

## Counting and measuring fish with baited video techniques - an overview

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### Abstract

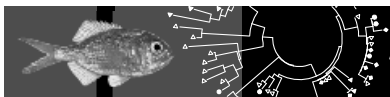
The use of remote, baited 'video fishing' techniques offer standardised, non-extractive methodologies for estimating relative abundance of a range of marine vertebrates and invertebrates, with the option of very precise and accurate length and biomass estimates when stereo-camera pairs are used. They have also been used to monitor the fate of bycatch discards and other food falls, and to help measure metabolic rates, swimming speed and foraging behaviour of abyssal scavengers. This paper gives a brief overview of the general methodology, benefits and limitations of the technique. We conclude that baited video techniques afford the only sampling option for some situations, but more often can complement other traditional methods to enhance the scope and capability of monitoring and stock assessment programs. Major advances will be made when models are developed for shallow waters to estimate absolute density of target species by accounting for the sampling area in the bait plume. Cheaper, better and smaller camera, lighting and deployment systems are inevitable, but focussed research and development is needed to overcome bottlenecks in data acquisition from tapes through incremental automation.

**Keywords:** stereo-video systems, baited video surveys, fish size, fish abundance, monitoring

### Introduction

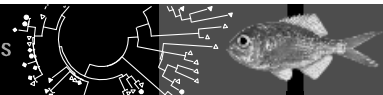
There has been a recent expansion in the application of baited video techniques to overcome the fish sampling limitations imposed by depth, fish behaviour, seafloor rugosity and the selectivity inherent in hook, trap and trawl methods. They are now proving particularly important for surveying numbers and lengths of animals in marine parks where non-destructive sampling is essential, and for animals of special conservation significance, such as sharks (see Table 1 and Cappo *et al.* 2003 for review). In general terms, a bait plume is used to attract vertebrates and invertebrates into the field of view of a video camera where they are identified, counted and often measured.

The history of the technique may be traced back to searches by Parrish (1989) for information on the location and nature of key nursery grounds for deepwater snappers on the Hawaiian shelf with simple camera systems. Initial application of stereo-video techniques were made to measure free-swimming sharks by Klimley and Brown (1983). Meanwhile, the University of Aberdeen's 'OceanLab' was developing autonomous underwater 'landers' with advanced camera systems (e.g. AUDOS and ROBIO) to assess the abundance, behaviour and metabolic rates of abyssal scavengers at immense depths (e.g. Priede *et al.* 1990, 1994). These systems have video or stills-flash camera units, onboard computer storage of data, and depth, temperature and current sensors. They are retrieved by means of acoustic release of sacrificial weights under buoy packs. Later use of closed-circuit television recording at the surface by Willis and Babcock (2000) sparked further applications to shallow reef species in studies making comparisons inside and outside marine reserves (Westera *et al.* 2003, Denny *et al.* 2004a,b). Coarse methods of length estimation were used by all these teams, until the development and testing of stereo-video techniques and software proved that remarkable accuracy and precision could be obtained efficiently (Harvey and Shortis 1996) with cheap camera systems (Figure 1a). On the Australian front, the research opportunities and gaps in all these developments were reviewed to develop a national investment strategy by the Fisheries Research and Development Corporation (Harvey and Cappo 2001). Internationally, NOAA-NMFS held a similar meeting to make progress in video techniques for fisheries science (Somerton and Gledhill 2005).

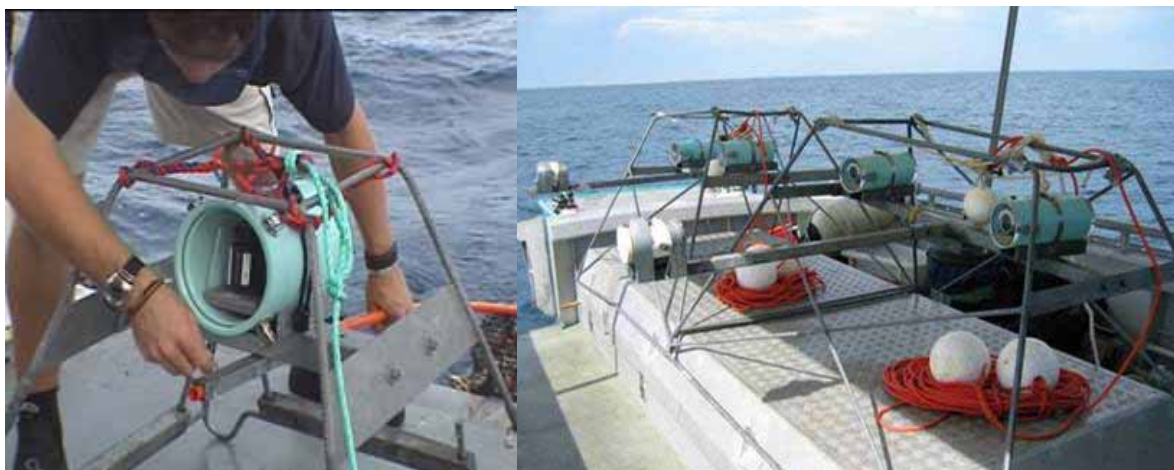


**Table 1:** Examples of baited video studies. Abbreviations are HBRUVS (Horizontal Baited Remote Underwater Video Stations), VBUV (Vertical baited underwater television), SBRUVS (stereo Horizontal Baited Remote Underwater Video Stations) and MPA (Marine Protected Areas/reserves).

