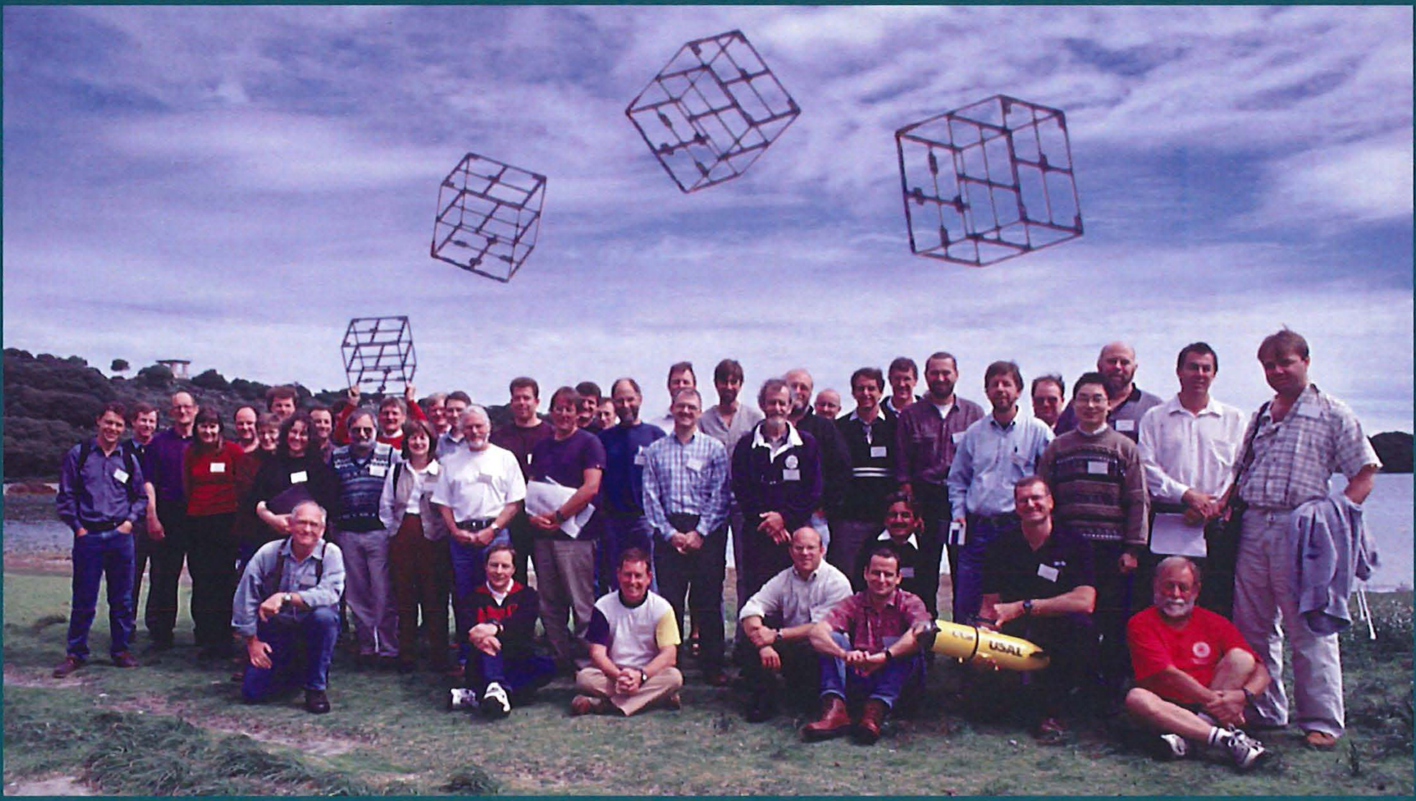
Video Sensing of the Size and Abundance of Target and non-Target Fauna in Australian Fisheries

- *a National Workshop* -



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Video sensing of the size and abundance of target and non-target fauna in Australian fisheries

- a national workshop -

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2000/187 Video sensing of the size and abundance of target and non-target fauna in Australian fisheries - a national workshop

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OBJECTIVES

1. To report on the present national state of knowledge regarding the use and applications of videography and stereo-videography for censusing fish populations and benthic habitats;

2. To report on: a) the limitations of stereo-photogrammetry and videography from the perspective of hardware, software and the behaviour of fishes and the complexities of benthic habitats; b) the opportunities and advantages of stereo-photogrammetry and videography from the perspective developing new techniques and methods for use in fisheries stock assessment;

3. To demonstrate the use of stereo-video software;

4. To outline further software developments, requirements and time lines for the development of a fully automated system for processing video records and gain suggestions on changes to software architecture and research priorities;

5. To share the cumulative knowledge of Australian based research groups experienced in the use of underwater video as a sampling tool;

6. To develop multi-disciplinary, multi-agency collaborative research projects to refine, apply and evaluate the techniques in critical fisheries.

NON-TECHNICAL SUMMARY

Increasing environmental concerns and policy shifts toward more holistic fishery ecosystem management have resulted in demand for rapid, non-destructive assessment techniques for sensing both target and non-target species in fisheries and mariculture, and for mapping benthic habitats. Underwater video is part of a suite of complimentary remote sensing tools that are being developed to fulfil this requirement in Australia and around the world. Rapid advances in video technology and image analysis have enabled wide adoption of this sampling approach to a variety of applications.

In September 2000, a three-day workshop was held on Rottnest Island, Western Australia, to share these advances, and identify gaps and opportunities in the national outlook for video techniques. The ultimate aim was to develop a Research and Development Plan for the Fisheries Research and Development Corporation, for a coordinated approach to new applications of the video tools and to help overcome bottlenecks in their development.

The workshop attracted 42 participants by invitation from key research and industry organisations in all States and from overseas. The workshop format aimed to share and concentrate experience and expertise from the full range of disciplines relevant to field deployment and application of the technique, image acquisition, calibration and analysis.

The workshop schedule of presentations and group discussions fell under four main themes:

1. use of video in mapping and monitoring of fisheries and mariculture habitats;

2. use of video in measuring harvested and cultured stocks – single and multiple camera approaches;

3. potential use of video for fisheries stock assessment – fish behaviour, community structure and indices of abundance;

4. developments and bottlenecks in image analysis and data analysis – towards automation of measurements and taxonomic recognition.

The entire proceedings consisting of electronic presentations, extended abstracts, summaries of group discussions and the R&D Plan, have been published on an interactive CD-Rom and mounted on a website (http://www.aims.gov.au/pages/research/video-sensing/index.html).

The proceedings document several sophisticated, slightly divergent approaches to habitat mapping by video borne by SCUBA, towed camera and remotely operated vehicle (ROV) in Australia. Underwater video techniques have not been widely applied in fishery-independent sampling for mobile organisms within their habitats, but the workshop demonstrated the potential advantages over traditional techniques to include:

- video is non-destructive and can be much less selective in collection of data on abundance and size – hybrid gears (e.g. video-trawls) could provide better fishery-independent techniques;

- video footage is an extremely effective medium for communicating complex information on habitats and operation of fishing gear to industry and the wider public;

- video is demonstrably less invasive than SCUBA divers in recording abundance and behaviour of a variety of important species;

- video collects large quantities of visual data very quickly, for which rapid archiving and repeated retrieval is feasible;

- video can be operated at all depths and below the visual sensitivity of target organisms: low-light, near-red and infra-red lighting enables records of undisturbed behaviour and abundance;

- recent, rapid advances in imaging technology have made possible very accurate and precise 2D and 3D measurements of size and position with digital image analysis software.

The presentations also highlighted the major limitations of the current technology and the need for further research, specifically:

- video is limited to areas of reasonable water clarity (in turbid water, laser line scanning systems have great potential but are currently too expensive for routine scientific use);

- processing of images and transformation into numerical data can be extremely labour-intensive, this is a major bottleneck in development;

- the footprint of video is much smaller than the scales at which habitat mapping, fisheries, and some existing fishery-independent sampling techniques operate; there is a need for hybridisation with side-scan sonar, and calibration with fishery data;

- a large initial capital outlay for equipment and image analysis software is often required, which may be beyond the scope of any single research agency for some applications.

To capitalise on the advantages of underwater video techniques the R&D Plan developed in the workshop proceedings specifies:

- the strategic need to set up a national virtual warehouse of modular hardware and enabling technologies to be coordinated and shared amongst agencies;

- the need to test new developments in automated computer analysis of imagery in a hierarchy from the simplest steps up to measurement and taxonomic recognition (e.g. with artificial neural networks);

- the tactical need to bring the well advanced Visual Measurement Software (VMS) from research versions into a properly supported product available for use in stereo-videography;
- the need for a simple "Guide to Underwater Videography" to help biologists choose best image acquisition and analysis approaches;
- the detail for testing new applications in counting gemfish with video-trawls and in measuring growth and biomass of cultured fish;
- the need to develop sets of test imagery with validated and quantified numerical data describing the contents of the images.

OUTCOMES

The workshop has shown the way forward in research on -- and the bottlenecks in development of -- underwater video systems as innovative, non-destructive, safe and efficient sensors of the identity, abundance and dynamics of the biodiversity in Australian marine ecosystems. Coordinated applications of the cumulative knowledge assembled at the workshop will lead to better mapping and monitoring of the vast seabed habitats of Australia's EEZ, and better assessment of the populations of organisms within them. Both are essential components of the emerging requirement for appropriate ecosystem management -- rather than traditional focus on single species or industries -- and are pre-requisites of regional marine planning in support of our mariculture and fishing industries.

The workshop identified that a suite of remote sensing, acoustic techniques and video techniques must be integrated in habitat and stock assessment, depending on the spatial scale of the questions at hand. Fundamental opportunities in improving quality, accuracy and precision in image analysis were also demonstrated. Both will yield efficiency dividends in the automation of the data collection, target recognition and measurement processes undertaken by marine researchers. Better extension techniques based on underwater video footage will offer immediate results for communicating the nature of marine habitats and activities amongst the Australian public, marine industries, their managers and researchers. This will lead to improved recognition and understanding of the opportunities for conservation and development of living marine resources in an otherwise invisible and intractable realm.

KEYWORDS:

Video sampling, benthos, habitat mapping, fish, stereo-video, image analysis.

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INTRODUCTION

From the 4th to the 7th of September 2000, a Fisheries Research Development Corporation (FRDC) funded national workshop was held on Rottnest Island, Western Australia. The workshop attracted forty-two participants from research organisations throughout Australia including various State Fisheries, the Australian Institute of Marine Science, Commonwealth Scientific and Industrial Research Organisation, South Australian Research and Development Institute and other academic institutions. The workshop also benefited from contributions by international scientists (from the UK, NZ and USA). The aim of the workshop was to share the experience and expertise of participants who have been using video as a tool for sensing the size and abundance of target and non-target fauna in Australian fisheries.

The workshop schedule consisted of a full day of presentations on the current uses of video technology and its advantages and disadvantages. The following two days consisted of four lively debated workshops.

BACKGROUND

National Research and Development reviews have recently called for fishery-independent sampling of all components of fishery ecosystems (FRDC 95/055). Yet there has been slow progress in the development and adoption of fishery-independent sampling techniques, with much emphasis still being placed on destructive sampling. A good example is research on deepwater demersal fin-fish fisheries on and around coral reef areas, where stock assessment techniques still focus on destructive and biased sampling techniques such as traps, hook and line methods or set nets and trawling. This is because:

- Australian demersal fishing grounds are often too deep for diver-based underwater visual census techniques;
- The multi-species nature of fisheries means that acoustics cannot distinguish between species;
- Acoustic techniques are imprecise and provide inaccurate information on the size/length frequency of individual species, even in mono-specific schools;
- Other capture techniques are biased by gear selectivity and are often destructive, even when a fish is released;
- The techniques currently used, such as trawling or fish pots and traps, result in some guilds of fishes evading capture.

It has been suggested that non-destructive video techniques using remote (Harvey 1998, Francour *et al.* 1999) and baited video stations (Cappo and Brown 1996, Willis and Babcock, 2000, Willis *et al.* 2000, Cappo pers com) may be more cost effective and precise techniques for sampling demersal fin fish than trap, trawl or UVC techniques.

Within Australia and New Zealand, there are a number of research groups that have been adapting and developing non-destructive video sampling techniques for fish and megabenthos. For example, in shallow water, diver-operated still and video cameras have been used to determine the stocks of sessile invertebrates such as shellfish (Miller 1999) and the distribution of intertidal (Whorff and Griffing 1991, 1992) and subtidal epifauna (Carleton and Done 1995) and for determining the growth rates of sponges (Evans-Illidge pers com) and corals (Done 1981, Christie 1983). More recently, research emphasis has been placed on the quantification of the impacts of fishing on fisheries ecosystems, and in particular benthos and megabenthos (Thrush 1998, Pitcher *et al.* 1999, FRDC 97205, CSIRO Sea Mount program). Again much of this work has relied on remote photography and videography (Harvey 1998). Underwater videography offers the opportunity to capture large quantities of dynamic data very quickly under low light conditions. With increasing restrictions on SCUBA diving due to Occupational Health and Safety Regulations, many researchers are using hand-held video and video systems mounted on sleds and Remote Operated Vehicles as data collection tools. Despite the widespread use of video technology in marine research, there appears to be very little standardisation or awareness of the developments and capabilities of other research groups or the techniques used by them. For example stereo-video technology (Harvey and Shortis 1996, Harvey 1998, Harvey and Shortis 1998, Harvey *et al.* 2001a,b) is an important tool for cost effectively measuring the lengths and biomass of target species *in situ*. To date, there are no published records of other users in the southern hemisphere marine research despite many potential applications in drop videos, baited camera stations, towed camera bodies and sleds and Remote Operated Vehicles (ROVs). Potential applications also occur in aquaculture research and management. For example assessing the growth rates or stocks of farmed Southern Blue Fin Tuna.

In proposing this project, we believed that there was a need to draw key individuals from the various research groups together to discuss and share their experiences and expertise in the use of video in fisheries research. There is also a need for the standardisation of data collection and analysis techniques to enable meaningful spatial and temporal comparisons of data sets. While developments in optical, acoustic and metric photo-optical systems and sampling techniques are providing huge gains in data acquisition in the marine environment, developments in high-speed data analysis have lagged far behind. As a result, a bottleneck has developed in data analysis. Marine researchers need to be aware not only of this bottleneck, but also of potential developments in the field of visual automation and pattern recognition which may assist to overcome this bottleneck (VIGO 1996). One of the objectives of the workshop is to increase the participants' awareness of the potential for automated or semi-automated image analysis and to determine research priorities for trialing of automation techniques in the Australian marine environment.

The Australian coastline covers a vast range of habitats. In those areas where water visibility is poor, video technology will not be useable. However, developing technology in the form of laser image scanning systems can operate under turbid conditions and can be used and analysed in the same way as video technology. Particularly relevant to any remote sensing application that might use remote video cameras or laser scanning systems on towed sleds or ROVs is the need to know the exact location where imagery was recorded.

NEED

Australian Fisheries Research and Development reviews (e.g. FRDC 95/055) have identified the need for non-destructive, fishery-independent, stock assessment techniques for both target and non-target species, and the benthic habitats that many species occupy. There is also the need to develop and validate cost-effective techniques that facilitate the comparison of data collected over a range of temporal and spatial scales for benthos, reef and inter-reef fishes. To allow *bona fide* spatial and temporal comparisons of data, techniques need to minimise many of the biases inherent in fisheries and benthic habitat assessments. Subsequently, there is also the need to standardise the methods and techniques that are being used by marine researchers around Australia in both shallow subtidal and deepwater environments.

Around Australia, and indeed the world, underwater video is seen as a tool that can satisfy many of the needs described above in both shallow and deepwater research. Consequently, underwater video is being quickly adopted for the non-destructive sampling of a very broad range of organisms. Unfortunately many researchers do not know how to maximise the information and data resulting from their recordings. Furthermore, while it is very easy to record a lot of information, the processing of images can be laborious, resulting in a bottleneck in data analysis. There is a need to make researchers aware of the possibilities and limitations of underwater videography as a tool and to determine the key concerns and research needs and wants. This was achieved by involving key individuals from state fisheries agencies and academic institutions in the workshop.

OBJECTIVES

1. To report on present national state of knowledge and applications of videography and stereo-videography to the sensing of fish populations and benthic habitats;

2. To report on: (a) the limitations of stereo-photogrammetry and videography from the perspective of hardware, software and the behaviour of fishes and the complexities of benthic habitats; (b)the opportunities and advantages of stereo-photogrammetry and videography from the perspective of developing new techniques and methods for use in fisheries stock assessment (e.g. the developments of towed camera array in SE and other trawl grounds or stationary arrays in trawl and hook fisheries);

3. To demonstrate the use of stereo-video software;

4. To outline further software developments, requirements and time lines for the development of a fully automated system for processing video records and gain suggestions on changes to software architecture and research priorities;

5. To share the cumulative knowledge of Australian-based research groups experienced in the use of underwater video as a sampling;

6. To develop multi-disciplinary, multi-agency collaborative research projects to refine, apply and evaluate the techniques in critical fisheries (e.g. SE trawl, dropline, seamount *lutjanids* etc).

PROCEEDINGS OF WORKSHOP

The first day of the workshop consisted of a series of presentations, listed below. The following two days were organised into group discussions on four major themes.

List of Presentations

(*presenter* Title of Presentation)

BACKGROUND
Fisheries and Mariculture Habitats

Dr Euan Harvey The uses of underwater television and video technology in fisheries sciences: A review

Dr Ian Brown Reef fish sampling using visual methods - an historical perspective

DATA GATHERING USING VIDEO MAPPING
1. Fisheries and mariculture habitats

Dr Gary Kendrick The use of videography in mapping and ground truthing the the distribution of seagrasses

Dr Alan Butler Use of towed video as part of resource assessment for the implementation of Australia's oceans policy

Mr Bruce Barker Use of towed deepwater video systems at CSIRO marine research

Dr Roland Pitcher Quantitative data from underwater video sources (tow-sled, drop-camera, ROV) for rapid characterisation / mapping of shelf seabed habitats and for measuring the dynamics of large sessile seabed fauna

Dr Andrew Heyward Emulation of diver-based video transect methods, for surveys of deeper water coral reefs in North West Australia, using a dual camera ROV system

Mr Peter Cavanagh From `SubSea' to `Lab' - Dependable submarine observation without the need to have anyone in the water!

Mr Andrew Woods Stereoscopic video for underwater surveys

Dr Warren Lee Long Underwater video techniques to estimate broadscale patterns in benthic vegetation and fauna in Great Barrier Reef lagoon and inter-reef areas (in absentia, audio-visual presented by Euan Harvey & Mike Cappo)

Mr Patrick Baker In water photography and photogrammetry; a 30 Year Trial

Dr Russell Cole Use of drop video to map habitats in a high energy shallow reef environment (in absentia, audio-visual presented by Euan Harvey & Mike Cappo)

2. Monitoring fisheries and mariculture habitats

Dr Christine Crawford Video assessments of environmental impacts of salmon farms

Dr Greg Jenkins The utility of underwater video in marine caging experiments

Dr Julie Lloyd Assessment of barotrauma in deepwater snappers using video techniques

Mr Mike Cappo Use of baited remote underwater video stations (BRUVS) to survey demersal fish - how deep and meaningful?

DATA PROCESSING
Video Analysis and measurements

Dr Joe Leach Oblique or vertical? - The science of biology verses the science of measurement in marine video.

Dr Euan Harvey A system for stereo-video measurement of sub-tidal organisms: Implications for assessments of reef fish stocks.

Dr Mark Shortis Design, calibration and stability of an underwater stereo-video system

Dr Stuart Robson Towards automatic characterisation of fish size and shape from metric image sequences

Dr Rob Ellis Automating taxonomic expertise: investigating connectionist solutions

Dr Dan Davis Quantitative Video at the Monterey Bay Aquarium Research Institute
(in absentia, presented by Bruce Barker)

Mr Gavin Ericson Database Management

Extended abstracts from the presentations are printed in Appendix 3. Extended abstracts (with colour figures and photos) and other presentation material (such as slide shows and movies) can also be viewed on the CD version of this report or by visiting the web-site.

Group Discussion Sessions

Main themes arising from workshops on days 2 and 3.

The chairpersons for each of the four themes synthesised the group discussions into major needs to be addressed in an R&D Plan for the FRDC. These were presented for further group discussion on Day 3 and short-listed under the following points.

Theme 1: Mapping and Monitoring Fisheries and Mariculture habitats

- Technical Bottlenecks dominated the issues and questions (e.g. in image acquisition, tape and image processing) – software development is needed to reduce the amount of time invested in processing images into numerical data time. The development of new software and refinement of existing software will require a multi-disciplinary approach. This should include adapting existing technology developed within other disciplines (e.g. medical science and engineering).

- While video can be used as a stand alone data collection tool, it is limited in the area (scale) over which it can sense data. Video imagery provides a powerful complementary tool to other data collection techniques (e.g. acoustics), particularly for validating and interpreting the efficacy of data collected at fine scales by other sensing techniques.

- The design and scaling of camera systems needs be driven by the research questions being addressed rather than the research question being limited by the design and configuration of systems. Where multi-scale and hierarchical questions are posed appropriate equipment designs need to be implemented.

- Pooling and sharing of hardware/software/expertise/support is required in a national facility – no single agency can afford the equipment, or has all the technical expertise and software required for some research applications in fisheries and mariculture. Greater collaboration between government research agencies and other research providers should be encouraged to maximise developments.

- To enable comparisons of data collected by different groups and agencies at different temporal and spatial scales standardised methods need to be developed ("Standard Operating Practices") for the collection of data for different habitats. Additionally standardising database management and the way in which raw and numerical data is stored and accessed is crucial.

Theme 2: Measuring animals in fisheries and mariculture -- 2D and 3D video

- The workshop highlighted that there is a lot more to successfully using video than most participants realised. Consequently an "Guide to Fisheries Videography" should be developed and maintained on a web site accessible to all Australian fisheries researchers.

- Stereo-video or stereo-stills can give precise/accurate measurements of length, area and volume – but calibration of the camera systems and the supporting structure fundamentally important.

- Imaging technology has advanced rapidly. Therefore the scale of research questions and the behaviour of the subjects will determine the optimum combinations of lenses, camera sensors and artificial lighting. One camera system will not answer all questions. Using modular systems where components are interchangeable has many advantages.

Theme 3: Video for fisheries stock assessment -- behaviour, counting and indices of abundance

- Video can be used to derive indices of relative abundance of fished stocks.

- Video can overcome some of the biases of fish attraction an repulsion associated with standard techniques and can provide behavioural information on interactions between fishing and sampling equipment and the fish themselves.

- a large fleet (>30) of unbaited units and 'drift-drop video' would be useful in deeper waters (as a nationally pooled facility).
- Video has great application in studies of effects of fishing on target species, on bycatch species, and on habitats.
- In some cases video could provide (complimentary) length-based stock assessment (e.g. Jeremy Prince concept of a 'video-trawl').
- Many of the benefits may be out weighed by the time required to analysis video tapes.
- When compared with diver based underwater visual census techniques the advantages of video include the removal or reduction of observer and inter observer biases and errors, the ability to make accurate measurements of fish length, volume distance between fish and cameras and angle measurements. Additionally the removal of changes in the behaviour of fish with some species being attracted to divers while others scared away, and the ability to undertake censuses in greater depths of water. Disadvantages include the time and cost of equipment and the processing tapes, the limited sensing area and the requirement for larger support vessels.

Theme 4: Video analysis and data analysis -- Automation of measurements and taxonomic recognition.

- The actual camera is the 'cheap' bit and the whole application of the video technique should be carefully planned with focus on the question at hand.
- Using Artificial Neural Networks and other tools it is possible to identify, classify and enumerate or quantify the area occupied by organisms within an image using computer software. Whilst not specifically developed for Fisheries Science this technology is available within the domain of the "machine vision" research community. By adapting it to Fisheries Research and investing in the research and development it is possible to semi automate and automate a range of image analysis applications. This should be one of the priority areas of R&D investment.
- To further the development of the technology described above real world 'test sets' of images that contain "truthed" data which has been verified needs to be made available for the experts in other disciplines (e.g. On the Web, coral images).
- There is the need for a strategy to develop "innovative enabling technology" to a point to where hardware and software can go into a national pool.
- Whilst advances have been made on Video Measurement Software (Mark Shortis and Stuart Robson), there is an urgent need to provide an environment in which code

can be developed or specific fisheries applications and supporting documentation can be developed for end users.

The issues identified above need to be incorporated into a Research and Development Plan that is endorsed by end user and funding agencies if the full benefits of video technology are to be realised to Australian Fisheries. We believe there is a rich opportunity for the advancement of video technology.

RESEARCH AND DEVELOPMENT PLAN

The National Outlook

Recent major reviews (e.g. Batterham 2001) and the technical papers that preceded the adoption of Australia's Oceans Policy (see Commonwealth of Australia, 1998) have highlighted the need for innovative tools to help achieve sustainable development of fisheries and mariculture in a more holistic, ecosystem-based context. Video techniques are part of a range of rapidly developing sensors being adapted from other industries and applied to these tasks, yet the national approach has been fragmented due to the differing needs and resources of different agencies, and a scattering of expertise across disciplines and institutions.

There is a clear need for FRDC to take a leading role in coordinating the development and application of these marine technologies in the mapping, monitoring and stock assessment of Australian marine habitats and fisheries. This role would likely be similar to the lead taken in the past by FRDC in coordinating the introduction and national development of fisheries modelling and statistical techniques, with one major difference – a national pool or "virtual warehouse" of expertise, equipment and "enabling technologies" is needed.

The set-up and maintenance cost of hardware platforms needed to deploy underwater video can be beyond most budgets, but true costs in image analysis (turning video footage into data and information) are often less obvious. This "bottleneck" occurs in all applications from the simplest to the most extensive. Overcoming it, for the Australian research community as a whole, needs a coordinator, research consortium or steering committee to keep up to date with, and adapt developments in, the fields of engineering, electronics and photogrammetry to develop common approaches to common problems in marine science.

Indeed, an unofficial research collaboration with links in Australia and overseas has produced research code for the "Video Measurement Software" (VMS) demonstrated at the Rottnest workshop. The delivery and support of this software to national users will not be simple, and there is a need for FRDC co-investment.

With a national pool of equipment and such a coordinating body, it should be possible for all agencies and institutions to have access to direct support and "modular" hardware and software for the particular research questions they are addressing with video and other sensors. This would allow development of Standard Operating Procedures to ensure data sets are consistent, comparable and contributing to national goals, whilst also improving the efficiency of all applications. As a start, there is a need for a "Guide to Underwater Videography".

There is also a need to develop sets of test imagery, with validated and quantified numerical data describing the contents of the images, to facilitate further research into automated processing of imagery by enabling software developers to trial their code.

The current status

Video has been used in Australia mainly in mapping and monitoring benthos at three scales:

fine-scale ground-truthing of the results of other remote sensing techniques covering much larger scales (10s-1000s km^2);

mid-scale mapping of benthic habitats and communities (1-10s of km^2);

small-scale observation of the abundance and size structure of benthic organisms and fishes (metres to 100s of m^2).

The workshop has shown that there are some common problems at each of these scales, representing "bottlenecks" in efficiency and accuracy. At the largest scales (for example when mapping offshore canyons or seagrass in major bays, or when using video in fishery-independent population surveys), there are problems of integration when scaling-up from a narrow video "footprint" to that of the larger sensors (such as aerial photographs and side-scan sonar), or to the scale of the fishery in question. Scaling up is needed to convert data into information useful in the broader context of critical management issues.

At all scales there are major costs in terms of manual processing time in interpretation and data gathering from the video footage. Incremental automation at all levels of the image selection, capture and analysis process is needed. Technologies that can recognise shapes and textures are in rapid advance in manufacturing and food industries -- "machine vision" that can sort, count and measure fruit, for example. There is obvious potential for these technologies to automate the various steps in image acquisition and data processing to overcome the major bottleneck identified in this workshop.

Stereo-video has been proven to be accurate and precise in underwater visual census and measurement of reef fishes yet there has been a lack of similar application in fishery-independent surveys in Australia. Immediate opportunities and benefits were identified in the workshop for use of stereo-video in measuring fish in mariculture and to support stock assessment of molluscs, crustacea and fishes. Video techniques will have a major role in linking habitat measures and habitat assessments with measures of fished/unfished community structure and spatial/temporal extent of fishing activities.

The pressing questions now relate to hardware/software and sampling design. How should video techniques be applied in conjunction with other sensors and how can national and international groups of specialists deliver the "enabling technologies" to that sampling effort?

This situation leads to the following recommendations to FRDC:

Table (next page): Recommended role for the FRDC.

Goals	Strategy and FRDC Role	Outcomes
Deliver better quality, more accessible information to managers and users of marine habitats, fisheries and mariculture with non-destructive sampling	Invest in a coordinator(s) to develop a FRDC "Marine Technology" Sub-Program including integrated software development	Real "Fishery Ecosystem Management" by contributing strongly to the national agenda on sub-tidal habitat mapping and monitoring with cost-effective, environmentally-friendly sensors
		Better communication outside marine biology to the suppliers of "enabling technologies" for automation to overcome bottlenecks in video analysis
		Overcome fragmentation and limitations of current approaches; keep pace with advances in technology
Maintain and advance the national adoption and acquisition of "enabling technologies" for the mapping, monitoring and assessment of fisheries and mariculture habitats, and the target and non-target species in them	Lead the development of a national "virtual warehouse" of modular technology, both hardware and software, for marine videography	National 'pool' of accessible technology with multi-disciplinary support for question-driven "modules" for mapping, measurement, taxonomic identification, etc.
		Shared capabilities amongst all agencies for the national common good
		Development of Standard Operating Procedures and compatible data sets
	Invest in an "equity share" of a research consortium and steering committee to deliver and support Video Measurement Software (VMS)	Satisfy the growing demand for measurement of wild and farmed marine animals without handling them
	Collaborate with other industries and R&D Corporations to pick and invest in showcase programs to prove the techniques	Compelling examples of the potential to scale-up habitat and fisheries data for better management of marine resources (eg seagrass-fisheries dynamics at bay-scale; open "video-trawl" surveys of gemfish)
	Commission a "Guidebook to Marine Videography"	Development of Standard Operating Procedures and compatible data sets in existing and future applications
	Commission sets of test imagery with validated descriptive data	Incremental automation of video image processing

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APPENDIX 1
BIBLIOGRAPHY

Appendix 1. Chronological summary of the use of video and UTV in marine sciences.

USE OF VIDEO \ UTV	AUTHOR(S)	YR
Possible use of underwater TV for marine biology	Barnes	1952
Underwater TV and fisheries research	Barnes	1953
Underwater TV in marine biology and geology: The equipment	Barnes	1953
Underwater TV in freshwater fisheries research	Cuerrier	1953
Use of underwater TV	Stamp	1953
Quantitative analysis of fine grained suspended material in waters	Knowles & Wells	1954
Uses of underwater TV in marine biology and geology	Barnes	1955
Direct observation of a midwater trawl net	Sand	1955
Underwater TV	Czihak	1956
Direct observation of a midwater trawl net	Sand	1956
Validating echo sounder observations of deepwater scattering	Backus & Barnes	1957
Direct observation of a midwater trawl net	Sand	1957
The future of underwater TV	Barnes	1958
Behaviour of marine fish in a trawl net	Livingstone	1959
Behaviour of captive herrings	Brawn	1960
Comparison of photography, TV & bottom sampling in benthic surveys	Czihak & Zei	1960
A semi –permanent underwater TV camera and acoustic array	Kumphe & Lowenstein	1962
Underwater television for sampling benthos	Barnes	1963
Description of cine and still photography equipment for research	Craig & Priestley	1963
The behaviour, schooling & sound production of reef fish	Cummings *et al.*	1964
Underwater TV camera on a towed sledge for sampling benthos	Holme	1964
Description of an underwater TV for bio-acoustic research	Kronengold *et al.*	1964
Underwater TV in bio-acoustic research	Kumphe	1964
Acoustic-video system for marine biology	Steinberg & Koczy	1964
Estimating the abundance of megabenthic epifauna	Bouhot *et al.*	1965
Bio-acoustic research	Steinberg *et al.*	1965
The behaviour, schooling & sound production of a reef fish	Cummings *et al.*	1966
Recommendations on the use of the bio-acoustic UTV housing	Myrberg Jr. *et al.*	1966
Fish behaviour	Stevenson Jr. & Myrberg Jr.	1966
Observations of the Norway Lobster with underwater TV	Cole	1967
Opportunities for utilising underwater TV for research projects	Holt	1967
Fish behaviour/reproduction	Myrberg Jr. *et al.*	1967
Seafloor underwater TV for behavioural studies	Stevenson	1967

Fish attraction to low frequency sound	Richard	1968
Marine animal behaviour	Myrberg Jr.	1969
Video acoustics for attracting sharks	Myrberg Jr. *et al.*	1969
Estimating the abundance of megabenthic epifauna, scallops	Caddy	1970
Fish behaviour and ecology	Colin	1970
Fish Behaviour	Colin	1971
Underwater television	Cummins Jr	1971
Fish behaviour	Colin	1972
Swimming and feeding behaviour of larval anchovy	Hunter	1972
Fish behaviour	Myrberg Jr.	1972
Marine animal behaviour	Myrberg Jr.	1972
Attracting sharks to an underwater sound	Myrberg Jr. *et al.*	1972
Fish behaviour	Myrberg Jr. & Spires	1972
Fish behaviour	Stevenson Jr.	1972
Cinefilms of suspension feeding by marine invertebrate larvae	Strathmann *et al.*	1972
Fish behaviour	Colin	1973
Towed camera systems for benthic surveys	Myrberg Jr.	1973
Fish behaviour	Myrberg Jr.	1973
Fish larvae behaviour: Shadow cinematography	Arnold & Nutall-Smith	1974
Fish behaviour	Myrberg Jr. & Thresher	1974
Fish behaviour	Slobodkin & Fishelson	1974
Cine transects of reef fish	Alevizon & Brooks	1975
Underwater performance of low light level television cameras	Hittleman *et al.*	1975
Television camera mounted in a towed sled for benthic surveys	Machan & Fedra	1975
An underwater TV system	Bascom	1976
Epibenthic surveys from submersibles	Caddy	1976
Epibenthic surveys using underwater TV	Rees	1976
Closed circuit television for fisheries research in the lab and field	Wardle & Priestley	1976
Feeding behaviour of a copepod &shadow cinematography	Edgerton	1977
Towed camera and television for benthic surveys	Holme & Barratt	1977
Surveying scallops with underwater TV	Franklin	1978
Behaviour of commercial fishing gear	Main & Sangster	1978
Underwater colour TV, uses, design considerations	Robinson	1978
Observations of the Norway Lobster with underwater TV	Chapman	1979
Survey of marine sediments	Farrow *et al.*	1979
Time-lapse cinematography for long term observations	Fedra & Machan	1979
Efficiency of commercial fishing equipment	Main & Sangster	1979
Cine-transects of reef fish	Ebeling *et al.*	1980
Cine-transects of reef fish	Ebeling *et al.*	1980
Surveying scallops with underwater TV	Franklin *et al.*	1980
Surveys of commercial fish habitats	Goeden	1980
Use of underwater TV	Merrien	1980
Video survey of fish abundance higher than trawl estimates	Powles & Barans	1980

Feeding behaviour of a crinoid	Byrne & Fontaine	1981
Unmanned instrument packages and video	Goeden	1981
Fish behaviour towards different types of bait	Johnstone & Hawkins	1981
Underwater TV	Patterson	1981
Time-lapse videomicroscopy: studies of echinoderm embyros	Schatten	1981
Performance of cod ends	Stewart & Robertson	1981
Closed circuit TV for validating fish counts by a resistivity counter	Dunkley & Shearer	1982
Videomicroscopy: Echinoderm sperm behaviour	Inoue & Tilney	1982
Video sediment profiling system	Rhoads & Germano	1982
Particle capture by cilia of bryozoans	Strathmann	1982
ROV's for fish population assessment	Thomson	1982
Remote studies of rocky subtidal communities using video	Christie	1983
Behaviour and feeding of *Cerianthus lloydi* Gosse	Eleftheriou & Basford	1983
The use of a wet submersible in fishing gear research	Main & Sangster	1983
Fish behaviour in commercial trap net pots	Rutecki *et al.*	1983
Survey of commercial groundfish species	Baran & Henry	1984
Surveys of macro-epifauna	Caddy & Carter	1984
Reorientation times of a milk conch after exposure to CU bioassays	Covich & Sanders	1984
Agassiz trawl & TV for sampling epibenthic macrofauna	Eleftheriou & Basford	1984
Video cameras placed in photosleds for fisheries research	Foulkes	1984
Video cameras and unmanned instrument packages	Holme	1984
Video & manned submersibles	Jasper	1984
Schooling behaviour of fish	Koltes	1984
Cine-transects of reef fish	Larson & DeMartini	1984
Fish behaviour to model nets	Matuda *et al.*	1984
Long-term remote underwater monitoring	Miller	1984
Distribution patterns of some large benthic epifauna	Patterson	1984
Video and unmanned instrument packages for geological research	Phillips *et al.*	1984
Stereo TV system to measure 3-D positions of fish in schools	Pitcher & Lawrence	1984
Observations of demersal fish communities	Sedberry & Van Dolah	1984
Video cameras placed in photosleds	Theroux	1984
Efficiency of fishing equipment	Twohig & Smolowitz	1984
Predation in the deep seas	Wilson Jr. & Smith Jr.	1984
Video Activity Counter For Monitoring Fish Locomotion	Arimoto & Inoue	1985
Sampling epibenthic sediment communities	Bourgoin *et al.*	1985
Sampling delicate gelatinous plankton	Chandler-Middleton	1985
Surveys of the abundance and size of the Norway lobster	Chapman	1985
A deep-sea towed photographic system	Chezar & Lee	1985
Videomicroscopy of interstitial meiofauna in sediments	Farris & O'leary	1985
Feeding movements of echinoderm larvae	Gilmour	1985
ROV used for Antarctica marine research	Hamada *et al.*	1985
Abundance of megalo-epibenthos with a deepsea towed TV system	Hashimoto & Hotta	1985
Video cameras and unmanned instrument packages	Holme	1985
Fish behaviour to nets	Kanehiro *et al.*	1985
Abundance of a rockfish from a deep-sea towed TV system	Kitagawa *et al.*	1985
Changes in fish behaviour due to varying CU concentrations	Koltes	1985
Fishing gear performance	Stewart & Robertson	1985
Video for analysing rapid movements of marine organisms	Svoboda	1985
Feeding behaviour of the white shark	Tricas	1985
In situ observations of the distribution of juvenile squid	Vecchione & Gaston	1985
Sediment transport studies	Wilkinson	1985
Surveys of Megafauna Associated With Bathyal Seamounts	Wilson Jr. *et al.*	1985

Behaviour of reef fish to different strength currents	Yasanuga	1985
Feeding behaviour of herrings	Batty *et al.*	1986
A ROV for deepwater monitoring	Benech & Boyce	1986
Determination of bacterioplankton biomass by image analysis	Bjornsen	1986
Abundance of demersal fish higher from video than trawl estimates	Boland & Lewbel	1986
Determining range, size and field of view in video images	Caimi & Tusting	1986
Future potential of video	Clark	1986
New equipment for research	Cook	1986
Feeding of larval fishes: shadow cinematography	Drost & van den Boogaart	1986
A TV technique used for bottom profile measurements	Georgiev *et al.*	1986
Behaviour of the stalkless crinoid, *Oligometra serripinna*	Holland *et al.*	1986
Time lapse video	Iwata *et al.*	1986
Fish behaviour to different hooks and bait: Fisheries Research	Johnstone & Mackie	1986
Efficiency of fishing gear	Lange	1986
Behaviour of fish trawl wings & head ropes of balloon trawls	Lange & Steinberg	1986
Fish behaviour to model fish traps	Matuda *et al.*	1986
Behaviour of abyssal grenadier	Priede & Smith	1986
Microtubule-based movements in supernatants of sea urchin eggs	Pryer *et al.*	1986
Video sediment profiling system	Rhoads & Germano	1986
Abundance estimates from simultaneous video and net sampling	Russel & Serafy	1986
Emergence behaviour of spanner crabs	Skinner & Hill	1986
Comparison of acoustic and visual estimates of sediment transport	Thorne	1986
Surveying the abundance of scallops	Thouzeau & Hily	1986
Fish behaviour to fishing gear	Wardle	1986
A ROV with high resolution video	Woodroffe	1986
Selectivity of scallop dredges	Worms & Lanteigne	1986
Use of larval tentacles by a reef-building polychaete	Amieva *et al.*	1987
Use of larval tentacles by a reef-building polychaete	Amieva *et al.*	1987
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Herring behaviour to light	Blaxter & Batty	1987
Research opportunities at NOAA: Realtime video observations	Busch	1987
Determining range, size and field of view in video images	Caimi *et al.*	1987
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Underwater TV estimates of snow crab abundance	Conan & Maynard	1987
Video digitiser for examining fish scale circuli spacing	Cook	1987
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Observation and trials of different types of cod ends	Cooper & Hickey	1987
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Studies of unequal cleavage in molluscs	Dan & Inoue	1987
The aiming and catch success of feeding larval fishes	Drost	1987
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Feeding behaviour of *Daphnia magna* & *D. pulex*	Gerritsen *et al.*	1987
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Foraging behaviour of a ctenophore	Hamner *et al.*	1987
A crinoid capturing food particles under surge conditions	Holland *et al.*	1987
Height and wavelength of sand and gravel ripples	Judge & Forbes	1987
Description of deepwater cold seep benthic communities	Juniper & Sibuet	1987
Video as a method of biological assessment of rocky reefs	Kingsford	1987
Visibility of nets and lures measured by underwater video	Kobayashi *et al.*	1987
Spatial patterns of emission of bioluminescence of a copepod	Latz *et al.*	1987
Diel activity and foraging behaviour of juvenile American Lobsters	Lawton	1987

Epibenthic surveys on the North Atlantic Slope and Rise	Maciolek *et al.*	1987
Surveys of deep-sea megalo-epibenthos with a deep towed TV system	Matsuzawa & Hashimoto	1987
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The predation of mackerel on herring eggs	Messieh	1987
Fish behaviour	Midling *et al.*	1987
Habitat survey	Nester & Poe	1987
Observations of the behaviour of 2 species of Euphausia	O'Brien	1987
Foraging behaviour of juvenile lobster	Potts *et al.*	1987
Video and manned submersibles	Rechnitzer	1987
Fish behaviour	Robinson & Doyle	1987
Fish behaviour	Rosenthal	1987
Measuring swimming velocity	Royce & Watson	1987
Fish behaviour in a water tank	Sannomiya *et al.*	1987
Monitoring benthic habitatas	Service	1987
Feeding and reproductive behaviour of spanner crabs	Skinner & Hill	1987
Behavioural responses of aquatic animals to chemical stimulants	Steele	1987
Physiological reactions of a copepod to selected dinoflagellates	Sykes & Huntley	1987
Abundance of brachyuran crabs near hydrothermal vents	Van Dover *et al.*	1987
Particle capture by *Daphnia*	Vanderploeg & Paffenhoefer	1987
The display of *Uca victoriana* , a new fiddler crab	Von Hagen	1987
Prawn behaviour to pots	Yamane and Iitaka	1987
Fish larvae escape swimming speeds	Yin & Blaxter	1987
Underwater TV system for sediment profiles	Yong & Kaiyao	1987
Estimating the abundance of megabenthic epifauna: scallops	Aschan	1988
Effects of handling procedures on farmed salmon	Bjordal *et al.*	1988
Changes in macroalgal vegetation of Kiel Bight	Breuer & Schramm	1988
Morphology of growth cones from *Aplysia californica*	Burmeister *et al.*	1988
Mechanism of turning of growth cones of *Aplysia californica*	Burmeister & Goldberg	1988
Kinetic behaviour of the tintinnid, *Favella sp.*	Buskey & Stoecker	1988
Horizontal swimming and sinking of lecithotrophic larvae	Butman *et al.*	1988
Identification of different marine sedimentary areas	Clabaut	1988
Comparison of range of TV & underwater laser imaging systems	Coles	1988
Time lapse video for fish migration	Cooke	1988
A video digitising technique for counting juvenile queen conch	Davis	1988
Feeding mechanism of the pelagic tunicate, *Doliolum nationalis*	Deibel & Paffenhoefer	1988
Resistance of ropes to fish bites	Feigenbaum *et al.*	1988
Bioenergetics & swimming behaviour of a marine oligotrich ciliate	Fenchel & Jonsson	1988
Image-analysing system for measuring the lengths of larval fish	Froese	1988
Morphometric measurements of larval fish with image analysis	Froese	1988
Measurements of surface wave modulations from internal waves	Gotwols & Sterner	1988
Surface roughness changes induced by internal waves	Gotwols *et al.*	1988
3-D video and computer analysis of fish schooling	Hamner *et al.*	1988
Video analysis of the tooth movements of the American Lobster	Heinzel	1988
Low light underwater TV: New products	Hudson	1988
Cell division in simple coccal cyanophytes	Kovacik	1988
Reconstruction of the shape of a trawl net	Kroeger	1988a
Behaviour of trawl gear	Kroeger	1988b
Comparison of underwater TV and scanning laser imaging systems	Kulp *et al.*	1988
Efficiency of fishing equipment	Lange & Steinberg	1988
Low light underwater TV: New products	Lemonier *et al.*	1988
Description of a lobate ctenophore from the California Bight	Matsumoto	1998
Behaviour of fish to a net	Matuda *et al.*	1988
Feeding of larvae using macroscopic video	McShaffrey & McCafferty	1988

Night time observations of emerged sea trout	Moore & Scott	1988
Video systems in deep water mining and oceanography	Mosley	1988
Particle capture by *Daphnia*	Shiel *et al.*	1988
Deepwater cold seep benthic communities	Sibuet *et al.*	1988
Trawl gear, fisheries research	Steinberg	1988
Potential uses of video in New Zealand fisheries stock assessment	Street	1988
Choosing underwater video cameras : Review of equipment	Van Heuklom	1988
In situ observations of squid spawning beds	Vecchione	1988
Automated 3-D tracking & video based motion analysis system	Walton	1988
Benthic community structure	Witman & Sebens	1988
Assessment of benthic aggregations of fish and invertebrates	Zaferman & Serebrov	1988
Wave run up on beaches	Aagaard & Holme	1989
Chemotactic effects of nutrients on kelp spores	Amsler & Neushul	1989
Fish behaviour in a trawl net and at the net mouth	Arimoto *et al.*	1989
Scientific imaging with ROV's: tools and techniques	Auster *et al.*	1989
The escape responses of herring larvae	Batty	1989
Lobster behaviour	Bayer	1989
Habitat and community structure for Lake Baikal whitefish	Binkowski	1989
Characterisation of sediment geoacoustic and roughness properties	Briggs *et al.*	1989
Foraging behaviour of a predacious cladoceran	Browman *et al.*	1989
Automated counting and morphological description of microalgae	Brown *et al.*	1989
Fish predation behaviour	Caine	1989
Microtubule motility in sea urchins	Cohn *et al.*	1989
The feeding activity of fish on benthic invertebrates	Collins	1989
Swimming behaviour of young salt-water crocodiles	Davenport & Sayer	1989
Cine-transects underestimate fish abundance	Davis & Anderson	1989
Assessing the effect of scallop dredging	Dredge	1989
Time-lapse cinematography of hemocytes	Eble *et al.*	1989
Habitat choice by demersal nekton	Felley *et al.*	1989
Behaviour of larval decapod crustaceans to light and pressure	Forward Jr. & Buswell	1989
Behaviour of larval decapod crustaceans to light and pressure	Forward Jr. & Wellins	1989
Behaviour of larval decapod crustaceans to light and pressure	Forward Jr.	1989
Behavioural responses of crab larvae to changes in salinity	Forward Jr.	1989
Behavioural responses of crab larvae to change in hydrostatic pressure	Forward Jr. *et al.*	1989
Fish behaviour	Franck & Ribowski	1989
Fish behaviour to trawl gear	Glass & Wardle	1989
Shrimp behaviour to celestial cues of orientation	Goddard & Forward	1989
Comparison of four techniques of censusing reef fish	Greene & Alevizon	1989
Scientific applications of a ROV: Broadcast quality TV images	Hattori	1989
Behaviour of spider crab sperm	Hernandez *et al.*	1989
Assessing and differentiating benthic habitats	Hily	1989
Digitised video images	Hinton *et al.*	1989
Hydrocarbon based communities	Hovland & Thomsen	1989
A remotely controlled television vehicle for fishing gear research	Hreinsson	1989
Fish behaviour	Huang & Fraser	1989
Video microscopy, a new sampling tool	Inoue	1989
Temperature-dependent swimming speed of 11 dinoflagellates	Kamykowski *et al.*	1989
Low light underwater TV for fisheries research	Lange & Steinberg	1989
Fish behaviour	Lee *et al.*	1989
Fish behaviour towards baited hooks	Lokkeborg *et al.*	1989
Squid behaviour	Long *et al.*	1989
Spatial distribution of marine hydrocarbon seep communities	MacDonald *et al.*	1989
Sediment distribution in Akhziv Canyon off Northern Israel	Mart	1989
Towed steerable vehicles & acoustics for fishing gear performance	McGregor	1989
Image enhancement software for underwater recovery operations	Partridge & Therrien	1989

The response of zooplankton to phytoplankton patches	Price	1989
Motion analysis of free swimming zooplankton	Ramcharan & Sprules	1989
Video assessment of the performance of benthic grab samplers	Riddle	1989
Fish behaviour in circular tanks	Rosenthal	1989
Influence of light on behaviour of freshwater snails	Rotenberg *et al.*	1989
Microcomputer based chlorophyll fluorescence	Sadar *et al.*	1989
Breeding activity and feeding behaviour of a cyclopoid copepod	Schnack *et al.*	1989
Deep sea sedimentary processes	Schwab *et al.*	1989
The abundance and spatio-temporal patterns of reef fish	Seaman Jr. *et al.*	1989
Migration of mesentodermal cells in early squid embryo	Segmueller & Marthy	1989
Video and a manned submersible	Shinn & Wicklund	1989
Fish behaviour	Smith & Bailey	1989
Crab behaviour at trap entrances	Smith & Sumpton	1989
Video to validate deep sea acoustic measurements	Smith *et al.*	1989
Fish behaviour	Srivastava *et al.*	1989
Applications of low cost ROV's in science	Stewart & Auster	1989
Selectivity of trawl nets altered by changing cod end mesh	Stewart & Galbraith	1989
Investigations of sea surface noise	Updegraff	1989
Video used for finding ship wrecks	Vrana & Schwartz	1989
The reactive distances of planktivorous fish to zooplankton	Wazenbock & Schiemer	1989
Bluefin tuna swimming speed	Wardle *et al.*	1989
Fish behaviour during trawling	Watson	1989
Sampling delicate gelatinous plankton	Widder *et al.*	1989
Swimming speed of fish larvae	Yin & Blaxter	1989
Study of starfish sperm motility	Yu *et al.*	1989
Fate of fish escaping from the net of a bottom trawl	Zaferman	1989
Videomicroscopy of the motility of teleost sperm	Amanze & Iyengar	1990
Video and computer aided otolith analysis	Aps *et al.*	1990
Swimming & settlement behaviour of *Haliotis* larvae	Barlow	1990
Herring feeding behaviour due to light and darkness	Batty *et al.*	1990
Line transect sampling with underwater video	Bergstedt	1990
Herring behaviour to light	Blaxter & Batty	1990
Swimming behaviour of the cownose ray	Blaylock	1990
Large linear trenches in lake bottom sediments made by the burbot	Boyer *et al.*	1990
Correlations with brittlestar arm movements & hyponeural nerves	Cobb	1990
Investigations of a deepwater Modiolus brachiopod assemblage	Collins	1990
Zooplankton capture by coral reef fish	Coughlin & Strickler	1990
Swimming behaviour and hydrodynamics of different size scallops	Dadswell & Weihs	1990
Performance of trawl gears	Dahm & Kroeger	1990
Video-microscopic analysis: Coelomocytes of *Halocynthia roretzi*	Dan Sohkawa	1990
Seaweed fly mating behaviour	Day *et al.*	1990
Video-microscopy for examining fish otoliths	De Vries	1990
Fish behaviour and the efficiency of a Norwegian bottom trawl	Engaas & Ona	1990
Flagellar waveform of sea-urchin sperm	Eshel *et al.*	1990
Fish behaviour and the efficiency of a pelagic trawl	Fischer *et al.*	1990
Behaviour of krill during laboratory experiments	Foote *et al.*	1990
Behavioural responses of crab larvae to changes in temperature	Forward	1990
A video system for recording ichthyoplankton and zooplankton	Froese *et al.*	1990
Behaviour of larval fish	Fukuhara *et al.*	1990
A multi-box corer equipped with an underwater video	Gerdes	1990
Fishing efficiency of prawn nets	Goeden *et al.*	1990
Fish behaviour during hydrodynamic surveys	Green & Dickie	1990
Behaviour of prawns under experimental conditions	Grove-Jones & Burnell	1990
Video observations of benthos and sediments	Hallock *et al.*	1990
Fish behaviour around underwater lamps	Hasegawa &	1990

