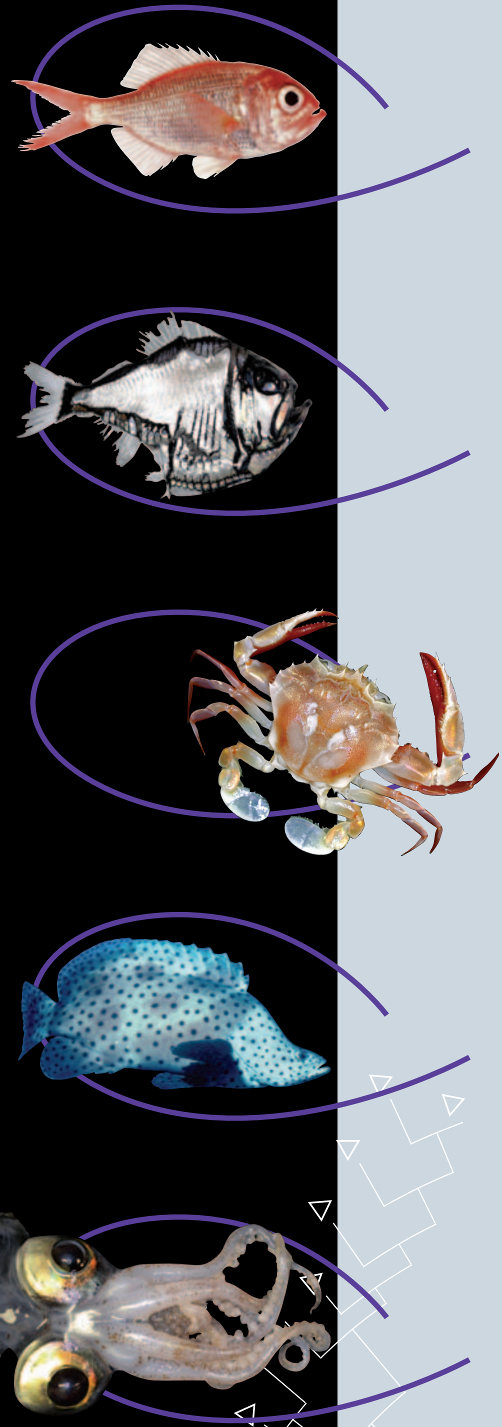

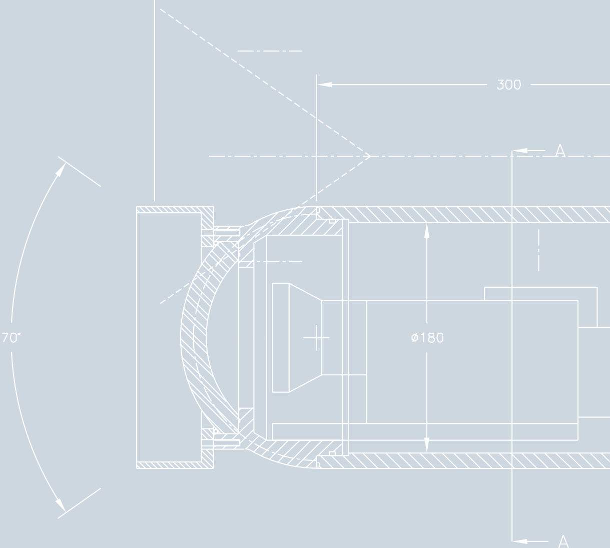

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2006

Workshop Proceedings

CUTTING-EDGE TECHNOLOGIES IN FISH AND FISHERIES SCIENCE

28-29 August, 2006

Hobart, Tasmania, Australia

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President’s Foreword

According to its charter, the objectives of the Australian Society for Fish Biology are to ‘promote research, education and management of fish and fisheries in Australia and to provide a forum for the exchange of information’. The ASFB workshops play a key role in delivering these objectives, and the 2006 workshop theme of ‘*Cutting-edge Technologies in Fish and Fisheries Science*’ was a timely one. In the face of shrinking research budgets and increasing pressure on fisheries, the need to find smart and innovative solutions to research and management questions has never been more apparent. As fisheries management is becoming increasingly more sophisticated, so the science and research underpinning management must also be leading edge. There have been significant advances in recent years on a range of fisheries investigation tools and techniques, and Australian fisheries researchers have been at the forefront of a number of these.

Approximately 230 delegates attended the workshop, including a large number of students; the future of fisheries science. The workshop organising committee assembled an outstanding program of 28 international and national presenters covering a diversity of cutting edge techniques grouped under four themes:

- Tagging and tracking
- Underwater vision and hydro-acoustics
- Chemical techniques, and
- Data capture and management.

I particularly thank Ron O’Dor and Pamela Mace, for their stimulating Plenary addresses, and the other keynote speakers and panellists for their efforts. The 2006 organising committee, headed by Jeremy Lyle and Dianne Furlani, did a sterling job in ensuring the workshop ran smoothly, along with the timely production of the workshop proceedings. I am sure that all delegates will have emerged from the workshop with some new ideas for future studies and collaboration, and the prompt delivery of the workshop proceedings provides a valuable resource for both new and experienced players to build upon such ideas.

2006 also represented the 21st anniversary of the commencement of the ASFB workshop series, with the first workshop held in Melbourne in 1985 on threatened fishes. The workshop series has developed into a much anticipated fisheries event on the Australian calendar, with the workshop outcomes influencing fisheries science for many years.

The workshop series is reliant on the support of corporate and agency sponsors and I thank the Fisheries Research & Development Corporation for their continued support of the ASFB workshops. FRDC was again the Principal Sponsor for the 2006 workshop, along with twelve Major Sponsors and seven other Sponsors.

2006 also represented the milestone of 35 years since the Society was formed. In 1971 the ASFB started with 79 members, and has now grown to in excess of 500 active members. The strength of the Society is in its membership, and I encourage all members to actively participate in the business of the ASFB. This means not just attending the workshops and conferences, but also participation in the various committees and at the AGM.

Mark Lintermans
President
Australian Society for Fish Biology

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Wrap-Up Session - Colin Buxton (Chair)

K. Radway Allen Presentation

Workshop Overview

Tasmania, as a major centre for marine research, was a fitting place to hold the ASFB Workshop 'Cutting Edge Technologies in Fish and Fisheries Science'.

Fisheries science now places a greater reliance on technology than ever before. The rapid global expansion in the development and application of technology enables information to be captured and interpreted in new and exciting ways. The wealth of data captured by these new techniques, their potential uses and the ways that data need to be managed, are also reliant on developing technologies.

The primary objective of this Workshop was to showcase and identify new techniques and technologies that enhance research capacity in fish and fisheries science. Secondary objectives were to identify opportunities to further develop research capacity and to consider the challenges and benefits that these opportunities may present.

The Workshop also provided an opportunity to identify emerging science-industry partnerships, and the potential for new collaborations between institutions and disciplines. It was hoped that cross-theme linkages would become evident, advancing the uses and application of available techniques. The limitations and associated pitfalls of technology were also worthy of deeper discussion, and would contribute to a fuller understanding of the future needs and directions in fish and fisheries science.

Workshop themes were:

- Tagging and tracking
- Underwater vision and hydro-acoustics
- Chemical techniques, and
- Data capture and management.

Each day of the Workshop commenced with a Plenary Address:

- *Ron O'Dor*, Census of Marine Life (day 1); and
- *Pamela Mace*, New Zealand Ministry of Fisheries (day 2).

Keynote speakers for the four themes were:

- Tagging and tracking – *Alistair Hobday*, CSIRO Marine & Atmospheric Research/ University of Tasmania;
- Underwater vision and hydro-acoustics – *John Penrose*, Curtin University;
- Chemical techniques – *Bronwyn Gillanders*, University of Adelaide; and
- Data capture and management – *Bruce Wallner*, Australian Fisheries Management Authority.

Within each theme area, invited panellists presented overviews and examples of specific technology applications. Presentations were followed by discussion sessions, in which the following steering questions were posed:

- How does the range of technologies presented deliver opportunities for the discipline?
- Why do these technologies offer better solutions?
- Can these technologies fully replace more traditional methods?
- What's the take-home message – where to from here?

Dianne Furlani
Workshop Convenor

Plenary and Keynote Speakers

Plenary Speakers

Ronald O’Dor

Consortium for Oceanographic Research and Education, Washington, DC, USA and Dalhousie University, Halifax, Nova Scotia, Canada

Currently Census of Marine Life (CoML) Senior Scientist, after degrees in biochemistry and medical physiology, a post-doc at Cambridge University and Stazione Zoologica, Naples, turned him to cephalopods and marine biology. Studies on cephalopod behaviour and physiology in nature using acoustic telemetry led to involvement in large scale tracking arrays. Within CoML he is developing the Network of Oceanic Acoustic Code Systems (NOACS) to monitor marine animals from 20g salmon to 20MT whales with arrays to detect globally unique codes. Tags lasting up to 20 years give new time-series perspectives on changes in individual movements in response to climate change.

Pamela Mace

Chief Scientist for the New Zealand Ministry of Fisheries

Pamela Mace is the Chief Scientist for the New Zealand Ministry of Fisheries. She has been involved in the field of fisheries science for 25 years, including several years of research and study in Canada and the United States. Her main areas of expertise are fish stock assessments, the development and implementation of fisheries harvest strategies, ecosystem approaches to fisheries, and the development of criteria for defining species at risk. She has chaired numerous working groups and task forces and published many papers and technical reports on these and related topics.

Keynote Speakers

Alistair Hobday

Senior Research Scientist, Pelagic Fisheries and Ecosystems Stream, CSIRO Marine and Atmospheric Research
Lecturer, School of Zoology, University of Tasmania

Alistair Hobday completed a BSc (Hons) in Biological Science at Stanford University, a PhD in Biological Oceanography at the Scripps Institution of Oceanography, and held a National Research Council Postgraduate Fellowship at the Pacific Fisheries Environmental Laboratory in Monterey, California. He is a Senior Research Scientist in the Pelagic Fisheries and Ecosystems Stream, at CSIRO Marine and Atmospheric Research, and a lecturer in the School of Zoology, University of Tasmania. His research includes spatial management, movement and migration of large pelagic species; environmental influences on marine species; and the impacts of climate change on marine resources. He has led a multi-year study using acoustic monitoring techniques to evaluate the migration paths of juvenile southern bluefin tuna in southern Western Australia. Recently he has been developing risk assessment methods for Australian fisheries, and advising the Marine Stewardship Council on methods for assessing sustainability of marine fisheries. Alistair has been an invited reviewer of several international programs, including the NMFS white abalone recovery program, and the Northeast US regional tagging program. He is a member of the steering committee for the international GLOBEC program CLIOTOP (Climate Impacts on Top Ocean Predators).

John Penrose

Manager, Coastal Water Habitat Mapping Project, CRC for Coastal Zone, Estuary and Waterway Management

John Penrose has spent most of his academic career in physics applied to marine science and technology. His major research interest has been in marine acoustics, with projects and publications in fisheries acoustics, seabed assessment and low frequency propagation. He was the founding Director of the Centre for Marine Science and Technology at Curtin University and is now completing a three year term as Manager of the Coastal Water Habitat Mapping Project of the CRC for Coastal Zone, Estuary and Waterway Management. He is a Councillor of the Australian National Maritime Museum and a member of the Western Australian Marine Parks and Reserves Authority.

Bronwyn Gillanders

Lecturer, School of Earth and Environmental Sciences University of Adelaide

Bronwyn Gillanders lectures at the University of Adelaide. She was a recipient of a Tall Poppy Science Award in 2005. Since completing her PhD at the University of Sydney in 1996, she has held an ARC QEII Fellowship (University of Adelaide), an ARC APD Fellowship (University of Sydney) and a research position at NSW Fisheries. Her research focuses on aquatic ecology, with a strong emphasis on fish and fisheries ecology. She is particularly interested in the use of chemical signatures (e.g. trace elements and isotopes) in organisms to track movements, determine population structure, identify population replenishment, and evaluate past environmental histories. Her current research projects involve determining population structure and movements of the giant Australian cuttlefish to help resolve conflict between ecotourism and fisheries, investigating methods for discrimination of hatchery-reared and wild fish to assist aquaculture and restocking, and determining population replenishment and movements of fish for fisheries management.

Bruce Wallner

Senior Manager, Australian Fisheries Management Authority

Bruce Wallner is the Senior Manager – Research and Data, at the Australian Fisheries Management Authority. In this capacity he is responsible for the provision of all data acquisition programs for Commonwealth fisheries such as logbooks and observer services, as well as research activities required for management. Gathering data from fishing boats at sea opens up opportunities for innovative electronic solutions. Bruce currently leads a number of projects making exciting headway in this area. Bruce has been involved in fisheries as a deckhand, biologist, fisheries scientist, consultant, manager and service provider for the past 25 years. He has a broad knowledge, a love of fisheries and a keen interest in the information needed to manage fisheries sustainably.

Plenary Presentations

Tracking marine species – taking the next steps

Ron K. O'Dor*[1]*, *M. Stokesbury*[2] *and G.D. Jackson*[3]

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Abstract

Media coverage of the recent founding meeting for the Ocean Tracking Network (OTN), referred to it as 'the Internet for fish.' The analogy is apt because, as with the Internet, a global group of users is pressing for standards and protocols to allow universal storage and sharing of a broad spectrum of information. Also like the Internet, once society makes a significant investment and stabilizes the playing field, industry will be able to invest, secure in the understanding that new products they develop with remain compatible with a wide-spread system. Here we summarize some recurring themes from tracking and telemetry workshops around the world - ways that industry believes it can deliver a picture of the complex interactions of physics and biology that are the world's oceans. This is a picture that scientists and managers need in order to protect and restore ocean productivity.

Introduction

Ocean biological science is now moving forward on a number of fronts with regard to monitoring animal movements and tracking migration pathways of important and iconic species. A major facilitator of this work is the Census of Marine Life (CoML) which is an international program designed to assess and explain marine life's diversity, distribution and abundance. This is a decade long program (2000-2010) which is worldwide in scope and involves over 70 countries in three data assembly and 14 field projects. The UN Intergovernmental Oceanographic Commission (IOC) has recently noted the progress of the CoML as an important tool for the international community to gain information on marine life. The IOC has encouraged member states to take an active part in the census and urged them to support active participation, with a view to contributing to the achievement of the goals of the Census of Marine Life by 2010 (IOC-XXIII/3).

Modern ocean observing and the tracking of important marine species have been greatly facilitated by ongoing technological advances and miniaturization in marine technology. The CoML has two projects devoted exclusively to the distribution of marine organisms; the Tagging of Pacific Pelagics (TOPP; www.toppcensus.org) based in California and Pacific Ocean Shelf Tracking (POST; www.postcoml.org) based in British Columbia. The Ocean Tracking Network (OTN; www.OceanTrackingNetwork.org) based in Nova Scotia is a new worldwide initiative to globalize biological tracking across all continents. The OTN will also result in a synthesis of both TOPP and POST and facilitate a new generation of biological tracking technologies (Holden 2006).

Understanding how marine organisms use their environment and delineating the scale and timing of important ocean migrations is critical for fisheries management, conservation of critically endangered species and for ecosystem management. Current technological innovations are providing for this. Proposed innovations will take this to a new level. Recent insights into large pelagic species reveal that transoceanic migrations are taking place (Bonfil *et al*. 2005, Block *et al*. 2005). Thus ocean management needs to take on an increasing global focus.

The POST project is based on deploying acoustic listening stations that record the passing of a uniquely coded organism that carries a sonic tag. For POST these receivers are placed in lines, also known as 'curtains', in strategic locations on the continental shelf or even in rivers to track the freshwater phase of diadramous fish (Welch *et al*. 2003). By building a continental scale array it is possible to not only determine home/feeding regions, and direction and timing of migrations but to also obtain critical stock characteristics such as freshwater and marine mortality rates. By placing 'curtains' in a series perpendicular to migrations, it is possible to identify areas in the ocean where mortality of certain species is high. Large scale tagging can also differentiate between freshwater arrival times of critically endangered versus healthy salmon stocks. So, in the future this technology will provide the level of resolution necessary for real time fisheries management. Furthermore, the value of POST for conservation has been recently demonstrated by detecting the unanticipated movement of rare white sturgeon that migrated over 1000 km along the western seaboard of North America, and resided in two very different riverine environments (Welch *et al*. 2006).

POST-like arrays of acoustic monitors have also been deployed in southeast Tasmania and have revealed important movement patterns of squid (Stark *et al*. 2005, Pecl *et al*. 2006). In Hawaii, acoustic monitors are in place along the entire archipelago (a distance of over 2200 km) and acoustically tagged tiger sharks (*Galeocerdo cuvier*) have been detected moving throughout the length of the island chain (Holland, unpublished data). Similarly, all of the fish aggregation devices (FADs) surrounding the island of Oahu, Hawaii, are equipped with acoustic monitors and this instrumented array is demonstrating the movement patterns and residence times of yellowfin and bigeye tuna within this array (Dagorn *et al*., in press)

The TOPP program uses different technologies to track large marine vertebrates and squid in the oceanic realm. The technologies used include a variety of archival tags providing geolocation, environmental and physiological records as well as Argos satellite tags that can be location-only tags or pop-up satellite archival (PSAT) tags (Block *et al*. 2003). TOPP has provided an amazing level of resolution of where animals spend their time in the open ocean across 1000s of kilometres and has pinpointed important feeding and spawning locations (Weng *et al*. 2005).

Taking the steps to the new technology

OTN plans to not only build on both POST and TOPP technologies, but to take ocean tracking to the next level by marrying both technologies for obtaining high resolution data on migrating animals in the ocean (Figure 1).

Step 1: First generation Business Card tags

To understand the 'business card tag' (BC), imagine a miniaturized 'Vemco VR2 receiver' (e.g., Heupel *et al*. 2006), that records an acoustic code when the predator carrying it comes near another tagged species, while also transmitting its own code. These types of tags would be ideal for quantifying the degree of school fidelity (or conversely, mixing) in schooling fish such as tunas, salmon or cod or for indicating when one species interacts with another such as when marlin associate with tuna schools. If these interactions occur near an acoustic monitor (such as one located on a FAD) it will also be possible to know the geographic location as well as the timing and frequency of these interactions. Similarly, if predators compete for the same prey this will be recorded. If a predator eats tagged prey, it will be detectible as the receiver will continually record the presence of the prey tag for a period of time while the tag resides within its digestive system. So, the predator becomes a mobile receiver 'platform', swimming around and recording its interactions in the ecosystem. Basic research and development of BC tags is being developed in a joint venture between Vemco and the Pelagic Fisheries Research Program at the University of Hawaii. A description of the business card concept and project outline is at http://www.soest.hawaii.edu/PFRP/biology/dagorn_business_tags.html. Coded tags could also be used as beacons in particular locations to provide additional geography. But, the biggest limitation of the BC tags is the lack of continuous information about where the interactions happen, especially in the open ocean.

Step 2: Double-tagging with BC tags and Geolocating archival tags to create first generation ocean-ecosystem platforms – the North Pacific Arena

The advantage of combining both archival and acoustic tag technology was initially demonstrated with cephalopods where individuals were tracked with acoustic tags that were physically glued to archival tags (Jackson *et al*. 2005). This enabled individual movements of tracked animals to be correlated to environmental depth and temperature and allowed a dramatic increase in archival tag recovery. The geolocation limitation of BC tags can be overcome most simply by a similar approach - double-tagging a single animal platform with both a BC tag and a Lotek geolocating archival tag. Combining predator-prey and environmental data with movement data will give us the clearest picture ever available of how organisms use the aquatic environment.

