

POTENTIAL OF VIDEO TECHNIQUES TO MONITOR DIVERSITY, ABUNDANCE AND SIZE OF FISH IN STUDIES OF MARINE PROTECTED AREAS

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Abstract

This paper briefly reviews applications of single-video and stereo-video techniques to help survey fish community composition and relative abundance, and fish length and weight. These techniques have potential application to the initial surveys of candidate habitats for Marine Protected Areas, and to the subsequent monitoring necessary to manage them. Remote video techniques can be used in shelf depths beyond the limits of diver-based Underwater Visual Census (UVC), and stereo-video systems can also be used to complement and enhance normal UVC by allowing very precise and accurate estimates of fish morphometrics (and hence weight). Some video techniques are very cost-effective and can help remove some major sources of observer bias in underwater observations, by removing the need for skilled observers in the field and by allowing simultaneous collection of a much wider suite of information in a permanent record that can be analysed later. This medium is directly accessible to an unlimited audience. Baited, remote video techniques offer a non-intrusive, depth-independent assessment tool with the advantages of both diver-based observation and capture techniques, but appropriate sampling statistics must be developed if relative abundance is to be measured adequately.

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

INTRODUCTION

Fish and fisheries management have been the focus of many Marine Protected Area (MPA) programs – with the expectation that they will “work” by protecting unique or endangered species, maintaining biodiversity in representative areas, restoring degraded habitats, protecting breeding stocks and having a beneficial spill-over effect into adjacent areas (e.g. Sladek-Nowlis and Roberts 1999). Consequently, there has been much research interest in “Rapid Assessment Techniques” for initial surveys and robust monitoring techniques that balance field costs and data quality with the need for very long data series (e.g. Samoilys and Carlos 2000; Samway and Hatton 2001). Underwater Visual Census (UVC) has been the predominant survey tool in studies focussing on shallower coral reefs and temperate rocky reefs. More recently, however, there has been recognition that vast areas of deeper “inter-reef” and shelf habitats inaccessible to research divers are worthy of exploration and conservation, and that important bioregions there should be included in marine reserves (e.g. Pitcher *et al.* 1999). For example, only 6% of the

Great Barrier Reef Marine Park is made up of shallow coral reefs, and the remainder below 20 m depth is very poorly surveyed and not included in fishery-independent monitoring programs. On tropical shelves these habitats can be dominated in clearer waters (~50–70 m depths) by phototrophic corals, seagrasses and algae, and in more turbid or deeper waters by filter-feeding gorgonians, sponges, ascidians and bryozoans (McManus 1997). In higher latitudes, kelp and seagrass communities can extend to 50 m, to be replaced by patches and “reefs” of sessile invertebrate communities in lower light regimes (see chapters in Andrew 1999).

With the exception of occasional use of staffed submersibles, UVC of fish communities is not possible in the vast habitats at these depths. Deeper fish surveys have relied mostly on extractive fishing techniques such as trawls, traps and lines depending on seabed topography (Gaudian *et al.* 1995; Newman *et al.* 1997; Wassenberg *et al.* 1997). There have also been promising tests of some video and hydro-acoustic techniques in topographically complex habitats (e.g. Parker *et al.* 1994; Gledhill *et al.* 1996).

At the same time, the image quality of underwater television and video has dramatically improved, whilst its price has plummeted in some forms, and there has been growth in its use in deeper surveys of marine habitats (see Harvey and Cappelletti 2001 for review). Most pertinent to our paper were the developments of

1. Single or dual baited video or still-camera systems to film deeper-water fish (eg Sainsbury *et al.* 1997; Yau *et al.* 2001), scavengers of by-catch (Hill and Wassenberg 2000) and juvenile predators (Ellis and DeMartini 1995) and fishes inside and outside a marine reserve (Willis *et al.* 2000),
2. stereo-video camera systems to measure free-swimming sharks (Klimley and Brown 1983) and reef fish (Harvey *et al.* 2002a), and to measure length and biomass of fishes in mariculture sorting systems (Petrell *et al.* 1997), and
3. the use of computer vision and neural networks to recognise fish species (Zion *et al.* 1999; Storbeck and Daan 2001).