	Kobayashi	
Swimming behaviour of sandy beach bivalve larvae	Higano & Yasunga	1990
Membrane fluidity of egg cortices of the sand dollar	Hirano	1990
Advantages and limitations of TV/video in comparison to film	Huggett	1990
Behaviour of fish larvae & small aquatic invertebrates	Huse & Skiftesvik	1990
Reduction in fish bycatch in a shrip trawl: Underwater TV	Isaksen *et al.*	1990
Permanent video quadrats and transects	Jaap *et al.*	1990
Feeding behaviour and prey detection of the copepod	Jonsson & Tiselius	1990
Morphology and mechanics of octopus suckers	Kier & Smith	1990
Intracellular changes of calcium ion density in oocytes of a starfish	Kikuyama & Hiramoto	1990
The impact of an otter board fishery on sediment	Krost	1990
Measurements of the eye movements of the mantis shrimp	Land *et al.*	1990
Fisheries research: Improvement in the efficiency of trawl gear	Lange	1990
Observations of rope trawls	Lange	1990
Estimating the abundance of megabenthic epifauna	Langton & Robinson	1990
Remote observations of sea ice benthic communities	Levenez	1990
Effects of pollutants on food collection by *Daphnia magna*	Lichtendahl & Bodar	1990
Behaviour of cod to different shapes of bait	Loekkeborg	1990
Development of the gut of the white shrimp	Lovett & Felder	1990
Aspects of jet propulsion in salps	Madin	1990
Description of the use of video for marine sampling	Maney Jr. *et al.*	1990
Territoriality in filter-feeding caddisfly larvae	Matczak & Mackay	1990
Tail flip of the Norway Lobster	Newland & Neil	1990
Counts of salmon in bypass and passage facilities	Nigro	1990
Copepod behaviour	Ohtsuka	1990
Video on a deep tow camera system	Otsuka	1990
Snap shot TV to monitor far away objects	Otsuka & Hotta	1990
Video for mapping visually distinct benthic communities	Phillips *et al.*	1990
Spatial and temporal distribution of sub-ice macrofauna	Pike & Welch	1990
Foraging behaviour of abyssal fish	Priede *et al.*	1990
Prawn behaviour	Reyes *et al.*	1990
Video for estimating copepod and euphausiid abundances	Sameoto *et al.*	1990
Fluorescence video-microscopy in microbial plankton ecology	Sieracki & Viles	1990
Fish behaviour	Smith & Bailey	1990
Use of sensory perception in social interactions by crayfish	Smith & Dunham	1990
Colony formation in Stylactis sp	Suzuki & Kakinuma	1990
Subtidal surveys using belt transects	Thomas *et al.*	1990
Water flow& particle movement associated with feeding barnacles	Tiselius & Jonsson	1990
Suspension-feeding behaviour of an adult barnacle	Trager *et al.*	1990
Motion of light buoys and detection range of their light signal	Tunnicliffe *et al.*	1990
Behaviour of released lobsters	van der Meeren *et al.*	1990
Videogrammetry on ROV's	Vial	1990
Behaviour and mortality of hydrothermal vent worms	Williams	1990
Video observations of gravel transport	Wroblewski & Mandler	1990
Prawn behaviour	Yamane	1990
Swimming tracks in swarms of two cladoceran species	Young & Taylor	1990
Mating behaviour of a podocopid ostracod	Abe & Vannier	1991
Distribution and habitat of chain dogfish	Able & Flescher	1991
ROV's and video cameras	Aksland & Alvsvaag	1991
Coagulation rates of suspended particles	Alldredge & McGillivary	1991
Burrow behaviour patterns of a Thalassinid shrimp	Anderson *et al.*	1991
Baited free fall video camera for attracting deep sea fish	Armstrong *et al.*	1991
ROV surveys of epibenthic fauna	Auster *et al.*	1991
The life cycle of Perkinsus atlanticus an endoparasite of a bivalve	Azevedo	1991

Swimming velocity of echinoderm plutei: 3-D video microscopy	Baba *et al.*	1991
Swimming speed, tail beat frequency of fish and ascidian larva	Batty *et al.*	1991
Low cost ROV's for shallow water surveying	Baxley	1991
Observations of feeding of *Placopecten magellanicus*	Beninger *et al.*	1991
Live observation of sponge cells	Bond	1991
Comparisons of reef fish censusing techniques	Bortone *et al.*	1991
Estimating the trajectory of a submersible from video images	Boucher *et al.*	1991
Bioluminescence from a gammarid and two hyperiid amphipods	Bowlby	1991
Video images of marine topographic features	Brooks	1991
Video images of marine topographic features	Brooks	1991
Video images of marine topographic features	Brooks & Wolff	1991
Video cameras: new products, applications and capabilities	Burns	1991
Behaviour of juvenile Sole under experimental conditions	Champalbert *et al.*	1991
Crab fishermen setting pots using Remote Operated Vehicles	Chandler	1991
Fish behaviour and energetics	Coleman & Fischer	1991
Infra red time lapse video for animal behaviour	Collins *et al.*	1991
Profiling and enumerating marine aggregated particles	Costello *et al.*	1991
Induced spawning behaviour of male and female zebra mussels	Crawford *et al.*	1991
Optokinesis in gonodactyloid mantis shrimps	Cronin *et al.*	1991
Trout behaviour in response to waves	de Walsche & Dumont	1991
Mechanisms of suction by the northern clingfish	Drucker	1991
Video transects monitor change in coral reef communities	Edmunds & Witman	1991
The behaviour and habitat of high antarctic notothenoid fish	Ekau & Gutt	1991
Jason, a ROV with four real time video channels	Elder	1991
The escape responses of herring larvae	Fuiman	1991
Particle capture and selection by mollusc larvae	Gallager *et al.*	1991
The motility and velocity of cyanobacterial filament	Haeder & Vogel	1991
The effects of bottom fishing gears on benthic communities	Hamon *et al.*	1991
Suspension feeding by echinoderm larvae	Hart	1991
Swimming behaviour and speed of fish	Hartwell *et al.*	1991
Enumeration of escapements of salmon through a fish way	Heizer	1991
The behaviour of nesting smallmouth bass	Hinch & Collins	1991
Feeding rates of the flagellate Spumella on three sizes of bacteria	Holen & Boraas	1991
Fish behaviour	Holm *et al.*	1991
Video estimation of subaerial beach profiles	Holman *et al.*	1991
The behaviour of tethered and free-swimming copepod	Hwang	1991
Underwater TV for time lapse recordings	Inoue *et al.*	1991
Beat & swimming patterns of flagellated cells of 3 seaweeds	Inouye & Hori	1991
Counting and measuring salmon	Irvine *et al.*	1991
Flagellar movement of the spermatozoa of a marine snail	Ishijima *et al.*	1991
Action spectra for phototaxis in zoospores of a brown algae	Kawai *et al.*	1991
Migratory behaviour of Atlantic salmon	Larinier & Boyer-Bernard	1991a
Downstream migration behaviour of Atlantic salmon smolts	Larinier & Boyer-Bernard	1991b
Foraging behaviour of decapod crustaceans	Lawton & Taylor	1991
Infection of the American lobster with a protozoan	Loughlin & Bayer	1991
Swimming behaviour of juvenile giant scallops	Manuel & Dadswell	1991
post-metamorphic drifting in the gastropod	Martel & Chia	1991
Faunal associates of an undescribed species of scyphomedusa	Martin & Kuck	1991
Abundance data on hagfish	Martini & Heiser	1991
Ciliary movement of ctenophores	Matsumoto	1991
Nest construction and reproductive behaviours of Nocomis species	Maurakis *et al.*	1991
A video equipped ROV for marine archaeology	McCann	1991
Morphology and mobility of oyster hemocytes	McCormick & Howard	1991
Detecting change in coral reef communities	Meier & Porter	1991
Flexibility of fish cages in heavy winter waves	Menton & Allen	1991

Image analysis of the accumulation of an anionic dye	Miller & Pritchard	1991
Settlement responses of barnacle (*Balanus amphitrite*) cyprids	Mullineaux & Butman	1991
Feeding activity in mussels	Newell	1991
Time lapse benthic video monitoring: feeding activity in mussels	Newell & Gallagher	1991
Video and manned submersibles for studying pelagic tunicates	Paffenhoeffer *et al.*	1991
Video image analysis software(PC) for measurements of otoliths	Planes *et al.*	1991
Position preference of shoaling Atlantic herring	Robinson & Arenas	1991
ROV survey of scallops	Robinson *et al.*	1991
ROV's and submersibles for geological instability surveys	Savoye	1991
Panoramic video on a ROV, conceptual design	Schloerb	1991
Water flow and particle movement	Sebens & Johnson	1991
Swimming behaviour of the Mediterranean slipper lobster	Spanier *et al.*	1991
Measuring growth in aquatic invertebrates without stress	Srivastava *et al.*	1991
Video observations of lobsters	Steneck	1991
Nuclear disassembly during germinal vesicle breakdown in starfish	Stricker & Schatten	1991
Automated enumeration of circuli in fish scales	Szedlmayer *et al.*	1991
The abundance and distribution of scallops	Thouzeau *et al.*	1991
Estimating the abundance of megabenthic epifauna	Thouzeau *et al.*	1991
Surveying the abundance of scallops	Thouzeau & Vine	1991
Fish sperm swimming speed	Trippel *et al.*	1991
ROV's for conducting research in marine microecosystems	Troutman	1991
Investigations of sea surface noise	Updegraff & Anderson	1991
Mechanisms of feeding and respiration in larval cod	van Herbing *et al.*	1991
Video observations of cephalopods from submersibles	Vecchione & Roper	1991
ROV survey of benthic communities	Voegele *et al.*	1991
Ecological surveys of sea bed using sleds with video	Vogt & Schramm	1991
A rapid non stressing technique for measuring growth in insects	Walsche & Dumont	1991
A new technique for observing the feeding in bivalves	Ward *et al.*	1991
Fish behaviour to bottom trawls	Wardle	1991
The use chemoreception by the blue crab to locate prey	Weissburg & Zimmer Faust	1991
Small-scale distribution of invertebrate & ichthyoplankton	Welsch *et al.*	1991
Video for sampling hard bottom benthic communities	Whorff & Griffing	1991
Diver operated sleds and video	Workman & Watson	1991
Changes in the mesh shape of a framed plane net	Yamane & Nishinokubi	1991
Swimming speed of planktonic organisms	Aleyev	1992
Counting fish in fish passage facilities	Anonymous	1992
Settlement of oyster larvae	Baker	1992
High speed video for burst swimming performance of fish larvae	Batty & Blaxter	1992
Pursuit speed of trout	Barrett *et al.*	1992
Mating behaviour of marine shrimps.	Bauer	1992
Feeding processes of *Placopecten magellanicus*: Endoscopic video	Benninger *et al.*	1992
Sampling delicate gelatinous plankton	Bergstroem *et al.*	1992
Quantitative video analysis of epibenthic invertebrates	Berkelmans	1992
Behaviour of fish exposed to herbicides	Bettoli & Clark	1992
Video moire for undersea mapping & surface determination	Blatt et al.	1992
Microflagellate feeding behaviour	Boraas *et al.*	1992
Filtration rates of Zebra mussels	Bunt *et al.*	1992
The effects of ghost gillnets	Carr *et al.*	1992
Fish behaviour near demersal trawls	Castro *et al.*	1992
Image analysis for acquisition of sclerochronological data	Chauvelon *et al.*	1992
Fish behaviour	Clarke & Pohle	1992
Boundary layer development under the crest of breaking waves	Conley & Inman	1992
Zebra mussel sperm & egg ejection, fertilisation and development	Crawford *et al.*	1992
Spatial distribution of oceanic plankton	Davis *et al.*	1992

A video plankton recorder	Davis *et al.*	1992
Reproduction of a population of terebellid worm	Duchen & Nozais	1992
Fish feeding behaviour	Dutta	1992
Underwater video habitat survey	Edsall *et al.*	1992
Microtubule disassembly in Actinocoryne contractilis	Febvre-Chevalier & Febvre	1992
Feeding behaviour of herring larvae	Gibson & Ezzi	1992
Colour variants and behavior of scamp & gag	Gilmore & Jones	1992
Behaviour & description of two new species of Octopus	Goncalves & Martins	1992
Vertical-distribution of suspended aggregates	Gorsky *et al.*	1992
Mating behaviour of a calonoid copepod	Grad & Maly	1992
Migration behaviour and bioluminescent activity of krill	Greene *et al.*	1992
Determining the pattern of flow in a sand crab circulatory system	Gribble & Reynolds	1992
In situ observations of giant appendicularians in Monterey Bay	Hamner & Robison	1992
Feeding behaviour of *Clione limacina*	Hermans & Satterlie	1992
Bioluminescence emissions in a mesopelagic squid	Herring *et al.*	1992
3-D video, particle velocity encountering eddies	Hill *et al.*	1992
Reproduction and larval biology in a hermaphroditic barnacle	Hoeg & Klepal	1992
Video technology permits volunteer involvement in surveys	Hunter & Maragos	1992
Measuring incremental structures in the hard parts of fish	Jenkins	1992
Developments in underwater TV	Johnston & Vigil	1992
Eye movements and structure of the mantis shrimp	Jones	1992
Interaction of substratum, organisms, and hydrothermal venting	Juniper *et al.*	1992
Videomicroscopy	Karnaky	1992
3-D reconstruction of net performance	Kroeger *et al.*	1992
Formation of bubble plumes and bubbles by breaking waves	Lamarre & Melville	1992
Behaviour of hyperiid amphipods & other mid-water crustaceans	Land	1992
Feeding by post larval and early juvenile American lobster	Lavalli	1992
Fish behaviour	Liang *et al.*	1992
Factors affecting the horizontal migration of the amphipod	Lindstroem & Fortelius	1992
Swimming velocities and behaviour of blue crab	Luckenbach & Orth	1992
Escape swimming in *Euplokamis dunlapae*	MacKie *et al.*	1992
ROV to map and monitor hydrothermal plumes	Malahoff	1992
Video transects of benthic megafauna	Malatesta *et al.*	1992
Mutualistic defence of cichlid and catfish young by their parents	McKaye *et al.*	1992
Predation rates of fish on zooplankton, bioluminescence	Mensinger & Case	1992
Fishing gear performance	Milliken *et al.*	1992
Image analysis at a fish ageing facility	Morrison & Smith	1992
Time lapse benthic video: studies of seasonal filtration by bivalves	Newell & Gallagher	1992
Attraction to bait of eight epibenthic scavenging invertebrates	Nickell & Moore	1992
Sea trial of an ultra-high sensitive underwater colour video camera	Otsuka *et al.*	1992
Swimming behaviour of the giant scallop	Parson & Dadswell	1992
Underwater TV assists geomorphology/geological mapping of sea floor	Rimskiy-Korsakov & Nafikov	1992
Sound attenuation in sea surface films : acoustic/video sampling	Rohr & Detsch	1992
Video and stereo-video recordings of the Titanic	Rosenthal & Olsson	1992
REMOTS sediment profiles	Rumohr & Schomann	1992
Behavioural testing of organisms to toxicology	Scherer	1992
Diel rhythms in the dogfish metabolic rate	Schulze *et al.*	1992
Geological observations	Stueben *et al.*	1992
Spawning behaviour of fish	Svedaeng	1992
Chemical inducers mediating settlement of oyster larvae	Tamburri *et al.*	1992
Measuring the swimming speed of fish	Tang & Wardle	1992
Behaviour of Acartia tonsa in patchy food environments	Tiselius	1992
Suspension-feeding activity patterns of benthic crustaceans	Trager	1992
Video measurements of sperm swimming speeds in teleost fish	Trippel & Neilson	1992
Quantitative marine videography aided by underwater lasers	Tusting & Davis	1992

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Measurement of marine picoplankton cell size	Viles & Sieracki	1992
Predation on tethered lobsters	Wahle & Steneck	1992
Prey attack behaviour of three European cyprinids	Wanzenboeck	1992
Direct observations of Epipyxis pulchra flagella	Wetherbee & Andersen	1992
Intertidal quadrats	Whorff & Griffing	1992
Video of bioluminescence with a Mixed Lighting Imaging System	Widder	1992
Bioluminescence were conducted in sound-scattering layers	Widder *et al.*	1992
A towed video system vs. an opening/closing zooplankton sampler	Wieland *et al.*	1992
Foraging behaviour of *Cricotopus bicinctus*	Wiley & Warren	1992
Disturbance to epibenthic fauna from hurricanes	Witman	1992
Video observations of tilefish habitat	Able *et al.*	1993
Time lapse video microscopy	Abraham *et al.*	1993
3-D video	Anonymous	1993
Fish behaviour to air bubble curtains: Set net fisheries	Arimoto *et al.*	1993
Video transects of coral cover	Aronson *et al.*	1993
Distribution and abundance of *Nephrops*	Bailey *et al.*	1993
Benthic video surveys using a Remote Operated Vehicle	Barry & Baxter	1993
Escape responses of herring larvae, fish behaviour	Batty *et al.*	1993
Spawning behaviour of Solea solea.	Baynes *et al.*	1993
Measuring fish length and biomass for aquacultural applications	Boyle *et al.*	1993
Underwater TV for geological survey	Briggs & Robertson	1993
Cultured fish behaviour	Bugrov & Muravjev	1993
Locomotory patterns of microzooplankton	Buskey *et al.*	1993
Video transects for coral monitoring	Bythell *et al.*	1993
Determining range, size and field of view in video images	Caimi *et al.*	1993
Survival of a branchial ectoparasite through ecdysis of the host	Cash & Bauer	1993
Foraging behaviour of *Brachionus calyciflorus*	Charoy & Clement	1993
Biomass estimates of deep sea hydrothermal vent polychaetes	Chevaldonne & Jollivet	1993
Surveys of megafaunal abundance	Christiansen	1993
Fish feeding behaviour and timelapse video & infrared illumination	Collins & Hinch	1993
Analysis of video imagery at MBARI	Davis & Pilskaln	1993
Digitisation to validate techniques for visual estimates of % cover	Dethier *et al.*	1993
Remote sensing techniques for monitoring giant kelp populations	Deysher	1993
Behavioural activity rhythms of the pike	Dicaro	1993
Video image analysis for morphometric data of fish	Douglas	1993
ROV surveys of burbot abundance	Edsall *et al.*	1993
Fish behaviour to infrasound	Enger *et al.*	1993
3-dimensional analysis of the flow field of feeding copepods	Fields & Yen	1993
Image analysis for detecting uneaten food pellets in sea cages	Foster *et al.*	1993
Flow-field generation by free-swimming & tethered bivalve larvae	Gallager	1993
Behaviour of fish to different types of net mesh	Glass *et al.*	1993
Comparison of visual and image analyser counts of aquatic bacteria	Got *et al.*	1993
Video database systems in the marine sciences	Gritton *et al.*	1993
Suspension-feeding behaviour & ciliation patterns in a pterobranch	Halanych	1993
ROV surveys of benthic anchor scars	Hardin *et al.*	1993
Behaviour of Atlantic cod towards cod traps	He	1993
Measurement of current flow	Helmuth & Sebens	1993
Bioluminescence of a poecilostomatoid copepod	Herring *et al.*	1993
Video image processing for studying near shore dynamics	Holman *et al.*	1993
Cytoplasmic reorganisation of a ctenophore	Houliston *et al.*	1993
Fish behaviour	Huang & Wang	1993
Surface activity of a deep burrowing echiuran worm	Hughes *et al.*	1993
Swimming behaviour of calanoid copepods	Hwang *et al.*	1993
Fish behaviour in response to trawl nets	Inoue *et al.*	1993
Escape of fish from cod ends during fishing	Isaksen & Lokkeborg	1993

Spermatozoa movement in Medaka & during fertilization	Iwamatsu *et al.*	1993
Morphogenetic responses of a green alga to changes in position	Jacobs	1993
Environmental impact of cage cultures	Jansen *et al.*	1993
Muscle responses of fish	Johnston *et al.*	1993
Cinematography of escape response of fish	Kasapi *et al.*	1993
Comparison of sampling techniques for whelks	Kideys	1993
Fish abundance and distribution	Korolev *et al.*	1993
Fish behaviour in response to trawl nets	Larsen	1993
Underwater TV assists to determine effects of a trawl fishery	Laurenson *et al.*	1993
Comparisons of benthic point quadrats and video transects	Leonard & Clark	1993
Ridge keel structure of sea ice ridges in the Baltic Sea ice pack	Leppaeranta & Hakala	1993
Quantifying deep reef fishes from a submersible	Libndquist & Clavijo	1993
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Swimming behaviour of juvenile scallops	Manuel & Dadswell	1993
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Behaviour of snails	Martel & Diefenbach	1993
Fish behaviour in relation to fishing gears	Matsushita *et al.*	1993
Fish behaviour in relation to fishing gears	Matuda *et al.*	1993
Comparison of transect and species time counts for video	Michalopoulos *et al.*	1993
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The ethologometry of fishes of the Black Sea littoral	Mochek & Budaev	1993
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Flow rate & particle concentration in a pelagic tunicate	Morris & Deibel	1993
Consummatory feeding behaviour in *Aplysia californica*	Morton & Chiel	1993
Stereo-video for non-invasively measuring fish size in sea cages	Naiberg *et al.*	1993
Digital imagery for enumerating and estimating size of fish schools	Nakashima & Borstad	1993
Mechanisms of particle transport and ingestion in the eastern oyster	Newell *et al.*	1993
Fluid motion and particle retention in mussel gills	Nielsen *et al.*	1993
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Examples of computer aided analysis of video and other images	Noji	1993
Computer aided analysis of images for fisheries & aquatic science	Noji	1993
Feeding behaviour of *Oncaea sp.* in a discarded larvacean house	Ohtsuka *et al.*	1993
Wave-breaking and breaker-type classification	Oumeraci *et al.*	1993
Fish behaviour	Pankhurst & Barnett	1993
Video for noninvasive counting fish in sea cages	Petrell *et al.*	1993
The effect of particle size on the burying ability of brown shrimp	Pinn & Ansell	1993
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Predation of crabs on oysters	Richardson *et al.*	1993
Assessing the abundance of euphasiids	Sameoto *et al.*	1993
Fish behaviour	Santos & Barreiros	1993
The behaviour and spreading rates of oil in brash ice	Sayed & Loeset	1993
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Artificial neural network system for classifying dinoflagellates	Simpson *et al.*	1993
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Fish behaviour	Skaala *et al.*	1993
Fish survivorship after escaping from trawl nets	Soldal *et al.*	1993
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Filter feeding & water transport in gravid & postgravid mussels	Tankersley & Dimock	1993
Settlement behaviour of the pediveliger of *Argopecten purpuratus*	Tapia *et al.*	1993
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Analysis of ionophore induced acrosome reactions of lobster sperm	Tsai & Talbot	1993
Feeding behaviour of *Calanus finmarchicus*	Turner *et al.*	1993
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Fish behaviour to trawl nets: Reduction of bycatch	van Marlen	1993
The biology of myodocopid ostracodes	Vannier & Abe	1993
Efficiency of snow crab traps	Vienneau *et al.*	1993
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An investigation of wave run up using video camera technology	Walton	1993
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Suspension-feeding mechanisms in bivalves	Ward *et al.*	1993
Mechanisms of suspension feeding in bivalves	Ward *et al.*	1993
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Automated video digitising of circulus spacing on fish scales	Willett	1993
Circatidal rhythms of cockles using time lapse video	Williams *et al.*	1993
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Monitoring vertical migration in *Daphnia*	Young & Watt	1993
The classification of surface wave types	Yu *et al.*	1993
Benthic video observations	Zaouali	1993
Spatial aggregation of prey fishes in lake littoral habitats	Aboul-Hosn & Downing	1994
Videomicroscopy of the motility of teleost sperm	Amanze	1994
Effect of XMAP230 on microtubule dynamics: video microscopy	Andersen *et al.*	1994
Observations of dugongs	Anderson	1994
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A deepwater robot with CCD cameras and distance sensors	Aust *et al.*	1994
The courtship and mating behaviour in the loggerhead musk turtle	Bels & Crama	1994
The role of mucus in particle transport on the bivalve pallial cavity	Benninger & St. Jean	1994
Mechanics of arm movement in the stalked crinoid	Birenheide & Motokawa	1994
Exploring the wreck of the Titanic, 3-D video	Blasco	1994
Water quality monitoring using fish behaviour tests	Bluebum-Gronau *et al.*	1994
Monitoring megabenthic communities in abyssal depths	Bluhm	1994
Assessing fish assemblages on artificial reefs	Bortone *et al.*	1994
Fish behaviour	Brantley & Bass	1994
UTV observations of the movements of flatfishes and predators	Burrows *et al.*	1994
Changes in escape responses due to the development of a copepod	Buskey	1994
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Surveys of deep-sea benthic fishes	Chave & Mundy	1994
A new deepwater imaging system	Chezar & Hagey	1994
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Dispersal of tagged scallops	Cliche *et al.*	1994
Effect of thermal hysteresis proteins on ice crystal growth	Coger *et al.*	1994
Prey capture by a medusan predator	Costello & Colin	1994
Swimming dynamics of a mesopelagic migrating penaeid shrimp	Cowles	1994
Substratum-induced morphological changes in a marine bacterium	Dalton *et al.*	1994
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Swimming behaviour of laboratory reared cod larvae	Doving *et al.*	1994
Video time-lapse study of hemocytes of the zebra mussel	Eble & Sampson	1994
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Effects of chemo-stimulation on the swim path of minnows	Essler & Kotrschal	1994
Sizing seals and assessing ice conditions	Estep *et al.*	1994
Size & settling velocity of estuarine cohesive suspended sediments	Fennessy	1994
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Mating behaviour of crabs	Fukui	1994

Fish behaviour and swimming motion	Fuwa *et al.*	1994
Vertical distribution of scallop larvae	Gallager *et al.*	1994
Comparison of sampling scallop populations with video and dredge	Giguere & Brulotte	1994
Locomotion of *Dolomedes* during prey capture	Gorb & Barth	1994
Aggregations of benthopelagic krill	Gutt & Siegel	1994
Time lapse video for estimation of escapement of Pacific Salmon	Hatch *et al.*	1994
Recordings of wave motion at collision points with a vertical wall	Hattori *et al.*	1994
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Device for volume and fluorescence analysis of macro plankton	Hueller *et al.*	1994
Feeding behaviour of a shallow water bonellid echiuran worm	Hughes *et al.*	1994
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Quantitative sampling of soft-bottom macroepifauna	Jean & Hily	1994
Behaviour of released Salmon smolt	Joerstad *et al.*	1994
Longshore and cross-shore ice-drift rates, Lake Michigan	Kempema & Holman	1994
Video imagery for sampling sizes of scallop shells	Kenchingotn & Full	1994
Bubble size distributions inside the bubble cloud of a wave	Kolaini & Crum	1994
Environmental effects of a floating fish farm	Krohn & Boisclair	1994
Stereo-video, estimating energy expenditure of free swimming fish	Krost *et al.*	1994
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Improving escapement of by catch in trawl fisheries sorting grids	Lange	1994
Fish behaviour	Levin & Gonzalez	1994
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Electric ray predatory motor patterns and electric organ discharges	Lowe *et al.*	1994
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The form, size & settling velocity of mud aggregates	ten Brinke	1994

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APPENDIX 2
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APPENDIX 3
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In-Water Photography and Photogrammetry – Old and New

Patrick Baker.

Department of Maritime Archaeology, Western Australian Maritime Museum

The first successful underwater photographs by a diving photographer were produced in the 1890s by French marine biologist Louis Boutan. He used the types of cameras that were available at that time; i.e. ones utilising large monochromatic glass plates, housed in watertight housings. This has been the *modus operandi* for photographic recording since that time, as photography has passed from glass to sheet film to roll film; through film movies to video; from monochrome to full colour; and now into various methods of digital image production.

Regardless of the particular medium used, there are basic principles that are common to most underwater photographic recording and are worth remembering. Primarily, this paper concerns diver operated photography, but many of the same principles apply to remote systems.

Any camera could be housed for underwater use. However, cameras with features such as automatic focussing and exposure, motor driven film-wind, and through-the-lens viewing are more valuable to the researcher. The compact, self contained amphibious cameras, especially the 35mm Nikonos, fitted with lenses designed for in-water use, are the most convenient and are in widespread use. Sea & Sea amphibious cameras are a cheaper but less versatile alternative.

Reduced visibility, sometimes close to zero, is perhaps the greatest drawback to photographing underwater. Obviously, the complete elimination of water is not an option but the use of very wide-angle lenses is. Such lenses, with angles of view from 90° to 180°, allow reduction of the water path between camera and subject, thus giving much better detail to the photograph. There are even computer-based programs available that allow "fish-eye" photographs and movies to be "stitched" together to give a 360° view: that is, an almost total "all-round" view. The custom designed lenses, such as the Nikon UW 15mm and 20mm and Sea & Sea's 12mm Fisheye, 15mm and 20mm, give the best off-the-shelf quality available in any standard production camera.

Sea & Sea amphibious cameras need supplementary wide-angle converter lenses, as do all consumer level video and digital still cameras. Such lenses, with a value of x 0.5, convert the camera field of view to four times its standard wide-angle setting. These lenses should be mounted behind a dome port in order to maintain their angle of view. Unfortunately all these lenses introduce barrel distortion into the image. This has little significance for general photography but needs to be corrected when the images are used for technical recording. The image distortion can be removed using computer-imaging software, such as PhotoShop.

The 35mm format is more than adequate, and usually superior, to other photographic systems; and this film size can be expected to give results of the highest quality. Only recent digital cameras with 3MB imaging chips are able to record detail similar to medium-speed, 35mm, colour transparency films, which permit good detailed prints of up to A2 size. Domestic format video cameras (Hi8 and MiniDV) can give acceptable still photographs of up to A5 size, even A4 in some cases.

Photo-mosaics are a valuable means of showing a far larger area of seabed than can ever be recorded in a single photograph. Replicating the principles of aerial mapping, a series of overlapping photographs are taken at near constant height by diver or by remote or towed underwater vehicle. A diver can quite simply include a square or cross-rod frame in each photograph, allowing photographs to be printed at a constant scale. The photographs are then joined together to give a single, continuous strip or area picture. Such overall views can assist in understanding and analysing geomorphology, species cover and other features. It may be that video cameras will be increasingly used for photo-mosaic-ing. An operator can "fly" over a site with ease, continuously filming to produce the overlapping photographs needed. Digital video is especially convenient, as it can be directly downloaded to computer. The limited print size available is seldom a problem for photo-mosaics that are usually made up from many individual photographs. Without an exact and known scale a photo-mosaic has limited value. Scale can be in the form of a physical visual scale (grid or graduated line), laser-ranging array or by precise instrumentation.

The usual way of "laying-up" photo-mosaics has been by physically joining the component prints by cutting and gluing. However, a preferable technique now is to scan the photographs and join them using PhotoShop, Live Picture or similar software. This allows a much easier rectification of scale, tilt and image tone than was ever possible with conventional darkroom techniques. (A warning! There is a temptation to use PhotoShop to produce a perfect image, disguising the margins between photographs, at the expense of details that are often hard to join up with accuracy).

An underwater photograph by itself usually lacks information as to precise, and often even gross, subject size. A 2D or 3D grid included in a photograph gives immediate size information for now and forever.

A stereoscopic image, taken using a pair of matched cameras, mounted alongside each other with their optical axis parallel, can be viewed in 3D at any time in the future. Indeed, the characteristic of any photograph, that of being able to be re-viewed for decades, at any time and place, is perhaps the greatest of its values. If stereo pairs of photographs are only to be viewed by eye, calibration is unnecessary. However, the human eye/brain interface cannot easily match stereo pairs that have different image scales. Wide-angle lenses must not be "toed-in" towards each other producing different perspective, nor must they contain strong linear distortions. Fortunately both types of distortion can be corrected easily with PhotoShop.

Any camera system used for photogrammetry should be calibrated. This calibration effectively eliminates any optical distortions from the analysed photographs, including the strong barrel distortion produced by wide-angle lenses. By knowing the optical geometry of the pair of cameras used, and their physical position relative to each other, precise measurements can be made. For moving subjects, a pair of cameras triggered simultaneously is essential. A single camera can be used to photograph a static subject, with a series of photographs taken from a number of viewpoints. These photographs must include a number of recognisable surveyed points. An analytical photogrammetric program can then be used to gain a comprehensive and precise survey of the whole subject.

Use of Towed Deepwater Video Systems at CSIRO Marine Research

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CSIRO Marine Research, Hobart

Introduction

CSIRO Marine Research has used underwater video imaging techniques as part of a toolkit to map seabed habitats of the deep shelf and mid-slope. Video imagery has provided unique information on the nature and extent of seafloor types, and has been particularly useful to record the distribution of epifauna on hard substrata that are difficult to sample with nets or sleds. Video complements other sampling tools by verifying or "ground-truthing" information from other sensors, especially acoustics. We have developed a series of towed platforms for video systems, and these have evolved according to need, new technologies and funding opportunities.

We developed the first towed camera array several years ago for surveys in shelf depths (20 - 200 m) (Barker *et al.* 1999, Bax and Williams 2000) to examine the role of habitats to fishery production in the South Eastern Fishery. We required a system that could provide video coverage of a range of topographical features and bottom types that included limestone reefs with reef-edge features several metres in height. Additionally, the system needed to be able to operate in rough open-ocean conditions, and able to operate effectively in areas of strong water currents.

We have since developed new versions, based on the same operating principal, to meet the needs of research in deeper water. We have updated cameras to record near-broadcast quality video and improved operational aspects of the system whilst on the seafloor and during deployment and retrieval. Recent survey areas include mid-slope seamounts that are spawning habitats for orange roughy, steep volcanic slopes in the protected areas adjacent to the fishery for Patagonian toothfish, and a seamount in the developing offshore fishery of the Cocos-Keeling region.

A major operational feature of the system is its ability to maintain the camera unit at a height of 1 to 2 metres off the seabed while the ship tows it along a transect at a speed of approximately 1 m/sec. This is achieved by having the camera unit trail almost horizontally behind a depressor weight (fig. 1). This position produces a favourable geometry that de-couples the wave-induced ship movement from the camera. The camera unit itself is buoyant and is held to the prescribed height above the seabed by trailing a suitable length chain. The height achieved is determined by the balance between the buoyancy of the camera unit and the weight of the length of chain suspended. The winch operator controls the height of the depressor weight to approximately 30 metres off the seabed with the aid of the acoustic altimeter. The trailing chain is attached with a "weak link" to enable the camera unit to break free in the event of the chain catching.

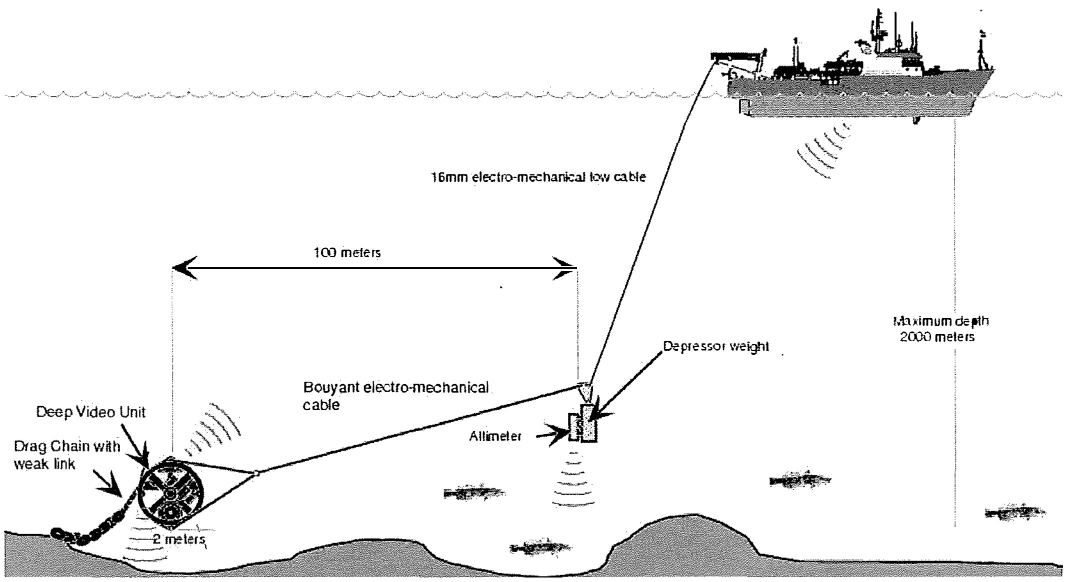

Figure 1 Schematic of towing configuration of the Medium Depth Video System (MDVS).

Operational details

The system can be separated into three primary components. On the ship there is a winch holding ~2500 metres of electro-mechanical tow cable and computer control for the video system. At the bottom end of the wire there is a depressor weight with an acoustic altimeter. Trailing behind the depressor weight, connected by a buoyant cable is the camera unit and ancillary sensors. Details of each component are described below.

Wire, computer control and feedback

Approximately 2500 metres of wire are contained on a purpose-built self-contained electric-hydraulic winch. It is powered by ship-supplied 3-phase power to drive the electric motor and in turn the hydraulic pumps. The wire is guided over the stern of the vessel via a travelling-gantry block.

The electro-mechanical tow wire provides the link between system and ship to supply power for lighting, transmission of sensor, and camera control information, and enables near-real-time feedback on seafloor type through transmitted frame-grab images.

In the operations room of the vessel, a customised system-sensor data-display on computer assists monitoring performance as well as providing feedback for the active control of the system through wire-out adjustments. The display also provides the interface for switching cameras controls, lights and lasers (fig. 2).

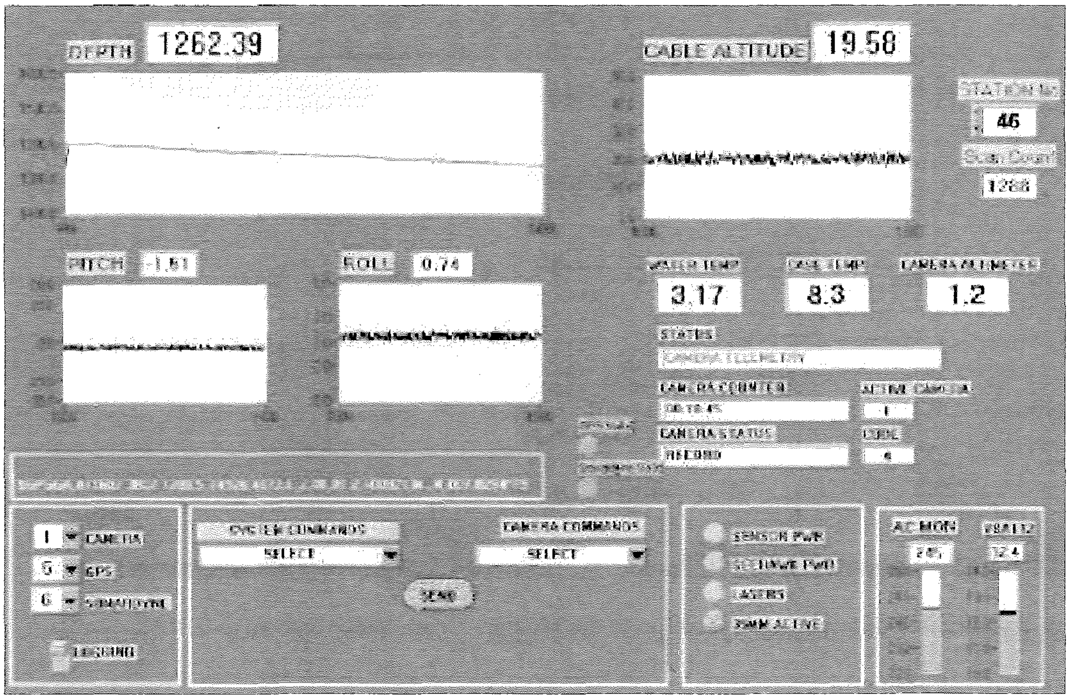

Figure 2 A sample readout display showing the system feedback and switching interface.

Depressor weight and altimeter

The depressor weight assists in de-coupling the camera unit from wave induced ship motion. It is also a reference point for detecting height above bottom so that adjustments to the amount of wire out can be made. An acoustic altimeter is located at this point and provides a height above bottom reading displayed on the vessel.

Camera unit and ancillary sensors

The Medium Depth Video System (MDVS) contains 2 digital DVCAM format video cameras; individually housed and separated by 250 mm (fig. 3). Lighting is supplied using 2 x 250 Watt incandescent lights. The underwater electronics component of the system consists of a low-power processor and interface circuits. The system handles the collection and transmission of data to the ship and responds to commands from the operator to activate lights, lasers and video cameras. Various sensors are incorporated into this package to measure pressure (indicating depth), pitch and roll angles, water temperature, housing temperature and height above bottom (altitude). Bi-directional data/control and slow scan images are transmitted as modem signals over wire pairs in the tow cable. The use of two cameras extends the available recording time from 40 to 80 minutes when used consecutively; optionally, the two cameras can record simultaneously for stereoscopic video. Switching between mono and stereo is via surface controls.

Due to limitations in transmitting video signal through 2000+ metres of wire, we have opted for *in situ* recording i.e. recording high-resolution video at the housed video. We are therefore without video images onboard until the recorded tape is retrieved.

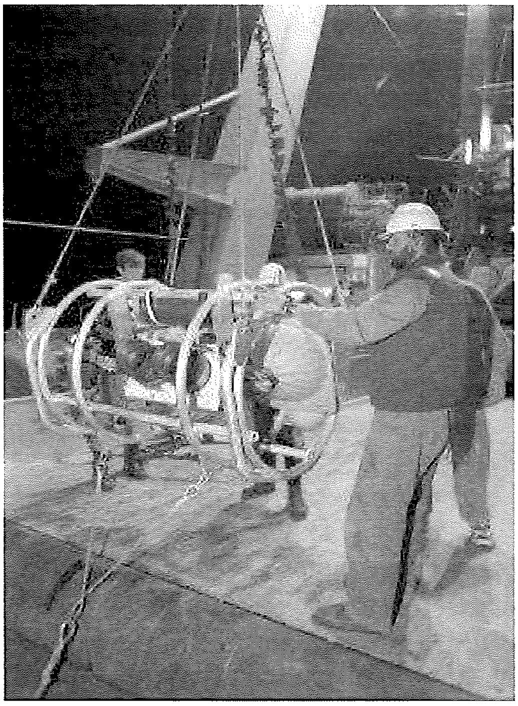

Figure 3 The MDVS being deployed from the stern of the RV Southern Surveyor.

However, some image feedback is available due to an electronics package that transmits a low-resolution frame grab image back to the surface, as modem signals, every 7 seconds. This level of feedback is useful in providing immediate information on seabed type as well as reassuring the operator that the systems performance is optimal.

The system includes a four-laser arrangement for image scaling and X and Y-axis measurements. The laser pressure casings were fabricated in-house and use 635 nm, 10 mW laser diodes. Scientists at Monterey Bay Aquarium Research Institute (MBARI), developed the configuration of four lasers around the camera and specially developed software - used with Optimas image analysis software - to enable measurements to be taken (see Davis, these proceedings).

Accurate seafloor mapping requires the use of Differential Global Positioning System (DGPS) technology to geo-locate the position of the vessel. Additionally, we need to accurately locate the position of the towed devices used to map sites. The towed video is often 1000m or more away from the research vessel when used in deeper water; to enable its geo-location we have added a Sonardyne tracking beacon. The beacon transmits a signal to a hull-mounted receiver on the vessel allowing the distance and bearing from the vessel to the beacon to be calculated. Subsequent linking of this information enables accurate plotting of seafloor attributes, as scored from the video, into a Geographic Information System (GIS) application.

Data logging and analysis

Vessel position and time from DGPS are logged to file during video surveys. The logged files include camera and sensor information. In particular, the files contain the time code from the videotape later used to enable linking of the video derived seabed attributes to the vessel position and the calculated "Sonardyne position". Video of the seafloor is reviewed back at the laboratory for analysis. We score the video using four categories of attributes: Substratum, Geomorphology, Fauna and Abundance (of fauna). Within each category there are several descriptors. We score video at 1-second intervals to capture variability over a small spatial scale (1 to 2 metres). Selected images can be analysed in detail back in the laboratory. Digitised frame grab images from the video can be scaled using the laser dot positions as projected onto the seafloor using "Laser Measure".

Discussion and future developments

Our deepwater towed-video system has largely met our needs; which are to negotiate a variety of seafloor and topographical environments in the open-ocean. These are often rough, current-swept environments. We have collected many hours of quality video in often challenging sea conditions and over steep and treacherous terrain (fig. 4). Success is dependent on the operators of the gear as well as its technical specifications. We operate with an experienced and skilled support team that is make up of electronics staff, field technicians, dedicated winch and deck-crew operators, and the vessel master. The system does lack the ability to examine small-scale features in detail as with an ROV or submersible, however this can be judged against the needs of the project.

Sampling in deepwater demands specialised materials, engineering and technologies. Suitably robust gear linked to the research vessel with a long length of conducting tow cable make for a seemingly expensive package. Add to this the cost of accurate deep-rated sensors and specialised electronics, the cost is considerable. However, deepwater research of this nature is inherently expensive and the cost of our system, judged against ocean-depth rated ROVs or submersibles makes it cost effective.

Future developments will include replacing the tow-cable (which presently has only wire conductors) with a combination wire containing fibre-optics and wire conductors, to enable real-time video to be displayed on the vessel. Operations around seamount topographies, with sheer and sometimes undercut outcrops, involve some level of risk of damage or even loss of the system. We continue to develop ways of decreasing these risks with break away weak-links and improved control and are evaluating the incorporation of thrusters which can react to forward looking sensors, to help avoid obstructions.

Streamlining deck-handling aspects has minimised the time taken to deploy and retrieve the system from the vessel. We have found that considerable time savings can also be made possible by moving between several adjacent/nearby sites, towing the system (at up to 3 knots) in shutdown mode, rather than retrieval and redeployment.

We plan to complement video with an additional camera to obtain high-resolution digital stills. To date we have often included a 35 mm photographic stills camera on the systems but plan to dispense with the need for onboard film processing. At this stage frame-grab images from digital video don't provide the detail and resolution that we require. The application of techniques to accurately scale images and make measurements of objects in 3 dimensions will be continued.

We also plan to develop our database and interface to link real-time scoring of selected seafloor attributes with positional and tape records, taking the lead from our colleagues in Cleveland (see Pitcher *et al.*, these proceedings).

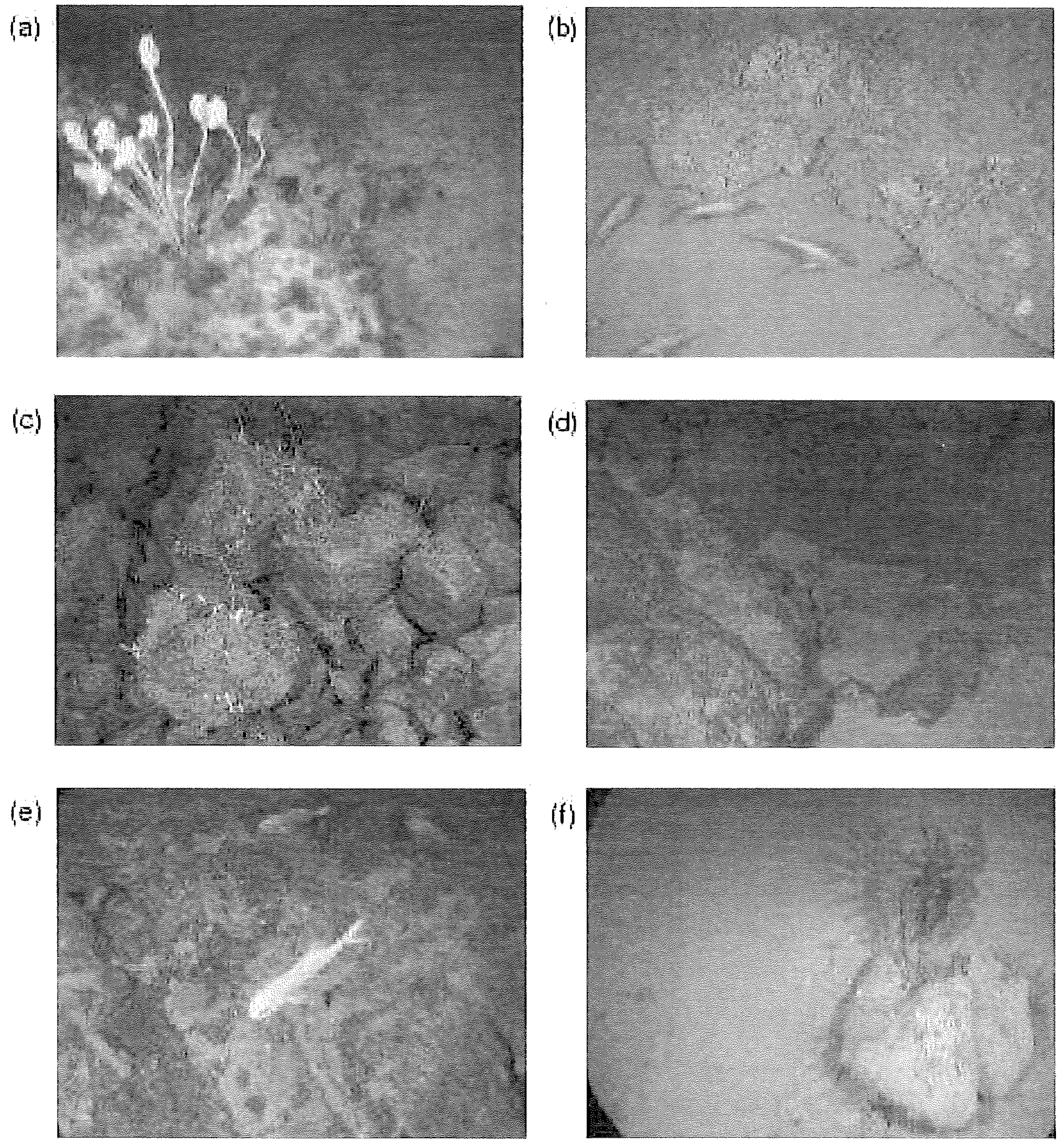

Figure 4 Selected frame grab images of a variety of seabed types successfully surveyed using towed video systems:
(a) low-relief limestone reef (Lacepede Shelf 80 m)
(b) low-relief limestone reef (eastern Bass Strait 120 m)
(c) steeply sloping talus field (Macquarie Island 850 m)
(d) outcrop and coarse debris (Muirfield seamount 550 m)
(e) mid-slope canyon (eastern Tasmania 800 m)
(f) boulder debris in slump field (The Horseshoe canyon 1500 m)

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Reef fish sampling using visual methods – an historical perspective

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Introduction

In the early stages of the experimental "Effects of Line Fishing" Program run by the Reef CRC we conducted a review of literature (mostly published before 1993) on methods of sampling commercially and recreationally important reef fish populations (Cappo and Brown, 1996). In this presentation we outline both the earlier history of underwater observation and some of the more recent literature, particularly studies comparing the effectiveness of different methods.

Historical context

Coral reef fish populations and communities are particularly difficult to census accurately because of the spatial patchiness of their habitat and their differing and frequently cryptic behavioural patterns. Population sampling by extractive fishing methods (such as hook-and-line and traps) can be unreliable, even under carefully-controlled experimental conditions, for reasons of variation in fisher skill, gear selectivity and unpredictable changes in behaviour of target species.

The clear and warm tropical waters facilitated a blossoming interest in recreational and scientific exploration of coral reefs and their biota when self-contained underwater breathing apparatus was invented. This SCUBA equipment had evolved from war-time oxygen re-breathing apparatus, and was successfully promoted by naturalist communicators such as Jacques-Yves Cousteau (Mediterranean Sea), Hans Haas (Red Sea) and, closer to home, Noel Monkman (Great Barrier Reef).

The availability of modestly priced SCUBA equipment during the early 1950's was a major stimulus to the *in situ* study and observation of reef fish communities, whose attractions included colour, sedentary nature, curious habits and quiet disposition. Vernon Brock's (1954) description of a new assessment technique for studying Hawaiian reef fish communities appears to be one of the earliest published applications of this type. With two SCUBA-equipped observers he used a strip transect method to enumerate populations of reef fish at nine localities around the Hawaiian Islands in 1952-3. In an attempt to compare the carrying capacity of tropical coral reef systems with that of temperate freshwater lakes, he developed a system for visually estimating fish lengths which were then converted to weights using mathematical relationships.

Even at that early time in the evolution of visual assessment techniques, it is notable that Brock foresaw the potential for sonic and optical recording. He reported: "The employment of sonar apparatus of proper design might serve as a possible way of estimating abundance of fishes ... (and) under proper circumstances the employment of automatic submarine cameras or submarine television cameras might serve the same purpose".

The following two decades saw the development and improvement of videotaping systems and underwater housings for cine-film, still frame and video cameras. Over the same period a number of underwater visual census (UVC) strategies evolved, including those using strip and belt transects (Mapstone and Ayling, 1993; McCormick and Choat, 1987), point sampling (Bohnsack and Bannerot, 1986; Samoilys and Carlos, 1992), timed-interval counts (Newman, 1995) and observations at baited stations (Gotshall, 1987).

During the 1970's video recording systems were used in conjunction with UVC to provide a permanent record of the underwater observations and aid with species identification and enumeration (Smith and Tyler, 1973; Alevizon and Brooks, 1975). Video systems, including those mounted on ROVs, also became tools in other areas of fishery research, including analysis of behaviour of target species and their interaction with fishing or sampling gear. The ability to lower a video camera to the bottom, tow or drive it remotely, or attach it to a trawl net was a major step forward in the researcher's ability to observe fish populations *in situ* beyond the depth capability of SCUBA divers. It also provided a means of mapping the habitat characteristics of large areas of the sea floor relatively quickly and inexpensively, yielding valuable information about the spatial distribution of fish populations and communities. This approach also enabled improvement of estimates of population density by using behavioural observations to adjust catch-rate estimates from commercial gear such as fish traps (eg Whitelaw *et al.*, 1991).

The ways in which video apparatus has been used in the study or assessment of reef fish can be categorised as follows:

- Direct enumeration - to estimate population size.
- In conjunction with 'standard' fishing/sampling gear - to determine "catchability", gear efficiency, interaction between target species and fishing gear etc.
- Independently - to determine or quantify habitat.
- Independently - to determine critical behaviour patterns in target species that may be relevant to other assessment processes.

Comparisons of techniques

Tests of the reliability of population estimates from UVC with video occurred as the cameras and housings entered the research domain. For example, Davis and Anderson (1989) evaluated three visual techniques (visual transects, video-taped transects and baited stations) to estimate fish populations in a Californian kelp forest. Compared with the "standard" population estimates from Schnabel multiple censuses, the diver transect method was most accurate, but the accuracy of all visual methods was low (8-38%). In a similar comparative study, Greene and Alevizon (1989) compared the results of three UVC techniques (using slate, audio-tape and videotape recording) against a "reference standard" in a large aquarium at the Walt Disney World EPCOT Centre. Of these techniques, the audiotape UVC was found to be the most effective and efficient in estimating the proportional abundance of a group of 44 coral reef species. Ellis and DeMartini (1995) compared the results of baited video stations with catch per unit of effort (CPUE) of longlines as measures of the relative abundance of juvenile snappers and other Hawaiian shelf species, and concluded that the video system was both accurate and cost-effective. While not specifically related to reef fish, the comparison by Adams *et al.* (1995) of ROV video transects with swept-area trawls is also of interest - highlighting the level of bias in population estimation that can result from species-specific gear selectivity. It also showed that the ROV estimates for most species were higher than those from the trawl catch, and had lower coefficients of variation.

These comparative studies involving video are becoming more sophisticated and powerful. Most informative was the recent comparison by Willis *et al.* (2000) of the performance of UVC, angling and baited underwater video in detecting the "effects" of marine reserves on blue cod and snapper size and abundance in New Zealand. The study revealed subtle effects of gear selection and diver bias in UVC and concluded that a suite of survey methods is needed based on the behaviour and biology of the target species.