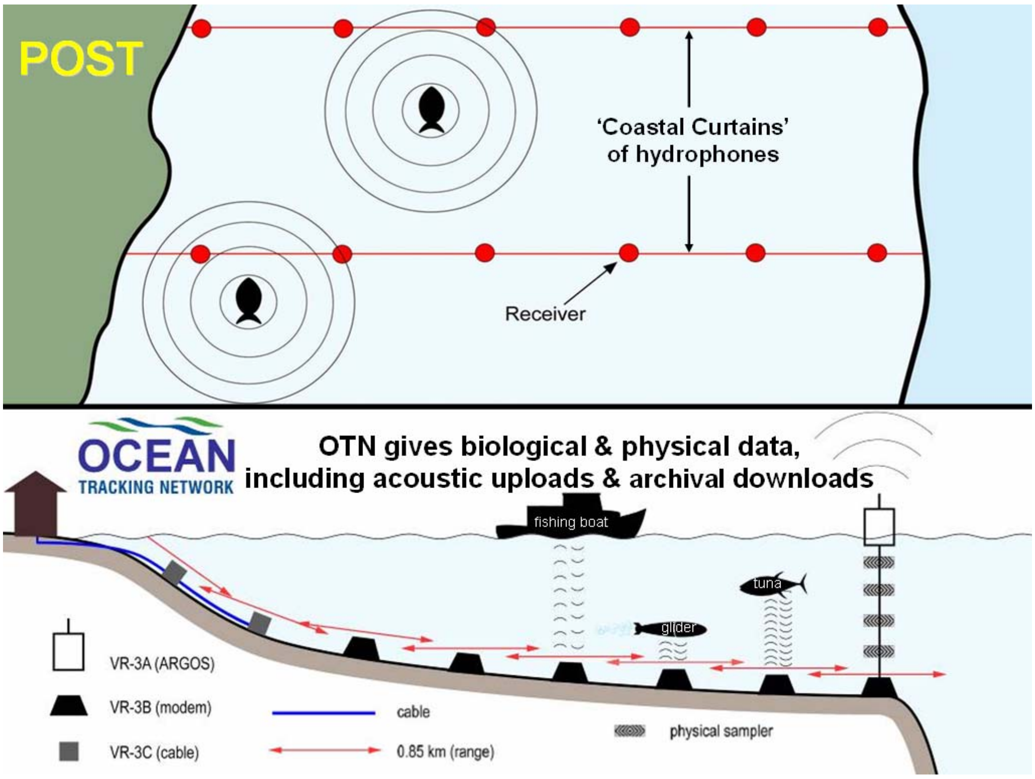

Figure 1: The OTN extends the Coastal Curtain concept of POST to create an integrated system for collecting physical oceanographic and biological information from oceans throughout the world.

A convenient species for testing this technology will be salmon sharks (*Lamna ditropis*) in Prince William Sound (PWS) Alaska. They have been used in a number of multi-tag tests, cross-calibrating geolocation and satellite triangulation technologies (see Weng *et al*. 2005). These sharks spend considerable time in PWS and then make large-scale migrations out of the sound to subtropical waters as far away as Hawaii. However, they routinely return to PWS. This research is revealing that salmon sharks show repetitive behaviours by migrating into the same oceanic habitats in consecutive years (Weng *et al*. 2005 supplementary information). This suggests the possibility that salmon sharks are migrating to particular 'home' feeding grounds where they know there will be prey. Salmon sharks are named after their prey, and perhaps they have a favourite stock of salmon that they feed on at sea that has already been tagged with an acoustic code by the coastal POST project. Decades of traditional salmon tagging has suggested that different salmon stocks are distributed differently in the Alaska Gyre (McKinnell 1995). Perhaps certain salmon shark individuals or stocks are tied to specific salmon stocks that reside in specific feeding grounds in the open ocean. This hypothesis can be tested by equipping salmon sharks with BC and archival geolocating tags, and determining if they interact in the open ocean with salmon stocks that have been tagged with acoustic tags during the POST project. This spatial-temporal targeting of specific prey is reminiscent of sooty shearwaters that migrate between the northern and southern hemispheres in continual summers to access food resources (Shaffer *et al*. 2006).

Summarizing, a salmon shark double-tagged in PWS swims out into the Pacific and continually records its geolocation, light and temperature profiles in the archival tag. The BC tag records any interactions it has with potential prey or other tagged species. Eventually the shark returns to PWS where it passes near a receiver at the narrow entry to the Sound. Knowing that the shark is in the

Sound, it can be pursued and recaptured in order to obtain the archival data. Data from the PWS receivers can be uploaded periodically via an acoustic modem or possibly in real-time via a cable, phone or satellite link. When the 'business card' tagged shark is picked up we need to re-locate it in order to recover the tags. We cannot manually search for our tagged salmon shark as its acoustic tag is pinging at long intervals, not easily detected or tracked with a vessel, so, there is a code-sensitive mode switch built in. We lower a powerful transmitting tag over the side of the boat that has a much longer range than a tag. When the shark's BC tag hears this particular code, it changes from infrequent codes to more frequent and powerful pings. We can then start manually tracking our business card tagged shark and recapture it to obtain the archival information and integrate the data sets for a full picture.

Step 3: Fast CHAT tags

Current Vemco CHAT tags have been successfully tested for their ability to archive and time stamp data and then download the stored data from free-swimming fish via 'acoustic modem technology' as they swim past underwater receivers (Holland *et al*, 2001). However, in its original format, this data transfer technology is quite limited. Fast CHAT will utilize spread spectrum technology to allow downloading of additional data like that on predator-prey interactions. This will also require changes in receivers, but should allow key data to be downloaded from animals that spend relatively little time near a receiver. When the predator crosses a curtain of acoustic monitors on the shelf it will download at least the most import archival data to be stored and recovered. Similar data summarization strategies are used now in satellite transmissions, but if the animal platform stays near a receiver long enough, it can dialog with the receiver until all data is captured or it can continue downloading at the next receiver it passes.

Step 4: Developing fully integrated tags that download archived business card and geolocation data to enhanced 3rd generation acoustic monitoring receivers – the North Atlantic arena.

The final step in the innovation of this technology is to totally integrate the business card tag, archival geolocating tag, and fast CHAT tag into a single tag that will store measurements of physical variables of the water column including light used for geolocation, and biological interaction data. When the animal carrying this tag swims over the acoustic receiver we will retrieve all of these data types. We then have data on where the predator went, how it behaved in the environment and what other individuals it interacted with or ate, and there is no need to re-capture the animal. In a sense, what is eventually created by this technology and its expansion across continental shelves, seamounts (Klimley *et al*. 2005) and oceanic fish aggregating devices FAD's (Dagorn *et al*. 2006) is a complete underwater Argos system independent of satellites. Many more species and individuals will be able to be tagged with increasingly smaller tags and archived data will be obtainable at a fraction of the cost.

The test case for the fully integrated tag (FIT) will be the North Atlantic. Many wild Atlantic salmon (*Salmo salar*) stocks are endangered on the Atlantic coast of North America. Salmon from North America migrate into the North Atlantic up toward Greenland and then disappear (Anderson *et al*. 2000). Seals from rookeries in North America also swim into the North Atlantic searching for salmon and other prey (Austin *et al*. 2004). The Atlantic coast of North America has a very wide continental shelf, and in some places it is not practical to construct a POST-type continental-scale array in this part of the world. However, the new business card technology can overcome this problem by using seals as mobile acoustic receivers to record where tagged salmon are in the North Atlantic. Furthermore, tag life is expected to last for a number of years (some may last 20 years). Thus, instead of a series of continental shelf 'curtains' as deployed by POST in the Pacific, the Atlantic equivalent will be a navy of seals (and other predators) armed with fully integrated tags, FITs. This navy of predators will continually collect critical data on movements of important prey species across the North Atlantic and download this data to strategically located new generation receivers, cables, cell phones or satellites.

Thus, the ultimate vision of the Ocean Tracking Network is to take older technologies that have done things separately and integrate them to new technologies that can do things together. These are only a few examples to illustrate the thousands of opportunities to better understand how animals use the ocean over the global expanse of OTN as indicated in Figure 2. Furthermore, the oceanographic sensors included with this technology enable large pelagic organisms to act as mobile oceanographic collecting platforms to also give us a clear picture of the structure and dynamics of the oceans themselves (Benfield *et al*. 2005).

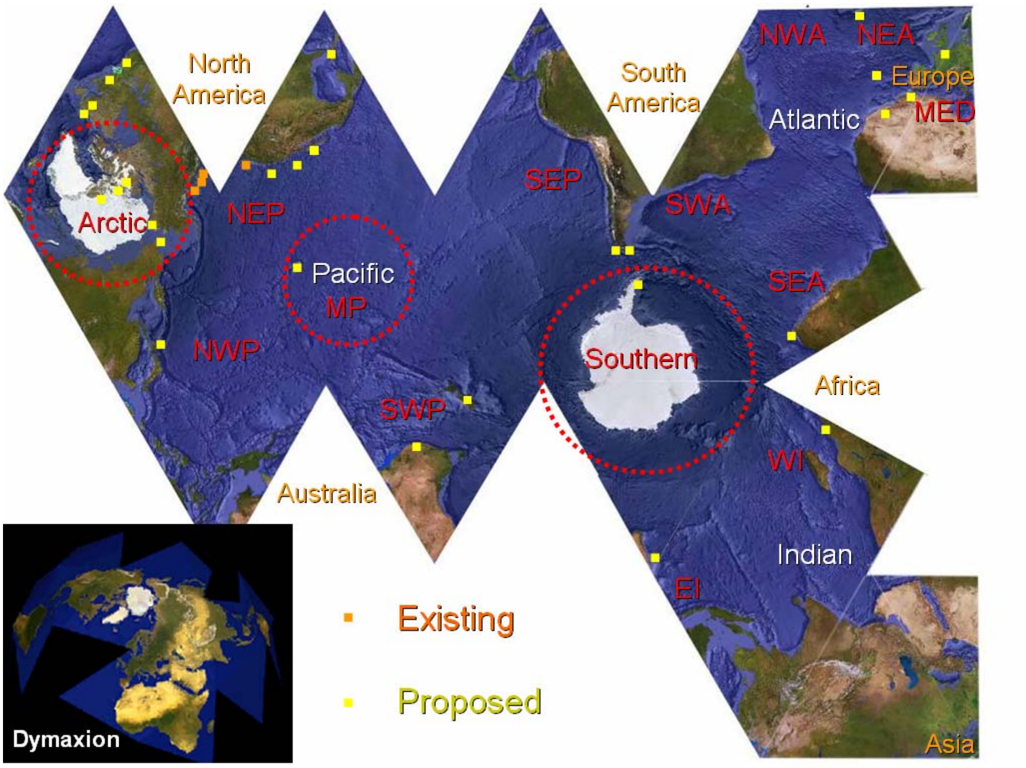

Figure 2: The Dymaxion projection unfolds from a spherical dodecahedron to represent the Earth with 95% spatial accuracy (Inset). The projection above emphasizes the oceans and their connectivity. The OTN will add to the existing POST network in 14 Ocean Regions giving a global perspective on ocean and animal movements.

Elephant seals have provided more CTD profiles of the North Pacific and Southern Oceans than Argo floats (Pala 2006, Palaciosa *et al*. 2006) in near real-time by diving a dozen times per day to hundreds of meters. They work in areas where nothing else can, for example under ice. Tuna dive to even greater depths, but tags cannot communicate directly to satellites because they do not surface (Stokesbury 2004). It would be much simpler if the animals could report such data acoustically without leaving their marine environment. To cover the full depth of the ocean there is another challenge – much of the ocean receives so little light that solar geolocation will not work. There is a looming technical solution – tags that record the precise arrival time of powerful low frequency beacons to triangulate their positions (Recksiek *et al*. 2006). Applications for such tags would be limited, if they had to be recovered, but not if their data could be downloaded acoustically along with everything else! We imagine Greenland sharks, also proven double-tag platforms (Stokesbury, 2005), patrolling the pitch black ocean floor reporting on their ocean and their neighbours.

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Technological needs for fish stock assessments and fisheries management

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Abstract

This paper focuses on four areas related to the theme of cutting-edge technologies, all of which are highly relevant to conducting reliable and robust stock assessments and implementing credible fisheries management: (a) cutting-edge technologies for providing robust and informative input data to stock assessments (e.g., relative or absolute biomass, size and/or age composition of the stock, stock structure and stock dynamics), (b) cutting-edge stock assessment modelling technologies and management paradigms; (c) cutting-edge technologies in compliance monitoring; and (d) cutting edge technologies for mitigating wasteful bycatch in fisheries.

The single-most important technologies for producing reliable stock assessments are those that enable us to ‘see’ and identify fish. These technologies are developing rapidly, but research survey results will always be subject to considerable uncertainty until we are able to see fish as well as we can see trees. Exponentially-increasing computer power has allowed new stock assessment modelling techniques to be developed and applied. These are immensely helpful in incorporating and *characterising* uncertainty, but *reducing* uncertainty in key model inputs is still the greater need.

The current move towards ecosystem approaches to fisheries has necessitated consideration of all species impacted by fishing, along with habitats. As well as optimising yields of target species, we need to avoid, remedy or mitigate adverse effects on non-target species and the rest of the ecosystem. This has created new fields of compliance and gear technologies designed to detect and reduce fishing practices that are detrimental to various components of marine ecosystems. For the most part, technologies to exploit fisheries resources have evolved faster than, and often without regard for, technologies to minimise secondary effects of fishing.

One challenge for the future is to make technology sufficiently cheap that its use in fisheries research and management can be cost-effective. For this to happen, there needs to be sufficient incentives and demand for particular technologies. A factor that is creating both the incentive and demand is the public’s increasing awareness of the opportunities and limitations of marine resources. As a result, governments and private institutions are funding large-scale survey programmes (such as the Census of Marine Life) and related research that are likely to further advance the development of appropriate research tools.

Key Words: Stock assessments, fish surveys, fisheries management, technological needs, compliance monitoring, Atlantic bluefin tuna, orange roughy

Introduction

This paper focuses on four areas related to the theme of cutting-edge technologies, all of which are highly relevant to conducting reliable and robust stock assessments and implementing credible fisheries management: (a) cutting-edge technologies for providing robust and informative input data to stock assessments, (b) cutting-edge stock assessment modelling technologies and management paradigms, (c) cutting-edge technologies in compliance monitoring, and (d) cutting-edge technologies for mitigating wasteful bycatch in fishing operations.

Robust and informative input data

The single-most important technologies for producing reliable stock assessments are those that enable us to ‘see’ and identify fish. These technologies are developing rapidly, but research survey results will always be subject to considerable uncertainty until we are able to see fish as well as we can see trees (although estimates of forest biomass can also be problematic). Being able to see and identify fish is essential for determining stock abundance and distribution. Commercial catch per unit effort (CPUE) is the most common, and often the only, source of information on stock abundance and distribution. However, there are many problems associated with using CPUE from commercial operations. In particular, the relationship between CPUE and abundance may not be linear and catchability may vary considerably between tows, depending on net configuration and deployment. Technological improvements in fishing methods have been so rapid that fishers can maintain high catch rates even as stocks decline (hyperstability: Doonan 1991, Clark 1996). The opposite problem, hyperdepletion (Hicks 2004), may occur for newly-exploited stocks due to disturbance and dispersal effects. While there is considerable innovative work currently underway to examine catchability (e.g. with cameras on trawl wings or sleds) and the effects of net configuration on catch rates (e.g. using electronic sensors for doorspread and headline height; Eayrs 1995), the fundamental problem of non-linearity between CPUE and abundance is likely to continue to be difficult to resolve.

Fishery-independent trawl surveys are generally a much more promising method of indexing abundance and distribution and there are long and valuable time series in several parts of the world (e.g. at the Northeast Fisheries Science Center of the U.S. National Marine Fisheries Service, www.nefsc.noaa.gov/sos/agtt/). However, the utility of trawl surveys is limited for species that form large and dense aggregations (Clark 1996, 2005).

Techniques for acoustic surveys have developed rapidly in the last few decades and they are now used routinely for several small pelagic species (Simmonds 2003, Jech 2004,). The expansion of acoustic methods into deepwater has also progressed considerably over the past 10-20 years, led primarily by New Zealand and Australia (Do and Coombs 1989, Elliot and Kloser 1993, Kloser *et al.* 1994). All acoustic methods have uncertainties associated with target strengths, shadow zones on sloping bottom, sound absorption in the water column and other factors (Ona and Mitson 1996, Rose *et al.* 2000, Boyer and Hampton 2001, Doonan *et al.* 2003, O'Driscoll 2004, Simmonds and MacLennan 2005). They often do not work well when the target species is mixed with other species (Clark 1996, Barr 2001, O'Driscoll 2003).

Other developing techniques for estimating stock abundance and distribution include statistically-designed tagging experiments, camera technologies for species identification and species composition of aggregations (e.g. towed camera systems on remotely operated vehicles (Koslow *et al.* 1995) and cameras attached to grabs), and combinations of acoustics and cameras (Ermolchev and Zaferman 2003, Rose *et al.* 2005).

Lack of visibility of fish is not the only thing that makes it much more difficult to assess fish stock status than it is to assess the status of forests. It is also important to understand stock structure and stock dynamics (including stock movements and mixing). Mitochondrial DNA, microsatellites, microconstituents analysis, isotope analysis, conventional tags, PIT tags, radio tags, acoustic tags, data storage tags (e.g. implantable archival tags, pop-up satellite archival tags (PSAT), and combined archival-acoustic tags) and genetic tags (Buckworth *et al.* 2007) are all being used with variable success to address these issues. Data storage tags offer a promising avenue for collecting more information on the movement patterns of individual fish, but are currently too expensive to obtain quantitative estimates of spatial dynamics and mixing.

Finally, as was discovered with orange roughy in New Zealand, it is not enough to be able to estimate abundance and distribution; it is also imperative to have reasonable estimates of stock productivity (Mace *et al.* 1990, Clark 1995, Francis and Clark 2005). Robust estimates of long-term sustainable yields are a function of both biomass and productivity. In the early days of the orange roughy fishery in New Zealand, scientists, managers and fishers alike were fooled by the large biomass and dense aggregations, implicitly equating high biomass with high productivity. In fact, fisheries scientists thought they were taking a conservative approach by assuming life history parameters that were similar to or lower than averages used for other temperate water teleosts (e.g. a natural mortality of 0.1, a Brody growth coefficient of 0.2, and ages of maturity and recruitment of 5; Robertson 1986, Robertson and Mace 1988). Subsequently, a partially-validated ageing method was developed (Mace *et al*. 1990) and this and later work has led to the conclusion that natural mortality is likely to be less than half the 'conservative' value previously assumed, the Brody growth coefficient is of the order of 0.06, age of maturity is about 25-30 and maximum age is probably in excess of 120 years.

The key biological (life history) parameters that have a strong influence on productivity are natural mortality (which is often approximated using longevity considerations, and can be further addressed to some extent by conventional and electronic tagging, as well as trophic studies and multispecies modelling (e.g. Multispecies Virtual Population Analysis; Vinter 2001)), the age or size of maturity, and the frequency of spawning (addressed in part by improved imaging techniques for histological sections), and growth and longevity (addressed by various ageing technologies including imaging software (Lagardère and Troadec 1997, Morison *et al.* 1998, Guillaud *et al*. 1999), radiometric methods (Fenton *et al*. 1991, Smith *et al.* 1991, Kimura and Kastelle 1995, Andrews and Tracey 2003, Stevens *et al*. 2004), and bomb radiocarbon studies (Kalish, 1993, Thorrold *et al*. 1997, Campana 1999, Begg and Weidman 2001, Campana and Thorrold 2001).

Two case studies

Two species will be used to illustrate some of the data needs in stock assessment and management: Atlantic bluefin tuna (*Thunnus thynnus*) and orange roughy (*Hoplostethus atlanticus*). The focus for the latter will be mainly on New Zealand stocks but most of the conclusions will be applicable to all fished orange roughy stocks. The question to be addressed is: what are the key data needs to better inform stock assessments and management for these two species?

Atlantic bluefin tuna

For several years, one of the key uncertainties in the assessment and management of Atlantic bluefin tuna has been whether there is one stock with two main spawning grounds or two biologically-distinct stocks. There are two known major spawning grounds: in the Gulf of Mexico (the western 'stock') and in the Mediterranean (possibly 3 or more spawning areas that may or may not be biologically distinct: the eastern 'stock'). Atlantic bluefin tuna grow to over 3 m and may weigh more than 650 kg. The age of maturity is about 8 years in the west and 4-5 years in the east. Maximum age is at least 20 years. Recent reported catches have been about 2000 t in the west and 27,000 t in the east (ICCAT 2005). There is severe overfishing in both areas, and the western stock has been in a depleted state since the 1980s. Western fishers seem to stay more or less within the ICCAT-determined quota, whereas there is rampant overcatching of the quota and misreporting in the east (WWF 2006).