Source	Region	Camera system	Depth Range (m)	Diversity	Study type
Ellis and DeMartini (1995)	Hawaii, slopes near embayments	HBRUVS CCD HandiCams	52-87	<i>Pristipomoides filamentosus</i> , <i>Torquigener florealis</i>	Comparisons of precision, accuracy and efficiency of time-based indices and <i>MaxN</i> from video with longlines; power analysis
Hill and Wassenberg (2000)	GBRMP; prawn trawl grounds	HBRUVS CCD HandiCam	10-29	9 fish taxa, unidentified sharks, crabs, squid and gastropod	Monitoring fate of discarded fish bycatch at night on the seabed
Willis <i>et al.</i> (2000)	NE New Zealand; sub-tropical rocky/algal reefs	Tethered VBUV high resolution TV camera	<20	<i>Pagrus auratus</i> , <i>Parapercis colias</i>	Comparisons of time-based indices, lengths, and <i>MaxN</i> inside/outside MPA with angling and underwater visual census (UVC)
Westera <i>et al.</i> (2003)	Ningaloo Reef; coral reef	HBRUVS CCD HandiCams	1.5-2	23 spp; Lethrinidae, Lutjanidae, Haemulidae, Serranidae, Choerodon (Labridae)	Comparisons of <i>MaxN</i> inside/outside MPA
Denny <i>et al.</i> (2004a)	NE New Zealand; sub-tropical rocky/algal reefs	Tethered VBUV high resolution colour camera	6-30	7 spp, Sparidae, Labridae, Monacanthidae, Pomacentridae, Carangidae, Muraenidae, Scorpidae	Comparisons of <i>MaxN</i> , length measurement inside/outside MPA
Denny <i>et al.</i> (2004b)	NE New Zealand; sub-tropical rocky/algal reefs	Tethered VBUV high resolution colour camera	≤50	<i>Pagrus auratus</i>	Temporal comparisons [4 yrs] of <i>MaxN</i> , length measurement
Watson <i>et al.</i> (2005)	Hamelin Bay;	SBRUVS CCD HandiCams	<10 ?	33 spp; 22 families of teleosts and chondrichthyans	Comparison of diver-swum video and remote baited and unbaited video; species richness and <i>MaxN</i>
Watson <i>et al.</i> (subm.)	Abrolhos Islands; sub-tropical coral/algal reefs	SBRUVS CCD HandiCams			
Langlois <i>et al.</i> (2006)	SW lagoon, New Caledonia; coral reef	VBUV CCD HandiCam X 1; HBRUVS CCD HandiCam	<10 ?	HBRUVS - 14spp; Serranidae, Lethrinidae, Carcharhinidae, Acanthuridae VBUV - 3 spp; Serranidae	Comparison of remote baited systems (presence/absence and <i>MaxN</i> )
Gledhill <i>et al.</i> (2005)	Gulf of Mexico banks	HBRUVS CCD HandiCams (changing to SBRUVS with low-light, monochrome cameras)	80-120 ?	<i>Lutjanus</i> , <i>Mycteroperca</i> , <i>Balistes</i>	Development of fishery-independent indices of abundance ( <i>MaxN</i> , presence/absence), measurement of length, analysis of fish-habitat associations


**Table 1:** Continued

Cappo <i>et al.</i> (2004)	GBRMP; tropical trawl grounds	HBRUVS CCD HandiCams	18-38	76 spp; 36 families	Comparison of prawn trawl and video species accumulation curves, community discriminations
Cappo <i>et al.</i> (in press.)	GBRMP; inter-reef and shoals	HBRUVS CCD HandiCams	8-110	347 spp; 58 families of teleosts, chondrichthyan and hydrophid seasnakes	Regional-scale community discrimination along spatial and depth gradients
Meekan <i>et al.</i> (2005)	NW shelf atoll reefs	Drifted/anchored HBRUVS CCD HandiCams	5-80	carcharhinid and sphyrnid sharks	Gear development, Effects of fishing
Merritt (2005)	Hawaiian shelf edge/slope	SBRUVS ultra low-light, monochrome board camera	200-400	<i>Pristipomoides</i> , <i>Seriola</i> , <i>Epinephelus</i>	Gear development, fishery-independent indices
Yau <i>et al.</i> (2001)		AUDOS downward facing colour film still camera/flash on 1 min time lapse	900-1735	<i>Dissostichus eleginoides</i> , lithodid crabs	Estimates of relative abundance using time of first arrival in Priede and Merrett (1996) model; length estimates
King <i>et al.</i> (2006)	Mid-Atlantic ridge	ROBust BIOdiversity lander (ROBIO) downward facing digital stills camera/ flash on 1.5 min time lapse	924 - 3420	22 taxa; chondrichthyan, holocephalan, teleosts, eels. Including <i>C. (Nematonorus) coryphaenoides</i> , <i>Synaphobranchus kaupii</i> , <i>Antimora rostrata</i>	Community structure analysis along depth and latitudinal gradients. *Density and length estimates for 3 species using Priede <i>et al.</i> (1990) models


**Figure 1:** Cheap single (a, left) and stereo (b, right) systems using PVC pipe and acrylic housings in galvanised iron frames used in Australian shelf waters.

The general benefits of the technique lie in three main areas. Firstly, baited video approaches are non-extractive and do not cause major disturbance to the substrata and its epibenthos. This means they can be used in marine reserves and rugose seabed topographies, and to gather information on numbers and size of animals of special conservation significance. Secondly, large, mobile animals that avoid SCUBA divers and extractive fishing gears are included in samples (Figures 2 & 3) (see Cappo and Brown 1996 for review). All animals passing through the field of view, in response to the effect of bait or not, can be recorded (see Armstrong *et al.* 1992). This lack of size selection, and the powerful

sampling replication afforded by multiple camera units, avoids ‘false negatives’ (Tyre *et al.* 2003) and allows standardised sampling at any depth, time of day and seabed topography. Thirdly, the acquisition of a permanent tape record removes the need for specialist observers to conduct all fieldwork, allows impartial, repeatable measurements, enables standardised data collection and training in association with remote taxonomists (via emailed imagery), and provides a remarkably popular format to communicate science to the public.



