A review of techniques used for assessing changes in fish assemblages

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1. INTRODUCTION

Accurate and precise information on length, density and diversity of fish facilitates estimates of recruitment, fishing intensity and rates of recovery from fishing or other disturbances. Such information is vital for the process of planning management strategies, e.g. the design of Marine Protected Areas (MPAs), to protect vulnerable fish species and their associated habitat. The more *accurate* and *precise* the information is, the more easily changes in the populations can be detected leading to informed decisions on their management. When measuring a single fish's length, accuracy is defined as the 'closeness' of the estimate to the actual length while precision is defined as the closeness of repeated measures to this fish's length.

Brock (1954) stated that if there is not a method that exists that is able to measure the results of management or regulation, any justification to manage or regulate disappears. Of concern is that there is no one sampling technique that is able to accurately and precisely do this without introducing its own bias(es). Systematic bias in the counting or sampling of fish can cause very precise estimates to be inaccurate. The degree to which a sample is biased is the degree to which it over or underestimates the true value of the parameters being measured (Underwood 1997).

Following is a short review of current literature on the advantages and disadvantages of currently used sampling techniques and their ability to effectively measure changes in fish assemblages. Where relevant, suggestions for improvements in design and implementation will be made.

The most common sampling techniques can be grouped into two broad categories; 1) Capture Methods and 2) Observational Methods (Table 1).

Table 1. Fish sampling techniques including observational and capture methods.

Catagory	**Technique**	**Variations/Examples**
Capture Methods	1. Explosives/Icthyocides	i. rotenone ii. clove oil
	2. Trapping	i. round ii. Antillean/z-trap
	3. Trawling/Netting	i. gill nets ii. trammel nets iii. drift nets iv. semi-pelagic trawls (e.g.) - 'Julie Anne' - 'McKenna wing' v. bottom-fish trawl (e.g.) - 'Paulegro'
	4. Hook and Line	i. drop-lines ii. long-lines iii. handlines - hooks - barbless hooks - lures
Observational Methods	1. Underwater Visual Census (UVC)	i. strip transects ii. stationary point counts iii. line transects iv. interval counts v. UVC with audio and/or visual devices
	2. Hydroacoustics	
	3. Video cameras	i. single underwater video camera ii. underwater stereo-video cameras iii. swimmable single or stereo-video cameras

2. CAPTURE METHODS

Many capture methods that are used for assessing the exploitation level of fish populations involve the removal, and in many cases elimination, of fish from the marine environment. Appropriately, Brock (1954) termed this "curing the disease but killing the patient" and with this statement he perhaps gives too much credit to the ability of those destructive capture techniques in obtaining meaningful and useful results. Having said this, there are capture techniques that, when used skillfully, more often than not return unharmed fish back into the water.

The design, implementation, advantages and disadvantages of the 4 broad capture method categories presented in Table 1, are briefly discussed below. For a more thorough discussion on each capture method see Cappo and Brown (1996) and Kingsford and Battershill (1998) for reviews.

2.1 Trapping

Traps are used worldwide for abundance and tag-and-release studies on tropical and subtropical fish species (e.g. Miller and Hunte 1987; Koslow *et al.* 1988; Arena *et al.* 1994) and to a lesser extent on temperate fishes (e.g. Crossland 1976). Traps vary in shape from square to round, z-shaped or the Antellian trap (Kingsford & Battershill 1998; Figure 1) however the basic principle is the same; fish enter through one or more entrance funnels and are inhibited from escaping by constriction at the inner end of the funnel (Cappo and Brown 1996). A few researchers use bait to attract fish (Miller & Hunte 1987) since bait provides more reliable estimates on fish abundance and attracts a greater diversity of species (D. Watson unpubl. data). The advantages and disadvantages of trapping for abundance and tag-and-release studies are numerous and are listed below.

Advantages

- provide specimens for study of age and reproduction and for tagging and release (Kingsford & Battershill 1998);
- traps may be left unattended and deployed to depths beyond the limits of SCUBA;
- can be robust and inexpensive;
- generally the only non-destructive capture method with most fish released alive;
- can sample small and aggregated fish communities on topographically complex seabeds.

Disadvantages

- high variances between traps and low catches are common therefore many replicate cages are required and then may be bulky to transport (Williams *et al.* 1997; Kingsford & Battershill 1998);
- it is possible to have a high turnover of fish with a relatively constant number remaining in the trap (Cappo & Brown 1996);

- catch rates vary for different species depending on soak time and mesh size, i.e. size bias with larger fish less likely to escape than smaller fish (Newman & Williams 1995; Gobert 1998; Robichaud *et al.* 1999; Anon 1990);
- fish may be eaten within the trap or fish may not enter the trap if a predator is present (Ward 1988; Moran & Jenke 1989);
- conspecific attraction may enhance the ingress of fish into the traps (High & Beardsley 1970);
- currents can disperse bait outside the trap (Anon 1990);
- difficult to convert catches to number of fish per unit area;
- difficult to target all species due to differences in arrival times and predator/prey relationships;
- may cause destruction to the seabed when deployed.

Observational sampling methods such as SCUBA divers (Munroe 1974 cited in Cappo & Brown 1996) and video (Anon 1990) have been used in conjunction with trapping to observe the dynamics and effectiveness of traps, ultimately improving their design and implementation. Until research can limit the numerous aforementioned disadvantages, trapping may only be most useful for sampling fish assemblages when specimens of live fish are required.