Conventional tagging has shown that bluefin tuna routinely cross the Atlantic in both directions (Sissenwine *et al*. 1998). Even so, Atlantic bluefin tuna have been assessed and managed as two separate stocks to date, primarily because there are still major uncertainties about when, why, and how often the stocks mix. Historically, almost all conventional tagging was done in the west, and most of the recaptures were in the west. One reason it is difficult to quantify trans-Atlantic crossings is because it is known that reporting rates of recovered tags in the east have been poor. Western fishers have argued that the assessments would be more optimistic if mixing were to be taken into account, and that overfishing in the east may be impeding rebuilding of the western stock (Magnuson *et al.* 2001). Thus the extent of mixing and the extent of spawning site fidelity need to be determined to effect improved management and to hold ICCAT member countries accountable for reducing overfishing and rebuilding the depleted western stock.

Recent work by Barbara Block and colleagues (e.g. Block *et al*. 2005) using implantable archival tags and PSAT tags strongly suggests natal fidelity, along with frequent crossings and considerable mixing. Block *et al*. (2005) were able to distinguish between western breeders (n=36) and potential eastern breeders (n=26), but the majority of the bluefin tuna included in the analysis (n=268) did not visit a spawning ground. So far, the results from these tagging studies have mostly been used as a basis for constructing alternative models or hypotheses rather than for direct estimation. Results from mixing models developed in 2002 (the year of the most recent Atlantic bluefin tuna assessment at the time of this paper) suggested that the stock size in 1970 at the beginning of the assessment was considerably lower, and the subsequent decline considerably less precipitous, than runs that ignored mixing

(ICCAT 2003). No doubt new stock assessments being conducted in 2006 will make more extensive use of the data derived from the implanted and PSAT tags.

Several researchers (e.g. Secor *et al*. 2002, Rooker and Secor 2003) have been investigating the utility of microconstituents analysis as a tool for discriminating between the western and eastern stocks. This tool seemed promising in initial trials but proved to provide inadequate levels of discrimination (60-80%) between known juveniles of the two stocks. Rooker and Secor (2003) are now pursuing stable isotopes (δ^{13}C and δ^{18}O) as an alternative tool. Recent trials have suggested levels of discrimination of about 98% for stable isotopes (Rooker and Secor 2003).

Orange roughy

A considerable amount of research has been conducted on orange roughy stocks, particularly in New Zealand, Australia, Namibia and Chile, yet all of the traditional data inputs to stock assessment models seem to be fraught with problems (e.g. Clark 1996, 2005, Branch 2001, Boyer *et al.* 2001). Commercial CPUE is problematic for orange roughy because it often seems to decline too rapidly at the beginning of a fishery to be attributed to a fishing down effect alone while, after the fishing down phase, it may be maintained by improvements in methods of capture and locating new, previously untouched aggregations. Trawl surveys have been useful in certain circumstances, but their utility is questionable if most of the orange roughy are contained in large, dense aggregations that saturate the trawl net. For the last few years, New Zealand, Australia, Namibia and Chile have focused on acoustic surveys as the primary means of estimating stock biomass. However, orange roughy have an oil-filled swim bladder and, as a result, have a very low target strength (McClatchie *et al.* 1999, Kloser and Horne 2003, McClatchie and Coombs 2005) that may be swamped by other species with much larger target strengths when they occur in mixed species aggregations. In addition, there is no definitive estimate of their actual target strength with the two primary estimates (Kloser and Horne 2003, Barr and Coombs 2005) resulting in a 2-fold difference in biomass estimates. Finally, they are frequently found associated with undersea knolls or seamounts and often seem to be hard on the bottom, which means that a potentially large but unknown tonnage may occur in the acoustic shadow zone.

Improved acoustic methods (including tilted transducers that reduce the size of the shadow zone; Hampton unpublished), acoustic methods combined with camera technologies (for species identification), and more detailed and conclusive target strength investigations (including swim bladder modelling; Macaulay 2002) are needed to provide a sound basis for estimating absolute or relative biomass.

In terms of stock structure and stock dynamics, there are too many hypotheses and too few relevant or robust data to differentiate between them. Technology is only just now advancing to the point it might be possible to use in-situ tagging (e.g. Sigurdsson *et al.* 2006, www.star-oddi.com), high quality cameras and lighting systems, and combined acoustics and cameras to test some of these hypotheses against one another.

In terms of productivity, a considerable amount of research has been put into fish ageing (modal analysis; Mace *et al.* 1990, radio-isotope analysis; Andrews and Tracey 2003, and bomb radiocarbon; Neil *et al. in prep.*) and it has been possible to conclude with a high degree of certainty that growth is slow, the age of maturity is about 25-30, and maximum age is of the order of 120-150; however, production ageing has proven to be very imprecise and inconsistent, to the extent that it is impossible to estimate the number of new fish recruiting to the fishery each year. In fact, ageing has proven to be so imprecise and inconsistent that the New Zealand Ministry of Fisheries has recently decided to abandon the use of ages in orange roughy stock assessment models (Ministry of Fisheries 2006). Research into ageing will still continue, but at a reduced level. In the meantime, the hypothesis that recruitment has been minimal for the last decade or two cannot be rejected, and this is critical to assessing the long-term sustainability of the fisheries (Clark 2001, Francis and Clark 2005).

The inability to estimate recruitment (resulting in part from imprecise and inconsistent ageing data) is probably the main reason why several recent orange roughy assessments in New Zealand have been problematic. In particular, the most recent assessment of the largest orange roughy stock (East

Chatham Rise, Ministry of Fisheries 2006) must be considered an example of a failed stock assessment. The assessment predicts a substantial rebuild of East Chatham Rise orange roughy since the early 1990's, despite the fact that most indices of stock size have been declining over the period from the early 1990's to the present. Regardless of which recent datasets are included or excluded (or even if all of them are excluded) in model runs, the extent of the rebuild is similar; i.e. the assessment model is essentially insensitive to recent data. Model projections indicate that catches of the order of 9000-14,000 t are likely to be sustainable in the short term, yet some fishers are concerned that the fishing industry may not even be able to catch the current TAC of 7250 t.

Stock assessment modelling technologies and management paradigms

An exponential increase in computing power has been the key driving force behind the recent development of stock assessment modelling technologies. In fact, the sophistication of models has far outstripped the quality of the data inputs.

Stock assessment models have evolved from equilibrium models (e.g. stock production models, yield per recruit analysis and spawning biomass per recruit analysis), to simulation models, stochastic models and finally estimation models that are capable of synthesising data from several different sources (e.g. virtual population analysis and, more recently, Bayesian models). This evolution has resulted in an increased ability to examine alternative model configurations, and to represent uncertainty (Mace and Sissenwine 2002). Bayesian models enable prior knowledge or inferences to be combined with data on life history parameters and stock abundance. A study conducted by the U.S. National Research Council (NRC 1998) showed that if the data were of high quality, then to a large extent, it did not matter which models were used as the assessment of stock status and management implications tended to be similar.

The evolution of management paradigms has largely followed the evolution of stock assessment techniques and modelling ability. Initially, Maximum Sustainable Yield (MSY) was calculated from equilibrium models (with little or no acknowledgement of uncertainty). The next step was to calculate confidence intervals (CIs) around target reference points (exact or bootstrapped CIs). Fisheries managers then asked what risk there was in setting quotas based on the upper end of the confidence interval. When scientists were unable to quantify risk, managers often did use the upper end of the CI. This led to the evolution of techniques for risk analysis of the consequences of alternative management decisions, which are now routinely used in stock assessments and management decisions.

More recently, several international organisations – e.g. the International Commission for the Exploration of the Sea (ICES; ICES 2003), the Northwest Atlantic Fisheries Organisation (NAFO; NAFO 2003, Shelton *et al*. 2003), and the International Convention for the Conservation of Atlantic Tunas (ICCAT 2000) – along with a number of national fisheries agencies – e.g. the National Marine Fisheries Service, USA; the Department of Fisheries and Oceans, Canada; Australia and South Africa (Butterworth and Punt 2003) – have developed harvest control rules, which specify target and limit fishing mortalities and catches to be applied as a function of the estimated current biomass or CPUE. In many cases, these control rules have redefined what were previously fishing targets to now be limits, and have set targets to be more conservative than limits. In addition, most harvest control rules require fishing mortality to be reduced rapidly once stock size falls below some threshold value.

Another relatively recent development that has appeared over the last decade or so is Management Strategy Evaluation (MSE; Smith *et al*. 1996), also called a Management Procedure or Operational Management Procedure. MSE is a modelling technique that uses one or more operating models that reflect various hypotheses about the dynamics of the species in question, a management model and sometimes an assessment model to explore the profitability, sustainability and robustness of various management strategies based on different amounts and types of information. MSE has been employed by international organisations such as the International Whaling Commission (IWC; IWC 1994), ICCAT (ICCAT 2000), the Convention for the Conservation of Southern Bluefin Tuna (CCSBT; Polacheck *et al*. 1999), and in several countries including Australia (Sainsbury *et al.* 2000), South Africa (Johnston and Butterworth 2005) and New Zealand (Bentley *et al.* 2005).

The current move towards Ecosystem Approaches to Fisheries (EAF; FAO 2003) has necessitated consideration of all species impacted by fishing, along with habitats. This has amplified the need for a range of technologies to characterise habitat (e.g. swath mapping, camera techniques, and refinements of methods for sampling benthic organisms), to study trophic relationships (e.g. isotope analysis), to estimate bycatch mortality (e.g. enhanced observer programmes and on-board video cameras), and to examine the relationships between climate and the population dynamics of marine species. In addition, along with optimising yields of target species, we now need to avoid, remedy or mitigate adverse effects on non-target species and the rest of the ecosystem. This has created new fields of compliance and gear technologies designed to detect and reduce fishing practices that are detrimental to various components of marine ecosystems.

Compliance monitoring technologies

Compliance monitoring has made remarkable advances in the last 15 years, particularly with the advent of satellite technology and remote electronic monitoring techniques. Satellite technologies include Vessel Monitoring Systems (VMS), Global Positioning Systems (GPS) and electronic communication tools. Remote electronic monitoring can be conducted from patrol boats and from aircraft on surveillance operations, and has proven effective at detecting dumping and bycatch of protected species. Pin hole cameras installed on wharves can be used to film unloading operations and may be able to detect some forms of misreporting. Video monitoring onboard fishing vessels has also been trialled recently in several fisheries. Electronic Data Transfer (EDT) enables information to be transmitted from vessels back to shore for faster access to fine-scale fisheries information and provides opportunities for real-time management. Electronic logbooks have now been introduced into several fisheries throughout the world.

Finally, the field of forensic science is one of the newer developments in compliance monitoring. DNA, RNA and microsatellites are being used for species and stock identification, and chemical analyses (including microconstituents analysis) of shells, bones or cartilage are being used for determining the likely areas in which fish were caught. These techniques have been useful for detecting cases of species misreporting in the case of processed products such as fillets, and area misreporting in cases where quotas are split into geographic areas.

Bycatch mitigation technologies

Bycatch has many different meanings: bycatch of individuals of the target species that are smaller (or larger) than optimal; bycatch of non-target fish or invertebrate species that are commercially valuable, bycatch of non-target fish or invertebrate species that are not commercially valuable, and bycatch of marine mammals, seabirds and other protected species that have no commercial value, but have a high existence value to the public. Considerable work has been done on the avoidance of non-target commercial bycatch in shrimp and prawn fisheries (Hall and Mainprize 2005), but studies on other fisheries have mostly focused on technologies to mitigate bycatch of protected species.

One example of the latter is warp strike mitigation devices that have been developed to prevent seabirds coming in contact with trawl warp cables when the birds (primarily albatrosses and petrels) forage on fish discards and waste at the stern of trawlers (Sullivan *et al*. 2006). Many of these prove that not all technologies need to be ‘high-tech’. For example, tori lines have a fishing rope backbone with streamers made of a variety of types of plastic tubing, garden hose or other sturdy, brightly-coloured non-biodegradable material. The streamers hang vertically from the backbone at regular intervals of about 2-5 m, covering the area between the backbone and the water with a highly visible, moving curtain that acts as a deterrent to birds attempting to enter this zone. Warp scarers are also made of fishing rope along the backbone, but include ‘bristles’ or streamers that clip directly onto the warp. They tend to be difficult to operate as they often get wrapped around the warp and crew members may need to lean out from the back of the boat to untangle them. Bird bafflers are more intricate designs of rope and plastic rods or cones that hang from dedicated booms extending from the sides and stern of the fishing vessels. Protected species bycatch is usually a rare event and, as a result, quantitative studies on the effectiveness of protected species mitigation technologies are sparse. Variation in the effectiveness of mitigation devices can be considerable (Sullivan *et al*. 2006), and their effectiveness, and any adverse effects of the devices themselves, may vary between fisheries.

Mitigation devices that exclude turtles and marine mammals such as seals and sealions are somewhat more complex. These are usually installed in front of the cod-end of trawl nets. Sealion exclusion devices are used extensively in the southern squid fishery in New Zealand (Thomas 2002).

For the most part, technologies to exploit fisheries resources have evolved faster than, and often without regard for, technologies to minimise secondary effects of fishing.

Future challenges

I suggest that there are at least four challenges for those at the forefront of technological developments in fisheries.

1. There is a need for even more rapid progress in the development of technologies for estimating fish numbers or biomass. Technologies for catching fish have evolved faster than technologies that can provide robust data for stock assessments and management. Atlantic bluefin tuna and orange roughy are two examples where better stock assessment and management could have been effected if the technologies that exist today were available 20 years ago.

2. Researchers and developers need to work more closely with stock assessment scientists and fisheries managers to ensure science ‘pays dividends’. For example, there have been numerous tagging studies in the past where the choice of geographic areas and individuals to tag was largely opportunistic. Such studies have often resulted in new and sometimes surprising results based on the first few tags, but results from subsequent tags have often added little more information. What is needed is statistically-designed tagging programmes formulated to answer specific, relevant questions quantitatively. In general, I would like to make a plea for cutting-edge technologies to be more focussed on relevant assessment and management questions, so that marine biological communities can be conserved for future generations to utilise, study and enjoy.

3. Technologies need to be made more cost effective; otherwise, it will be difficult to secure funding for their use in fisheries and other areas of marine science. There are at least three ways of reducing the costs of technologies. The first is simply to wait until they have been employed sufficiently intensively in other disciplines to the extent that they are being mass-produced and/or are in the process of being replaced with newer technologies. In fact, many of the technologies discussed at this ASFB workshop are not very new to the world, but it has taken time for them to become sufficiently cost-effective for fisheries work. The second method of reducing costs is to develop cooperative programmes with other entities; for example, the commercial fishing industry, recreational fishers, the petroleum and ocean mining industries, the armed forces and the coast guard. Many of these groups already use technologies that are of use to fisheries research and/or can easily be modified to be of use, and some groups – particularly the armed forces – have welcomed the opportunity to make better use of the technologies they already possess. The third method of reducing costs is to promote large multi-national programmes that employ the required technologies; for example, the Census of Marine Life, the Global Ocean Observing System (GOOS), Global Ocean Ecosystem Dynamics (GLOBEC), the International Polar Year (IPY), ICCAT’s International Bluefin Tuna Year and many other international ‘year’ programmes (which often run much longer than a year).

4. We need to promote public awareness of the benefits of fisheries and marine science, and to get the public more involved in understanding and promoting the need for a strong scientific foundation for conserving and utilising the world’s oceans resources. However, I believe the current ‘doom and gloom’ approach being used by many to ‘raise’ public awareness about marine issues is self-defeating. People just tend to give up when they think there’s no hope. Yes, marine resources can and should be managed much better than they have been, but most commercially-exploited marine resources have high resilience, and robust and reliable data that compel appropriate management actions are becoming more prevalent (Mace 2004).

Overall, we need to balance utilisation and sustainability, and cost-effective cutting-edge technologies (and advances in existing technologies) are a large part of the answer to providing the essential data needed to achieve this balance.

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Session 1: Tagging And Tracking

Ron O’Dor (Chair)

Tagging and tracking technologies for marine fish

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Abstract

You have probably all seen the email signoff ‘studying fish in the ocean is just like studying trees, except they are invisible and they move’. That simple line conceals a major challenge for biologists studying marine species: where are my fish and what are they doing? Beginning with conventional tagging, we began to understand that movements can occur, but knew nothing about the time between marking and recapture. Acoustic tags allowed a human to tag along behind a fish for the limits of human and boat time, but provided insight into one recently tagged animal at a time – a slow way to make progress. The development of ‘smart tags’, instruments that could be carried with a fish and provide information about the behaviour of each animal, has been a breakthrough in the study of marine fish. A variety of archival tag types, including live and pop-up satellite tags, and remote acoustic monitoring technologies, now provide researchers with a rich supply of data. We have generated remarkable insights into what fish do … and we want more, perhaps before we have solved some issues with existing data. Can we design tags to collect information on conspecifics, prey fields, feeding choices? Challenges involve integration with oceanographic data to understand fish preferences, and require moving beyond ‘overlays’ of fish movement with environmental data. Despite the advances in understanding, how has the new insight translated into areas such as sustainable management? Has a marine reserve been created on the basis of home range estimation? Have fishing practises changed to avoid interactions? Has fisheries management redefined stock boundaries based on movement patterns? To assist sustainable management, targeted experiments are needed, as are closer partnerships with fisheries management agencies.

Key Words: Smart tags, acoustic, archival, satellite, habitat models, sustainable fisheries management

Introduction

Challenges for marine science – determining the state of the ecological system

A central challenge for marine biological scientists is to determine the state of the ecological system of interest. This state can be estimated by considering the abundance (including recruitment), productivity (including growth), or distribution (including movement) of species in the system. There are a range of tools suitable for addressing this central challenge, and at this ASFB workshop, technology breakthroughs in several toolsets are being considered, including the focus of this keynote paper: tagging and tracking.

There have been dual ‘technology’ breakthroughs that are relevant to marine ecologists interested in tagging and tracking. The first is availability of physical information on a suitable space-time scale from satellites and ocean models. Satellite-derived data provides comprehensive surface information about the state of the physical environment, while recent ocean models provide three dimensional information about the past (hindcast) and future (forecast) state of the marine environment. Access to these datasets, while sometimes challenging for the PC -based scientist (or Macintosh, the point is ‘non-supercomputer’), is improving, and should not be considered an obstacle to use. The second breakthrough, and the subject of this paper, is in the development and application of novel electronic tags and monitoring systems.

Tagging and tracking technologies continue to develop rapidly; this progress is crucial to overcome a primary limitation in the study of many marine organisms: they live out of human sight and they often show considerable mobility. Tags give access to that hidden environment. The particular tag technology selected for a study depends on the information required, but tags can provide information on a wide variety of population-level biological attributes including, abundance, maximum age, growth rates, mortality rates, mixing rates, residency times, migration routes, habitat use, and spawning grounds. Intrinsic attributes can also be measured by tags; examples include swimming speed, depth preferences, heart rates, feeding levels, muscle or stomach temperature, and body condition (e.g. Lowe and Goldman 2001). A range of marine species can be studied, including marine mammals and reptiles, birds, invertebrates such as squid and crustaceans, sharks and rays, and teleosts. The examples discussed for several of the tagging approaches below are selected from studies on a single species of fish. This represents the author's experience, but should also illustrate that each technology should be carefully selected for the question, and one approach does not fit one species. It should also be evident that these approaches may be applied to a range of taxa, providing certain criteria, such as minimum size and recapture probabilities, are met. Examples from the literature are provided as an entry to the topic areas, but this paper is not a comprehensive review of published material.

The electronic tags suitable for mobile marine organisms can be classed into three categories, acoustic, archival, and satellite (Table 1). Central to the selection of the appropriate tag is an understanding of the time and space scale of the problem to be considered by employing these tags. Each has particular strengths and weaknesses: the goal of this paper is not so much to review these tags, but to demonstrate their use in the marine environment. Collectively these electronic tags are known as 'smart tags', for the ability to collect data while the observer is absent from the system. They have provided researchers with an unprecedented view of the life of many marine species and are growing in popularity as the tool-of-choice for a range of problems (e.g. Arnold and Dewar 2001, Gunn and Block 2001).