Such studies are lacking at present for coral reef fishes and, of all the 'optical' assessment procedures currently available, those involving human eyesight still prevail. Indeed there is major investment in SCUBA-based UVC of fishes as part of long-term monitoring of the Great Barrier Reef Marine Park (see Halford and Thompson, 1996). There is growing recognition that SCUBA-based UVC does not work equally well for all coral reef species, especially the premium species of commercial and recreational value. In the context of the GBR line fishery, it has been shown that coral trout *Plectropomus* and red-throat emperor *Lethrinus miniatus* can be censussed quite well by divers in certain depths with appropriate sampling design, but adult red emperor *Lutjanus sebae* and other snappers, cods and emperors cannot.

There is a need for tests of underwater video in UVC of these species, and for "calibration" of the effects of divers (see Harvey *et al.*, these proceedings).

The future

In locations where SCUBA operations are logistically or economically impossible the data collection process must be transferred from human to machine – from diver to camera. The use of submersibles with human observers may have some specific applications in extreme environments, but because of their very high capital and operating costs they are unlikely to be used routinely for fish stock assessment and monitoring. Drifted or towed video cameras remain to be tested on Australian reefs, while applications of hybrid systems involving video cameras trained on traps or exposed baits are yielding promising results (see Willis *et al.*, 2000; Cappo *et al.*, these proceedings). The decreasing relative cost, increasing optical sensitivity and resolution, and progressive miniaturisation of underwater video cameras will undoubtedly add to the potential value of this method. Indications are that these sorts of applications may provide a valuable means of calibrating and refining population estimates from fishing apparatus that would otherwise be too variable to be of much value in detecting changes in stock size. Technological advances of the type mentioned above are also leading to the development of semi-automated computer-assisted object measurement, shape analysis and recognition systems that could help reduce the workload in processing video tapes.

Finally, with growing community concern about the performance of marine protected areas and the environmental effects of certain types of fishing gear, there is little doubt that the next decades will see rapid development of video and acoustic techniques in the large-scale mapping and classification of the sea floor and its flora and fauna. This will be of great value to the process of traditional fish stock monitoring and assessment, particularly where habitats are patchy and subject to natural or human-induced change.

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Use of Towed video as part of resource assessment for the implementation of Australia's Oceans Policy

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Summary

Australia is one of the first countries to adopt an Oceans Policy recognising its responsibility to understand, manage and conserve its marine territories.

A major plank in Australia's Oceans Policy is the idea of Regional Marine Planning. This is based on the concepts of Large Marine Ecosystems, and of sustainable, ecosystem-based, multiple-use management. It is intended to transcend (to supplement, not to replace) the arrangements already in place for managing individual industrial sectors. Around Australia, Large Marine Domains (LMD) were identified (using a combination of biological and geological information) in the process leading to adoption of the Oceans Policy. The first of those domains to be the subject of a Regional Marine Plan is the South-East LMD, now generally called the South-East Region.

The South East Region stretches from southern NSW to south-eastern South Australia, including the whole of Tasmania and Macquarie Island, so the task of understanding it, assessing its resources and managing it is a large one. Obviously, to do so for the rest of Australia's poorly known Marine Jurisdiction is a massive commitment.

In a project funded jointly by the National Oceans Office and CSIRO Marine Research and conducted in collaboration with the Australian Geological Survey Organisation (AGSO), the research vessel *Southern Surveyor* sailed in April 2000 on a cruise with several functions. The cruise was planned in part to contribute to the task of exploring the EEZ under the Oceans Policy, but the relevant aspects for this paper are its concentration on the development and evaluation of surrogate-based survey methods. Thus one of the goals of the voyage was to "test and refine techniques for mapping and classifying marine benthic habitats and their biological communities using surrogate variables, and develop protocols for ground-truthing such assessments".

A Simrad EM1002 multibeam swath-mapper was used, together with other acoustic instruments, deep-water video and still cameras, and direct sampling for both biology and sediments using a range of devices. Part of the work was done over areas already mapped by AGSO using a Simrad EM12 swath-mapper on the French vessel *L'Atalante*. The cruise covered areas off southeastern NSW, Gippsland, eastern Tasmania, the Lacepede shelf off SA, and in the Great Australian Bight.

It is well-known that multibeam acoustics (swath mappers) provide superb bathymetry. The greater challenge in the assessment of resources, including habitats and biodiversity, is to determine how much additional information we can extract from the backscatter from the same instruments. Backscatter is obviously a function of bottom type; hard surfaces reflect more strongly than soft ones. But it is also a

function of many other potentially confounding variables, and the challenge is to develop algorithms that can reliably interpret backscatter, in combination with other information such as bottom slope, to give an index of bottom type. Perhaps, in combination with additional variables (such as bottom stress from currents) it will enable us to predict biological communities.

This is where underwater video comes in: surrogates such as swath-mapper backscatter will never directly sample biodiversity. They provide a basis for prediction. They provide a means for rapid mapping of large areas *but only* in the form of a model-based, predicted map. It is necessary to ground-truth such a prediction.

On the cruise, in order to develop algorithms for making predictions from the swath-mapper output, we deployed multibeam acoustics (high-resolution, shelf-depth - Simrad EM1002) over areas known from previous research. We compared its backscatter with that from another multibeam system (low resolution, deep-water – Simrad EM12) and with a single beam, multifrequency system familiar to our staff (Simrad EK500). Transects with towed video were stratified by examining printouts of the swath-mapper backscatter on board, and targeting the video tows on areas of contrasting backscatter. And finally, direct biological and sedimentary sampling was done in the swath-mapped and video-surveyed areas using conventional samplers (grab, corer, benthic sled, fish trawl).

The video system used was the Mid-depth Video System (see Barker, these proceedings). Its use, in this and other related projects, is in:

- Community description (structure, relative distributions etc.)
- Geological and geomorphological inspection
- Measurements
- bottom features/texture to calibrate acoustics
- organisms
- Counts, etc.
- Ground-truthing - testing predictions

Whilst still a "surrogate" (only a limited range of organisms can actually be identified in a video frame), video provides a far more informative image than a classification of backscatter can ever do, and in certain respects more than direct samplers (grabs, trawls etc.) can do. It shows how the organisms are positioned, *in situ*, relative to one another and can, if required, provide counts, measurements, etc.

The long-term vision can be outlined as follows:

- Swath-mapping covers a large area of seafloor economically.

- Interpretation of the swath backscatter tells us where there are varying areas of seafloor, or features that should be investigated more closely (conversely, it tells us where there are large, homogeneous areas that do not need dense sampling).

- Interpretation of the swath backscatter together with other variables predicts what communities we are likely to find there.

- In this way, the swath-mapper enables us to target other sampling tools most efficiently.

- Video covers less seafloor per unit time or cost, but provides far more detail.

- Direct sampling, used even more sparingly, is needed to detect small or cryptic animals, and for identification, taxonomic study, etc.

To give one (hypothetical) example: an algorithm for interpreting swath mapper backscatter in conjunction with other variables such as current speed and water temperature, may predict that a certain area of rocky seafloor will support a "garden" of large sessile suspension feeders (sponges, gorgonians, etc.). The video camera is capable of confirming that prediction, because a "garden" of sponges, etc., can be seen (and identified to phylum or order) with the naked eye. But the species of sponges etc. off NW Australia, and the smaller motile fauna associated with them, may be entirely different from the species in a similar-looking community off SE Australia. So, finally, direct sampling is needed to complete the characterisation of the biodiversity.

Thus, a national program of seafloor mapping and resource assessment (needed under the Oceans Policy) cannot be dependent only on acoustics, which could never give the necessary biological (or geological) detail, but is likely to depend heavily on video for ground-truthing at the "community" level. The output from the acoustics will be used to optimise the sampling design for the deployment of video. Direct sampling, optimally targeted using both acoustics and video, will be necessary to take the assessment to the species level.

I should stress that this whole discussion has been about "mapping" – a very static idea and in my view merely a starting point. *Understanding* biodiversity and its dynamics, and caring for it (all of which are intended under the Oceans Policy) are tasks that require different (albeit related) tools and protocols.

To summarise our impressions from this cruise (because the results have not been analysed yet):

- The acoustic instruments agree with one another sufficiently to be promising, but not completely, which means that the development of algorithms for classifying backscatter is a nontrivial challenge,

- the mid-depth video has provided excellent footage,

- the ship's dynamic positioning system, together with position-locating beacons on the underwater instruments, has given us a precision of deployment to within 10 m even in depths greater than 1000 m,

- this means that the concept of video and direct sampling being "targeted" under the guidance of the interpretation of the acoustic information, is now feasible.

Acknowledgements

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This survey, particularly the use of video in deep water, would not have been possible without the support of many people. Special contributions were made by staff of the CSIRO Marine Research Ocean Engineering group, the Electronics group, the Engineering Workshop, the officers and crew of FRV *Southern Surveyor*, and the CSIRO and AGSO staff who participated in the cruise.

Disclaimer

The Use of Baited Remote Underwater Video Stations (BRUVS) to Survey Demersal Fish Stocks -- How Deep and Meaningful?

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Introduction

Tropical demersal fish of commercial and recreational importance often have low densities and/or have highly clumped distributions, inhabit rugose topography and closely associate with specific sediment types or megabenthos patches. These distributions and associations make stock assessment very difficult when using trapping and Underwater Visual Census (UVC); there are a few samples with high catches/sightings but the most common samples have zero catches/sightings. In trapping surveys there is a significant linear correlation between the mean of a sample and its standard deviation (Williams *et al.*, 1997), and in UVC there is a similar relationship between the mean and its variance (Cappo and Brown, 1996). For both techniques, relatively high levels of variance occur at all densities of fish and increasing the levels of replication does little to reduce the variance after a certain point. In the case of fish trapping, the sampling effort needed to overcome the poor power of statistical tests may prove either logistically or socially unacceptable, or both, when employing catch-and-release, even to detect major changes such as halving of the population size (Williams *et al.*, 1997).

Following the lead of Hill and Wassenberg (2000) and as part of FRDC Project 97/205[1], we sought to develop a fleet of low-cost, baited video camera systems to enhance the advantages, but overcome the biases, of both trapping and UVC to census demersal fish beyond the limits of SCUBA. Here we report on pilot results of the comparative advantages, sampling power and limitations of data obtained from BRUVS (Baited Remote Underwater Video Stations) surveys in reef lagoon and inter-reef habitats in Scott Reef Lagoon on Australia's north-west shelf, and from sets made around Palm Islands in the central section of the Great Barrier Reef Marine Park.

Methods

BRUVS had dome ports housing Sony Hi-8 Handicams with wide-angle lenses. Exposure was set to "Auto", focus was set to infinity/manual, short-play mode (90 minutes) was selected, and date/time codes were overlaid on footage. A fleet of 6

[1] FRDC 97/205 "Dynamics of large sessile seabed fauna, important for structural fisheries habitat and biodiversity of marine ecosystems - and use of these habitats by key finfish species" CSIRO DMR, AIMS, Qld Museum; In Progress.

BRUVS were deployed in 30-70 m depth with crushed pilchard bait in the middle field of view (see fig. 1; and video 1, available in electronic version of report).

They were deployed and retrieved in the same manner as fish traps, with polypropylene rope and marker buoys attached, and the time, depth, latitude and longitude was recorded for each set. Interrogation of each tape provided:

- a classification of the habitat at each set;
- the time the BRUVS settle on the seabed (TOB);
- the time of first sighting of a taxa (TFS);
- first feeding of taxa (TFF) in the field of view;
- the maximum number of each taxa seen together in any one time on the whole tape (MaxN);
- the intraspecific and interspecific behaviour (in 8 categories) of each taxa;
- the time at which all bait was exhausted if such an event occurred;
- size estimates of fish directly above a scale bar on the bait canister.

Results

BRUVS recorded an outstanding array of aquatic animals, ranging from thresher sharks (*Alopias vulpinus*) to cryptic serranids rarely seen by divers (*Epinephelus cyanopodus*). Throughout South Scott lagoon we recorded 207 taxa from 37 fish families. Each tape recorded an average of 18 taxa (range 4 to 39). In decreasing order of occurrence on tapes, lethrinids (sweetlips), serranids (cods and groupers), lutjanids (snappers or sea-perches), chaetodontids (butterflyfishes) and nemipterids (coral breams) were most frequently recorded. Figure 2 indicates the occurrence of taxa on all tapes and highlights the predominance of infrequently recorded taxa. Thirty-one percent of taxa were recorded only once, 16% twice, and 10% on only three tapes. Over 57% of taxa were seen on 3 tapes or less. Only 2% were seen on 50 or more tapes - most notably a large mobile predator, the green jobfish (*Aprion virescens*). This may relate to the dynamics of attraction of taxa by the BRUVS and bait plume, the rarity of taxa, their patterns of abundance and mobility, and the high biodiversity of the South Scott communities.

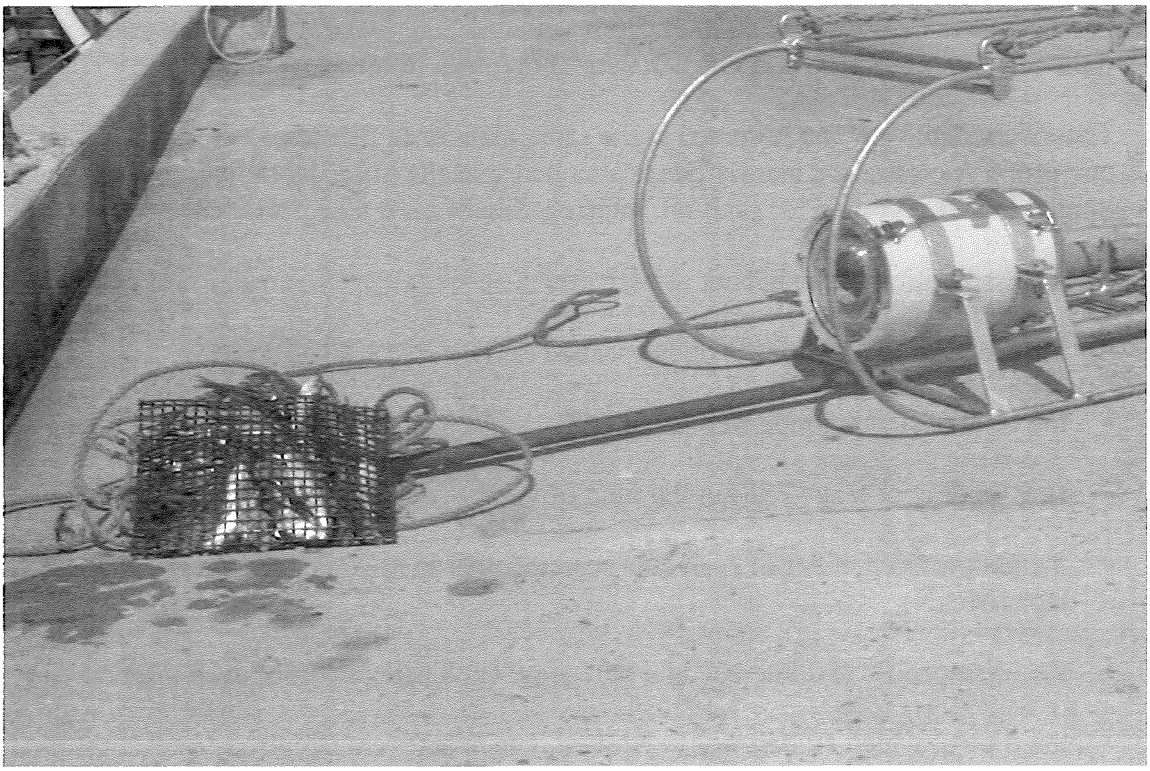

Figure 1 The BRUVS developed by AIMS workshop.

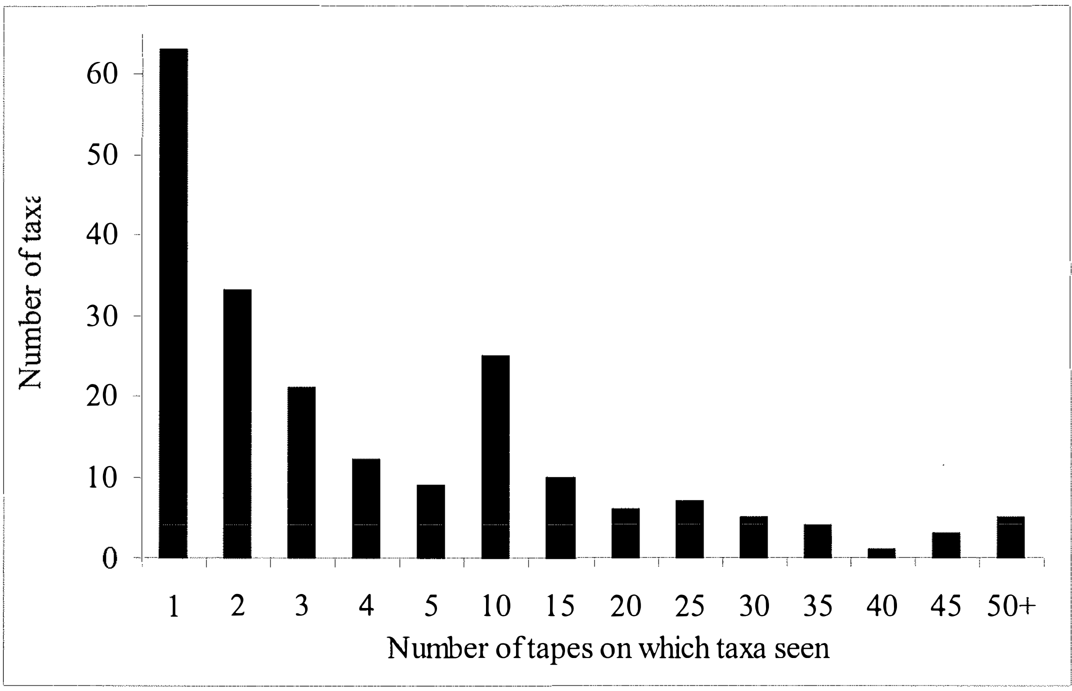

Figure 2 The number of tapes on which individual taxa were sighted for 207 taxa on 87 tapes from South Scott Lagoon.

The time of first sighting of a taxa on a tape (*TFS*) was assigned to one of thirty 3-minute segments. For all the tapes (without any stratification by location or habitat type, see fig. 3), the average rate of accumulation of a species list for fishes in South

Scott lagoon rapidly approached a rate of approximately 1 new taxa for each new 3-minute increment.

It might be expected from chance alone that the less frequently recorded taxa would be sighted at random throughout a 90 minute tape, but figure 4 shows that at least half of the many taxa recorded on only one tape were sighted in the first 27 minutes of that particular tape. Those taxa seen on only two tapes were recorded mainly within the first 9 minutes of soak time of those tapes; and those sighted on 3 tapes were recorded mainly within the first 3 minutes of tape footage. The trend was even more pronounced for the more commonly sighted taxa. It is evident from only 87 sets that BRUVS "captured" sightings of both rare and abundant species of fish in the initial period of deployment.

Multivariate analyses of untransformed data on abundance and spatial distribution of 110 species of fish and elasmobranchs indicated reasonably distinct communities associated with the various regions of South Scott lagoon. In particular, the marginal areas of East Hook (EH), East Hook Entrance (EHE) and Western Lagoon (WL) were distinct from the internal lagoonal areas of South Lagoon (SL), Eastern Lagoon (EL) and Central Lagoon (CL).

We set BRUVS in strings of 6 replicates which fell within or across the recognised regions in South Scott lagoon, ranging from *N*=12 (EH) to *N*=22 (EL). If we wish to hindcast the optimum number of tapes to accumulate a species list for each region the order in which the tapes are analysed becomes very important. This is because benthic communities are patchy, and the strings of BRUVS may have been set within patches. If, for example, the first string of BRUVS sampled sandy areas with lower diversity within a region, and the last string sampled rugose habitat with high diversity within a region, then sequential interrogation of the tapes from first to last would indicate that a species list is accumulated slowly - and that many BRUVS sets are needed. To exclude this bias we ran 50 random sequences of tape selection and we took an average of the 50 species accumulation curves for five of the survey regions.

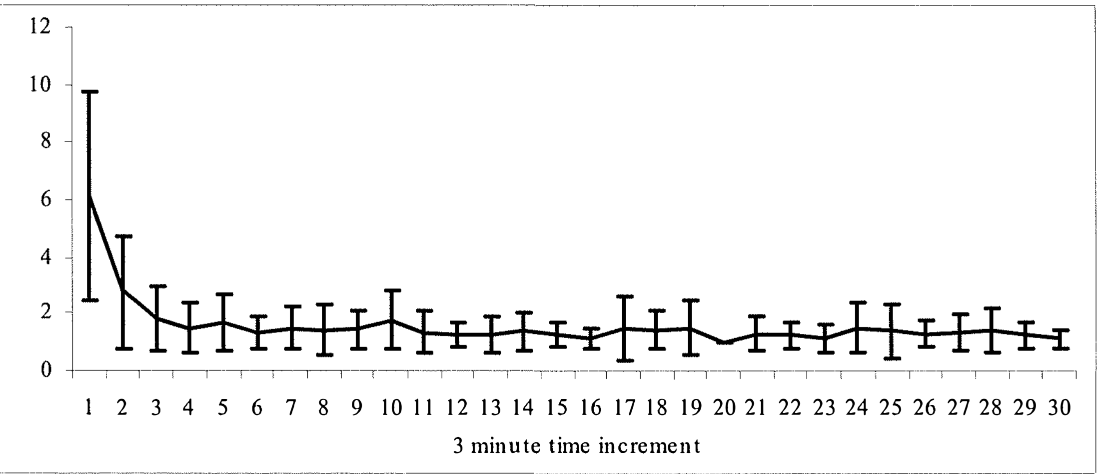

Figure 3 The number of new taxa sighted in the series of thirty 3 minute time increments within a full 90 minute tape for 207 taxa on 87 tapes from South Scott Lagoon. One standard deviation either side of the mean value is shown.

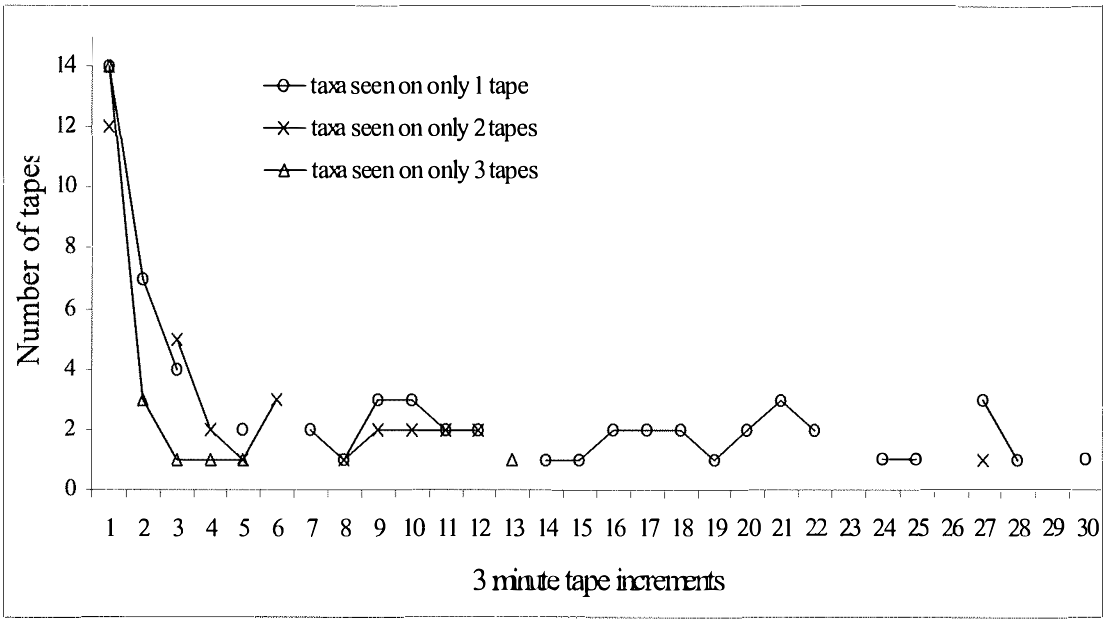

Figure 4 The number of tapes on which "rare" taxa were sighted first within particular time increments. The 3 lines represent taxa seen on only n=1,2 or 3 tapes.

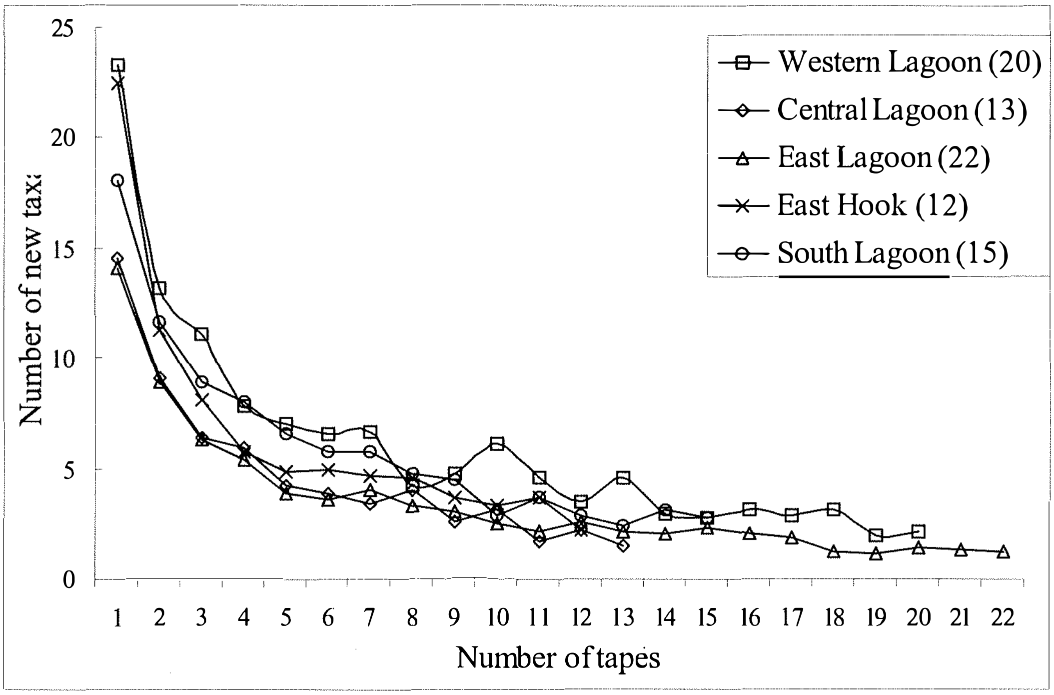

Figure 5 The average of 50 species accumulation curves for each of 5 survey regions in South Scott lagoon obtained from 50 randomly selected sequences of tape interrogation.

Figure 5 shows the patterns of accumulation of newly recorded species with successive 90 minute tapes. Interrogation of 12 randomly selected tapes accumulated an average of 99 species from WL, 83 species from SL, 80 species from EH, 61 species from CL and 60 species from EL. None of the curves reached the X-axis, indicating that species lists were incomplete, but the curve for EL suggests that only one new species per tape would be expected beyond the sample size of N=22 tapes. The curves for CL and EL were essentially superimposed. The curves for WL and EH shared a common starting point but the trajectory of EH rapidly fell away due to lower species diversity. There is a strong indication that, irrespective of the number of species within the South Scott survey area and the type of habitat, there is a rapidly diminishing "return" stabilising somewhere beyond 12 tapes. We are therefore confident that BRUVS will provide a rapid assessment tool for surveys of fish biodiversity below limits of SCUBA.

BRUVS Sampling power

An example of the power of BRUVS in detecting changes in abundance can be investigated using an abundant and frequently encountered species, *Lethrinus semicinctus*. It was recorded on 63 of the 87 tapes. Figure 6 shows the results of sampling power calculations of the number of BRUVS sets (tapes) required for a 95% chance of detecting a specified change in the mean abundance of *Lethrinus semisinctus* 90% of the time. With stratification of the data by habitat type the predictions of sampling requirements ranged from only 10 sets in Central lagoon to detect a 30% change, to 70 sets in East Hook to detect a 50% change in the mean. The influence of "zeroes" in the data is very strong. For example, 2 to 6 individuals of *L. semisinctus* were recorded on every Central Lagoon set (mean *MaxN* = 3.69, CV = 0.51), whereas East Hook sets produced either no sightings (50% of sets there) or high *MaxN* ranging up to 26 fish, with mean *MaxN* = 6.58 fish and CV = 13.35.

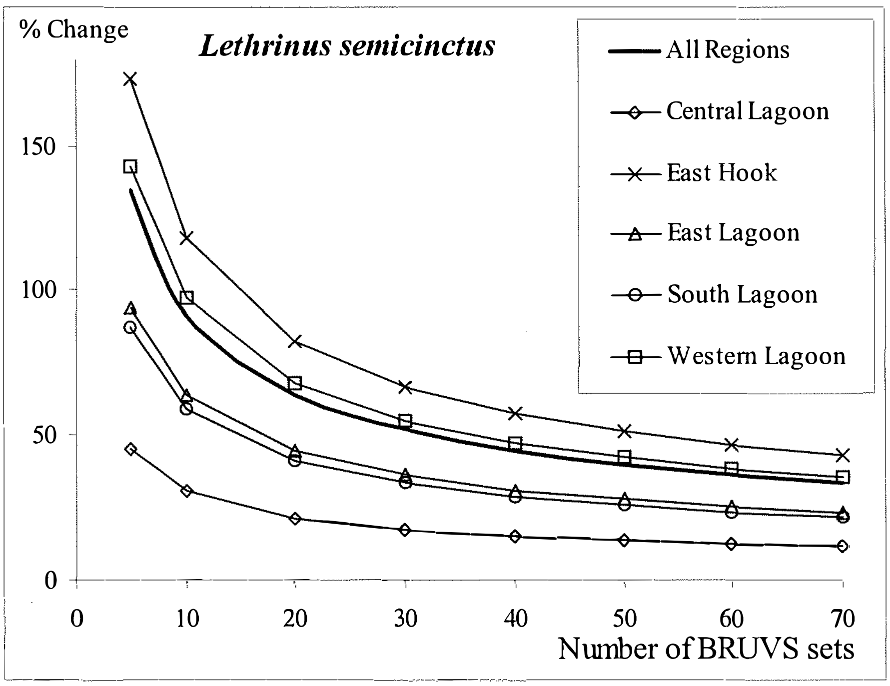

Figure 6 Power calculations of the number of BRUVS sets (X axis) required for a 95% chance of detecting a specified change (Y axis) in the mean abundance of Lethrinus semisinctus 90% of the time, in various regions of South Scott lagoon.

The same species was the single most abundant lethrinid (and second most abundant species) in trapping studies using baited "O" traps done by Williams *et al.* (1997) on the central Great Barrier Reef. Their "best case" scenario stratified by habitat produced mean catches of 3.77 *L.semisinctus* (CV = 1.60). Subsequent power estimations predicted that 100 trap sets would be needed to detect a 50% decline in the population and 178 trap sets would be needed to detect a 50% increase (see tables 8.2 and 9.3 in Williams *et al.* 1997).

Our preliminary power analysis with a relatively small number of BRUVS sets predicted that only 25% to 40% of this sample size (~ 40 BRUVS deployments) would be needed to detect the same change on South Scott Reef, irrespective of habitat type. This could be obtained easily within 3 days sea-time using a 6 metre boat carrying a fleet of 6 BRUVS deployed 3 times per day. To make the same sampling "effort" following the procedure of Williams *et al.* (1997) would require 9-15 days sea-time on the 29 metre AIMS vessel RV "Lady Basten" because only 12 rigid "O" traps could be carried on the deck at any one time. Using these figures and current charter rates, we predict that BRUVS could be orders of magnitude cheaper than such fish traps for detecting the same level of population change in an abundant species.

Non-independence of replicates

However, there is a snag in this logic - we have assumed that the BRUVS replicates are independent, yet there is clear evidence for some taxa that the same individuals (e.g. long-nose emperor *Lethrinus olivaceous*) that are large and mobile can visit more than one BRUVS in a string. This invalidates any assumption of independence of samples of the abundance statistic *MaxN* at the level of the whole 90 minute tape. In traps, fish can only be caught in one trap in any given set, even if they enter/leave/enter a series of traps. In BRUVS, they might potentially travel up a berley plume and visit all the "replicates" in one string - particularly if sets are close together and aligned with the prevailing current. The closeness of sets is unavoidable if replication is sought in patches of megabenthos, which are often small (see Pitcher *et al.*, 1999).

An obvious way to avoid this bias is to derive *MaxN* from the same time segments on all replicate tapes or from segments where it is impossible that the same group(s) of fish could have been sighted at multiple BRUVS. Fish cannot be in two places at once, and if BRUVS are deployed 200 metres apart a 200 mm *L. semisinctus* would take 16 minutes to swim at one body length per second from one BRUV to another (12 metres per minute; 0.720 kilometres per hour) to reach another BRUVS. Given that the first 15 minutes of a tape was most informative at South Scott lagoon, in terms of species accumulation, the assumptions of independence of replicates may prove valid for some early parts of the tapes for some species. It must also be kept in mind that the presence of zero sightings inflates CV's and hence reduces sampling power, so random choice of "sampling times" amongst a string of sets will probably not be optimal to obtain *MaxN*.

There is rich opportunity to investigate such dynamics further, with close attention to the timing at which *Max N* occurs, and to model BRUVS spacing, species-specific behaviour, swimming speeds and areas of attraction (of both baited and unbaited deployments) to estimate the thresholds at which we can decide that "replicates" are "fishing" independently. These thresholds will undoubtedly be specific to different fish families and sizes. Scott Reef tapes strongly suggested that large schooling carangids and whaler sharks were visiting several or all 6 BRUVS in a string, covering over a kilometre of seabed in the course of the 90 minute tapes. For such large taxa it should be possible to use the tape time codes and body marks and scale patterns to recognise individuals and exclude them from analysis of more than one tape. Such identification of individuals will not be feasible for small abundant species like *L. semisinctus*.

We chose *MaxN* as a convenient under-estimator of the number of fish in a BRUVS sample (as did Willis *et al.*, 2000), but there remains a need to thoroughly explore other statistics available from the tapes which may better estimate relative, if not absolute, abundance. On the premise that abundance is related to prevalence of sightings amongst replicates in a string (*n*/*N* BRUVS), and time lapsed before first sighting (*TFS* - *TOB*), as well as *MaxN*, a useful index of abundance for each species could be:

$$\textit{Index of Abundance} = \text{mean } \textit{MaxN}\ (n/N)\ /\ \text{mean}\ (\ \textit{TFS} - \textit{TOB})$$

A species usually seen very early, and with a large number in any one field of view on every BRUVS replicate in a string will have a high index. Species seen late, on few replicates, and in small numbers will have a low index.

The dynamics of attraction-arrival-interaction-feeding-satiation-departure are especially worthy of further investigation. During the feeding stage in this process, a "berleying effect" (*sensu* Whitelaw *et al.*, 1991) operates in which the intense activity itself attracts conspecifics, competitors, predators and other species. As fish become satiated this attraction diminishes. This is evident in figure 7 as "humps" in the proportion of fish feeding at the bait canister, and a marked drop in feeding activity after one hour soak time.

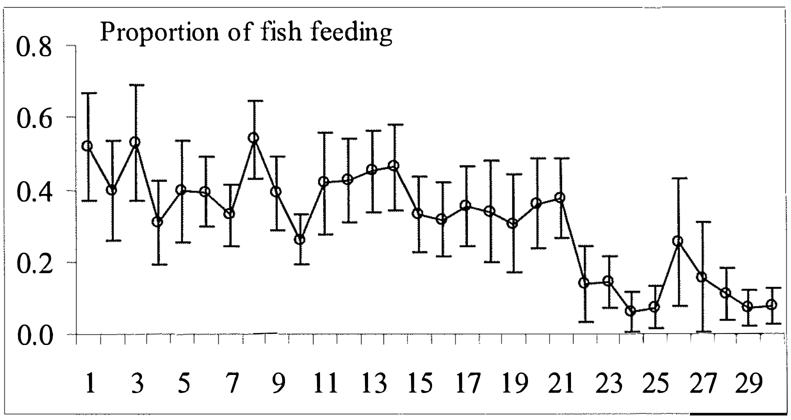

Figure 7 Mean proportion (± Standard Error) of fish feeding on the bait canister in different 3 minute time segments of 23 BRUVS sets around Palm Islands, central GBR.

Summary

We believe that BRUVS offer a superb rapid assessment tool for fish biodiversity in waters beyond the limits of SCUBA, and also that they will be very useful to estimate relative or absolute abundance of a variety of species in a non-destructive manner. However, more work is needed on developing appropriate sampling statistics to best quantify abundance and to overcome potential problems with non-independence of replicates. Current research is also focussing on calibration of BRUVS with fish traps and UVC, and on comparisons of baited and unbaited performance to gain insight into the effects of bait attraction.

Acknowledgments

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From 'SubSea' to 'Lab' – Dependable submarine observation without the need to have anyone in the water!

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Driven by industry and supported by the development of sophisticated subsea Remotely Operated Vehicle (ROV) technology, ROV businesses have been built on the professionalism and skill of their pilots and technicians. As new successful operations generate new skills, this in turn prompts advances in vehicle technology and the execution offshore of a large range of work, from the survey of the seabed, through to the servicing of equipment used in exploiting subsea oil and gas fields.

Remote submersible technology is an exciting, dynamic, interdisciplinary field of study. The purpose of this paper is to highlight recent developments and the growing support for submersible ROV's and, in particular, the need for specialised training and competency needed to support offshore marine activities.

One of the key strategies adopted by training regimes in the Asia Pacific area of operation is to examine the development of sophisticated subsea technology and to provide the necessary specialised training to support growth of the industry in Western Australia. ROV training and product development already provided by centres such as the Fremantle Maritime Centre (FMC) will continue to provide training to personnel in the oil and gas industry, in marine telecommunications and in search and recovery. As well as providing a useful tool for scientific observation purposes, including research and analysis into seabed habitat and maritime archaeology 'ground-truthing'.

Currently, ROV training consists of one competency-based package (industry specific) that has been accredited to national standards through the College's accreditation procedures. The competency scheme is supported by an industry based ROV Board of Management (BOM) and consists of seven foundation member companies and the Australian Oil and Gas Industry Training Centre (AOGITC), which is a consortium of three West Australian technical colleges. The scheme has established a benchmark for the training and safety requirements of the local industry. It has achieved international recognition for its expertise, as well as providing benefits to the member companies and to ROV industry personnel.

International recognition and endorsement of the training is effected through a license agreement with a specialist UK training company and strictly follows the guidelines set by the International Marine Contractors Association (IMCA). Under this management and alliance with the UK Company, the Perth based TAFE consortium, acting as a satellite centre, has added recognition and endorsements from the company under the Offshore Petroleum Industry Training Organisation (OPITO) system.

The main benefit of this accreditation is global recognition of course standards, and competitive international employment opportunities for delegates who complete training under this accreditation scheme. This can only be achieved through specialised training delivery of competency services and full cooperation with the ROV industry.

In summary, the ROV industry is a highly specialised industry where course graduates find work with offshore enterprises or move into the technical maintenance of the ROV systems as submersible engineers. Many of the enterprises involved in the industry are transnational companies with subsidiaries and partnering relationships. In particular, transnational member ROV companies based in the Asia Pacific area of operation fully appreciate the long-term benefits of this scheme and are committed to supporting and instituting the most suitable and cost effective training regime through this infrastructure.

It is evident that there exists a need for this unique VET training scheme, not only to support those industries involved in oil and gas exploration, but also to provide training and expertise that can support new technologies in marine research.

Use of Drop Video to Map Habitats in a High Energy Shallow Reef Environment

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Introduction

As part of a study to optimise the placement of clean dredged sands from Port Taranaki (fig. 1), we undertook an investigation of benthic habitats near New Plymouth, New Zealand (174° 11'E 41° 03'S). Until recently, there had been few *in situ* ecological investigations of this coast, in no small part due to the harsh physical environment; dominated by long-period (12-16 second) swell with wave heights of up to 6 m (McComb *et al.,* 1999a, b). Underwater visibility is frequently very poor. It is therefore imperative that when suitable conditions occur, ecological information is gathered quickly and efficiently.

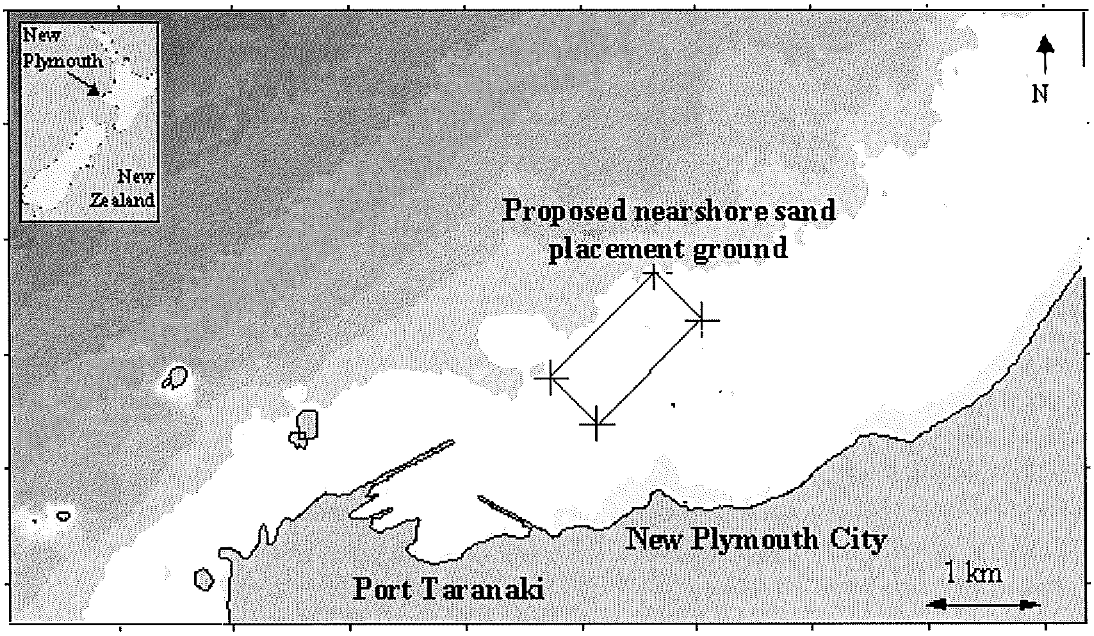


Figure 1 Location map showing the New Plymouth coast with land coloured green, intertidal in yellow, and 5m depth contours in shades of blue. The proposed placement area is outlined in black. Location of New Plymouth on the west coast of North Island, New Zealand given in inset.

A four-year study has recently gathered much information regarding the physical oceanographic and sedimentary environment at New Plymouth (McComb *et al.*, 1997; McComb *et al.*, 1999a,b; McComb and Black, 2000). That study used an intensive field data collection program (including sidescan sonar, wave and current meters, sediment trapping, sediment tracing) and numerical modelling to identify a nearshore (6-10 m water depth) placement ground for clean sand dredged from the harbour (fig. 1). Instead of offshore placement, the use of a nearshore ground retains the harbour-trapped littoral sediments within the nearshore littoral cell – thereby mitigating downstream erosion / depletion effects.

The key aim of this work was to optimise the benefits of nearshore placement (i.e. renourishing city beaches) while at the same time minimising the biological impacts (i.e. inundating important ecological habitats). To identify the habitats that may be affected by the proposed nearshore sand placement, we needed to map a relatively large area. Furthermore, as we were faced with adverse conditions for much of the time, we required a technique that allowed us to map biological habitats across a broad area in a short period.

In areas of shallow water and good water clarity remote sensing techniques (e.g. aerial photography) can be used effectively to map underwater habitats and variations in substratum type (e.g. Andrew and O'Neill, 2000; review of Kingsford and Battershill, 1998). However, many temperate systems have murky water and therefore do not lend themselves readily to aerial photographic techniques. Sonar-based techniques have not been found to be suitable for distinguishing biological habitats either, as they cannot distinguish between presence and absence of seaweed beds, for example. The most common alternative to these remote sensing techniques is to use SCUBA divers. However, the resulting data are often spatially inaccurate, and are very time-consuming and expensive to collect if the study site covers a large area. An alternative to using SCUBA divers is to use drop video. We have found that the drop video technique can be used to map habitats rapidly and accurately when combined with modern navigation techniques. To this end we employed a vessel-mounted drop-video to record the benthic habitat over a grid pattern. Subsequently, quantitative sample sites for SCUBA divers were allocated on the basis of the area occupied by the different habitats.

Presentation of Results

It is important for the future of coastal management that the results of habitat surveys can be effectively communicated to a non-technical audience. In our experience aerial-photographs, maps, graphs and tables often fail to convey to the audience the presence of crucial variations in habitat (such as those examples demonstrated in Choat and Schiel, 1982; Taylor, 1998). Recent technological developments have made it possible to present raw qualitative data, such as video recordings (e.g. Fabricius and Wolanski, 2000), which have potential for much higher audience impact. To this end, an important part of our study is the production of an interactive CD to present the findings of our study to the public. The CD contains excerpts of video footage from some 217 sites. Each video excerpt is linked to a site on a locality a map.

Methods

The bathymetry and physical features surrounding the proposed placement area at New Plymouth had been comprehensively surveyed (McComb *et al.*, 1997), with high-resolution depth information interpolated to a grid of 25 m spacing. A survey region was defined that both circumscribed the proposed placement ground and encompassed regions 'downstream' from the ground (fig. 2). This region, covering some 3.15 km^2, was gridded at 150m spacings to extract sites for video recording. The water depth ranged from 1.54 to 16.15 m below lowest astronomical tide.

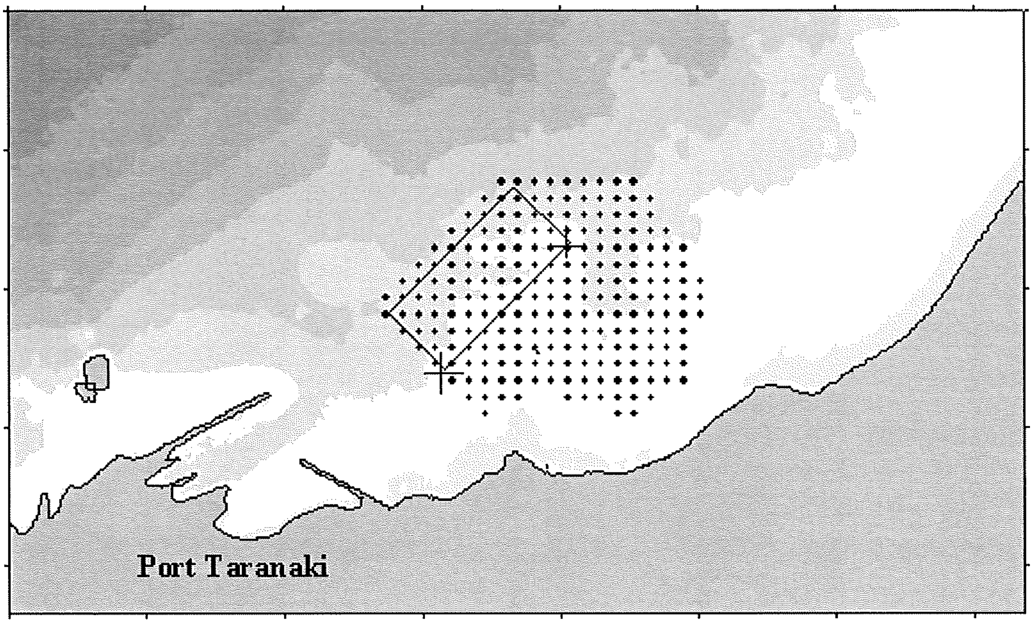


Figure 2 Location map showing the New Plymouth coast as for figure 1, and including map of sampling sites over 3.15 km^2.

Benthic habitats at each site were observed using a dropped video camera. This consists of an underwater lens and lights on a 100m cable attached to a handheld Hi-8 video recorder on the boat. In an 11 hour period over two days in February 2000, we surveyed 217 sites in that area with the drop video from a survey vessel with differential GPS. At each site, around 30 seconds of data was recorded along with real-time observational notes and a habitat classification. We ascribed four generic habitats; sand, coralline pavement, mixed macro-algae, or kelp (*Ecklonia radiata*) forest. These data were subsequently mapped and quantitative sample sites allocated on the basis of the area occupied by reef. They were sampled with divers by use of 1 m^2 quadrats (n=5).

The video data formed the basis of the interactive CD. Between 10 and 30 seconds of analogue video footage was converted to digital images and saved as *.mpg files. The site name and depth information was edited onto the video images. An interactive HTML structure was written to allow the digital video from each site to be accessed by clicking positions on a map. Further, habitat and location maps were included, along with an explanation of the methodology. The HTML file structure was then burned to CD.

Results

The video survey was carried out during a period of calm weather with exceptional water clarity. The video data revealed the rocky substratum comprised coralline pavements, with an area of seaweed habitat on a raised topographical feature immediately shoreward of the proposed placement region. Indeed, it was found that the shoreward boundary of the ground transgressed the seaweed habitat (fig. 3).

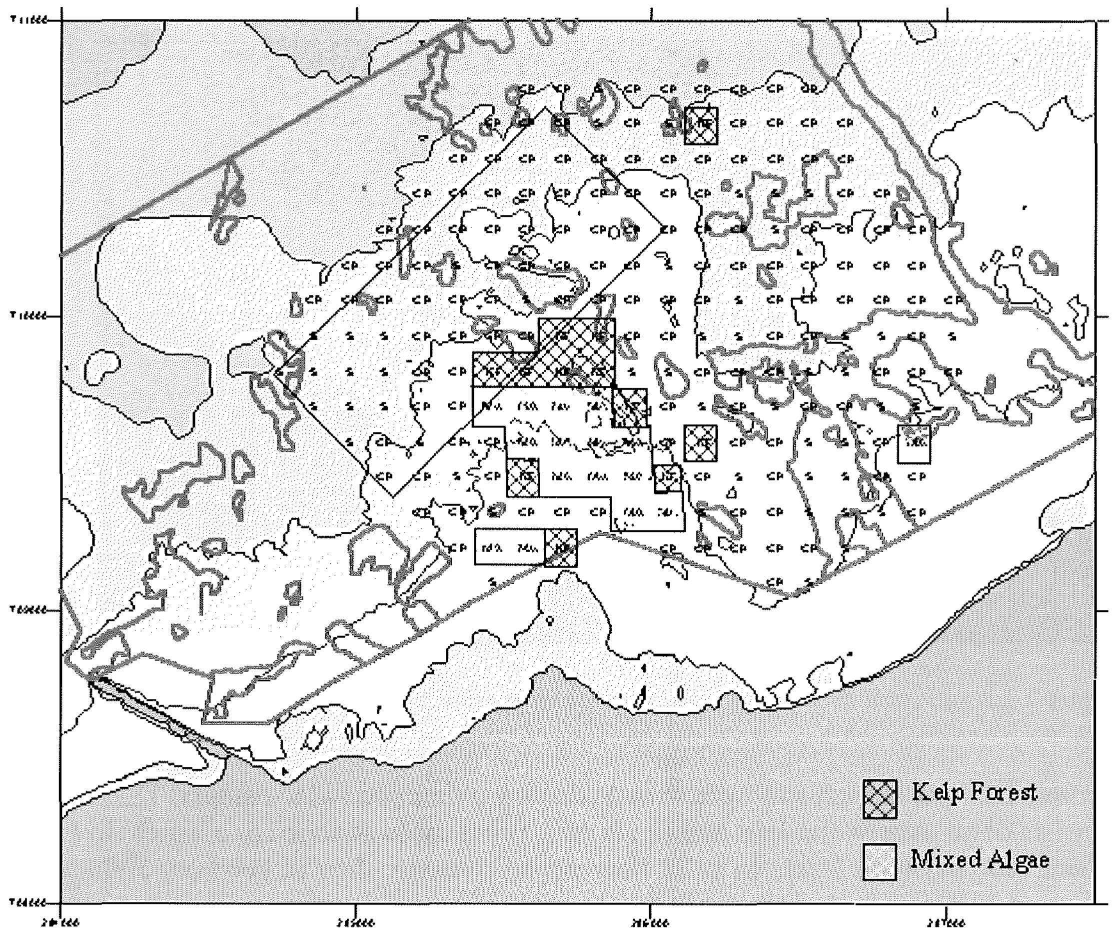
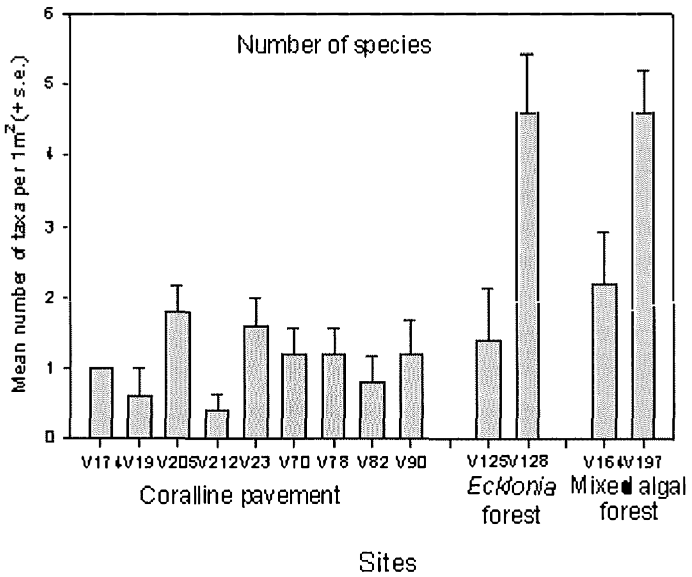


Figure 3 Map of habitats derived from video survey. CP = coralline pavement; S = sand, kelp forest (*Ecklonia radiata* only) is cross-hatched blue, and mixed algae (*Ecklonia radiata* and *Carpophyllum maschalocarpum*) is cross-hatched yellow. Sand – rock borders from sidescan surveys are indicated by the red line.

On the basis of the observed habitats, nine quantitative sampling sites were allocated to coralline pavements, and two quantitative sampling sites were allocated to each of mixed macroalgae and kelp forest, for a total of 13 quantitative sample sites. That sampling was conducted over a 10-hour period. Overall, the fauna was found to be generally depauperate, with low abundances of all organisms. However, the results show that seaweed habitats had greater numbers of species and individuals within them than the coralline pavements (fig. 4). It is clear that inundation of part of the seaweed habitat is not desirable. Accordingly, the boundaries of the placement ground were adjusted to avoid the seaweeds, retaining a 150m buffer between seaweed stands and the edge of the placement ground.