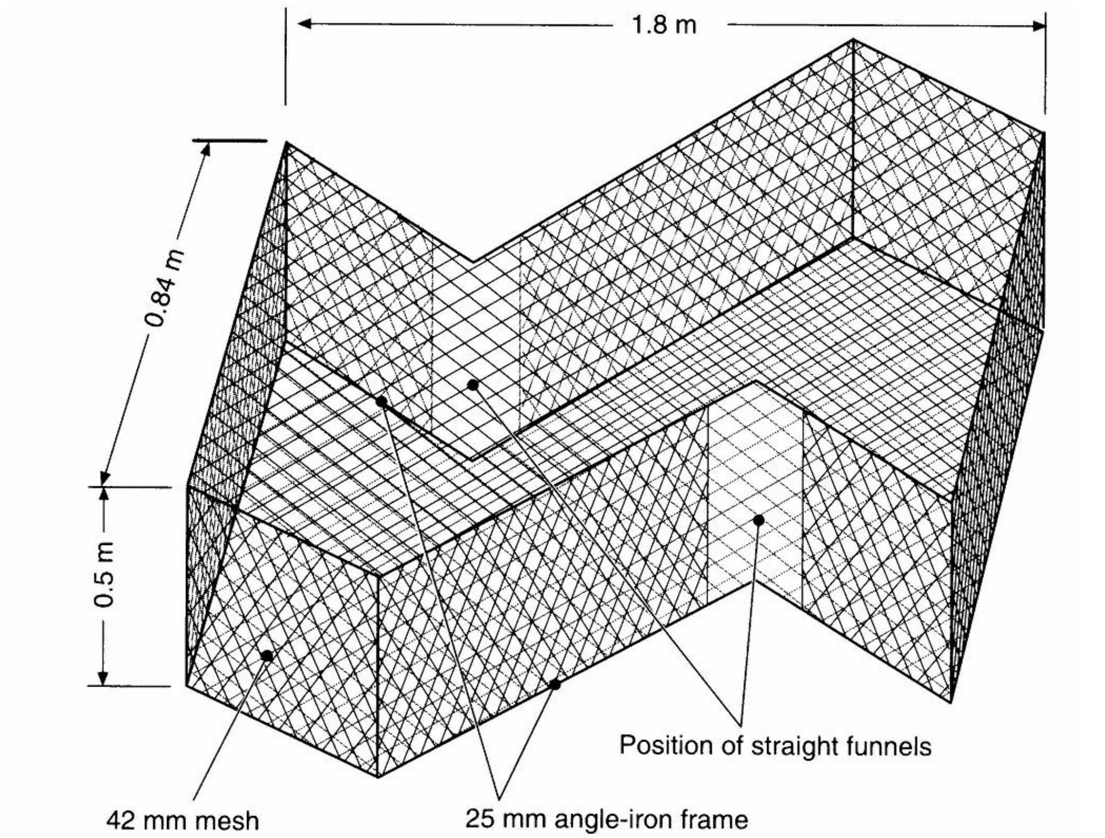

Figure 1. Diagram of an Antellian or Z trap. Funnels are posisitoned in the V of each limb of the Z shape. From Kingsford & Battershill (1998).

2.2 Hook and Line

Since the Stone Age and most likely before, a length of line ending in a baited hook has been used to catch fish (Wardle 1984). Today, barbless hooks can be used in shallow water (to avoid venting swimbladder) for fishing with the purpose of tag-and-release and replicate longlines, droplines or handlines for defined periods of time can be used for measures of catch per unit effort (CPUE) (Kingsford & Battershill 1998). Cappo & Brown (1996) state that hook and lines methods are the primary method used in both recreational and commercial fisheries on the Great Barrier Reef with descriptions of the methods given by Higgs (1993), Williams and Russ (1994) and Davies (1995) each cited in Cappo & Brown (1996).

Advantages

- sampling is conducted from above water;
- gear is light, inexpensive and widely available;

- capable of quick replication of sampling to increase precision levels;
- able to obtain specimens for determination of age, sex, feeding and reproduction habits.
- High survival rates after capture have been reported (Diggles & Ernst 1997)
- can be used beyond the limits of SCUBA.

Disadvantages

- There are many factors that affect the vulnerability of fish to capture, e.g. schooling, gear saturation, gear selectivity for certain species and size classes and learned gear avoidance (Davies 1995) therefore catches may not accurately reflect the assemblage structure or fish abundances;
- Behaviour of fish towards others may influence catchability and thus bias counts made;
- High mortality due to damaged swimbladders, hook damage and predation while hooked;
- CPUE highly variable between fishers.

2.3 Explosives/icthyocides

Explosives and icthyocides are used in scientific fish sampling studies. Some researchers have used explosives/icthyocides to sample fish in the same area as they have conducted diver surveys in order to calibrate their results (e.g. Anon 1978; Stone *et al.* 1979; Dibble 1991; Samoilys and Carlos 1992; Ackerman & Bellwood 2000, 2002; Willis & Anderson 2003).

Advantages

- provides good collections of fish species and accurate and precise estimates of numbers of species, abundances, sizes and weights (Anon 1978; Ackermann & Bellwood 2000; 2002);
- overcomes limitations caused by irregular substrates.