Table 1: Classes of electronic tags used for study of mobile marine species. The primary factors to consider when selecting each technology, such as recapture limitations, are illustrated. Conventional tags are also included as a comparison.

Tagging or tracking type	Primary factors for consideration	Recapture required	Example of common use
Conventional tags	Tag and recapture information only (typically location and size). Primary approach for large-scale programs.	Yes	Mark-recapture studies Growth rates Stock structure
Acoustic tracking	Short-term, detailed information, limited by stamina of tracking team. Animal behaviour may be modified by trackers or after-effects of tagging.	No	Vertical movements Swimming speed
Acoustic monitoring	Requires local residence, or receivers deployed over a wide scale.	No	Residence times Migration pathways
Archival tags	Provide daily position estimates if light curves can be obtained (resolution to 60 nm is possible, better in constrained conditions).	Yes	Migration pathways Stomach temperature Depth preferences Habitat preferences
Satellite tags (GPS or archival)	Limited to large animals. Expensive. Data may be tabulated prior to transmission, so fine-scale behaviour information lost. GPS tags useful when animal spends time at surface, archival form when sub-surface behaviour prevents satellite uplink until tag detaches.	No	Movement Survival following release Habitat preferences

Examples of three smart tag technologies

Acoustic tags and tracking approaches, archival tags, and pop-up satellite tags have all been used to study an important commercial species in Australia: Southern Bluefin Tuna (*Thunnus maccoyii*). This species has been the subject of study by CSIRO and other organisations since the 1960's; this attention is due in part to its status as a valuable and heavily exploited highly migratory species (e.g. Gunn and Block 2001). In the following sections, I first briefly describe each of three smart tag technologies, and then how use of each approach has resulted in new insights for the study species.

Archival tags

Archival tags with geo-positioning capability for marine fish were pioneered in the early 1990's at CSIRO Marine Research (Gunn *et al*. 1994), and have since been widely developed at a number of research and commercial institutions. These tags record data at a pre-specified interval, and archive that data. The information is downloaded from the tag when the fish is recaptured and the tag returned to the scientific team. Tags can be external or internal; longer deployment times generally require internal deployment via surgical implantation. Sensors vary between tag designs; in the simplest case, time, depth and temperature are recorded, while in more expensive versions, time, depth, internal and external temperature, and light are recorded. The recoding interval depends on the battery life and memory; however, records every minute for up to four years are now routine for some tag designs. When the fish is recaptured and the tag returned, the position of the fish can be estimated via a process known as 'geolocation'. In simple terms, the light curve, in combination with the tag clock, allows the position of the fish to be estimated (Welch and Eveson 1999, Musyl *et al*. 2001). The difference between local-noon, and GMT-noon according to the clock allows longitude to be estimated. The earth rotates 360 degrees in 24 hours, thus, a difference of four hours in the time of local-noon and GMT-noon indicates that the fish is 60 degrees to the east or west of GMT (depending on whether local-noon preceded or lagged GMT-noon). Local noon is estimated as the midpoint between dawn and dusk, which are detected in the light curve. Latitude is estimated on the basis of daylength, the time between dawn and dusk. This daylength at each latitude is unique (think long days in southern hemisphere summer and short days in the corresponding northern hemisphere winter), except during the two equinoxes, when daylength is the same at all latitudes. At these times, latitude cannot be estimated using this approach. Various improvements to this basic light curve approach have been developed over recent years, and include constraining the estimates of position by matching sea surface temperature (Domeier *et al*. 2005, Nielson *et al*. 2006), tides (Hunter *et al*. 2003), or bathymetry. Filtering approaches have also improved the resolution of the position data (e.g. Sibert *et al*. 2003, Nielson *et al*. 2006).

Archival tags also provide information on vertical behaviour, via the depth recordings (e.g. Schaefer and Fuller 2005), temperature preference from temperature readings (e.g. Schaefer and Fuller 2003) and in the case of southern bluefin tuna, feeding activity as indicated by changes in internal body temperature (Gunn *et al*. 2001).

Archival tagging of southern bluefin tuna has resulted in improved understanding of the biology, ecology and management prospects. For example, the Pelagic Fisheries Research Group at CSIRO has learned through the use of these tags that juvenile tuna move out of the Great Australia Bight at the end of every summer, and then return in subsequent years until about age 5 (Gunn and Young 2000; Gunn *et al*. unpublished, Polacheck *et al*. 2006). In the winters, they range widely in the Indian Ocean and Tasman Sea (Polacheck *et al*. 2006). With regard to individual biology, placement of the tags close to the stomach of the fish has allowed estimates of feeding frequency to be determined (Gunn *et al*. 2001, Gunn *et al*. unpublished). This information, when matched with environmental data allows habitat usage to be determined. A combination of these results was used in the development of a fishery-independent abundance index for juvenile SBT in southern Australia (Cowling *et al*. 2003). The insight on movement from tagging is now being further advanced through high seas in multi-nation tagging programs (e.g. Polacheck *et al*. 2006), and the results are expected to improve mixing parameters for assessment models.

Acoustic tags and listening stations (acoustic monitoring)

Acoustic tags were originally used for live tracking, where the individual fish was followed by the tracking vessel (e.g. Gunn *et al*. 1999, Lutcavage *et al*. 2000, Davis and Stanley 2002). That approach yielded fine scale information on swimming speed and vertical movements, but was limited in time and replication. Beginning in about 2000, automated listening stations were developed (Voegeli *et al*. 2001). These automated stations allowed multiple fish to be monitored for longer periods of time while they remained in the local vicinity.

Acoustic tags that can be detected at acoustic receivers, or listening stations, have been a recent popular approach for animal movements on a scale of meters to hundreds of kilometres (Hobday 2002, Welch *et al*. 2002, Heupel *et al*. 2006). Typically these tags have a unique code that is detected when the tagged animal passes close to the listening station (up to 500 m). The tags can be detected at listening stations deployed in a variety of configurations (Heupel *et al*. 2006). Only the listening station need be recovered; when downloaded the details on the date and time of each unique detection are recovered.

In southern bluefin tuna, coded acoustic tags and listening stations (acoustic monitoring) have been used since 2001 to study the movements of juvenile animals in southern Australia (Hobday 2002). In particular, since 2003, a cross-shelf array has been deployed during the austral summer to investigate alongshelf movements of age-1 and age-2 fish in southern Western Australia (Hobday 2004, Hobday *et al*. 2005). A vessel-based acoustic survey is conducted in these waters to generate a fishery-independent index of abundance. The acoustic monitoring project was initiated to determine if tuna were passing inshore of the survey area, or at a different time of year. The project results showed that in some years, the majority of fish moved from west to east close to the coast, and would not be counted in the offshore survey area. This would lead to the impression from the survey data, that few fish were present, and hence abundance index would be low for that year. In addition, movement between the cross shelf lines were not all one way, and indicated that double counting of fish within the survey was possible. This research has been valuable in modifying the survey design and the addition of supplemental surveys to better define the abundance of SBT within the survey area. Finally, differences in the regional oceanography have been linked to these behaviours of the juvenile SBT (Hobday *et al*, unpublished).

Pop-up satellite tags (PSAT, or PAT)

Position can be estimated just as for archival tags, however, due to the way in which data is aggregated on board the tag before transmission to the satellite, the resolution is poorer, and the estimation worse (Block *et al*. 2005). Similar approaches to those described for archival tags are being used to improve position estimates (e.g. Domeier *et al*. 2005, Nielson *et al*. 2006). These tags have been used for a variety of large pelagic species including tuna (e.g. Block *et al*. 1999, Lutcavage *et al*. 1999), sharks (e.g. Bonfil *et al*. 2005), mola mola (Dewar unpublished), jellyfish, and squid (Gilly *et al*. 2006

These tags are being used to underpin a habitat prediction model for SBT on the east coast of Australia (Hobday and Hartmann, in press). Iterations of this model have been used to assist eastern tuna and billfish (ETBF) fishery managers restrict access by non-SBT-quota holders to waters where SBT are unlikely to occur for the past four years. Fishers holding SBT quota are permitted to fish in the zones where SBT are predicted to occur. The management zones are updated every two weeks during the period when SBT occur on the east coast longline fishery grounds. The habitat model is based on information obtained from large SBT tagged with PATs. When the temperature preference at different depths is obtained from the satellite-tagged fish (habitat preferences), these preferences can be located in a now-cast of the marine environment (Bluelink ocean model, www.marine.csiro.au/bluelink), and summed to create a three dimensional picture of the tuna habitat preference. The coupling of the oceanographic model with the tuna habitat preference has allowed managers to implement an adaptive, near-real-time spatial management strategy to mitigate unwanted catch of SBT. This is one of the few examples of environmental information being used for in-season adaptive management (Hobday and Hartmann, in press).

Future challenges

We have generated remarkable insights into what fish do using these approaches … and we want more, perhaps before we have solved some issues with existing data. I chose to consider challenges in three categories (1) technical tag development (2) analysis and integration, and (3) uptake of information.

Challenge 1: Tag development

Marine scientists are interested in not only where a fish is living or moving, but what it is doing while at a location. Tags that can collect information on conspecifics, prey fields, and feeding choices are mooted by a range of researchers (Holland pers. comm.). Acoustic tags that can collect data when far from the acoustic receivers and then transmit information when the fish move into range have been developed for testing. These so-called CHAT tags will likely become available in the next five years. A second improvement, would be the 'business card tag' (Kim Holland, pers. comm.), which would record when individuals encountered another tagged individual. Both tags would record the 'encounter', such that if only one animal was recaptured, details on both would be recovered. A similar tag, called a proximity logger, has been developed for terrestrial purposes (http://www.sirtrack.com). Tags that measure stomach pH, and hence feeding activity in animals without a temperature signal have also been recently trialled (Kim Holland, pers. comm., VEMCO Ltd). These pH tags will offer insight on feeding ecology for species other than tuna.

Challenge 2: Analysis and integration

The volume of data recovered from acoustic archival and PAT tags requires considerable data processing, archiving and manipulation. While visualization of data is a necessary first step crucial for communication of results, a challenge for tag users is to move beyond 'overlays' of fish movement with environmental data. Integration of location information or behaviour with oceanographic data is important to understand fish preferences, and require both access to ocean data as well as development of statistical approaches (e.g. Luo *et al*. 2006, Hobday and Hartmann in press). Partnerships with physical oceanographers are likely to yield improved project outcomes (e.g. Block *et al*. 2003, Palacios *et al*. 2006). One integrated approach is to develop individual-based models that integrate movement rules derived from electronic tags, and allow foraging and movement behaviours to be explored in a model ocean (e.g. Hobday and Bestley 2002, Hobday unpublished). These models can then be used to test hypothesis or suggest crucial experiments to reduce uncertainty.

Challenge 3: Uptake of information, collaboration and dissemination

This new insight has not been rapidly translated into applied areas such as sustainable management. For example, marine reserves have not been created on the basis of smart tag-based home range estimation. As yet, fisheries management agencies have not redefined stock boundaries based on movement patterns (e.g. Northern Bluefin Tuna in the Atlantic Ocean). A comparison with the rapid uptake of information (such as fishing mortality estimates) from conventional tagging programs is interesting, and may be due to several factors. Firstly, the history of conventional tagging is longer and thus may be more easily incorporated into stock assessments. Thus, the lag in management utilization with regard to electronic tags is simply because they are new. Alternatively, because parameters from conventional tagging programs are better understood it may be easier to incorporate derived information in existing assessment work. This synthesis may be more easily achieved because stock assessment scientists have often been directly involved in conventional tagging programs (e.g. tuna scientists Hampton, Hearn, Sibert, Polacheck). This is beginning to change and as statistical frameworks are developed, electronic tagging results may be included in stock assessment processes (e.g. Polacheck *et al*. and CCSBT). In the meantime, I suggest that to assist sustainable management, targeted experiments using smart tags are needed, as are closer partnerships with fisheries management agencies.

The cost of smart tag projects will likely remain high for some time, and so a challenge is to make best use of data and equipment. In response to this recognized need, collaborative programs may soon appear in Australia. For example with acoustic arrays, Australia has a large number of users (e.g. Figure 1), who could make use of arrays in place, and return information on animals that pass existing sensors. A number of initiatives are under development in Australia (NCRIS-IMOS, Ocean Tracking Network) that may lead to greater formal collaboration in this area in future. These initiatives will also result in greater outreach and education opportunities, as seen as part of the Census of Marine Life projects (www.coml.org).

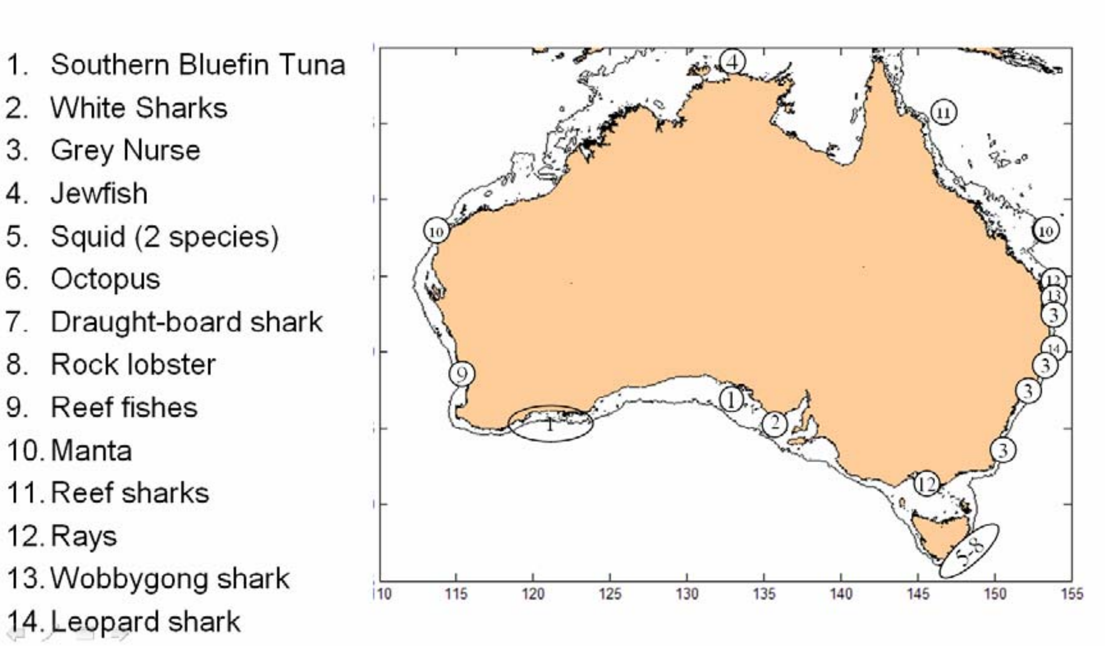

Figure 1: Location of acoustic listening stations and study species around Australia as at December 2005.

Conclusion

The technology improvements in tagging and tracking discussed here illustrate some new insights that have been generated. The technology that is best for each problem differs, and perhaps the primary determinant of the best approach is the accuracy of position estimates that are required and if recapture of the tagged animal is likely. This is usually a function of the scale of the movements being considered. The synthesis of biology and physics is important, and use of ocean models and satellite data to understand the environment in which the fish live will grow in importance. Management questions can be addressed and supported by the technology as evidenced by the example of Hobday and Hartmann (2006). Cooperation and collaboration can enhance the information extraction, and should be fostered in Australia. In future, with interest in spatial management and ecosystem-based fishery management on the rise, the importance of gathering information on fish movements will increase.

Acknowledgements

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New instruments to observe pelagic fish around FADs: satellite-linked acoustic receivers and buoys with sonar and cameras

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Abstract

Pelagic fish such as tropical tunas are known to aggregate around floating objects also called fish aggregating devices (FADs). FADs have assumed a hugely important role in the industrial fisheries of the world – well over half of the world's tuna catch is now harvested from around drifting FADs. These drifting FADs usually occur in remote areas, difficult to access, which explains why this phenomenon has rarely been addressed by scientists.

FADIO (Fish Aggregating Devices as Instrumented Observatories of pelagic ecosystems), a European-funded project, aims at developing and testing new observational instruments to help scientists study this phenomenon. During the project, a satellite-linked acoustic receiver was developed by Vemco (ARGOS-VR3) and successfully tested during FADIO cruises off the Seychelles (Indian Ocean). These new receivers can detect signals from acoustically tagged animals around FADs, and transmit data through ARGOS. An Iridium-linked buoy equipped with a Simrad omnidirectional sonar and three cameras was developed by Martec, following results obtained from observations on the behavior of fish around drifting FADs (such as maximum distance of tuna schools to FAD). Specialized software is being developed to visualize and analyze sonar data.

These instruments can be used in the future (i) to understand the effects of FADs on tuna and other associated species, even in remote areas, (ii) to develop methods to reduce by-catch around FADs, (iii) to build the foundation for future observatories of pelagic ecosystems, using FADs as scientific platforms.

Key Words: FAD, instrumented buoy, acoustic receiver, sonar, camera, tuna

Importance of FADs in tuna fisheries

More than half of the world catch of tropical tuna (yellowfin tuna, *Thunnus albacares*, bigeye tuna, *T. obsesus*, skipjack tuna, *Katsuwonus pelamis*) come from fish associated to floating objects, usually referred to as fish aggregating devices (FADs). A lot of juvenile tuna as well as by-catch species (dolphinfish, *Coryphaena hippurus*, wahoo, *Acanthocybium solandri*, silky shark, *Carcharhinus falciformis*, etc.) are captured around drifting FADs, which raises ecological concerns. The international tuna commissions (Indian Ocean Tuna Commission - IOTC, International Commission for the Conservation of Atlantic Tuna - ICCAT, Inter-American Tropical Tuna Commission - IATTC, Secretariat of Pacific Commission - SPC, Western and Central Pacific Fisheries Commission - WCPFC) have underlined the need for better understanding of the effects of FADs on the behavior of tuna, to improve stock assessment of these species.

In order to better understand the behaviour of pelagic fish around drifting FADs, usually located in remote areas which are difficult to access, a first pre-requisite to future studies was to develop scientific tools and methods adapted specifically for this environment.

FADIO objectives

A European-funded project named FADIO (Fish Aggregating Devices as Instrumented Observatories of pelagic ecosystems, www.fadio.ird.fr) has been developed with the main objective of developing prototypes of new autonomous instruments (electronic tags and instrumented buoys) to create observatories of pelagic life.

Satellite-linked acoustic receiver (Vemco ARGOS-VR3)

Measuring how much time fish spend around FADs is one of the first priorities in order to study the impacts of the deployment of thousands of FADs on fish populations. The best tools to measure residence time of fish, as well as swimming depths of fish around drifting FADs, are coded acoustic tags and acoustic receivers. Existing acoustic receivers require physical downloading of a receiver to collect data. Because FADs usually drift in remote areas, far away from any land and difficult to access, there was a need to develop satellite-linked acoustic receivers.

Vemco, in collaboration with FADIO, developed the ARGOS-VR3 (Figure 1). This new acoustic receiver is similar to the Vemco VR2, with the advantage of having ARGOS transmission to transfer data from the VR2 to the lab.

