak-time, videos enabled the direct observation and analysis of relevant trap parameters. This is especially useful for calibration and assessment of new trap designs, but also offers much potential for estimation of density indices based on the timing of arrivals at bait stations or baited traps.

The density index used is most easily interpreted as an estimate of the arrival rate of fish at an unbaited trap at that location during any 2 minute interval of time. The model removes the feedback effect of fish in the trap (which are sources of high variance and bias), but still allows the use of baited traps so that a density index for a particular site can be quickly determined. However, the index is theoretically confounded by the parameters determining the area of influence of the bait plume - a large plume in a low density area is difficult to distinguish from a small plume in a high density area - and seasonality in responsiveness to bait. The estimation of a density index is most successful if each trap set provides observations over a wide range of bait fluxes. Ideally, the bait should be removed for some, relatively brief, period during each trap set - although it is not clear how this could be done.

Other studies have attempted to calibrate the effectiveness of traps with visual censuses (Ferry and Kohler 1987; Miller and Hunte 1987; Recksieck *et al.* 1991). In the context of this review of techniques suitable for the GBR, it is important to recognise that these studies were done in shallow reef environments on small mainly reef-restricted (Type A) families (eg. scarids,

acanthurids, holocentrids, balistids, chaetodontids) with unbaited traps relying on visual attraction to entice ingress.

Miller and Hunte (1987) intended that taxon-specific calibrations for 'effective area fished' might be used 'as a convenient but imprecise method for estimating absolute fish abundance'. That study, and subsequent work by Recksieck *et al.* (1991) estimated effective fishing area of traps (EFA, in m<sup>2</sup> trap haul<sup>-1</sup>) as follows:

$$EFA = \frac{\left(\frac{c}{f}\right)}{D}$$

where  $c/f$  = number of fish per trap haul and  $D$  (estimated from visual census) is the number of fish per m<sup>2</sup>. This equation is derived from Ricker's (1975) 'catchability' or 'vulnerability to fishing' equation

$$q = \frac{\left(\frac{c}{f}\right)}{N}$$

where  $q$  is the fraction of the stock taken by a single unit of effort,  $c/f$  is catch per unit effort, and  $N$  is stock size. Miller and Hunte's (1987) juxtaposition of units to produce EFA is **not** the 'actual area fished' by a trap (this would require 100% of fish be caught from inside the area, and none from outside), and EFA tells nothing about the distance or direction fish travel to enter a trap.

Estimation of effective fishing area is at best imprecise, because of the characteristic high variability in trap catches and the numerous difficulties associated with visual census counts of target species. EFA could not be estimated for the commercially important *Haemulon* spp. which are clumped in daytime aggregations and disperse at night to forage (Miller and Hunte 1987; Recksieck *et al.* 1991), nor for secretive reef-resident snappers and groupers (Recksieck *et al.* 1991).

Arena *et al.* (1994) adapted the 'swept area method' (*sensu* Alverson and Pereyra 1969) to trap characteristics in a theoretical evaluation of trap captures for stock enumeration, and propose

an attractive method for calculating real shapes of deep slope sampling strata from horizontal projections on charts. Their model assumes a circular shape in the area of influence of a trap. This approximation may be applicable for trap soaks of long duration which cover a complete tidal cycle in areas without persistent currents, but inaccurate estimates are likely to arise from soak times of shorter duration when the bait plume is certain to be more elliptical in shape. However, it is possible that further development of this model may allow for estimation of *relative* area fished.

It is worth briefly reviewing some important observations regarding the major factors believed to affect the effectiveness of traps, particularly as sampling devices.

#### **5.1.1. Bait Effects**

In some artisanal trap fisheries (particularly in the Caribbean) traps are typically set for long periods without baits. Several studies (High and Ellis 1973; Munro 1974; Stevenson and Stuart-Sharkey 1980; Newman 1990) have reported little difference in overall catch rate between baited and unbaited traps over very long soaks (in the order of days). The catches from baited and unbaited traps tended to converge with increasing soak-time due to the exhaustion of the bait. However, a significant difference in catch composition between baited and unbaited traps was noted by Newman (1990), with species of recreational and commercial significance being taken predominantly in the baited traps.

Oily, soft-fleshed baits such as pilchards and herring are clearly superior (4-5 times more effective) to white-fleshed baits such as *Lethrinus choerorhynchus* (Whitelaw *et al.* 1991) and octopus (High 1980) in terms of attractiveness, but not longevity. Whitelaw *et al.* (1991) reported that the white-flesh bait of *L. choerorhynchus* (when compared to pilchard bait) resulted in seventy-five percent fewer fish being caught. There is some evidence that this result may possibly be biased due to a tendency for *L. choerorhynchus* to avoid dead conspecifics, as this species comprised the bulk of the trap catch when pilchards were used.

Baits are located by olfaction in the depths fished for lethrinids, lutjanids and some serranids. The probability of arrival of a fish at the baited trap or hook is governed by the type and freshness of the bait, and the search pattern, appetite and response time of the fish. Seasonal, reproductive and lunar patterns of activity in the swimming speed, schooling behaviour and appetite of the fish presumably all affect this probability function. For example Miller (1983)

found that large decapods are more responsive to bait than small ones, males more than females, post-moult more than pre-moult, and hungry more than satiated. Current velocity can have a major effect on the extent of the bait plume, and Anon. (1990) reported that the probability of ingress increases by about 50% when the trap entrance faces down-current.

Lethrinids feed on the bait in traps and remain quiescent for periods, until feeding is triggered again by other fish. Lutjanids (especially *L. sebae*) eat for longer periods, and do so aggressively. In contrast serranids tend to ignore the bait and pursue trapped fish. In the case of serranids, there is some evidence to suggest that traps are essentially 'self baiting' (Munro 1974; Whitelaw *et al.* 1991).

Whitelaw *et al.* (1991) found that 50% of the pilchard bait was lost from 4 kg mesh bags in the first hour of soak, and all was gone by 4-5 hours on average. Moran and Jenke (1989) reported that 20-30 minute sets were best in the Shark Bay trap fishery for snapper (*Pagrus auratus*).

There is scope for improvements in design of bait containers as Sheaves (1995) demonstrated that containers with more, but smaller, holes retained bait and produced higher catches than rigid containers with large holes.

### **5.1.2. Behavioural Factors**

Various factors such as conspecific attraction, curiosity, inadvertent entry, the presence or absence of predators in traps, thigmotactic associations, and random movements can also determine whether fish actually enter traps (Munro *et al.* 1971; Munro 1974; Newman 1990).

Rates of ingress and egress have been shown to be markedly affected by these behavioural factors. Newman (1990) has shown that herbivores dominate the catches of unbaited traps in the absence of predators and has suggested that herbivores may be discouraged from entering baited traps due to the presence of predators. The presence of large serranid predators (Moran and Jenke 1989; Anon. 1990) and balistids (Ward 1988) have been shown to discourage many species of reef fish from entering traps. Additionally, conspecific attraction enhances ingress (High and Beardsley 1970; Munro 1974, Davies 1989). For example, the gregarious nature of lethrinids may lead to very large ingress rates but may also act to impede movement of individuals into a trap (Anon. 1990). Video observations also showed that fish learn an escape route by seeing other fish entering the trap. The size of the home range of individual species is

also believed to influence their responsiveness to traps. Hartsuijker and Nicholson (1981) considered that the presence of serranids in trap catches (and their size) was a function of the distance of the trap set from the reef.

The factors listed above can lead to gear saturation. Anon. (1990) found that weight of fish in a trap is the best measure of saturation, and a saturation parameter value of 13 kg caused a halving of the entry probability of a fish in the available pool around the trap. High and Beardsley (1970) reported that once 25 fish were inside a trap, the rate of ingress of other fish decreased abruptly.

Finally, the ability to escape varies markedly among taxa, with serranids (Anon. 1990) and snappers such as *Lutjanus griseus* (Luckhurst and Ward 1986) having high documented egress rates. This may be due to the different patterns of use of the topographically complex substrata of reefs for shelter and feeding. For example, serranids habitually squeeze into crevices and other openings in search of prey or ambush sites.

#### **5.1.3. Trap Design**

Trap shape, volume, mesh size, entrance dimensions and age have all been shown to affect the efficiency of traps and the size composition of trap catches (Harper and McClellan 1983; Bohnsack *et al.* 1988; Sutherland *et al.* 1991; Ward 1988; Collins 1990; Moran and Jenke 1990; Sheaves 1995).

Funnel alignment with respect to the prevailing current is an important factor in governing ingress and egress rates. Video observations have shown that fish move up-current to baited traps, and congregate on the downstream side of the trap - rarely above it (Anon. 1990; see also High and Ellis 1973). Once inside a trap, captives usually face up-current in the direction of the bait plume, whether actively feeding or resting.

#### 5.1.3.1. Entrance funnel characteristics

Anon. (1990) and Moran and Jenke (1990) found that fish entry and escape probabilities are closely correlated across trap designs, being relatively high for 'O' and 'S' designs and low for 'Z' traps. The North West Shelf 'O' trap, common to both studies, has a single slit entrance of a vertical dimension equal to the trap height, whilst the former study also examined Cuban 'S' traps (with similar, top to bottom slit entrances) and Caribbean 'Z' traps with 'horseneck' funnel entrances.

The superiority of having 2 entrances is shown by the 'S' trap data where 13% of the available fish around the trap entered every 2 minutes, but captives had a 57% chance of leaving within the first hour, compared with 38% for an 'O' trap and only a 14% chance for fish in 'Z' traps. Two entrances increase the likelihood that (i) one of the entrances will face into the current, thus enhancing the escape of up-current-swimming captives, and (ii) one entrance will face down-current, thus enhancing the entry of fishes swimming up-current into the bait plume.