We are focussing on amalgamating developments on these three fronts to produce depth-independent video tools to harmlessly recognise, count and measure fishes *in situ* in natural and mariculture systems (e.g. Harvey *et al.* in press; Harman *et al.* in press). Here we give a selective review of the progress of video techniques in surveying fish biodiversity, and in counting and measuring individuals, with reference to their potential use in the design and monitoring of MPAs.

Potential benefits of video techniques in detecting changes inside and outside reserves

The preferred option to study the effects of reserves are spatial and temporal comparisons of multiple reserves and control areas, with long-term monitoring (Jones *et al.* 1993; Russ 2002), but suitable contrasts in the amount of disturbance have also been sought or constructed for inclusion in experimental designs (e.g. Campbell *et al.* 2001). The period before an effect becomes apparent depends on the recruitment patterns of particular organisms, their movements and migrations, their longevity, and their interactions with habitats and each other. In general, the most common effects measured have been changes in community structure, and abundance and size of organisms through time, and Jones *et al.* (1993) argue that although focus in studies of marine reserves is usually placed on popular, exploited species, reserve effects may manifest in unforeseen, long-term changes in formerly rare or absent species (or their biotic habitats) not subject to harvesting.

Without early information it is impossible to chronicle these changes.

There are two recent developments in video techniques that can play a role in making these measurements and widening the focus of fish monitoring studies – swimmable stereo-video systems to enhance UVC, and remote baited and unbaited video systems deployed to offer video surveillance of fish communities without the presence of a diver.

Swimmable video tools to enhance UVC

Underwater visual census has been a successful first choice as a sampling method in many studies of the effects of MPAs (see Russ 2002 for reviews). Jones *et al.* (1993) recommend that the variables that may be measured in UVC fall along a continuum of increasing effort, cost and sensitivity – from simply recording the presence or absence of an organism, to allocating it to an abundance category, to estimating its density per area of substratum, to estimating its size. They note that compromises must be made in UVC between the quantity of information (e.g. the number of species sampled) and its quality. Estimation of sampling area is also inherent in the complex tasks undertaken simultaneously by the SCUBA observer. Consequently, the highest levels of data collection in UVC rely heavily on relatively few specialist fish researchers who must repeatedly calibrate their performance to avoid the numerous, known sources of observer bias (see Thompson and Mapstone 1997; Kulbicki 1998; Watson *et al.* 1995 for examples).

We believe it is desirable and feasible to remove this observer bias and extend monitoring programs to less specialised staff associated with MPAs, by overcoming the need for specialist observers, by automating as many of their data-collection tasks as possible, and by providing permanent video records of their entire sample. These records allow better standardisation of data collection over long time series and can be revisited repeatedly by other observers. Short segments of footage, or still-frame grabs, of the habitats and fauna therein can be mounted in Geographic Information Systems (GIS) to provide visual tools for joint decision making by marine stakeholders and managers in selecting reserve areas, and for scientists to visually portray results of their monitoring to an unlimited audience via the Internet.

Estimates of fish size are important for detecting recruitment events, for estimating fish growth and weight, and for following cohorts through time inside and outside marine reserves (Russ 2002). In this regard, the development by Shortis and Harvey (1998) of a swimmable stereo-video

system to measure fish size, range and bearing anywhere in the field of view, and transect width, could considerably improve the performance of UVC. Underwater stereo-video systems have known, fixed focal lengths, and known distances of separation and angles of convergence of the cameras. Calibration cubes are employed to determine the three-dimensional orientations of both cameras and subjects in the fields of view. The geometric principles of airborne topographic mapping are then applied in measuring fish lengths in paired, synchronised video images (see Harvey and Shortis 1998; Harvey *et al.* 2001a, 2001b, 2002a, 2002b). Customised software has been designed to provide these measurements (VMS – see www.geomsoft.com.au) and is featured in Harvey and Cappel (2001).

Theoretical and empirical tests of such systems are now appearing in the literature (see Harvey *et al.* 2002a for review). Whereas the system of Petrell *et al.* (1997) could measure the fork length of anaesthetised salmon to within 3.0% of known length, recent improvements by Harvey *et al.* (in press) produced estimates of free-swimming southern bluefin tuna length within 0.5% of on-deck measurements of the same fish.