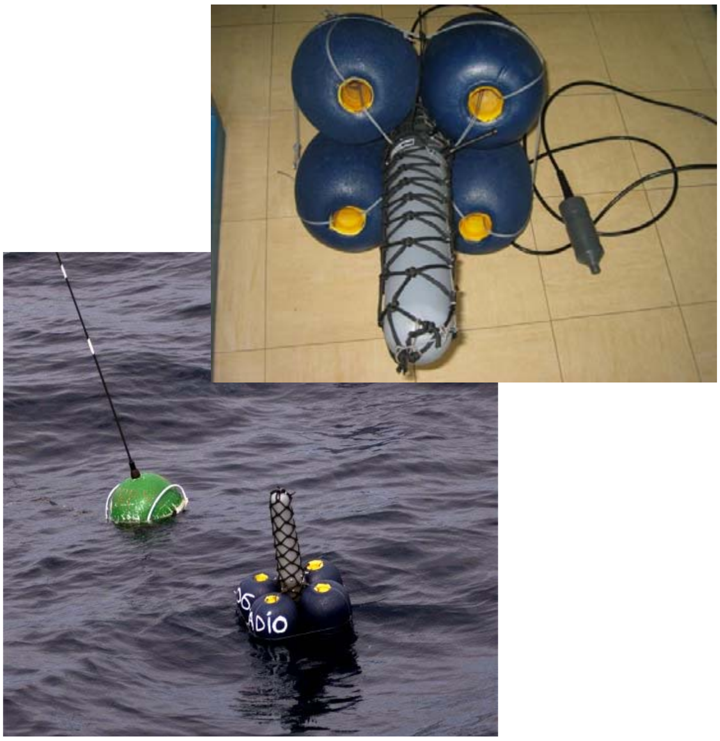

Figure 1: The Vemco ARGOS-VR3: a satellite-linked acoustic receiver

The ARGOS-VR3 records all tag detections in internal flash memory. If it is recovered, it is possible to read all the raw detection data through a Service Port (similar to the VR2). Over the course of a long deployment the unit could collect several megabytes of raw data.

It is not possible to send all the raw data through Argos due to the limited data rate, so the ARGOS-VR3 compresses it. A long sequence of detections of a given tag are reduced to a single data record, which indicates the times when that tag entered and exited the detection range of the receiver, and the number of detections during that interval. The tag is assumed to have remained within range during the entire time.

The ARGOS-V3 contains a GPS receiver which serves two purposes. First, it supports the creation of time stamped positions which are stored, and transmitted along with tag data so it is possible to track movement of the platform over time far more accurately than the positions provided by Argos. Second, it allows us to ensure that the on-board clock is synchronized to UTC so that, in cases when data is not scheduled to be sent every day, the transmission day can be fully utilized without the risk of accidentally spanning two different days. Otherwise, one would have to take clock drift into account in the scheduling of these transmissions.

The following lines show examples of messages sent by the Vemco ARGOS-VR3:

>83,1,A,R256,**39**,443,2004-10-19,07:07:47,2004-10-20,01:12:05
>86,1,C,S256,**104**,1151,856,292,0,0,0,0,0,0,2005-02-07,00:38:32,2005-02-08,00:45:37

The first line indicates that tag ID **39** was detected successfully 443 times from the 19th of October 2004 at 07:07:47 to the 20th of October 2004 at 01:12:05. This tag was a simple pinger, with no depth sensor.

The second line indicates that tag ID **104** was detected 1151 times from the 7th of February 2005 at 00:38:32 to the 8th of February 2005 at 00:45:37. After the number of detections (1151 in this case), there are 8 values representing the number of samples in each bin of the histogram (depth). In cases where large numbers of samples are anticipated in the histogram, there is provision (not used in this deployment) to scale the sample numbers down by factors of 2 and thus reduce the number of bits that need to be transmitted.

Vemco ARGOS-VR3 has been successfully tested on drifting FADs in the Western Indian Ocean, during cruises of the FADIO project. Data on residence times and swimming depths of 7 pelagic species could be collected: yellowfin tuna, bigeye tuna, skipjack tuna, dolphinfish, wahoo, silky shark, and rough triggerfish (*Canthidermis maculatus*). We found that there is no loss of information in terms of residence times as a result of aggregating the data. In terms of swimming depths, because data are aggregated, some information (collected by the unit, but not transmitted through satellites) could be missing, depending on the objectives of the study. It would be interesting to have the possibility to have histograms of depths per day and night, when diel patterns are one of the objectives of the study. While the capability was not provided to users in the initial units, this is very feasible at the expense of creating more Argos data.

The new Vemco ARGOS-VR3 now allows scientists to collect data on the residence times and swimming depths of fish that can be located in areas difficult to access.

A 360° sweeping sonar buoy with cameras and satellite links

The objective was to develop an autonomous buoy able to assess the biomass of tuna around a FAD, as well as information on the other species around the FAD. It has been decided to use a 360° sonar already available in the market (Simrad SL-35) rather than several echosounders looking to the sides of the buoy.

The buoy is 2 m long and weighs 150 kg (Figure 2). It comprises:

- A Simrad sonar: SL-35, able to observe fish schools up to 500 m. It is set to operate a few minutes every 2 hours, with two 360° scans for 3 different tilts. The transducer is located at the lower end of the buoy, but receiver and other electronics are in the head
- 3 webcams located in the bottom, before the sonar transducer. These webcams are set to take pictures every 2 hours, before each scan of the sonar
- Rechargeable batteries with solar panels to achieve an autonomy of about 170 days
- Iridium connection to collect data through satellites.

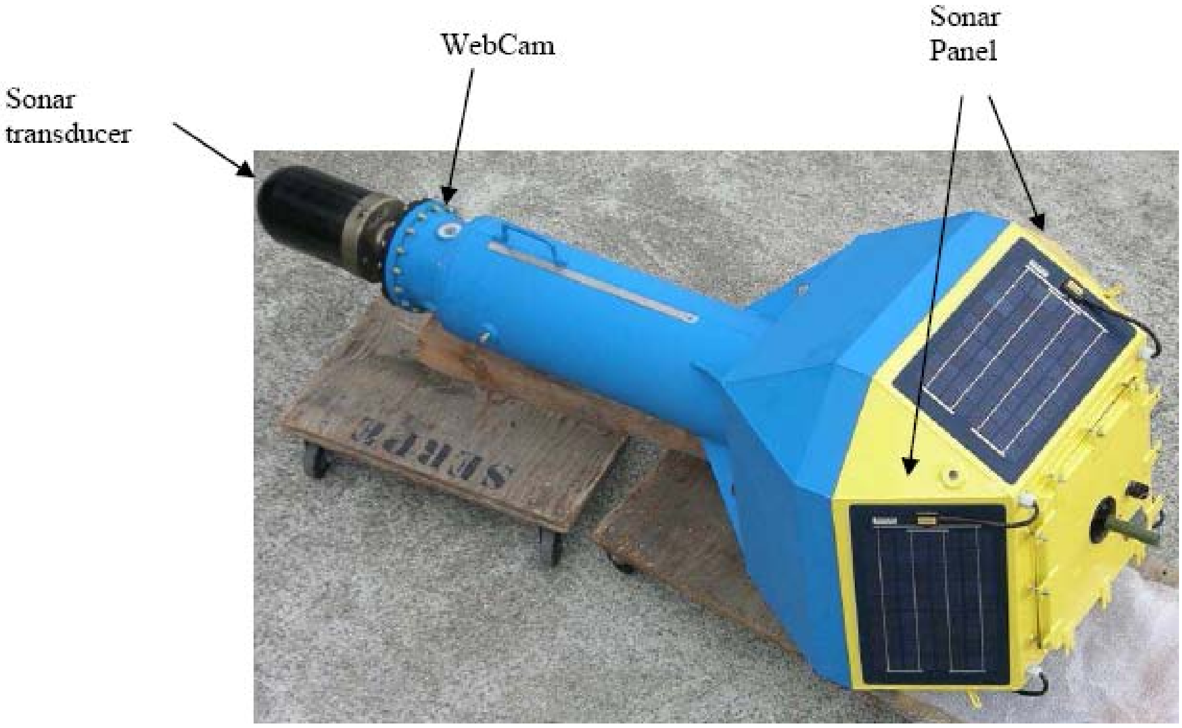

Figure 2: The 'FADIO' buoy (Martec)

The user can set how the buoy operates. For future observations around FADs, the buoy has been set to complete cycles of observation every 2 hours:

- Perform two 360° scans with the sonar for each of the three defined tilts
- Record the position of the compass to locate schools
- Take a picture with each of the three webcams

At the end of each day, the biggest sonar file with the corresponding pictures are sent via Iridium.

Preliminary tests have been performed. Further tests should be done in order to better compare this buoy with other methods to estimate fish biomass around FADs (echo-sounder onboard vessels).

In addition to using this buoy around FADs, it can be used to study other fish aggregations, or to observe fish schools passing through particular areas (channels, etc.).

Conclusion

These instruments have been developed to help future research on FADs, due to the need in tuna fisheries. They can be used in the future (i) to understand the effects of FADs on tuna and other associated species, even in remote areas, (ii) to develop methods to reduce by-catch around FADs, (iii) to build the foundation for future observatories of pelagic ecosystems, using FADs as scientific platforms. Of course, these instruments have more possible applications. Due to their satellite links, they are particularly designed to be used in remote areas difficult to access.

Making sense of fish* tracks by looking at the oceanography

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Abstract

Tagging fish* tells us where they go, but making sense of that data is clearly a challenge, no matter how well instrumented the tag might be. The more we know about the fish's environment, the better equipped we are to understand its behaviour. Satellites, combined with computer modelling, have much potential to help in this regard, but for many scientists, the task of actually coming to grips with those data is somewhat daunting. I will try and convince you that this task is now becoming both easier, and worth doing.

Key Words: BLUElink, ocean modelling

**fish=something that lives in the ocean*

Passive vs active movement

As terrestrial creatures, we sometimes neglect the fact that fish do not have to swim in order to move great distances. In the East Australian Current, for example, the water is moving at several hundred km per day. This is well known but I still hear people attributing the movement of a fish from one place to another as swimming, without considering the possibility that the fish was simply drifting with the current.

One reason the 'passive drift' hypothesis for explaining fish movements is not given as much attention as it might is that it requires accurate estimates of ocean currents – something that has not been, and still is not, generally available. The statistical properties (means, variances, etc) of the ocean currents have been known for some time, but to make sense of data on the movement of individual fish, contemporaneous point-estimates of the current are required.

The oceanographic information revolution

The advent of satellite altimetry – the measurement of sea level from space – coupled with the rapid advance of the power of super-computers, is bringing about a revolution in the field of physical oceanography. The field is now 'mature' enough that operational ocean forecasting systems are being constructed in several centres around the world. To be truly useful, however, for applications such as interpreting the behaviour of fish, these models must be able to resolve individual ocean eddies, where and when they occurred.

BLUElink (http://www.marine.csiro.au/bluelink/) is one such project, and is close to realising its goal of implementing an operational ocean forecasting system at the Bureau of Meteorology. At the heart of this system is a global ocean model with ~10km horizontal and 10m vertical resolution in the Australian region.

The other 'information revolution' - broadband internet, fast desktop PCs and cheap disk storage – has come along just in time to make the distribution of the products of projects like BLUElink possible.

The remaining hurdle is the make access to this information easy. Data standards, exchange protocols, even the descriptive names for ocean data, are not yet standardized. The result is that a data-query that is easy for a physical oceanographer is not yet easy for all people.

Example Products

The most straightforward way to make information readily available to all is to publish pre-prepared graphics on a website - http://www.marine.csiro.au/bluelink/exproducts/index.htm has links to products from both modelling and remote sensing. This solves the needs of some, and helps others decide whether it is worth investing the time to obtain the information in a form more suited to their needs. We have utilized three ways of delivering information graphically: single images that can be viewed using a standard web browser, animations that can be viewed using a media player, and most recently, imagery that can be viewed using Google Earth. A Google Earth screen-grab for model output is shown in Figure 1, while an example showing some remote sensing data is shown in Figure 2. The advantage of using a tool like Google Earth is that the user can zoom in on their region of interest and overlay other types of data.

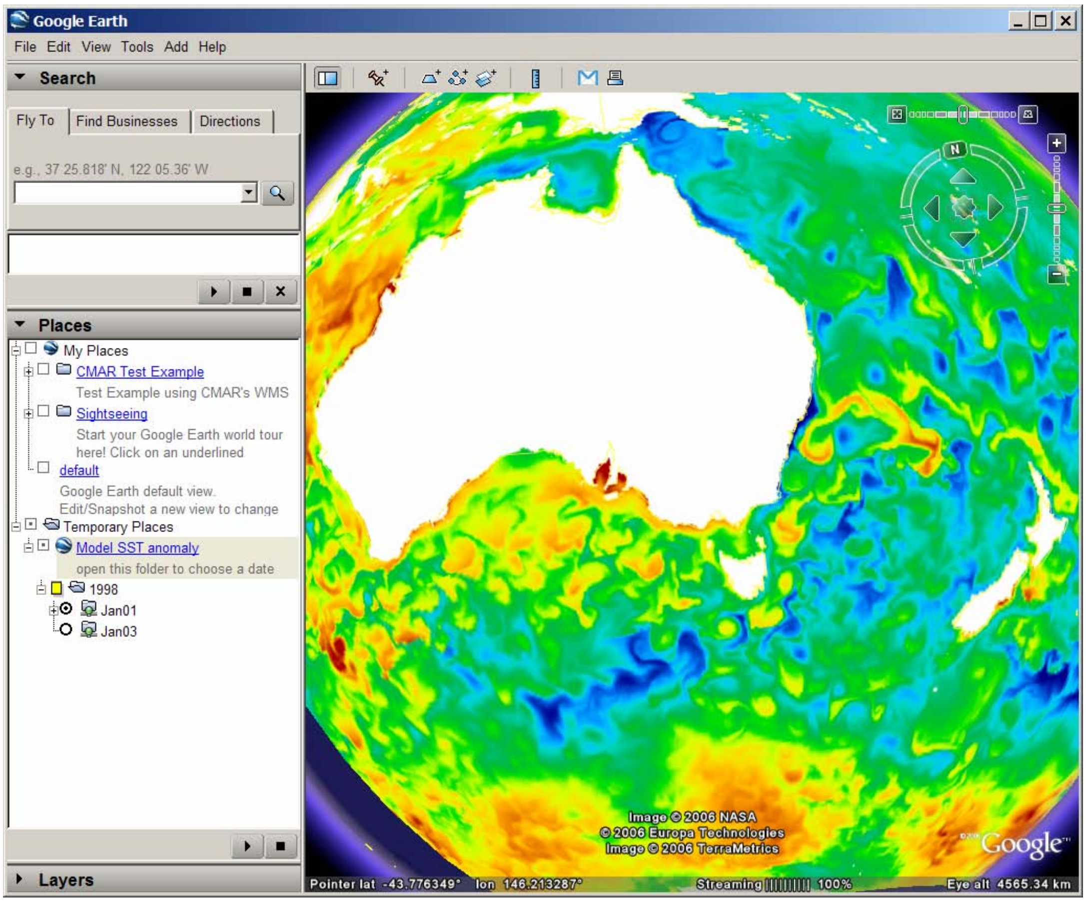

Figure 1: Google Earth screen-grab showing the anomaly (difference from what is normal for the time of year) of sea surface temperature, as estimated by the BLUElink global model for 1 January 1998 – the height of the El Nino.

For numerical access, you need numbers

One can only go so far with graphical overlays of various data. For quantitative analysis, access to the actual data fields is required. One technology that allows users to randomly access large datasets over the internet is OPeNDAP (http://www.opendap.org/). Bluelink products are available via OPeNDAP for research purposes to registered users.

Conclusions

It is becoming increasingly easy for the non-specialist to obtain the physical oceanographic information that one needs in order to interpret point measurements from tags in a regional perspective. This is a result not just of several technical revolutions, but also a cultural revolution – from ‘data hoarding’ to ‘data sharing’.

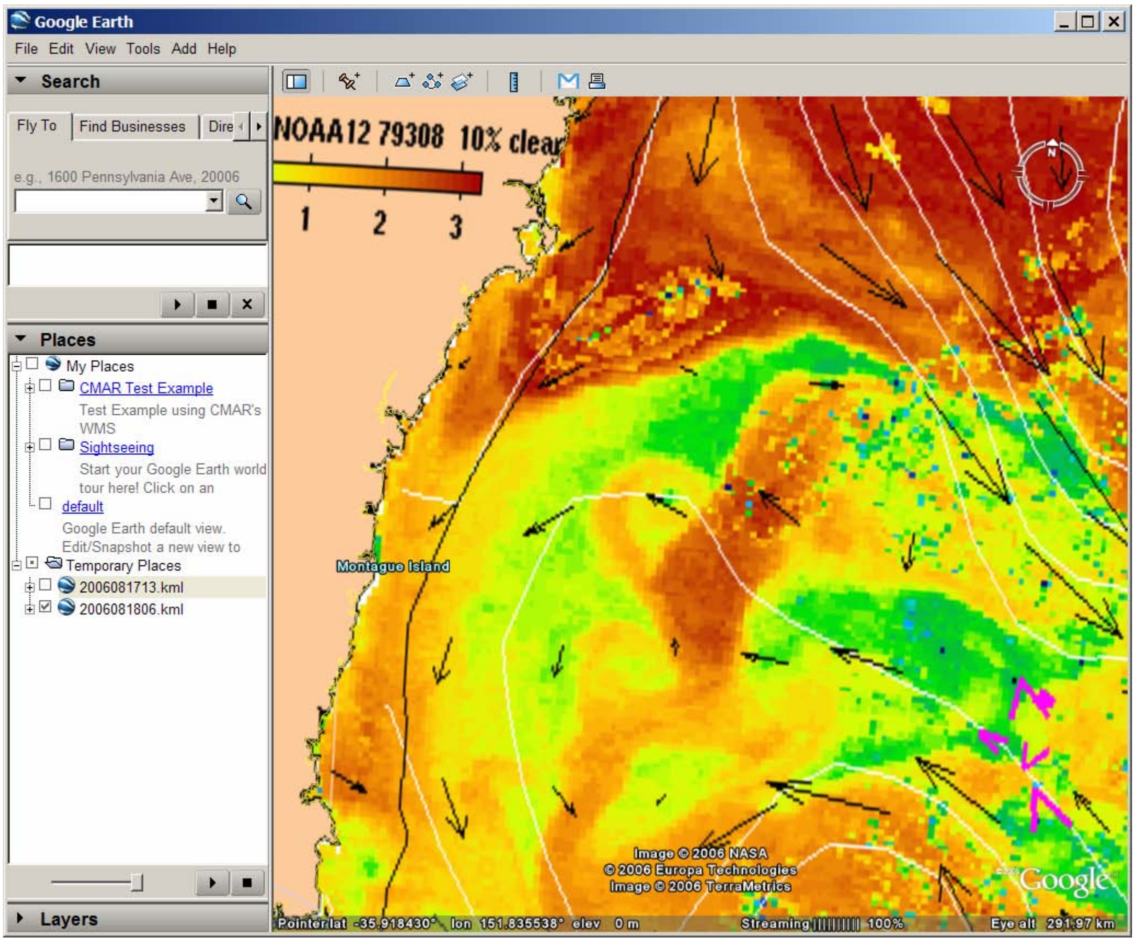

Figure 2: An example screen-grab of Google Earth zoomed-in on the south coast of New South Wales, showing satellite estimates of the geostrophic surface current overlain on satellite estimates of SST anomaly.

Genetag: Monitoring fishing mortality rates and catchability using remote biopsy and genetic mark–recapture

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Abstract

Mark-recapture (tagging) can be a powerful tool for monitoring fisheries. Relatively few tags are necessary to provide effective monitoring, that is fairly robust to spatial complexity and environmental variability. Unfortunately, tagging is usually hampered by three serious limitations: tag shedding, mortality due to capture, and under-reporting of recaptures. Experimentation to quantify these rates, as well as the careful capture and tagging of sufficient individuals, may be prohibitively expensive.

Genetic mark-recapture – Genetag – addresses these problems. In Genetag, an individual is genetically 'tagged' by remotely sampling tissue using a special hook and identified by microsatellite DNA techniques (msDNA). A sample of the known total catch is then screened for recaptures. An individuals genotype is permanent (no tag shredding). With very little tissue needed for msDNA, biopsies can be taken with minimal mortality risks. Sampling a known fraction of the catch (given total catch) can be more tractable analytically than estimating a reporting fraction. Monitoring a fishery using Genetag may be comparable in cost to otolith-based monitoring of age structure. Additionally, a combined genetag/conventional tag approach can be informative and can harness the enthusiasm for catch-release in the recreational sector.

A joint NT-Qld-WA project with major FRDC backing is applying and refining the combined Genetag approach as a monitoring method, at a fishery scale. We have demonstrated novel techniques for *in situ* tissue collection and efficient genetic processing and mark-recapture matching. We have achieved proof of concept. This 'clever' technology overcomes a paucity of information on fishery impact on NT Spanish mackerel, but nevertheless indicates the need for careful management.