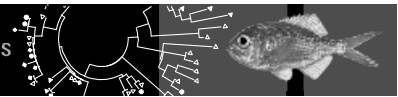
**Figure 2:** Digital still image with strobe flash showing activity around a BRUVS bait canister at 92m depth on the north-western Australian shelf, showing predatory *Lutjanus sebae*, *Pristipomoides typus*, *Lethrinus lentjan* and the parrotfish *Scarus ghobban*. Image courtesy A. Heyward AIMS.

### General Approaches and Applications

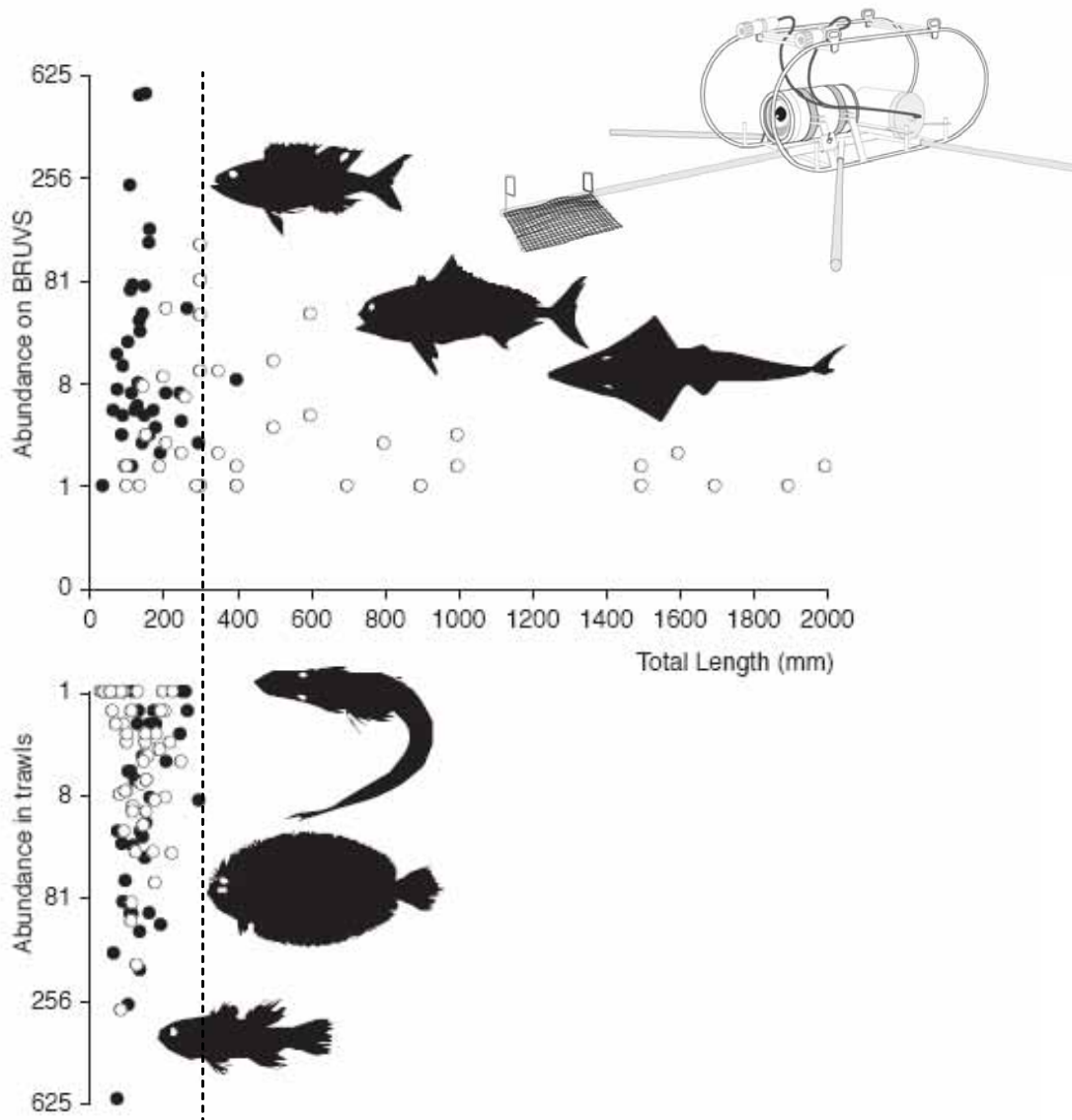
There are two main orientations of bait and camera. Vertical, look-down systems utilise a camera filming a bait canister fixed to a scale bar within a frame on the seabed (e.g. Willis *et al.* 2000). This gives a fixed depth of field and a good reference for measurements, but the subjects must be identified by the view of their dorsum from above and the full length of larger animals cannot be seen. Indeed, large sharks and rays cannot physically fit between the camera and the bait. A field comparison by Langlois *et al.* (2006) showed that some major reef fish families were shy of entering the field of view underneath a look-down camera.

Horizontal look-outward systems are used to film bait canisters lying on the seabed (Cappo *et al.* 2004), suspended above the seabed (Merritt 2005), or suspended just below the sea surface to sample pelagic species (E. Heagney and I. Suthers UNSW pers. comm.). The depth of field is generally not fixed or measured with such systems, although this parameter can be fixed accurately using stereo-video systems (see below). To identify and count fish all around the bait station, the ‘SEAMAP’ system used by NOAA-NMFS has 4 cameras filming simultaneously at all points of the compass (Gledhill *et al.* 2005).