In the case of UVC to monitor fish populations, Harvey *et al.* (2001a, 2001b, 2002a) showed that under optimal conditions divers' estimates of model fish size were accurate (mean error = 0.87 cm) but lacked precision (mean S.D. = 5.29 cm), which greatly reduced the statistical "power" (*sensu* Peterman 1990) of their sampling to detect changes in fish length. Significant improvements in accuracy and precision were provided by a stereo-video system (mean error –0.6 cm).

Given a 10% chance of mistakenly retaining a null hypothesis of no difference (a power of 90%), a stereo-video system detected a 15% (~5 cm) difference in the mean length of blue cod (*Parapercis colias*) in New Zealand with 63% fewer samples than those required by experienced divers (Harvey *et al.* 2001b), saving both time and money in visual surveys for this sedentary species. With modification of the angles of convergence and distance of separation of the cameras, such systems can potentially measure very large animals (e.g. whale sharks) and very small fish (including new recruits), as well as rugosity and other parameters of the underlying physical habitat (Doucette *et al.* 2002). Progressive scan cameras must be employed for swimmable stereo-systems, rather than the common interlaced scanning systems, to avoid blurring of imagery by movement of both target and camera.

Unlike swimmable stereo-video systems, single video cameras cannot be used to routinely measure fish in UVC. Stationary single-video

systems can provide accurate measurement opportunities only if the subject is swimming in precisely the same plane as a calibration scale, and perpendicular to the camera. This has allowed measurement of abyssal grenadiers and detected significant differences inside and outside reserves in length of shallow-water fishes such as snapper (*Pagrus auratus*) (e.g. Priede *et al.* 1994; Willis and Babcock 2000). However, recent trials in the full envelope of ranges and angles of subject orientation by Harvey *et al.* (2002b) showed the length estimates from both digital and Hi8 stereo-video systems were substantially more accurate and precise than those obtained by single video camera systems. The best mean measurement error (13.62 ± 1.41 mm) with use of a single camera in that study was similar to that reported by Willis and Babcock (2000) of 16.9 ± 2.4 mm. In contrast, the digital stereo-video system consistently produced a mean error of only 0.22 mm, or 0.05% of target lengths, and had the great advantage that the position (range, bearing, height) and orientation of a fish target could be measured directly, anywhere in the field of stereo coverage (Harvey *et al.* 2002b).

Fish swimming speed can also be measured with the data available from stereo-video (Petrell *et al.* 1997) and, with more image analysis, a three-dimensional half-model of each fish can be constructed – allowing weight and volume to be accurately and precisely measured. Accurate estimation of weight from video image area is being tested for applications in industrial-scale fish processing (e.g. Storbeck and Daan 2001), and Zion *et al.* (1999) reported correlation coefficients between fish mass and fish image area ranging from 0.954 to 0.986 for three cultured species. The estimation of length alone, or with body depth also, can accurately estimate individual fish weights from published regressions (e.g. Santos *et al.* 2002). Advances in fish species recognition through the use of computer vision and artificial neural networks are also worthy of consideration in future development of swimmable video techniques to enhance UVC (Storbeck and Daan 2001).

Finally, the majority of observers in UVC employing strip transect or point counts do not physically mark the boundary of their sample unit, and need to rapidly estimate the distance to each fish, in order to decide whether it is inside the sampling unit. Harvey (1998) demonstrated that the magnitude of error for estimates of distance made by experienced divers may potentially result in an 82% underestimate, or 194% overestimate, of the actual area surveyed in UVC, and could greatly affect the density estimates for target species. This error was substantially reduced by use of a stereo-video

system (mean relative error = -0.9%, SD = 2.6%), where targets outside a specified sampling area can be objectively identified in video interrogation using VMS. This could also allow the distances and sighting angles required by original line-transect theory (*sensu* Burnham *et al.* 1980) to be accurately measured and applied in line-transect estimations of fish density.

This objective identification of targets inside sampling transects was used by Harman *et al.* (in press), who used a swimmable stereo-video system to estimate the densities of 50 species of fishes associated with algal reefs in south-western Australia. Like normal UVC, those surveys overlooked very small and cryptic species, but did include the major mobile and sedentary reef fish families present. This video technique allowed detection of significant differences in fish abundance in all the treatments explored – bedrock type, topography and algal community composition. Given the success of Harman *et al.* (in press) in obtaining density estimates, there is obvious potential to raise stereo-video estimates of densities and length compositions with length-weight curves to overall biomass of reef fish communities.