The hourly rate of egress from Z traps from the NW shelf (Whitelaw *et. al.* 1991) was considerably greater than that reported by Munro (1974) in the Caribbean, possibly because the early studies were unable to observe the high turnover of fish in traps witnessed by Whitelaw *et. al.* (1991) in video recordings. At soak times more than 4 hours, 'Z' trap catches are higher than 'S' and 'O' traps, whilst 'S' traps caught more fish than 'Z' traps in shorter soaks because they reach a peak in catch rate at much shorter time (Whitelaw *et. al.* 1991). The modified NW style 'O' trap used by Newman and Williams (1995) and Williams *et. al.* (1995) has two entrance funnels, increasing the probability of one entrance facing down-current. Additionally, the smaller (25 x 10 cm) modified funnel entrance used by Newman and Williams (1995) and Williams *et al.* (1995) was considered to decrease the egress of trapped fish, while maintaining some of the characteristically high rates of ingress of fish to the NW Shelf trap. It was not determined if these dimensions prevented entry of fish with body depths greater than 25 cm.

In general terms, the North West Shelf study (Anon. 1990) found that the probability of entry to fish traps was related to the ratio of entrance(s) area to the total surface area of the trap sides. Escapement was proportional to the size of the entrance and inversely proportional to trap volume - the latter partly because of saturation effects. They recommended that large traps should be soaked for long periods to avoid saturation effects limiting the catch at an early stage

and thus wasting much of the soak period. Sheaves (1995) compared the performance of different trap volumes in tropical estuaries and found significant advantages with larger traps for only one species (*Lutjanus russelli*) amongst the serranids, sparids and lutjanids caught.

Funnel design affects the way in which trap catches build up over time (Luckhurst and Ward 1986; Grove-Jones and Burnell 1990), and horseneck funnels have reduced rates of entry and escape when compared to straight funnels. Hartsuijker and Nicholson (1981) found evidence for an accumulation of larger fish sizes in traps over long soaks, and suggested that larger fish have greater difficulty in escaping through the horseneck funnel. Sheaves (1995) reported that significantly higher catch rates occurred in traps with straight, conical entrances during short (2 hr) trap soaks than during long (1.5 day) soaks, while trap catches with horseneck entrance funnels did not differ significantly between the two soak times. In contrast, an analysis of the effects of varying the internal dimensions of horseneck funnels by about 30%, by Brown (unpublished data), found no significant difference in either the length composition of the catch or the catch rate in twin-funnel, wire-mesh, box traps fished on the southern GBR.

#### 5.1.3.2. Mesh selection

A number of studies have compared catch rates and size composition of numerous mesh sizes ranging from 1.3 x 1.3 cm to 7.6 x 15.2 cm (Harper and McClellan 1983; Bohnsack *et al.* 1988; Ward 1988; Sutherland *et al.* 1991; Moran and Jenke 1990; Sheaves 1995). While Hartsuijker and Nicholson (1981) suggested that selection by mesh size is not of prime importance in the selectivity of fish traps due to the high escapement through funnels, Bohnsack *et al.* (1988) found that traps with intermediate mesh sizes (4 cm hexagonal) caught significantly more fish, both by number and weight, than did those with smaller or larger mesh sizes. These authors also conducted laboratory escapement experiments from which they developed relationships between mesh shape and size and individual retention rate for lutjanids, serranids, carangids, sparids and acanthurids, and concluded that catchability was greatly affected by mesh size.

Body shape is an important factor in determining retention of species by different mesh sizes. Sutherland *et al.* (1991) considered that escape through a particular square mesh was least likely for laterally compressed species (eg. chaetodonts) more likely for fusiform (lutjanid) body shapes, and most likely for terete forms such as eels. In their escapement trials, Moran and Jenke (1990) found that laterally compressed lutjanids and lethrinids were able to escape



through 15 x 5 cm mesh, whereas wide-bodied serranids were not. They concluded, however, that the efficiency of different mesh sizes is independent of simple retention models. Newman and Williams (1995) also concluded that mesh selectivity in fish traps was not a simple function of the ability of a given mesh aperture to retain individuals of a certain body depth, and suggested that the behaviour and activity patterns of reef fish in response to the visual outline of the traps was of major importance in determining the mesh selectivity of fish traps.

These studies have often been inconclusive for some mesh dimensions because of low sample sizes, inherent variability in trap catch data (Sutherland *et al.* 1991) or (as pointed out by Moran and Jenke 1990) the relative scarcity of fish of a large enough size to be retained by the larger meshes used in some shallow water studies.

#### 5.1.4. Visual cues

Although they did not test for such a factor, Moran and Jenke (1990) found a close positive relationship between catch per haul and the inverse of the area of the mesh. This was an index of the 'closeness' of the mesh, and was implicated in the surprisingly low efficiency of large-mesh (10 x 10 cm, 15 x 5 cm) traps for the fishes they caught best (*L. nebulosus*, *L. sebae*, *E. multinotatus*). The trap entrance was less visible to the fish against the more open background of the large mesh, and finding a 10 cm-wide entrance into a trap of 10 cm x 10 cm mesh may be very difficult. Luckhurst and Ward (1986) and Newman and Williams (1995) also suggested that the stronger visual image presented by small mesh traps allowed fish to better perceive the funnel opening and increase the rates of egress of trapped fish. Additionally, small mesh funnels in large mesh traps also offer a strong visual image and may enhance escapement.

Although fish are attracted to baited traps by olfactory cues, upon arrival the visual impact of a trap may influence the rate of ingress of target species and hence calculations of the area fished. After the bait has been exhausted, the fishing power of traps relies on visual attributes such as the ability to retain small fishes, eg. as prey for serranids ('self-baiting'), and conspecific attraction, as well as the ability of the trap to reduce egress of fish already trapped. Anon. (1990) observed that fish spent an average of only 12 minutes around a trap before leaving. It was not possible to determine whether such fish returned. Funnel entrances and designs that aid the rate of ingress of fish will affect the magnitude of trap catches.

Apart from the rotating 'O' trap developed by CSIRO during the North West shelf study, there is little evidence in the literature of significant technical advances in trap design which might enhance the ingress of fish while simultaneously inhibiting egress or escapement. Devices such as pigeon-bars and flexible 'finger arrays', which fold away when a fish enters through them then spring back to point inward and block egress, have a number of intuitive advantages but have not been tested against conventional designs. It appears that surprisingly little technical improvements have been made to the traditional trap designs, and this will benefit from some technical input.

#### **5.1.5. Comparison of trap catch statistics between studies**

Comparative catch rates of different trap designs, baited trapping methods and regions are shown in Table 3. Catch rates tend to be reported in terms of kilograms per unit time, rather than in fish numbers, which makes for difficult comparisons with trapping done within the GBR and amongst regions. The North West Shelf catch rates are in the same order of magnitude as some of those reported by Wolf and Chislett (1974) for snapper, grouper and jacks in Jamaican waters, but catch rates in both of the GBR studies were about an order of magnitude lower. Trap catches in the Townsville region (as reported by Williams *et al.* 1995) were similar to those for the Capricorn-Bunker Group (Brown, unpublished), which were lower than those from the Swain Reefs that are less heavily fished.

To gauge the precision of trap studies, mean catch rates and associated coefficients of variation, either reported or reconstructed, are shown in Tables 4, 5 and 6. There is a surprising lack of information about the variance of catch rates in the trapping literature, so our comparison is limited to the three Australian studies.

Whitelaw *et al.* (1991) did not provide coefficients of variation for their trap catches on the NW Shelf but we were able to derive approximations by back-calculating standard deviations from the published 95% confidence limits and associated sample sizes (Table 4). CVs of catch rates in these studies were consistently less than those from the central GBR, ranging from approximately 0.4 to 1.4, with a mean of 0.76. There are a number of possible explanations, the most likely of which is related to the much higher catch rates referred to earlier. A major conclusion of Williams *et al.* (1995) was that CVs were negatively related to catch rates. Differences in catch rates between the two studies may be due to the NW Shelf study being

based on normal commercial fishing activities with an experienced fisherman, while the central GBR studies were carried out by scientists with a broader agenda than maximising catch rates.

**Table 4.** Calculation of estimated coefficients of variation (CV) from means (kg trap<sup>-1</sup> haul<sup>-1</sup>) and 95% confidence intervals (CI) given by Whitelaw *et al.* (1991) for North West Shelf 'O' trap studies.

Zone	Soak times	1 hr	2 hr	3 hr	6 hr	9 hr	24 hr
Outer 20 m	n	47	34	36	15	8	16
	mean	7.91	12.19	13.89	13.18	16.61	7.01
	95% CI	4.5-10.8	9.4-15.4	10-18.5	9.6-17.3	12-22	4.4-10.2
	<b>*estimated CV</b>	<b>1.16</b>	<b>0.71</b>	<b>0.89</b>	<b>0.53</b>	<b>0.37</b>	<b>0.78</b>
Inner 7-10 m	n	18	10	15	1	8	3
	mean	4.41	7.03	6.05	9	16.23	2.79
	95% CI	1.9-8.0	4.8-0.6	2.9-10.3	-	10-23.9	0.1-9.4
	<b>*estimated CV</b>	<b>1.40</b>	<b>0.48</b>	<b>1.11</b>	<b>-</b>	<b>0.53</b>	<b>0.91</b>

\* CV = SD/mean, where SD = 0.5 (Upper CL - Lower CL). $\sqrt{t_{0.05}(2),n}$

It is also possible that fish densities were much less on the reefs studied in the central GBR. Rib, John Brewer and Lodestone reefs are all close to Townsville, a major population centre, and suffer considerable fishing pressure. In fact Williams *et al.* (1995) reported much higher trap catches on two outer shelf reefs protected from fishing. Catch rates on these reefs were an order of magnitude higher than the other reefs, and on Dip Reef the daytime catch rates of *Lethrinus miniatus* had a CV of 0.71, very similar to the mean value in the North West Shelf study. Since the statistical power of trap sampling is inversely related to the square of the CV, fish traps may yet prove to be a useful monitoring tool in areas of relatively high fish density.

Williams *et al.* (1995) found significant day/night, day to day and habitat differences in catch rates of snappers and lethrinids on Rib, John Brewer and Lodestone reefs in the central GBR. Their data were characterised by a dominance of zero catches, low means, high variances and a correlation between mean catch rates (in terms of fish numbers) and standard deviations. They demonstrated that given the correlation between mean catch rates and their standard deviations (SD), the statistical power to detect a specified change in catch rate was closely related to the CV (SD/mean) of the sample.