Disadvantages

- non-selective destruction of all organisms in the area (Anon 1978; Bortone & Kimmel 1991);

- transient species can flee the area of prior to the introduction of rotenone causing a bias in sampling (Stone *et al.* 1979, cited in Cappo & Brown 1996; Ackermann & Bellwood 2002);
- set-up is time consuming;
- icthyocides: it is difficult to delineate the area of samples (Anon 1978);
- explosives: attraction of sharks to the noise and to dead and dying organisms can hamper the recording performance of researchers (Russell *et al.* 1978).

2.4 Netting/Trawling

Nets that gill and tangle the fish are skillfully used in many parts of the world (Wardle 1984). Gill nets, drift nets and trammel nets rely on the fish not being aware of the nets presence until it is too late to avoid capture (Wardle 1984). For scientific sampling 'experimental nets' that vary in mesh sizes are used to capture fish of different sizes.

Modern trawls have developed from the historical techniques of beach seining and bream trawling (Wardle 1984). Modern trawls are made in many sizes for different target species and are generally towed at a maximum speed of 3-4 knots behind a boat. For estimating densities of fishes, a trawl technique known as the 'swept area method' is commonly used (Cappo & Brown 1996). In the simplest case, the method divides the trawl catch by the area of the trawl path to estimate density.

Advantages

- deployment at all depths;
- provide specimens for study of age and reproduction;
- some fishes are hardy enough to survive for tag and release studies (Kingsford & Battershill 1998);
- not restricted by time of day.

Disadvantages

- only work when they stimulate no behaviour response of the fish (Wardle 1984; Ramm & Xiao 1997, cited in Cappo & Brown 1996);
- effective path width generally unknown so it is difficult to determine area sampled;
- some methods cause damage to the seafloor (Lipej *et al.* 2003);

- have great impact on local fishes and the capture of many non-targeted organisms can be high and unacceptable;
- If markers of the net are lost and it becomes adrift, or bad weather prevents retrieval, the net can continue to fish and may pose a hazard to divers (Kingsford & Battershill 1998);
- serial depletion of fishes that have high reef fidelity is likely to be high;
- geometry of trawls sensitive to changes in towing conditions (e.g. towing speed, water depth);
- do not necessarily record a representative sample of fish communities with larger more mobile species often underrepresented (Cappo *et al.* 2004).

2. 5 Summary

As shown in the discussions above, some capture methods are destructive although they may have non-destructive applications; e.g. applications for tag and release estimates of abundance of species (Kingsford & Battershill 1998). For these types of studies capture method are necessary, however, when live samples are not required these techniques should not be not be used for studies on fish length, density and diversity. The disadvantages associated with each method generally outweigh their associated advantages and as shown in Section 3, these advantages may all be achieved by observational methods with fewer biases.

3. OBSERVATIONAL METHODS

The use of capture methods such as trawls and poisons are prohibited in Marine Protected Areas (Harmelin-Vivien & Francour 1991; Lipej *et al.* 2003) and therefore observational methods are necessary for studies on fish assemblages. As the name states, these methods involve the observation of fish *in situ*.

3.1 Underwater Visual Census (UVC)

The UVC technique was first used by Brock (1954) and has since become the most popular method for studying the distribution of tropical and temperate reef fishes (Kulbicki 1998). A vast and growing quantity of information exists on the visual estimation of fish abundance and length (see Samoilys and Carlos 1992; Rowley 1994; Cappo & Brown 1996 for reviews).

3.1.1 Advantages and Disadvantages

The popularity of SCUBA (Self Contained Breathing Apparatus) diver surveys is largely because they are non-destructive/extractive, simple, quick to execute, inexpensive and permit measurements of fish density (English *et al.* 1994). However, the inherent biases and errors associated with UVC techniques are numerous and have been studied many times. These include:

- failure of divers to notice individuals (Anon 1978; Brock 1982; Sale and Sharp 1983; Watson & Quinn II 1995;1997);
- failure of divers to correctly measure individuals (Anon 1978; Bortone & Mille 1999; Harvey *et al.* 2001a;b & 2002);
- diver speed (Lincoln Smith 1988; 1989);
- diver experience (Bohnsack 1995; Mumby *et al.* 1995);
- fish detectibility (Lincoln Smith 1988 & 1989; Willis 2001);
- fish behavioural changes in response to divers (Chapman *et al.* 1974; Chapman & Atkinson 1986; Cole 1994; Kulbicki 1998).

All result in a reduction in accuracy and precision, and often an underestimation of abundances and diversity. Furthermore, restrictions to UVC include; depth, time of day and visibility.

3.1.2 UVC techniques

Brief descriptions of six different UVC techniques and studies that have used them are presented in Table 2. The advantages and disadvantages of all UVC sampling techniques are quite similar and overlap, therefore any further discussion is limited to the strip transect method, the most common UVC sampling technique.

Strip transects are regularly used for estimating fish abundance on coral reefs (e.g. Bellwood & Alcala 1988; Friedlander & DeMartini 2002), temperate reefs (e.g. McCormick & Choat 1987, Lincoln-Smith 1988; 1989; Ruitton *et al.* 2000; Willis &

Babcock 2000) and artificial reefs (Rilov & Benayahu 2000). The strip transect method involves a diver swimming along lanes (usually marked with measuring tape, lines or fixed stakes) while recording the number, size and sometimes position or activity of fish (Figure 2).