Controlled assessments of swimmable video techniques using 3-chip, progressive-scan cameras in comparison with normal UVC are urgently needed to test the utility and biases of such video systems to estimate diversity and density of fishes along transects. Although it may be argued that the deployment of a swimmable system, requiring a camera separation of 1.0–1.5 m depending on transect dimensions, may make the presence of a dive team even more intrusive, there is clearly some potential to remove the need for divers skilled in both fish identification and estimation of fish length and transect dimensions. Only careful comparisons and calibrations with other techniques, similar to the long history of research on UVC, will allow the true potential of such complementary video techniques to be identified (e.g. Francour *et al.* 1999).

Even if these tests prove that skilled observers cannot be wholly replaced in UVC, the miniaturisation occurring now in camera systems provides the potential for the specialist diver to combine opportunistic video measurements with routine census of diversity and numbers along transects. Camera housings are now one-fifth of the size of the units originally employed by Harvey and Shortis (1998). Combined with an underwater navigation capability (for example using GPS on an underwater computer), such video measurement tools would allow the number, size and precise location of reef fish to be mapped in “roving swims” (*sensu* Newman *et al.* 1997), which are effective in finding rarer fish

such as very large wrasses, carangids and serranids.

Remote video tools in deeper waters

Below the depth limits and beyond time limits of codes of scientific diving practice, video techniques offer great potential to record the community composition, relative abundance and size of fish without most of the “gear selection” inherent in extractive fishing techniques. Video sampling is non-extractive and, unlike research trawling, does not affect the seabed, so it allows information on protected species and “charismatic megafauna” (such as very large fish, including sharks and rays) to be repeatedly gathered in an acceptable manner in the widest range of marine park protection zones. Unlike normal fishing techniques, video also gives a detailed image of the habitat types in the sampling area.

With adequate lighting and housing materials, and control over timing of image acquisition, video techniques can be used for long durations at any time of day and potentially any depth. Three main approaches have been used: a remote camera system (the Aberdeen University Deep Ocean Submersible “AUDOS”) deployed in abyssal depths (Priede *et al.* 1994); a live-feed, television camera system tethered by an umbilical cable to an anchored boat (the “BUV” of Willis and Babcock 2000); and single or replicate remote camera systems deployed with float ropes (Ellis and DeMartini 1995; Hill and Wassenberg 2000). Whilst Priede and Merrett (1996) and Willis and Babcock (2000) have sequentially deployed a single baited underwater video at small scales, our ongoing studies are simultaneously deploying fleets of 3–10 stations with or without bait, with or without stratification by habitat and depth, in studies of seafloor fish biodiversity at large scales.

Two major advantages of this approach are an ability to greatly increase sampling replication and sampling area, and to attract fish from potentially large areas by use of bait (see section below). These advantages can be used to reduce “zero counts” in surveys of deeper waters – to raise sample means, reduce coefficients of variation and thereby increase “sampling power” (Peterman 1990). For example, previous trapping surveys in the GBRMP had many “false negatives” caused by gear selectivity and other factors (see Cappo and Brown 1996 for review), and Williams *et al.* (1997) found that there was a significant linear correlation between the mean of a trapping sample and its standard deviation.

The fleet of single baited, remote underwater video stations, or “BRUVS” (Australian Institute of Marine Science), were designed for deployment on the rugose topography of deep coral reefs, and

inter-reef shoals and soft substrata. The cameras lie 20 cm above the seabed with small scale-bars on the bait arm to allow for coarse measurements of fish in close proximity to them. The baited stereo-video pairs (University of Western Australia) are raised in a trestle-like frame 80 cm above the seabed, to allow unobstructed observations and precise measurements of demersal and pelagic fishes in heavily vegetated habitats of high latitudes, such as dense *Posidonia* seagrass beds and thick *Ecklonia* stands. Both sampling gears use cheaper single-chip digital "HandiCams" (Sony™ TRV18E MiniDV) in simple housings made from PVC pipe and acrylic sheet. They are deployed and retrieved with buoy ropes like traps and were developed for use on any seabed topography to provide a "hybrid" of the logistical advantages offered by UVC and baited fish traps, whilst avoiding some of the selectivity associated with both these methods. Unlike previous studies, we record all species identifiable in wide and deep vistas with independent, untethered cameras set in a horizontal plane, although the stereo-pairs allow definition of a specified field of view, outside which fish are not included in counts and measurements. Measurement protocols for both these systems were outlined in detail by Harvey *et al.* (2002b).