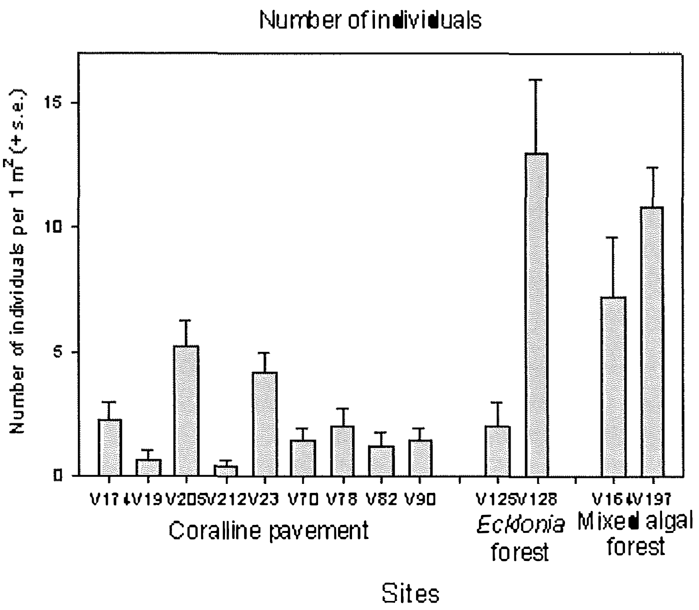


Figure 4 Species richness and number of individuals for each site, with seaweeds excluded. Data are means + 1 s.e. from 1 m^2 quadrats (n=5) from sites allocated randomly to each habitat. X-axis labels represent the individual sites; they are not indicated on figure 1.

Discussion

The interactive CD containing underwater images and maps has formed the basis of the public liaison for the effects assessment of the nearshore sand placement proposal. Its strength is that it allows the public to see what only divers might otherwise see, and it also places the video data within a useful spatial context. Thus, this technique lends itself both to archiving the video data, and to providing a simple, yet effective, medium for the presentation of multiple survey images for long-term effects monitoring. Further, the justification for adjusting the boundaries of the proposed placement ground (to avoid inundating seaweed stands) is readily apparent. Fieldwork, data reduction and analysis, and CD production were both time- and cost-effective. Further, the mapping exercise has also formed the basis of further investigations into the reasons for the localisation of stands of seaweed in one small area of reef (Cole *et al.*, in prep.).While in the present study the technique was applied in excellent conditions for both weather conditions and underwater visibility, we believe that it may also be effective in less than ideal conditions. Some difficulties may be encountered including the possibility of snagging the camera lens in rugose rocky areas, in kelp forests with surface canopies, or among corals. However, for most situations on rocky reefs or sand flats the approach we have used is straightforward, very efficient, and has good positional accuracy.

Aerial imagery presents an alternative to this technique. Differences in costs are probably small, but aerial photography cannot readily distinguish among different species of seaweeds (unless they have surface canopies), and cannot operate to depths more than 10 m unless water clarity is very high. The drop video is capable of being used in very low underwater visibility, and in our experience Hi-8 images are often clearer than divers' observations. It would be possible to carry out the mapping at night, by attaching suitable lights to the video lens. While we were able to compile a species list of fishes off the video footage, the addition of bait would permit an index of abundance to be derived (e.g. Willis, *et al.,* 2000) that is independent of diver-negative reactions.

This habitat mapping exercise has demonstrated that the reefs of New Plymouth are not organised like those in northeastern New Zealand (e.g. Choat and Schiel, 1982; Babcock *et al.,* 1999). Areas dominated by corallines have low abundances of grazing gastropods and sea urchins, in contrast to those in northeastern New Zealand. Most species of invertebrates and seaweeds occur at highest abundances in shallow water. The distribution of habitats may be controlled by sedimentation (Cole *et al.,* in prep.). The video data have been crucial to describing the pattern of habitats in the area, to structuring our quantitative survey, and to the preparation of the interactive CD. We will be using the drop video technique routinely in future surveys, and suggest that it has numerous advantages for many studies on temperate reefs.

Acknowledgments

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Video Assessment of Environmental Impacts of Salmon Farms

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Introduction

Video recordings are increasingly being used for a wide variety of environmental assessments in the marine area; for example, environmental monitoring of marine farms, port surveys for introduced marine pests, and environmental impact assessments of developments in coastal waters. This increased usage has been occurring for a number of reasons. Video recordings are relatively easy to collect, and have improved in quality while decreasing in price in recent years. They provide an instantaneous and permanent record, which is easily viewed and interpreted. Additionally, video recordings are readily stored and retrieved at a later date for comparisons over time.

Compliance monitoring of marine farms in Tasmania

In Tasmania video recordings have become an important component of baseline assessments and environmental monitoring of salmon farms. This monitoring is required by the Tasmanian State Government to ensure that the marine farming activities are not having an unacceptable impact on the marine environment. The current requirements by state government for monitoring salmon farms in Tasmania are detailed in the Marine Farming Development Plans for each growing area (available at http://www.dpif.tas.gov.au/domino/dpif/Fishing.nsf). In summary they require video recordings to be collected every six months at several sites on each farm. Every two years a more comprehensive monitoring program is conducted which includes recording the abundance and community composition of benthic invertebrate fauna, and physical/chemical measures such as redox and organic matter. Video recordings are thus the most regular method used to investigate impact, and these can trigger more intensive sampling if signs of impact are evident.

The video footage of salmon farms is collected along transects at and just beyond the farm boundaries, thus following Tasmanian Government legislation which stipulates that there must be no unacceptable impact 35m beyond the boundary. Some footage is also collected within the farms, generally along a transect out from, and perpendicular to, the edge of a cage.

Videos are also increasingly being used by salmon farmers for farm management purposes. The video recordings provide valuable information on sediment condition in and around cages of salmon. This information can assist the farmers to determine when to remove fish from cages before the sediments become too degraded, and also when the sediments have sufficiently recovered to accommodate cages of fish again.

Research on quantitative assessments of video recordings

As part of the development of a monitoring program by state government, research was conducted at the Tasmanian Aquaculture and Fisheries Institute to investigate which environmental variables were the most practical, cost effective and scientifically credible for environmental monitoring of salmon farms. This included investigating the suitability of video recordings. Video monitoring of marine farms in other countries has generally involved detailed written descriptions of benthic conditions, which are time consuming, can't be analysed quantitatively and difficult to use to detect changes over time. We attempted to develop a quantitative assessment of videos that would be relatively simple and quick to conduct, and appropriate for a long term monitoring program. We also compared video assessments with other established measures of benthic impact, in particular benthic community structure.

Video footage was collected at two salmon farms from along transects perpendicular to farm boundaries, at reference sites, and around farm cages using divers and ROV (see Crawford *et al.* 2001 for more details). The filming procedures that were developed were slow speed (approx. 5 $m.min^{-1}$) with fixed focus, dual lighting and the camera being held approximately 0.5 m of the bottom. Environmental variables observed on the videos were investigated for their suitability for a monitoring program, largely based on their ability to show change and for consistency between reviewers. These variables were generally assessed at 10 m intervals along the transects, and variables were recorded as an average for all frames observed over the 10 m interval. Where transect lines were not present, video recordings were assessed approximately 5 m either side of specific locations (such as benthic infaunal sampling sites at the cage edges). Standard recording sheets and an assessment reference sheet were developed.

Preliminary comparative assessments conducted by three reviewers allowed us to determine appropriate environmental variables for a monitoring program. These were: sediment colour; bacterial mat cover; algal cover; burrow density; abundance of molluscs, echinoderms, fishes, crustaceans and annelids; density of pellets and faeces; and presence of debris, gas bubbles and faunal tracks. These variables were ranked according to presence/absence, or their level of density, e.g. sparse, dense.

In order to determine which environmental variables were the most useful for classification of levels of impact at each site, the presence/absence of each variable at each site was tabulated. The sites were classified a priori as unimpacted (all boundary and reference sites), moderately impacted (10-35 m from a cage) and major impact (0-10 m from a cage), based on their proximity to stocked cages and results from previous experiments. The variables that clearly classified impacted sites were a grey/black sediment colour, extensive cover of Beggiatoa bacterial mats, and pellets and faeces (video 1, available in electronic version of report). These variables were present at nearly all impacted sites and absent from all unimpacted sites (video 2, available in electronic version of report). Algal cover was significantly higher at unimpacted than impacted sites at one farm, but was rarely observed at any sites at the other farm, suggesting it is a site specific indicator of impact. Subsequent research at another extensively used salmon farm has shown that the emission of gas bubbles from the sediment is also a strong indicator of an impacted site (video 3, available in electronic version of report).

The results of the ranked environmental variables from selected sites at the two farms were compared by multivariate analysis using PRIMER software. At both farm sites cluster analysis separated the sites into two main groups. One group consisted of impacted sites at the edge of farm cages on all occasions and one site between cages. The other group contained intermediate and unimpacted sites consisting of boundary and reference sites, and sites more than 10 m from the cage. The video results at the farm cage sites were compared with reference and boundary transects using ANOSIM and the two groups were highly significantly different at both farms.

The patterns in the distribution of environmental variables in video recordings and in benthic faunal assemblages taken from the same sites were analysed using clustering and MDS ordination. At both farms, the main groupings of sites based on video data and on benthic species composition were very similar, although there were subtle differences. The video data separated the sites at the edge of the cage from all other sites, whereas the benthic infaunal data separated sites within 35 m of cages from all other sites. The relationships between the biotic and video data matrices were highly significant at both farms.

These results of the video analyses thus suggest that video data can be used to separate heavily impacted cage transects from unimpacted ones, but can not readily discriminate between intermediate and unimpacted sites. The comparisons of video and benthic data also indicated that once an impact, such as organic enrichment, is removed, the video data can indicate a more rapid rate of recovery than the benthic fauna. This is probably because the video data grouped sites based on visual characteristics of the sediment surface, whereas the benthic community structure reflected conditions within the sediment.

These results suggest that video recordings can be quantitatively assessed and used to monitor environmental change around fish farms. However, other environmental variables should also be measured periodically because video assessments generally only detect major change. Further research will be required to refine the assessment techniques, especially under different environmental conditions. Techniques to reduce the time spent diving in the water also need investigating because diving around fish farms is relatively hazardous. These include reducing the time spent underwater by using timed diver swims, thus eliminating the laying-out of transect lines. Remote collection of video footage by camera drops in strategic locations should also be examined.

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Quantitative Video at the Monterey Bay Aquarium Research Institute

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The Monterey Bay Aquarium Research Institute (MBARI) was founded in 1987 by the late Silicon Valley pioneer David Packard. The mission of MBARI is: "to achieve and maintain a position as a world center for advanced research and education in ocean science and technology, and to do so through the development of better instruments, systems and methods for scientific research in the deep waters of the oceans." From its earliest days MBARI has focused on the use of ROV technologies to achieve this mission. A key feature of ROV technology is the use of video to view and record the ocean environment. The use of video for quantitative purposes grew naturally out of the effort to make ROVs as scientifically capable as possible.

My interest in the Workshop has been to become familiar with the work being done in Australia in this area, and hopefully to share with others the related work that has and is being done at MBARI. Although I was not able to be personally present, I am very grateful to Euan Harvey and Bruce Barker for the opportunity to have a presence anyway.

The primary goal of the quantitative video work at MBARI over the last ten years is best described as image-based measurement: determining the size of objects imaged by ROV cameras, whether the objects are on the seafloor, on a canyon wall, or in the mid-water. Image based measurement can include length, surface area, percent coverage, distribution by size, and abundance of objects. The need for different types of measurements by different MBARI researchers has led to the development of a variety of techniques. Some of these techniques provide fairly general capabilities, while others provide narrowly specialized capabilities.

MBARI ROV cameras are typically highly controllable. MBARI's latest ROV, TIBURON, has dual, high-resolution cameras on separately controllable high-resolution pan-tilts. MBARI's other main ROV system, VENTANA, has a state-of-the-art HDTV main camera. All ROV cameras are zoomable, and have full focus and zoom telemetry feedback. A very early effort was made to calibrate the feedback telemetry to actual camera properties underwater. Thus the current ROV camera control systems convert and display focus telemetry as actual focus distance in centimetres in water, and zoom telemetry to actual zoom angle in water. From both focus and zoom telemetry we can calculate the width in centimetres of the camera view at the current focus distance and zoom angle. This camera data is also regularly logged and time stamped along with other data logged by the ROV system and is available post-cruise. Thus the field width data for each video frame, as well as navigation data, such as camera direction, depth, latitude and longitude, and scientific data, such as oxygen level and transmissometer value, are available to researchers post-cruise.

Starting in 1991, paired lasers were used to provide a linear scale for benthic work. Paired lasers, however, only provide scale for a target that is at right angles to the lasers. Algorithms were developed at MBARI that use a configuration of three lasers for fixed focal length cameras, or four lasers for zooming cameras, to provide a capability for laying a planar measurement grid over a target surface that is not at right angles to the camera axis. The four laser based referencing system is self-calibrating, and does not require any feedback camera telemetry for its use, or in water calibration. Basically laser based referencing provides a cost effective, accurate, technique for benthic use when the objects to be measured are on a semi-planar surface such as the sea floor or a canyon wall.

The techniques described above are relatively general purpose. Calibrated camera feedback displayed as focus distance, zoom angle, and field width are standard capabilities available on all ROV dives. The laser system is always available as well and can be turned on for use on benthic dives. There is also a specialized structured lighting system developed at MBARI that has been used for measurement to support marine snow studies.

Obtaining measurements of size, and abundance by size, of marine snow is a challenging problem. Prior to the work at MBARI, others had built structured lighting systems for marine snow with still cameras. Our goal was to build a system using live video for a ROV. The concept is to create a slab of light of uniform thickness a specified distance in front of a camera, to illuminate and film only the particles in the volume defined by the viewing cone of the camera and the slab. In MBARI's system the slab is 10 centimetres thick, at 100 centimetres from the camera, and the volume had dimensions 20 by 15 by 10 centimetres. Particles down to 0.5 millimeters are resolvable with a Sony DXC-3000 BetaCam three chip color camera, using dual lights with a total of 600W of power. Marine snow particles are shown in a measurable size, since they are imaged at a known distance from the camera, in a volume of known size (there is at most a 10% change in size from the front to the back of the volume).

The mode of operation of the structured lighting system is to make short, horizontal, transects with the ROV at slow speed at depth intervals of 25 meters, from the surface down to 250 meters. Software was developed at MBARI to then sample the horizontal transects, use automated filtering, and image processing to identify and classify by size individual particles, and integrate the results for each horizontal transect at a specified depth. The data for all depths was then written to files for further analysis and display. Over 15,000 images have been automatically processed using this system. Dives were typically conducted subsequent to major primary production bloom events to determine the size spectrum of particles of marine snow as a function of depth during and after such events.

One of the most challenging image based measurement challenges we have had is the measurement of organisms in the mid-water. Estimates of length for large siphonophores (up to 35 meters long) have been made using high frequency imaging sonar. The smaller organisms have been difficult to measure from video images. One technique that has been developed makes use of paired cameras. We make a distinction between the terms *stereo* and *paired* when used in reference to quantitative video. The reason is that stereo is more properly used for creating the sense of depth perception for the viewer. This means that the cameras are necessarily parallel, and narrowly separated. This is not an optimal configuration for making measurements, since accuracy ultimately depends on camera separation. In the case of the ROV Tiburon, the cameras are on separate pan-tilts spaced at least a meter apart and are independently zoomable. If the cameras are used to view an object separately they could have very different orientations and view angles, but still provide a paired view. We have developed an algorithm at MBARI that enables a user to locate a point in 3D centimetre coordinates relative to the ROV, providing that the point can be identified in both views. The tool is called Point Locator and is still in the development stage. But the idea is: the user makes a simultaneous frame grab of the two views of the object to be measured, together with the ROV telemetry that establishes the telephoto setting of each camera, and their current pan-tilt orientation. Then using a pointing device on the image (such as a mouse) the user selects the same point in each view, from which the algorithm calculates the position of that point on the object in 3D space relative to the ROV. By locating the 3D positions of a number of points on the object, size measurements of the object can be obtained. The process of selecting the same point in each view can be automated in some cases, but our experience is that the greatest utility at the least cost is obtained by having users perform this task.

In this discussion we have illustrated a variety of techniques for achieving image-based measurements from underwater imagery. Although MBARI has significant technological capabilities, the goal of much of the work at MBARI is to develop techniques that are broadly useful in the community of ocean researchers, and thus cost effective, and if possible, minimize the need for complex technology. Our basic experience has shown that such tools keep the user in the loop and simply enhance or aid in tasks best done by the user. If a task is sufficiently routine and well understood, it can be more cost effective to automate the task. Our experience is that it is risky to place too much confidence in automation until a task is very well understood and there is confidence that it is both cost-effective and accurate to automate the task. Otherwise, in an effort to automate prematurely, biases created by the constraints imposed by the technology can fundamentally negate its usefulness and cost effectiveness.

MBARI is a non-profit privately funded research and technology development institute. Any knowledge, techniques, or software discussed above is freely available to any educator or researcher in the ocean sciences by contacting the author at MBARI. The only condition is that MBARI's intellectual rights to its developments are appropriately acknowledged by those who make use of this work, and none of this intellectual property is used for commercial purposes without the consent and a license from MBARI.

The software and documentation for the laser based referencing system is available from the author on a royalty free license for use by researchers worldwide. It is called Laser Measure. It is presently available in Australia, by contacting Bruce Barker at the CSIRO Marine Laboratory, Hobart.

Automating Taxonomic Expertise: Investigating Connectionist Solutions

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New technologies have allowed marine scientists to collect a massive variety and quantity of visual data, often by remote and automatic devices. The utility of these tools is severely limited by the lack of a corresponding development in automatic analysis of these data and expert human judgements are frequently required for quite mundane tasks. Our work has focused on attempting to eliminate this bottleneck by devising machine vision systems for some aspects of routine, taxonomic analysis.

A traditional 'expert system' approach to automating taxonomic expertise would attempt to formalise the basis of classification schemes and embed these in software. Such a rule-based approach has a number of problems.

1. The problem of knowledge extraction is notorious. Experts can often not articulate the basis of their expertise (Michie, 1990). Visual taxonomic analysis may be particularly dependent on learning by example: an expert 'knows' this is creature x because of the thousands of previous cases she has seen. The rules that underlie this skill in visual pattern recognition may be entirely opaque to the expert.

2. Consensus classifications have been shown to arise in a community of taxonomists even when each taxonomist claims to use different criteria for the classification (Sokal, 1977).

3. Where a rule-based scheme of classification derivable it would not generalise, obviously, to new categories. That is, a scheme would be needed for each category of interest.

In order to escape these difficulties we have investigated the use of connectionist networks (or artificial neural networks) as visual pattern classifiers. Connectionist networks are modelled on neural processes (see Ellis and Humphreys, 1999, for an introduction to connectionism). Simple units influence each other by excitatory and inhibitory connections. If some units are designated as inputs and some others as outputs, such networks may be said to classify the inputs in terms of their outputs. For instance, if the input units were some visual properties of organisms and the outputs were the names of species, the network would be classifying species by visual analysis. The problem of course is arranging for the correct mapping between input and output units!

Connectionist networks can in fact be trained to produce the correct mapping. The connections between units may be tuned or adapted by the application of (simple) mathematical procedures discovered in the past decade or so. Typically, training a network consists of applying examples of inputs and adjusting weightings on the connections as a function of the output error. Several such procedures have been developed which will reduce the output error for a population of inputs to some optimal value. It is these developments which we have exploited in our attempts to automate visual taxonomic expertise.

More specifically we have devised connectionist networks for the identification of species in images of plankton (Culverhouse et al., 1996; Ellis et al., 1997). The images were pre-processed to produce five different classes of information: (1) edge orientation, (2) junction type, (3) texture measurements, (4) boundary measurements, and (5) two-dimensional Fourier descriptions. Each of these processes produced a vector for each image and the set of vectors served as the input to a Radial Basis Function network (see Ellis and Humphreys, 1999, pp38-41 for an introduction to the latter). During training (on 23 species) the network was presented with labelled inputs and the connection weights were adapted as a function of the error in output. In effect the network had to discover the combination of input data which formed the basis of the classification, and store this as the set of connection weights. This procedure was effective! Following the training the network was tested with new examples of the 23 species and overall accuracy was 83%. This compares with 85% accuracy for a group of human taxonomists tested on the same materials and 56% for a standard statistical technique (quadratic discriminant analysis). Figure 1 illustrates network performance in terms of percentage correct for each of the species.

The plankton classifier demonstrates the potential of connectionist solutions to the analysis bottleneck. A number of their virtues are worth emphasising.

- The problem of knowledge elicitation is totally eliminated. The system was developed without any knowledge of the basis of the classification, needing only a set of labeled examples for training.

- The solutions are general. In principle such networks can be trained on any visual classification, provided the pre-processing extracts data which can be partitioned (in some way or other) into the underlying categories. In our case we deliberately chose five sources or channels of widely different data to increase the likelihood of the network finding useful partitions. As a very preliminary assessment of the generality of our solution we have tested the success of similar techniques in classifying images of three types of coral (Pocillopora damicornis, Stylophora pistillata, and Pocillopora verrucosa). Despite the huge difference in image properties compared to the plankton data, a network trained on the coral data, using similar pre-processing techniques, achieved an overall accuracy of 54% on novel coral images. We envisage future developments in which the number of channels is increased by an order of magnitude so as to increase generality.

- The systems are adaptive in that the user may extend the range of organisms to be identified by training with new examples. This property combined with their generality persuades us that connectionist networks may provide the basis, in the medium term, for devices that could be described as Electronic Taxonomic Assistants.

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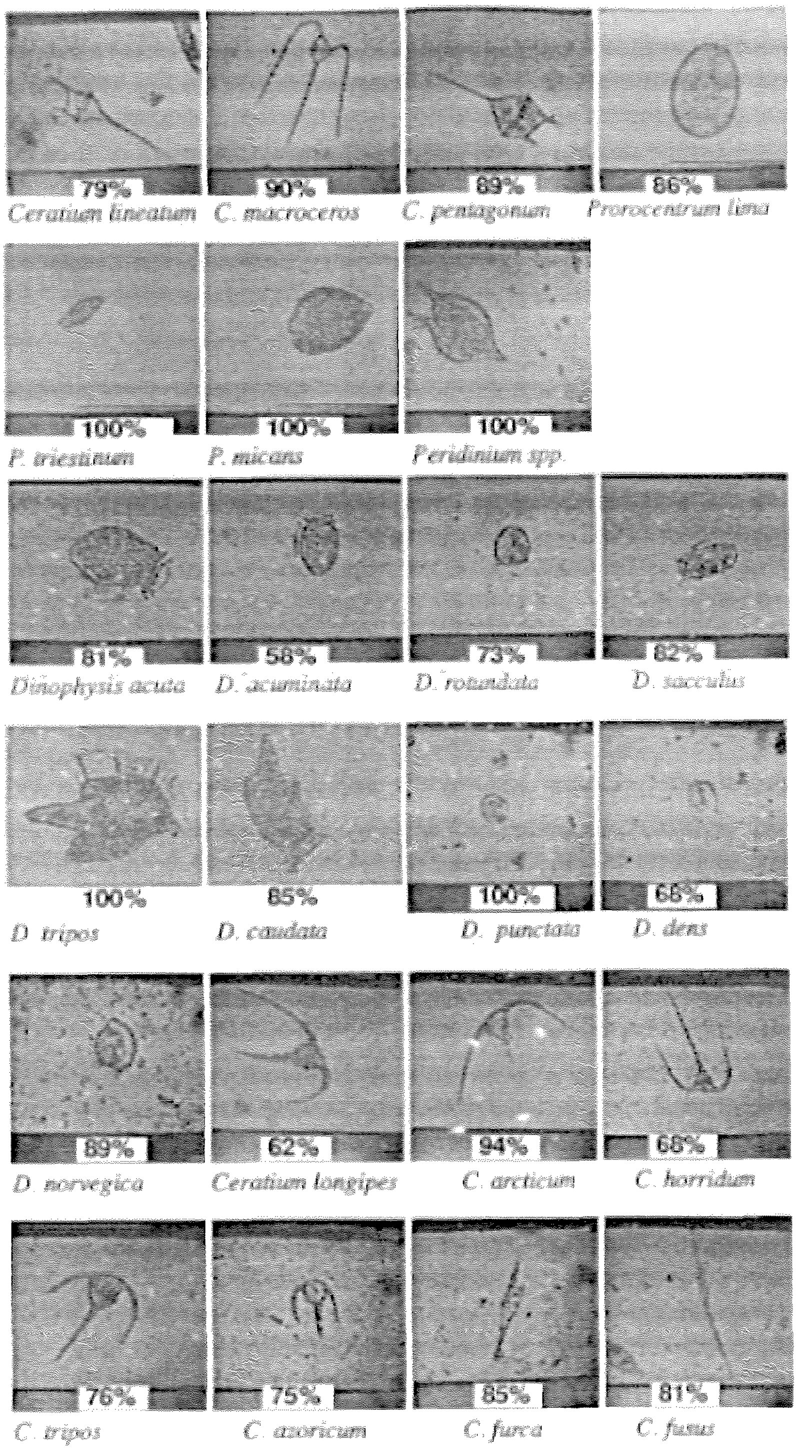

Figure 1 Illustrates network performance in terms of percentage correct for each of the species.

The Uses of Underwater Television and Video Technology in Fisheries Science: A Review

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Introduction

The use of Underwater Television (UTV) and video in fisheries science has evolved from shipboard applications (Barnes 1952, 1953a, 1953b, 1955) to in situ remote long-term studies (Momma *et al.*, 1995) with the capability of precise metric measurements (Harvey and Shortis 1996, Li *et al.* 1996, Li *et al.* 1997, Petrell *et al.* 1997, Steeves *et al.* 1998). The advent of SCUBA during the 1960's allowed marine researchers to make direct observations in the top 40 metres of the sub-littoral environment. The development of hand-held underwater still and cine cameras in the 1970's came in the wake of the development of SCUBA. Together, these two technological breakthroughs have revolutionised the way in which marine scientists have studied the upper 40 metres of the sub-littoral environment by allowing direct and real-time observations of the behaviour, distribution and abundance of organisms. Videomicroscopy has facilitated quantitative behavioural and physiological studies of larvae, embryology, bacteria and other micro-organisms. These technological developments, combined with engineering breakthroughs, are now permitting research and near real-time observations of the oceans' depths through the use of Remotely Operated Vehicles (ROVs), submersibles and sleds mounted with video or UTV.

A review of the scientific literature between from 1952 to June 2000 found 1 232 papers where video or UTV were utilised in marine research. A chronological summary of these papers is presented in Appendix 1 of these proceedings. In addition an "ENDNOTE"© library and word document listing the references may be down loaded from the workshop CD or http://www.aims.gov.au/pages/research/video-sensing/index.html.

Since 1983 there has been a substantial increase in the number of papers published where video or UTV has been used as a sampling tool (Figure 1). This increase is most likely associated with the decreasing cost, increasing availability, reliability and improving resolution of video cameras.

The applications that video or UTV were predominantly used for included monitoring the behaviour of fish, crustaceans and other invertebrates. Video or UTV were also commonly used in research on fisheries and fishing equipment, the abundance and distribution of epibenthic flora and fauna, the abundance, distribution and behaviour of plankton and microflagellates.

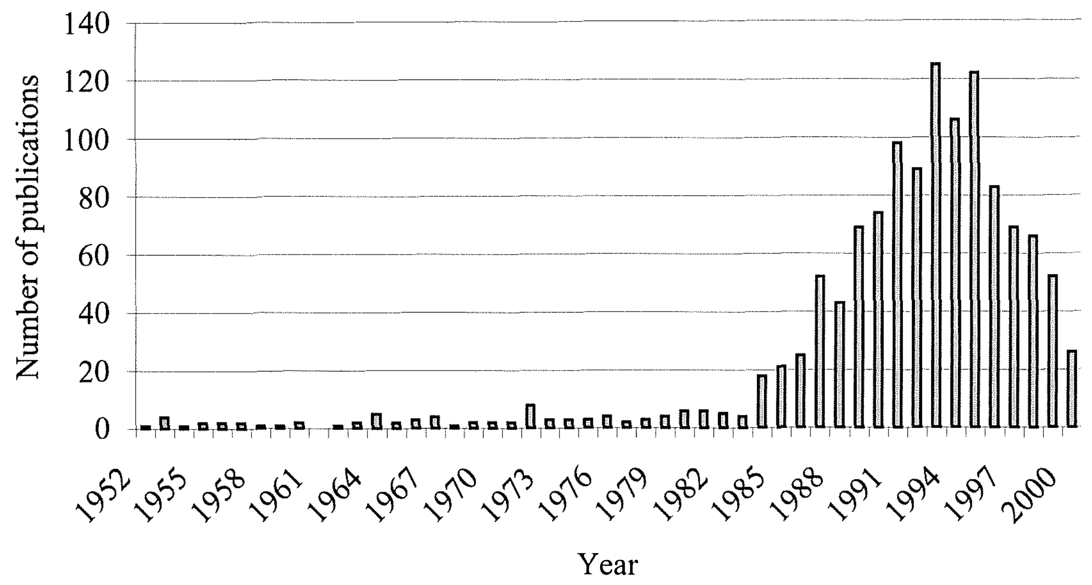

Figure 1. The use of underwater video or television increased greatly after 1985, peaking in the mid 90's. Decreasing citations since then may be due to the common acceptance of video as a sampling tool, and lags in appearance of journal articles in bibliographic databases.

This review specifically focuses on the use of video for sampling epibenthic flora and fauna, fish assemblages and fauna of soft sediments. These studies are most relevant to this workshop.

Sampling of epifaunal benthic communities

Since the 1960's SCUBA has been used for investigating the fauna and flora of shallow (<40m) sub-tidal regions. In situ visual counts of the fauna and flora within quadrats and strip transects are commonly cited methods of data collection, with data being recorded by researchers on slates or underwater paper. These direct counts and measurements of sub-tidal and intertidal flora and fauna produce high quality data. However, in the sub-tidal environment they are often time consuming and physically exhausting. Additionally, depth constraints and available bottom time associated with SCUBA diving limit the number of samples that can be recorded (Littler 1980, Malatesta *et al.* 1992).

Photography, (Bohnsack 1979), stereo-photography (Lundalv 1971, 1976, Christie 1980, Done 1981), videography (Maney Jr *et al.* 1990, Berkelmans 1992, Whorff and Griffing 1991, 1992, Christie 1983, Carleton and Done 1995), and stereo-videography (Naiberg *et al.* 1993, Harvey and Shortis 1996, Li *et al.* 1996, 1997, Petrell *et al.* 1997, Steeves *et al.* 1998) have become popular sub-tidal sampling techniques.

Photographic or video sampling techniques have the advantage of being non-destructive, rapid and repeatable. Stereo-photography has been used to obtain information on the growth and competition of species without destroying the communities (Lundalv 1971, 1976, Christie 1980, Done 1981). The same could be achieved with stereo-video technology (Harvey and Shortis 1996). Single and stereo imagery facilitates the determination of composition, density, cover, size distribution, and biomass of epibenthic invertebrate communities. Population dynamics, growth rates and productivity can be studied by the comparison of images from precisely the same area obtained on different occasions - perhaps years or decades apart (Torlegard and Lundalv 1974, Christie 1980, Done 1981).

Underwater video has been used for recording epibenthic communities on temperate (Ballantine 1995) and coral reefs (Maney Jr *et al.* 1990, Edmunds and Witman 1991, Aronson *et al.* 1993, Porter and Meier 1994, Carleton & Done 1995), in rocky shore intertidal areas (Whorff and Griffing 1991, 1992), soft sediment (see Crawford *et al.*, these proceedings) and deep-sea environments (Benech and Boyce 1986, Phillips *et al.* 1990, Voegele *et al.* 1991, Auster *et al.* 1991, Auster *et al.* 1995). Video technology offers an alternative technique to still photography and can increase the data acquisition over a particular dive by a ROV, submersible or SCUBA diver (Malatesta *et al.* 1992).

For epibenthic studies utilising underwater video the size of the sampling unit is usually dictated by the required resolution and the size, composition and dispersion of the community being investigated (Maney Jr *et al.* 1990). The ability of video to record data across broad spatial scales has proven useful in documenting large spatial scale differences between reefs, areas and regions (Leonard and Clarke 1993, Carleton and Done 1995). Additionally, video recordings often satisfy many of the requirements of benthic monitoring programmes. The data collected by the equipment does not suffer from inter-observer variability or observer bias. The equipment can collect large quantities of information cheaply and reliably and may be hand operated by a SCUBA diver, or mounted on ROVs, submersibles, sleds or other underwater vehicles. Additionally, data are collected in a repeatable, non-destructive manner with a permanent record being obtained. Optionally, audio tracks can be simultaneously recorded to accompany visual images greatly enhancing the information collected and assisting in later analysis of videotapes.

Quantitative image analysis

Since video was first used for making quantitative counts and measurements of organisms, a variety of techniques have been developed for post-recording analysis. A single video image can be converted from analogue to digital computer format, using a video capture board. The video image can then be quantitatively analysed using one of the many computer image analysis programmes like NIH IMAGE© or OPTIMAS© (Maney Jr *et al.* 1990, Whorff and Griffing1992, Davis and Pilskaln 1993) or Laser Measure (see Barker *et al.*, these proceedings and Davis, these proceedings). Percent cover analysis can be performed by digitising the image (Maney Jr *et al.* 1990), or by using random dot patterns superimposed on the image (Edmunds and Witman 1990, Sebens and Johnson 1991). It is possible to play back the video on a VCR, pausing the tape at random time intervals and counting the organisms, or a predetermined cover type, appearing underneath a marked spot on the screen (Berkelmans 1992). Increasing the number of spots and computerising the system has further refined this system. The computer program randomly selects the spot to be sampled and the intervals between stops. A set menu of options for cover type exists on the computer screen with the observer making the appropriate selection. Data are automatically tallied at the end of each series of images and percent cover is calculated, graphed and stored (Berkelmans 1992, Carleton and Done 1995). Variations of these concepts have been developed to score marine habitats and features in real time (see Barker *et al.*, these proceedings and Pitcher *et al.*, these proceedings).

Scaling of video imagery

When making size measurements from images it is important to have some form of calibration within the field of view. This is commonly achieved by mounting a quadrat on the front of the camera. More recently low power lasers have been used for aiming and ranging systems and as measuring devices in video systems. A system of laser dots was developed at Harbour Branch Oceanographic Institution (Caimi and Tusting 1986) and has subsequently been described by Caimi *et al.* (1987), Tusting and Davis (1992, 1993), Caimi *et al.* (1993), Davis and Pilskaln (1993), and Caimi and Bessios, (1994). Laser beams are set up perfectly parallel to one another. The paired lasers are then positioned so that the laser dots appear in the field of view of video images. Because the lasers are parallel, the distance between the centres of the lasers will be the distance between the laser dots in the field of view. It is therefore possible to calibrate the scale of the image and make quantitative measurements. Range finding using lasers is similar but applies simple trigonometry. The two lasers are set at a pre-established angle. Knowing these angles and the distance between the origins of the laser beams it is relatively straight forward to calculate the distance from each laser where the laser dots intersect, and then calculate the distance from the centre of the camera lens to the intersection of the laser dots. If four parallel lasers were used to delineate the four corners of a square or rectangular shaped quadrat, a physical quadrat is no longer needed. Unlike fixed quadrapods / quadrats, laser beams do not disturb the substrata or the organisms being recorded - an important issue in procuring clear images of sensitive organisms.

Videographic sampling of fish

Determining the abundance of reef fish

Visual techniques were first used for quantifying the population densities and community structure of coral reef fishes in 1954 by Vernon Brock (Brock 1954). The destructive nature of many quantitative methods of coral reef fish assessment has resulted in the widespread adoption and modification of visual census techniques (for example Odum and Odum 1955, Bardach 1959, Alevizon and Brooks 1975, Brock *et al.* 1979, Harmelin-Vivien and Bouchon-Navaro 1981, Alevizon *et al.* 1985, McCormick and Choat 1987, Bellwood and Alcala 1988, Davis and Anderson 1989, Kulibicki 1989, Francour 1994).

Visual census techniques were rapidly adapted to use underwater movie, television or video cameras (Alevizon and Brooks 1975, Ebeling *et al.* 1980a, 1980b, Larson and DeMartini 1983, Parker *et al.* 1994, Gledhill *et al.* 1996). Counts and identifications of reef fishes made from underwater video imagery have been aided by voice recordings on self-contained audio tape recorders, or directly onto the videotape (Alevizon *et al.* 1985, Greene and Alevizon 1989, Bortone *et al.* 1991, Bortone *et al.* 1994). Reef fishes in deeper water have been surveyed by video cameras mounted on remotely operated vehicles (Thompson 1982, Edsall *et al.* 1993, Adams *et al.* 1995, Hall 1996) and manned submersibles (Parker and Ross 1986, Shipp *et al.* 1986, Able & Flescher 1991, Able *et al.* 1993, Auster *et al.* 1995, Love *et al.* 2000, Yokalivich *et al.* 2000).

Early comparative research into different techniques for visual surveys (Greene and Alevizon 1989, Bortone *et al.* 1991) found that video recorded results were less accurate than direct observations by a diver onto a slate or audiotape. The differences were attributed to the narrow field of view, the poor light gathering ability, and poor resolution of the video cameras used. With the rapid development in video technology in the decade since these publications, and the introduction of progressive scan digital cameras with options for a variety of wide-angle lens, these conclusions need revision.

Video cameras have been used to record transect surveys of reef fishes where the camera is held by SCUBA divers (Ebeling *et al.* 1980a, Larson and DeMartini 1983, Davis 1989, Seaman Jr. *et al.* 1989, Parker *et al.* 1994, Gledhill *et al.* 1996) or mounted on manned submersibles (Seaman Jr. *et al.* 1989, Auster *et al.* 1995, Love *et al.* 2000, Yokalivich *et al.* 2000). Video transects are effective for rapidly sampling large, mobile fish in complex environments where the water is reasonably clear. However, they tend to underestimate fish abundance (Davis and Anderson 1989) and the densities of small and cryptic species (Ebeling *et al.* 1980a). More recently remote baited and unbaited video cameras have been effectively deployed with great success (Ellis and DeMartini 1995, Harvey 1998, Francour *et al.* 1999, Willis and Babcock 2000, Willis *et al.* 2000, Cappo *et al.*, these proceedings). These drop cameras are usually used to record a timed point count of the fishing entering a set area. Using baited camera systems Willis and Babcock (2000) and Willis *et al.* (2000) recorded significant differences in the abundance and length frequency of two species of fish inside and outside a marine reserve. SCUBA diver visual transects failed to detect the magnitude of the trend.

Diver estimates of fish length

Accurate and precise, non-destructive data on the length of fishes is difficult to obtain due to the range of habitats occupied by fishes and varying behaviour both within and between species over a range of spatial and temporal scales. However, information on the length frequency or mean length of a fish population is very informative. When linked with even a rudimentary knowledge of the biology of a species, it may allow estimates of recruitment to the adult population, fishing intensity and rates of recovery from fishing (McCormick and Choat 1987).

During visual reef fish surveys it is common for SCUBA divers to count and visually estimate the length of individual reef fish (Jones and Chase 1975, Harmelin-Vivien and Bouchon-Navaro 1981, Bellwood and Alcala 1988, Samoilys 1988, English *et al.* 1994). Two important sources of error affect the accuracy and precision of visual length estimates by SCUBA divers:

The estimation of the length of reef fish underwater is complicated by the air-water interface in the diver's mask, which causes objects to be magnified in size by a factor of 1.3, and to appear to be closer to the observer than they actually are,

Researchers using SCUBA have been shown to be inefficient when performance underwater is compared to similar activities in air (Hollien and Rothman 1975). The accuracy and precision of diver's estimates of reef fish length are probably also affected by the detrimental physiological effects related to SCUBA diving (Baddeley 1965, Baddeley *et al.* 1968, Baddeley 1971).

The level of precision and accuracy associated with visual length estimates influence comparisons of data over different temporal or spatial scales in two distinct ways. Firstly, bias in the estimates can make the results of the analysis less reliable. Secondly, any lack of precision in the estimates arising from both sampling error and measurement error tends to reduce the power of the statistical analysis. Harvey *et al.* (2001a,b, In press, these proceedings) demonstrate how variance in the accuracy and precision of SCUBA diver estimates of fish length caused by observer and inter-observer variability (Thompson and Mapstone 1997) influence the results of fish surveys. The removal of observer and inter-observer variability requires extensive training and recalibration during fieldwork. Another solution is to supplement diver estimates with those determined by computer analysis of video imagery -- effectively removing any inter-observer variability, or within-observer changes over time (Harvey and Shortis 1996).

Remote video measurements

Single camera techniques

Single video camera systems have been used to measure the length frequency distribution of fish assemblages in shallow (Willis *et al.* 2000, Willis and Babcock 2000) and deepwater habitats (Love *et al.* 2000, Yoklavich *et al.* 2000). Harvey *et al.* (In review) report on the accuracy (mean error = 13.62 mm) and precision (standard error = 1.41 mm) of length measurements of plastic silhouettes of fish using a single camera. There results are similar to those reported by Willis *et al.* (2000) and Willis and Babcock (2000) (mean error = 16.9 mm, standard error = 2.4 mm). Harvey *et al.* (In review) demonstrated that measuring a fish that is closer to the single camera system than the original point of scaling will result in significant over-estimates in length measurements.

This issue might be partially overcome by using paired, parallel laser dots as scaling points (Love *et al.* 2000, Yoklavich *et al.* 2000). The distance between the laser dots reflecting off the body of a fish provide a constant scaling regardless of distance, provided the fish traverses the beams. However, Harvey *et al.* (In review) showed that as the angle of rotation of the fish increases toward or away from the camera the accuracy of such measurement system is severely compromised. A rotation greater than 20 degrees increases the measurement error proportionately above 10% of the body length. Accurate measurements using laser dots are also restricted to the particular fish on which the lasers dots are displayed - and any particular fish must traverse the paired beam. Measuring fish that are in front of or behind that fish, or >=50 cm to the left or right of the fish used for scaling an image, will result in substantial decreases in accuracy and precision. Thus, laser measuring systems using single cameras are limited to measurements of single fish in any one image and, depending on the requirements for measurement accuracy, are limited to measuring fish that are perpendicular to the camera system. Furthermore, it is impossible to make measurements of distance using a single camera system unless a triangulating laser system is used (Caimi and Bessios 1994).

Stereo-video camera systems

Harvey and Shortis (1996) and Harvey *et al.* (2001a,b, In press, these proceedings) demonstrate that subjectivity in visual length estimates of fish can be overcome, and the accuracy and precision enhanced, by using a simple and relatively inexpensive underwater stereo-video system. Stereo-videography is an extension of stereo still photography. Stereo still photography has been used to determine the size, density and dispersion of schools of free swimming sharks (Klimley and Brown 1983) and to measure the three dimensional structure of fish schools (Dill *et al.* 1981). Stereo-photogrammetric techniques have the advantage that accurate length estimates are obtained of individuals while not disturbing or removing the individual from the sample population. The principles of stereo-photography have been applied to paired video camera systems (Boland and Lewbel 1986, Krohn and Boisclair 1994, Li *et al.* 1997).

Underwater stereo-video is a research tool that can make very accurate, precise, non-invasive measurements of fish length (Naiberg *et al.* 1993, Harvey and Shortis 1996, Li *et al.* 1996, Petrell *et al.* 1997, Steeves *et al.* 1998, Harvey *et al.* 2001 a, b) and the distance and angle of a fish from the camera system (Harvey *et al.* In review). For example Harvey *et al.* (2001c) recently recorded a mean error in the length of caged Southern Bluefin Tuna of 1.72 mm, for fish ranging in known "true" length from 830 to 1412 mm. Accurate measurements of range and angle measurements now permit line transect theory (Burnham 1980, Buckland *et al.* 1993) to be objectively applied to surveys of reef fish. Additionally, it is possible to determine the swimming speed of fish (Petrell *et al.* 1997, Harvey *et al.* 2001c).

Visual estimates of the length of fish are often converted to biomass estimates based on the relationship between the length and the weight of an individual fish of a certain species (Kulbicki, 1989). The use of accurate and precise stereo-video measurements of targeted morphometric parameters facilitates very accurate predictions of fish biomass (Petrell *et al.* 1997, Harvey, Shortis and Cappo, unpublished data). One of the main difficulties of video counts of fish lies in converting raw counts of fish recorded on video tape to numbers per unit area arising from the difficulty of correctly determining the area or volume surveyed (Barnes 1963, Boland and Lewbel 1986). This can be overcome by the use of a stereo-video system where it is possible to determine the x, y, z locations of fish relative to the stereo-cameras. These x, y, z locations can be used to calculate the area and or volume within which measurements or observations were made.

Infaunal sediment assemblages

Traditional methods of biological sampling of sub-tidal sediments involves trawling or collecting cores or grab samples. Rhoads and Cande (1971) demonstrated that sediment profile photography was an efficient technique for the in situ documentation of organism-sediment relationships. The use of cores, dredges or trawls usually destroys the sediment matrix preventing the observation of patterns created by organisms living within the sediment. The "Rhoads-Cande Profile Camera" (Rhoads & Cande 1971) vertically slices through the sediment-water interface and views the sediment profile. More recently, a profiling system (REMOTS), which incorporates a high resolution video camera in place of the still camera has been developed (Rhoads & Germano 1982, 1986, Rumohr & Schomann 1992). The REMOTS system is based on the same principle as the Rhoads-Cande profiling camera. The lens of the video and lighting being placed in a wedge shaped prism. This prism is supported within a frame. The face of the prism is made of a translucent material allowing the video to view a profile of the sediment. The image of this remotely viewed profile is then relayed to the support vessel for viewing.

There are many advantages arising from the use of sediment profile imaging over traditional methods. Traditional sample processing methods (sieving, straining, sorting and species identification) are extremely labour intensive making data return slow and expensive. By contrast, organism-sediment relations, recorded by REMOTS, are readily observable in sediment profile images and data acquisition is fast. Either photographs or videotape can be easily filed, allowing storage of a large amount of data in a very small space. This is a distinct advantage as opposed to using archive sample jars. Rhoads and Germano (1982) estimate that the interpretation of data is orders of magnitude quicker than traditional processing methods.

Discussion

Underwater video has been used for a broad range of applications in marine science (Appendix 1). Amongst these applications are innovative techniques for recording plankton communities (Bergstroem *et al.* 1992, Davis *et al.* 1992), measuring the size of floccs (Maldiney and Mouchel 1996, Pfeiffer 1996) and the development of videomicroscopy -- which facilitated quantitative behavioural and physiological studies of larvae, embryology, bacteria and other micro-organisms (Schatten 1981, Inoue and Tilney 1982, Farris and O'leary 1985). The disadvantages and advantages of using video for marine research need to be carefully considered.

Disadvantages

The initial cost of a video camera, an underwater housing (if required), videotapes and viewing equipment (ie. a television or computer screen) are a great dis-incentive to the adoption of video technology. Additionally, maintenance costs and the costs associated with lost field time due to equipment failure (eg. flat batteries, leaking housings, faulty connections, camera exposure and focal length set incorrectly) need to be incorporated (Myrberg 1973, Kingsford and Battershill 1998). Unlike a SCUBA diver, video imagery can not interact with the surrounding environment at a range of sampling scales in quick succession. Subsequently, underwater video and photography has been used to sample three-dimensional epibenthic habitats with limited success (Foster *et al.* 1991, Kingsford and Battershill 1998). In coral reefs or kelp beds where canopies form as a result of animals and plants over-growing one another, or occupying niches under the shelter of taller species photogrammetric sampling is biased towards the visually dominant species in the upper canopy. It is possible to record the canopy and the destructively remove it, or push it out of the field of view before recording the understorey.

One of the main limitations of underwater video is the deterioration of image quality under conditions of poor water visibility. High sedimentation or suspended particles in the water column usually limit the distance over which recordings can be made. Suspended particles are particularly noticeable on video recordings aided by artificial light, as the particles reflect light and show up as bright specks in the imagery. It should also be noted that artificial lighting might affect the behaviour of some subjects (Spanier *et al.* 1994), unless its wavelength is carefully chosen to suit the study subject's visual acuity. The resolution obtained by video is not currently equivalent to that of film and may be a limiting factor in some investigations.

Leonard and Clarke (1993) noted that the resolution of the video they used did not enable them to distinguish between uncommon species of red algae. Their results and conclusions led to a presumption that the low-resolution video is best suited to sampling megafauna. However, the resolution of sampling and the ability to identify organisms in video images is a function of the scale of the area recorded. Consequently, the size of a sample unit needs to be determined by the resolution of the video camera and the size of the target organisms, rather than statistical optimisation. For example, while it may be extremely difficult to identify to species level and count all the barnacles with a 1 m2 quadrat, it may be quite feasible within a smaller sample unit (0.25 m2) where a greater number of pixels per cm2 are allocated to the discrimination of organisms within the sampling unit. Videotape has a limited life span depending on the number of times it is replayed or recorded over - perhaps 15 years or less for Hi8 tape. During this lifetime, magnetic tape can stretch and wear resulting in a deterioration of image quality, although the effect this has on the accuracy and precision of metric measurements is unknown. The digital archiving of Hi8 and other magnetic tape media to overcome this problem presents a major financial cost, although new software and hardware is evolving to cope with this demand. Video recordings can potentially remove inter-observer biases, but the initial image quality is still dependent on the skills of the staff deploying the cameras, and then the interpretation is dependent on the skills of the observers interrogating the footage. Perhaps the most unattractive disadvantage is that lengthy viewing time and analyses of the tape footage can escalate the cost of studies.

Advantages

Underwater video records a permanent archive of long-term qualitative and quantitative observations on the physical conditions and biological structure of marine communities and habitats at a particular location (Rutecki *et al.* 1983, Chandler-Middleton 1985, Kingsford and Battershill 1998). Non-destructive video sampling facilitates repeated temporal sampling at specific sites (e.g. in a monitoring program) (Kingsford and Battershill 1998). Where data are required on the persistence or natural variability of the composition, relative abundance, size or length frequency of a population or assemblage of marine organisms, the objective is compromised if the sampling design employs destructive sampling, particularly where individuals are present in low numbers (Harvey *et al.* 2001a, b). Remote baited and unbaited drop video cameras can record the relative abundance and species composition of fishes and mobile invertebrates from far greater depths than SCUBA divers (Ellis and DeMartini 1995, Harvey 1998, Francour *et al.* 1999, Cappo *et al.*, these proceedings). Additionally, modern video cameras are extremely sensitive in low light conditions and to near red and infra red light. Near and infrared light is beyond the visual sensitivity of many coastal fishes (Lythgoe *et al.* 1994) and light sensitive invertebrates Momma *et al.* (1995). Therefore, a light source emitting a near red light (650 nm +) combined with a video sensitive to this wavelength of light could be used to survey nocturnal or deepwater fishes and light sensitive invertebrates without affecting their behaviour (Bascom 1976, Potts *et al.* 1987). Drop video surveys remove the biases associated with the positive (Chapman *et al.* 1974) and negative (Chapman and Atkinson 1986, English *et al.* 1994) attractions of fish to divers using SCUBA. Hemmings (1971) suggested that the noise generated by compressed air released from an aqualung demand valve produced avoidance reactions from fish. This is supported by a number of qualitative observations (Chapman *et al.* 1974, Chapman and Atkinson 1986, Harvey 1998, Francour *et al.* 1999). Baited drop cameras also overcome some of the biases associated with fish trap surveys of fish abundance and size frequency. Namely, the aggressive interaction between dominant fishes already inside a fish trap inhibiting the capture of a full size range or suite of the species that are actually present in the area of a trap (Cappo *et al.*, these proceedings). Time-lapse video allows undisturbed observations of the natural behaviour of marine organisms in situ. A big advantage of video is the ability view images in the field to ensure that recordings have been successful (Maney Jr. *et al.* 1990). Additionally computer image analysis video recordings is feasible by frame grabbing single images or video stream. It is then possible to determine the length or area of organisms within the image (Whorff and Griffing 1992) or to make three dimensional measurements if stereo-video images are available (Harvey and Shortis 1996). Stereo-video also facilitates the determination of the rate of movement of biological or physical parameters (Krohn and Boisclair 1994, Harvey and Shortis 1996, Peterell *et al.* 1997). Video is also able to rapidly acquire a large amount of data over quite broad spatial scales.

Finally, one of the major advantages of video seldom acknowledged by scientists is its power as a communications tool for demonstrating habitat structure, animal behaviour and, long-term changes in such features to lay people and managers (Kingsford and Battershill 1998).

Conclusion

Despite the disadvantages highlighted above underwater video is a powerful sampling tool and communication medium for marine scientists and managers. Rapid technological changes are occurring in digital recording and storage technology that will improve the reliability and resolution of images and storage media. For example, the "new generation", digital still cameras are approaching -- and in some instances surpassing -- the resolution of still photography. Whilst the disadvantage do exist they are far outweighed by the advantages.

One of the biggest drawbacks of video sampling is the time required to post process imagery. The automation of the recognition and measurement of organisms from video images is both desirable and achievable (Culverhouse *et al.* 1996, Ellis *et al.* 1997, Zion *et al.* 1999, Ellis, these proceedings, Robson *et al.*, these proceedings) and should be a focus for research investment.

The challenge of understanding the marine environment has been met in many ways by marine scientists. Traditional shipboard techniques, such as dredges, trawls and grab samples, are selective in their sampling, and destructive. Alternate techniques are required for sampling and monitoring sub-tidal and deep-sea environments that are efficient, effective, repeatable, reliable and statistically defensible. High-resolution underwater video is part of the suite of hybrid technologies that provide such a solution without compromising the requirements of accuracy and precision.

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A System for Stereo-Video Measurement of Sub-Tidal Organisms: Implications for assessments of reef fish stocks

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Introduction

Underwater visual census (UVC) techniques were first used by Brock (1954) to investigate Hawaiian reef fish communities. Since that time they have been modified (see review by Thresher and Gunn, 1986) and have become widely used as a technique for determining the relative abundance, species composition and length frequency of reef fish assemblages (Francour, 1991, 1994; Polunin and Roberts, 1993; Russ and Alcala, 1996 a, b; Edgar and Barrett, 1997; Willis and Babcock, 2000; Willis *et al.*, 2000). The advantages of UVC techniques, when compared with other sampling techniques, are that they are quantitative, quick, non-destructive, and repeatable (English *et al.*, 1994; Kingsford and Battershill, 1998). There are a number of methodological errors associated with almost all UVC techniques, most of which result in the underestimation of population densities (Jones and Chase, 1975; Andrew and Mapstone, 1987; Mapstone, 1988; Greene and Alevizon, 1989; Thompson and Mapstone, 1997; Willis and Babcock, 2000). Due to the apparent conspicuousness of many reef fish, and the often-clear water over tropical reefs, many of the errors inherent in visual census techniques are not obvious (Thresher and Gunn, 1986).