Figure 2. Department of Fisheries, Western Australia researchers conducting a strip transect at the Houtman Abrolhos Islands, Western Australia.

The accuracy, precision and biases associated with strip transects have been widely scrutinized (e.g. Davis and Anderson 1989; Harvey *et al.* 2001a;b). In addition to the inherent and general biases associated with UVC sampling techniques already listed, there are additional biases that affect the results produced by strip transect sampling. Cappo & Brown (1996) listed the most important ones as:

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

Harvey (1998) showed that divers may under or overestimate the area surveyed by as much as 70% and as a consequence the numbers of fish counted. Furthermore, and perhaps most importantly, data obtained for most taxa for transects of all sizes are not consistent with the assumptions underpinning most parametric statistical procedures (Cappo & Brown 1996).

To date, the ease and efficiency with which strip transects can be conducted, combined with the seemingly lacking availability of a method devoid of similar biases, has promoted their continued widespread application.

Table 2. Underwater visual census (UVC) sampling techniques and examples of studies that have used each.

UVC sampling technique	Description of method	Examples of researchers that have used the particular UVC method
Strip transect	The strip transect method involves a diver swimming along lanes (usually marked with measuring tape, lines or fixed stakes) while recording the number, size and sometimes position or activity of fish.	Brock 1954; Bortone *et al.* 1989; Francour 1994; Willis 2001; Friedlander & DeMartini 2002; Thompson & Mapstone 2002.
Stationary point count	Diver counts fish in a circular space up to 10m distance from a stationary point for duration of usually 5-10 minutes.	Sale & Douglas 1981; Bohnsack & Bannerot 1986; Bortone *et al.* 1989; Bortone & Marton 1991; Halunsky *et al.* 1994; Bohnsack 1995; Watson & Quinn II 1997; Francour *et al.* 1999.
Line transect	A diver records information on the sighting angle and the distance of individual fish from themselves allowing for calculation of the perpendicular distance between the subject and the line. Length is its only dimension.	Bortone *et al.* 1989; Dibble 1991; Chater *et al.* 1995; Mumby *et al.* 1995; Kulbicki & Sarramēgna 1999; Cole *et al.* 2001; Lipej *et al.* 2003.
Interval counts (or Rapid Visual Censuses)	Also known as timed SCUBA swims where a diver records all fish seen while swimming for a specified time. Often area is not known.	Branden *et al.* 1986; DeMartini & Roberts 1982; Kimmel 1985; Jones & Kimmel 1985; Sanderson & Solonsky 1986.
Audiotape	A diver records fish observed on an underwater tape recorder	Greene & Alvezion 1989 Bortone & Martin 1991
Audiotape + video	A diver swims a single or stereo-video set-up whilst recording numbers of fish observed through a full-face mask onto the video tape. This may be done with two divers, one operating the video positioned behind and below another making audio observation r a single diver.	Bortone & Martin 1991; Harvey *et al.* 2002; Westera *et al.* 2003; D. Watson unpubl. data.

The standard technique of recording observations on an underwater slate has, in some studies, been replaced more sophisticated audio recording devices (e.g. Alvezion *et al.* 1985; Greene & Alvezion 1989 Bortone & Martin 1991: Table 2). Greene & Alvezion (1989) showed that this sampling method was more accurate and efficient in estimates of proportionate abundance of coral reef fishes. In contrast, Bortone & Martin (1991), who used larger sample sizes, did not find this method significantly more accurate for assessing reef fish assemblages.

A combination of audio and video recording devices has been suggested to be the best method for accurately recording observations made by a diver swimming a strip transect (Bortone & Martin 1991; Harvey *et al.* 2002; Harvey *et al.* in press). Here, voice recordings can be made over a video recording (Table 2). Bortone & Martin (1991) used a method in which a diver operated a single video camera while making recordings by observing fish over the top of the camera. They stated that while the video recording provided a permanent visual record of the sampling conditions serving to aid in species identification, the field of vision was smaller than the human eye thus the lowest number of species and individuals were recorded using this method. Harvey *et al.* (2002) advanced this method further through the use of stereo-video (Figure 3).

In addition to recording abundance data, the stereo-video cameras can very accurate measure fish length thus removing a significant limitation of the strip transect method. The stereo-video system itself is detailed more in Section 3.3.2. A more accurate depiction of fish assemblages may be made with one diver swimming a stereo-video system (Figure 3) slightly in front and above another diver that makes voice recordings over the video recording into a full-face mask (Figure 4). Here, the diver has a larger field of view and therefore is likely to see more individuals than the recording. Alternatively, a single diver may operate the stereo-video system and make voice recordings at the same time (Westera 2003, unpubl. data). The video recording may be used to verify the divers observations, perhaps assess diver errors and for making accurate length estimates of fish.