The diversity of species of fishes recorded has been exceptional: 228 in the deep lagoon at Scott Reef off north-western Australia (14°S), 194 in the inter-reef lagoon and shoals of the Central GBRMP (18°S), 42 in a pilot study of the urchin barrens and kelp reefs of the Solitary Islands of northern New South Wales (30°S), and 98 in the seagrass, bare sand, deep rhodolith beds and reefs, and kelp reef habitats of the Recherche Archipelago of south-western Australia (34°S). These included 50 mm monacanthids to 3 m sharks and rays. Set times ranged from 30 to 90 min, and the basic times of first arrival, time of first feeding, maximum number sighted in any one frame or period (*MaxN*), time of *MaxN* and other parameters have been recorded at the level of the entire tape, or in 1 min intervals, although the permanent record allows us to revisit the footage and break it up for analysis in any time increments like the studies reviewed above.

A theme of our applications across latitudes has been to characterise the associations between mobile fishes and biotic habitats at scales useful to management. Notable taxa that separate the habitats have included herbivores (scarids, kyphosids, girellids and odacids), corallivores (chaetodontids, pomacanthids) and planktivores, as well as the expected carnivores and scavengers (eg carcharhinids, mustelids, labrids, lutjanids, nemipterids, lethrinids) and generalists (monacanthids, balistids). Many of the species

sighted are notoriously shy of divers (e.g. gummy sharks *Mustelus antarcticus*, snapper *Pagrus auratus*), or not previously photographed underwater (e.g. southern sawshark *Pristiophorus cirratus*). Some of these groups, notably the sharks and carangids, have had little attention in the reef-fish literature.

Estimating relative abundance of fish by use of baited video stations

Baited videos record species attracted to the bait plume or camera station, species attracted to the commotion caused by feeding and aggregation at the station, species occupying territories within the field of view of the camera, and species indifferent to the station but present in or passing through the field of view during the deployment. The time of first arrival of a given species, the duration of its visit(s), the number present in the field of view in sequential time intervals, and the maximum number sighted in any one field of view (hereafter referred to as *MaxN*), and time of persistence of baits, are all readily available from time-coded video records. These parameters have been the focus of various models to estimate absolute density (individuals per area of sea floor) of abyssal scavenger fish (see Sainte-Marie and Hargrave 1987; Priede and Merrett 1996 for review) and relative density of predatory fishes (e.g. Ellis and DeMartini 1995; Willis and Babcock 2000; Yau *et al.* 2001).

The n_{peak} of Priede *et al.* (1994), the *MAXNO* of Ellis and DeMartini (1995), the *MAX* of Willis and Babcock (2000) and the *MaxN* of our studies are all homologous. This statistic under-estimates the true abundance of visiting fish in the bait plume. The occurrence of separate visits by different individuals of the same species is recorded as *MaxN*=1, and only a portion of a partially visible fish school contributes to *MaxN*. This usage implies more conservative estimates of abundance in high-density areas, and therefore differences detected between areas of high and low abundance (e.g. inside and outside reserves) are also likely to be more conservative.

Both Priede and Merrett (1996) and Willis and Babcock (2000) used a camera pointing downwards onto a fixed field of view on the seabed. Ellis and DeMartini (1995), Hill and Wassenberg (2000), and our studies use cameras lying on or parallel to the seabed, with no fixed depth of field – although this can be measured with stereo-video. The approaches and conclusions regarding abundance indices diverge further, with the studies of deepwater species in sets >11 h accounting for plume area of attraction in models (Sainte-Marie and Hargrave 1987; Priede and Merrett 1996; Yau *et al.* 2001), and the studies of shallower predators ignoring plume

dispersal and using various calibrations of abundance indices during short sets (10–90 min).