The bait plume aggregates fish for counting and measurement through olfactory, auditory and behavioural cues (Armstrong *et al.* 1992). Vertebrates such as bony fishes, sharks and rays, and seasnakes come not just to feed, but are also influenced by the general activity in the field of view.



Some species (especially wrasses) are highly territorial and, if a video system lands in their home range, they will move about in the field of view in agonistic encounters. Others, like some herbivorous scarids and corallivorous chaetodontids, are indifferent to the bait, but seem interested in the general activity around it. Fish feeding behaviour at the bait canister stimulates others to approach (Watson *et al.* 2005), and it is probable that some large predatory carangids and sphyraenids are attracted by the presence of small prey species. Large sharks and rays attended by schools of carangids and scombrids will often investigate the bait and their attendant species are identified and counted. Only 58% of species actually touched the bait canister in the diverse trawl-ground fauna sampled by Cappo *et al.* (2004).



**Figure 3:** Differences in vertebrate size and form recorded by baited video techniques and trawls, adapted from Cappo *et al.* (2004). Each symbol represents the average total length of one species of vertebrate. Filled symbols are species recorded by both techniques. Open symbols are species recorded by only one technique. The dotted line marks total length of 300 mm. Silhouettes indicate some of the species unique to each technique.

There are a number of measures of the timing and magnitude of sightings of vertebrates that can be derived from tapes to produce counts and indices of abundance. The first type concern the time elapsed before arrival and departure of species in the field of view. The difference between the two

times is the duration on tape. The second type comprises the counts of maximum number of individuals (*MaxN* or *npeak*) within particular short segments [usually 30 seconds or 1 minute] or frames of video. In some applications, the sediment, topography and epibenthos in the field of view is classified before tape reading begins, and measurements of targets are made by comparison with simple scale bars, between paired lasers targets falling on the fish, or anywhere in the field of view with stereo-video (see below).

Given the nature and expense of field conditions and logistics it is somewhat surprising that the greatest advances in the theory to estimate densities from baited video have been made in the studies of abyssal scavengers (e.g. Priede *et al.* 1990, Priede and Merrett 1996, Sainte-Marie and Hargrave 1987). These models do not translate directly to shallow water species, so there has been a marked divergence in indices of abundance between abyssal and shallow studies. These divergent approaches are reviewed here.

### **Deepwater density estimation**

Baited video has been used in very long deployments (tens of hours to days) to study abyssal scavengers. The foundation of these studies is the theory developed by Priede and Merrett (1996) that the number of fish visible at the bait is the result of an equilibrium between arrivals and departures, and the 'staying time' or 'giving up time' is governed by Charnov's marginal value theorem of optimal foraging. This states that the staying time of an animal at an exhaustible food source is inversely related to the probability of finding an alternative food source. Thus Priede *et al.* (1994) found the *npeak* of abyssal grenadiers was higher at an oligotrophic location with low fish population and low food abundance because individuals stayed longer at the bait, whereas in a food rich area with high population density the arrival rate was high because of the higher population, but *npeak* was low because individuals gave up trying to gain access to the bait and left within an hour.

Using strict assumptions that all fish are distributed randomly and evenly, and that they respond immediately, positively and independently from one another, to interception of a bait plume, Priede *et al.* (1990) developed a model of fish density using the 'shark's fin curve' (Figure 4). In a plot of number of fish at time *t* (*Nt*) against the soak time (*t* minutes) an initial fish arrival rate is relatively rapid, rising to a peak (*npeak*) and declining as fish depart. A curve fitted to the data cloud can be broken up into a steeper arrival curve and a shallower departure curve, which are identical in shape, but are separated by a time that corresponds to the mean 'staying time' of fish. The difference between the two curves gives the actual number present in the OceanLab studies (e.g. King *et al.* 2006).

Theoretical population densities were calculated by Priede *et al.* (1990) from the time of arrival of the first scavengers to the bait using an inverse square law:

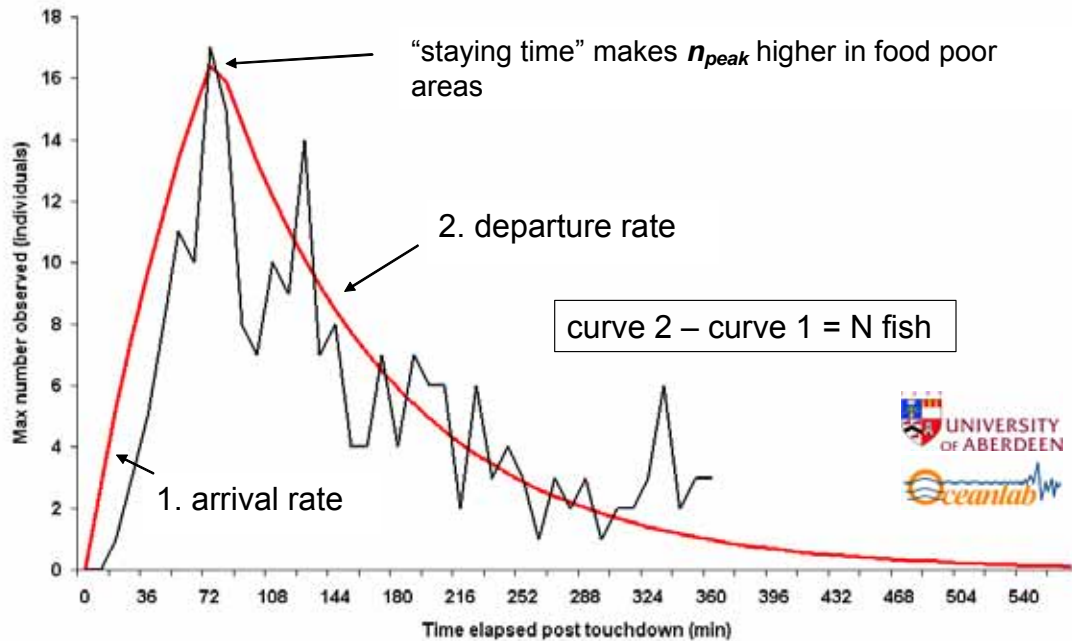
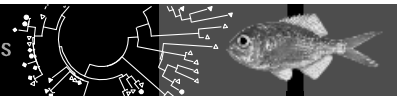
$$N = C/t_{arr}^2$$