Estimates of CV ranged from 1.1 and 3.8, although the great majority were between 1.2 and 2.6 (Table 5). With CVs of 1.2-2.6 and a logistic limit of 12 traps per set, Williams *et al.* (1995) concluded that despite a demonstrated ability to determine differences in distributions of fish over several spatial scales - within-reef, among reefs and cross-shelf - and growth and age structures among reefs, their fish traps were not a suitable method for monitoring changes in catch rates of the target species on the reefs examined (Newman *et al.*, submitted a; submitted b). For example, they calculated that between 7 and 25 days of sampling would be required to detect a 50% decrease in catch rates ( $a = 0.05$ ,  $b = 0.10$ ).

**Table 5.** Coefficients of Variation (CV) and mean catch rates (number of fish trap<sup>-1</sup> haul<sup>-1</sup>) by reef and habitat (Habitat 2 on each reef was sampled on two different occasions) for small lutjanids and lethrinids at two reefs in the central section of the Great Barrier Reef. From Williams *et al.* (1995)<sup>1</sup>.

Taxon\ Habitat		RIB REEF			DAVIES REEF		
		H1	H2t <sub>1</sub>	H2t <sub>2</sub>	H1	H2t <sub>1</sub>	H2t <sub>2</sub>
<i>Lutjanus adetii</i>	CV	2.59	1.63	3.77	-	-	-
	mean	2.93	7.87	4.52			
<i>L. quinquelineatus</i>	CV	1.93	1.24	1.22	1.55	1.86	2.06
	mean	0.27	2.37	1.75	0.83	1.40	0.94
<i>L. russelli</i>	CV	2.40	1.63	1.56	-	-	-
	mean	0.20	0.80	0.73			
<i>L. sebae</i>	CV	2.40	1.25	2.00	-	-	-
	mean	0.20	0.67	0.31			
All <i>Lutjanus</i> spp.	CV	2.07	1.10	2.46	1.47	1.47	1.62
	mean	3.70	11.97	7.63	1.17	2.23	1.75
<i>Lethrinus</i> sp.2	CV	2.63	2.21	3.18	-	-	-
	mean	0.30	1.00	0.38			
<i>L. semicinctus</i>	CV	-	-	-	2.61	1.47	2.55
	mean				0.90	0.87	1.85

<sup>1</sup> Depths fished were 40-45 m. H1 = flat bottom habitat; H2 = broken bottom habitat.

This level of replication may not be attainable given the number of traps that can be carried on a vessel, deployment and handling times, and the amount of suitable habitat on a reef in which traps can be placed  $\geq 100$  m apart to avoid interference during fishing. The serial depletion caused by this level of sampling may result in a major decline in population size, independent of any other source of change that is being looked for in a monitoring program (see section 6).

Similar levels of variability were found by Brown (unpublished.) in the southern GBR area using different traps. Coefficients of Variation ranged from 0.45 in an extended soak (95 hr) set to 2.99 in a deep-water set using box traps with reduced internal funnel dimensions (Table 6).

**Table 6.** Mean catch rates (numbers of fish trap<sup>-1</sup> haul<sup>-1</sup>) and associated CVs (coefficients of variation) for box<sup>a</sup> and soft<sup>b</sup> traps deployed on the southern Great Barrier Reef (Brown, unpublished data).

Area/comparison	Number of traps set	Mean catch rate no. lift <sup>-1</sup>	CV
<b>Capricorn-Bunkers</b>			
Large funnel			
<31 m	21	3.76	1.65
>31 m	9	0.00	--
Small funnel			
<31 m	21	3.95	1.81
>31 m	9	1.65	2.99
Short soak	8	3.62	2.01
Long soak	4	9.75	0.45
<b>Swain Reefs</b>			
22-140 (box)	12	13.67	1.58
(soft)	11	3.45	1.76
22-140 (box)	11	7.27	1.81
(soft)	11	2.55	1.18
22-140 (box)	10	3.70	1.51
(soft)	9	0.78	1.54
<b>Banana Cay</b>			
35 m (box)	12	1.891	0.71
(soft)	12	5.58	1.40
35 m (box)	12	14.33	0.87
(soft)	11	5.73	1.32
25 m (box)	12	6.17	1.39
(soft)	11	2.55	0.69
25 m (box)	12	8.33	0.88
(soft)	11	5.91	1.25

<sup>a</sup> Box trap: Rigid, 2-entrance, chicken-wire covered; 1830 x 630 x 890 mm

<sup>b</sup> Soft trap: Collapsible, 2-entrance, covered with cod-end webbing; cylindrical 1 x 0.8 m.

## 5.2. Trawling

The 'swept area method' has been widely used in fish trawling surveys to estimate absolute densities of fishes in major industrial fisheries for groundfish (eg. Alverson and Pereyra 1969). There is a need to evaluate the potential of this method as a sampling technique for inter-reef areas of the Great Barrier Reef, as lutjanids, lethrinids and serranids have been commercially exploited by fish trawling in other waters of northern Australia for many years (Sainsbury *et al.* 1992; Moran *et al.* in press; Ramm and Xiao in press). Apart from sampling biases discussed below, major considerations include the effects on benthos, and bycatch, in trawling and the restrictions on its use in different zones of the GBR marine park. A large amount of recent research by three Australian research agencies has been devoted to development of trawl efficiency devices to reduce these effects (Brewer *et al.* in press).

In the simplest case, the swept area method divides the trawl catch by the area of the trawl path to estimate density. Although the length of the trawl path can be accurately measured, the effective path width of the trawl is generally unknown and is commonly assumed to be the net width or the door spread. These parameters can be measured by underwater observation using netsonde equipment. The behavioural interactions of the fish with the trawl gear has been far more difficult to assess and it is now known that herding of some groundfish by the bridles, sweeps and doors of a fish trawl can result in notorious over-estimates of fish density when the traditional estimates of path width are used. These parts of the trawl apparatus stimulate fish directly and through the disturbance of sediments with subsequent plumes. Fish may swim into the path of the net (herding) or away from it.

Ramm and Xiao (in press) developed a model relating fish catch to net width and door spread that allowed estimation of effective herding distance, catch due to the net, catch due to herding, and effective path width. This model significantly improves the swept-area method by making no essential assumptions about constant swimming speeds and homogeneous spatial aggregations of fish. They did, however, assume that all fish at the centreline of the net were captured and that escapement over the headrope height of 2.9 m was minimal. This was not observed directly, but was inferred mainly from the failure to detect a significant difference in catch of species of interest (particularly *L. malabaricus*) with an increase in headrope height of 2.9 to 4.5 metres. The influence of the trawl warps was not considered.

Research trawls were made with three configurations of a Frank and Bryce demersal fish trawl to collect data for the model. This design has the net headrope and footrope joined to the sweeps by bridles. The sweeps are joined to large doors that act as paravanes to open the net. The doors are towed from trawl warps. The study trawl had a headrope length of 26 m and the three configurations consisted of : the net with 30 m bridles and no sweeps (FB30); the net with 30 m bridles and 30 m sweeps (FB60); and the net with 30 m bridles and 90 m sweeps (FB120). Netsonde observations showed that door spread was significantly different with means of 42.3 m for FB30, 60.1 m for FB60 and 80.6 m for FB120. The net width varied slightly from 13.7 m to 15.6 m with these configurations.

There was no significant correlation with door spread for catches of *Lutjanus sebae*, *L. erythropterus*, *L. johnii*, *L. vitta*, *L. lutjanus*, *Lethrinus lentjan* and *Carangoides chrysophrys*. There was sufficient data for reliable estimation of herding parameters only for *Lutjanus malabaricus*. The FB60 trawl configuration had been used in recent biomass surveys of this species in the study area and the effective path width estimated for this configuration in the model was 35.64 m with a door spread of 60 m and a net width of about 15 m. Ramm and Xiao (in press) concluded that previous biomass estimates, using net width as effective path width in the swept area method, could have led to the collapse of the *L. malabaricus* fishery.

Ramm *et al.* (1993) developed a semi-pelagic trawl to reduce bycatch and seabed damage, and increase catch quality, in the fledgling north Australian Finfish Trawl Fishery. The 'Julie Anne' trawl had the footrope set at a minimum of 30 cm above the seabed and opened to a height of 10 m. It was compared with a standard bottom-fish 'Paulegro' trawl rigged with bobbins to roll across the sea-bed, and opening to a height of 4-5 m.

Catches of *Lutjanus sebae* were significantly less in the semi-pelagic trawl, but catches of other snappers were not significantly different between the two trawls - despite the catch rate ratios of Julie Anne to Paulegro of 293:192 for *L. malabaricus*, 27.3:22.2 for *L. erythropterus*; 10.5:2.5 for *L. johnii*, and 1.7:4.0 for *L. vittus*. The footchains of the Julie Anne trawl did make contact with the seabed during trawls, and there were other subtle differences in snapper catch composition. For example, *L. russelli* was 1-3 cm larger in the Julie Anne trawl and *L. malabaricus* was 2 cm larger in the Paulegro.

Most relevant to this review, Ramm *et al.* (1993) report that the fork rigging of the semi-pelagic trawl can be adjusted to bring the footrope up to any height to avoid substrata

dominated by large sponges and dense benthos, but few lutjanids were taken when the footrope was rigged to fish at a height of 1 m or more above the seabed. This is a further consideration to the usual concerns over trawl hook-ups over reef habitats. Raising the footrope may prevent hook-ups, but catch may be compromised.

Brewer *et al.* (in press) found in subsequent tests that the geometry of the Julie Anne trawl was sensitive to changes in towing conditions, including towing speed, water depth and length of warp. The trawl required constant monitoring and adjustment and took longer to deploy and retrieve. An alternative semi-pelagic trawl was designed (the 'McKenna wing trawl') and fished by Brewer *et al.* (in press) on the seabed and semi-pelagically, with the ground-rope removed and the footrope set at 0.4 - 0.5 m and then 0.8 - 0.9 m above the seabed. The handling problems of the fork-rigged Julie Anne trawl were overcome by using the sweep and bridle configuration used in most demersal operations. However, the sweeps, the large otterboards (1000 kg) needed to generate large wingend spreads, and the 10 - 40 kg weights suspended from the footrope, still contacted the seabed and their effects on benthos was not measured.