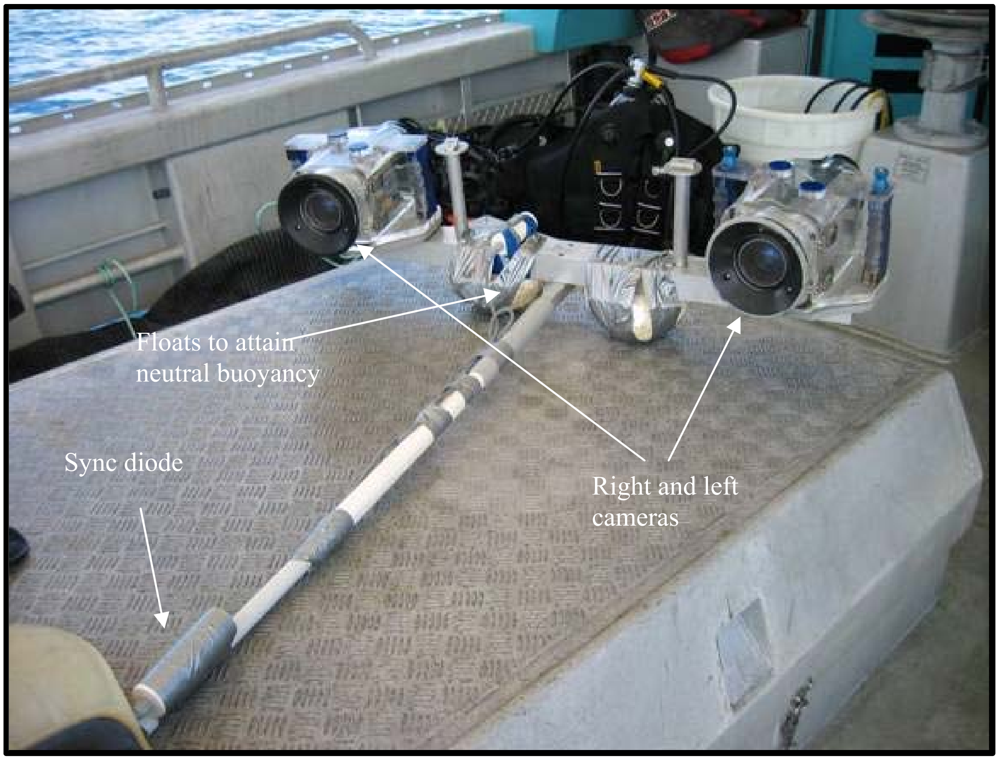

Figure 3. The swimmable underwater stereo-video system. One diver swims holding onto the two vertical bars while another diver (Figure 4) makes voice recordings of all fish seen within the transect boundaries.

Figure 4. Kim Nardi from the Department of Fisheries, Western Australia wears a full-face mask in which he makes voice recordings of all fish seen within the transects boundaries. The voice recordings are directly overlayed onto the video images captured by the left camera (Figure 2).

3.1.3 Improving the application of UVC

In order to improve UVC sampling techniques we must first have a greater understanding of how the numerous biases the technique introduces affect results both spatially and temporally.

The first step may be to examine how fish assemblage structure changes when a diver enters the water, i.e. examine fish behavioural changes in response to the presence of a SCUBA diver. This may be achieved through the use of underwater video, a project I am currently undertaking as part of my PhD studies. If, for example, a diver does not see lutjanids or lethrinids, as discussed by Cappo & Brown (1996) for the Great Barrier Reef (GBR), but underwater stereo-video does, then calibrations may be investigated that can be incorporated into UVC results.

Another method of improving the accuracy of UVC is through promotion of marine conservation by education. Whether it involves teaching students how to conduct UVC's as a profession, or tourists at popular dive locations. In this way, if conducted often enough, results would benefit management while increasing community understanding and appreciation of the marine environment. A technique that is used universally (e.g. same distance, time, number of divers, equipment etc), rather than there being variations on transect methods (see Table 2) would be more useful by promoting a greater understanding of results produced from different areas and perhaps even allowing for comparisons of these results in certain instances.

Furthermore, advances in technologies that assist UVC by increasing accuracy and precision of results, e.g. underwater video, may become more affordable, accessible, prevalent, simple and more accurate than at present.

3.2 Hydroacoustics

Commercial and recreational fisheries customarily use remote acoustic sensing of the seafloor and fish aggregations to locate fish and as such provide the majority of data for stock assessment estimates of a variety of pelagic and demersal temperate fish (Thorne

1983 cited in Cappo & Brown 1996). The advantages and disadvantages of remote acoustic sensing of fish aggregations are presented in Table 3.

In Australia, companies such as SonarData Pty Ltd, Hobart Australia (www.sonardata.com), are continually developing and upgrading software such as *Echoview* that is fast, flexible, powerful and modular. *Echoview* offers scientists powerful and efficient tools for assessing the biomass of aggregated fish and zooplankton by echointegration methods (SonarData 2004). Acoustics are effective at examining schools of single species and well defined mixes of species that are in the water column. The technique is particularly useful for studying fish such as tuna or with side-looking instruments for salmon in a river environment. Acoustic techniques are continually being developed by SonarData to provide information on species identification, stock assessment, tracking and behavioural studies of individual fish, however, at this stage such techniques are not feasible for assessing the abundance and diversity of schools of multispecies of reef fish over topographically complex reef structures.

There are large differences in the acoustic signals produced by different species of fish due to unique characteristics of their swimbladders. Differences in target strength can arise from fish length, aspect, tilt angle and position in the sound field (Cappo & Brown 1996). Species identification from acoustic signals is at an early stage of development (Cappo & Brown 1996), however, with improvements in biases in echogram interpretation and resolution of species close together and near complex seabeds (Barans 1982); acoustic signals may become a very useful sampling technique.

Table 3 The advantages and disadvantages of acoustic remote sensing in the censusing of fish assemblages and examples of studies that have used or reported on the method.