Introduction

Most modern fisheries management strategies require some monitoring of the impact of fishing. For example, constant harvest rate strategies, in which a constant proportion of the fish stock is caught each year, potentially deliver near optimum catches over time (Hilborn and Walters 1992), yet are conceptually simple and fairly resilient to environmentally driven fluctuation in recruitment (Walters and Parma 1996). For many fisheries, however, obtaining monitoring information to apply such strategies is problematic. The Northern Territory fishery for narrow-barred Spanish mackerel, *Scomberomorus commerson*, has been one of these but we have addressed the technical challenge of developing a monitoring technique that suits this fishery and species. Using a genetic tagging approach, termed 'Genetag', we have largely overcome the stringent requirements for the estimation of fishing mortality rates that mark-recapture usually entails. In this paper we describe the technique and our progress in demonstrating the feasibility of this novel approach.

Background

Approaches to population monitoring may be problematic. Like many fisheries, the Northern Territory fishery for Spanish mackerel is spatially extensive but of modest economic value, and would be technically difficult to survey for abundance. The fish are fast-swimming, pelagic, reef-associated and aggregative, so that catch rates are poorly indicative of abundance. Trawl or gillnet surveys would be difficult. Northern Australia's turbid coastal waters hamper aerial survey, a difficulty exacerbated by the variety of species of scombroids of similar size and habits in northern waters (Lyle and Read 1985). Spatial heterogeneity (Buckworth *et al*. 2007) makes size composition difficult to sample representatively. An alternative to estimating fishable biomass might be to directly measure fishing mortality rates using mark-recapture (Martell and Walters 2001). Relatively few tags are necessary to provide effective monitoring of fishing mortality rates, and tagging is fairly robust to spatial complexity (Buckworth 2004). Unfortunately, tagging is usually hampered by three serious limitations: tag shedding, mortality due to capture and tagging, and under-reporting of recaptures. Quantification of these as rates, as well as the careful capture and tagging of sufficient individuals, may be not be technically and economically feasible for many fisheries. We have addressed these as essentially technological constraints that can be overcome by development of a genetic tagging approach.

The Genetag approach

Genetic mark-recapture - Genetag - addresses the limitations described above. In Genetag, an individual is genetically ‘tagged’ by, firstly, remotely sampling its tissue, then from this, identifying it by its microsatellite DNA (msDNA) genotype (‘DNA fingerprinting’). The genotypes of individuals in subsequent samples of the known total catch are compared to those of Genetagged fish, with any matches corresponding to the recaptures of a typical mark-recapture experiment. Additional information comes from the individuals which are Genetagged twice. This basic approach mitigates the problems associated with using mark-recapture to estimate fishing mortality rates. As an individual’s genotype is permanent, there is no tag shedding, so that the first problem is eliminated. Very little tissue is needed for msDNA, so that biopsies can be taken with minimal mortality risk, thus addressing the second limitation. Sampling a known fraction of the catch (given total commercial catch from logbooks) can be more tractable than experimentally estimating a reporting fraction. The Genetag approach then has real potential for monitoring fishing mortality rates. The challenge is to make it workable in a cost-effective manner.

Demonstrating the feasibility of a Genetag system

The essential requirements of the Genetag approach are a means of tagging the fish – an *in situ* method of tissue collection - and then identification of that tag. The device we developed for collecting tissue (Buckworth 2004) is essentially a hook, while microsatellite DNA genotypes of the tissue samples identify the individuals. The hooks are deployed on a lure type frequently used in the commercial fishery for Spanish mackerel, so that that a similar size selectivity to that of the fishery is maintained. The hook is constructed of copper tubing with a sharpened steel tip, so that it penetrates the skin of the jaw region as the fish attacks: the copper tube hook bends straight with the continued weight of the line and the actions of the fish, so that the fish is disengaged. The tip is designed to retain a small piece of tissue for later genotyping. Double-hooked lures produce visible tissue on about 60% of strikes (Buckworth 2004). Between 2002 and 2005, more than 1000 Genetag lures were deployed and struck by Spanish mackerel. Given the chemical processes to which the tissue is later subjected, the preservation of the tissue is critical. Tips from the struck lures are preserved in 80% ethanol and maintained where possible at less than minus 20^{o} C. Storage of initial samples in saturated dimethyl sulphide (DMSO) solution resulted in failure of DNA preservation and extraction, due to reactions between the salts and the traces of copper retained in the tips. As the amount of tissue retrieved in the struck lures is very small (< 1 g), we have found that it is critically important that the struck lures are well handled and that tips are placed into the preservative as soon as is practicable.

Sampling of the landed catch has been achieved by asking commercial fishers to retain paired ventral fins from fish landed in the Darwin area. All fins from a fishing session are bagged together and labelled with date and location of capture, then frozen until collected for analysis. Our target has been to sample 10-20% of the landed catch, a target that simulation indicates should provide a reasonable precision of mortality rate estimates in a monitoring program, yet is achievable given the costs of sampling and screening. In practice, some fishers retain most fins, and many retain none.

The requirement to genetically identify a large number of individuals, potentially tens of thousands or more, imposes the need to develop genotyping protocols that are as efficient as possible. The number and choice of loci involved in screening is a trade off between ensuring sufficient genetic information, yet containing the operational costs of routine genotyping. This trade off has required the development of a suitable set of loci that are amenable to PCR and gel-separation multiplexing. (Broderick *et al.* in prep) have identified a set of polymorphic loci that can be efficiently used in combination to provide genotypes of individuals with a very low probability that separate individuals have the same genotype (termed the 'probability of identity', PID. The choice among combinations of loci to maximise efficiency has been guided by SHADOWBOXER and LOCUSEATER (Hoyle *et al*. 2005), simulation software designed specifically to optimise the choice of loci combinations for this project. The number of comparisons (millions) possible among Genetagged fish and with landed fish exponentially increases the number of samples in the database, and has emphasised the requirement for database software development. All samples from Genetagged fish are genotyped but only a sample of the landed fish is screened, to contain costs. As the dataset of Genetagged fish in the NT Spanish mackerel fishery grows, so will the need to develop even more efficient data handling protocols and comparison software.

So far there have been relatively few Genetag recaptures identified (genotyping, screening and analysis have yet to be completed). Several fish have been Genetagged twice. For one fish, there was an interval of 6 weeks between the two Genetag events, and the fish had moved nearly 180 km. Several fish have been Genetagged twice within a fishing trip, at the same locations at which they were first Genetagged, and with intervals between tagging of minutes to three days. There have been twenty Genetagged fish detected in the landed catch. All were at liberty for mere hours, and were recaptured on the same vessel and at the site at which they were tagged. While not especially informative of fishing mortality rates, these recaptures all demonstrate the basic feasibility of the Genetag protocols, and that some Genetagged fish remain available to the fishery. It also provides information on catchabilities at a local scale.

To further explore the Genetag concept, we also developed suitable protocols for conventionally tagging *S. commerson*. The goal of this part of the project has been to establish a raw recapture rate (i.e. uncorrected for tag shedding or tag induced mortality) against which the recapture rate provided by the Genetag component of the project might be compared. In similar fisheries, conventional tagging of Spanish mackerel has produced return rates of around 2-3% (McPherson 1992); we expected a comparable return rate. To overcome the labour costs of tagging, we have utilised a panel of volunteer recreational fishers to undertake the tagging. Tagging is consequently undertaken in areas that are principally fished by anglers. Requirements are that fish are caught on relatively heavy line (to reduce the time fish spend fighting), and tagged with individually numbered Hallprint pelagic intramuscular tags. Most fish are tagged and released without removal from the water. A small tissue sample is collected for comparison of these individuals with the Genetagged set, and their potential detection in landings from the commercial fishery, even if there is significant tag shedding (Buckworth and Martell 2003; Buckworth 2004).

Producing a recapture rate of around 2% from nearly 1000 releases, the conventional tagging component of the project may provide a recapture rate and preliminary estimate of fishing mortality rates against which the Genetag approach can be compared. With spatial separation of the sectors, the estimates primarily relate to the recreational rather than the commercial sectors. Most of these returns have come from the recreational fishery but a significant number have also come from the commercial Offshore Net and Line (ONL) fishery. The ONL fishery targets shark and grey mackerel (*S. semifasciatus*) and takes *S. commerson* as a bycatch. At the same time, very few recaptures have come from the commercial troll fishery that is the target of the Genetag development project.

Discussion

Our results so far have provided proof of concept for the Genetag approach. The number of recaptures detected over the full course of the project will, as in any mark-recapture experiment, depend upon the number of fish tagged, the overall fishing and natural mortality rates, emigration of tagged fish away from the study location and the extent to which tagged fish mix with the population in the study area. Practically, the proportion of the landings screened is a trade off between economy and can be adjusted during the program in the light of available funds and the precision required. In the absence of extensive mixing, the highest precision is gained by maximising screening of samples from areas where releases and effort are both highest. This also provides precise estimates of fishing mortality rates and catchabilities at local scales. With the prospect of reductions in processing costs, it may also be feasible to store samples with the intention of providing greater precision some time in the future. It is fairly clear that a Genetag approach for determination of fishing mortality rates will be most accurate and economical where it can be applied to relatively small populations and that its utility will improve if the target species is heavily fished i.e. in circumstances in which the probabilities of recaptures are high.

Interpretation of this project's results is also dependent upon movement rates. (Buckworth *et al.* 2007) have shown that adult *S. commerson* undergo relatively little movement in northern Australia, with otolith isotope ratios and parasite abundances usually distinct at scales as small as a few hundred kilometres. The pattern of recaptures from the conventionally tagged fish from this project suggests that movements may typically be even more restricted. There is little spatial overlap between the commercial troll and the recreational fisheries for Spanish mackerel in the Darwin area, with the recreational fishery typically concentrated around inshore shoals and reefs. There is, however, significantly more spatial overlap between the recreational and ONL fisheries. The preliminary results from conventional tagging, with little movement between release and recapture sites, suggest that there is little movement of fish between the areas targeted by the different fishery sectors. This single long-distance movement by one of the twice-Genetagged fish is assumed at this time to be atypical.

We have focussed the screening on landed fish from areas where there is a high density of Genetagged fish, to ensure that fishing mortality rates and catchabilities estimated are as precise as can be achieved within budget limits. However, better determination of movement rates may be an incentive to screen more fish, or to screen landings from localities and times where predicted probability of recapture is lower. Similarly, information on natural mortality rates is also provided by the Genetag approach if there is sufficient spatial and temporal contrast in fishing effort. An adaptive approach to the proportion and distribution of landings screened provides the opportunity to identify trade offs, between the acquisition of potential additional information in samples, and cost.

Although we have estimated that a monitoring program for Spanish mackerel based around Genetag would be of similar cost to monitoring of age structure using sectioned otoliths (Buckworth 2004), there are many opportunities to reduce the cost of a Genetag monitoring program. Firstly, experimentation to improve the performance of the Genetag hooks could be undertaken, to secure not only increases in the number of struck lures retaining tissue, but also in increasing strike rates. To this end, we have begun experiments with baited Genetag hooks. The use of squid as bait provides very clear genetic distinction between the bait and the target species.

The most expensive part of the project is the genetics component (assuming fishers rather than researchers deploy the Genetag hooks), principally because there are a very large number of samples to screen. Our initial target was to keep screening to below $5 per sample (operational, non-staff costs). With steady reductions in costs of the various components of genetic analysis, this has now become closer to $4/ sample, and with increasing application of genetic technology, is likely to be reduced further.

There is little practical experience anywhere with genetic mark-recapture of experiments of the size we have attempted. There will be opportunities as well as pitfalls recognized as we accumulate experience, particularly in the application of high-throughput genetic screening (see Broderick *et al.* in prep). The management of the large number of samples and data subjected to several steps in the collection and analysis processes could be improved by application of logistic approaches developed, for example, in management of blood donations and products. Improvements in protocols to maximise the quality of samples and thus the information yield from each tag will also be valuable in reducing costs.

The incorporation of a conventional tagging component in this project has provided a substantial information yield, and importantly will guard against misinterpretation of a low recapture rate as a low fishing mortality rate. Potentially, conventional tagging can provide not only additional information on fishing mortality rates but also on tag shedding and mortality due to tagging (Buckworth and Martell 2003; Buckworth 2004). However, in our current experiment, the lack of sufficient spatial mixing of fish and fishers between sectors will preclude estimation of these tag losses. Although this might be accommodated in a future monitoring program, the conventional tagging has nevertheless been informative and has been kept as a relatively inexpensive part of the project by harnessing the enthusiasm for catch-release in the recreational sector.

Finally, an area for future study is the development of appropriate monitoring rules and management controls to maximise the value of the information that might be provided by a Genetag monitoring program. The clever technology of the Genetag approach overcomes the paucity of information on the impact of fishing in Spanish mackerel fisheries, and thus creates opportunities for equally clever management.

Acknowledgements

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Advances in the use of radio telemetry and PIT tags to study movements of Australian freshwater fish

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Abstract

Radio-tags and PIT (Passive Integrated Transponder) tags have provided new and complementary methods to advance our ability to study freshwater fish. Radio-tags were first used in Australia in 1992, and have since been applied to study a broad range of species. There have been considerable developments in their use, associated technology and capabilities. For example, radio-tags have been used to determine movement patterns, with an increasing reliance on remote, automated loggers for data capture. Additionally, PIT tags are increasingly being used as a lower cost individual fish tagging option that can also allow long-term data to be collected automatically. Over 20 000 fish have been PIT tagged in a range of studies in the Murray-Darling Basin and automated loggers have been installed at seven fishways along the Murray River, providing coverage of over 1 300 km of the main river. Over 2 000 ‘recaptures’ have been recorded to date, providing data on travel times, locations, numbers of fish movements and population dispersal patterns in both upstream and downstream directions at catchment scales. This work forms part of the monitoring component of the Murray-Darling Basin Commission’s *Sea to Hume Dam fishway program*. The advantages of these new technologies over traditional tag and recapture methods are discussed along with case study examples, future opportunities and technological advances identified.

Key Words: Radio-tags, PIT tags, freshwater fish, automated logging

Introduction

Limitations of traditional tag and recapture techniques have highlighted the need for new methods to effectively study freshwater fish in Australia. As fish are not generally readily visible in their natural environments, there has been a necessity to physically recapture tagged fish and hence, knowledge of fish movements has usually been assembled from isolated and discontinuous observations (Priede 1980). This poses problems for data collection, as only low percentages (often < 15%) of tagged fish are usually recaptured; hence there is the potential for capture bias. Indeed, many tag and recapture studies are now considered biased against detecting movements (Gowan *et al*. 1994, Rodriguez 2002) and the use of other tagging techniques such as radio-tracking, has revealed many fish species to be more mobile than previously recognised (Gowan and Fausch 1996, Young 1996, Koehn 2006). The collection of more ‘recapture’ points means that patterns of movement can be more accurately constructed. This can be obtained through the ability to follow individuals, potentially on a continuous basis, through multiple ‘recaptures’ or movements past particular locations. Without the need for physical recapture, data can be collected more easily, potentially from a larger percentage of tagged fish, and on multiple occasions.

Radio-tags and PIT (Passive Integrated Transponder) tags allow for data collection on individual fish and have provided new and complementary methods to advance our ability to study freshwater fish movements. This paper describes these two tagging techniques and discusses the merits of these new technologies over traditional tagging methods using two case study examples. The case studies examined are the use of radio-tags to study the movements of Murray cod, *Maccullochella peelii peelii*, and the use of PIT tags to assess the success of fishways in the Murray-Darling Basin Commission’s (MDBC) *Sea to Hume Dam Fishway Program* for a range of species. The benefits of these tagging techniques are compared and their complimentary nature, future opportunities and technological advances discussed.

Radio-tags

Both radio and ultrasonic tagging have been used widely in overseas fish studies (see Priede 1980, Eiler *et al*. 2000 1999), with a wide range of telemetry equipment and techniques available (Amlaner and MacDonald 1980). Radio-tracking has been widely used in a range of studies of Australian terrestrial fauna (e.g. O'Connor and Pyke 1987, Newell, 1999), but was only first used to study Australian freshwater fish in 1992 (Koehn 1997, 2006). Radio-tracking provides a convenient and cost-effective means of remotely monitoring movements of wild animals (Millspaugh and Marzluff 2001), including fish. The benefits of using radio-tags over other tagging methods to study freshwater fish have previously been discussed (Koehn 2000). In a review of fish tracking literature, Stasko and Pincock (1977) concluded that "the advantages of radio-tracking are so compelling that the use of ultrasonic signals is rapidly becoming limited to those applications for which radio signals are unacceptable" (mainly saltwater). In Australia, radio-tags have now been used to study the movements of a range of species including: Murray cod (Koehn 1997, 2006), Eastern freshwater cod, *Maccullochella ikeii* (Butler 2001), Mary river cod, *Maccullochella peelii mariensis*, (Simpson and Maplestone 2002), trout cod, *Maccullochella macquariensis* (Koehn and Nicol 1998, Nicol *et al*. 2004, in press, Ebner at al. 2005), Australian lungfish, *Neoceratodus forsteri* (Brooks and Kind 2002) golden perch, *Macquaria ambigua* (Koehn and Nicol 1998, Crook *et al*. 2001, Crook 2004, Nicol *et al*. 2004, O'Connor *et al*. 2005) and non-native common carp, *Cyprinus carpio* (Stuart and Jones 2002, Diggle *et al*. 2004).

Radio-tags consist of a circuit, a battery (that contributes most of the size and weight and determines the longevity of the tag) encased in resin, and a transmitting aerial (Figure 1). Transmitters can be fitted with mortality sensors, which activate a different pulse rate if the transmitter has not been moved for 8 h (Eiler 1995). Transmitters can be attached to fish either externally or internally. Internal tags (Figure 2) implanted into the body cavity have been successfully used and avoid the potential for entanglement in natural environments, especially if the species utilises habitats such as woody debris or vegetation. Such implantation procedures are more difficult and are likely to require some veterinary training, but encapsulate the tag within the fish. It has been a commonly accepted 'rule' that transmitters should not weigh more than 2% of the body weight of the fish (Knights and Lasee 1996, Brown *et al*. 1999) in air or 1.25 % of the weight in water (Winter 1983). This therefore determines the minimum size of the fish that can be tagged. Care should be taken to ensure that the size and shape of the transmitter is appropriate for the body cavity of the fish to avoid contact with vital organs. This may be particularly difficult if female fish are in spawning condition.

Tracking of radio-tagged fish can be undertaken by land, boat or by aircraft. Signal range varies with environmental conditions and transmitter/receiver type, but ranges of 1 km by boat and several km by air are common (Koehn 2006). The signal range of radio-transmitters decreases with increasing water conductivity and radio-telemetry is only considered suitable in conductivities of less than 600 EC (Winter 1983, Koehn 2006).

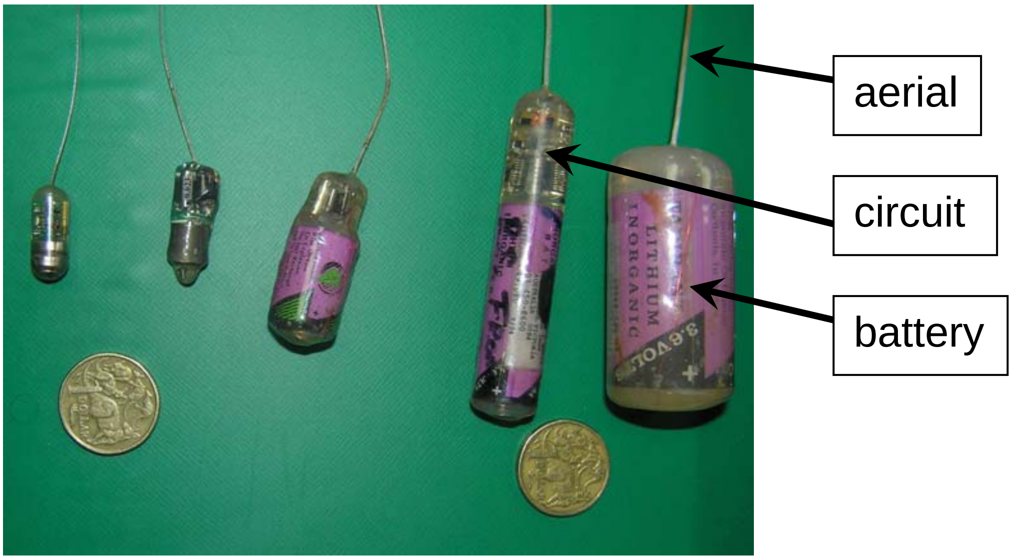

Figure 1: Examples of some different sized radio-transmitters used recently for tracking Murray cod, indicating the battery, circuit and aerial in comparison to the size of an Australian $1 coin. Battery sizes range from a double watch battery (far left) to a C-cell (far right).