The two target species, *Lutjanus malabaricus* and *L. erythropterus* showed no significant differences in catches amongst the trawl types, but did appear to be caught in greater abundance in the trawl fished at 0.4 - 0.5 m above the seabed. There was great variability amongst catches - occurrence in trawl catches was only 17% for *L. erythropterus* and 33% for *L. malabaricus* - and the higher apparent catches at 0.4 - 0.5 m arose from inflation of the mean by one or two catches, perhaps as schools were encountered. Catches of *Lutjanus argentimaculatus*, *L. russelli* and *L. sebae* were essentially the same in the demersal and semi-pelagic trawls, but mean catches of *Lethrinus laticaudis* and *L. lentjan* were higher in the demersal trawl.

Moran *et al.* (in press) were concerned that the studies of Ramm *et al.* (1993) and Sainsbury *et al.* (in press) did not include any measurement of the effect of sweeps on macrobenthos, and therefore their statements about the comparative reduction in bycatch of benthos should be carefully considered to apply to the net only. Consequently, Moran *et al.* (in press) examined the effects of benthos of a well-tuned semi-pelagic net (similar to the Julie Anne trawl), including effects of the sweeps, and to study the effects of tuning the net on catches of fish and benthos in north-west Australia. Unlike the previous studies reported here, the semi-pelagic trawl caught fish well when it was fished hard on the seabed and poorly when fished above it on the NW Shelf. There was a strong positive correlation between numbers of benthos and fish



caught. Moran *et al.* (in press) attribute this in part to an inability to target schools of *L. malabaricus* and *L. erythropterus* under the sampling design on the NW Shelf, unlike the operations in the Arafura Sea where the Julie Anne trawl was originally tried. However, Brewer *et al.* (in press) stated that they did not target schools either during semi-pelagic trawl trials and there are probably distinct differences in the distribution and abundance of the 'red snappers' across their Australian range.

Mesh selectivity in trawl nets has been studied mainly by counting and measuring fish which have escaped through the net into a cod-end cover or bags made from small mesh placed on the outside of the trawl net. In this way Liu *et al.* (1985) calculated mesh selectivity for many of the species taken by the Taiwanese pair-trawl fishery on the NW Shelf. Moran *et al.* (in press) used a more comprehensive approach that measures overall efficiency of a trawl, combining the effects of mesh selection and herding by the sweeps. This involved trawling repeatedly over the same area and recording the numbers and sizes of fish in the first, second, third and fourth trawl passes. For fish larger than 35 cm the proportion of individuals in the area caught by a single pass was around 0.6. For the 26-35 cm group, which was the most abundant, the proportion fell to 0.3, while for fish smaller than 26 cm the proportion was less than 0.1. The fishery implications of this are that large serranids, lutjanids and lethrinids are subject, if fishing is random, to double the fishing mortality of smaller species. In terms of sampling efficiency, this could severely underestimate natural mortality based on relative abundance of age classes if catch curves are used and sampling is not intensive.

We believe there will be a role for semi-pelagic trawls for sampling lutjanids and lethrinids in some inter-reef habitats, especially in combination with headrope-mounted cameras or netsonde to monitor escapement. A Frank and Bryce fish trawl has been used in the northern waters of the GBR to compare fish catches in prawn and fish trawls, inside and outside areas closed to trawling, and between day and night (Blaber *et al.* 1994). All these factors produced significant differences, but lutjanids, lethrinids and serranids were not in the top 17 species in terms of weight caught per hour of trawl. This may not reflect their overall abundance, as other top predators were caught in high abundance. For example, cobia *Rachycentron canadum* (15.1 kg hr<sup>-1</sup>) and Painted sweetlip *Diagramma pictum* (12.7 kg hr<sup>-1</sup>) were caught in greater abundance than *Lutjanus sebae* (2.1 kg hr<sup>-1</sup>), *L. malabaricus* (2.1 kg hr<sup>-1</sup>) and *Lethrinus nebulosus* (1.9 kg hr<sup>-1</sup>). These catch rates could, no doubt, be improved greatly by trawling in a sampling design with stratification based on habitats empirically determined to be suitable habitat for

target species. There were also significant differences in the nature of catches made during day and night, with *L. sebae* caught only during the day in the Frank and Bryce fish trawl.

Net design is of profound importance, and the fish catch in records of GBR prawn trawlers must be used cautiously to make wider inferences, as Blaber *et al.* (1994) reported that prawn trawls rarely caught any of the important commercial or angling species, all of which were caught in the same area by a Frank and Bryce fish trawl. Large fish of all taxa were less often caught in the prawn trawl than in the fish trawl, and large mackerels (*Scomberomorus* spp.) and carangids were only caught in the fish trawl.

### 5.3. Hook And Line Methods

Hook and line fishing represents one of the oldest methods of capturing fish, and is arguably one of the most cost-effective in terms of the gear used. The method is used widely in tropical and sub-tropical fisheries, particularly those based on high-level predators living in close association with hard substrata. It is the primary method used in both the recreational and commercial fisheries on the Great Barrier Reef and the various methods are well described by Higgs (1993), Williams and Russ (1994) and Davies (1995). Handline, demersal longline and drop-line fishing are the main fishing methods that offer potential for stock enumeration by inference from catch rates.

In the GBR handline fishery commercial fishing units or 'dories' are usually 4-5 m in length and are highly mobile. During morning and afternoon sessions many stops to anchor or drift are made for about 10-30 minutes, depending on catch rates, and these are called 'hangs'. Commonly an 80 lb (36 kg) handline is used with a single 8/0 or 9/0 hook below a light running sinker. A single WA pilchard is used for bait. This has been termed 'tinny' fishing by Williams and Russ (1994) because of the widespread use of alloy hulls and outboard motors.

Sampling in this manner has several important advantages over UVC. It is possible to sample over the entire depth range of the resource, a large proportion of the reef area can be sampled and, with the use of skilled professional fisherman, total sample sizes are usually large for each reef. A fleet of mobile fishing units are inexpensive to operate, and therefore capable of quick replication of sampling to increase precision levels. It is also possible to obtain specimens for determination of the age and sex structure, and feeding and spawning habits, of the population.

There are several major sources of variation and gear selectivity that must be considered or studied to optimise the use of this sampling technique. In particular, the action of baits, on hooks as well as in traps, is a complex process, and is poorly understood. Most studies have inferred capture dynamics from examination of the catch and underwater observations are lacking. These observations have often been surprising. For example, High (1980) monitored the action of a baited halibut longline from a submersible, and found that a considerable number of fish became hooked on bare hooks that had previously lost their baits. The 'berley effect' (Section 5.1.1) and behavioural effects (Section 5.1.2) operate when fish attack baits, and therefore the early success or failure of a baited hook to attract a strike may govern whether or not nearby fish are excited into striking - leading to an uncontrollable source of 'nuisance' variation in analysis of variance in catches.

One factor that has received insufficient attention is uncoupling of CPUE and abundance at high densities through gear saturation and handling time. In essence, CPUE using 'tinny' fishing has a ceiling beyond which even the most skilled operators cannot pass, as the time taken to bait the single hook, sink the line, and retrieve and unhook the fish is finite. Differences in this 'handling time' can be marked and constitute a large part of the variation attributed to operator skill. This problem will be worst for schooling species, such as *Lethrinus miniatus* and the three 'red snappers', where maximum, constant catch rates could be sustained during fishing sessions above schools of widely varying size, yet CPUE would not vary significantly. There is scope for much more experimental work and empirical observation to determine handling times and gear saturation for 'tinny' fishing as a sampling tool. Where possible, professional operators should be used to do the fishing and fishing teams should be kept consistent in both membership and technique. Professional dorymen handlined about ten times as many coral trout as a similar number of anglers in the pulse of fishing after the re-opening of Bramble reef to fishing (Anon., 1995). However, care must be taken to ensure that professional operators allocate similar effort and efficiency to 'hangs' in sampling strata known or suspected by them to have poor fishing, as by nature they seek areas of high catch rates in which to operate.

Another serious consideration for GBR sampling using this technique is the weather and its effect on sea state (Richards and Schnute 1986). The prevailing trade winds can often make exposed reef faces unfishable, or reduce the efficiency there and raise the handling time for operators. This would lead to missed samples and unbalanced sampling designs. 'Tinny' fishing is only done during the day and may not adequately sample some nocturnal species. There is also potential for hook selectivity at both ends of the size range - small fish cannot

accommodate the gape of large hooks and large fish can tear free, or snag and break lines (Ralston 1982; 1990). Such gear selectivity will bias age estimates and mortality rates. In the case of coral trout, there is excellent opportunity for UVC to estimate fish size in comparison with handline catches made in the same area, and for spearfishing to be conducted in concert with handline fishing to estimate vulnerability of different size classes to handline gear.

The most serious disadvantage of handline fishing is variation in vulnerability, or 'catchability', over space, time and stock density, resulting in CPUE not being directly proportional to abundance (Davies 1995).

In an attempt to estimate the vulnerability of coral trout on a 'closed' reef, Beinssen (1989) used a combination of UVC, 'tinny' fishing and a tagging program to examine depletion of the population after the reef was opened to fishing. One of the most interesting and relevant findings from this study was the tendency for coral trout to become progressively harder to catch at densities below about 20 fish ha<sup>-1</sup>. This phenomenon, which Beinssen (1989) referred to as 'hook-shyness' invalidated the use of the Leslie method (a regression of cumulative catch on CPUE, where the x intercept = population size of fully recruited fish) to estimate population size. The author had to rely upon (higher) population estimates from tag recoveries (see section 6.1). Beinssen (1989) estimated that 25% of the Boulton Reef population was caught during the first 14 days after the reef (which had previously been closed to fishing) was opened, and that only 25% remained 18 months after opening. The point of inflection in catchability at 20 coral trout.ha<sup>-1</sup> was believed to be due to feeding and non-feeding phases in coral trout behaviour, which seems reasonable in view of the fact that speared coral trout generally have more stomach contents than line-caught fish (J. St John JCUNQ, pers. comm.).