Advantages	Disadvantages	References
• Non-destructive/extractive • May be useful for estimating population sizes when used in conjunction with ground-truthing methods • Wide area coverage • Reduced effects on fish behaviour • No deployment of gear	• Analyst bias in echogram interpretation • Need for species identifications • Acoustic resolution of fish close together or near the sea bed not strong.	SonarData 2004; Barans 1982; Barans & Holliday 1983; Cappo & Brown 1996; Arrhenius *et al.* 2000.

3.3 Underwater video cameras

Rapid advances in technology have fuelled the use of underwater video cameras to obtain accurate and precise estimates of relative fish abundance, diversity and length in shallow water (Willis *et al.* 2000; Willis & Babcock 2000; Harvey *et al.* 2001a,b;2002) and deepwater (Priede & Merret 1998; Yau *et al.* 2001) habitats. The two main types of underwater video are single video and stereo-video. Each may be deployed to film either a fixed field of view (downward facing) or no fixed depth of field (parallel to seabed) and may be baited to attract a greater number and diversity of fish. Cameras may be equipped with infrared lighting for studies at night or at depths exceeding light penetration.

3.3.1 Single video

For single video, few researchers use a downward facing camera mounted on a stand that has a fixed field of view over the seabed (e.g. Sainte-Marie & Hargrave 1987; Priede & Merret 1996; Willis & Babcock 2000; Figure 5). This method relies on counts of the number of fish that pass through a very limited filed of view. More common is the use of single video in a stand that rests on the seafloor and films parallel to it (e.g. Ellis & DeMartini 1994; Harvey *et al.* 2002; Cappo *et al.* 2003;b; Figure 6). As discussed previously, another option is for a SCUBA diver to swim a single video camera in the same manner as an UVC strip transect (Davis & Anderson 1989; Bortone & Martin 1991) or for a boat to tow a video camera mounted in a frame over the seabed (Bowland and Lewbel 1986). Visit www.aims.gov.au for footage from studies and additional information on single video.

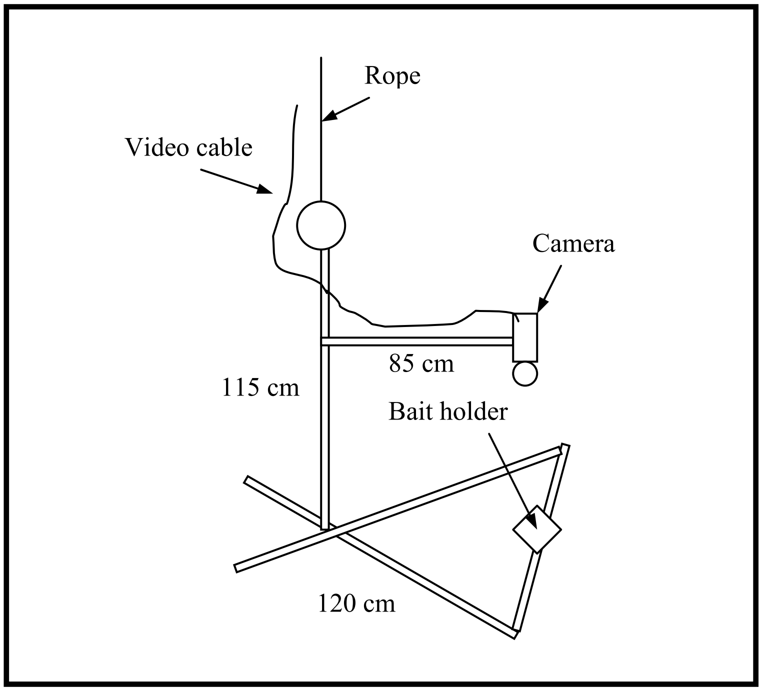

Figure 5. Baited underwater single video assembly, with dimensions of the stand- used by and modified from Willis & Babcock (2000).

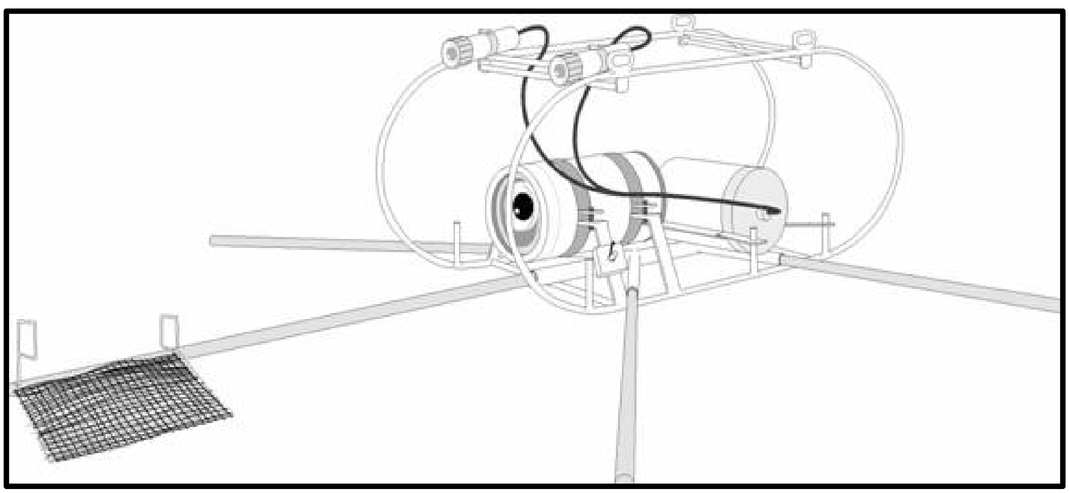

Figure 6. A single video camera system equipped with lights that rests on the bottom and films parallel to it (Cappo *et al.* 2004).