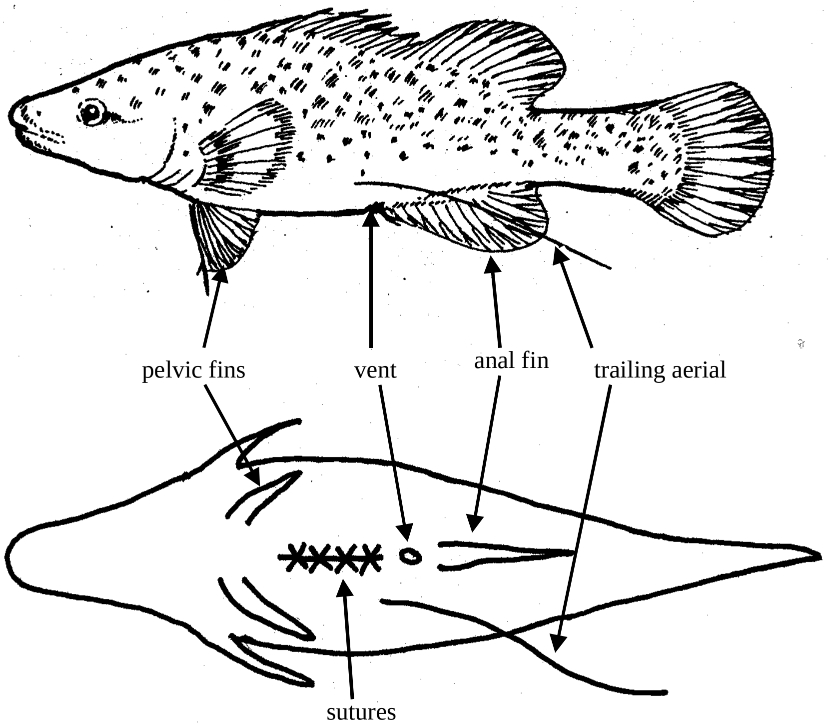

Figure 2: Diagram indicating the location of implanted radio-transmitters in a cod.

Tag and recapture studies are usually unable to elucidate detailed movement patterns. The radio-tracking data presented in Figure 3 highlights the need for the movement patterns of fish to be examined over a full range of seasons, using frequent sampling, to ensure that the false interpretation of results does not occur. For example, the data presented on the movements of a Murray cod over a 12 month period elucidated distinct movements in both upstream and downstream directions. A simple tag and recapture study may have provided different interpretations of likely movements depending on when the fish was recaptured. For example, if the fish tagged in August (at point A) was captured at point B, C or D it may be considered to have moved either about 35 or 60 km, whereas a capture at E may have suggested that the fish had not moved at all.

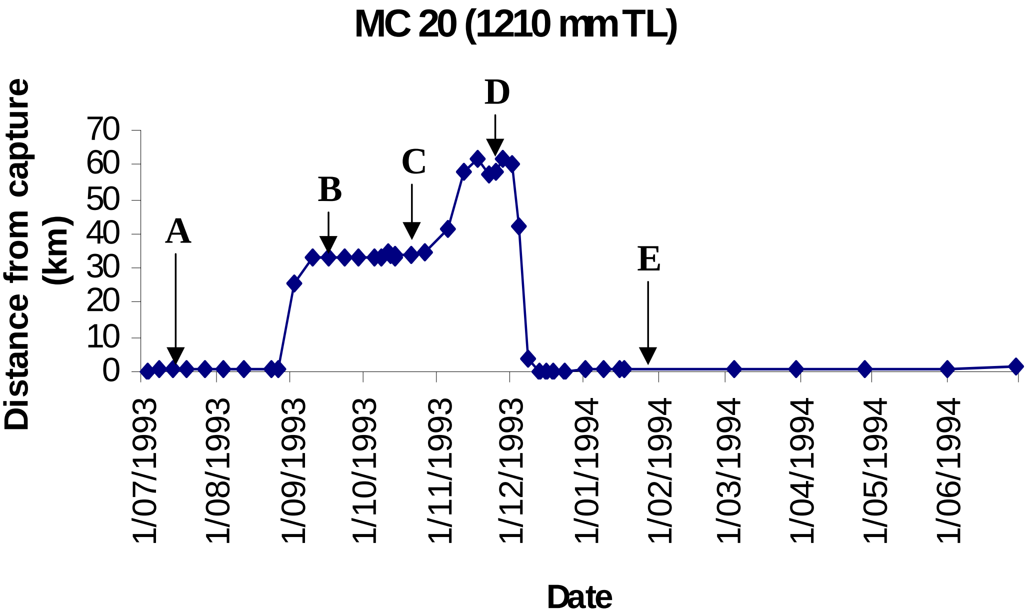

Figure 3: Movement locations obtained over a 12 month period by radio-tracking for a Murray cod from the Ovens River (modified from Koehn 2006).A, B, C, D and E represent different points in time where traditional tag recaptures could have occurred, potentially leading to differing conclusions.

Advances in radio-tag technology

Many applications of fish radio-tracking have concentrated on small-scale studies, which have detailed aspects such as movements and habitat use (see Eiler *et al*. 2000). Advances in technology however, are also providing new tools for collecting detailed information (Eiler 2000). Radio-telemetry studies are now under way on larger scales, in which large numbers of fish are tagged. Adams *et al*. (2000) reported behavioural data from over 4 000 juvenile salmon, while Eiler (2000) and Bjornn *et al*. (2000a,b) reported telemetry studies where more than 3 000 individual fish were tagged per year. Such large-scale tagging now allows radio-tracking to provide information previously obtained by more traditional tagging methods including abundance estimates (e.g. English *et al*. 1999, Hasbrouck *et al*. 2000), survival rates (English *et al*. 1999), and stock assessments (Fish 1999). Behavioural studies on fish have included schooling (Johnsen 1980a), the effects of heated effluent (Johnsen 1980b), temperature and oxygen preferences (Douglas and Jahn 1987), homing and spawning activity (Weatherly *et al*. 1996) and tracking around and through fishways (Adams *et al*. 2000).

Additional functions for radio-tags now include pressure-depth sensors (Beeman *et al*. 1998), temperature sensors (Venditti and Rondorf 1999), movement sensors, temperature probes, heart rate/metabolism monitors and other physiological and environmental monitoring (Miller *et al*. 1980, Lucas *et al*. 1993). Long-term data records for these functions can also be stored on the tag itself. Functions used by acoustic tags, such as those for swimming speeds on marine fish or ambient light measurement for geo-location (Webber *et al*. 2000), could also be added as options to radio-tags. Micro-controller tags can be pre-set to determine the pulse cycle, providing considerable savings on battery power, hence extending tag life. Similarly, trade-offs can be made between power outputs and pulse intervals to reduce power consumption. Additionally, the new generation digitally encoded radio-tags allow more efficient automatic tracking of large numbers of fish on a single frequency, with improved operational life and a reduced chance of ambient noise interference.

Remote logging stations

As manual tracking can be labour intensive, there is an increasing reliance on remote automated loggers for data capture. Remote, automated logging towers (see Eiler *et al*. 2000, O'Connor *et al*. 2003) that can detect radio-tagged fish and save the relevant data (frequency, time, signal strength, date) have now been in use along the Murray River for about 5 years. More advanced systems that include directional antennas and the ability to remotely download data are also now used. The ability to remotely track fish with logging stations can be cost-effective (about $15,000 per station) and provide reference points to a fish's location. A series of fixed logging stations along an extended river reach can be used to monitor longer distance movements without using aircraft. Solar panels provide dependable power for both the logging units and modems in remote areas.

PIT tags

In the mid 1980's passive integrated transponder (PIT) tags were developed and used in fish. PIT tags have several advantages over radio-tags in that they are relatively low cost (A$ 3-4 each), have unlimited life expectancy and have the ability to be used in both small and large fish (Prentice *et al*. 1990). There are a variety of PIT tags on the market but the type most generally used for studying movement in freshwater fish within the Murray-Darling Basin (MDB) are manufactured by Texas Instruments, USA. These are half-duplex, 23 mm long and 3-4 mm in diameter, weighing about 0.6 g, each consists of an antenna coil, capacitor and circuit board encased in a glass capsule (Figure 4). As the tag enters the range of the reader the transceiver energises the tag, which returns a signal with the unique tag code.

Tags can be readily inserted into the dorsal musculature of the fish (Brooks and Kind 2002), though the 23 mm tags are limited to larger fish (> 100 mm long). Tag loss was initially reported as <1% for the 12 mm long PIT tags (Prentice *et al*. 1990) but more recent studies, of 23 mm long tags, have reported considerably higher loss rates of 7.2- 15.2 % (Roussel *et al*. 2000, Hill *et al*. 2006). However, for fish species that are commonly consumed by anglers, researchers should consider implanting the tag directly into the abdominal cavity. A New Zealand company (Ensid Technologies) have recently manufactured a full-duplex PIT tag encased in surgical plastic that provides a food-safe alternative (Figure 4). Hallprint tags (South Australia) have now manufacture a half-duplex prototype food-safe PIT tag and also manufacture a combined external dart tag with a PIT tag inside.

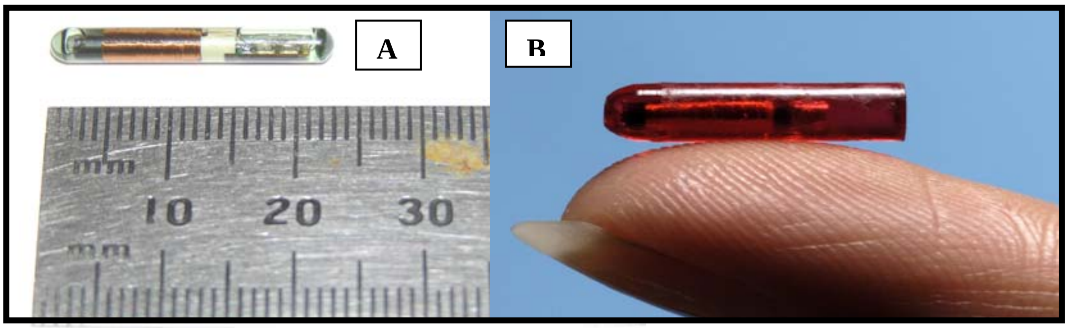

Figure 4: (A) The Texas Instruments half-duplex 23 mm long glass encapsulated PIT tag and (B) the Ensid food-safe plastic coated tag (photos: Brenton Zampatti, SARDI; and Ross Clarke, Ensid).

PIT tag reading systems

PIT tags have been used to monitor the movements of fish through experimental fishways, with high detection efficiencies having been reported of between 88 and 96% (Castro-Santos *et al*. 1996). Antennas can be built into the fishway (e.g. around a vertical-slot) with automatic reading and logging of tagged fish data (location, passage efficiency and time of arrival) recorded (Lucas *et al*. 1999). The range of detection of PIT tags is limited to approximately 60 cm, hence antennae arrays must be carefully positioned. Fixed PIT readers have been used on fishways (Castro-Santos *et al*. 1996) shallow rock bars in small streams (Lucas and Baras 2000) and on hydroelectric powerplants (Boubee and Williams 2006). This system seems efficient unless large numbers of tagged fish enter the detection zone simultaneously (Castro-Santos *et al*. 1996) in which case the risk of non-detection may increase. PIT tags can also be read by a hand held reader ($350 each) with a 30 cm range. In the USA, development of mobile PIT readers is underway for capture-independent assessment of habitat use by tagged fish in wadable streams (Hill *et al*. 2006).

PIT readers on Murray River fishways

Fixed PIT reading systems were first used in the Burnett River, Queensland, Australia, on a fishway at Walla Weir (Berghuis *et al*. 2000). Since then, the fixed reader technology has rapidly been deployed by the MDBC funded tri-state Murray fishway assessment team, involving the Arthur Rylah Institute, NSW DPI (Narrandera) and SARDI researchers (see Stuart *et al*. 2004). To date, seven fixed readers have been installed on mid-Murray River fishways at Locks 7, 8, 9, 10, 15, 26 and Yarrawonga Weir; covering 1 300 km of river (Figure 5). By 2011, an entire 2 500-km length of the main stem of the Murray River will include PIT readers on 13 fishways, as part of the MDBC *Sea to Hume Fish Passage Restoration Program*. Additionally, several other PIT readers will be present on Murray River tributaries.

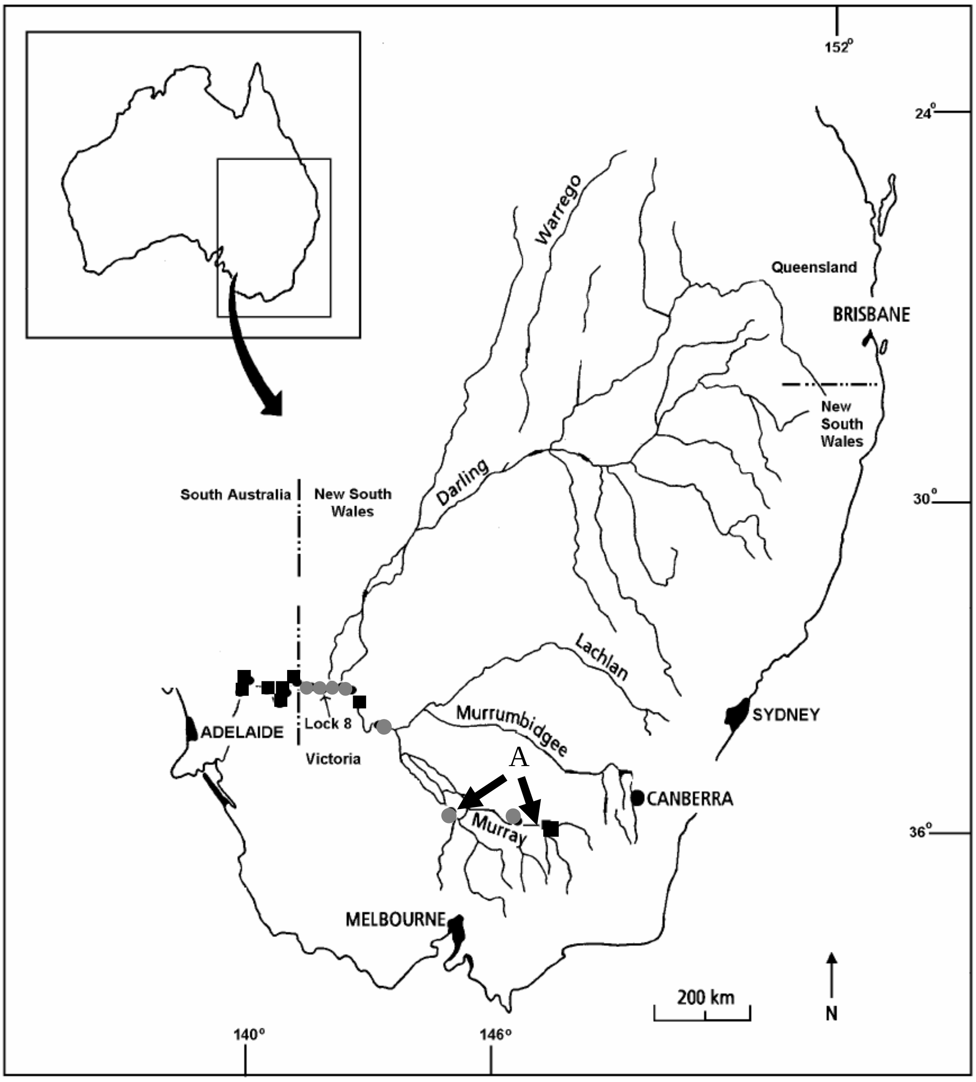

Figure 5: Map of the Murray-Darling Basin showing new Murray River fishways with PIT tag reader systems (round grey symbol) and weirs to be fitted with fishways (square black symbol) as part of the MDBC *Sea to Hume Fish Passage Restoration Program*. A indicates the extent of downstream movement for a large pit-tagged Murray cod.

The PIT tag reader at Yarrawonga Weir includes eight antennas: the four fishway entrances, the two entrance gates to the vertical chamber, the gate at the start of the bottom of the exit channel, 20 m into the exit channel and on the upstream end of the stainless steel flume. Similar to that described by Castro-Santos *et al*. (1996), the antennae loops were constructed from high-current power cable (630/0.12 mm) strung through 20-mm PVC pipe for protection, with each completely surrounding each fishway entrance (0.4 m wide), and exit (0.6 m wide). Each antenna was attached to a TIRFID/RDR, Series-2000 tuner and reader, connected via a USB serial port hub to a computer with TIRIS Multi-reader Program software (Conte Anadromous Fish Research Centre – USGS-BRD, version 2). The read range of the antennas was approximately 0.4 m. When a tagged fish was detected, the computer recorded the PIT data (antenna number, unique PIT number, date and time). A software program developed at Arthur Rylah Institute for Environmental Research (Victoria), then zipped and saved the data every 24-h in a text file. Each Monday, the computer and modem automatically e-mailed one-week of data, as a single zip file, to the research team. To remotely access and periodically update the software system, a remote desktop server provided a virtual desktop of the logger unit and allowed complete live control from a remote location.

Summary of PIT tag results

Over 1 500 ‘recaptures’ (or about 15% of tagged fish) have been recorded to date, providing data on travel times, locations, numbers of fish movements and population dispersal in both upstream and downstream directions at a catchment scale. This work forms part of the monitoring component of the MDBC’s *Sea to Hume Fish Passage Restoration Program*. The readers have provided important information on how fish use fishways, their success rates, environmental cues and movement patterns over larger distances between weirs. For example, a 1 120 mm long, 30 kg, Murray cod tagged in Boiling Downs Creek (upstream of Yarrawonga Weir and Lake Mulwala) in early May 2005 was detected by the Torrumbarry Weir fishway logger in late September 2005 (Figure 5). The fish had moved at least 420 km downstream in 137 days (3 km/d) before moving back upstream. These data will be important in determining the effect of weirs on upstream/downstream passage of large Murray cod. Other results will be summarised and discussed in forthcoming publications by the tri-state fishway team (Stuart *et al*. 2007).

Complimentary use of radio tags and PIT tags

These two tagging techniques have different attributes (Table 1) and different applicability to different situations. They can also provide complimentary aspects to tagging studies; for example, a recent study at Yarrawonga Weir fish lock utilised both techniques to measure fish exit success. Native fish were tagged with both radio-transmitters and PIT tags and released into the exit race of the fish lock. The eight-antenna PIT reader system monitored behaviour of fish within the fishway and their exact moment of exit. From there, the radio-tags were monitored to determine the path fish took to successfully enter Lake Mulwala or determine if some fish were swept into the adjacent hyrdro-power station by high water velocities. The complimentary use of both techniques allowed researchers to determine the fate of 72 tagged fish and demonstrated the usefulness of both tags types in the same study.

Table 1: Comparison of the attributes of radio and PIT tags.