The major disagreement of these studies concerns the value of $MaxN$ as an indicator of abundance. Priede and Merrett (1996) have argued that the number of fish visible 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 n_{peak} of abyssal grenadiers was higher (>10) at an oligotrophic location with low fish population and low food abundance because individuals stayed longer at the bait; in contrast, in a food-rich area with high population density the arrival rate was high because of the higher population, but n_{peak} was low (<5) because individuals gave up and left within an hour.

Ellis and De Martini (1995) used two baited video units with 10 min set times and recorded $MaxN$ as the maximum number 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. They found that $MAXNO$ for the opakapaka (sharp-tooth snapper) *Pristipomoides filamentosus* and puffers *Torquigener florealis* was highly correlated with the total duration on film and time to first appearance of the respective species. They also found a correlation between $MAXNO$ and long-line catch rates, and concluded that baited-video studies on shallow, productive grounds with short soak times could not be compared directly with the work on scavengers in abyssal waters with very long sets. $MAXNO$ and $TFAP$ were highly correlated, suggesting that the greater the snapper and puffer density, the faster the fish arrived at the bait. They estimated that only 18 sets of baited video would allow detection of a two-fold change in sharp-tooth snapper abundance.

Willis and Babcock (2000) and Willis *et al.* (2000) compared the MAX_n from baited underwater video (BUV) with UVC and angling, and also found that this index was correlated with fish abundance. They suggested that the lack of continuous monitoring in the various abyssal studies over very long sets resulted in potentially important losses of information as fish moved in and out of view. The focus of their studies, inside and outside a marine reserve, were snapper *Pagrus auratus* and blue cod *Parapercis colias*. During a 30 min BUV deployment, the number of each species at the bait in 30 s intervals was

recorded to derive the MAX_{sna} and MAX_{cod} present in a sequence, together with the time at which these maxima were recorded ($t_{MAX_{sna}}$), the time of first arrival of each species ($t_{1st_{sna}}$), and the persistence of the external bait (t_{BG}). They demonstrated BUV to be an effective and sometimes superior alternative to UVC. MAX_n was the best index, but of the time-based indices $t_{1st_{cod}}$ was best, because it appeared that blue cod responded to bait so well that speed of arrival did reflect abundance. Statistically significant differences between reserve and non-reserve were detected after only 5 min set time, and became more significant only with increasing time of deployment of the BUV.

Although indices of relative abundance are available from baited, stationary video techniques, the area of influence of the bait plume must be accounted for in order to estimate sampling areas and convert the indices to density estimates. Studies of abyssal and deep-sea fishes have sought to use $MaxN$ and arrival time, in conjunction with knowledge of current velocities, fish swimming speeds and models of bait-plume behaviour, to derive absolute density estimates. Sainte-Marie and Hargrave (1987) used patterns of arrival, times of first arrival on bait, and instantaneous numbers of animals on bait to estimate abundance and distance of attraction for scavenging fish and invertebrates. They used a simple Gaussian model to account for the rate of odour production by bait, chemosensory thresholds of scavengers, swimming speed of scavengers relative to current velocity, and satiation time (“staying time” of Priede *et al.* 1994). They listed six major working assumptions and data requirements, concerning current velocities and swimming speeds, behaviour and distribution of the scavengers, the rate of bait-odour release and chemosensory thresholds of the animals. They could then estimate abundance from the curve of cumulative arrivals and from the arrival times of the first individual on bait.

Priede *et al.* (1990) developed the AUDOS to estimate abyssal fish densities; it was a free-fall, pop-up instrument package that carried a camera system, a current meter, scanning sonar and electronic compass. It was suspended in a mooring, with the downward-looking camera suspended 1.43 m above bait tied to ballast resting on the seafloor. Photographs of a 3–6 m² field of view containing a standard bait were usually taken at 1 min intervals for 13 h or more. The maximum number within frame within 15 min increments was used as n_{peak} , since this was presumed to overcome the problem of fish entering and leaving the field of view.

They proposed that, in a plot of number of fish at time t (N_t) against the soak time (t min), an initial

fish arrival rate is relatively rapid, rising to a peak (n_{peak}) and declining as fish depart. A curve fitted to the data cloud could then 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 was used to give the actual number present in the subsequent AUDOS studies.