Tagging studies have shown that coral trout are relatively sedentary, at least at the level of a 'home' reef (Davies 1995), and depletion-based estimates of lethrinid and lutjanid population sizes may be even more challenging if movement amongst reefs is widespread.

Davies (1995) presented detailed information from carefully standardised handline fishing on the species composition, CPUE and size distribution within catches from five mid-shelf reefs in the northern section of the GBR over a period of approximately 2 years. The objective was to identify the major sources of spatial and temporal variation in both species composition of the catch, and CPUE and size of coral trout from line fishing. The perimeter of each reef was divided into a series of blocks and teams of dories were assigned to fish a block in four hour

sessions by dividing effort between shallow (1-5 m) and deep (25-30 m) 'hangs'. It was decided to stratify effort according to tide state in order to maximise CPUE and reduce variation due to poor catches in the 'run off' tide. CPUE data were analysed using a 'hang' by a dory as a replicate with units of line hours as time passed between setting and retrieving the anchor. The effects of trip, block and reef on mean CPUE of *Plectropomus leopardus* were tested.

The general pattern of species composition among reefs and trips was similar, with *P. leopardus* dominant on all reefs, but there were significant effects of trip, possibly due to high September-October catches of *P. leopardus*, and reef. There was also a significant effect of block, and a significant interaction between block and trip, for the length composition and CPUE of *P. leopardus* catches. These patterns probably related to the aggregation of *P. leopardus* to spawn in particular blocks and an increased feeding activity at this time. Effects of depth of 'hang' were not tested for, but there was evidence that efficiency of fishing varied amongst reef habitats, and that the fishing teams learned how to raise their efficiency on steep reef fronts between trips. Other interesting patterns were observed in the relative CPUE of serranids, lutjanids and lethrinids, particularly *Cephalopholis cyanostigma* and *P. leopardus*, but Davies (1995) stressed that additional information on the dynamics of capture and independent estimates of abundance are required to determine if the relative abundance of other species influences the 'catchability' of primary and secondary target species of handline fisheries.

The significant effects in this study highlight the need to stratify sampling programmes amongst tidal state, lunar cycle and season, as well as front/back of reefs and deep/shallow, to remove a large part of the variation in estimates of relative abundance. The effects of block, and the interaction between block and trip, implies that samples taken from different locations within a reef at different times may provide significantly different estimates of mean size and size structure, even when there has been no overall change in these parameters for the population on a reef. Again, this emphasises the need for stratification of sampling within reefs.

The tests presented by Davies (1995) give some summaries of an extensive data set. That thesis has only recently been accepted and manuscripts are currently in preparation. Therefore, it would be inappropriate to construct further summaries here of mean catch rates and their associated CVs. This study will provide definitive bounds to the power and precision of 'tinny' fishing as a sampling tool, in a similar way that Williams *et al.* (1995) did for fish traps.

Sundberg and Richards (1984) reported data on catch rates in deep-water fishing operations in three widely-separated localities on outer reef slopes in Papua New Guinea. The mean catch rates (in kg.line-hr<sup>-1</sup>) were 3.99 (Port Moresby, n=7), 2.50 (Milne Bay, n=4), and 4.55 (Manus Is, n=4). The trials were not able to detect significant differences in means between areas, time of day, or depth fished, most probably because of lack of sufficient replication. The coefficients of variation estimated from the means and confidence intervals presented in Sundberg and Richards' (1984) Table 1 are 0.56, 0.19, and 0.24. The overall (pooled) CV was 0.42.

Results of preliminary analysis of line-fishing operations at three locations in the southern GBR (Brown, unpublished data) are shown in Table 7. In this study the fishing sessions involved one or two fishers operating from a small tender vessel or runabout, either at anchor or drifting (depending on wind and current conditions) over relatively shallow reef-slope and bommie-field habitats, and using simple handline apparatus with a single or twin-hook terminal rig baited with WA pilchard. Sessions ranged in duration from about 30 min to 4 hours, and CPUE figures are presented in terms of numbers of fish per hook-hour. The catch rates, pooled across habitats within areas, ranged from 2.69 at Maori and Gibson Reefs (presumably heavily-fished inner shelf reefs midway between Innisfail and Cairns) to 6.33 in the Capricorn-Bunker Group off Gladstone. The associated coefficients of variation (range: 0.47-0.77) were somewhat greater than those reported by Sundberg and Richards (1984) for the deeper-water habitat in PNG, possibly because of the greater complexity of habitat in the shallow reef areas and consequently more heterogeneous distribution of fish.

Other hook-and-line sampling techniques for reef fishes include drop-lines (Williams *et al.* 1994), bottom-set longlines (Anon. 1982), and trotlines with 'kali' poles (Matlock *et al.* 1991). Hook-selectivity is a major factor and the Sri Lankan BOBP study found that hooks with wide gape caught approximately 1.8 times as many fish as standard, long-shank longline hooks. Kulbicki (1988b) reported that nylon snoods caught better than wire trace, and that larger longline hooks caught larger fish on average than those caught by handline or observed by UVC. Both the CPUE, and the average size of fish caught increased with depth to 35 m in the southwest lagoon of New Caledonia. Serranids and lutjanids were caught mainly near the barrier reef or in coralline areas, whereas lethrinids were usually found over coarse sand.

**Table 7.** Catch rates of lutjanids, serranids and lethrinids from handlining operations on the GBR (Brown, unpublished data). Note that the catch (untransformed numbers of fish) per hook-hr is the mean of the  $n$  individual session CPUEs.

Location	Catch (no.)	Sessions	Catch per session	Total hook-hrs.	Catch per hook-hr	CV
Capricorn-Bunker Group	106	7	15.14	25.8	6.33	0.68
Capricorn-Bunker Group	133	5	26.60	25.8	5.51	0.77
Maori & Gibson Reefs	128	11	11.64	50.6	2.69	0.47
Gable Reef	302	18	16.78	78.0	4.37	0.63

Like the trap dynamics discussed earlier, we believe that the operation of baited hooks on lines requires further empirical observation by underwater video to calibrate the technique as a sampling tool. For example, drop-line catches were very low in Williams *et al.* (1995) study, but bait loss (presumably by pickers not vulnerable to the hook sizes used) was very rapid, and the effective fishing effort may have been reduced to several minutes in some cases. With five tuna-circle hooks per dropline and three sets of a fleet of six droplines equating to 13.5 line hours, the maximum catch was 11 fish. This represented  $0.8 \text{ fish.line-hr}^{-1}$ ; in other operations the catch rate was as low as  $0.12 \text{ fish.line-hr}^{-1}$ .

## 6. PROBLEMS WITH CAPTURE METHODS AND CATCH AND RELEASE

To attain sufficient power to detect change, extractive techniques will need to capture large numbers of fish to overcome their lack of precision. The effects of such extractive sampling on lutjanids, lethrinids and serranids may cause significant localised depletion itself, independent of any other influence, and despite catch-and-release being employed. This would be a serious problem in repeated sampling on reefs and isolated pinnacles for species which show strong site-fidelity and attain advanced ages (Newman *et al.* submitted c; Davies 1995). Recent revision of age and growth curves for the serranids, lethrinids and lutjanids have generally shown these fishes to attain ages of 20 years, or more, after relatively fast growth to reproductive maturity (Newman *et al.* submitted b; Brown *et al.* 1994). Aggregation to spawn and protogyny in the serranids, lethrinids and protandry in some sparids will cause further problems with extractive sampling techniques. In Florida, repeated fishing of some spawning aggregations is thought to have caused profound changes in sex ratios by selective removal of larger, male serranids (C. Grimes, NOAA/NMFS pers. comm.).

Release of the catch alive after processing will not guarantee that sequential depletion is avoided in such sampling. There is a paucity of literature on mortality and effects of embolism in catch-and-release programs for saltwater fisheries and most studies rely on inference from caging or tagging rather than underwater observations (Moran and Jenke 1989; Muoneke and Childress 1994). Swimbladder distension is obvious for fish trapped or handlined in moderate depths and even for fish caught in shallow water (<10 m) if they are held at the surface for long periods. For deeper water captures there can be embolism of vascular tissues behind the eyes and gills with eversion of the stomach lining and swimbladder. Susceptibility to this short-term trauma varies amongst species, with *Lutjanus sebae* and *Lethrinus nebulosus* being noted for their ability to restrain or vent the swimbladder and retreat quickly from the surface when released. In the same depths *Lutjanus malabaricus* is badly embolised around the eyes and ventral aorta with protrusion of the swimbladder and stomach through the mouth. Large serranids are also noted for this trauma. The extent and effects of these problems are unknown, with only a single study reporting data on condition of fish released from handlines (Higgs 1993), and the observation that *Lutjanus sebae* flapped vigorously and had a good chance of survival but *Plectropomus maculatus* was dead or dying when a trawl codend was spilled on deck (Moran *et al.* in press).

Mortality rates in the longer term after release are also unknown, but have been attributed to stress due to changes in blood chemistry and wounds caused by hooks, tags, scale loss and bruising for a variety of families. The latter damage varies amongst species and is a feature of capture and release using traps retrieved from the water for processing of the catch. Handling the catch underwater using SCUBA (Davies 1989, 1995). This approach would not be feasible for trapping programs at larger scales in deeper waters because of the trap handling times and the 'bounce' diving needed to visit the replicates within sites and among locations. A further source of unknown mortality commonly reported by anglers is predation on released fish during their descent away from the surface by sharks, carangids and other pelagic predators. Nearer the seabed large serranids and *Lutjanus bohar* have been reported by divers to capture newly-released fish, which are presumably disoriented from the displacements endured during capture.

### **6.1. Mark, release and recapture studies**

Tagging studies have been widely and effectively used for age and growth validation and for studies of movement, home range size and behaviour in reef fish populations (eg. Barrett 1995;



Davies 1995; Newman *et al.* submitted a). Unfortunately estimation of population size is the least reliable product of such tagging studies. All such estimators rely somehow on the ratio of tagged to untagged fish to infer total population abundance, and the basic assumption that the tagged fish 'behave' the same as the unmarked fish is seriously flawed in the majority of cases.