3.3.2 Stereo-video

The stereo-video camera system (two video cameras calibrated together) was developed as it provides much more accurate and precise position (range and bearing) and orientation of a fish target that can be measured directly (Harvey 2002). Measurements are made using digitally captured images in the VMS computer software program

(Shortis & Robson 2003; visit www.geomsoft.com). Stereo-video is much less restricted by range and subject orientation than single video. Researchers most commonly deploy the stereo-video system fixed to a frame that rests on the seafloor filming parallel to it (e.g. Harvey & Shortis 1996; Petrell *et al.* 1997; Harvey *et al.* 2001a;b; 2002; Figure 7).

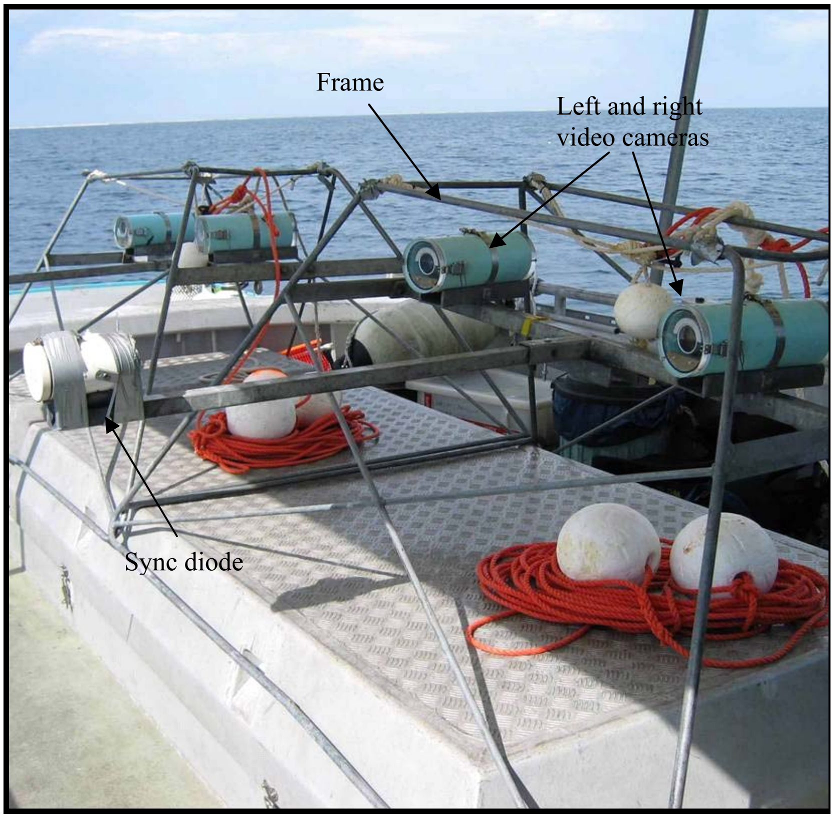

Figure 7. The stereo-video camera system developed by Dr. Euan Harvey from The University of Western Australia. This particular frame was designed for use in temperate environments for elevation above seagrass beds.

Since accurate information on length frequency, width and height of fish, and the distance between individual fishes can be measured very simply, the stereo-video camera technique has become a useful tool for data collection on wild and cultured finfish. Many aquaculturists worldwide now employ the technique, either filming parallel to the cage floor or from the top of cages looking down, to measure fish during transfers (e.g. Petrell *et al.* 1997; Harvey *et al.* 2001; Harvey *et al.* in press). As with the single video, and as discussed previously, a SCUBA diver conducting a strip transect may swim a stereo-video camera set-up (Figure 3). As mentioned, this allows for correct definition of transect boundaries and therefore more accurate and precise estimates on relative fish abundance as well as the ability to obtain length measurements and retain images for future use.

3.3.3 Advantages and Disadvantages

The advantages and disadvantages of underwater video (single and stereo) are presented in Table 4. Of the numerous ones listed, perhaps the biggest advantages of using underwater video cameras to assess changes in fish assemblages is that they allow for very accurate and precise length measurements, can be deployed to depths exceeding 250m, are non-invasive and retain information on a permanent record. None of these are achievable by SCUBA divers conducting UVC's. There is the general misconception that video techniques are costly. Whilst the initial costs of setting up a stereo-video system may appear high (approximately $5000 for a single frame and 2-camera set-up; Figure 7), the associated reduction in costs with subsequent usage is high due to the significant reduction of time required in the field.

The greatest pitfalls of underwater video as a fish assemblage assessment tool are the initial cost of setting up the equipment and its inability to measure the absolute density of fish. Only the relative density of fish is obtainable to avoid repeated counts of the same fish. Relative density is defined as the maximum number of individuals belonging to a single species present in the field of view at one given time (hereafter referred to as MaxN) and is a conservative measure. The measure is further confounded when bait is used to attract a greater number and diversity of fish to the camera station (Table 4). The total area effectively sampled when using bait may be greater than in the absence of bait (depending on currents and feeding activity at the bait bag). Some studies have attempted to derive the absolute density of abyssal and deep sea fishes by using data on MaxN, arrival times, current velocities, fish swimming speeds and models of bait plume dynamics (see Priede and Merret 1996 for a review). While the models do provide useful information on fish behaviour, determination of absolute density is undermined by the large and numerous assumptions that had to be made to obtain it.