where *N* is the density of fish per square kilometre, *t<sub>arr</sub>* is the time delay between the bait landing on the seafloor and the arrival of the first fish in seconds;

$$C = 0.3848(1/V_f + 1/V_w)^2$$

The constant *C* depends on the water velocity in (*V<sub>w</sub>* ms<sup>-1</sup>) dispersing the bait plume down-current, and swimming velocity of the fish toward the bait (*V<sub>f</sub>* ms<sup>-1</sup>).

Bailey and Priede (2002) qualified why such estimates are strongly affected by the assumed foraging behaviour of the fish species concerned. They modelled three of the possible foraging strategies (cross-current foraging, sit-and-wait, and passive drifting) of abyssal scavengers and the likely patterns of fish arrival at bait stations were calculated for the same fish density, swimming and current velocities and odour plume properties. Each model produced a distinctive pattern of animal arrivals that may be diagnostic of each foraging strategy.



**Figure 4:** An application of the Priede *et al.* (1990) method of estimating the absolute number of an abyssal scavenger *Coryphaenoides (Nematonurus) armatus* visiting a bait station for a deployment of ROBIO by King *et al.* (2006). The number of fish present at time  $t$  (minutes) post touchdown was recorded in 9-10 minute intervals, and a curve was fitted to this data using the model :

$$N_t = \alpha_0 / \chi e^{-\chi t} (e^{\beta \chi - 1}) \text{ if } t > \beta$$

$$N_t = \alpha_0 / \chi (1 - e^{-\chi t}) \text{ if } t \leq \beta$$

where  $\alpha_0$  is the initial arrival rate of the fish (individuals  $\text{min}^{-1}$ ),  $\beta$  is the mean staying time of the fish (minutes) and  $\chi$  is the bait decay constant. The model produces a characteristic 'shark's fin' curve (courtesy of Dr Nikki King, OceanLab, University of Aberdeen).

### Relative abundance in shallow water

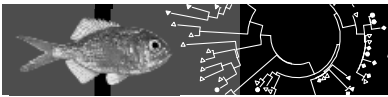
The abyssal scavenger model was tested for Patagonian toothfish by Yau *et al.* (2001) who noted that, for shallow-water applications, the inverse relationship between abundance and the square of the average arrival time will cause problems. Since abundance is proportional to the reciprocal of the square of the arrival time, a doubling of the arrival time produces a four-fold decline in Priede and Merrett's (1996) abundance estimate. Mean arrival times in shallow deployments occur at the level of seconds to minutes, rather than the tens of minutes to hours in abyssal studies. Shallower deployments also can produce far larger numbers of fish in the field of view. Shallow water studies have therefore neglected Priede and Merretts' theoretical approach to density estimation in favour of informative comparisons of indices of relative abundance amongst treatments, times and places.

Ellis and De Martini (1995) recorded the maximum number of fish seen in a one second interval (*MAXNO*), the time of arrival (*TFAP*), and a total duration of visit during a sequence (*TOTTM*). Their best video indices of relative abundance were calculated as means to standardise for multiple deployments per station and were derived as:

$$\text{Log of Means (LM)} = \ln[(\sum_{i=1}^n x_i / n) + 1]$$

Where  $x_i$  = the individual datum for a variable (*MAXNO*, *TFAP*, or *TOTTM*) for each deployment at a station, and  $n$  = the number of deployments per station.

They found that *MAXNO* for the sharp-tooth snapper *Pristipomoides filamentosus* and puffers *Torquigener florealis* was highly correlated with the total duration on video and time to first appearance of the respective species. They also found a positive correlation between *MAXNO* and long-line catch rates. *MAXNO* and *TFAP* were highly correlated, suggesting the greater the snapper and puffer density, the faster the fish arrived at the bait.



Willis and Babcock (2000) and Willis *et al.* (2000) compared the *MAXn* from baited underwater video (BUV) with Underwater Visual Census (UVC) and angling, and also found that *MAXn* was positively correlated with fish abundance. Their studies, inside and outside a marine reserve, included snapper *Pagrus auratus* and blue cod *Parapercis colias*. During a 30 minute BUV deployment, the number of each species recorded at the bait in 30 second intervals was recorded to derive the *MAXsna* and *MAXcod* present in a sequence, together with the time at which these maxima were recorded (*t MAXsna*), the time of first arrival of each species (*t1<sup>st</sup>sna*), and the persistence of the external bait (*tBG*). *MAXn* was the best index, but blue cod responded to bait so well that speed of arrival *t1<sup>st</sup>cod* also reflected abundance. Statistically significant effects were detected after only 5 minutes, and only became more significant with increasing time of deployment of the BUV. Later use of the same technique documented replenishment of snapper onto reefs closed to fishing (Denny *et al.* 2004b).