The major assumptions underpinning these estimates of population size are:

- tagging does not affect the fitness or vulnerability to recapture of an individual,
- complete mixing of tagged fish to a uniform distribution over the population,
- emigration and immigration rates are known and constant for the population,
- tags are not shed by fish, or are shed at a constant, known rate,
- the percentage of tags returned from recaptured fish is assumed to be known and unbiased,
- recovery effort is uniform across, and covers, the whole population,
- the total catch is accurately known.

Most of these assumptions are discussed in detail by Kearney (1989) but a further consideration that is seldom addressed is the tagging coverage and number of recoveries needed to make robust inferences from tag recoveries. Hilborn and Walters (1992) do not recommend tagging studies as a way of estimating fish abundance unless more than 25% of the population can be tagged. This proportion should be raised to cover the potential mortality induced by the capture and release of coral reef species outlined in section 6.

The problems of tag loss in coral reef situations are even worse than those in temperate or pelagic habitats where most evaluations of tagging biases are made (eg. Beinssen 1989). Reef fishes scrub off tags against coral and other hard substrata and a wide variety of tropical fish, including conspecifics, are known to bite off newly applied tags or old ones overgrown with filamentous algae. Comparative tag shedding rates have been estimated for 'dart' and 'T-Bar anchor' (TBA) tags for *Lutjanus carponotatus* in aquaria by Whitelaw and Sainsbury (1986), and for *Lutjanus carponotatus* and *Plectropomus leopardus* in the field by Davies (1995). Davies (1995) estimated the proportion of TBA tags lost after 100 days was 32% for *L. carponotatus* and 39% for *P. leopardus*. After one year the proportion of these tags lost was 72% for *L. carponotatus* and 60% for *P. leopardus*. If 2 TBA tags were applied to all fish (double-tagging) the loss of identifiable individuals was predicted by Davies (1995) to be reduced to 10% after a period of 100 days. No effects of tag colour on shedding rate were detected in that study and it was concluded that T-bar anchor tags with long shafts were best

for use on *P. leopardus*. The failure of dart tags was considered by Whitelaw and Sainsbury (1986) to be the result of mortality and tag loss due to damage to pterygiophores during tag application. Davies (1995) also demonstrated that the rate of loss of dart tags was higher for *P. leopardus* than T-bar anchor tags. 'Loop' tags are of little use on coral reef fish, due to the wounds and entanglement in coral they cause, and Beinssen (1989) concluded that 72% of *P. leopardus* had lost one or both loop tags after a period of only 90 days at Boulton Reef. Body cavity tags were tested in that study and are considered to have potential for development (M. Hall 'Hallprint' manuf. pers. comm.). In recognition of these problems several major tagging programs in place along the GBR now double-tag all fish, rather than just double-tagging subsets for shedding estimates (Davies, 1995; M. Sheaves, pers. comm.; S. Newman, pers. comm.).

Another major consideration for the design of tagging studies to estimate population size is misreporting of tag recoveries amongst the 'open' and 'closed' (to fishing) reefs comprising the GBR Marine Park zoning plans. A tagging study of *P. leopardus* movement amongst reefs reported by Davies (1995) analysed tag returns from the public and research fishing. The research fishing spread carefully amongst open and closed reefs recorded only 0.78% movement amongst reefs. Public returns reported 37% of coral trout to have been caught away from the reef at which they were tagged. This mainly comprised fish tagged in closed areas. Most of these recaptures were considered to represent deliberate or inadvertent infringements on the closed reefs, with subsequent misreporting of the recovery location as being on open reefs. The number of tags that were never returned from such infringement was not estimated but would presumably be significant. A greater temporal spread of research fishing, particularly around the months of spawning aggregation, was identified by Davies (1995) as one means of separating the true extent of inter-reef movement from misreporting. To our knowledge, no studies have been done to determine optimal allocation of sampling effort to recapture sufficient tagged individuals of any reef species to account for emigration, mortality and tag loss. The fishing effort needed may be very expensive - Barrett (1995) set traps to recapture tagged reef fish every week for the first nine months, then at three-monthly intervals for the duration of a 2.5 year study of movements of temperate reef fish amongst reef systems.

Beinssen (1989) used the simple Petersen method to multiply ratios of tag recaptures:tag releases upward to obtain a population size of 8613 (SE=873) for *P. leopardus* inhabiting Boulton Reef (4.5 × 3.0 km). It was considered that all tags recovered were returned immediately

to the researchers at hand during the intense public effort after the opening of the reef to fishing.

## **7. CALIBRATION ATTEMPTS**

### **7.1. UVC vs explosives/ichthyocides**

The common lack of an absolute standard against which to calibrate UVC techniques has led several authors to use explosives or ichthyocides to collect fish in the same area (Stone *et al.* 1979; Samoilys and Carlos 1992). Such techniques also have some bias, more so in the case of ichthyocides where carangids, lutjanids and other 'transient' species flee the introduction of rotenone (Stone *et al.* 1979). In relation to the fish killed by explosives, Samoilys and Carlos (1992) found that UVC point counts accounted for 46% of the lethrinids present, 70% of the lutjanids, 56% of the roving serranids and only 11% of the sedentary serranids.

Repeated trials of the same technique over time will highlight its precision. Samoilys and Carlos (1992) argue that the consistency of UVC is good - citing Ayling and Ayling's (1986) 6.6-8.0 coral trout 1000 m<sup>2</sup> sighted at Heron Reef in 1986 with an estimate of 6.3-8.2 coral trout 1000 m<sup>2</sup> in the same area during 1985. Ayling and Ayling (1992) report similar consistencies in estimates of common coral trout densities over several years at reefs off Townsville.

The method of data recording during UVC can also have a bearing on the reliability of the technique. In the EPCOT centre aquarium, where the absolute abundance of reef fishes was known beforehand, a diver equipped with an underwater audio tape recorder produced the greatest accuracy and efficiency in estimates of proportional abundance compared to usual slate and pencil records (Bortone *et al.* 1991).

### **7.2. UVC vs. line-fishing**

Kulbicki (1988a) visually surveyed 45 of 363 longline sets in the southwest lagoon of New Caledonia to raise CPUE to density contours and standing stock of all soft-bottom fishes there. Intuitively, this was an attractive approach as good coverage of the entire lagoon was made by longline sets within 3 n.mi. of each other. Several sources of bias were mentioned, but no

account was given of the problems of diving along a baited line. Hooked fish were not counted, but presumably fish were attracted to the survey line by the bait plume.

Kulbicki (1988a) describes the 'heaping' of sighting distances from the line, but many taxa were caught in small numbers and not seen during UVC (*Lutjanus fulvivflamma*, *L. gibbus*, *L. sebae*) or were seen in such small and variable numbers (eg. *Lethrinus nebulosus*) that no clear relationship existed between CPUE and visual density estimates. Commonly hooked schooling species that are shy of divers and difficult to see have a confounding effect in such comparisons, as they are either very vulnerable to the gear or under-sampled by the visual survey technique. UVC could only be carried out during daylight, whereas many lutjanid species and some lethrinids leave daytime aggregations on the reef margins or in the lagoon proper to disperse at dusk and feed over sediments. Such fish would not be seen in UVC, but could be caught in large numbers by hook and line. Consequently, Kulbicki (1988a) had to pool taxa within species groups and found marked differences in the relationship between CPUE and visual density estimates. Log-log transformations were chosen to relate the two parameters, and as the intercept was not significantly different from zero, the relationship was forced through the origin. The best fit of the model was for the sedentary, home-ranging wrasse, *Bodianus perditio*.

Richards (1987) generalised the errors-in-variables model of Richards and Schnute (1986) (see section 5.3) to extend its application to any pair of abundance indices for which the ratio of variances in the two indices can be estimated. This model was used to relate density estimates from UVC using SCUBA and CPUE indices from handline fishing. For *Sebastes maliger* (in many ways similar to serranids of the GBR) the relationship between density and CPUE was one of strict proportionality.

### **7.3. Submersible vs. hook-and-line**

Several studies have compared UVC from submersibles with longline or handlining to calibrate the two techniques.

Richards and Schnute (1986) used UVC from a submersible to estimate the densities of 5 species of *Sebastes* and the lingcod *Ophiodon*, for comparison with research angling to examine the suitability of line-fishing CPUE as an index of abundance. Their approach was not to assume a linear, through-the-origin, relationship between CPUE and abundance, but rather

to allow for 5 biologically meaningful functions and employ statistical tests to decide among them.

These scenarios included the classical assumption that CPUE is directly proportional to the field abundance, that catchability decreases to 0 as density becomes large (asymptotic relationship), that CPUE is a constant regardless of density (catchability small for large density, large for small density), that the relationship is linear but does not pass through the origin (catchability different at low density) and that the relationship is asymptotic but does not pass through the origin (catchability different at high and low density). Two error structures were considered in modelling the relationship between CPUE and UVC density estimates. The 'errors in variables' (EV) model includes errors in estimation of both CPUE and density variables, and the 'ordinary least squares' (OLS) model assumes that density is known exactly, and that error is confined to prediction of CPUE.

When all species were pooled, it was difficult to reject strict proportionality in the relationship, except at low densities, using the EV model, but the OLS modelling of the same data indicated an asymptote at high densities. This key difference arises from the fact that EV can explain a low CPUE at high density by allowing for error in the density measurement, but OLS assumes density is measured perfectly and must explain the same datum by an asymptotic relationship at high density.

Richards and Schnute (1986) suggested that larger samples could overcome this ambiguity, but submersible time was expensive, and replication was traded off against the number of sites that could be visited. The review presented by Mapstone and Ayling (1993) only partly supports their suggestion - high variance is probably a characteristic of reef fish count data not simply due to levels of replication. In one novel approach to this problem, Bannerot and Austin (1983) found that the relative frequency of zero catch and its natural-log and square-root transforms had higher correlations with abundance than mean CPUE. Richards and Schnute (1986) concluded that the assumption of strict proportionality between CPUE and abundance was best for single species data collected over uniform weather conditions. They also consider that an earlier, similar study by Ralston *et al.* (1986) may have obscured trends in deepwater reef fish data by combining densities and catch across species with very different behaviours.