Table 4. Advantages and disadvantages of the most common underwater video fish sampling techniques.

Video technique	Advantages	Disadvantages	References
Unbaited single video camera	• Non-destructive/extractive • Less restricted by time of day • Diver effects and observer bias can be avoided • Measurements of fish length can be estimated in an objective and unbiased manner • Information retained on a permanent record allows for more variables to be measured and choices of which organisms to sample • Replication of samples simple	• Cameras unlikely to record cryptic/hiding reef species • Influenced largely by visibility • Due to the inability of cameras to recognise repeated entrances of the same fish, the maximum number of fish sighted in a single field of view (*MaxN)* may only be used to calculate fish density and length frequency = underestimation of true abundance and inaccurate length estimates as a result of possible variations in fish behaviour. • Measurements of fish length are not as precise or accurate as stereo-video	Sainte-Marie & Hargrave 1987; Priede & Merret 1996; Willis & Babcock 2000 Ellis & DeMartini 1994; Harvey *et al.* 2001a,b; 2002; Cappo *et al.* 2004; in press.
Baited single video camera	• As per unbaited single video camera, + • Attracts a greater number and diversity of fish species = more representative of whole community than unbaited cameras	• As per unbaited single camera, + • Many biases are introduced that may need to be accounted for: 1) distance of bait plume (current speed and direction, fish swimming speed) 2) behaviour of fish to bait (arrival time, staying time, swimming speed) 3) behaviour of fish to other fish around the bait (displacement or attraction, size class differences)	Ellis & DeMartini 1994; Priede & Merret 1996;1998; Willis & Babcock 2000; Willis *et al.* 2000; Collins *et al.* 2002; Cappo *et al.* 2004; in press.
Swimmable single video camera	• As per unbaited single video + • Video data can be compared to and/or combined with diver counts to provide more information	• As per unbaited single video camera, + • Numerous other biases introduced with a diver swimming a transect: 1) diver speed 2) diver fatigue, age 3) diver experience 4) fish behavioural changes in response to a diver	Gotshall 1986; Davis & Anderson 1989; Bortone & Martin 1991.

Unbaited stereo-video camera system	• As per unbaited single video camera, + • Diver effects and observer bias can be measured • Precise and accurate estimates of fish size and sampling area in an objective, unbiased manner	• As per unbaited single camera, although superior to single video in obtaining length measurements	Boland & Lewbel 1986; Cappo & Brown 1996; Lines *et al.* 2001; Cappo *et al.* 2004; in press; Harvey *et al.* in press; D. Watson unpubl. data.
Baited stereo-video camera system	• As per unbaited stereo-video cameras, + • Attracts a greater number and diversity of fish species = more representative of whole community than unbaited cameras	• As per unbaited stereo-video cameras, + biases that need to be measured listed for baited single video cameras above	Cappo & Brown 1996; Cappo *et al.* 2004;in press; Westera *et al.* 2003; D. Watson unpubl. data.
Swimmable stereo-video camera system	• As per unbaited stereo-video cameras • Can be used in conjunction with a voice overlay of counts made from a SCUBA diver for comparisons of accuracy and later verification of species and length estimates	• As per swimmable single video camera, however accurate and precise fish estimates are possible	Harman *et al.* 2003; Westera 2003; D. Watson unpubl. data.

3.3.4 Improving the application of underwater video

The goal of underwater video, as with all other techniques, is to obtain accurate and precise measurements of fish density, diversity and length so that management of fish assemblages can occur effectively at an assemblage level. While diversity and length measurements are accurate and precise at present, measurements of density are not. Furthermore, the process of making measurements of fish length is time consuming and presents a bottleneck in analysis. A solution to this problem is currently being worked on by Prof. Mark Shortis, and Dr. Stuart Robson at the Royal Melbourne Institute of Technology and by Dr. Jim Seager at The University of Western Australia. These researchers are developing software that will be fully automated and able to identify, measure and count individual fish in a field of view with one click of the mouse. This software should be fully developed and ready for use by 2006 which will significantly reduce analysis time. Ultimately, there is the hope that one-day cameras will "see" as well as the human eye. Technology is rapidly advancing towards the development of cameras that are able to view multiple angles at one time, i.e. creation of a 360-degree lens that can be used underwater. Significant advances in technology are continually making video-cameras more affordable and simple techniques for studying fish assemblages.

4. CONCLUSION

As shown, there are many different methods that are used for studying fish assemblages; therefore, it is essential that research objectives are clearly defined so that the most appropriate technique may be chosen. It is paramount that the sampling design be representative of the areas of interest and have sufficient replication to detect patterns over time and space. In order to ascertain the true effects of fishing or protection on fish assemblages, studies must unobtrusively be able to accurately and precisely measure absolute density, diversity and length of all fish species, not just the target ones, to the greatest depths in the area of interest, without modifying fish behaviour. Until the necessary advances in underwater video and hydroacoustic techniques are made, perhaps the only way to achieve this is to use a combination of sampling methods.

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