Estimation of the distance from which the first fish was attracted to the bait from the current velocity and fish swimming speed has also formed the basis for Priede’s estimates of relative abundance. However, Yau *et al.* (2001) noted for Patagonian toothfish, and other shallow-water fishes, that the inverse relationship between abundance and the square of the average arrival time in Priede’s model will cause problems, because small changes in arrival times cause major changes in theoretical density estimates. Shallow-water sets usually produce visitors very quickly and can also produce far larger numbers of fish in the field of view than the abyssal deployments.

Our studies in both low and high latitudes have shown that, although only a small percentage of visitors actually feed at the bait, the effect of the bait plume is to bring in more species – not just from a few carnivorous or scavenging functional groups, but also from herbivores, corallivores and most other mobile functional groups. Unpublished species-accumulation curves for baited ($N_{\text{species}} = 27.5 \ln(N_{\text{sets}}) + 20.39$) and unbaited ($N_{\text{species}} = 6.59 \ln(N_{\text{sets}}) + 1.26$) video sets in the GBRMP showed that, on average, baited videos recorded 5 times more species in the first two deployments than unbaited stations. The curves showed no evidence of convergence, indicating that increasing replication of unbaited sets would not approach the efficiency of baited sets. A similar phenomenon was evident in several high-latitude habitat types in the Recherche Archipelago.

The only ways to discern the biases of the baited video technique are to compare it with UVC and common extractive techniques, such as trawling and trapping. In this regard, Cappo *et al.* (unpublished) found that a prawn trawl and BRUVS recorded significantly different components of the fish fauna on soft-bottom inter-reef habitats. Trawls caught mainly small, sedentary or cryptic, demersal species – such as flatfishes, apogonids, saurids, triglids and callionymids. The BRUVS recorded more larger, mobile species from a much wider size range of families, including large elasmobranchs, more pelagic species (such as carangids and scombrids), and numerous eels. The BRUVS performed best in the day, and trawls caught more species at

night. Multivariate analyses showed that both techniques indicated the presence of very similar patterns of grouping of fish species assemblages, despite sampling quite different components of the fauna. Six fish assemblages were recognized, based on day and night in three sampling locations.

In summary, there are three major challenges in exploring the potential for stationary video techniques to estimate relative abundances of fish and convert them to density estimates: separating repeated visits of the same fish from new arrivals within video tapes to get a better *MaxN* and more accurate measurements of length–frequency compositions of visitors, estimating the sampling area, and addressing the notion that *MaxN* is related more to the prevailing feeding opportunities in a habitat than to fish abundance. These topics will require calibrations with other sampling techniques, better, ground-truthed models of bait-plume dynamics, and closer attention to the species replacements and dynamics of fish visits and interactions within single tapes.

CONCLUSIONS

Survey methods for the initial exploration and later monitoring of Marine Protected Areas must accommodate wide variability in the behaviour and habitat requirements of numerous fish groups, and newly emerging video techniques can play an increasing role. Swimmable, stereo-video systems could enhance the performance of unskilled (and skilled) SCUBA observers by postponing subjective, difficult tasks of estimating fish identities, numbers, lengths and positions underwater, to objective interrogations of tapes at leisure in the laboratory for an unlimited audience. Integration of the geostationary positioning capacity of underwater computers with digital stereo cameras swum by divers along transects, or in roving swims, could allow accurate mapping of the position, length and biomass of important fish species in a geographic information system. Non-extractive, remote video sampling stations can be operated in low-visibility conditions, independent of depth or seabed rugosity, with fewer staff. They provide information on the immediate habitat in the sampling area, and are less prone to return low (or zero) abundance estimates for a range of species – implying that statistical power of comparisons of relative abundance is likely to be greater, with lower field costs, than some types of fishing techniques. They are biased by the use of bait, but they may avoid many of the problems with size-selectivity of capture gear, variable vulnerability to capture, and inter- and intra-specific competition for hooks or trap ingress.

The disadvantages are related mostly to the uncertainty surrounding the best estimator of fish numbers within tapes, and the actual area sampled, to estimate relative and absolute abundance. The interrogation time needed to analyse tapes broken up into time increments is also a "bottleneck" in application of the technique. Although length measurements obtained by stereo-video are now known to be better than those provided by divers, field tests and calibrations with other techniques are urgently required to fully appraise the potential of the swimmable and stationary video techniques to estimate fish densities.

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