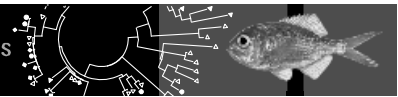
Since 1992, the annual Southeast Area Monitoring and Assessment Program (SEAMAP) baited video survey has aimed to provide a fishery-independent index of the relative abundances of lutjanid snappers and serranid groupers associated with offshore banks and ledges on the shelf of the Gulf of Mexico. The SEAMAP system uses a single 'pod', baited with squid, with four cameras mounted orthogonally at a height of 30 cm above the seabed. Analysts interrogate 20 minutes of one video tape from each station to identify and enumerate all species. The time when each individual fish enters and leaves the field of view is recorded. This is referred to as a time in - time out procedure (TITO). Tapes are sub-sampled if a large number of fish of a given species makes following individual fish difficult, if large numbers of fish occur in pulses periodically during the tape, and if single or multiple schools of fish pass in the field of view. Three estimators of relative abundance are derived from the video data -- presence and absence, the maximum count (each individual of each species is counted repeatedly each time it appears in the field of view), and the greatest number of each species that appear at once, termed 'minimum count' (*mincount*). A delta-lognormal model (Lo *et al.* 1992) is employed to make a combined annual *mincount* index from two distinct generalized linear models -- a binomial (logistic) model which describes the proportion of positive *mincount* (presence/absence) and a lognormal model which describes variability in the non-zero *mincount* data.

The *mincount* of Gledhill *et al.* (2005), the *Maxsna* of Willis *et al.* (2000), the *MAXNO* of Ellis and DeMartini (1995), the *MaxN* of Cappo *et al.* (2004) and the *npeak* of Priede *et al.* (1996) are all homologous. They have the advantage of avoiding multiple counts of the separate visits of the same individual fish to the field of view, and they offer conservative comparisons. The laboratory time consumed by tape interrogation and data recording, coupled with observer fatigue, are a major bottleneck in the tape segment and TITO approaches described above. Tape processing ratios of about 1:1 tape reading time to tape duration were reported for single-species interrogation of BUV tapes by T. Willis (pers. comm.) and 13:1 for SEAMAP stations by Gledhill *et al.* (2005).

Faced with the prospect of large species lists in the tropics (it is not uncommon to record 40 species on one tape), high abundances and numerous replicates, research teams at the Australian Institute of Marine Science (AIMS) and University of Western Australia (UWA) have profitably derived the statistic *MaxN* at the level of the whole tape in biodiversity surveys, rather than individual segments (see Cappo *et al.* 2003, 2004 for review). Tape processing ratios of about 0.5:1 prevail in accumulating *MaxN* and related events and times with support by a software interface (see below). We have used *MaxN* directly in analyses, but not yet applied indices using *t<sub>arr</sub>*, although we presume that abundant species will be prevalent (high *n*) on most replicates set within a station (*N*), and have a low *t<sub>arr</sub>*, a high *MaxN*, and a short time elapsed before *MaxN* occurs (*t<sub>MaxN</sub>*). This could be formalised by combining these different metrics in an untested index as:

$$\text{BRUVS Index of Abundance} = (\text{mean } MaxN)(n/N) / \text{mean}(t_{arr}).$$

Current deployments by the Hawaii Undersea Research Laboratory aim to compare cost-benefit ratios and indices of relative abundance of all tape interrogation approaches (pers. comm., D. Merritt) to derive standard procedures in studies of shelf-edge snappers and groupers. These trials will use the BOTCAM low-light stereo-video system (see <http://www.pifsc.noaa.gov/cred/botcam.php>).



### **The effect of bait**

Striking differences have been recorded in catches from baited and unbaited fish traps (Munro 1974, Cappo and Brown 1996) so it is commonly presumed that samples from baited video are also biased towards predatory or scavenging species and exclude herbivorous or omnivorous species. Such dynamics would severely bias the discrimination of fish assemblages in biodiversity surveys. Instead, field comparisons of baited and unbaited remote underwater video stations by Watson *et al.* (2005) and Harvey *et al.* (in press) showed the use of bait actually increased the ability to discriminate fish assemblages in distinctive benthic habitats in tropical and temperate Australia. This was due to the increased numbers of individuals and species sampled at the baited stations. Similarly, baited video stations consistently sampled more individuals and a higher species diversity of the species recognised as herbivores or feeders on invertebrates/algae than the unbaited stations. The use of bait also increased the similarity of samples within a habitat, which improved the statistical power to detect changes in fish populations at the assemblage level, and attracted more individuals closer to stereo-video camera systems for measurement.

Watson *et al.* (2005) compared estimates of species richness and relative abundance of reef fishes using diver-operated stereo-video strip transects, baited remote stereo-video and unbaited remote stereo-video. There was an interaction between topographic relief and main effects of survey method, but the use of bait provided the richest species lists and most individuals, regardless of reef relief, with the least sampling effort. Baited remote video recorded the large predatory fish species known to be shy of divers, such as the Samson fish *Seriola hippos*, West Australian dhufish *Glaucosoma hebraicum* and the Port Jackson shark *Heterodontus portusjacksoni*. None of the techniques sampled small cryptic fish families such as gobies and blennies, and a combination of survey techniques was recommended for comprehensive surveys of fish assemblages for biodiversity inventories.