In that particular study there was a 1 month lag between UVC surveys by submersible and fishing by a hook-and-line vessel, and the spatial coincidence of the two surveys was not

precise. With a sample size of only 6 observations and data pooled across taxa, a positive but insignificant correlation was found between density and CPUE using a functional regression that passed near the origin. Using the slope of this regression, Ralston *et al.* (1986) estimated the catchability coefficient ( $q = 0.0215$ ) in hectares per line hour, and considered that one line hour of the survey vessel removed about 2.2% of the bottom fish inhabiting 1 hectare of habitat.

Matlock *et al.* (1991) adopted a comprehensive approach involving allocation of sampling effort to habitat strata based on empirical knowledge of fish density. A large area (95 km) in the depth range 183 - 457 m was surveyed by exploratory longline sets and acoustic soundings of fish schools and seabed topography to locate concentrations of tilefish and yellowedge grouper. Study areas for submersible UVC and longline fishing were chosen accordingly for tilefish (1.9 by 1.1 km) on soft sandy-clay sediments and for yellowedge grouper (1.28 by 1.28 km) in boulder fields amongst rocky ridges and epibenthic anemones and seapens. One 'box' in each of these areas was fished with longlines, and UVC along 'accordian' type transects was conducted inside and outside the fished box in each area. Starting points for the transects were selected randomly and alternating legs (366 m east-west; 91 m north-south) were run (up to 2652 m per dive) at 1.9 km hr<sup>-1</sup> about 1 m above the seabed. Tilefish burrows were counted within 7.3 m on either side of the submersible and the larger grouper and their burrows were counted within of 11 m of each side.

Population densities and sizes were estimated using a modification of the Leslie method (Section 5.3 ) for the longline CPUE data, and from counting individual burrows and fish during UVC. Their use of the Leslie method assumed direct proportionality between CPUE and fish abundance, constant fishing effort and vulnerability, a 'closed' population and no natural mortality. There was no significant regression of yellowedge grouper CPUE on cumulative catch, so vulnerability and population size could not be estimated using this method. In the fished area, UVC of burrows and individual grouper gave the same mean estimate of population size, while UVC of observed tilefish gave higher estimates (134 ) than the longline data (81). The UVC estimates for tilefish were considered to be over-estimates of density because 'active' burrows were overestimated, the width of each transect was underestimated, and double counting occurred when transect legs crossed or came close together.

## 8. DISCUSSION

Sufficient advances have been made in understanding of the power and precision of visual surveys and fish trapping by Mapstone and Ayling (1993) and Williams *et al.* (1995) to make definitive statements about their role in monitoring fish populations on the GBR. The same cannot be said of sampling methods such as line-fishing and trawling. The use of underwater video cameras has enabled the dynamics of trap fishing to be modelled and exemplifies the insights that should be gained by underwater observation of the dynamics of other extractive gears, such as lines and trawls. These observations will build on knowledge gained through inference from catches and from comparison of capture and observational methods to enable definitive studies to be made on the data properties, power and precision of line-fishing and trawling. The advantages of using bait to attract fish, and of using underwater video to observe them without the selectivity or destruction caused by capture, could theoretically be combined in development of baited stations as a non-destructive sampling technique for use in all habitats on the GBR.

Williams *et al.* (1995) note that distributions of data from traps are most similar to those from visual census counts in areas with very low densities of fish. 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 its standard deviation. In the visual surveys there is a similar relationship between the mean and its 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 does little to reduce the variance after a certain point. Most of these properties are associated with species that have highly clumped distributions, and the trap data for lethrinids and lutjanids caught by Williams *et al.* (1995) support SCUBA observations that these fish are more highly clumped than coral trout in their distribution. Spatially stratifying trapping 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.

A theme of the review for all sampling techniques has been the need to map the habitat requirements of the lutjanids, lethrinids and serranids of commercial and recreational interest in order to allocate sampling effort appropriately. This is especially important for the inter-reef areas on the GBR which are very poorly known in comparison to the shallow coral reefs within

the reach of SCUBA. A range of technologies has been developed to map the bathymetry, substratum hardness and macrobenthos in these deeper waters, such as the LADS (laser airborne depth sounder), hydroacoustics and ROV (remotely operated video), but these have not been systematically applied to the GBR line fishery.

Extensive tests of the statistical properties and power of line fishing and trawling have not been carried out yet, although suitable data sets may exist already for line-fishing (eg Davies 1995) to which the approach of Williams *et al.* (1995) can be applied. Despite their limitations, therefore, traps may still be the most effective sampling tool for most lutjanids, lethrinids, nocturnal species and others below the limits of SCUBA. If this is so, management authorities and fisheries scientists will have to allow for an ability to detect only great changes in population size - in the order of three-fold or greater - or allocate large amounts of time to sample each critical habitat on a reef.

As a consequence, the greatest challenge facing biologists is to educate managers about the coarseness of scales at which population change can be detected and to convince managers and funding agencies of the need to promote the necessary technological development for obtaining more accurate estimates of population size (Barans 1982). The need for accuracy in estimates of fish abundance increases directly as exploitation of the stock and the need for proper regulation increases (Gulland 1969), yet there has been relatively little work done on the GBR reef fish fauna below the ~20 m SCUBA limits of UVC - despite concerns about falling catch rates and average sizes of coral trout and red-throat sweetlip (*Lethrinus miniatus*) (Craik 1989).

Experience elsewhere in lutjanid and serranid stock assessment (Barans 1982; Haynes 1988) indicates that an integrated plan of cooperative, multidisciplinary research is necessary, on species distributions, species behaviour, gear efficiency and cost effectiveness - toward providing estimates and confidence intervals suitable for pre-defined management goals. On the GBR, 'target' and (critical) 'limit' biological reference points have not yet been set, as acceptable change is still being defined and discussed against the growing knowledge of the vast spatial and temporal natural variation in the system. So, in the case of reef fish assessment, researchers may have to advise management what levels of change can be measured, for a given cost, rather than respond to the data requirements of pre-determined management goals.



Significant refinement of visual survey methods has occurred in recent years, and to a large extent on the Great Barrier Reef. Strip, or belt, transects and point counts by SCUBA divers are useful in estimating common coral trout abundances, but are restricted to depths less than about 20 m, and appear to be of very limited use in counting lutjanids and lethrinids. Timed intensive searches for lutjanids and lethrinids can increase the mean numbers sighted, with improved precision over belt transects. Further investigations are required to test and develop this technique further. However, the restriction of all UVC to shallow habitats has an unknown bias in relation to abundance of *Lethrinus miniatus*, *L. nebulosus* and the large lutjanids that occur in deep water also. For example, *Lutjanus sebae* are seen only as juveniles by SCUBA divers, and *L. malabaricus* and *L. erythropterus* are seen only as juveniles also, but only on inshore reefs. The possible movement of coral trout up and down reef slopes, out of SCUBA range, is also an unknown source of error in visual survey.

The use of submersible vehicles extends the capacity for visual survey methods into deeper waters. Their limited availability (in Australia especially) and very high operating cost would exclude them from routine survey work on the GBR. In addition, there are several accounts in the literature of unpredictable patterns of behaviour of certain fish species in relation to the underwater vehicles, leading to significant bias in enumeration results. It might be argued that similar problems could also occur with SCUBA-based visual surveys, but such changes in the behaviour of fish may be greater in the presence of a large, highly visible vehicle equipped with bright lights. Perhaps the best role for submersibles on the GBR will be use in identifying and mapping habitat at a variety of scales, studying fish behaviour in relation to extractive sampling gears, and calibrating such gears by doing comparative visual surveys. This will give many of the insights necessary for further development of sampling gears for the inter-reef areas.

We believe there is much potential for application of video cameras with increasingly high resolution, and capacity to operate effectively at low levels of illumination, to stock enumeration. Significant advances in video-camera technology are making these devices more affordable, smaller and less obtrusive as potential fish assessment tools. The sampling potential of, for example, strings of 'set-and-leave' video/bait stations probably greatly exceeds that of handline fishing, where crews must visit each site for some period of time and standardisation of effort is difficult or impossible due to sea state, and of trapping, where deck space and handling of the catch constrain deployments. While the human eye is still far better at

discriminating species and accommodating a greater field-width than video cameras, CCD cameras will certainly find increasing application in the areas of reef fish stock assessment.

To overcome the problems of gear selectivity (trap mesh size and angling hook-size) and having to actually capture fish, we believe there is potential for use of bait stations monitored by underwater video and infrared lighting. Like the CSIRO North West Shelf study, the arrival times and abundance of responsive fish could be modelled from video recordings to estimate an index of abundance. The problems still remain, however, of differential responsiveness to bait due to seasonal or biological factors and difficulties in identifying individual fish as they arrive, feed and leave - perhaps returning later. Video/bait stations could be accurately deployed within habitats, in association with GPS, at levels of replication independent of soak time and less dependent on deck space and weather conditions than traps. The production cost of individual stations would be relatively high, but overall monitoring costs would be lower compared to sea-time needed to detect even large population changes by low precision trapping. At this theoretical stage, one of the major considerations is how to incorporate into process models the visits of fish that leave the field of view and return later to be counted more than once.

There appear to have been few technological breakthroughs in capture methods, but some major refinements have been made with existing gears. The CSIRO combination of trap and video recorder has enabled informative modelling of the dynamics of fish trapping with data unobtainable from traditional inference from catches. The rotating 'O' trap has potential for ensuring that trap entrances are oriented favourably in relation to current flow, thereby maximising catch and reducing variability in catch rates. A series of recent developments of semi-pelagic trawls and trawl-efficiency-devices (TEDs) have reduced destruction of macrobenthos and bycatch without compromising catch of some fish of major commercial and recreational importance (eg. Brewer *et al.* in press; Robins-Troeger *et al.* 1995). These trawl designs could be coupled with the recent advances in estimating the critical parameter of effective trawl path-width (Ramm and Xiao in press) to make fish trawling a feasible enumeration technique for some lutjanids in some habitats.

Several features of trap construction and deployment have been identified as highly desirable if these devices are to be used as fish population sampling tools. Considering the need to maximise means, and hence optimise precision and power, traps should:

- be baited with high quality baits (pilchards are ideal) in large quantities that provide optimal bait flux,
- have large easily accessible entrances that face into the current (a rotating 'O' trap has been developed by CSIRO to address this requirement),
- be large enough to avoid early saturation,
- be hauled after short, empirically determined (video) times at which catch rates (ingress) peak and before bait is exhausted,
- be set accurately on known habitats.