Recently some researchers have tried to identify potential sources of error, and have attempted to quantify their magnitude or effect. Sources of error that have been identified and investigated include:

- the method of counting (Sale and Douglas, 1981; DeMartini and Roberts, 1982; Kimmel, 1985; Bortone *et al.*, 1986; Sanderson and Solonsky, 1986; Thresher and Gunn, 1986; Greene and Alevizon, 1989; Bortone *et al.*, 1991; Samoilys, 1992; Mapstone and Ayling, 1993; Willis and Babcock, 2000; Willis *et al.*, 2000);

- the number of species of fish that can be effectively counted simultaneously (Russell *et al.*, 1978; Greene and Alevizon, 1989; Lincoln- Smith, 1989);

- the swimming speed at which counts are undertaken (Mapstone and Fowler, 1988; Lincoln-Smith, 1988; St. John *et al.*, 1990);

- the shape and size of sample units (Sale and Sharp, 1983; Fowler, 1987; McCormick and Choat, 1987; Mapstone and Fowler, 1988; Buckley and Hueckel, 1989; Mapstone and Ayling, 1993);

- the behaviour of fish towards a SCUBA observer (Chapman *et al.*, 1974; Chapman, 1976; Chapman and Atkinson, 1986; Cole, 1994; Kulbicki, 1998; Willis and Babcock, 2000; Wills *et al.*, 2000);

- the non-random movement of fish (Watson *et al.*, 1995);

- the effect of between-observer variability (Darwall and Dulvy, 1996; Thompson and Mapstone, 1997),

- errors in length estimation of reef fish (Bell *et al.*, 1985; St. John *et al.*, 1990; Darwall and Dulvy, 1996; Harvey *et al.*, 2001 a, b).

This paper aims to demonstrate the magnitude and potential effects of errors associated with UVC estimates of the distance to a fish and fish length on programs monitoring the relative abundance and length frequency of reef fish assemblages or populations. The paper also compares length and distance estimates made by scientific SCUBA divers with measurements made using an underwater stereo-video system.

The stereo-video systems used in this experiment were designed to make size estimates of marine flora and fauna at distances of 1.4 to 10 metres, depending on water visibility. With the stereo-video systems trialed, two video cameras are mounted in underwater housings and fixed to a base bar separated by a distance of 144.4 cm. Each camera is inwardly converged at 8 degrees to gain an optimised field of view. A Light Emitting Device (LED) is mounted 1.4 metres in front of the cameras above a control plate. The LED serves as a simple means of synchronising the left and right images from which measurements are made. The system and the calibration procedure are described in detail in Harvey and Shortis (1996, 1998) and (Shortis *et al.*, these proceedings). Two single Charged Couple Device (CCD) Sony TRV516 Hi-8 camcorders were trialed as well as two 3 CCD Sony TRV900 E digital camcorders.

Testing methodology

The accuracy and precision of both length and distance estimates from the two stereo-video systems and experienced and novice scientific divers were tested using a simple procedure used for calibrating diver estimates of the lengths of reef fish. PVC silhouettes of fish of a known length were placed in a swimming pool and the lengths (GBRMPA, 1979; Bell *et al.*, 1985; English *et al.*, 1994) and distances to the silhouette estimated. Full descriptions of the testing methodology may be found in Harvey *et al.* (2001a) and Harvey *et al.* (2001c, submitted to MTSJ). The accuracy of estimates can then be assessed by the difference between the real size and the estimate.

Results

Digital stereo-video is more accurate and precise in its length estimates than either the Hi 8 stereo-video system or the novice and experienced scientific divers (table 1). Distance estimates have a similar trend (table 2).

The important question is whether the increases in the accuracy and precision of length and distances estimates made by a stereo-video system actually improve the ability of a sampling program to detect changes in the mean length or relative abundance of a population of reef fish.

Table 1 The accuracy (mean error) and precision (standard error and coefficient of variation) of visual length estimates made from digital and Hi8 stereo-video systems, a single camera system and novice and experienced scientific divers.

	Stereo-video		Single video	Scientific Divers	
	Digital	**Hi 8**	**Digital**	**Novice**	**Experienced**
Mean error (mm)	-0.22	-0.98	-14.34	23	21
Std error (mm)	0.37	1.12	1.86	5.5	5
CV (%)	0.38%	1.15%	1.62%	17%	17%

Table 2 The accuracy (mean error) and precision (standard error and coefficient of variation) of distance estimates made from digital and Hi8 stereo-video systems and novice and experienced scientific divers.

	Stereo-video		Scientific Divers	
	Digital	**Hi 8**	**Novice**	**Experienced**
Mean error (cm)	-6.38	31.08	-6.34	-46.22
Std error (cm)	0.98	3.11	7.46	7.72
CV (%)	0.37%	1.08%	17.9%	21.4%

To demonstrate the effect of increased accuracy and precision on length estimates Harvey *et al.* (2001 b) have modelled the theoretical statistical power of a Hi 8 stereo-video system, and both experienced and novice scientific divers to detect changes in the mean length of three species of fish (blue cod (*Parapercis colias*), red cod (*Pseudophycis bachus*), and snapper (*Pagrus auratus*)) found in coastal waters from around New Zealand. Length estimates from a stereo-video system had much greater power for blue cod (mean length=33.1 cm., range 19.5–50.1 cm.) and snapper (mean length=31.7 cm., range 23–71 cm.) (fig. 1). For a third species, red cod (mean length=42.5 cm., range 13–74 cm.), the statistical power of diver and stereo-video estimates were much less for an equivalent number of samples (fig. 1) owing to the greater variation in the true mean length of red cod recorded at different sites (Harvey *et al.*, 2001b). At 90% power, a stereo-video system detected a 15% (~5-cm) change in the mean length of blue cod with 63% less samples (10) than those required by the experienced scientific divers (27). Novice scientific divers required 28 samples (fig. 2).

As the numbers of fish recorded per sample decreases (for example from 30 to 10 to 1), the number of samples that need to be recorded to maintain an equivalent level of power increases.

For example, to detect an effect size of 15% with 90% power for blue cod when only one fish is being recorded per sample, 30 samples per site need to be recorded with the stereo-video system, 70 with experienced scientific divers, and 71 with novice scientific divers. When 30 fish are recorded per sample only 10, 27, and 28 samples are required, respectively (fig. 3).

Distance errors associated with UVC have the potential to greatly affect the actual area surveyed. A review of 65 studies utilising strip transects as a sample unit for censusing reef fish showed that only 8 authors (Bell, 1983; Choat and Bellwood, 1985; McCormick and Choat, 1987; Lincoln-Smith, 1988; Bortone *et al.*, 1989; Davis and Anderson, 1989; Russ and Acala, 1996; Rakitin and Kramer, 1997) physically marked the boundary of their sample unit. In an unmarked transect a diver needs to estimate the distance to a fish and the angle to the fish relative to the centre of the transect, to decide whether a fish is inside or outside the border. They also have to identify, count and in some instances estimate the length of all fish seen. Overestimates in distance (ie when a fish is 5 m from the diver and it is estimated as being at 7 m) will decrease the area surveyed whilst underestimates (ie. when a fish is 5 m from the diver and it is estimated as being at 3 m) will greatly increase the area actually censused. Harvey (1998) showed that experienced scientific divers tended to underestimate distances while novices tended to overestimate. By comparison, a stereo-video was more accurate (table 2).

To elaborate further a point count with a 7 m radius encompasses a total area of 154.1 m^2. Using the 7 m point count as a benchmark tables 3 and 4 show that underestimates, as made by the experienced scientific divers, are more serious than the overestimates by the novice scientific divers as they proportionally increase the area censused, and potentially the actual numbers of fish observed. Although we have not tested the accuracy of angle estimates, given that both length (position of 3D coordinates) and distance measurements are correct the angle estimates must be correct. Given accurate distance and angle measurements it is possible that line transect theory (Burnham 1980, Buckland *et al.*, 1993) could be successfully adapted to surveys of reef fish.

Table 3 Confidence limits for the true radial distance and area censused during a point count. All limits are expressed as percentages of the estimate, for a point count with a nominal radial distance of 7 m.

		Novice Observer	Experienced Observer	Stereo-Video
Distance	Lower	76%	91%	96%
	Upper	116%	139%	106%
Area	Lower	58%	82%	93%
	Upper	134%	194%	113%

Table 4 Confidence limits for the actual area censused during a point count. All limits are expressed as m^2 with a nominal radial distance of 7 m.

		Novice Observer	Experienced Observer	Stereo-Video
Area	Lower	89.0	127.7	143.7
	Upper	207.4	286.8	173.9
	Actual	154.1	154.1	154.1

Conclusion

Both within and between diver variability in estimates of the length of a fish and the distance from a diver will seriously affect the ability of monitoring programs to detect spatial and temporal changes in the mean length and relative abundance of reef fish assemblages with any certainty. Stereo-video decreases the within and between site measurement variability and greatly increases the accuracy of visual measurements. Unbaited (Francour *et al.*, 1999) and baited drop video systems (Cappo *et al.*, these proceedings; Willis *et al.*, 2000; Willis and Babcock, 2000) have great potential to overcome diver disturbance (Cole, 1994; Harvey, 1998; Willis *et al.*, 2000). Remote video camera systems can sample fish populations at depths beyond those accessible to SCUBA divers and with greater precision (Ellis and Demartini, 1995; Francour *et al.*, 1999; Willis and Babcock, 2000). Stereo-videography will compliment these developments by enabling accurate measurements of distance and the length of fish.

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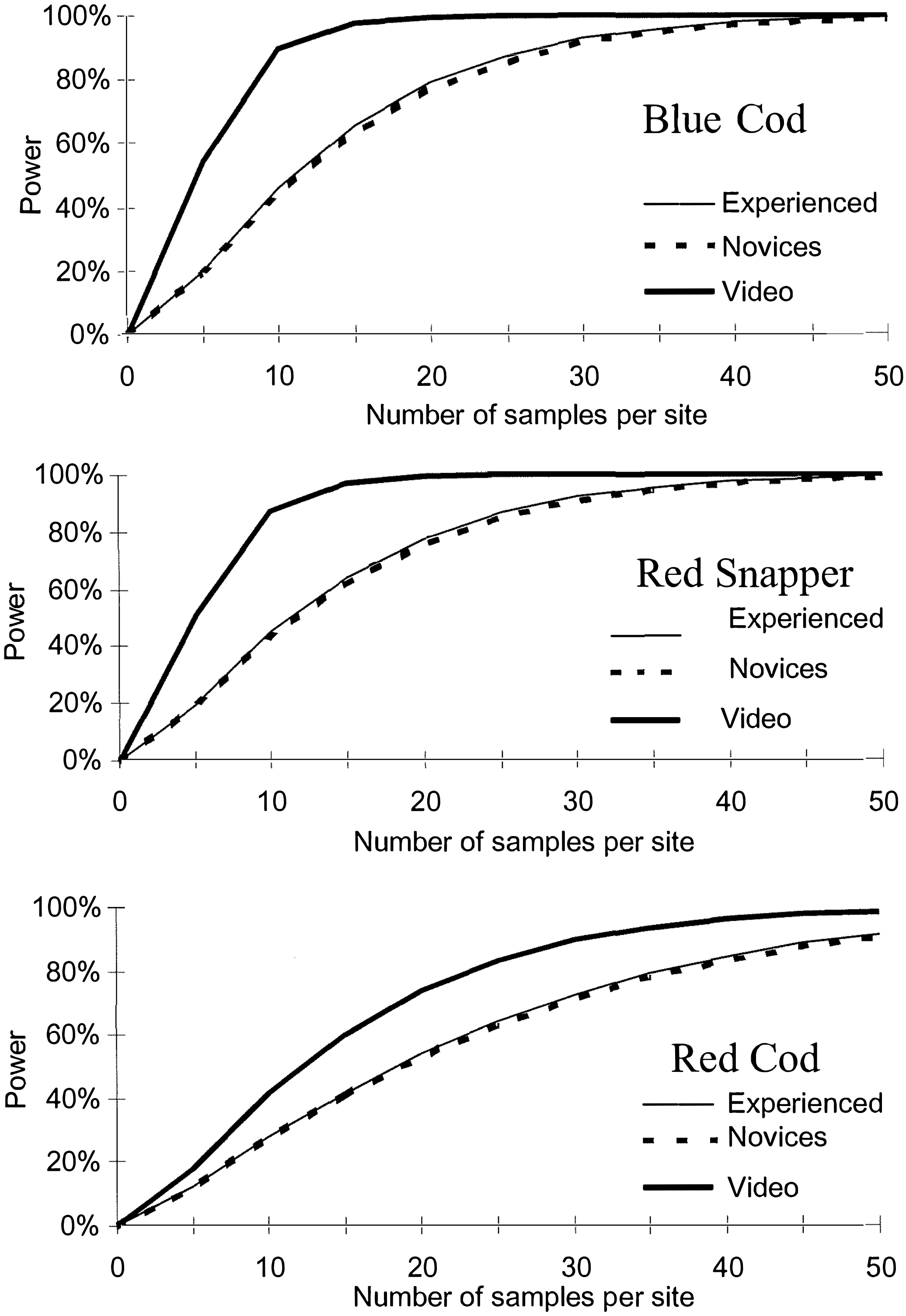


Figure 1 The power of novice scientific divers, experienced scientific divers and a stereo-video to detect a 15% change in the mean length of a population of Blue Cod, Snapper, and Red Cod. Based on 30 fish per sample, with α= 5% (after *Harvey et al.*, 2001b).

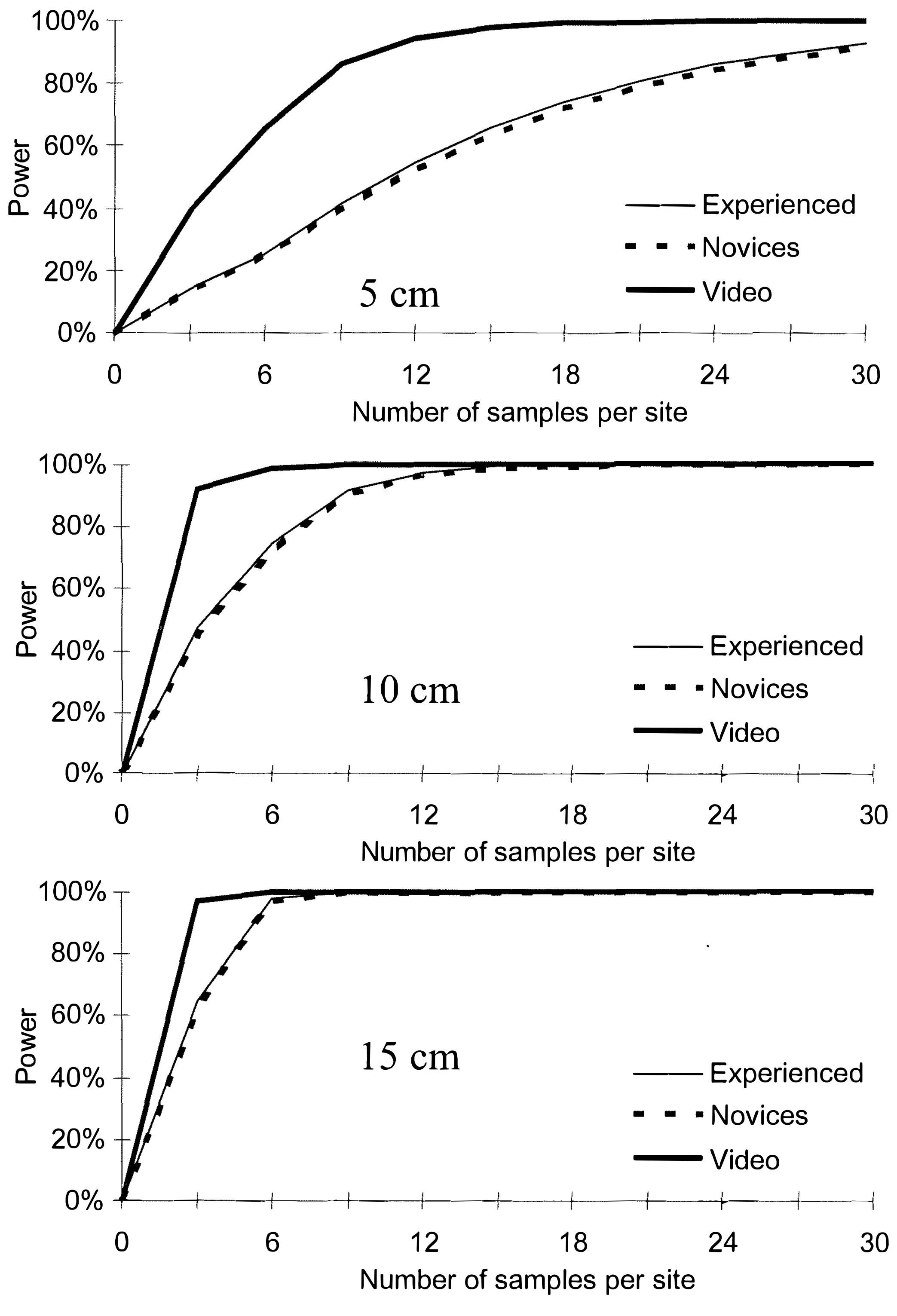
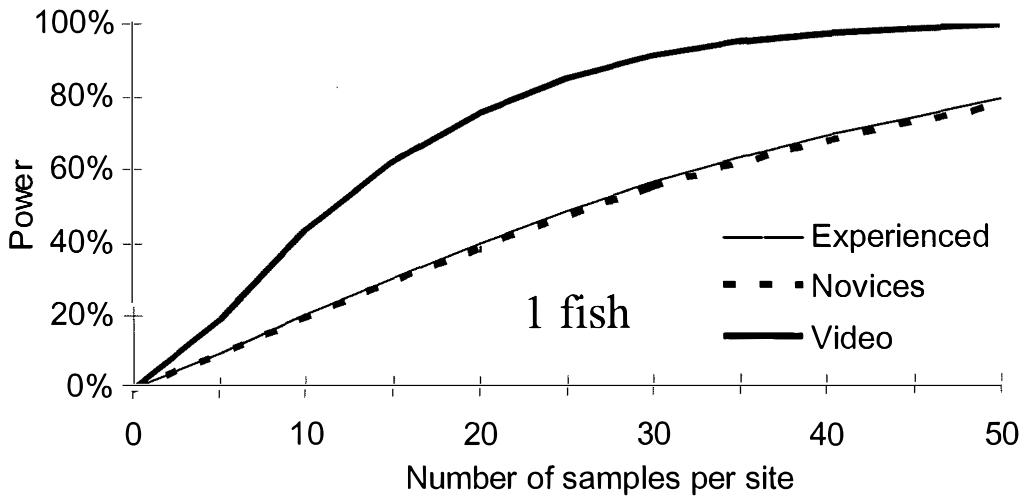
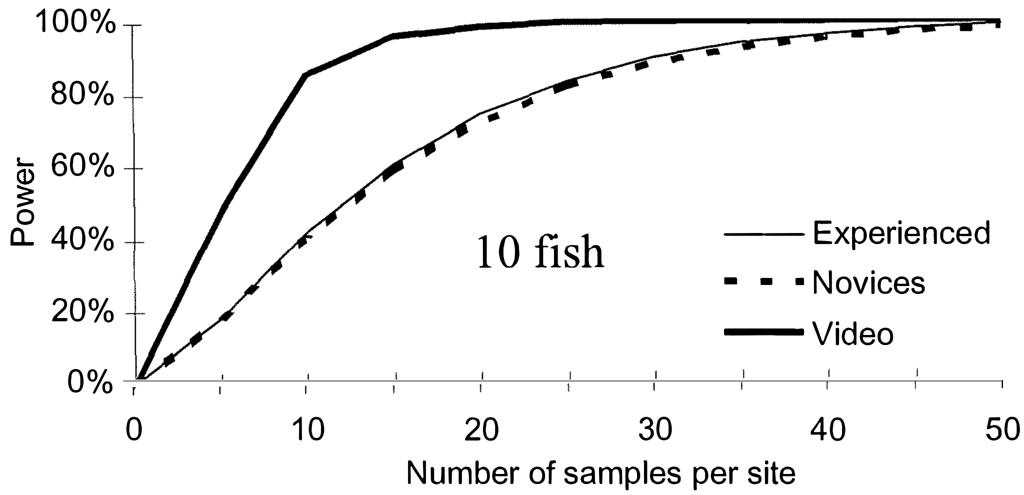


Figure 2 The influence of different effect sizes on the power of novice scientific divers, experienced scientific divers and a stereo-video to detect changes in the mean length of a population of Blue Cod. Based on 30 fish per sample, with α= 5% (after *Harvey et al.*, 2001b).





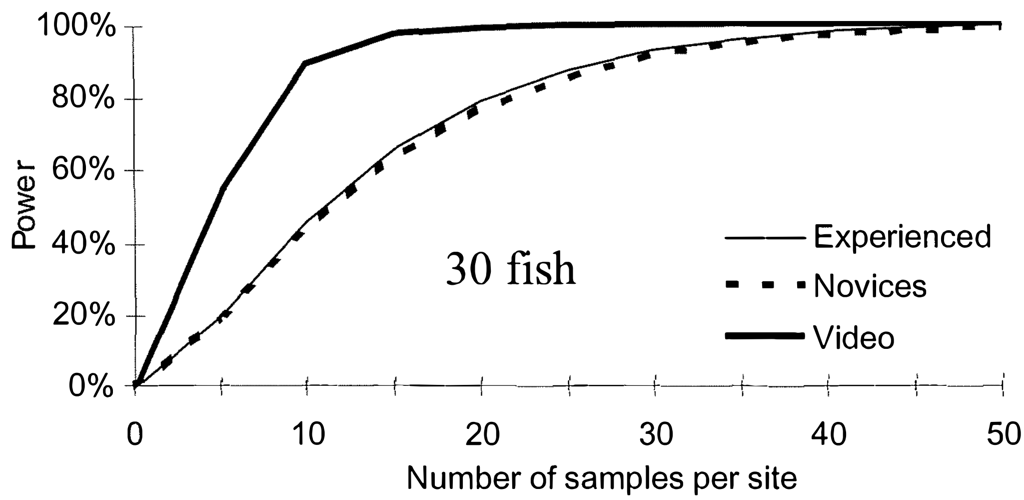


Figure 3 The effect of different numbers of fish being recorded per sample on the power of novice scientific divers, experienced scientific divers and a stereo-video to detect changes in the mean length of a population of Blue Cod. Based on a 15% effect size, with α= 5% (after *Harvey et al.*, 2001b).

Emulation of Diver-based Video Transect Methods, for Surveys of Deeper Water Coral Reefs in North West Australia, using a Dual Camera ROV System

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Australian Institute of Marine Science, Dampier WA 6713

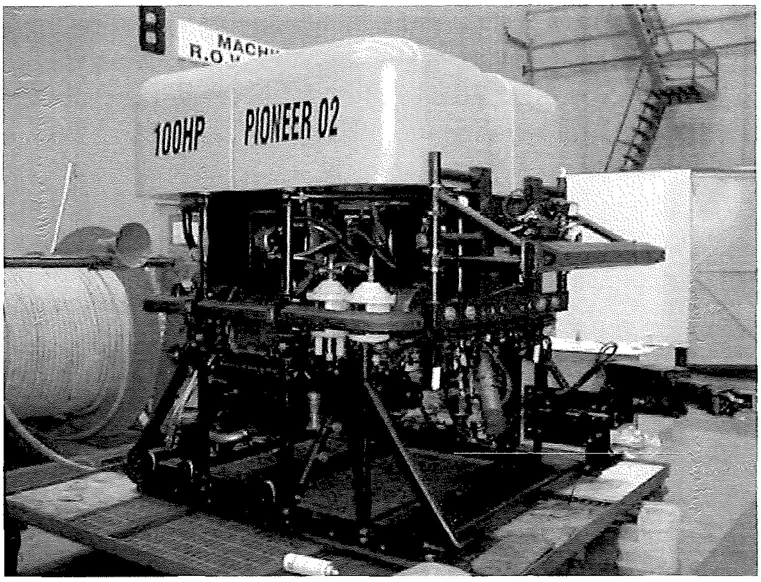
The detailed benthic transect component of the long-term reef monitoring project by the Australian Institute of Marine Science (AIMS), on the Great Barrier Reef and in Western Australia, has been based on diver-held video transect surveys. The methods for obtaining and interpreting this particular type of videographic data are well documented and statistically proven to be sufficient to characterise the major aspects of abundance and diversity for given areas of benthic reef communities. This major focus on gathering and interpreting underwater video footage of tropical benthic communities has also highlighted some of the limitations on the level of information, for example, for taxonomic identification, that can reliably be obtained from video.

In order to maximise the amount of information on benthic biodiversity that can be extracted from video, our experience suggests that camera perspective, evenness and colour balance of illumination, camera speed over the seabed and resolving power of the image capture, storage and playback system are fundamental. Technological innovation, including advances in video electronics, optics and data storage media continue to improve video for benthic assessment. As a result we now have the ability to greatly improve the quality of images obtained in surveys of marine habitats and, subsequently, to learn much more from them. It is foreseeable that the level of information obtainable from underwater video on marine biodiversity will match then ultimately exceed that achievable by divers collecting data *in situ*.

Using divers to collect video for subsequent analysis has some great benefits, including speed of survey and excellent control of camera perspective obtained over rugose microhabitats. Nonetheless, reliance on divers brings its own significant constraints. Safety and efficiency issues result in most scientific, diver-based video surveys being limited to depths less than 20m and three non-decompression repetitive dives per day. The consequences include limitation of the amount of video sampling per day and a serious depth bias in what still remains relatively limited sampling of coral reef habitats.

Since the mid-1990's, AIMS in Western Australia has analysed the videotapes from Remotely Operated Vehicle (ROV) surveys of benthic habitats in various petroleum exploration zones from the Timor Sea (fig. 1). The quality of videographic data delivered by standard industry ROVs has varied significantly, greatly influencing the ability of marine biologists to reliably evaluate the status of the habitats in question. Notable contributing factors have included, the skill of the pilot, the presence during survey of a consultant marine biologist to advise the pilot, the configuration of the video camera equipment on the ROV, the camera perspective, illumination of the field of view and the quality of the video equipment used. Following the receipt of some poor quality footage from industry operations early on, we have advised a specification for image quality and perspective, based on our diver held video experience that has increased the percentage of video footage suitable for quantitative percent cover assessments of benthic communities.

(a)



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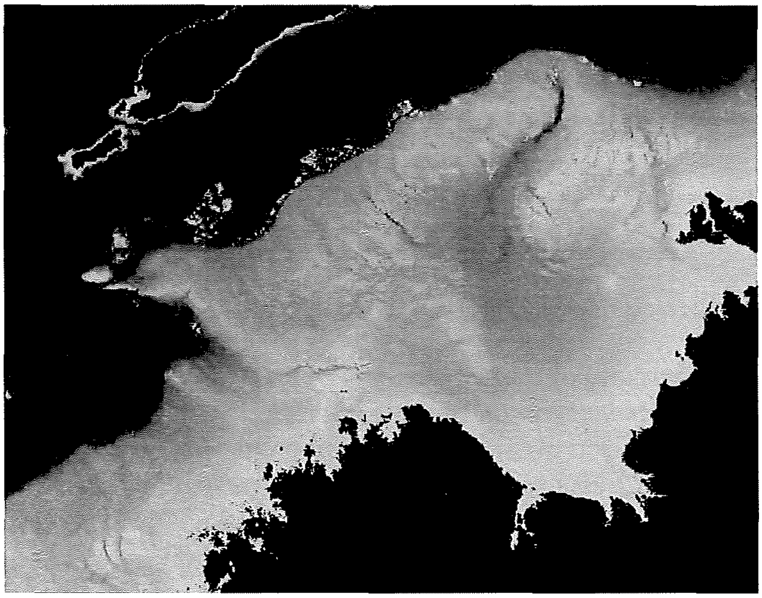


Figure 1 (a) A typical large industry ROV; (b) Sahul Shelf Shoals and Bonaparte Basin where many ROV surveys have been conducted by the Petroleum industry (image from AGSO after Heyward *et al.*, 1997).

ROVs fitted with appropriate video equipment provide a convenient platform for video surveys in coral reef environments and certainly overcome the depth and bottom time limitations of diver-based methods. A variety of ROV designs are currently used by offshore industry in the north west of Australia and several types of machine have been used to attempt detailed video transect surveys in reef environments. Most standard industry ROVs are bulky in design (fig. 1a) and can be a cumbersome object when attempting to navigate in fine scales to maintain the ideal perspective and distance while shooting video over a coral reef. Another limitation to their application to scientific research has been their high purchase and maintenance costs.

We have subsequently sought to develop a small, relatively low cost specialist ROV designed to provide high quality video transect images in coral reef habitats down to approximately 100m depth (fig. 2). This paper reports on the key design attributes of this dual camera ROV instrument which is delivering image quality at depth comparable to that delivered by SCUBA divers in shallow reef zones. The dual camera system allows very close proximity to the seafloor while avoiding collisions by using a forward camera that is used predominantly for flying the vehicle. We present examples from surveys down to 70 m and identify some key issues concerning maximising the capture of biodiversity data from these types of video images. Input from the workshop is sought to further optimise this design approach and develop complementary tools, such as dual camera towed video, for broader scale rapid surveys.

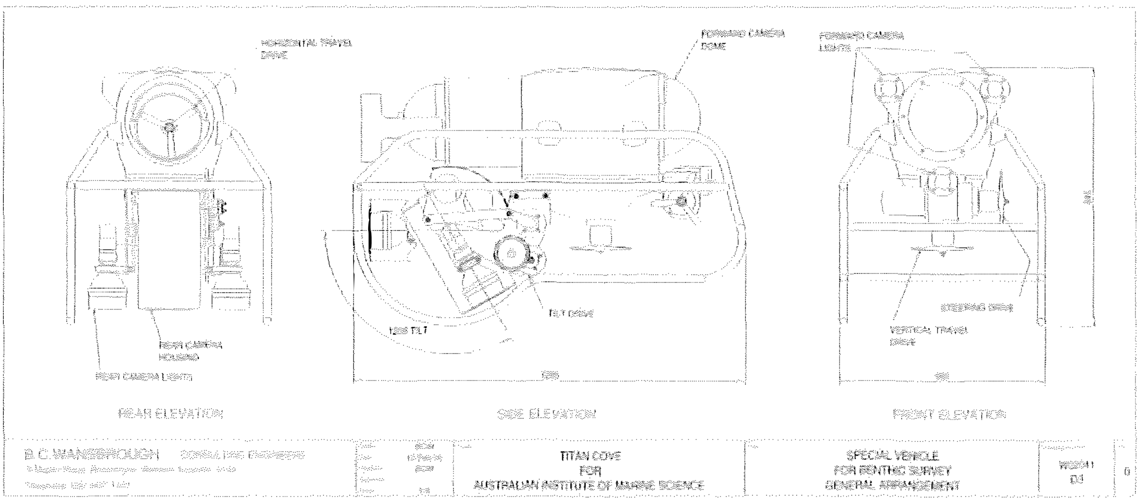
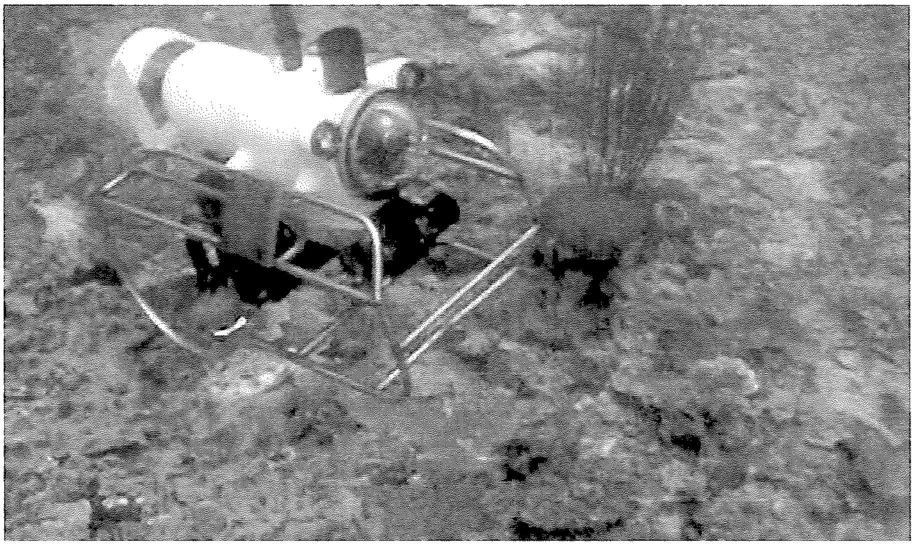


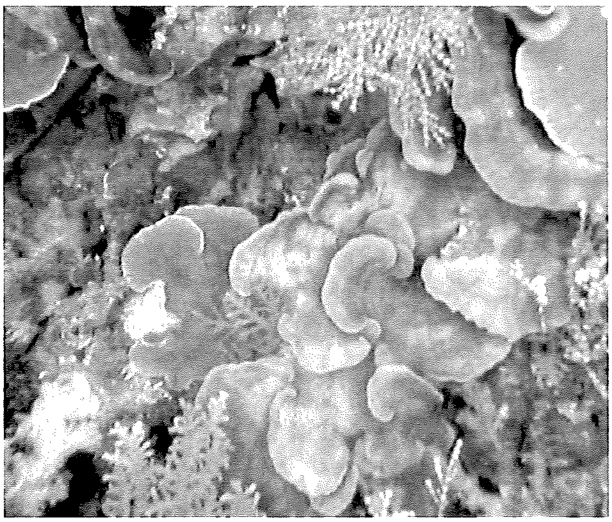
Figure 2 General arrangement of the newly developed ROV by Titan Cove/AIMS.

Our aims during the development of our specialist ROV were to emulate the high quality of video footage obtained by divers on shallow coral reefs (fig. 3). Considerable emphasis must be placed on maximising image quality in the costly and logistically complex procedure of ROV deployments to capture video footage. Almost any video camera, lighting and video cable system in combination will provide an image. An issue of great importance is the fidelity of these images to the real world below the sea surface. It is always of great benefit to an interpreter to view an image that is clear, steady, sharp and illuminated evenly with colours accurately balanced.

Future directions of AIMS include aspirations to develop elements of autonomous control in our ROV, thereby enabling similar guidance systems to be implemented, ultimately on an AUV. In order to streamline video analysis we are investigating the benefits of multi-spectral filtering when implemented on benthic video transects and the capacity to highlight a particular suite of organisms that strongly return a known range of reflective light bandwidth. Other video analysis tools are expected from the development of neural networks and machine recognition that has potential to dramatically shorten the amount of post field analysis performed on video data as well as providing a standardised and easily quantified error margin on identifications. Finally we have initiated the development of a high capability towed platform that will expand AIMS interests of tropical benthic organisms down to depths of 1000 m. This towed system will incorporate already proven design methods for deep-sea tow cable configuration utilised by the CSIRO Division of Marine Research, with a towed platform incorporating the dual camera and illumination systems utilised successfully in our small ROV. The project is in the final design stages and will most likely be organised for assembly and field trials over the coming months.



(a)



(b)

Figure 3 (a) AIMS ROV at work surveying habitat in 50m of seawater in the Timor Sea, December 1999. (b) Video grab of the habitat displays clarity, even illumination and good colour balance.

The Utility of Underwater Video in Marine Caging Experiments

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Introduction

Manipulative field experiments can potentially provide the most rigorous and persuasive tests of hypotheses in ecology (Raffaelli and Moller, 2000), particularly those pertaining to predation, and much of the research to date has used exclusion cages to manipulate abundances of predatory fishes (Doherty and Sale, 1985). Cage controls, that allow predatory fishes to forage 'naturally' in areas enclosed by cage structure, are necessary to separate predation effects from processes directly related to the provision of artificial structure (Virnstein, 1978; Steele, 1996; Connell, 1997). Furthermore, results should not be confounded by attraction of potential prey to the structure provided by cages and cage controls (Bell *et al.*, 1985; Bohnsack *et al.*, 1997 Carr and Hixon, 1997; Clarke and Aeby, 1998). Therefore, direct observations are needed to determine whether caging materials attract fishes or differentially alter foraging by predatory fishes inside cage controls compared with uncaged areas (see Connell, 1997). Recording predator behaviour also helps to explain variation in predation by providing quantitative estimates of how transient predatory fishes may be using alternative habitats at different times. Underwater video affords researchers with an opportunity to accurately quantify fishes whose temporal patchiness and transient nature may preclude accurate estimations using divers (Burrows *et al.*, 1994; Morrisey *et al.*, 1998).

This paper describes a pilot study using underwater video to investigate artefacts in caging experiments designed to evaluate the role of piscivory in structuring assemblages of small fish in seagrass and unvegetated habitats of Port Phillip Bay (Hindell *et al.*, in review).

Materials and Methods

Study Area

The study was carried out near Blairgowrie in Port Phillip Bay, Victoria, Australia (fig. 1). This site has patches of seagrass, *Heterozostera tasmanica* interspersed with relatively coarse sand. Because of its location near Port Phillip Heads, this site has relatively high water clarity. Experiments and video recordings were conducted in approximately 1 m water depth.

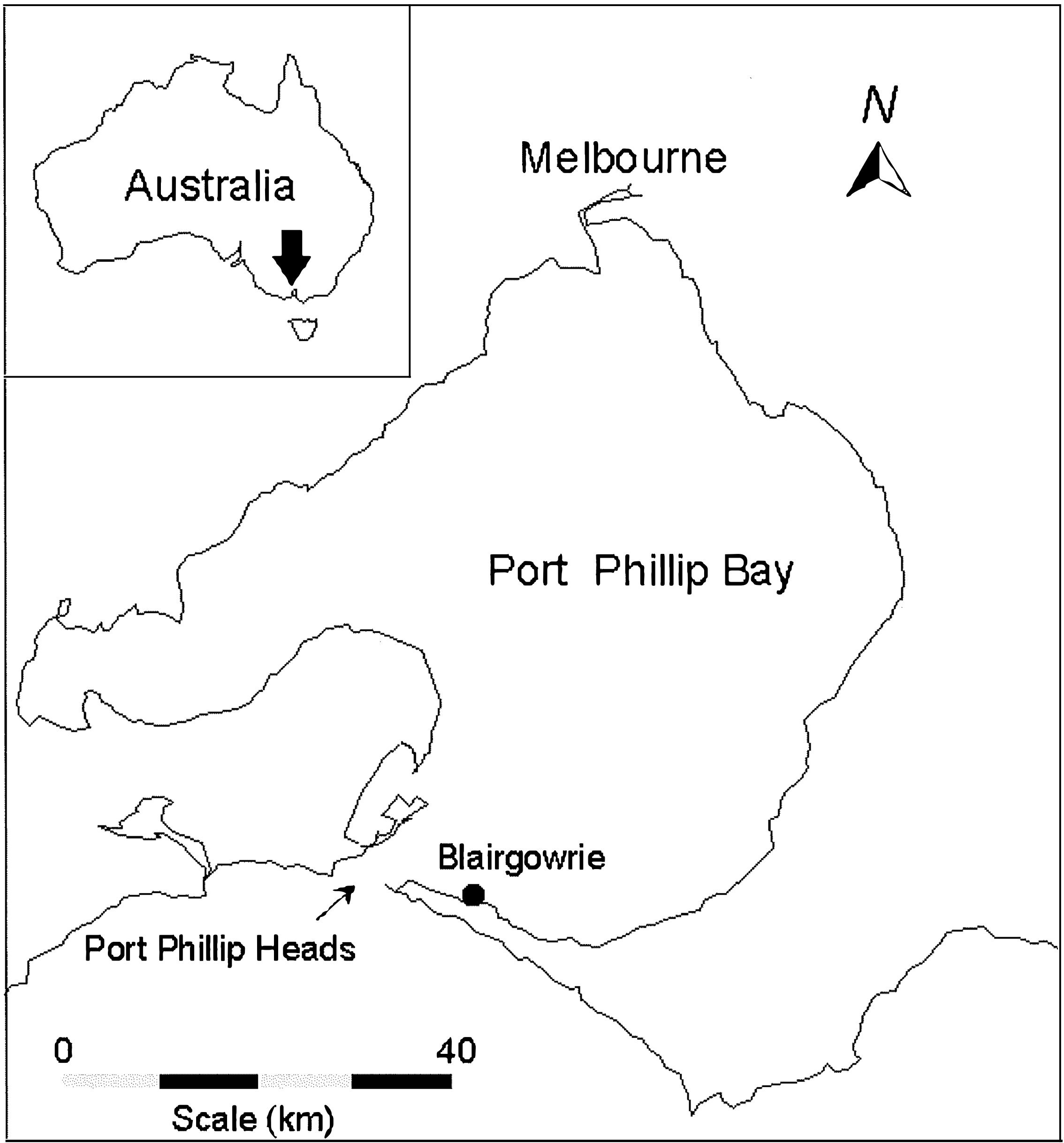


Figure 1 Location of the Blairgowrie study site in Port Phillip Bay. Inset: Location of Port Phillip Bay within Australia.

Cage construction

Piscivorous fishes were excluded from 16 m^2 patches of unvegetated sand and seagrass at each site using cages. Each exclusion cage was constructed from four steel stakes hammered into the substrate at each corner of a 4 × 4 m square plot. Around this, a 16 m length of black polypropylene netting, 1.5 m high with a mesh size of 15 mm, was attached (fig. 2a). The top of each cage was not enclosed with mesh, but the height of the cage (1.5 m) precluded the cage from being submerged even during spring high tides and thus prevented predatory fish from entering the cage. To prevent predatory fish swimming between the substrate and the cage walls, the bottom of each mesh wall was weighted using a 3 m length of steel rod (10 mm diameter). Cage controls were built from exactly the same materials, and in the same dimensions, as exclusion cages. But, to allow predatory fish access to the interior of cage controls while controlling for any effect of cage structure, the top or bottom half of each wall was filled-in alternatively around the four sides (fig. 2 b). Uncaged areas were simply 16 m^2 plots without cage structure.

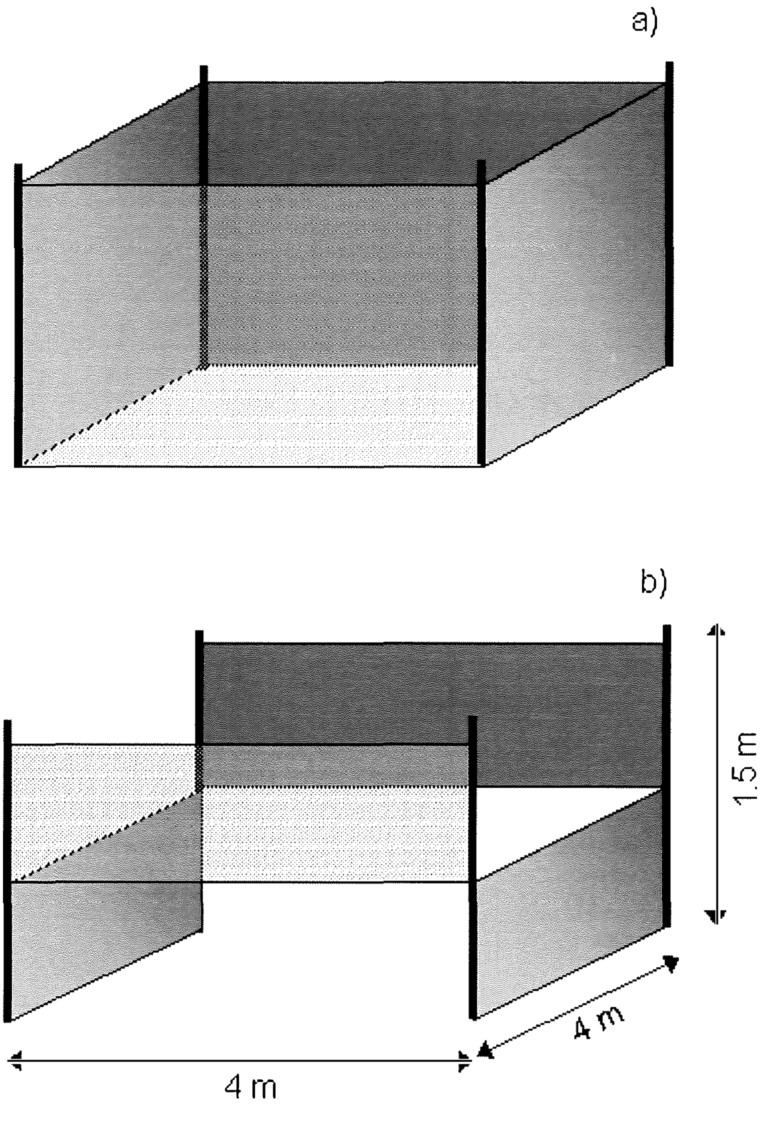


Figure 2 Design of (a) exclusion cage used to exclude predatory fish from areas of seagrass and unvegetated sand, and (b) partial cage used to assess artefacts associated with the structure of the cage.

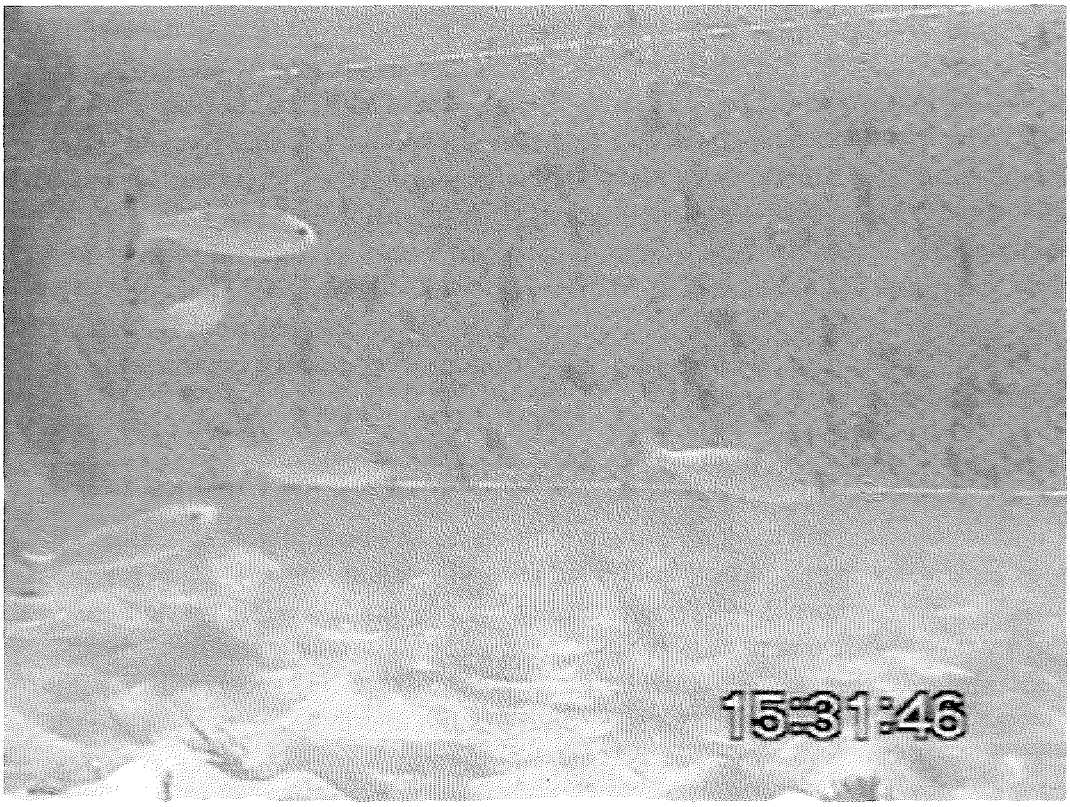
Underwater video observations

Sony standard 8 mm Handycam video cameras, enclosed in underwater housings, were used to measure the variability in abundances of *Arripis truttacea*, one of the most important predatory fish in Port Phillip Bay (Hindell *et al.*, 2000) between cage treatments and habitats (unvegetated sand and seagrass). In either unvegetated sand or seagrass, depending on what was randomly chosen, a single replicate of each caging treatment was set-up. A single video camera was placed inside each cage treatment, and the videos were linked using a "CamelCam" automated underwater video system (JK instruments Ltd, NZ) which enables the user to pre-program recording regimes via "CameraTalk" software. One of the three housings contained a controller that allowed each camera to follow the pre-programmed regime simultaneously. Cameras were fitted with wide-angle lenses to correct for underwater distortion. Videos were set to simultaneously begin recording 3 hr before mean high water, and to record the first 10 min of each half hour time interval for 6 hr so that they 'captured' the movement of fish during flood and ebb tides. This procedure was replicated twice in each habitat. Video analysis was conducted from December 1999 to January 2000. The numbers of *A. truttacea* observed in each combination of habitat and cage were counted.

Results

Underwater video proved very effective for observing both predatory and potential prey fish, and was particularly useful for observing transient, schooling species such as Australian salmon, *Arripis truttacea* and tommy rough, *Arripis georgianus* (fig. 3). Potential prey fishes such as blue sprat, *Spratelloides robustus* and hardy heads, Atherinidae were easily observed. Other commonly recorded species were King George whiting, *Sillaginodes punctata* and smooth toadfish, *Tetractenos glaber*.

Abundances of *Arripis truttacea* varied significantly between cage treatments (fig. 4). Underwater video showed that *A. truttacea* occurred in seagrass only once in 480 minutes of video time taken over 24 hours on four separate days. In this case, the small school of *A. truttacea* (n=6) passed through the field of vision in less than 1.5 seconds. Therefore, we re-analysed our data for unvegetated sand habitats only. In this habitat, abundances of *A. truttacea* varied significantly between cage treatments ($df_{2,4}$, MS=2.764, P=0.025). The design of our cages ensured that no *A. truttacea* were observed inside exclusion cages. There were clearly more fish in partial cages and uncaged areas than exclusion cages (fig. 4), and abundances of *A. truttacea* inside partial cages did not differ to those inside uncaged areas over unvegetated sand ($df_{1,4}$, MS=4.000, P=0.374). Importantly, neither *A. truttacea* nor their potential prey, such as atherinids and clupeids, appeared to congregate around the walls of cages.



(a)

(b)

Figure 3 Western Australian salmon (*Arripis truttacea*) and tommy rough (*A. georgianus*) inside: (a) partial cages, and (b) uncaged areas over unvegetated sand at Blairgowrie.

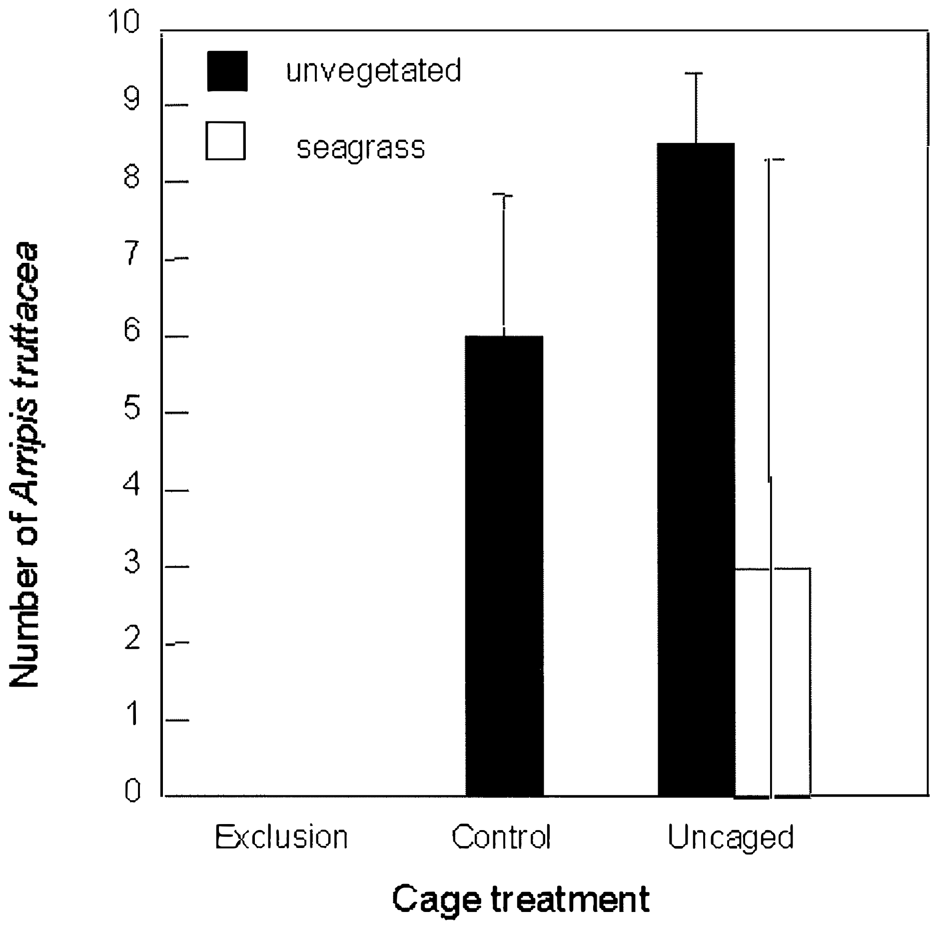


Figure 4 Mean abundance (±SE) of *Arripis truttacea* observed using underwater video in exclusion cages, partial cages and uncaged areas within seagrass and unvegetated sand habitats at Blairgowrie.

Discussion

Underwater video proved very successful for investigating caging artefacts in our study of the effects of piscivory on assemblages of small fish. Connell (1996, 1998) measured abundances of predatory fishes visually, but diver observations potentially underestimate abundances of fast-swimming and transient predatory fishes that are difficult to observe and count (Hickford and Schiel, 1995; Connell *et al.*, 1998; Tupper and Hunte, 1998). Therefore, less intrusive techniques, such as underwater video cameras, may be quantitatively more accurate in measuring local abundances of predatory fishes and their prey (Burrows *et al.*, 1994). In our study, underwater observations showed that *Arripis truttacea* occurred inside partial cages over unvegetated sand in similar numbers to those observed over uncaged areas, and therefore, it is reasonable to conclude that the foraging pressure inside partially caged areas is similar to that over uncaged areas. Observations also suggested that results were not being confounded by the attraction of predator and prey fish to the structure provided by cages. Of particular interest was the observation that piscivorous fish were very rare in any seagrass treatment. Thus, the lack of a significant predation effect observed in seagrass habitat (Hindell *et al.*, in review) was due to a behavioural preference of predators not to enter seagrass beds, rather than the amelioration of predation by seagrass structure, which is the usual explanation for such a result.