Whilst shallow water studies are yet to directly estimate the area of attraction caused by bait plumes, there have been some attempts to ensure that replicates are independent of one another. Ellis and DeMartini (1995) proposed that at distances of greater than 100m separation their replicate 10 minute sets of baited videos were independent, because the greatest distance of fish attraction was only 48-90 m for a 200 mm fish in a current velocity of 0.1- 0.2 ms<sup>-1</sup>. This assumed a maximum swimming speed of approximately three body lengths per second for a 200 mm fish ( $V_f = 0.6 \text{ ms}^{-1}$ ). Given a seasonal prevalence of current ( $V_c \sim 0.2 \text{ ms}^{-1}$ ) in Australian studies, 60 minute soaks ( $St$ ) of baited videos may have an effective range of attraction ( $AR$ ) of ~480 m for fish of ~200-300 mm length. This comprises 40 minutes of advection of the bait plume down-current and 20 minutes of fish swimming time up-current to reach the field of view in time to be recorded on the tapes. This relationship was presented by Cappo *et al.* (2004) as:

$$AR = 60 \times (St) \times ((V_f \times V_c) - V_c^2) / V_f$$

in justification of distances of separation of 450 m between BRUVS replicates in biodiversity surveys.

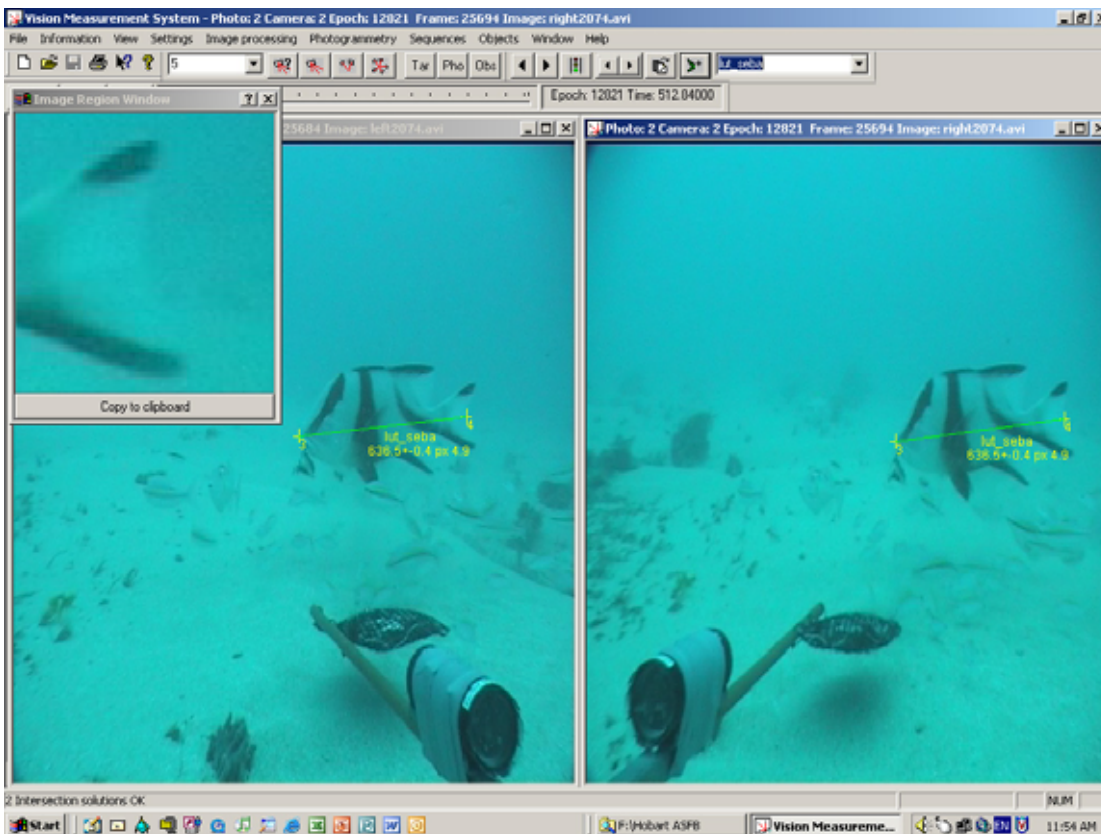
### **Target Measurement**

Fish are measured on video footage by comparison with scale bars or laser spots in the field of view, or by using paired images supplied by stereo-video. Advanced image analysis packages such as SigmaScan™, Image-Pro Plus™ or simple alternatives such as ScreenCalipers™ can be used to make measurements calibrated by scale bars. However, Harvey *et al.* (2002) showed that accuracy of such a procedure is degraded by the rotation of the subject beyond 20° relative to the camera, reduced when the subject is in the same plane as the calibration bar but more than one metre away from it, and severely compromised when fish were behind or in front of the calibration bar. The use of paired lasers is limited by the infrequency of occurrence of measurement opportunities when laser spots fall broadside on fish passing through the beams. Gledhill *et al.* (2005) reported only 50 measurements of *Mycteroperca* in 8 years of deployments of the SEAMAP baited video system. Such measurements are also severely compromised by angles of rotation of the fish relative to the focal plane of the camera, and estimates of distance (range) are not available unless triangulating laser systems are used (see Harvey *et al.* 2002 for review).

### Stereo-video systems

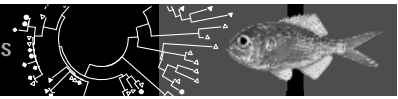
Such coarse estimates of length from single-video have proven useful in studies of effects of marine park zonation on fish size (Willis and Babcock 2000, Denny *et al.* 2004a, b). However, the remarkable accuracy and precision provided by underwater stereo-video systems promise much more powerful detection of subtle differences in length, biomass and body condition from small sample sizes. Small differences in length not detectable by UVC can equate to quite significant differences in the potential spawning biomass between fished and unfished areas (e.g. Watson *et al.* *subm.*).