Line fishing has been shown to be a useful sampling tool in the heterogeneous coral reef environment. The gear requirements are simple and cost-effective, all depths can be sampled, catch rates are high relative to trapping, support logistics are comparatively minor, and precision estimates (as measured by coefficients of variation) are of the same order as those from traps. However, the technique is labor intensive and many factors affect handline fishing success and standardisation of effort - even at the level of one end of a dinghy consistently out-fishing the other (M. Kulbicki, ORSTOM pers. comm.). Prevailing winds on the GBR will mean that weather conditions will often make sampling some habitats more difficult than others - introducing imbalance into sampling designs when samples are missed, and other 'nuisance' variability.

We believe that the coral trout fishery on the GBR provides an ideal testing ground for critically assessing the use of CPUE from handline fishing as an index of abundance. Useful data sets already exist on the spatial and temporal features providing highest catch rates, coral trout are relatively site-attached and only active during the day, much of the fishery occurs in depths where visual surveys can be done, and UVC protocols have been well established and tested for coral trout. Comparing UVC with line-fishing in the same areas will enable determination of the form of the functional relationship between CPUE and field abundance. Furthermore, coral trout are easily speared and the size and age compositions of line fished and speared collections can be used to examine gear selectivity.

In the context of the Effects of Line Fishing Experiment our review supports line-fishing and visual surveys along strip transects as the best combination of methods for estimation of stock abundance of coral trout. However, a suite of complementary sampling techniques will need to

be developed to provide abundance estimates for lethrinids and lutjanids around and between reefs. Baited traps and standardised handline fishing offer potential for development in these deeper habitats with complementary calibration by underwater video and infrared lighting essential to address the problems of gear selectivity. These combinations depend on the behaviour and distribution of these families and will involve GPS positioning, calibration (eg. video camera on traps), species verification (eg. trawls in deep aggregations), density confirmation (eg. depletion experiments) and other refinements to enable comparability of results. Each method has certain advantages and disadvantages with respect to each other; a compilation of these may be found in Table 8. Unfortunately there is unlikely to be a single technique available that will satisfy all the requirements of speed, cost, species coverage, accuracy, precision, habitat depth, and provision of biological material.

After testing a number of sampling methods specifically targeting the same taxonomic groups that are of greatest importance on the GBR, Haynes (1988) also concluded that a combination of video, trapping and line fishing techniques is the best way to assess overall reef fish abundance in the Gulf of Mexico. This study compared the results of underwater video-cameras, fish traps, gill nets, bottom longlines and handlines. Handlines and longlines were considered the best methods for larger snappers and groupers, while other gears (gill nets were specifically mentioned here) were considered 'less useful'. Haynes (1988) recommended that future work must include developing more efficient trap designs and deployment methods, quantifying video sampling methods, reducing sampling variance, and substituting non-lethal for lethal methods of sampling reef fish.

The challenges associated with developing sampling techniques for the vast inter-reefal areas on the GBR are more formidable, due to the lack of knowledge of the extent of 'off-reef' habitat for lethrinids, serranids and lutjanids. Depth, benthic cover and subtle bathymetric features are apparently important features of the habitat and aggregations of fishes occur in relation to these.

**Table 8.** Advantages and disadvantages of major sampling methods for reef fish and off-reef fish.

Method	Advantages	Disadvantages
Traps	<ul style="list-style-type: none"> <li>• can fish unattended</li> <li>• can fish a large area per set</li> <li>• can be handled from small or large vessels</li> <li>• are inexpensive and robust</li> <li>• are suitable for most substrata</li> <li>• can fish over entire depth range of resource</li> <li>• catch is usually live, offering choice of collection of biological data and specimens for tag and release</li> <li>• can be deployed with pin-point accuracy on features on the seabed</li> <li>• some fish can be tagged and released</li> </ul>	<ul style="list-style-type: none"> <li>• variances are invariably high</li> <li>• numerous factors other than fish density affect catch rates</li> <li>• effort cannot easily be calibrated to convert CPUE to fish density</li> <li>• soak times of baited traps may need to be short, reducing the number of simultaneous sets possible</li> <li>• gear saturation can occur</li> <li>• lice/pickers remove bait</li> <li>• ghost fishing is perceived to be a problem by fishing public</li> <li>• currents can sink trap floats and lines</li> <li>• high quality bait in sufficient volume is expensive</li> </ul>
Visual Census (SCUBA)	<ul style="list-style-type: none"> <li>• simple</li> <li>• inexpensive</li> <li>• quick</li> <li>• non-destructive</li> <li>• independent of fishing methods</li> <li>• provide rapid estimates of relative abundance, biomass, length frequency distributions</li> </ul>	<ul style="list-style-type: none"> <li>• cannot be used for nocturnal species</li> <li>• restricted to shallow water (&lt;20 m)</li> <li>• observers must be familiar with rapid identification of fish</li> <li>• infrequent observers must be retained to ensure accuracy of length estimation/distance estimation</li> <li>• observer may frighten fish</li> <li>• water clarity affects precision and accuracy</li> <li>• fish not available for later biological study or for sale to offset costs.</li> </ul>

Table 8 (continued)

Method	Advantages	Disadvantages
Handlines	<ul style="list-style-type: none"> <li>• handled from small or large vessels</li> <li>• inexpensive gear</li> <li>• suitable for all depths and substrata</li> <li>• can be deployed with pin-point accuracy on habitat features</li> <li>• mobile, can fish very close to reef crest</li> <li>• can use existing commercial fleet to carry out/ assist sampling</li> <li>• biological material available from carcasses</li> <li>• some fish can be tagged and released</li> </ul>	<ul style="list-style-type: none"> <li>• variability is high</li> <li>• hook selectivity is a major consideration</li> <li>• fish not always responsive to bait, or are hook shy</li> <li>• pickers remove bait</li> <li>• cannot easily convert CPUE to density estimates as <math>q</math> not constant over all densities</li> <li>• handling time of captives causes rapid gear saturation at high density</li> <li>• positive feedback process means hooks not independent units of effort - hooked fish attract others to nearby hooks</li> <li>• sea state alters catching efficiency</li> <li>• difficult to standardise effort</li> <li>• high levels of staff power for low levels of replication</li> <li>• bycatch detracts from effective effort</li> <li>• many (particularly biggest and smallest) fish escape hooks on retrieval</li> </ul>
Trawling (semi-pelagic)	<ul style="list-style-type: none"> <li>• can sample large, easily defined areas during day or night</li> <li>• 'swept area' method can be used to relate CPUE to fish density</li> <li>• can sample in deep waters</li> <li>• proven record in capture of Lutjanids, Lethrinids and exposed Serranids</li> <li>• small and large stages can be caught</li> <li>• 'Julie Anne' trawl can be used from existing vessels in east coast prawn trawl fishery</li> </ul>	<ul style="list-style-type: none"> <li>• difficult to target sampling on specific habitat feature</li> <li>• hook-ups on reef are expensive</li> <li>• net &gt;1 m above seabed may not catch some Lutjanids</li> <li>• boat noise and trawl scare/herd fish away from opening</li> <li>• catch is mostly dead, or dying, for most taxa</li> <li>• localised patches of fish are not discernible in integrated picture presented by trawl catch.</li> </ul>

A progression of tasks in evaluation of enumeration techniques in these areas might include:

- acoustic and underwater video surveys of fish schools and benthos to define major fish distributions to assist in development of stratified sampling strategy,
- family or group specific behavioural studies, possibly by video/bait station, UVC or submersible, to define microhabitat distributions and provide information necessary for rational choice of assessment techniques for that family,
- tests, evaluations and calibrations of the chosen combination of extractive gears/ techniques for standardised long-term monitoring (emphasising underwater observations of gear dynamics), and
- verification of assessment estimates by statistical comparison with fishery dependent (CPUE logbooks) or independent (depletion experiments) assessment methods.

Peer review and cost-efficiency analyses should be carried out at the end of each step, similar to those already undertaken in evaluation of UVC techniques (Samoilys and Carlos 1992; Mapstone and Ayling 1993).

Development of technological advances in acoustics and in remote habitat identification and mapping, and in data analyses, will require high levels of inter-agency gear sharing and multidisciplinary cooperation of specialists in disparate fields. Seed funding will be expensive, but should be equated with long-term benefits accrued from obtaining more accurate and precise estimates of abundance.

### **8.1. Tactical research needs**

Throughout this review we have identified and discussed unresolved issues associated with each enumeration technique. We were also given the task of specifying which of these could be addressed with short-term research funds, and the following items are most feasible:

- supplementary experimental fishing in contrasting circumstances, and statistical analysis of precision and power to detect change in existing data sets on handline ('tinny') fishing in the GBR (eg Davies 1995) to define the limits of the technique. There may also be sufficient data behind Ramm and Xiao (in press) to do the same for *L. malabaricus* and *L. erythropterus* in semi-pelagic trawls.

- simultaneous, or other, informative comparisons of strip transect counts (densities and fish sizes) with handline fishing and spearfishing to assess how handline CPUE and length composition of coral trout relates to field abundance.
- construction of a fleet of traps with video cameras mounted on them to determine whether the properties of Williams' *et al.* (1995) data are due to clumped distributions of lethrinids and lutjanids, or just the dynamics of trap operation, in order to determine if the efficiency of their design can be improved.
- construction of a fleet of bait stations ( $\geq 4$  kg pilchards) with video cameras mounted on them to determine if this technique can be used in inter-reef areas to record visits of lethrinids, lutjanids and serranids as an enumeration technique.
- mapping and intensive sampling of some deep, reef-slope (coral trout and *L. miniatus*) and inter-reef habitats (*L. malabaricus*, *L. erythropterus*, *L. sebae*) known to contain fish with video/bait stations, video/trap and handline to assess comparative performance of each. Reefs normally closed to fishing may be the best testing grounds.
- determination of rates of mortality of fish released from intensive, catch-and-release sampling with traps and lines in 20 - 40 m depths.

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