In conclusion, experiments were designed to investigate the role of piscivorous fish in the structure of assemblages of small fish associated with seagrass and unvegetated habitats. Underwater video proved to be highly effective for examining artefacts that may be associated with such caging experiments. We recommend the further use and development of this technique for investigating artefacts associated with manipulative experiments in marine environments.

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Use of Towed Video to Accurately Map Seagrass Assemblages in Shallow Water (<10 m) in Owen Anchorage and Cockburn Sound, Western Australia

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Introduction

Seagrass habitats in temperate Australia are dynamic systems with changes in cover observed at scales of square metres to hectares over periods of years to decades (Kendrick *et al.*, 1999). Changes have involved both gains (Kendrick *et al.*, 2000) and losses of seagrass cover (Cambridge and McComb, 1984), and changes in the location and structure of seagrass beds (Kendrick *et al.*, 2000). To monitor and manage seagrass systems, it is necessary to accurately and objectively record changes in cover and meadow structure. In shallow marine environments (<10 m), benthic habitat mapping from remotely sensed imagery has been shown to be both effective and efficient for this task when there is equal effort expended to adequate ground-truthing of remote data. This paper summarises how towed and drop-down video was used to ground-truth a recent seagrass habitat survey of Owen Anchorage and Cockburn Sound, Western Australia. The major aim was to accurately map both seagrass coverage and distribution of seagrass assemblages.

Methods

Ground-truth Surveys

Detailed ground-truth surveys were conducted between late-February and May, 1999. These ground-truth surveys were undertaken using a combination of diver-operated towed video (manta tow) and a downward-looking surface deployed (drop-down) video throughout the Owen Anchorage and Cockburn Sound study regions (fig. 1). Following the completion of the formal ground-truth surveys, a series of ad hoc dives were also undertaken opportunistically to establish the habitat type in specific areas of interest.

Manta tow transects were conducted by towing a diver on a manta board with a hand operated underwater video at a speed of approximately 1–2km/hr. The video camera was generally set to capture a field of view of the bottom of approximately 5 m^2. A time stamp was placed on the video during capture. This time stamp was later used to position the video camera by reference to a series of DGPS waypoints which were automatically logged every 20 seconds on the tow boat during the transect. The offset (60 m) between the GPS antenna and the video camera was considered in determining the positions of the video footage. A total of 22 manta tow transects were completed: 18 in Owen Anchorage and 4 in Cockburn Sound. The individual transects were between 1 and 4km in length and provided a total video coverage of 42 km. Detailed ground-truth mapping using the manta tow technique was undertaken at two sites on Success Bank: near Mewstone and east of the second shipping channel. The detailed ground-truth mapping areas were 0.5 x 0.5 km, and within each area 11 manta tows were conducted at 50 m intervals. A total of 3,403 manta tow video logs were recorded.

During the 1995 mapping of seagrass assemblages in Owen Anchorage and Cockburn Sound (LeProvost, Dames & Moore, 1996) there were a large number of mapped polygons in which the seagrass assemblages were not defined. Several of the larger of these polygons were surveyed during the present investigation using a drop-down video. A total of 152 drop-down video sites were visited and the majority (114) of these were located in Cockburn Sound and the remainder (38) were located in Owen Anchorage. Core samples of the benthic habitats were obtained by divers at 21 of the drop-down video sites that aided in interpreting seagrasses from the drop-down video footage.

Interpretation of Video Footage

The manta tow videos were analysed by pausing the video at 20 second intervals (corresponding with the DGPS waypoint times). At each of these video pauses an estimate of the percentage seagrass coverage was determined using the following cover index scale (over an area of approximately 5 m^2):
- 0 to <5%;
- 5% to <25%;
- 25 to <50%;
- 50% to <75%;
- and 75% to 100%.

Percentage cover was assessed visually using a visual cue card with cover estimates drawn on it (Dethier *et al.*, 1993).

During each video log, the proportional representation of the following seagrass species and/or habitat type was also recorded:
- *Amphibolis antarctica*;
- *Amphibolis griffithii*;
- *Posidonia australis*;
- *Posidonia coriacea*;
- *Posidonia sinuosa*;
- *Halophila ovalis*;
- *Heterozostera tasmanica*;
- *Syringodium isoetifolium*; and
- limestone reef.

It was not possible to separate the species of *Posidonia sinuosa* and *Posidonia angustifolia* from the video data as this requires an examination of their rhizome fibres (Cambridge and Kuo, 1979). Ground-truth dives indicated that *Posidonia sinuosa* was generally more common than *Posidonia angustifolia* (greater than 90% except in the Cockburn Sound East region where both species were co-dominant). Consequently, in the present mapping exercise these two species were both mapped as *Posidonia sinuosa* meadows.

The seagrass cover and species type was similarly determined for the drop-down videos by averaging across the footage obtained at each site. If the seagrass coverage varied noticeably at a drop-down video log site then the site was sub-divided to more accurately represent the seagrass coverage.

A total of 3,555 (3,403 manta tow and 152 drop-down) video logs were generated during the ground-truthing exercise and these were combined with 398 ground-truth points obtained during the 1995 mapping exercise of the area (LeProvost, Dames and Moore, 1996).

Mapping of Benthic Habitats

The maps of the 1999 vegetated and unvegetated areas, as determined from the two-staged semi-automated method, were combined with the ground-truth data to produce a benthic habitat map (fig. 1). Within the mapping region, the following habitat types were distinguished:

- shallow bare sand (<10m depth);
- *Posidonia sinuosa*;
- *Posidonia sinuosa* and *Posidonia australis*;
- *Posidonia australis*;
- *Posidonia coriacea*;
- *Amphibolis griffithii*;
- *Amphibolis griffithii* and *Posidonia coriacea*;
- *Amphibolis antarctica*;
- *Amphibolis griffithii, Amphibolis antarctica, Posidonia coriacea, Posidonia sinuosa* and *Posidonia australis*;
- unclassified seagrass;
- reef.

Single species meadows were defined when a single species had greater than 70% proportional representation. Two-species assemblages were defined when two species were equally represented (proportional representation of any one species could range between 30 and 70%). The mixed-species assemblage of five co-dominant seagrasses was defined in areas where the five species were present, but with generally 20% or less proportional representation.

The ground-truthing undertaken in the present study was augmented by previous ground-truth information (Marsh and Devaney, 1978; Wilson *et al.*, 1978; Environmental Resources of Australia [ERA], 1970, 1971a, b; Soros-Longworth and McKenzie, 1978; LeProvost, Dames and Moore, 1996; Stewart, 1998; Halpern Glick Maunsell, 1997; PPK, 1999). In addition to the above, the reef areas could often be distinguished from a visual examination of the aerial photography due to their dark tones, sharp edges and a halo of sand around the edge of the reef.

Mapping Seagrass Coverage from Purpose Flown Aerial Photographs

The flights to collect imagery for seagrass mapping of this area were purpose-flown in the late-summer/early-autumn of 1999 when conditions were optimal. These conditions include: maximum seagrass leaf cover; maximum water clarity; minimum industrial haze from the adjacent industrial zone; minimum turbidity from dredging, river outflow or industrial activities; minimum cloud cover; weak prevailing winds; and incident sun angle at 20 to 30°. Late-February to early-March was considered to be the most likely time to achieve these conditions. Several flights were made during this period in 1999 and colour photography collected at two altitudes. High altitude imagery was collected at 10,000 m (scale: 1:55,000) for ortho-rectification purposes. The high-altitude images provided numerous land-based geo-reference points for accurate rectification. The resulting rectified imagery was used as a rectification base for the low-altitude imagery that was obtained at an altitude of 3800 m, resulting in each image covering as area approximately 2.5 km^2.

Images were photogrammatically scanned into three colour bands (Red, Green and Blue) and rectified to UTM zone 50, Australian Map Grid, Spheroid WGS-84 (with ERMapper-6). Initially a resolution of 0.5 - 0.6 m was used. However, at this resolution feathering of sharp boundaries was evident suggesting that the resolution was too high. A pixel/raster cell size of 2.0 m was subsequently found to be the maximum useful working resolution. Artifacts such as feathering were generated during rectification at greater resolutions, and data was lost through generalisation at lower resolutions. Accordingly, all imagery was rectified to a final pixel size of 2.0 m. It was found that the red band of the colour images contained almost no information for marine benthic habitat, as red light was severely attenuated by its passage through the water column. The blue band showed the best contrast between seagrass beds and bare sand, the green band was similar to the blue, though with reduced contrast due to atmospheric losses. For this reason, the blue band was used as a single band grey-scale image. The rectified imagery was stored in ERMapper as 8-bit (256 grey-scales) raster files.

All processing of the rectified imagery was completed using the Geographic Resources Analysis Support System (GRASS) GIS software application. GRASS is raster-based GIS and the 2.0 m cell size was strictly maintained through all analysis to maintain the spatial integrity of the data. The Spann-Wilson Segmentation (Spann and Wilson, 1985) was used to map seagrass distribution. It combines a locally adaptive segmentation (local centroid) with pre-processing using multi-level quad-tree smoothing. The size of the moving histogram window and the number of quad-tree smoothing levels are controlled by parameters supplied by the operator. It was determined that this method was effective in extracting detailed maps of seagrass meadows from the grey-scale images. Rather than simply dividing the image into background (white), and foreground (black), the image is broken into several grey-scale levels.

It was noted that benthic features become difficult to resolve from aerial photographs at depths greater than 10 m and that the density of seagrass beds declines rapidly at these depths. Hence, it was decided to use the 10m isobath and the coastline to delineate the mapping boundaries (fig. 1.).

To enable consistent coverage mapping across the study area, a series of control rules previously developed for seagrass mapping in the area were used (Kendrick *et al.*, 2000). The vegetated areas and reef were distinguished from the unvegetated areas as they had a distinct photo-tone of medium to dark grey on the black and white imagery. The control rules, which were employed in the mapping project, were as follows. Vegetated patches that were isolated and less than 30m^2 were not mapped. Vegetated patches, that were greater than 30 m^2 and less than 100 m^2 were mapped as separate patches when the distance between one patch and another was greater than the diameter of the patch. Vegetated patches, that were greater than 30 m^2 and less than 100 m^2 were mapped as a single meadow when the distance between one patch and another was less than the diameter of the patch. The edges of these (patchy) meadows were outlined with a smoothed line with an accuracy of 10 m. Unvegetated areas within the meadow with an area greater than100 m^2 were mapped. Vegetated patches, greater than 100 m^2 were mapped and the edges of these areas were traced accurately. Unvegetated regions within these patches with areas greater than 100 m^2 were mapped. In considering the choice of digital mapping methods it was necessary to consider how these rules could be applied during processing.

Results and Discussion

Distribution of Seagrass Assemblages

Dominant seagrass assemblages differed between Success Bank and Owen Anchorage (fig. 1, Table 1). In 1999, the majority of the seagrasses in Cockburn Sound were in the Cockburn Sound West region and on the Southern Flats area within the Cockburn Sound South region. The seagrass meadows in Cockburn Sound were predominantly *Posidonia sinuosa* meadows with a small area on the Southern Flats dominated by *Posidonia australis.* It has previously been determined that *Posidonia sinuosa* is a species that prefers moderate- to low-levels of wave energy and has two types of rhizome growth, a colonising horizontal and a space filling vertical mode (Cambridge, 1999).

In the Owen Anchorage area, seagrass and shallow bare sand habitats are the most common habitats and account for over 90% of the mapping areas. The reef habitat was restricted to the Mewstone and Carnac mapping regions and to Fish Rocks in the Success Bank East mapping region (fig. 1, Table 1). The reef in the Mewstone and Carnac mapping regions is part of the Garden Island Ridge which is a limestone ridge of Pleistocene dune sands that trends in a north north-easterly direction and outcrops above sea level at several points, including Garden Island, Carnac Island and Mewstone and Straggler Rocks.

Success and Parmelia Banks contained different seagrass assemblages (fig. 1, Table 1). *Amphibolis griffithii*, *Posidonia coriacea* and the mixed-species assemblage of *Amphibolis griffithii* and *Posidonia coriacea* dominate success Bank. In the inshore area of Success Bank East (near Fremantle Harbour) species of *Posidonia sinuosa*, *Posidonia australis* and mixed multi-species assemblages (*Amphibolis griffithii, Amphibolis antarctica, Posidonia coriacea, Posidonia sinuosa* and *Posidonia australis)* occurred; whereas along the deepwater edges of Success Bank, *Posidonia sinuosa* species dominated. On Parmelia Bank, *Posidonia sinuosa*, *Posidonia australis* and multi-species meadows were dominant. The Owen Anchorage East region was dominated by *Posidonia sinuosa.*

Conclusions

The coverage of seagrasses can be mapped remotely using aerial photography, with purpose-flown imagery, computer automation of mapping and the use of raster-based GIS. However, different seagrass assemblages cannot be differentiated from aerial photographs. Here we demonstrate the use of towed video to generate information on coverage and distribution of seagrass species in a region where seagrass diversity is high (9 species). The data obtained from video was then used to define and map seagrass assemblages in Owen Anchorage and Cockburn Sound, Western Australia.

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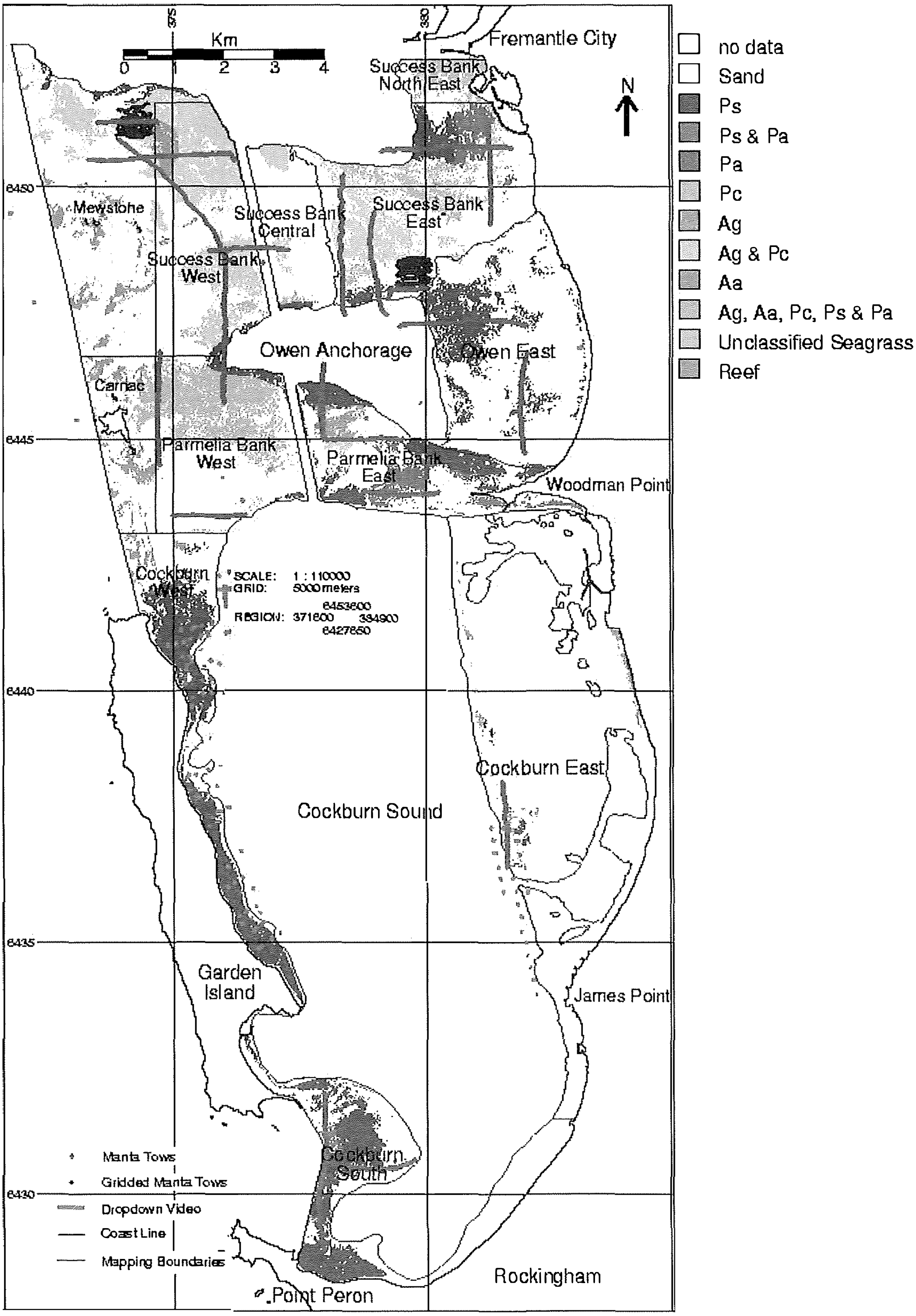

Figure 1 Benthic habitat map of Owen Anchorage and Cockburn Sound areas.

Table 1 Assemblage areas (in ha) determined from 1999 seagrass mapping.

MAPPING REGION	TOTAL AREA	Amphibolis antarctica	Amphibolis griffithii	Amphibolis griffithii and Posidonia coriacea	Ag, Aa, Pc, Ps and Pa *	Posidonia australis	Posidonia coriacea	Posidonia sinuosa	Posidonia sinuosa and Posidonia australis	Unclassified Seagrass	TOTAL SEAGRASS	Reef	Shallow bare sand	Dredged
OA East	1,250.7	0.0	0.0	0.0	0.0	0.0	1.2	244.7	0.0	0.0	245.9	0.0	1,004.8	0.0
SB North East	129.3	0.0	0.0	0.0	67.4	0.2	0.0	0.0	0.0	0.0	67.6	0.0	61.7	0.0
SB East	1,128.7	0.0	0.0	163.5	14.5	64.2	128.4	91.9	0.0	0.0	462.5	0.0	666.2	0.0
SB Central	386.3	0.0	0.1	35.7	0.0	0.0	5.5	7.2	0.0	0.0	48.5	0.0	161.5	176.3
SB West	904.1	0.0	40.9	364.9	0.0	0.0	15.0	18.1	0.0	0.0	438.9	0.1	465.1	0.0
MW	1,184.7	0.0	4.6	131.1	0.0	0.0	0.0	24.0	0.0	3.0	162.7	75.8	946.2	0.0
PB East	736.9	1.8	37.5	7.4	0.0	78.6	1.3	162.5	27.3	0.0	316.4	0.0	367.2	53.3
PB West	876.4	0.0	0.0	0.0	287.4	0.0	8.9	31.6	0.0	0.2	328.1	1.1	547.2	0.0
Carnac	371.4	0.0	0.0	0.0	28.0	0.0	0.0	0.0	0.0	6.2	34.2	60.6	276.6	0.0
OA TOTAL	6,968.5	1.8	83.1	702.6	397.3	143.0	160.3	580.0	27.3	9.4	2,104.8	137.6	4,496.5	229.6
CS East	2,138.7	0.0	0.0	0.0	0.0	0.0	0.0	13.4	0.0	0.0	13.4	25.3	2,100.0	0.0
CS South	817.9	0.0	0.0	0.0	0.0	11.0	0.0	278.8	2.2	0.0	292	0.0	525.9	0.0
CS West	710	0.0	0.0	0.0	0.0	0.0	0.0	355.7	0.0	0.0	355.7	20.6	333.7	0.0
CS TOTAL	3,666.6	0.0	0.0	0.0	0.0	11.0	0.0	647.9	2.2	0.0	661.1	45.9	2,959.6	0.0
ALL TOTAL	10,635.1	1.8	83.1	702.6	397.3	154.0	160.3	1,227.9	29.5	9.4	2,765.9	183.5	7,456.1	229.6

OW = Owen Anchorage; SB = Success Bank; MW = Mewstone; PB = Parmelia Bank; CS = Cockburn Sound.
**Amphibolis griffithii, Amphibolis antarctica, Posidonia coriacea, Posidonia sinuosa and Posidonia australis.*

Oblique or Vertical? - The Science of Biology Verses the Science of Measurement in Marine Video

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Introduction

Video has many applications in marine research, ranging from species identification to the ground-truthing of non-optical data. Biologists need a simple, inexpensive method for collecting qualitative data that will allow species identification. Those involved with the ecological mapping and characterisation of the sea floor, however, require a system with a consistent, stable and known geometry. There is an obvious discrepancy between the data needs for biological analysis, where a single, relatively inexpensive video camera can be used to take high angle obliques, and those of quantitative measurement, where two calibrated, vertically mounted cameras are needed.

Oblique Viewing

Qualitative video data used in biological research are generally captured from a single video camera with an oblique viewing angle. The oblique angle not only increases the ease of species identification, but also enables a wider viewing area to allow greater coverage. The CSIRO TACOS is an example of such a system. The TACOS has been described in detail elsewhere (Wadley and Barker, 1996). It uses a passive balance between a bottom weight and the platform's buoyancy to maintain a roughly constant altitude. It has both still and video forward looking oblique cameras. The system has been used to great effect in fisheries studies in the southeastern Australian waters.

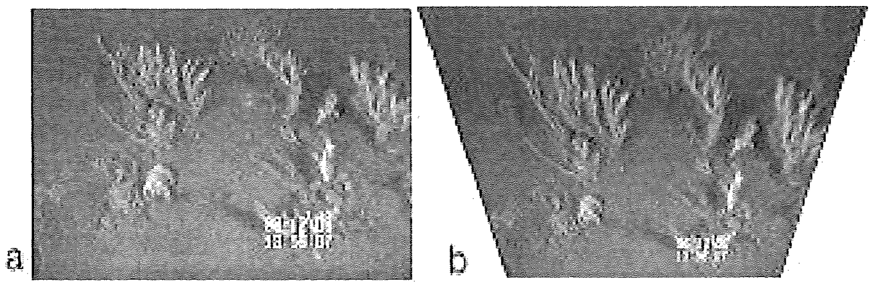


Figure 1 A TACOS frame. The original frame (a) shows prominent sponges with some in the foreground masking parts of those in the rear. The vertical rectification (b) does not look vertical because the three dimensional sponges have been mapped onto a two-dimensional sea floor. Foreground masking is still evident.

Oblique viewing, however, results in difficulties in image rectification and in the generation of spatially accurate mosaics. There are two major problems with mapping from single oblique cameras. The first is that objects in the foreground will mask objects behind them and the second is that objects above the nominal image plane will be mismapped when a rectification to a vertical mapping perspective is performed. This problem is shown in Figure 1. Here a TACOS frame has been rectified to a vertical perspective. However, the sponges in the foreground still mask those in the rear and the foreground sponges themselves have been mismapped onto the sea floor. The image still looks oblique.

Both of these problems stem from the fact that in order to perform a mapping projection, without the real depth information that a stereo camera system could give, you must assume that the image area is planar. This is normally not the case and it means that accurate vertical maps and mosaics can not be created. This is illustrated in Figure 2, which is a mosaic created from vertically rectified TACOS frames. Note the general lack of image continuity. In particular, note that the mismapped vertical sponges are cut off by subsequent mosaic frames.

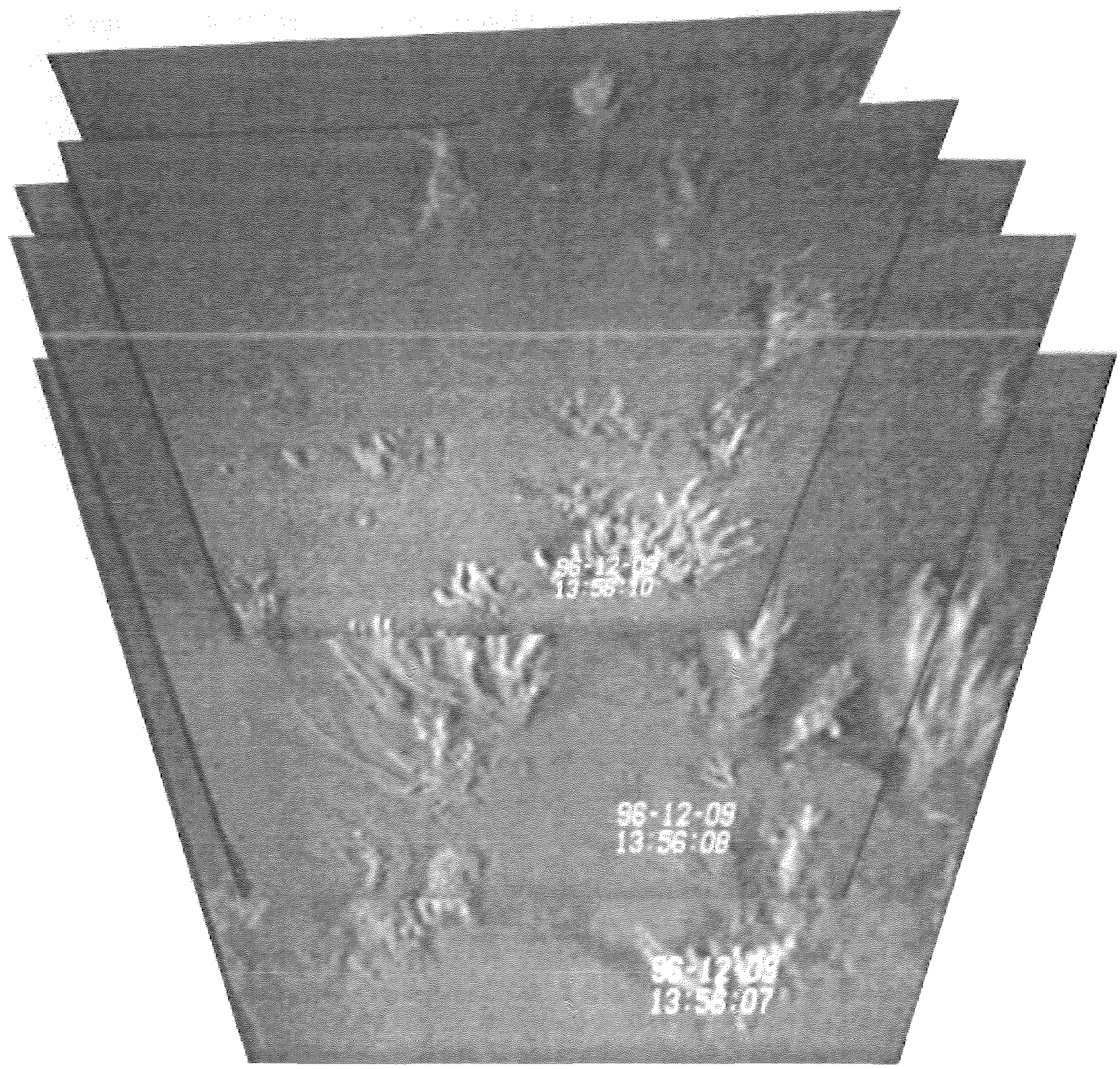


Figure 2 Mosaic constructed from vertically rectified TACOS frames. Note the cut off of mismapped high sponges by subsequent frames. Leading to a lack of overall image continuity.

As a result of these problems, the use of single camera, oblique image data in mapping or quantitative analysis is limited. The system geometry for data intended for mapping and quantitative spatial measurement is quite different to that suited to biological data. Two camera oblique systems will give stereo imagery from which height information can be calculated. This will remove the necessity for the planar assumption. However, it will not remove the problem of foreground masking.

Vertical viewing

Vertical viewing eliminates many of the problems associated with oblique systems. The image geometry is more constrained and mosaics and along track stereo pairs are easier to generate. This is particularly true in video systems where radial panoramic distortion is minimised but the narrow field of view. This allows more precise sea floor characterisation and mapping. However, single camera systems such as the drop camera system belonging to Marine and Fresh Water Research Institute (MAFRI) of Victoria or the *Korrong* still have difficulties in determining scale. Camera stability and the movement of the bottom vegetation in shallow water also cause problems.

The Geomatics Department at the University of Melbourne developed a semi-submersible vessel, named the *Korrong* designed to provide an experimental imagery platform for the marine environment. The most important component of the *Korrong* system is the retractable observation pod, which is lowered into position through a moon pool. When fully extended, the floor of the pod is one meter below the surface (fig. 3).

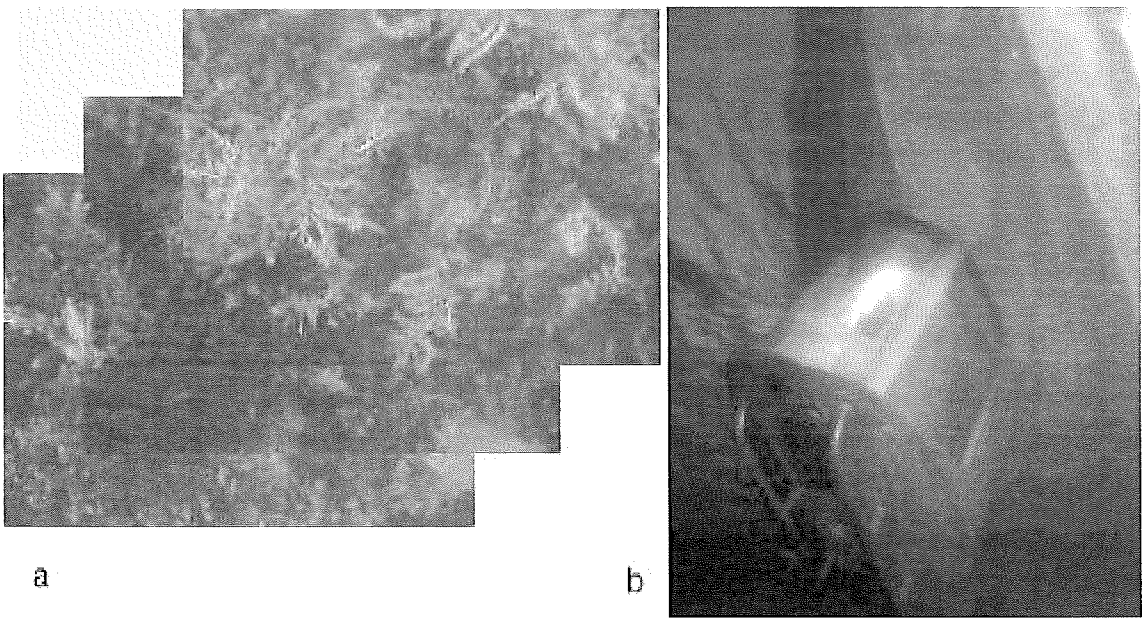


Figure 3 (a) Mosaic constructed from video transect data near Mt. Martha, Port Phillip Bay. (b) Image of the *Korrong* with the observation pod extended .

The observation pod is designed to carry an observer and is equipped with three view ports as well as four camera ports in the floor of the pod, each of which has a generic camera mount associated with it. The system is designed to be flexible enough to take any reasonable imaging system with only minimal modifications. The most common method of use of the *Korrong* is to take vertical video transects from the camera ports. Selected portions of these transects are then used to construct mosaics which are used in environmental mapping and to ground truth satellite or airborne imagery.

As part of a marine reserve survey, MAFRI captured video data along the Victorian coastline in 1995, with depths ranging from 7 to 87 metres. A drop video system was used to collect near-vertical video data. The system comprised a video camera mounted on a metal frame, a Global Positioning System (GPS) receiver for providing location data, a depth sounder, and a computer for data logging (Roob and Currie, 1996). The frame was lowered to the seafloor; once settled the camera was suspended at a known height above the seafloor, ensuring that the starting scale for each video sequence was known. The frame was then raised from the bottom and allowed to drift. A near-vertical camera angle was maintained in calm waters (Williams and Leach, 1999).

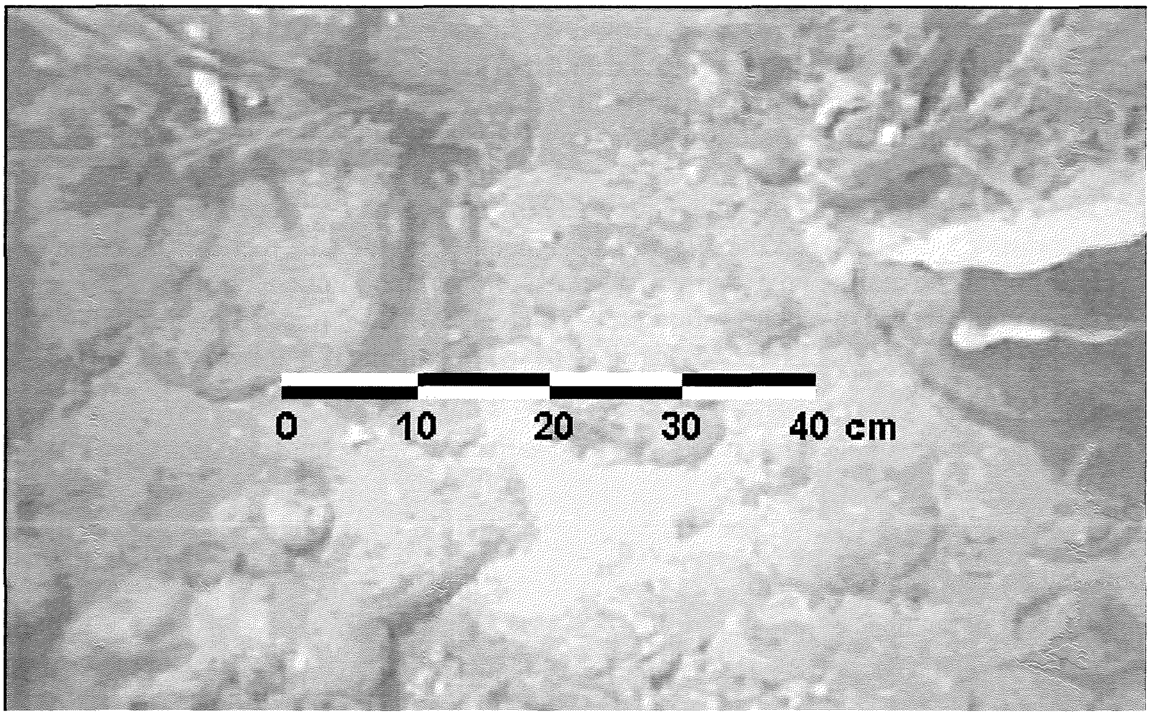


Figure 4 Initial frame from a MAFRI drop-video transect of Rams Head, Victoria.

The ground area covered by the starting image of each transect was 85×53 cm, as can be seen in figure 4. The starting scale is only accurate for flat terrain where the drop video frame settled vertically. For small study sites this data is extremely important as it enables enormous detail to be seen in an image. Information on species health and density can be gathered by viewing selected individual frames. These data can also be used to assist in substrate identification when not obscured by overlying species. Therefore, single video transects can be used quantitatively for planimetric measurements and species coverage studies, or qualitatively for species identification and for noting species distribution. Single frame imagery is valuable to projects involving phenomena that occur in small study sites, however its use in large area projects is limited. It is difficult to visualise large-area phenomena by viewing a video sequence, or from a sequence of still imagery. It is not possible to ground truth or analyse a large area of acoustic data using a single video frame, therefore mosaicing of video frames can be used to increase the value of the data as it provides a view of the area as a whole (see figure 5).

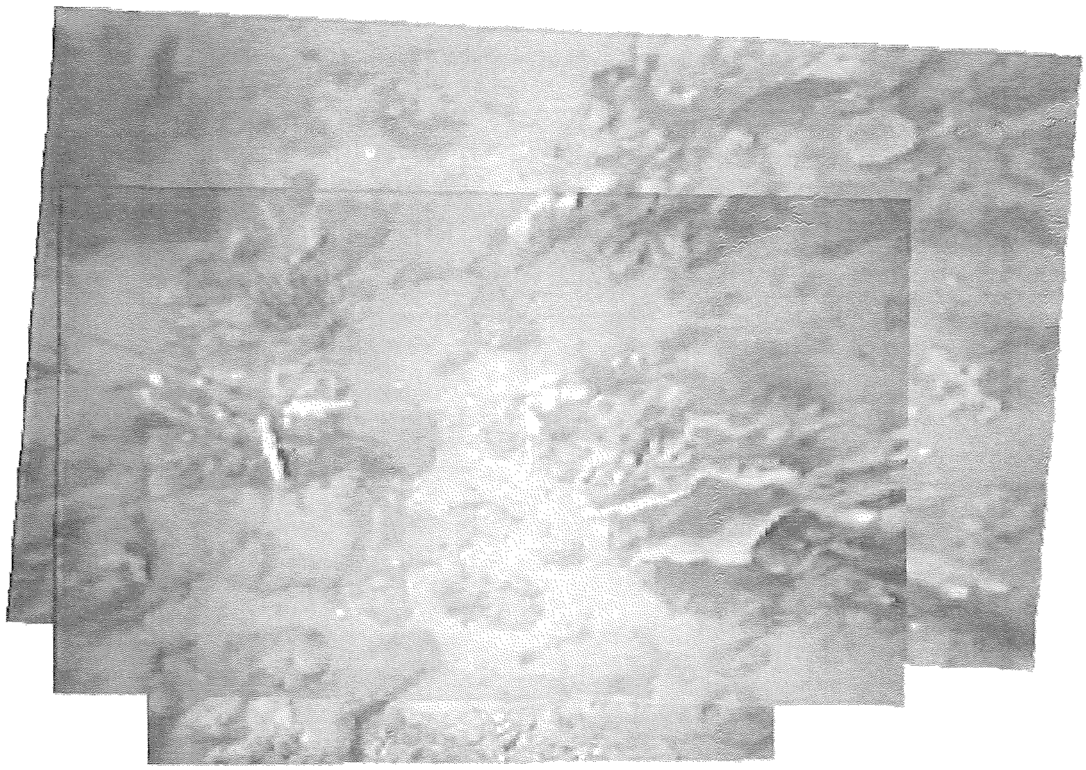


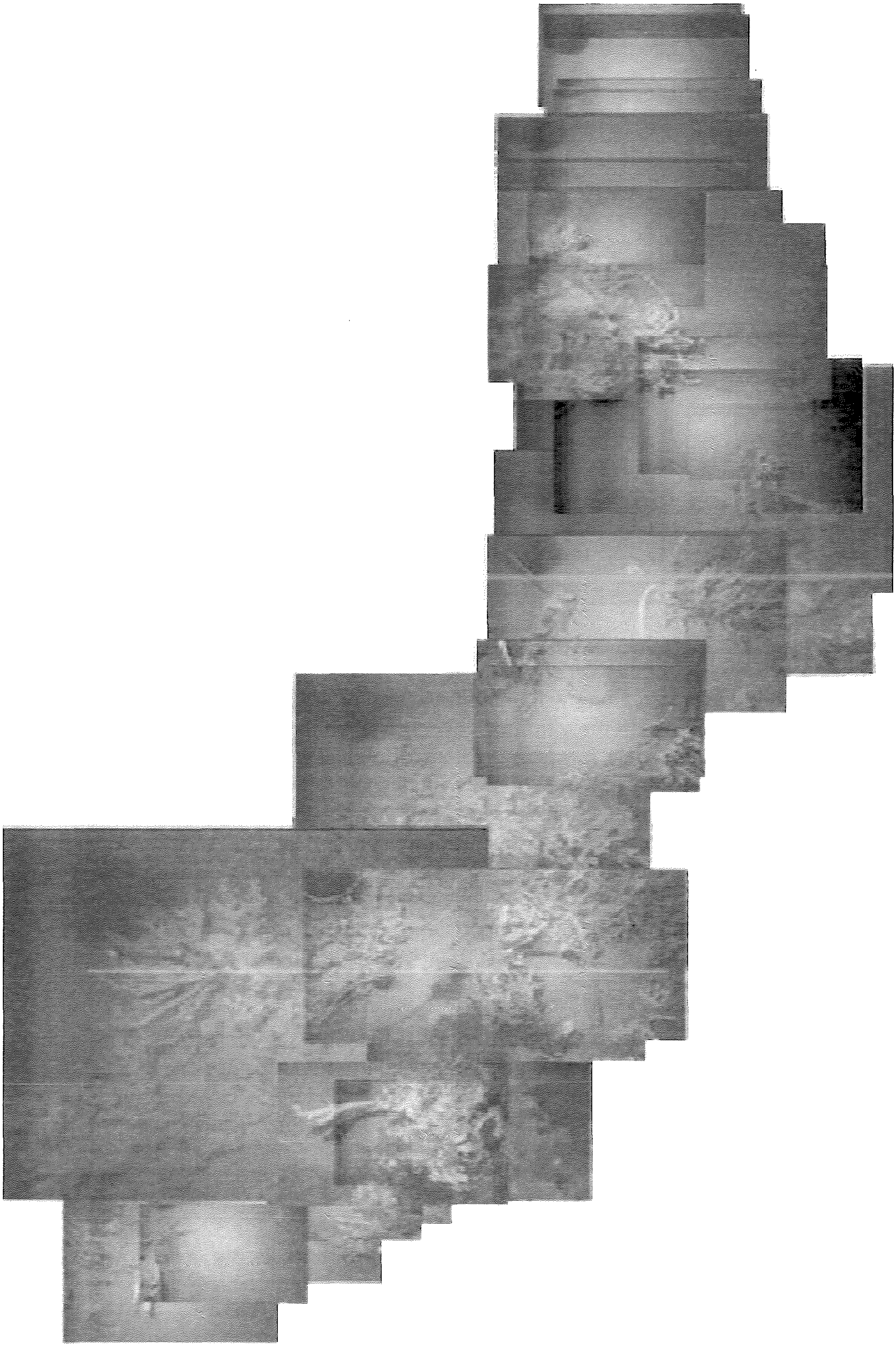
Figure 5 Small mosaic constructed from the Rams Head video transect.

Poor visibility in water, along with the limited size of video CCD sensors, results in video data having an extremely limited coverage. Even in clear coastal waters, this coverage is no more than a few metres for an individual frame. The coverage size of a single video frame results in an extremely small snapshot of the benthic habitat, meaning the study is limited to localised, small-site phenomena. Single frames can be successfully used as a means of ground truthing non-optical data, such as side-scan sonar, however the imagery scale difference is such that extended video views would provide greater information. A video sequence can be used to ground truth acoustic data, however the overlaying and comparison of imagery simplifies the task. Therefore, mosaics are used to successfully increase the coverage of video frame grabs.

Note that the vertical imagery mosaics do not suffer from the same limitations as the oblique imagery mosaics - there is good image continuity. Mosaics can be used to significantly extend the effective swath of sea floor imagery. A large mosaic constructed from MAFRI drop-video data off Cape Howe in Victoria is shown in figure 6.

NEXT PAGE:

Figure 6 Large Mosaic constructed from MAFRI Drop Video Frames. Surface swell has altered the camera altitude and effected the image scale and lighting.



Stereo Systems

The optimal collection system for quantitative data is a two-camera system producing instantaneous stereo video. Such a system should allow accurate three-dimensional measurements to be extracted and proper spatial registration for mapping. One such system currently being researched is SWIMS: a surface mounted system for shallow water mapping. The system is based around a sea kayak, which provides an ideal platform for shallow water work (fig. 7). The early data from this system are still being analysed but simple depths have already been extracted and mosaics and depth profiles are expected in the near future.

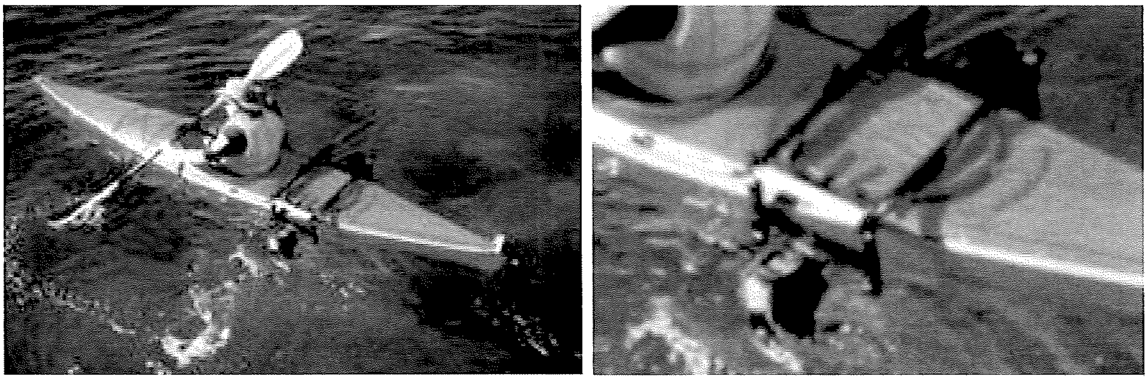


Figure 7 SWIMS - a stereo imaging system for mapping in shallow water.

Conclusion

This research highlights the differences between applications in data requirements. In mapping the characteristics of the sea floor, one of the major limitations of video data is its small area cover. This makes it difficult to determine spatial relationships and interactions. Scaled mosaics are one way to overcome this limitation and provide a greater area coverage. However, accurate mosaics are almost impossible to create from single camera oblique imagery. Creating visually correct mosaics from single camera vertical imagery is straightforward, if time consuming, but reliable, accurate scale can only be provided by a stereo system.

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Assessment of Barotrauma in Deep Water Snappers using Video Techniques

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Introduction

High priorities in stock assessment research include the need to track fish movements and to validate growth estimates. Tagging is a method commonly used for collecting such data. Although tagging is routinely undertaken for shallow water species, there has been a limited amount of work done on deeper water species due to the problem of barotrauma. To overcome this problem some researchers have investigated the use of breakaway tags (Grimes *et al.*, 1983, Horn, 1989). While this technique provides information on fish movement, it does not provide information on the species type until the tags are recovered. Other workers have tagged fish underwater (Parrish and Moffit, 1993), but this is a very expensive, labour-intensive exercise, and only a small number of fish can be tagged at a time. Therefore further work needs to be undertaken to develop techniques to minimise the effects of barotrauma, which would enable an effective large-scale tagging project to be established. From examination of the literature it appears that most studies examining barotrauma in fish have used hook and line capture method. The focus of this study was to examine whether capture method affected the incidence and severity of barotrauma. Video techniques were used to observe recovery rates when fish were sent back to original capture depth.

Material and Methods

For this experiment two different capture methods were used: droplines (vertical longlines), which is the commercial method for capturing snappers (fig. 1); and Western Australian "D style" traps which were lined with knotless netting to reduce scale loss (fig. 2). Fishing took place in an area 90 miles west of Darwin (12°30, 128°52), over a three day period from 6th to 8th of May 1998. The depth range for this experiment was 80-90 metres.

Only one capture method was used at a time and fish were treated and released before fishing continued with the next method. All fish were landed on a foam mattress to reduce trauma, then had their gas bladders deflated using a 16 gauge sterile disposable needle inserted behind the pectoral fin, level with fourth dorsal spine. The fish were gently squeezed until their gas bladders were deflated. Fish were measured to the nearest mm (fork length), tagged and placed in a swim tank (measuring 1 m x 2.5 m x 0.5 m) which was aerated with oxygen. This was used as a holding pen while waiting for a sufficient quantity of fish to be caught. The length of time spent in the swim tank ranged from 20-60 minutes.

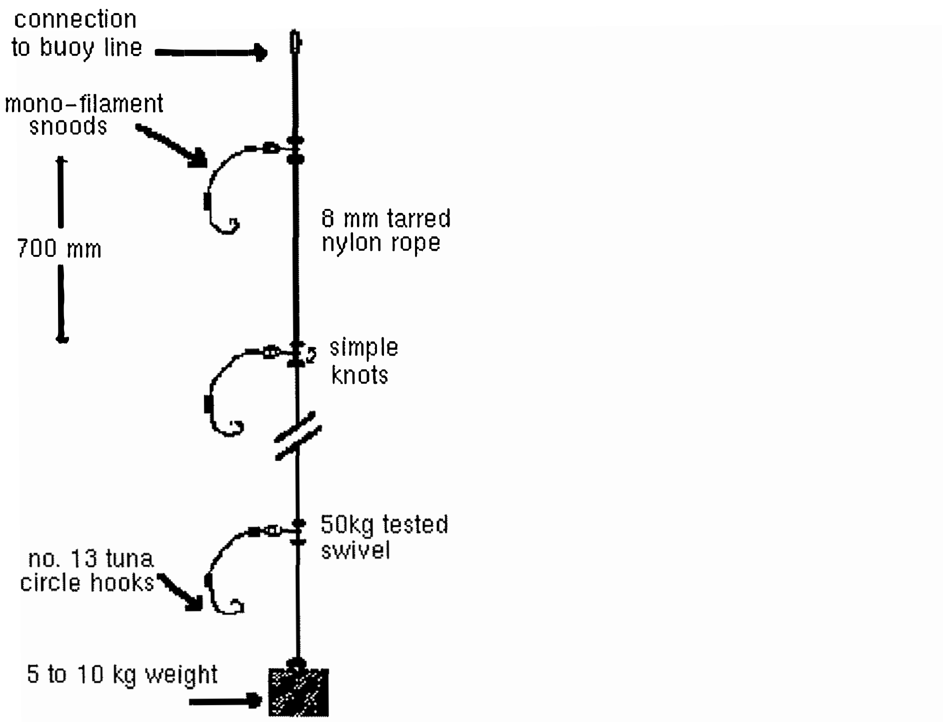

Figure 1 Diagram showing lower section of dropline rig.

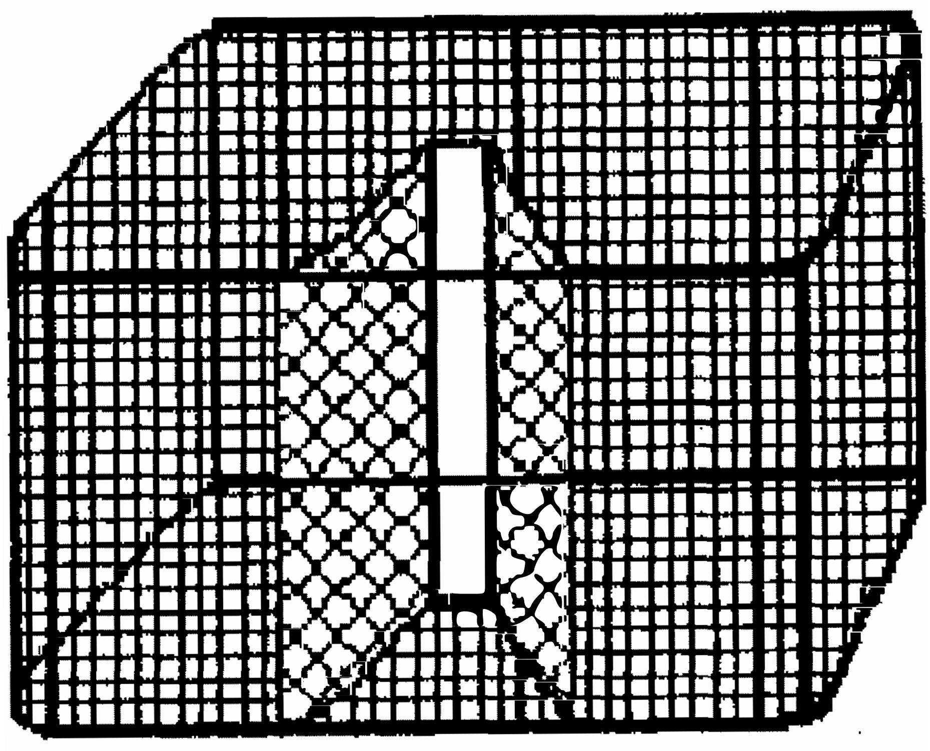

Figure 2 Western Australian style trap used in this experiment

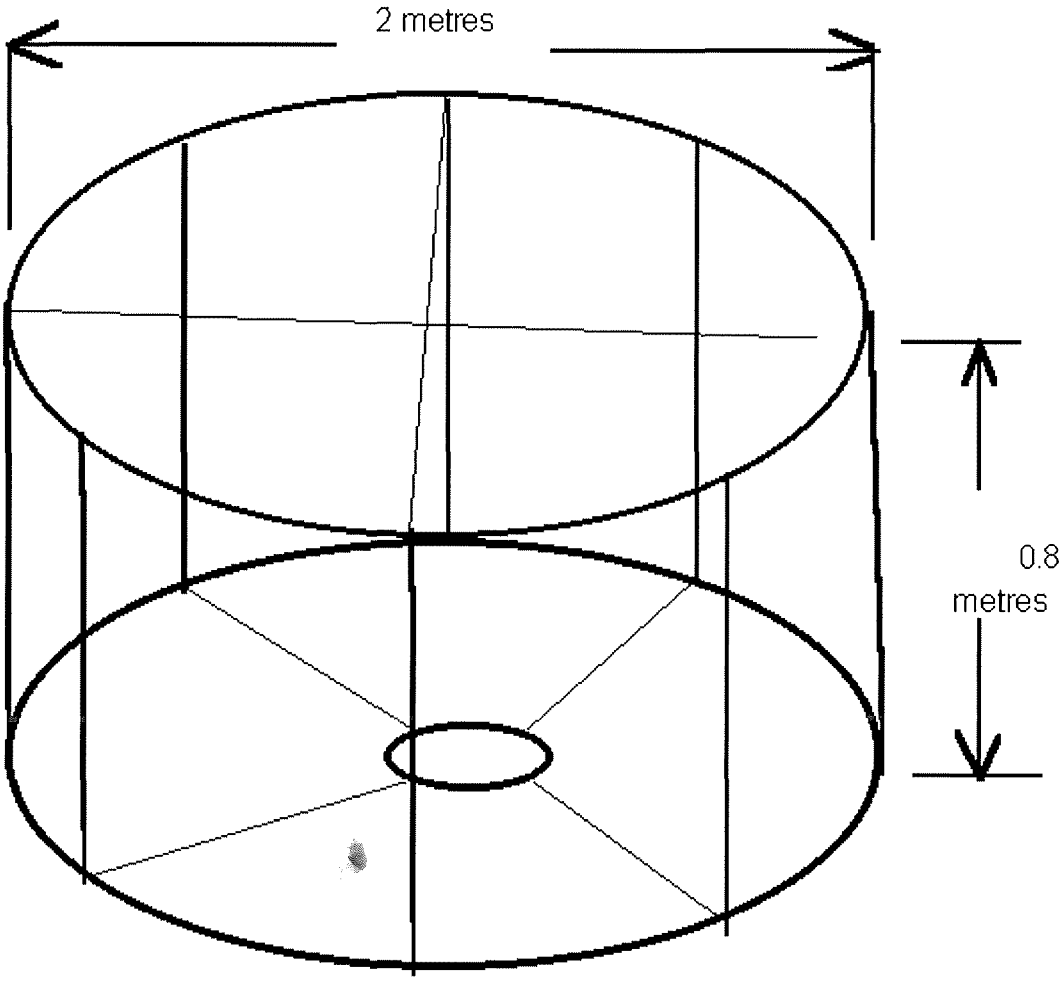

Figure 3 Diagram of release cage. The floor of the cage was held in place with a drawstring attached to a thin cord that was designed to break when hauled, thereby allowing the bottom to fall open and fish to escape.