A stereo-video or stereo-digital still camera system comprises two or more cameras in housings fixed to a base bar where the separation and angle of convergence (relative orientation) of the camera lenses to one another remain fixed and stable, providing points of perspective. The choice of camera separation and convergence depends on the broad range of target lengths and ranges expected. Given some basic starting information and a set of calibration images, the relative orientation and the focal lengths of each camera are determined using calibration software. Using these calibration files it is possible to measure the location of points in three dimensions relative to the cameras and base bar (X,Y and Z coordinates) (Figure 5). These three coordinates allow computation of the length, range, angle and bearing of targets anywhere in the field of view (Shortis and Harvey 1998).



**Figure 5:** Screen-dump of stereo-video measurement windows in the Vision Metrology Systems (VMS) showing measurement of a red emperor *Lutjanus sebae* 636 mm in fork length.

Two types of stereo-video calibration and measurement software are now available – the Vision Metrology System™ (VMS; <http://www.geomsoft.com/>) and the SeaGis PhotoMeasure™ system (<http://www.seagis.com.au/>). The SeaGis™ system incorporates measurements of volume and surface area for complex objects (see Abdo *et al.* 2006). Field tests with captive tuna and measurement of plastic fish silhouettes show fish can be routinely measured to within 1-2 % of their true length, independent of the skill of the operator and with consistent repeatability (see Harvey *et al.* 2002b, 2003). Small pomacentrid damselfishes (~30 mm) to very large tiger sharks (~3100 mm) are now being measured at ranges up to 9 m (depending on fish size) using the same camera systems with the



same relative accuracy (e.g. Watson *et al.* subm.). The software is simple to use and provides a permanent record, removing the need for specialist observers and allowing the involvement of volunteers in monitoring programs.

The ability to determine target range and direction allows the precise definition of a sampling hypervolume in three dimensions. This enables decisions on whether or not a fish is inside or outside a prescribed sampling unit and enables direct measurement of fish swimming speeds – an essential parameter in Priede's density model. The inability to measure the distance to targets with single baited video cameras prevents standardisation of depth of field in sampling protocols. Changes in water visibility amongst times and locations will affect the field of view in which fish are identified and counted. Ideally, this change should be accounted for in multivariate comparisons of relative abundance in space and time.

### **Future advances to overcome limitations**

The greatest limitations on baited video techniques are imposed by water clarity and the unknown sampling area induced by bait plumes. Recent advances in developments of diodes that emit red light in the spectra invisible to marine fish offer promise of strong, even lighting with long battery life for night deployments using cheap HandiCams. For higher budgets, low-light camera systems offer crisp, clear images under natural light at remarkable depths (see <http://www.pifsc.noaa.gov/cred/botcam.php> for examples from 'BOTCAM'). Video cameras may eventually be replaced for some applications by rapid time-lapse flash photography using digital still cameras if the effect of the flash is found not to affect fish behaviour (see Figure 2). In turbid waters no lighting system or camera can provide useful imagery (see instead the DIDSON acoustic camera system described in this volume). The lack of a theoretical background to model shallow water fish densities and areas of attraction from bait plumes has been highlighted in sections above, and the other major limitations of the prevailing baited video techniques involve mainly hardware deployment and bottlenecks in tape interrogation time.

Our deployments in shelf waters to 100m shows that the use of ropes and floats to retrieve remote video units presents a number of risks, especially in areas where currents are strong. Deeper waters require longer hauling ropes, which cause more drag on both the camera unit and the floats. More floats have to be applied to prevent the hauling rope being dragged underwater and lost. This causes more drag at the seabed when waves snatch at the floats. To prevent the camera unit toppling under these influences more ballast must be applied, and a risk of snagging occurs when the camera unit is dragged into rough ground when hauling commences. With even a fast pot-hauler, grappling floats and hauling ropes consumes large amounts of daylight and ship-time when widely-spaced replicates are used within stations. Overcoming the limitations imposed by strong current and deep waters on the shelf will require the development of cheap lift-bag systems that inflate from a pony-bottle under acoustic command from the surface. More expensive solutions have been engineered and tested by Merritt (2005) who also developed novel bait mixtures and timed bait release systems for use in deep Hawaiian waters with a low-light stereo-video system.

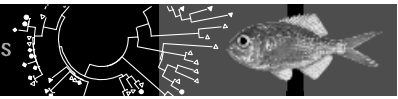
A number of promising advances in incremental automation of the analysis of the video tape records are overcoming the greatest expense and bottleneck in use of baited video – the tape interrogation and archiving time. The stereo-video measurement software mentioned above incorporate a range of image analysis features to save time in fish measurement. The BRUVS2.1.mdb<sup>®</sup> tape reading interface was built at AIMS to record species identifications, species images, event codes and event times in a relational environment with field operations data, using drop-down menus. It has a number of quality control features built in to save keystrokes, prevent coding errors and reduce observer fatigue. The collection and maintenance of a reference collection of species images allows immediate comparison of new species seen on tape with an image library. This approach facilitates training of new observers and standardisation of identifications within and amongst research teams in consultation with specialist taxonomists.

Algorithms for motion detection and pattern recognition are being adapted to the task of reducing the amount of tape to be viewed and to automatically identify targets for measurement (J. Seager pers comm.). Further automation of fish identification is probable in the future, given recent advances in

computer vision and applications to aquaculture and fish processing lines (Storbeck and Daan 2001, White *et al.* 2006). These developments will continue in a market dominated by demand for cheap, reliable systems and approaches from scientists involved in fish biology and fisheries science.

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