Fish were then placed in a round release cage measuring 2 m in diameter, by 0.8 m in height. Panels were made of standard 51 mm, 30-ply prawn netting (fig. 3). The bottom panel was held in place with a drawstring that was attached to a thin cord that was designed to break when hauled. This allowed the bottom of the cage to fall open and allow the tagged fish to escape. The maximum number of fish in a release cage at any one time was 20, but in most cases fish numbers were kept between 10-15. Only fish in good condition were placed in the release cages. During the three day study there were ten release cage deployments of trap captured fish and nine release cage deployments of dropline captured fish.

Video equipment and lights were attached inside the release cages. Fish were filmed underwater for 90 minutes to observe their recovery rates and compare gear effectiveness.

Results

Video footage of observations (figs 4, 5) was scored as follows: percentage dead, percentage laboured swimming, percentage normal swimming, percentage not seen in footage (Table 1). These categories refer to the status of the fish at the end of the filming period, e.g. if a fish which showed laboured swimming during the majority of the viewing period, died at the end of filming, it would be classified in the dead category. Only footage which showed good visibility during the entire filming period was used.

Table 1. Comparison of gear effectiveness as scored from underwater video footage

GEAR	TOTAL # FISH	% DEAD	% LABOURED SWIMMING	% NORMAL SWIMMING	% NOT SEEN
Dropline	12	42		25	35
	8	62	13	13	13
	9	100		0	
	7	29		43	29
Trap	13	8	8	15	69
	2	100		0	
	5	0		100	
	3	0		100	
	7	29		43	29

Results from Table 1 indicate that trap-captured fish showed fewer effects of barotrauma than fish caught on dropline ($\chi^2 = 9.26$, $P<0.01$). This also reflected general observations when fish were initially landed onboard, i.e. dropline fish more frequently showed physical signs of severe barotrauma (such as everted stomachs) than trap fish, which were far livelier when landed.

Discussion and Conclusions

The results of this study indicate that capture method has an effect on barotrauma in the snapper species studied. This is possibly due to the amount of stress fish experience when caught on lines as they struggle to free themselves. Underwater video footage taken during normal fishing operations using droplines, shows fish struggling in an effort to shake the hooks free from their mouths (fig. 6). It is possible that this additional stress may make them more vulnerable to the effects of barotrauma (fig. 7). It may also explain the general observation that there is a difference in survival rate between species. Red emperor (*Lutjanus sebae)* seem less prone to external barotrauma problems, such as *popeye* and had a less bloated appearance when landed on board, whereas saddletail snapper (*Lutjanus malabaricus*) were difficult to deflate and commonly had bulging eyes. Red snapper (*Lutjanus erythropterus*) and goldband snapper (*Pristipomoides multidens*) were in between these two extremes. One goldband snapper was kept for 20 hours, whereas red emperor from this experiment were kept for several months in aquaculture tanks.

Although this study measured the effects of barotrauma only in terms of visible external signs, the results show that the potential exists for further investigation in this area. Future studies would investigate whether it is necessary to pierce the swim bladder, or whether returning fish to recapture depth in a cage might be just as effective. Further experiments would also determine whether some commercially important snapper species were more predisposed to barotrauma than others. This is an important consideration if the development of a live fish market is envisaged.

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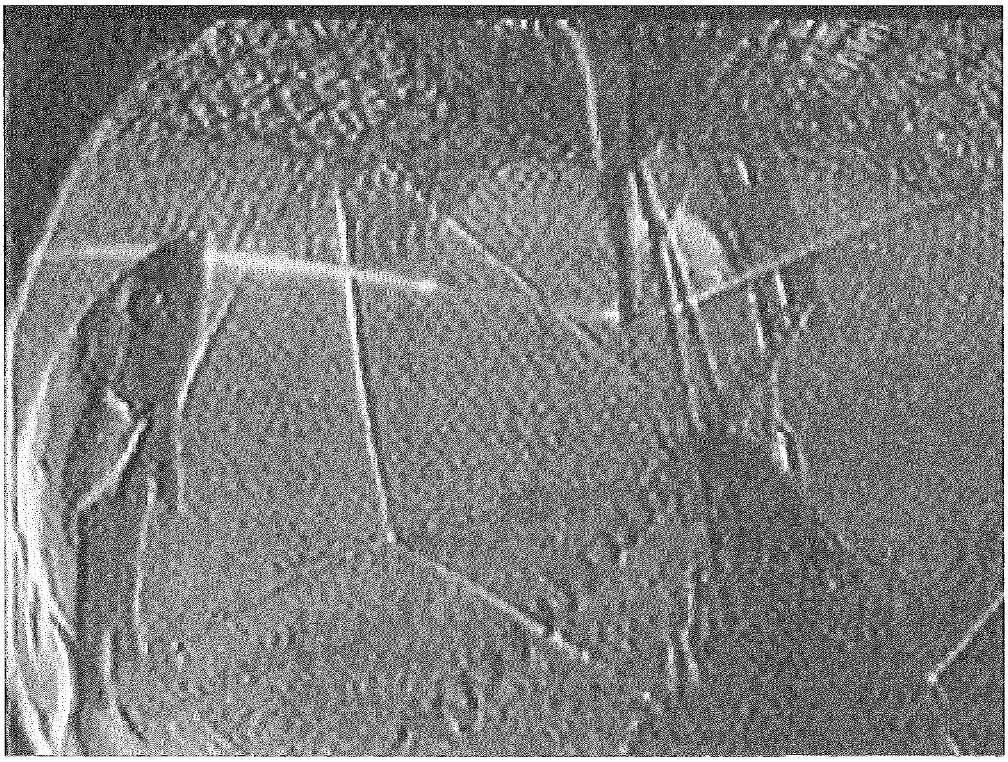

Figure 4 Goldband snapper swimming in laboured manner after being returned to original capture depth.

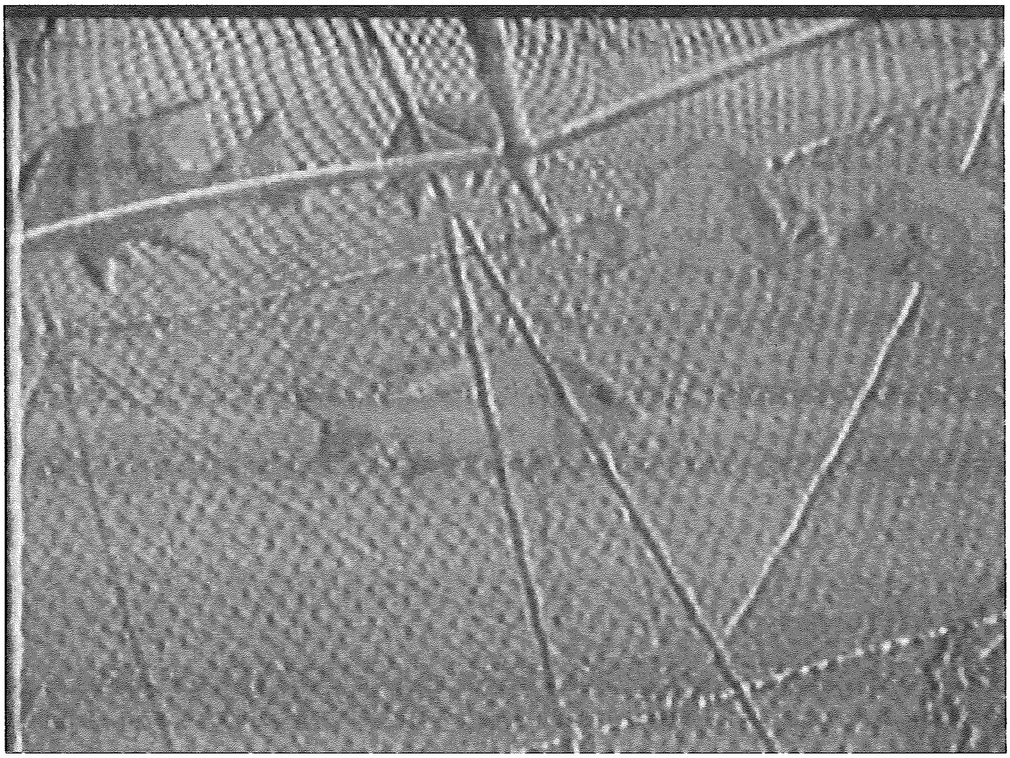

Figure 5 Fish displaying "normal" swimming behavior

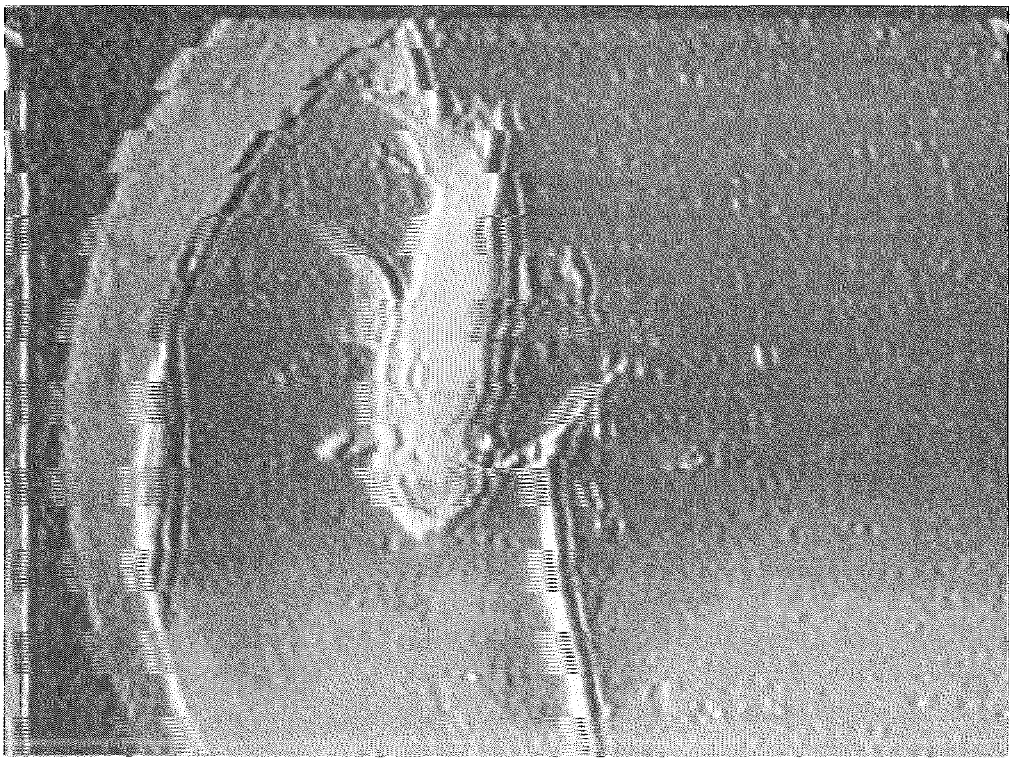

Figure 6 Dropline captured fish struggles in an effort to free itself.

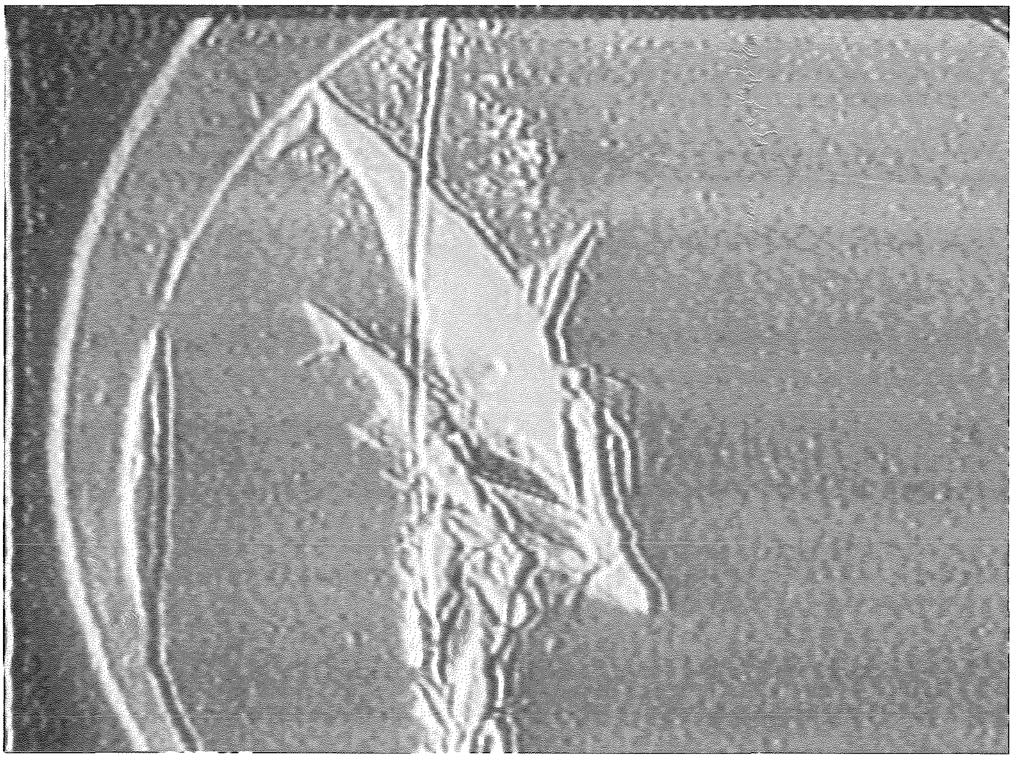

Figure 7 Goldband snapper showing external signs of barotrauma while being hauled to the surface.

Quantitative Data From Underwater Video Sources (Tow-Sled, Drop-Camera, ROV) for Rapid Characterisation/Mapping of Shelf Seabed Habitats and for Measuring the Dynamics of Large Sessile Seabed Fauna

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Introduction

Research on the distribution and abundance of shelf seabed habitats, and sampling of their biodiversity, is providing basic scientific understanding of the meso-scale physical factors driving seabed habitat patterns and biodiversity. This understanding will provide a valuable basis for surrogate mapping of seabed biodiversity. The maps can then be used for selecting representative areas for conservation planning, and for evaluating scenarios for sustainable management of multiple-use zones.

The ecology and dynamics of assemblages of structural megafauna on shelf seabeds are virtually unknown, despite their importance as fisheries habitats and their contribution to biodiversity of the marine environment (Pitcher, 1997). Consequently, there is great potential for new knowledge to be gained; and scientific understanding will be significantly advanced by fundamental studies of the dynamics of these megafauna assemblages. Sessile megabenthos assemblages are vulnerable to anthropogenic impacts (Poiner *et al.*, 1998), and research on these impacts is providing basic scientific information on resilience and recovery that is also valuable for conservation planning and multiple-use management.

The increasing pressure to conduct research more efficiently (time and costs) means that the need for more effective technology to support marine research also increases. While there is satellite-based remote sensing for terrestrial habitats, this is severely limited for seabed habitats. Research on acoustic remote sensing technology (Pitcher *et al.*, 1999a) and development of remote-vehicle/remote-video capability (Pitcher *et al.*, 1999b) is enhancing our ability to map and study the dynamics of, and impacts on, seabed habitats. In addition, these techniques make new research initiatives possible in deeper, topographically complex habitats, where pre-existing technology is unsuitable (i.e. beyond SCUBA diving range).

Underwater video development objectives

Our objective is to develop and implement new technologies that are useful for conducting cost-effective research on tropical shelf seabed ecosystems and resources; research which includes broad-scale (cross-sectional) mapping and fine-scale (longitudinal) studies. To meet this objective, we have a pragmatic underwater technology project that customises, develops and maintains systems suitable for research applications. These include a remotely operated vehicle (ROV, figs 1, 4); towed sled and drop-camera observation vehicles (TOV's, figs 2,3); Side Scan Sonar; u/w tracking/logging/video recording systems; and laboratory semi-automated video analysis and database systems.

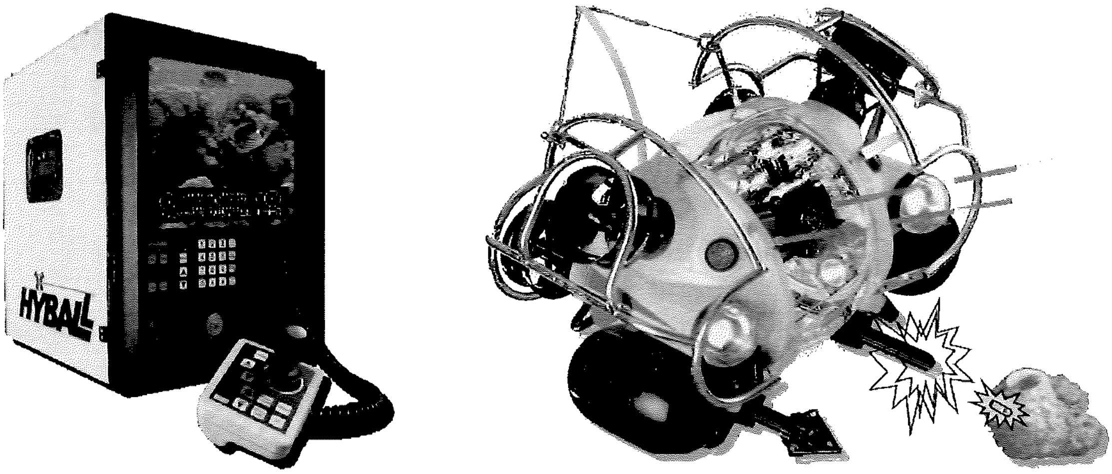

Figure 1 Offshore Hyball observation ROV system, showing vehicle fitted with parallel lasers and tag-interrogator system.

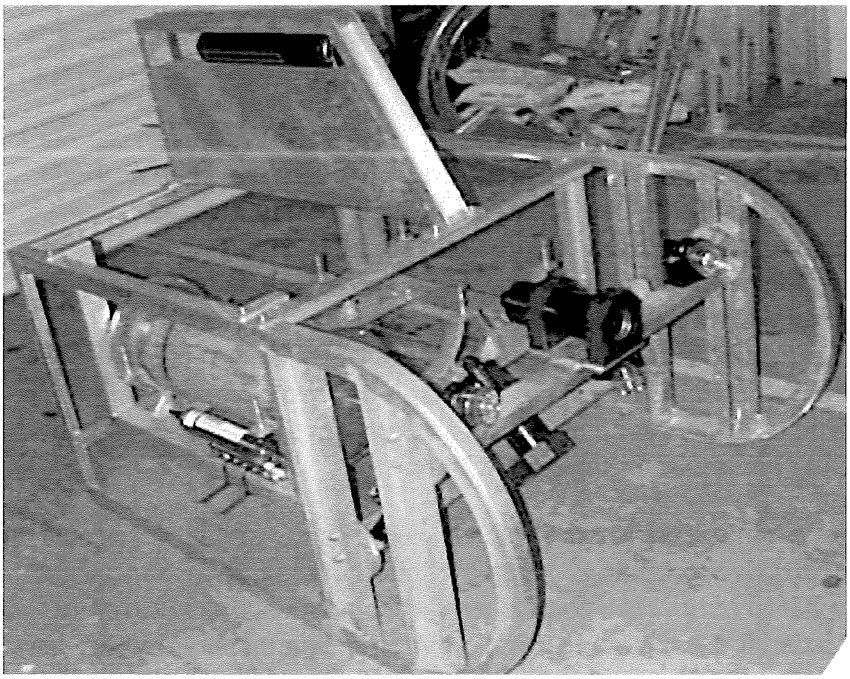

Figure 2 Drop-camera TOV system, showing platform fitted with video cameras, lights, computer/power-supply housing, CTD, side-scan sonar, and altimeter.

Seabed Mapping Approach

For mapping of seabed habitats and biodiversity, a suite of simultaneous rapid deployment methods is used: video camera transects with acoustics, side-scan sonar, benthic dredge, sediment samplers, and other devices (e.g. trawls) as appropriate (fig. 3). Typically, sites are located on a <5 to >10 km grid, depending on the complexity of habitat patterns. The position of the remote camera is tracked by an acoustic tracking system and acquired data are logged to a computer database and key information is overlaid onto the video image. Semi-quantitative physical and biological characterisation of the video are entered in real time (1 Hz). On-deck processing provides dredge catch data, megafauna biomass and qualitative sediment classification. These data are immediately available for applications (e.g. GIS, for presentation as maps). The video and biotic samples are retained, providing capacity for detailed enumeration and mensuration as required. The system for detailed post-processing of towed camera video is described in Section "Video tape analysis system" below.

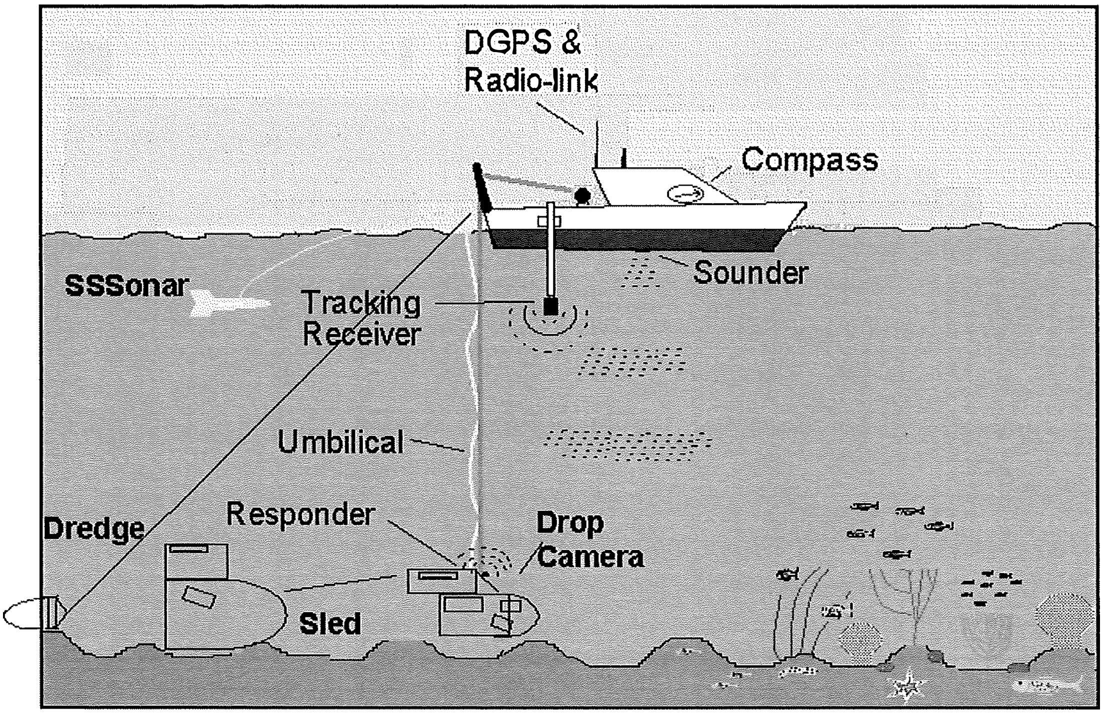

Figure 3 Schematic of TOV deployment methods, showing drop camera on winch cable with separate umbilical attached. When the sled is used, the drop-camera position is replaced with a heavy lead-weight and the sled trails on a 30 m cable.

Seabed Habitat Dynamics Approach

For studies of the dynamics of seabed fauna, other devices such as ROV, SSBA (where shallow) may be used to deploy 2-laser, scaled video systems to provide more detailed information from particular sites or where repeated visits are required to sites or to individual sessile organisms (fig. 4). Positioning and other acquired data are logged as described in Section "Video/data acquisition system" below. Individual organisms may be tagged with RF-transponders and tag-ID's automatically link to a database of previous images. Fauna at sites are carefully observed, mapped, identified and measured for growth, condition and mortality. Videotapes are post-analysed with a semi-automated image measurement system as described in Section "Video tape analysis system" below.

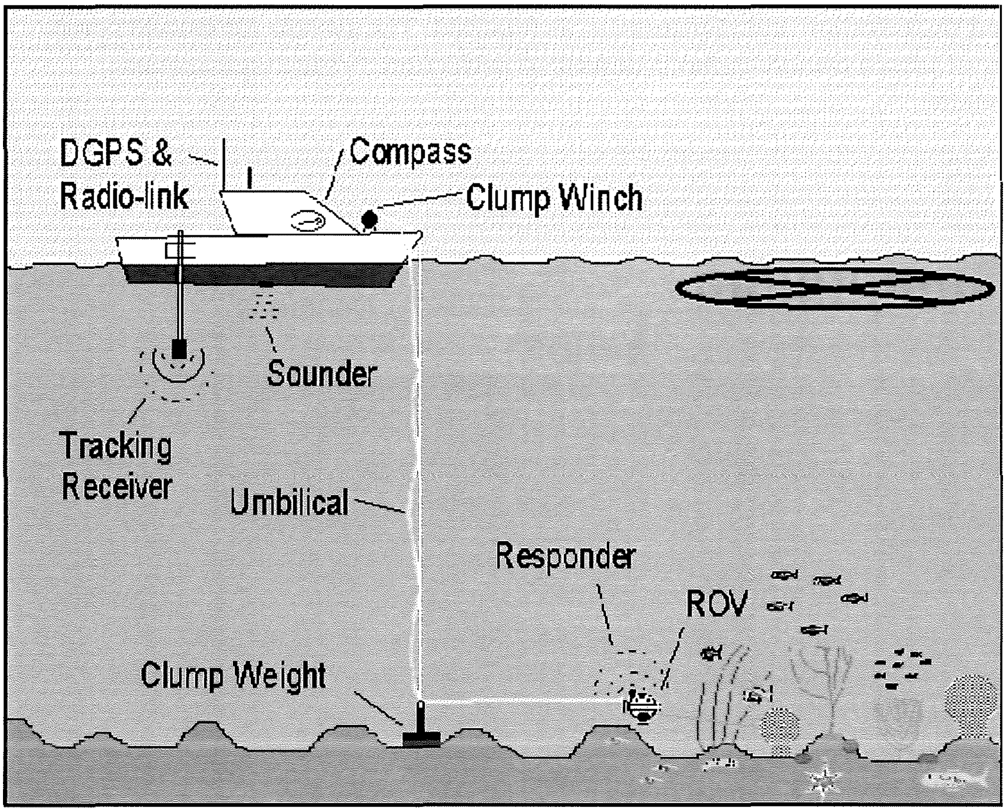

Figure 4 Schematic of ROV deployment method, showing anchoring a 20 m vessel over the study sites on a high-stretch nylon rope, with umbilical attached to minimise effects of currents. It is simple, repeatable and effective in moderate conditions for wind and currents.

Current/recent video-based applications

ROV system

- Effects of prawn trawling: measure in situ changes in the benthic communities of experimentally trawled sites compared with untrawled control sites. 1993-1996 (Poiner *et al.*, 1998).

- Recovery after trawling: non-destructively measuring the recovery of fauna in patches of benthic habitat after cessation of experimental trawling. 1996-2002 (Pitcher *et al.*, 2000).

- Megabenthos population dynamics: measure recruitment, growth and mortality of structurally dominant sessile epibenthic organisms (tagged individuals) to determine the population dynamics of benthos important for fisheries habitat and maintenance of biodiversity of the environment. 1997-2000 (Pitcher *et al.*, 1999b).

Sled/Drop-camera system

- Effects of prawn trawling: describe and map seabed habitat in the FN GBR (area ~10,000 km^2); surveys to search for experimental sites; measure in situ changes in the benthic communities of experimentally trawled plots and tracks compared with untrawled control plots and tracks. 1993-1996 (Poiner *et al.*, 1998).

- Recovery after trawling: non-destructively measuring the recovery of benthic fauna along experimentally trawled tracks. 1996-2002 (Pitcher *et al.*, 2000).

- Several 'rapid' seabed habitat surveys in Torres Strait, each ~10,000 km², in the vicinity of possible pipeline routes and landfalls, to produce maps of physical and biological seabed habitat. 1996-1997 (Skewes *et al.*, 1996, Long *et al.*, 1997).

- Survey of Timor MOU Box shoals (to 50 m) measure distribution and abundance of sedentary marine living resources (and their habitats) of the shoals in the Timor Box to develop appropriate management plans for the sustainable harvesting of the biological resources of the area. 1998 (Skewes *et al.*, 1999).

- Inventory and mapping of GBR inter-reefal seabed biodiversity (with AIMS, QDPI, QM) to stratify inter-reefal areas of GBR based on bathymetry, sediments and forcing factors, eg. current stress. Conduct rapid representative sampling of physical and biological habitat and species composition/biodiversity, cross-shelf and latitudinally using remote-video, trawl, dredge, and acoustics. Produce maps of the distribution and abundance of biotic assemblages, based on spatial modelling of physical and biological data. 2000-2006.

Technical Details of current video/data systems

Video/data acquisition system:

Video, position and sonar data from TOV's and ROV's are acquired with the same computer logging system (figs 3-6). An acoustic tracking system, the ORE LXT, with an accuracy of ± 1 m, was used to locate the position of the video sled or ROV (Hydrovision Offshore Hyball) relative to the vessel's position. The ORE LXT incorporates a transceiver hydrophone mounted under the vessel and a multibeacon model 4330A mounted on the video sled or ROV. A DGPS (Differential Global Positioning System, Trimble) is used to locate the position of the vessel. These, in conjunction with the ship's gyro compass heading allows the position of the tracked remote camera to be calculated in real time and displayed on a navigation plotter and overlaid on the video recording. Waypoint positions of sites, individual benthic fauna, other objects of interest can be displayed in the navigation plotter window from data in an MS Access database.

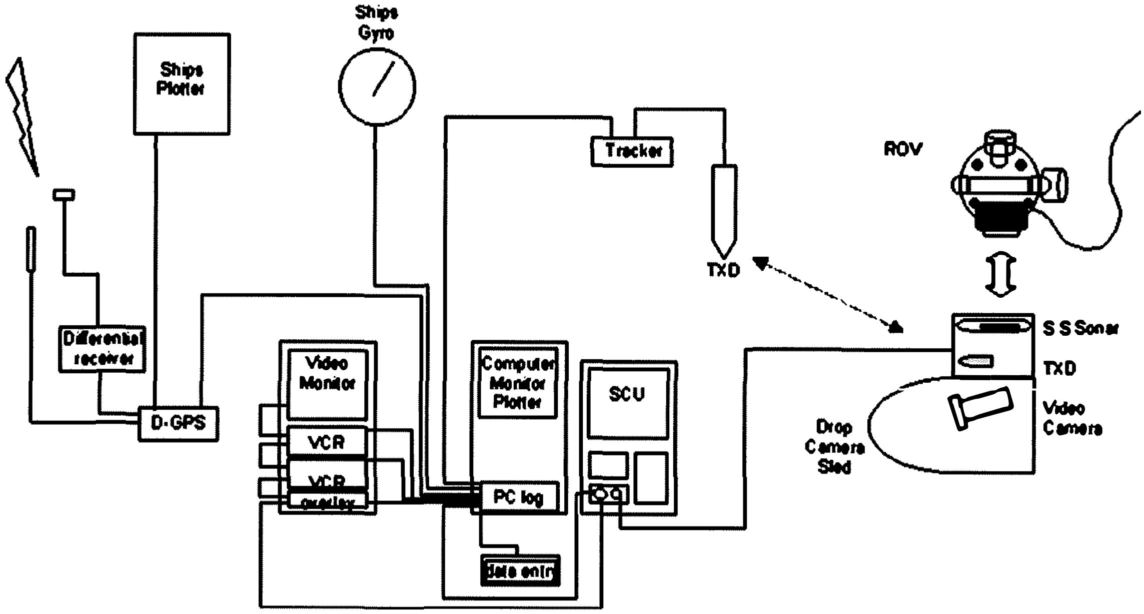

Figure 5 System diagram showing integration of components necessary for automated tracking of the ROV and synchronous logging of position, tracking, tag numbers and video data, to facilitate post-analysis and measurement of sessile benthic fauna.

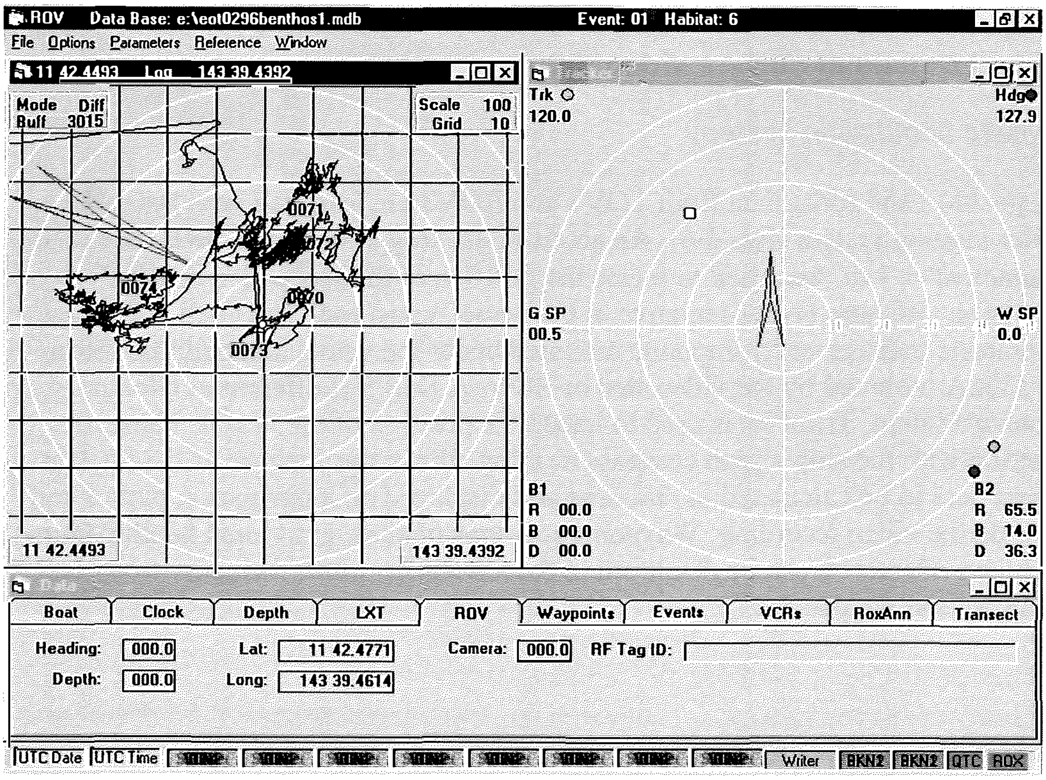

Figure 6 User interface of the custom acquisition, tracking and logging software, showing vessel-relative ROV tracker (right window) and ROV navigation plotter (left window) with waypoints (eg. 0071 to 0074), ROV track (irregular black line), vessel position (arrowhead), ROV position (circle near 0073). The lower window shows data acquired and status.

The GPS differential corrections are transmitted to the vessel's DGPS receiver from a reference base station set-up at an appropriate location. The differential base station comprised a Trimble differential-GPS reference station, transmitting SC104 DGPS correction data via VHF radios (Midland) and packet modems (Kantronics KPC3); a mirror-image set-up on the vessel received and processed the differential corrections giving average vessel positioning precision of <1 m CEP.

Both the TOV and ROV systems use Panasonic colour video cameras with 3.5 mm lens mounted in water proof housings. The composite video image is transmitted to the vessel through an umbilical cable. A data encoder (C-Systems "Screen Writer") continuously overlays the UTC time/date (from the GPS and positional data on the video images) into two computer-controlled SVHS video recorders (Panasonic AG5700 VCR's) and then to high-resolution video monitors.

Sonar images (Imagenex 588 Imaging Sonar system) can be acquired from both remote video devices. During TOV transects, a continuous side-scan sonar image (up to 100 m each side) is recorded and logged with the sled data. With the ROV, 360° scanning sonar images of the seabed features can be recorded.

The acquired data (GPS, acoustic tracker, gyro heading, sounder depth, and VCR time-code) are logged into an MS Access database table by a customised tracking-navigating-logging software application (fig. 6) running on a Windows NT4 Pentium PC. The data recorded consists of data from: GPS (UTC date, time, latitude, longitude, speed, track), sounder (depth), gyro (heading), LXT (acoustic target bearing, slant-range, depression angle), VCR's (tape frame positions, time-code), and operator (seabed habitat code).

To facilitate the measurement of seabed objects, two diode lasers (Laserex 5 mW) are mounted either side of the video camera in the ROV (fig. 1). The lasers provide two parallel beams that project onto objects as two points 100 mm apart, for scaling and ranging. It is a requirement that the ROV be positioned perpendicular to the axes of measurement. The lasers are checked for accuracy in water and confirmed to be 100 mm apart at distances ranging from 0--4 m.

A tagging system can also be used on the ROV (fig. 1), eg. for individual based studies of sessile seabed fauna. The tags used are radio-frequency transponder tags in 23x4mm glass capsule form (Texas Instruments RI-TRP-RRHP), that are read automatically by an induction transceiver (Texas Instruments TIRIS Series 2000 module) mounted in an underwater housing on the ROV. The ROV telemetry link also allows tag-number data to be automatically acquired in real time, displayed, logged to database along with corresponding position information, etc, and captured image file names. The positions of tagged objects are shown as waypoints on the navigation system's plotter window to facilitate their relocation (fig. 6). When a tagged object is detected, previous images of that subject are displayed for confirmation and to enable the same image orientation and perspective to be re-captured.

Video tape analysis system

The video tapes are analysed with a semi-automated image measurement system comprising a computer controlled SVHS video recorder (Panasonic AG5700) connected to a monitor and a Pentium computer running Windows NT4, a Flashpoint video capture card and Optimus 6.5 video analysis package. The control software is a custom written application that accepts operator inputs to control the VCR frame position; maintains DDE links between the original tracking database and the video frames; pauses the VCR at selected images (when the laser points are visible on the object); and passes control and instructions to the Optimus software. The Optimus software captures the selected frame and executes a macro that allows the operator to digitise the laser points (=100 mm scale, in the case of ROV video), the height, width, and cross-sectional area of the object (fig. 7).

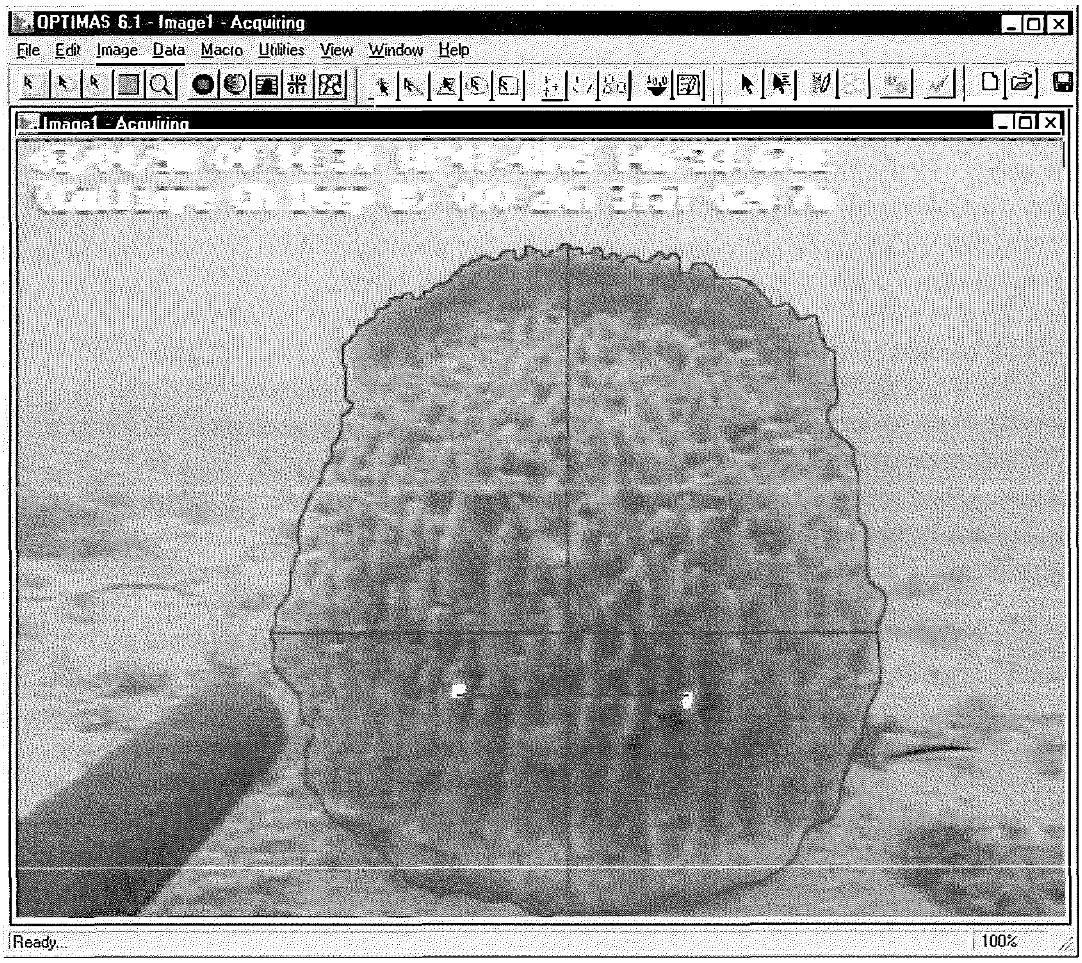

Figure 7. Captured image of a computer screen showing results of the macro run on Optimas by the custom control software, to measure benthic fauna observed by ROV – *Xestospongia* sp. in this example. The tag interrogator antenna is visible in the lower left of the image.

These data are rectified (to remove spherical aberration) then passed back to the control software. The software allows user verification of the measurements, species selection and entry of condition information. These data are then committed to the database along with matching position data from the tracking database. The captured images are also saved to disk both before and after the measurement lines are overlaid on the image. When measuring images of tagged megafauna, tag-numbers are also cross-referenced in the analysis system.

In the case of the towed sled, the video camera has a fixed attitude to the seabed and a horizontal scale bar mounted 50 cm above the seabed and marked in 10 cm intervals. The position of the seabed directly below the bar is constant in video image. The height of attached seabed fauna can be digitised from captured images as the fauna pass the baseline, and calculated with reference to the bar height and interval scale, and with appropriate corrections for photogrammetric angles and spherical aberration (fig. 8).

Figure 8 Captured image of a computer screen showing results of the macro run on Optimas by the custom control software, to measure the height of trawled gorgonians observed by the Sled. The curved line at the bottom shows the ground-line under the bar, the short horizontal line below the bar is 100 mm.

Future developments

Archiving of video is a now a major priority, due to the short life of analogue videotapes (5-10 years). Digital videotapes have a longer lifespan, but are not a long-term solution. We are investigating capture of full resolution analogue and digital video onto computer hard disk and writing to DVD-ROM or DVD-RAM. However, these options are quite expensive for a routine solution, presently costing about \$60-\$80 per 2 hours of video. Captured streaming video would also obviate the need for video image analysis work-stations to have a video capture card and a VCR directly attached, instead the video can be sourced from disk or network server — this would enable more time-efficient analysis of video.

We are currently developing a new drop-camera system for rapid assessment of seabed habitats and fauna. The system is being designed for high-speed deployment with a deck handling system and armoured fibre-optic cable, so that there will be no need to handle a second data/video cable. The system will be towed at about 2 kn ground-speed. This drop-camera will 'terrain follow' the seabed based on feedback from an acoustic altimeter and computerised control of winch valves. The platform may have up to 4 video cameras (including a single 3-chip digital video camera), 4 × 500 W lights, CTD, high resolution digital still camera and strobes, which will all be controlled with an on-board computer and telemetry to the surface, via the F/O cable. The video will provide rapid assessment while the digital stills, to be downloaded while underway, will provide higher resolution 'frozen' images to enable detailed enumeration. The MBARI 4-laser-measure system (see Davis, these proceedings) will be implemented on the drop-camera, as will paired video cameras for making measurements.

CSIRO Marine Research is planning to purchase a more capable ROV to meet future demands. The new system will have greater thrust (to operate in currents), more reliable brushless-DC thrusters, greater payload, multiple-function manipulator(s) for sampling and manipulation, and F/O cable. Digital video and stereo/paired measurement video systems will also be possible.

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Towards Automatic Characterisation of Fish Size and Shape from Metric Image Sequences

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Introduction

Underwater stereo-video systems are beginning to demonstrate their potential as tools for the accurate measurement of length distribution in large samples of fish. However, the potential of modern electronic camera systems to generate large quantities of image data, which must subsequently be measured, is vast. Accordingly, it is necessary to investigate automated, or at least semi-automated, image measurement methods that will allow the accurate and reliable determination of length, surface shape and, where image sequence data permits, volume.

This paper explores some established image measurement and analysis techniques that are in regular use by the photogrammetric and machine vision communities. Emphasis is placed on presenting some appropriate techniques for fish location, the identification of boundary information and methods for surface measurement from both single pairs and sequences of images. Some results from a methodology for the interactive incorporation of additional information available from continuous image sequences to allow the determination of volume, given a static subject, and motion through tracking a number of fish are also presented. Finally the importance of image quality, geometry and content in allowing such methods to be applied accurately and automatically are noted.

Image Acquisition

Given a 3D structure of uncertain geometry, such as a fish, assumptions that can often be made with manufactured objects, for example “the structure is planar”, cannot be reliably made. Accordingly if accurate measurements are to be made from images, at the very least, it is necessary to obtain synchronised images of the object from at least two cameras (Kraus 1993). The most common configuration for this is a stereo pair where two cameras are arranged such that where images from both overlap, it is possible to make 3D measurements (fig. 1). Further if the cameras are calibrated for the underwater environment measurements can be made accurately (see Harvey *et al.*, Shortis *et al.*, these proceedings).

Imagery from a stereo pair of cameras can be acquired either as single image pairs if the cameras are still cameras or, if movie cameras are available, in the form of synchronised sequences of images. In the first case fish length and other linear “point to point” dimensions can be ascertained, whilst the extent of other information such as surface shape or form will be limited by the overlapping coverage of the images taken. The use of sequences of images can provide not only length information, but also data such as change in position, rate of change and, if sufficient surface shape information can be extracted, the form of any movement.

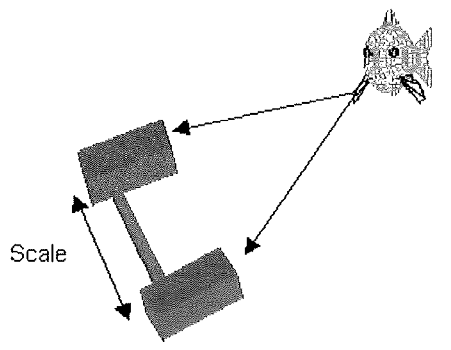

Figure 1 Stereo from a rigidly connected pair of stereo cameras, calibration provides object scale

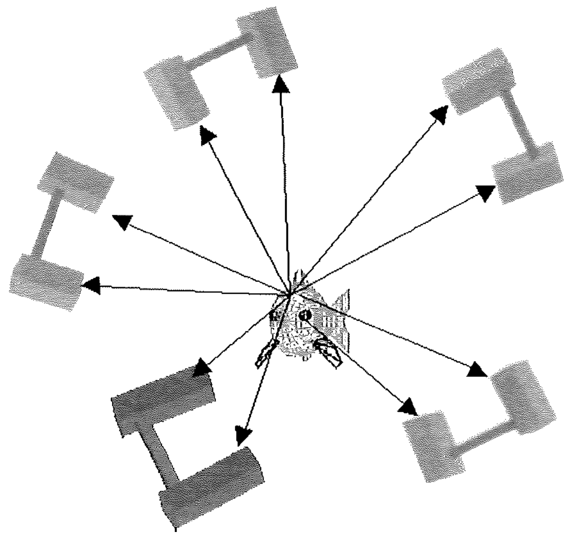

Figure 2 A network of images used to acquire images appropriate for volume determination.

Digital still cameras currently on the market that are appropriate for synchronised stereo can be expected to provide the most accurate dimensional measurements. The primary reason for this is their large pixel count enabling images of several million pixels to be acquired and stored internally for subsequent processing. However, such cameras do not yet have the capability of acquiring sequences of images at the frame rates that would allow individual fish to be tracked. Accordingly if image sequences are to be acquired, the reduced pixel count and image compression methods used in digital video cameras must be accepted.

A further method of image capture is also possible, but to the author's knowledge, has not yet been proven for the measurement of fish or indeed other underwater structures. It is common practice in industry to acquire a network of images taken from all around an object to be measured. Such a network may be acquired either with a single camera or stereo camera pair if the object is static, or for dynamic objects a set of cameras can be used (fig. 2). The key advantage of such a process is that the complete surface of a complicated object can be imaged with at least stereo, and often a greater number of overlapping images. In such a case, parameters that can be determined are limited only by occlusion and for dynamic objects by the coverage of the number of synchronised cameras used. Such an image set can then be processed using established image measurement and analysis techniques (Atkinson 1997) to provide not only surface shape but also volume. Where multiple synchronised images are available, or a slow growing object (such as a sponge or coral) is periodically visited, change in shape and volume can be determined.

Information from image networks

Given a single pair or a network of images covering a fish at a specific instant of time, it is possible to identify the key stages in the data acquisition and subsequent image measurement and analysis process that must be undertaken to compute the information required. Figure 3 provides a flow chart documenting each of the processing steps required. This section identifies some of the measurement and analysis problems and to give some pointers towards possible solutions that would allow automatic, or at least user assisted automation.

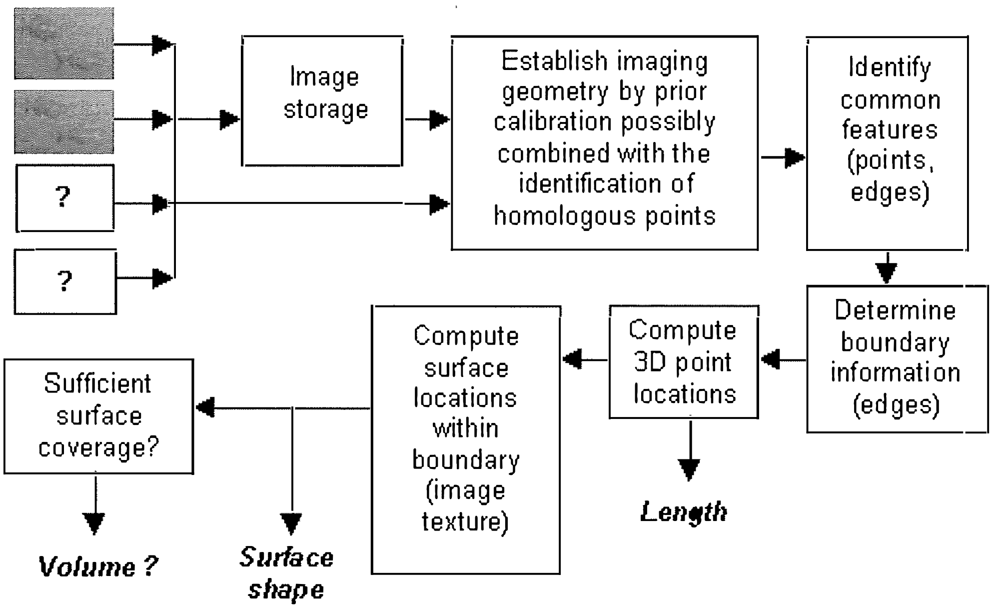

Figure 3 Data flow for determination of 3D parameters from a single set of synchronised images

Technological advances in digital image recording equipment coupled with reliable photogrammetric calibration will provide, and to a certain extend already have provided, automated solutions to the storage and 2D to 3D computation necessary to transform measurements made in the images to measurements on the object.

Those tasks still requiring automation are the identification of features on a fish that are common to a pair of images and are appropriate for the measurement task being undertaken. For example it is necessary to identify at least the extremities of the head and an appropriate part of the tail of an imaged fish if a measurement of length is to be made. Given image measurement of appropriate quality and a photogrammetrically calibrated system it is a trivial matter to compute the 3D location of each of the identified points and subsequently the distance between them. (see Harvey *et al.*, Shortis *et al.*, these proceedings).

Identification of common points

Many image measurement processes have been designed to identify point features of interest within an image. Whilst there are many different types of operator, the best known amongst the photogrammetric and machine vision communities is the Förstner operator (Förstner & Gülch ,1987). Such operators rely on automatically scanning an image and making an assessment of the changes in intensity distribution, or image texture, to identify distinct locations. Whilst those mentioned above are general purpose operations and, for example, are not tuned to suit the often degraded image content of underwater imagery, it is useful to apply them to imagery attainable from the current generation of digital video cameras to ascertain if useful information is extractable. Figure 4 demonstrates the use of a Förstner operator on a grey scale stereo pair containing fish, background clutter, and image synchronisation equipment.

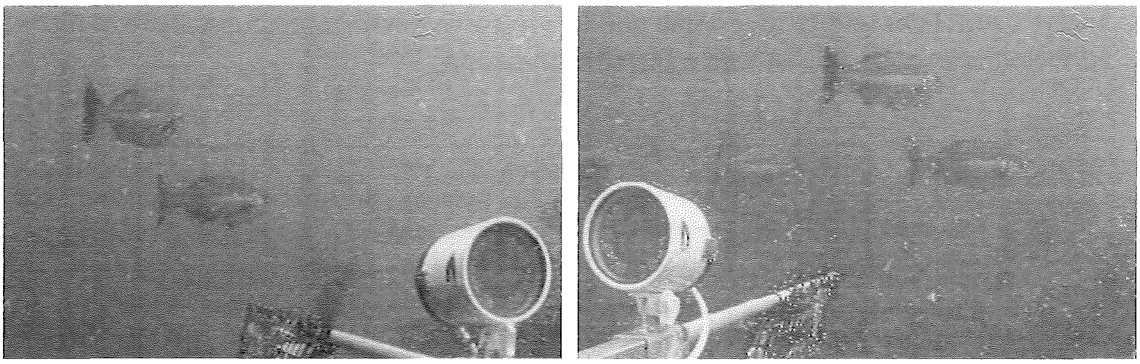

Figure 4 Results from a Förstner operator on a typical underwater video stereopair.

Figure 4 illustrates three of the potential difficulties arising from the imaging situation: image noise; back scatter; and the variability in surface characteristics within the scene. All of these must be accounted for with appropriate imaging and choice of digital camera equipment to suit conditions. Given appropriate images, the final difficulty is to identify which, if any, of the feature points are on the fish. This final point is key and must be solved at the data processing stage. Current techniques using such imagery require a completely manual approach. However, whilst it is doubtful that a general automated solution will be achieved in the near future, it is possible that the operator can be guided during measurement if the interest operator can be tuned, or even trained, to identify only locations with appropriate boundary characteristics.

It may be possible to provide an appropriate solution through the combination of an interest operator with an automatic edge extractor such as the canny or the recursive gaussian filter (Petrou, 2000). As an example of these second processes, figure 5a demonstrates edges, automatically extracted from the same pair of images using a recursive gaussian filter that has been carefully tuned to minimise its sensitivity to image noise and back scatter.

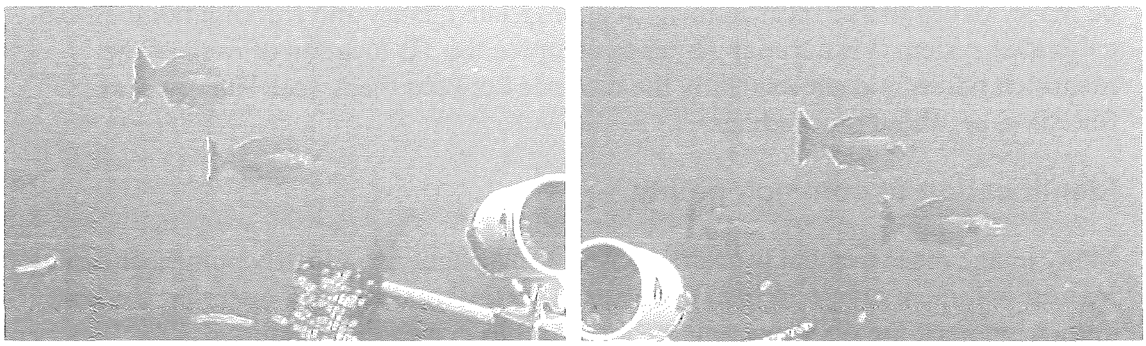

Figure 5a Results of a tuned recursive gaussian edge detector

It is particularly significant in this case that any appropriate boundary information has been found at all. Prior to the acquisition of these images using a digital video system, all imagery available to the author's had been acquired with conventional video systems. The noise inherent in such systems was sufficient to prevent the extraction of any pertinent features or useful edges. Whilst the above results demonstrate potential there are limitations in identifying common boundaries between images due to differences in perspective between the camera views and in distinguishing between edges on fish and those from other sources. Whilst information such as colour and shape could be used, information only attainable with sequences of images rather than single image pairs could provide a more readily attainable solution (see section: "Information from image sequences").

Determination of boundary information

Given an appropriate method of edge extraction, if shape and surface information are required it is necessary to determine the boundary of the fish of interest. Whilst there are many techniques that can be adopted, a method for this process could begin with image morphology which incorporates the processes of dilation and erosion to join individual lines and remove gaps (Petrou, 2000). Subsequent processes are: thinning where boundary information are reduced to single pixel width and are expressed as a chain of pixel locations; vectorisation where each chain of pixel locations are expressed numerically in the form of vectors and; cleanup where data are joined together to form a consistent closed boundary.

The derived boundary can then be used to define the region in which a surface determination process, such as least squares image matching (Atkinson 1997), is used to determine homologous points on the fish surface. The 3D location of each matched set of points can then be computed either integrally, within the matching process, or subsequently using photogrammetric intersection. Finally, a topological or a parametric description can be generated of the fish. It should be noted however that this complete process presupposes that the imaged object has been recognised as a fish, such recognition is very difficult from single stereo pairs that may contain images of more than one fish and also background information.

Figure 5b presents an example of a deformable parametric structure being transformed from its starting point of a regular grid to a fish boundary. Nodes within the grid can be set to correspond either directly with stereo matched points or through a more regular grid interpolated through the extracted data. (Tu, 1996).

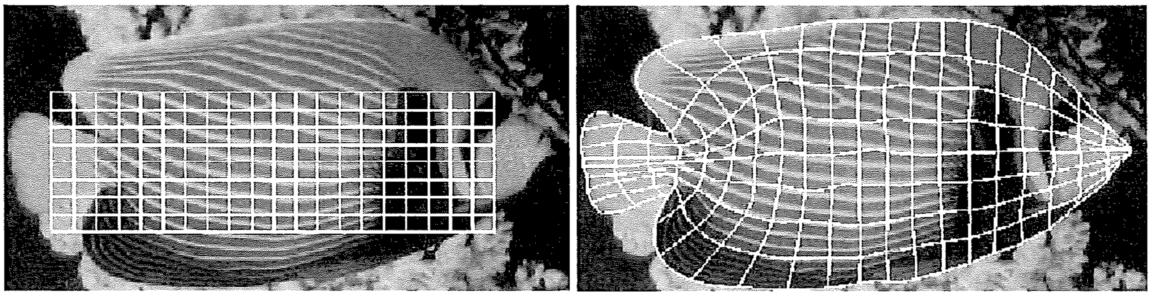

Figure 5b Warping of a deformable grid to fish boundary information (after Tu, 1996)

An alternative method of representing surface information is shown in figure 6, where homologous surface points on a poor quality stereo pair of images have been measured manually, then triangulated to provide a surface description. In this case no boundary information could be extracted due to the poor quality of the image data. Accordingly, this example provides a clear indication that image quality must be appropriate to the task.

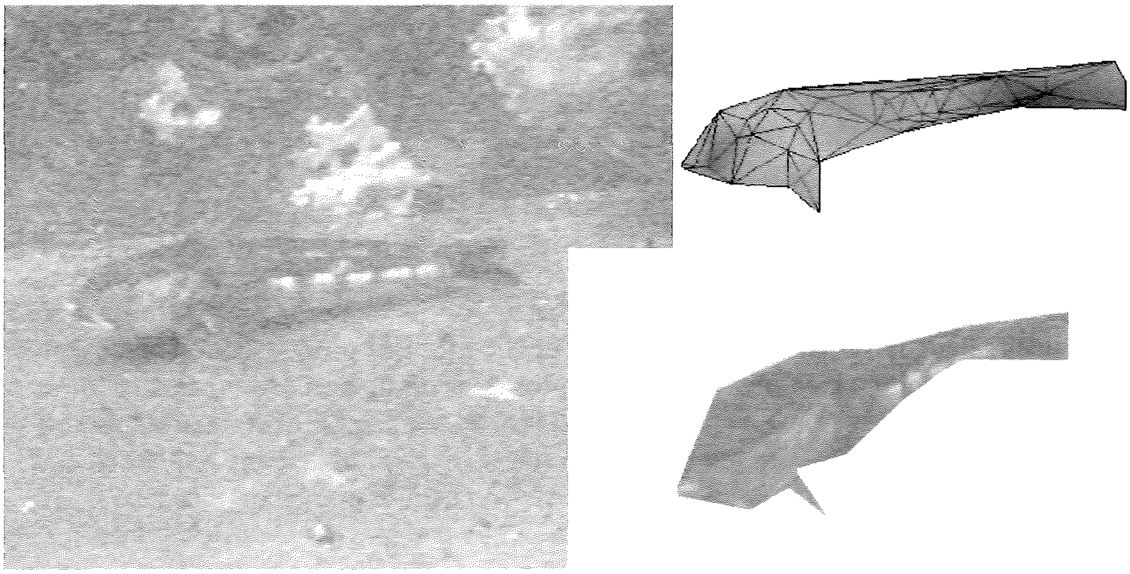

Figure 6 Surface representation through stereo measurement and subsequent triangulation

Information from image sequences

In the section: "Information from image networks" it was identified that there are problems in trying to measure fish automatically from pairs or even networks of synchronised images. Given images of appropriate quality, both in terms of content and geometry, the key problem is one of extracting natural features against a varying background. A useful method that is available to assist in this process and which is readily available to fisheries researchers is the use of image sequences to provide additional information in the form of dynamic change.

Figure 7 represents the key components in the measurement and analysis chain given two or more sequences of fish imagery in which dynamic change is occurring. As before, image storage, geometry and measurement tasks are similar in basic concept to those given for a single stereo pair. Where the process differs is in the recognition process and in the availability of algorithms that allow the detection of small changes within a sequence of images.

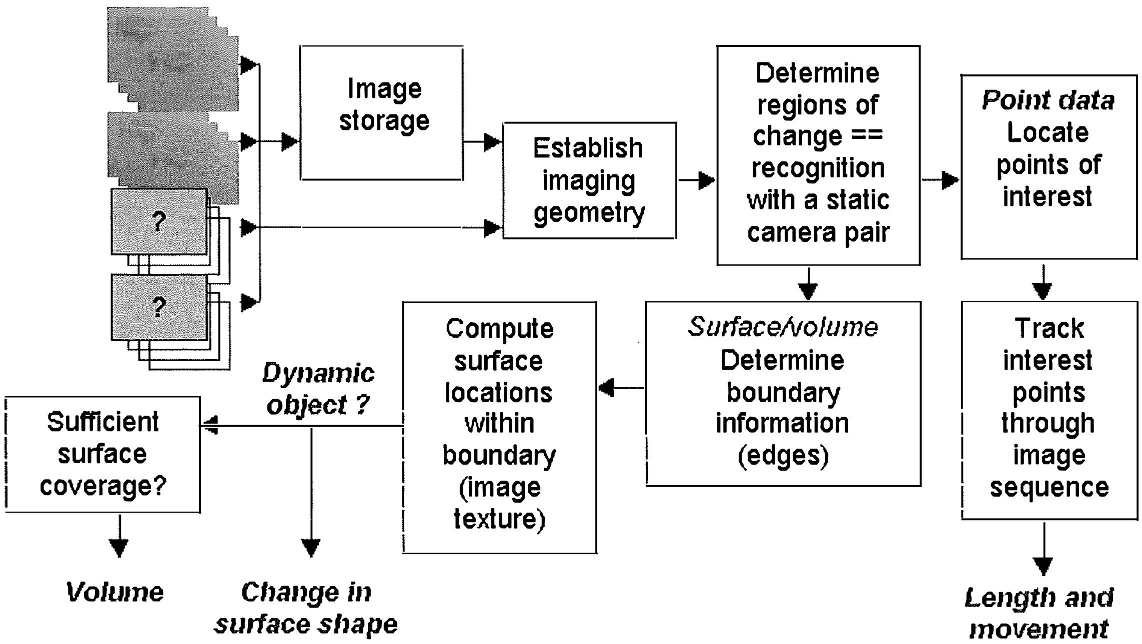

Figure 7 Data flow for determination of parameters from a set of synchronised image sequences

Recognition using sequence information

One of the key processes required for recognition is illustrated in figure 8, where temporal changes occurring in the camera field of view are compared by computing an average image which can be periodically updated to form a moving average. When any individual frame is compared against its appropriate moving average, changes in image intensity can be identified. Such changes are attributable to a combination of camera motion, object motion, backscatter and other sources of noise. As can be seen in figure 8, following filtering to remove high frequency changes caused by backscatter, it is possible to clearly identify regions of change. The identified regions are immediately useful as they have distinct boundaries that can be more easily identified using edge and boundary extraction methods (see section: "Identification of common points"). A further advantage of this process is that camera related equipment such as synchronisation lights, calibration plates and any bait which are static with respect to the camera system are automatically eliminated since their location does not change from image to image.

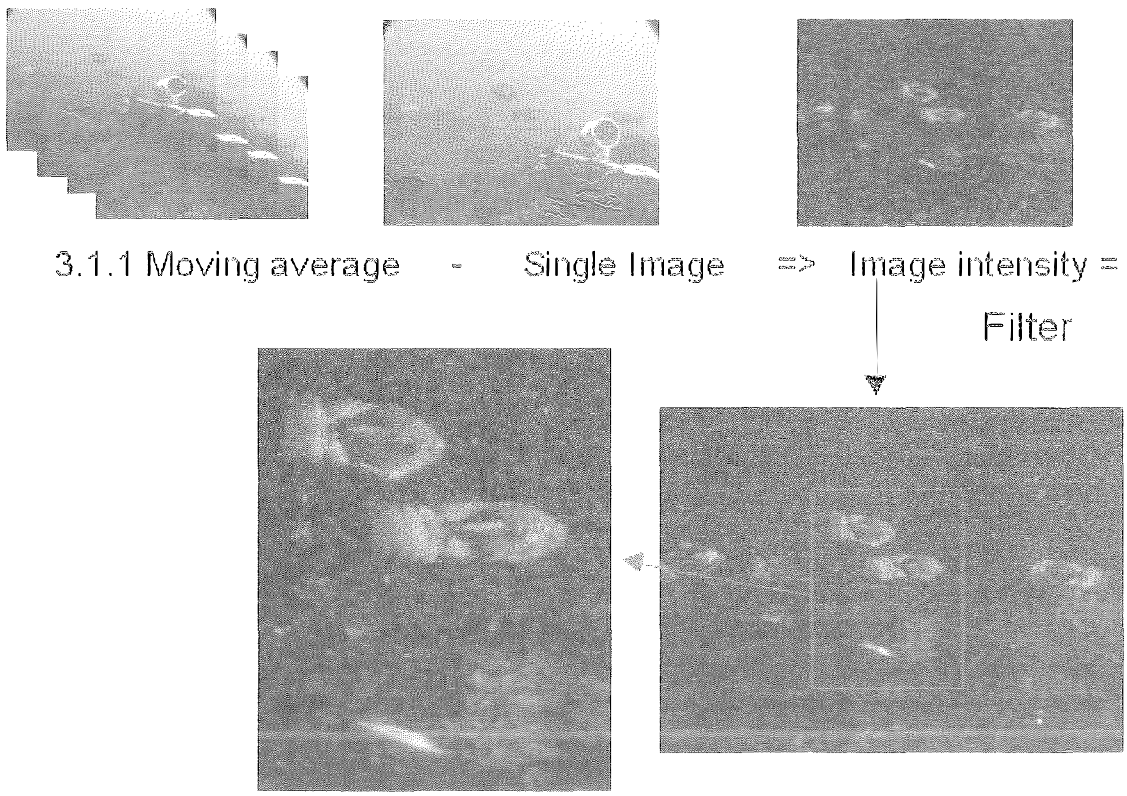

Figure 8 An example of using image sequence information to filter background information through the detection of movement.

Motion Analysis

Given an appropriate image sequence it is also possible to track features within the image sequence. If these features can be tracked across two or more camera views it is possible to determine not only fish direction but also relative motion. The example (illustrated in figs 9 and 10), in which points are currently tracked manually, demonstrates such a system.

Summary

The examples given in this paper demonstrate that many opportunities exist to exploit stereo and multi-camera digital imaging systems for the measurement of fish and other objects within the marine environment. Current systems are in their infancy and are typically reliant on manual measurement but, through further research and where image quality permits, it will be possible to automate, or at least semi-automate, the measurement process. Such research is needed in the short term to alleviate the data processing bottleneck that will inevitably result from the ability of the marine science community to employ current technology to acquire, but not efficiently process, large amounts of underwater video data.

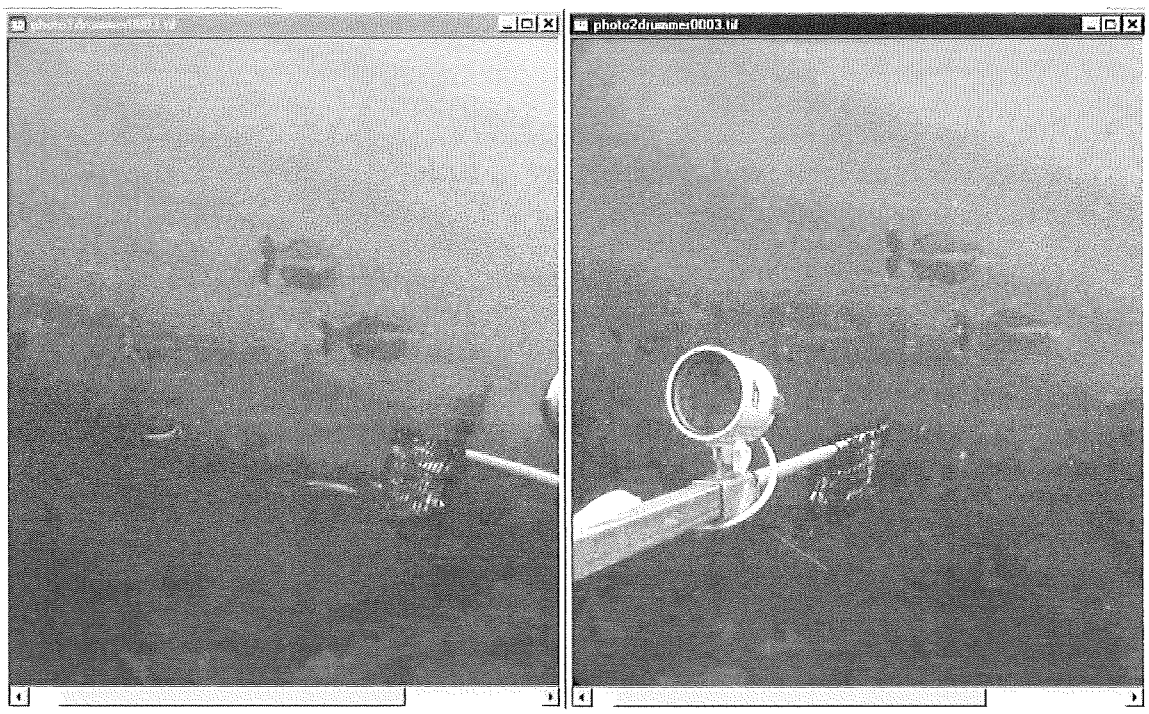

Figure 9. Identification of seed feature points (white crosses) prior to tracking.

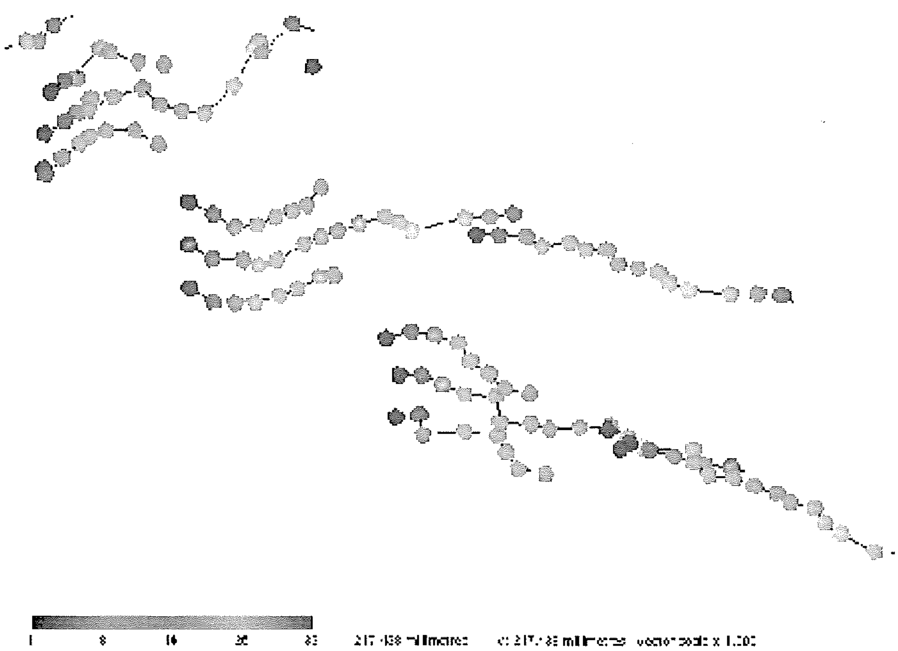

Figure 10 Single view of an extracted 3D motion graphic demonstrating sinusoidal swimming motion.

To achieve this short term goal research will need to address:

- recognition and identification of key features such as heads and tails from image sequences
- robust methods for boundary detection and its subsequent 3D description

- automated surface measurement processes tuned to both image quality and fish surface characteristics
- best imaging practice to enable the production of image data of appropriate quality and geometry thereby ensuring that the image archives constitute a viable long term marine science resource

Looking towards the future, as volumes of captured data increase it can be expected that there will be a greater need for automation to reduce reliance on labour intensive manual measurement methods across a wide range of underwater stereo imaging tasks. The possibilities given in this paper only represent a small subset of the methods that have been and are under development by the photogrammetric and machine vision communities.

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The Design, Calibration and Stability of an Underwater Stereo-video System

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Introduction

A main theme of global ecosystem monitoring programs is how the marine ecosystems of our planet will be affected by environmental impacts and how, in turn, this will effect global climate change. To this end, major research is required on the response of the marine fauna and flora to changes in physical and biological factors. Estimates of changes in the length, volume and shape of both biological and physical parameters will be important as indicators of disturbance and to assess natural variability. To overcome the problem of subjectivity in visual estimates (Harvey *et al.*, 2001a, b) and to enhance accuracy and precision, an impersonal system of measurement is preferable. Clearly, any impersonal system of measurement must be technology based, but within the limits imposed by the underwater environment and finite resources of research organisations.

Subsequently many marine scientists and biologists have experimented with conventional and video imagery. For example, Klimley and Brown (1983) describe the use of stereophotography for estimating the size and dispersion of free swimming sharks. The system was viable underwater, convenient to use for measurement and could be developed or purchased at a reasonable cost. As a consequence, stereo-video cameras were quickly adopted for a wide range of applications in the marine environment (Hamner *et al.*, 1987; Vrana and Schwartz, 1989). In recent times there have been rapid technological improvements in video cameras, which has improved the utility and accuracy from both single camera (Schewe *et al.*, 1996) and stereo-video systems (Harvey and Shortis, 1996).

This paper details the continuing development of a stereo-video system, discusses design and calibration issues and describes the measurement process. The long-term aim of our research and development is a reliable system that can accurately and precisely determine the size and shape of objects underwater. Current development of the measurement and calibration software is concentrated on enabling a very high level of automation of the calibration and measurement processes to facilitate wider use of the system by marine scientists.

System Design

The design of a stereo-video system is influenced by many factors. For example in the system described by Harvey *et al.* (these proceedings) the principal design aim was to make precise size estimates of large mobile reef fish at distances of 3 to 10 metres. One of the critical factors affecting the precision of measurement is the base separation, or distance, between the cameras. The separation is dictated by the size of the camera base bar. From a practical perspective the separation influences the manoeuvrability of the cameras underwater. A larger frame improves the overall measurement precision due to the increase in the base separation of the cameras, but is more difficult to manoeuvre underwater.

The focal lengths for the system used in Harvey *et al.* (these proceedings) are typically set at 4.7 mm in air (3.6 mm in water) to obtain fields of view of 5 metres at a range of 5 metres. Each camera is inwardly converged at 8° to gain an optimised field of view (fig. 1). Like the base separation, these design issues are adopted as a compromise between competing considerations. For example, shorter focal lengths increase the field of view, but decrease the measurement precision. Similarly, a more acute convergence would improve the measurement precision, but will decrease the useable field of view and increase the apparent perspective distortion.

In this system a calibration check plate (fig. 1 and 3) is mounted at 2.5 metres from the centre of the camera base bar and can be used to verify the stability of the camera relative orientation. The check plate is positioned so that it can be seen in the images recorded by both cameras whilst not unduly intruding in the images. Periodic measurement of the points on the check plate can be made to detect any variability during a dive. A light emitting diode is mounted above the check plate. The diode can be switched on and off manually by the operator at appropriate times to indicate when useful measurements can be made. It also serves as a means of synchronising the left and right images, as the camcorder frame rates tend to drift with time. Synchronisation avoids motion parallax from movement of the cameras or the object of interest, which would decrease the accuracy of measurements due to the introduced systematic error. Future systems will utilise a time code generator that will simultaneously write the time code onto the images on both recorders making the light emitting diode redundant. Video images are grabbed as either tif or avi files using an IBM PC compatible frame grabber. Once in these formats the images can be readily adjusted for brightness and/or contrast if necessary, and image locations can be measured within the frames. Grey scale images are often grabbed (using the S-VHS luminance signal only) to simplify subsequent processing during calibration, whilst colour images are generally used for size measurements to enhance the interpretation of the images.

For the photogrammetric technique to be accurate, it is necessary to make accurate measurements of homologous features in a stereo pair of images. Accordingly the images taken must be of an appropriate quality. Image quality in a digital underwater system is subject to many factors the most primary of which is water turbidity followed by the imaging properties of the camera system. In the monitoring and measurement of marine organisms clear advantages are obtained through the use of sequences of images rather than pairs of still images. Systems available are therefore of two main types --analog video and digital video. The former, whilst of lower cost, should be avoided where possible since the analog camera systems are generally of lower resolution than their digital counterparts, but more importantly the recording method does not lend itself to the level of geometrical repeatability between frames achievable through the use of digital systems. Given current technology, the better systems are typified by three CCD sensors (one per colour channel), designed for the High Definition TV market, recording onto a digital tape system. In the future it is anticipated that systems based upon fire wire technology and separate recording units will offer significant benefits. Such systems will enable direct synchronisation of two or more cameras and will allow the use of small geometrically stable camera housings coupled to external recording systems.

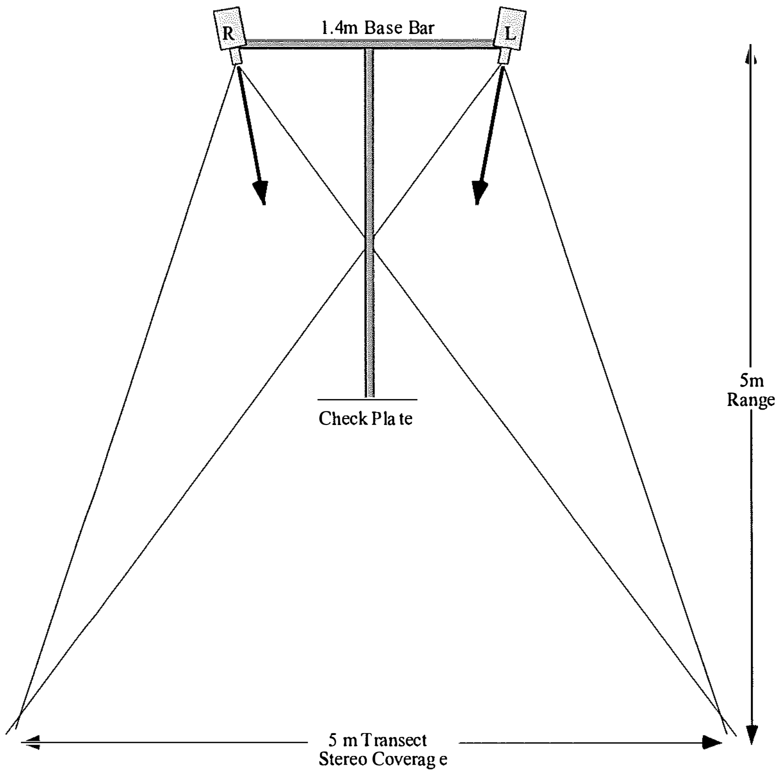

Figure 1 Geometry of the underwater stereo-video system.

System Calibration

Calibration of the system is necessary for two reasons. First, the interior orientation of the cameras must be defined to determine the internal geometric characteristics of the cameras, using physical parameters for principal distance, principal point location, radial and decentring lens distortions, plus affinity and orthogonality terms to compensate for bias in the spacing of the pixels on the CCD sensor, any misalignment between the sensor and lens system, and effects of the analog tape recording (Shortis *et al.*, 1993). Second, the relative orientation of the two cameras with respect to one another must be determined. The relative orientation effectively defines the separation of the perspective centres of the two lenses, the pointing angles of the two optical axes of the cameras and the roll rotations of the two CCD sensors.

The camera calibration model does not contain explicit terms for the refractive effects of the perspex camera ports and the refractive interfaces, as analysis of the effects of the refractive surfaces in the optical path in an ideal camera housing shows that images are displaced radially from the principal point (Li *et al.*, 1996). Whilst the assumptions that the optical components of the housing are symmetric around the optical axis of the camera and refractive surfaces are in general perpendicular to the optical axis are unlikely to be perfectly fulfilled in practice, it is clear that the principal component of the refractive effect is radial. As a consequence, the approach that has been widely adopted has been to allow the refractive effects of the optical components and refractive interfaces to be absorbed by the conventional, physical camera calibration parameters. The principal component is implicitly taken up by the standard, odd-ordered polynomial model for radial distortion, whilst any residual effects from asymmetric components of the housing are partly or wholly absorbed into other parameters of the camera calibration, such as decentring lens distortion or the affinity term. Providing the calibration is carried out under similar conditions to those in which the system will be used, no assumptions need to be made concerning the refractive indices of the air, glass or water media, and modelling of the optical components of the underwater housing is unnecessary. This approach has been used successfully by previous systems (Turner, 1992; Schewe *et al.*, 1996), whereas a rigorous approach to optical ray tracing requires a two phase calibration approach and assumed values for the refractive indices of the media (Li *et al.*, 1997). The refractive index of water is known to change with depth, temperature and salinity (Newton, 1989) and the shape of the camera housings and port may change with depth due to the changing pressure. A procedure that incorporates implicit calibration of the complete system under prevailing conditions is likely to be more accurate and reliable.

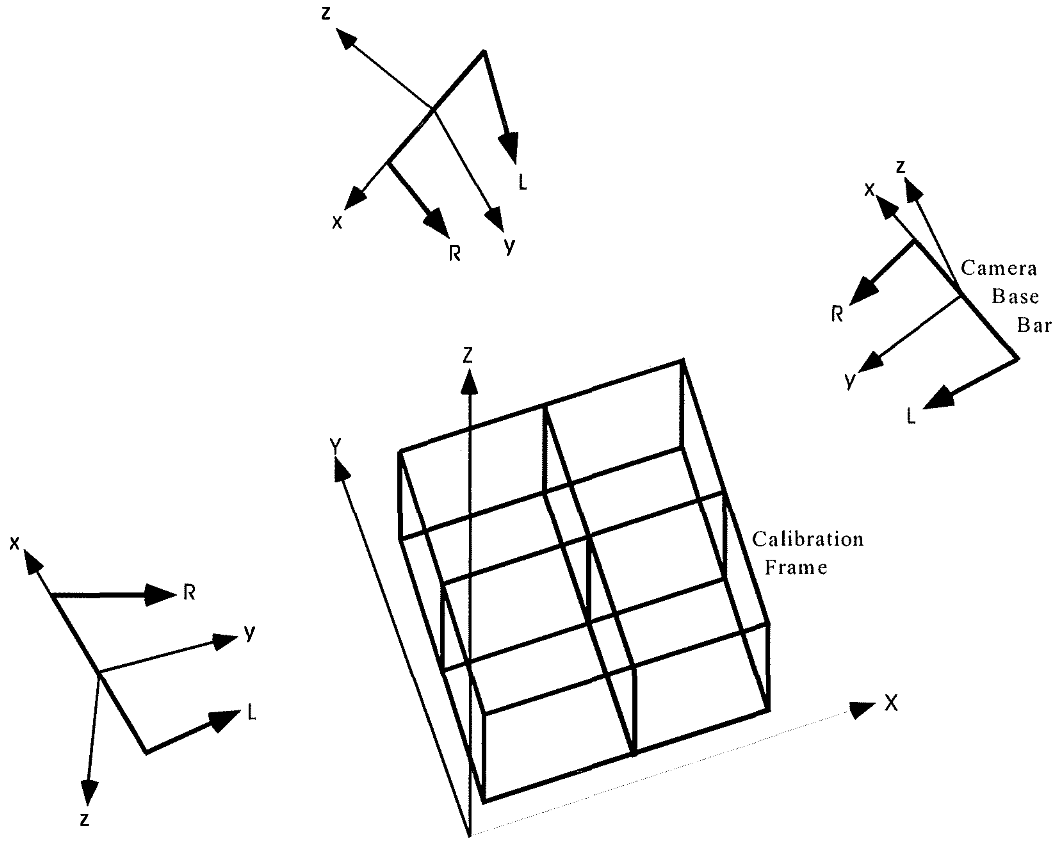

Figure 2 Calibration of the cameras and camera base bar using a calibration frame.

The camera and relative orientation calibration is accomplished using a purpose built frame (fig. 2 and 3). The frame is an open cuboid constructed from lightweight aluminium. It is black in colour and has between 56 and 120 white, circular targets mounted on plates that are riveted to the surface. The targets provide high contrast, unambiguous points that allow a simultaneous, self-calibration of both cameras. Video footage is captured during five rotations of the frame held at an oblique angle by a diver (fig. 3), the first rotation with the camera base in the "normal" horizontal position, and the following rotations with the camera base vertical and in other orientations. The rotation of the frame is more efficient than the diver manoeuvring the cameras around the frame, and emulates a set of convergent camera stations surrounding the frame (fig. 2). The rotation of the camera base is necessary to de-couple external and internal parameters of the self-calibration, such as the principal point position and camera station locations. Note that accurate information for the positions of the targets on the frame is not required, as coordinates of the targets are derived as part of the self-calibration procedure. Hence it is immaterial if the frame distorts or is dis-assembled between calibrations, however the frame must retain its structural integrity during a calibration sequence.

From the video footage, 20 synchronised pairs of frames are gathered and the locations of the target images measured. The bundle solution provides estimates of the magnitude and precision of the camera calibration parameters and the locations and orientations of the cameras at each synchronised pair of exposures. Whilst the camera calibration data are used directly in the subsequent calculations, the location and orientation data must first be transformed. The data for the 20 pairs of synchronised exposures are initially in the frame of reference of the calibration frame. Each pair is transformed into a local frame of reference for the camera base (fig. 2). The local frame of reference is adopted as the centre of the base between the camera perspective centres, with the axes aligned with the base direction and the mean optical axis pointing direction. The final parameters for the relative orientation are computed as the average of the values for the 20 pairs. Whilst the computation of the relative orientation is currently a post-process after the bundle solution, a future development of the system will be the incorporation of a stereo-pair constraint solution such as that developed by King (1995).

Measurement System

Once the relative orientation is established, measurements within the common field of view of the cameras can be made by locating objects of interest in the left and right stereo images. Again, the images must be synchronised to avoid systematic errors caused by the false shift of objects in one frame relative to the other.

The computer interface for calibration or stereo measurement is shown in Figure 3. The left and right images are shown along with a variable zoom window showing the current measurement point. Measurements in the two selected fields of view are made by simple mouse clicks which instigate a centroid computation or an operator defined position within the zoom window. In order to minimise gross errors, operator measurements are aided by displaying epipolar lines in all other images. In calibration mode the system operates as an image comparator which compiles image observations for the self-calibrating photogrammetric solution. The two camera calibrations are simultaneously computed as a multi-camera block-invariant solution.

In image sequence mode, the two pairs of image space coordinates are converted into three object space coordinates using a straightforward intersection computation based on the camera calibration and relative orientation data. To provide an estimator of the quality of the image measurement the Root Mean Square (RMS) image error is also computed. The operator can step through a declared image sequence in order, for example, to make multiple length measurements of a single fish or to be certain of the identification and measurement of individual fish through the recognition of distinctive patterns of motion.

It is well known, from the geometry of stereo-photogrammetry, that the precision of the computed intersection degrades with distance and the square of the distance for the lateral and depth directions respectively. Experience with the system has shown that, as expected, the RMS image residual values used as an image quality estimator does deteriorate markedly with distance. However the principal use of the quality estimator is to detect mistakes in the image measurements. Measurements made with the stereo-video system are dependent on the clear definition of the objects to be measured. The discrete sampling of the CCD sensors combined with noise artefacts from the video tape recording and frame grabber tends to smear edges and blur detail, which can lead to mis-identification of left and right images of objects to be measured. The quality estimator is tested against a preset criterion and non-identical points always produce very poor quality estimators. Image measurements that fail the test can be immediately re-observed to correct the error.

Figure 3 The image measurement computer interface.

Calibration Stability

There are many issues to be considered when predicting or testing the stability of the calibration of cameras used for quantitative measurements. Perhaps the first consideration should be that no camera would be perfectly stable because all cameras are handled in some way during routine operations. The influence of handling is greater for cameras that are not designed for quantitative measurement, such as video camcorders. Like 35mm SLR based digital still cameras, the flexing of the body of the camera and possible movement of the focal plane CCD sensor contribute to the variation, both instigated by handling during photography (Shortis and Beyer, 1997). The stereo-video system introduces the additional stability issue of the relative orientation. Once more, use of the system could be expected to vary the relative orientation due to handling, pressure changes and movement stresses on the camera frame and housings, as well as the possibility of the cameras moving within the housings. However, substantive changes to the camera calibration are unlikely whilst the cameras are sealed in the waterproof housings and the frame remains rigid. Therefore, small variations in the camera calibration and relative orientation might be expected to result from routine use, such as a single dive where the cameras are being manipulated in the underwater environment. Larger changes would be likely to occur between dives, as the waterproof housings must be opened and the cameras are handled more to retrieve videotapes. More fundamental changes such as camera disassembly (Shortis and Beyer, 1997) or refocussing (Shortis *et al.*, 1996) would of course result in dramatic changes in the camera calibrations. Similarly, a disassembly of the frame or camera housings and mountings would have a similar affect on the relative orientation. Many of the problems associated with the instability of systems are found in the system's design and can be overcome with a good engineering solution. For example the need to remove cameras to change tapes and batteries can be avoided by using security type cameras that are permanently mounted in an underwater housing. Removable recorders and batteries to power the system are located on the surface or in a separate waterproof housing.

Conclusions

Biologists making visual estimates of size or length should aim for the maximum achievable accuracy and precision realistically available to them. As the accuracy and precision of size or length estimates improves, so does the ability to detect real or relative changes in variables involving biological length or size. Stereo-video offers an alternative to standard visual census techniques where data collection emphasis is on accurate and precise estimates of size or length. Further, the measuring system can be applied to tasks other than recording lengths, especially those measurements that are too complex or too inefficient to be carried out through visual estimation by divers. For example, biomass estimation for environment monitoring requires the accurate three-dimensional mapping of reef communities in order to assess changes in volume. Periodic determinations of reef biomass may be feasible using a combination of image matching and shape fitting templates. The stereo-video system is also well suited to population studies based on correlation from indirect information, such as the external tubes or sand funnels of bottom dwelling marine animals. Visual estimation is not sufficiently accurate to detect very small dimensional changes, and the fragility of these structures demands a non-contact measurement method.

The conceptual design for the stereo-video system can be scaled down or up for various applications with corresponding changes in accuracy and precision (Shortis *et al.*, 2000). The technique is robust and insensitive to user experience, therefore removing biases resulting from inter-observer variability. Underwater stereo-video measurement has many advantages over visual census techniques. It is anticipated that stereo-video systems will gain widespread acceptance in many applications in the future, especially as systems are developed to incorporate automated and accurate calibration and measurement routines. The increased power of statistical testing enabled by large quantities of accurate data generated from automated analysis will revolutionise environmental monitoring programs dependent on the visual classification, enumeration and/or manual measurement of specimens.

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Stereoscopic Video for Underwater Surveys

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Introduction

The Centre for Marine Science & Technology (CMST) has been active in the development and application of a wide range of stereoscopic video technologies for over a decade. Figure 1 illustrates the stereoscopic video system developed for Woodside Offshore Petroleum. The system consists of an underwater stereoscopic video camera (containing a pair of video cameras mounted side-by-side in a single housing) and a stereoscopic video display which can display full-colour flicker-free stereoscopic video images. The system was designed for use on Woodside's Triton Underwater Remotely Operated Vehicle (ROV) (fig. 2) which is used to perform a wide range of inspection and maintenance tasks at their offshore gas production platforms on the North West Shelf. In this configuration, the camera has been used to provide the ROV operator with improved depth perception while navigating the vehicle and controlling the ROV's manipulator arms (Woods, 1997).

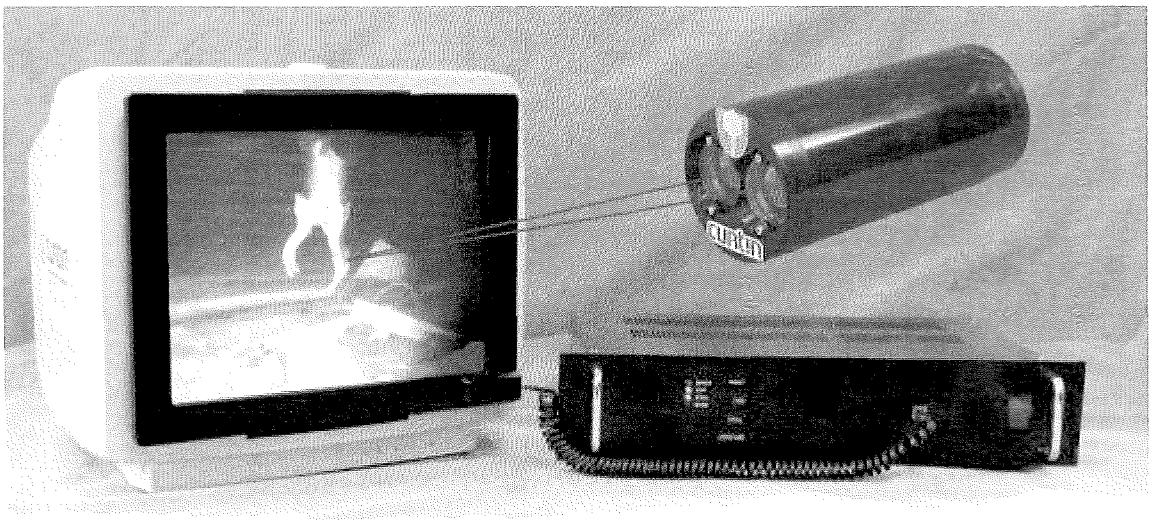
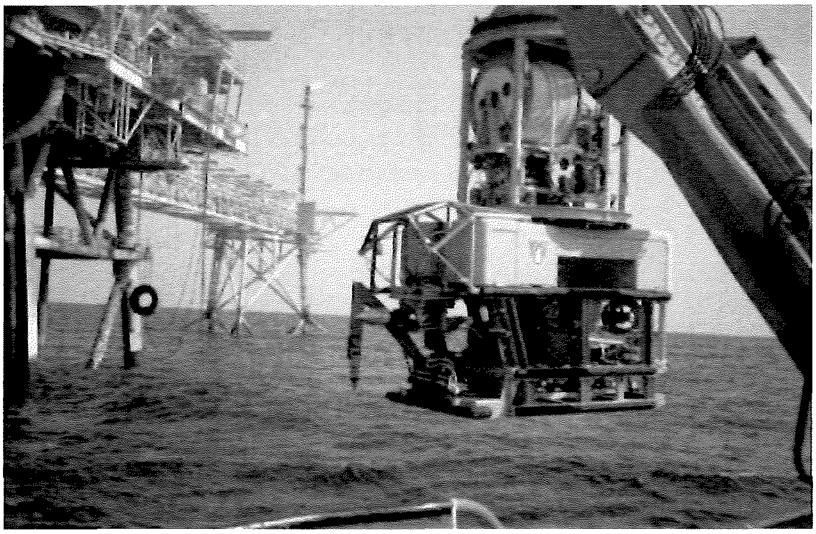
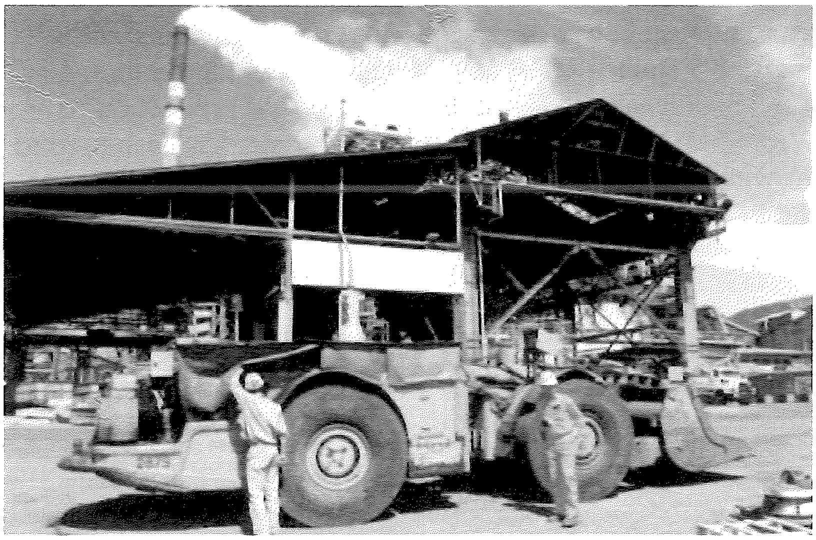


Figure 1 Stereoscopic video display and underwater stereoscopic video camera.

CMST has also installed a stereoscopic video system on a remotely controlled front-end loader at Mount Isa Mine's copper smelter (fig. 3). In this application stereoscopic video provides the driver with a better knowledge of the vehicle's position in relation to other equipment and thereby allows the vehicle to be driven with greater accuracy and greater safety.

More recently we have been working with Murdoch University on the development of a system for measurement and tracking with stereoscopic video images for use in ROV dynamic positioning. (Woods *et al.*, 1998, and Nelissen *et al.*, 2000).





Figures 2 and 3 The Triton ROV at Woodside's North Rankin gas production platform, and a remotely controlled front-end loader at Mount Isa Mines' copper smelter - both fitted with stereoscopic video.

Stereoscopic Video in the Underwater Environment

Stereoscopic video offers a number of benefits to visual inspection in the underwater environment that can be particularly relevant to underwater surveys:

- *Improved image understanding.*
  In the underwater environment, marine growth can present a very confusing array of different sizes, shapes, colours and textures. Stereoscopic video can help an operator make sense of what can otherwise be hard to distinguish when viewed with conventional (2D) video.

- *Improved ability to see through turbid water.*
  Suspended matter in the water column can very quickly reduce the visibility. Stereoscopic viewing improves an observer's ability to see through turbid water by two main mechanisms:

1. If the particles are small, the suspended matter acts as noise in the image and acts to mask or mute the background. The brain is able to correlate the images from the two eyes to remove noise and see the true signal or background image. This results in a perceived improvement in image quality and improved visibility. The perceived improvement in signal to noise ratio has been measured at about 3dB (Pastoor *et al.*, 1989).

2. If the particles are large, that part of the background image which a particle obscures for one eye can probably be seen by the other eye. In effect the observer can see around the particles.

- *Improved ability to judge distance and size.*
  Binocular vision is the dominant technique by which we perceive depth in the world around us. When conventional (2D) video systems are used, the ability to perceive depth by stereopsis is lost. The use of stereoscopic video allows an observer to intuitively perceive depth in a scene as he or she normally would. Knowing the distance of an object (a fish for example) is also a very important step in perceiving the size of an object from a video image. A small object close up will cast the same image size on the retina as a larger object far away hence being able to perceive distance also aids in the perception of object size.

- *Improved ability to see through visual clutter.*
  Surveying a school of fish presents a situation where objects varying randomly in size and moving randomly in a featureless, three-dimensional volume have to be identified or counted. With a 2D display it can be hard (or impossible) to cope with the visual complexity of this situation. Stereoscopic viewing allows the operator to make sense of the visual clutter, and also allows the operator to focus attention on individual areas within an image.

Stereoscopic video also improves an operator's ability to control a remotely controlled manipulator because the operator is able to intuitively perceive the relative location of the manipulator to its environment.

Depth Resolution of Stereoscopic Cameras

The discussion so far has focussed on the use of stereoscopic video for viewing but stereoscopic video also provides the ability to perform underwater-based measurement. The slight perspective difference between the two camera views allows measurement using the principles of photogrammetry.

The depth resolution of a stereoscopic camera is determined by a range of factors:

- camera separation - increased separation provides increased depth resolution,

- resolution of the cameras - higher resolution cameras will provide higher depth resolution (unfortunately, processes such as video recording will usually reduce the image resolution),

- field-of-view of the cameras - a stereo camera with a narrow field-of-view will have higher depth resolution than a stereo camera with a wide field-of-view, and

- object distance from the cameras - a stereo camera has higher depth resolution close to the camera than it does further away from the camera.

Figure 4 provides an illustration of the theoretical depth resolution of a stereoscopic camera (albeit with very low resolution for illustration purposes). The cross-hatched area represents the area of overlap of the view of the two cameras. Closer inspection of the cross-hatched area will reveal that it is made up of diamonds of various sizes. These diamonds (also known as lozenges) represent the area that is uniquely imaged by a pair of pixels (i.e. the intersection of the view angle of a single pixel from one camera with the view angle of a single pixel from the other camera). The figure aptly illustrates the fall-off of depth resolution with increased distance from the cameras. Several lozenges at various distances have been coloured to illustrate this point - larger lozenges represent lower depth resolution and therefore lower measurement accuracy.

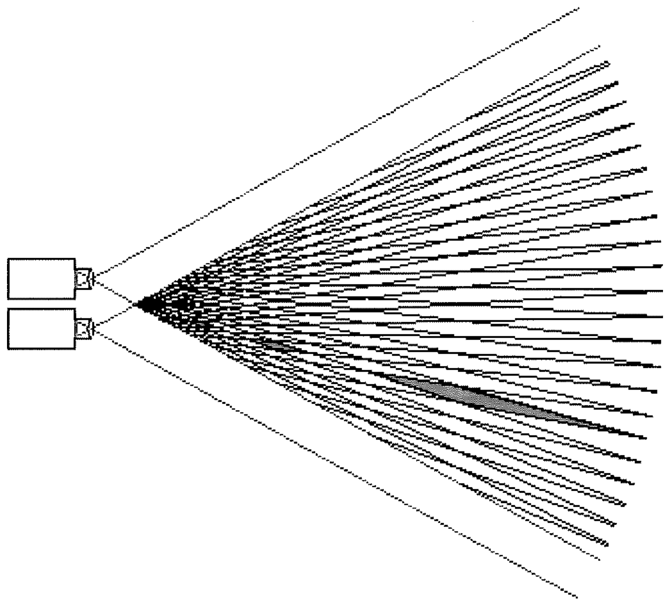


Figure 4 An illustration of the theoretical depth resolution of a stereoscopic camera.

It should also be noted that the accuracy of measurement will also be determined by how well the cameras have been calibrated for their optical parameters and any optical aberrations.

Although all of this is fairly straight forward photogrammetry, the reason for covering it is to introduce the compromises to be considered between configuring a stereoscopic video camera for direct viewing by an operator and configuring a stereoscopic video camera for 3D measurement.

Stereoscopic Cameras for Viewing and/or Measurement

If a stereoscopic camera is being set up for measurement, the camera separation, field-of-view and camera resolution will be chosen to yield a certain depth resolution at the desired working distance. In contrast, if a stereoscopic camera is being set up for viewing by human operator, human visual requirements must be considered so that the stereoscopic image will be comfortable to view (Woods *et al.*, 1993). If, for example, the cameras are too widely spaced, the stereoscopic image will be very hard (or impossible) to view. The maximum camera separation that will produce a viewable stereoscopic image can be calculated, and it will be based on parameters such as camera field-of-view, and screen size and viewing distance at the stereoscopic display.

So in summary, if a stereoscopic camera is to be used for viewing, the maximum amount of camera separation that can be used will be limited compared to the range of camera separation that could be used for measurement only applications.[2] That being said, the combination of the gradual increase in the sensor resolution of cameras (with improved technology) and the introduction of digital transfer and storage technology, the depth resolution of a camera configured for viewing may well be sufficient for a chosen application.

Due to the benefits provided by being able to comfortably view the images captured by a stereoscopic camera, it is advantageous if the same system would provide maximum depth resolution and yet still allow viewing by a human operator in stereo. One possible way of doing this is to use a three camera system. Two of the cameras would be located fairly close together (this pair would be used for stereoscopic viewing) and a third camera would be located off to the side at a much greater camera separation (this camera in combination with one of the first cameras would be used for 3D measurement). Thus a single system would allow 3D viewing and high-resolution 3D measurement. CMST are interested in working with outside parties who have a suitable application to apply this concept.

Stereoscopic Camera Configuration - Some Other Issues

Image alignment is the most important aspect in configuring a stereoscopic camera for viewing. If the left and right images that constitute a stereo-pair are not correctly aligned, the image can be difficult or impossible to view. Care must therefore be taken to avoid vertical misalignment, rotation of the camera images, and magnification differences between the two camera images. There are also a number of guidelines which should be followed to reduce image distortions in the stereoscopic images (Woods *et al.*, 1993).

Stereoscopic cameras must also be stably mounted otherwise the alignment may change during use, which can cause viewing discomfort and invalidate any possible 3D measurements. In the case of the camera shown in Figure 1, both camera heads are contained within a single housing. This reduces the risk of the cameras becoming misaligned.

Other Underwater Survey Capabilities

CMST also has an active program in marine acoustics, including projects relevant to underwater survey. A High Precision Acoustic Survey System (HPASS) has been used to map a variety of underwater structures including the wreck of the *Pandora* on the Great Barrier Reef and the foundations of a 4th Century Roman bridge over the

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[2] Camera separation will also have a maximum limit in measurement applications but this will be based on the nature of the environment you are photographing, and the amount of deviation that can be tolerated between the stereo-pair images before it becomes too hard to identify common (homologous) points between the two images.

river Mass at Maastricht. Of relevance to fisheries and benthic habitat survey are a series of projects in fisheries acoustics. CMST undertook an extensive program of acoustic target strength measurement as part of the Australian Antarctic research program in the 1990's. This contributed to a reformulation of the acoustic backscatter vs. biomass relationship for Antarctic krill and hence to the assessment of krill biomass in the region. Several current projects involve the use of acoustics in seabed assessment. One project uses side-scan sonar data to provide numeric descriptors of bottom roughness. Two others, with CSIRO DMR, are exploring the use of echo sounder data and swath sounder data to provide seabed descriptors for comparison with benthic trawl and photographic data.

Conclusion

Video technology is currently undergoing a revolution with the widespread availability of digital video cameras, the introduction of firewire (serial digital video interface standard – IEEE1394), and the implementation of digital video broadcast and HDTV in Australia in January 2001. As has been explained, stereoscopic video offers many advantages in the underwater environment and CMST is keen to work with external clients on the use of stereoscopic video using these new technologies in new underwater applications.

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