Attribute	Radio-tag	PIT tag
Cost (each)	$300	$3
Ease of implantation	Need some veterinary training	Easy for dorsal musculature Moderate training for abdominal implants
Read range	km	60 cm
Tracking methods	Fixed, mobile, Land, boat, aircraft	Fixed or hand held after fish capture
Salinity	Up to 600 EC	To sea water
Remote loggers	Yes	Yes
Other accessories	Yes (see text)	Yes (see text)
Rejection rate	Species dependent but usually low (i.e. <15%)	More research needed, appears to be between 3 and 15%
Mortality rate	Species dependent but usually low	< 2%
Tag size	Depends on battery size	10 to 32 mm+
Directional	Yes	No (but antenna arrays can provide some directionality)

Discussion

Since radio-tags were first used in Australia, they have proven to be a successful tool in investigating movement patterns and habitat use of a range of freshwater fish (e.g. Koehn 1997 and 2006, O'Connor *et al*. 2003, Brooks and Kind 2002). These data have been important in developing a much more comprehensive understanding of native/non-native fish ecology and in adapting our management of fish populations. For example, the identification of upstream spawning movements of adult Murray cod (Koehn 1997, 2006) has strong implications for maintaining migratory pathways and in re-snagging geographically separate habitat units. Such new knowledge for this and other species has fundamentally changed the movement models used to manage these fish

Integration of available technologies in ecological studies has the power to produce a very specific and detailed study of both a small number of radio-tagged individuals (i.e. 50 radio-tagged fish) and broader tagged populations (i.e. thousands of PIT tagged fish). Importantly, while the batteries on radio-tags become exhausted, like PIT tags, they continue to allow researchers to gather periodic data over the fish's entire lifetime (i.e. >30 years for many large-bodied MDB fishes).

Both radio-telemetry and PIT tag technology has advanced rapidly over the past 15 years providing researchers with new research tools and data. Various options are now available to researchers including depth, light, and temperature and fish activity measurement. These new options and an increasing reliance on data collected by remote automated logging stations has exponentially increased the amount of information researchers need to analyse. This, in turn, has highlighted an urgent need for more effective radio-tag data archiving, software filtering, analysis and modelling techniques. Many research agencies will need to upgrade their database capabilities to store and effectively summarise the increased quantities of data that remote telemetry and PIT tag systems can provide. Similarly, the nature of these methods and their application require new technological skills.

There is a need to research fish tag rejection and mortality rates for Australian native fish. Reliable estimates of mortality or rejection allow more rigour in interpreting fish population dynamics data and allow error boundaries to be placed on our interpretations of fish behaviour. We should also continue to develop stronger hardware systems for reliably gathering remote data and the associated software to remotely retrieve and archive information. This type of cost-effective technology will allow more project time to be allocated to analysing results and reporting.

In conclusion, methods to study the spatial behaviour of fish populations continue to progress and provide a clearer understanding of fish ecology. As fish researchers continue to deploy new tagging systems, the increased amounts of data gathered will improve riverine management but also places additional importance in simultaneous upgrading of database archiving and interrogation systems. There is a continuing need to investigate tag loss rates and error boundaries within our detection and interpretation systems but use of a variety of techniques (PIT tags and radio-tags) provides a new direction in the study of migratory fish biology.

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Conventional tags: new tricks with 'old' technology

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Abstract

Tagging is still the most appropriate method for obtaining key fisheries parameters necessary for management of marine fish stocks. Growth, movement, fishing and natural mortality, gear selectivity and catchability can all be estimated by tagging programs. Although there have been significant advances in technology that have led to new micro-tags, acoustics tags and an exciting array of data logging (archival) tags, the conventional externally attached individually numbered tag still has an important role to play.

While conventional external tags may seem old technology, many of the new developments in tagging models require a considerable number of tags to be reported for precise estimates. Conventional tags provide a cost effective method for obtaining data that requires such larger sample sizes. Recent developments have involved the inclusion of the newer technology with conventional tags to improve tag reporting rate and to enhance the accuracy of fishing mortality and exploitation rate estimation.

This presentation will outline the benefits of conventional tags, list some of the recent methodologies that are providing new ways of estimating key fisheries parameters, and suggest where future developments can occur.

Introduction

Tagging is still the most appropriate method for obtaining key fisheries parameters necessary for management of marine fish stocks. Growth, movement, abundance, fishing and natural mortality, gear selectivity and catchability can all be estimated by tagging programs. Because they are relatively cheap, conventional external fish tags remain the tag of choice in fisheries where commercial or recreational volunteers are relied upon to tag the fish or report the recapture of the fish from visual observation. Conventional tagging also remains popular in aquaculture where identification of individuals associated with genetic lines is required and for monitoring broodstock performance.

Although there have been significant advances in technology that have led to new micro-tags, acoustic tags, satellite tags, RFID PIT tags and an exciting array of data logging (archival) tags, the conventional externally attached individually numbered tag still has an important role to play.

Future 'conventional' tags

Conventional tags are continually being refined to meet the demands required by scientists.

Improved retention rates are being addressed through miniaturisation of tags and investigating new molecular coatings that minimise tag rejection or tag loss through wound infection. New coatings to address biofouling and infection are also aimed at minimising the impact of tagging on stress, growth and survival of the tagged animal.

Estimating tag reporting rates has been identified as one of the most cost effective ways of improving outputs from tagging programs (Frusher and Hoenig, 2001a). Improved detection rates can be achieved by using new developments in materials (i.e. 'an even better piece of plastic') that improve longevity and also legibility of tags. Hallprint has been exploring the incorporation of miniaturised electronic RFID tags into the conventional tag. The example of the combined RFID tag and T-Bar tag described below is an example of the two technologies combining.

Finally, the ideal tag, whether conventional or otherwise, needs to be cost effective and easy to apply.

An example of combined technologies

Understanding the tag reporting rate is crucial for estimating key fisheries parameters in tagging models. In most models tag reporting rate is held constant between years. However, it is common for tag reporting rate to vary between years. For example, fishers can loose their initial enthusiasm for returning tags or they may become disaffected by a Government decision and decide not to return tags. These can also affect models that split the fishing season into discrete units (e.g. days, weeks, months etc.). Tags may not be recorded on days when the weather is rough (seasonal variation) or when catch rates are high and there is limited time to record tag information or the checking of animals for tags is minimised due to time constraints.

There are two main types of radio tags, passive tags which require no internal power source and active tags which do require a power source, usually a battery with a defined lifetime. The passive tag derives its power from the electromagnetic field created by a RFID transceiver. That generates sufficient power for the tag to respond to the reader, i.e. to supply its information (e.g. unique tag number and time). Passive tags (often called PIT or Passive Integrated Transponder tags) have a shorter range than active tags, varying from a few centimetres to a few metres and their readability can be affected negatively by metal or stray radio frequency waves. However, the absence of an integrated power source means that they can be smaller than a rice grain, potentially more resilient to pressure and heat, substantially cheaper than powered radio or acoustic tags and far more capable of remaining functional beyond the life span of any known fish species. In addition the tags can be read through a wide variety of non metallic objects and the orientation of the tag is not critical to read performance. In Tasmania, we have been exploring the combination of PIT tags and conventional tags to improve our estimates of tag reporting rate in southern rock lobster.

If there are ‘bottlenecks’ within the capture and/or processing pathways then it is possible to have PIT tag transceivers located in strategic positions so they intercept and record all fish carrying a PIT tag. As lobster fishers keep their product alive by placing them in wells in their vessels, we developed PIT tag transceivers to fit individual fisher’s vessels so that each lobster has to pass by the transceiver to reach the fisher’s well. We have also placed transceivers at selected processors so that all lobsters will be interrogated by a transceiver. This project has been supported financially by the Fisheries Research and Development Corporation.

New analytical developments

In addition to improvements in tags, there have been considerable improvements in methodologies used to analysis tag return data. Most of these technologies are reliant on reasonable numbers of returns and are thus dependent on cost effective conventional tags. Careful design of tagging programs can now enable scientists to generate substantially greater outcomes than previously considered. The remainder of this presentation will give an introduction to some of the recent developments in mark recapture programs using examples directly related to fisheries. This research has been supported by the Fisheries Research and Development Corporation.

Tag methodology and associated software has improved significantly over the last two decades. An example of some of the programs available are listed in Table 1. A more complete list can be found at www.phidot.org/software

Table 1: Examples of mark-recapture software applicable to fisheries science.

Program	Use
NOREMARK	abundance estimation
ESTIMATE	recovery analysis
CAPTURE	abundance estimation - closed populations
JOLLY	mark-recapture - open population - abundance & survival estimation
JOLLYAGE	open population - mark-recapture - abundance & survival estimation with age structure
SURVIV	programming language for survival estimation - open populations
MS-SURVIV	mark-recapture - movement models
RELEASE	mark-recapture - GOF testing - open populations
The next generation...	
POPAN	population analysis
SURPH	allows for individual co-variates
MARK	Handles almost all kinds of analyses: both recovery and recapture analysis (including open and closed-population models), telemetry analysis, multistate (i.e., movement models), and a variety of other permutations on the standard paradigm (including the ability to handle joint estimation from combined sources of data, and individual covariates!).
DISTANCE	abundance estimation from transect surveys

Many of the latest models are built around the multiple year mark recapture matrix (Figure 1.)

	Expected recoveries			
	End of Year			
Year of tagging	**1**	**2**	**3**	**4**
1	$N_1 f_1$	$N_1 S_1 f_2$	$N_1 S_1 S_2 f_3$	$N_1 S_1 S_2 S_3 f_4$
2		$N_2 f_2$	$N_2 S_2 f_3$	$N_2 S_2 S_3 f_4$
3			$N_3 f_3$	$N_3 S_3 f_4$

N_i = Number of animals tagged in i^{th} year

f_i = recovery rate parameter = probability that a tagged animal, alive when the given cohort is tagged, is recaptured and reported during the harvest period of the i^{th} year

S_i = number of animals that survived the i^{th} year

Figure 1: Example of the standard tag recover

Kleiber *et al*. (1987) and Hoenig *et al*. (1998) re-parameterised the multiyear tagging models in terms of tag reporting rate and fishing and natural mortality. Variations of these models including a twice per year tagging model developed by Hearn *et al*. (1998) and applied by Frusher and Hoenig (2001b, 2003) have demonstrated the value of such models. Frusher and Hoenig (2003) were also able to re-parameterise the models to estimate catchability in addition to fishing and natural mortality (Figure 2). These models use the software program SURVIV as it is the only program in Table 1 that enables you to re-parameterise the survival parameter into its fishery components (*F* and *M*).

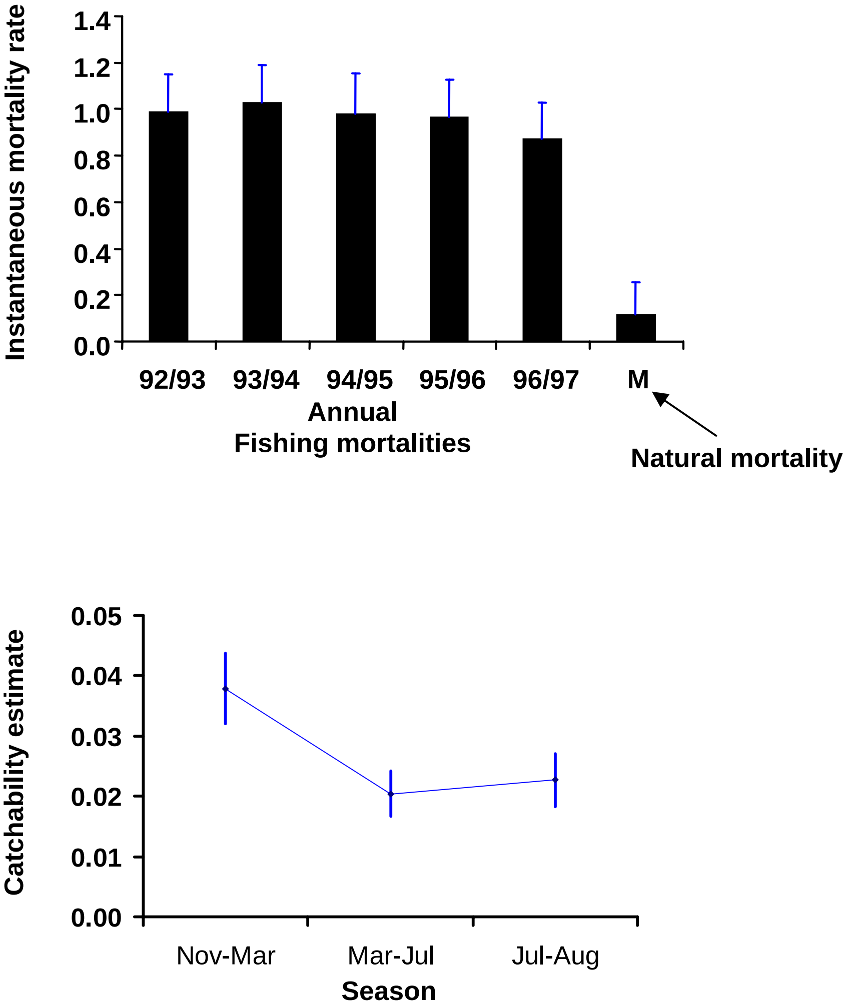
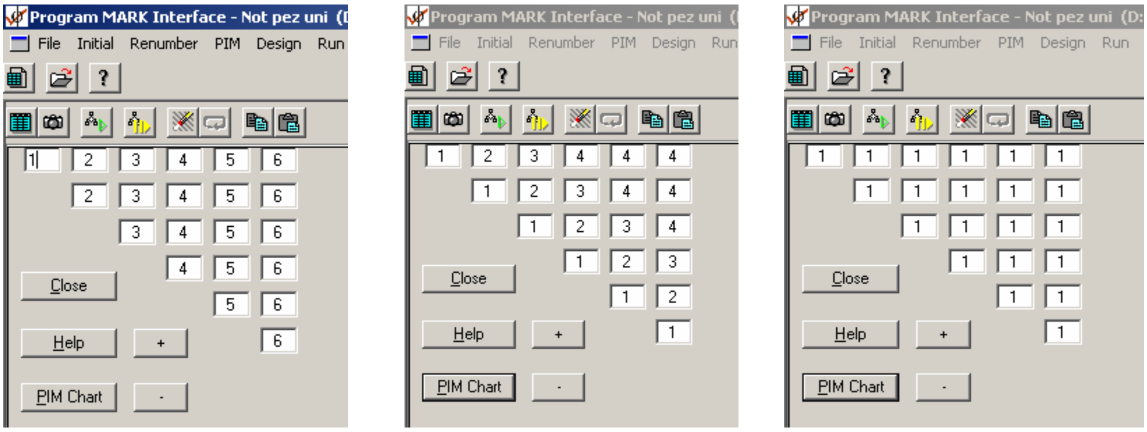


Figure 2: Example of annual fishing mortality estimates, natural mortality estimate and seasonal catchability estimates for southern rock lobsters in northeastern Tasmania using a multi-period mark-recapture model.

To determine survival estimates, Program MARK is our preferred choice. The documentation is both informative, easy to read and guides you through the development of most models. Some of the basic model types available in Program MARK include models that handle:

(a) live encounters -these are applicable in situation when the tag is sighted and animal released alive.
(b) dead encounters – tag recovery studies
(c) live and dead encounters – these models can combine fishery data (dead) with research data (live).
(d) known fate - examples include radio tracking where specific animals are tracked/recorded for set periods of time.
(e) multistrata design – allow for transitions from one strata to another (e.g. immature to mature, cryptic to non-cryptic).
(f) Jolly-Seber – these models allow for recruitment.

Program MARK also works on the basic recapture matrix (Figure 3).



Time dependent

1	2	3	4	5	6
	2	3	4	5	6
		3	4	5	6
			4	5	6
				5	6
					6

Age (cohort) dependent

1	2	3	4	4	4
	1	2	3	4	4
		1	2	3	4
			1	2	3
				1	2
					1

Constant

1	1	1	1	1	1
	1	1	1	1	1
		1	1	1	1
			1	1	1
				1	1
					1

Figure 3: Examples of three basic model types. The time dependent model would compare survival between seasons or years; the age dependent model would compare cohorts and in these examples assumes that there is no difference beyond the fourth year after initial release. The constant model assumes that survival is constant over time and cohort.

Recently, as part of an FRDC funded project we have used several models to evaluate the impact of tagging on lobsters. Using data from a protected population (live encounters) we used the age dependent model to evaluate the initial impact of tagging. To determine if there was a size related effects we used size bins as covariates in a multistrata design. A growth matrix was used to grow animals into different length bins within the model. This was to ensure that the survival rate of animals in year 3 after tagging were being compared to animals of the same size (tagging length plus 2 or 3 years of growth depending on recapture time) rather than their initial length at tagging. The most parsimonious model was found when all years except the first were combined and thus indicated that the largest difference in apparent survival rates was between the first and subsequent years confirming that there is an initial tag mortality impact (Figure 4).

Other examples were we have adapted the basic Brownie style model has been to look at in-situ tag induced mortality and the impact of tagging and handling on growth.

(a)

Survey	**Tagging Period**	**Recapture Period**					
		1	**2**	**3**	**4**	**5**	**6**
1	T1	▤	■	■	■	■	■
2	T2		▤	■	■	■	■
3	T3			▤	■	■	■
4	T4				▤	■	■
5	T5					▤	■
6	T6						▤

(b)

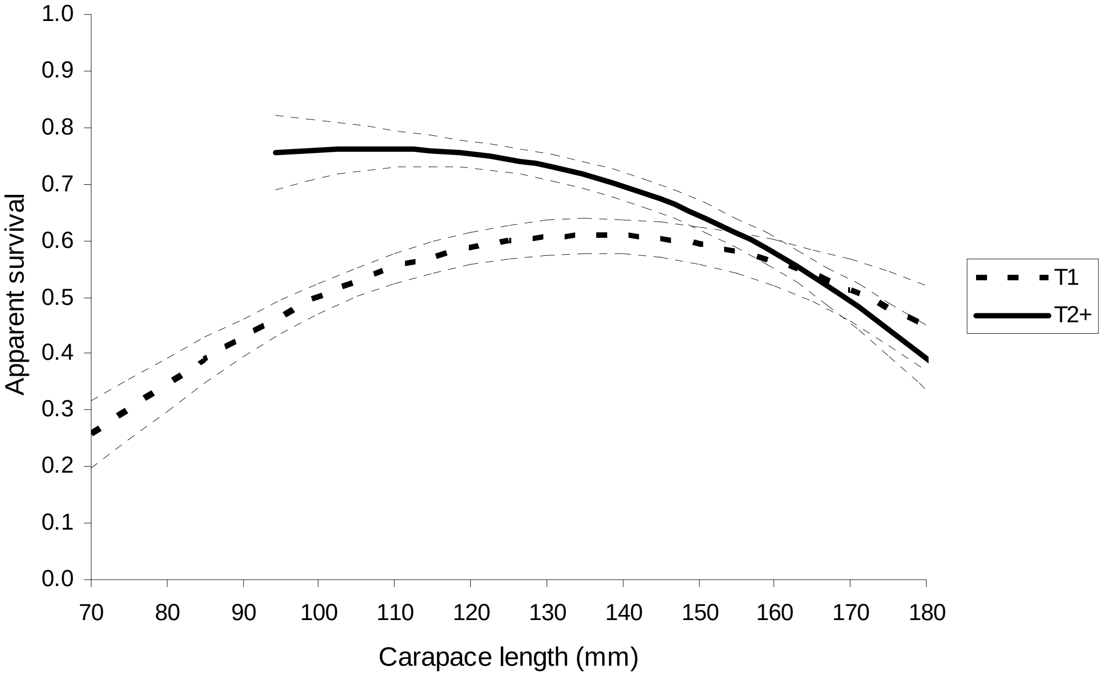


Figure 4: Example of (a) the recapture matrix and (b) apparent survival graph demonstrating the difference between survival of the first year (T1, dashed line) and subsequent years (T2+, solid line).

Future trends in the development of mark-recapture models

The above models aggregate tag recoveries into finite time bins (e.g. months, year, etc.). By splitting the year into smaller periods we were able to obtain estimates of catchability from a model using a strong effort assumption (Frusher and Hoenig, 2003). One of the new areas of investigation is the use of individual tag recaptures rather than aggregated recaptures. These ‘exact’ time-of-recapture models are useful for providing more information on the certain parameters (e.g. catchability) and enable the models to respond to finer temporal change. For example, we have used an exact time at recapture model (i.e. each time bin is a day) and have been able to develop estimates of catchability. These estimates appear to match biological patterns such as increases in catchability following moulting and during mating (males are searching for females and have an increases probability of encountering a trap) (Figure 5).

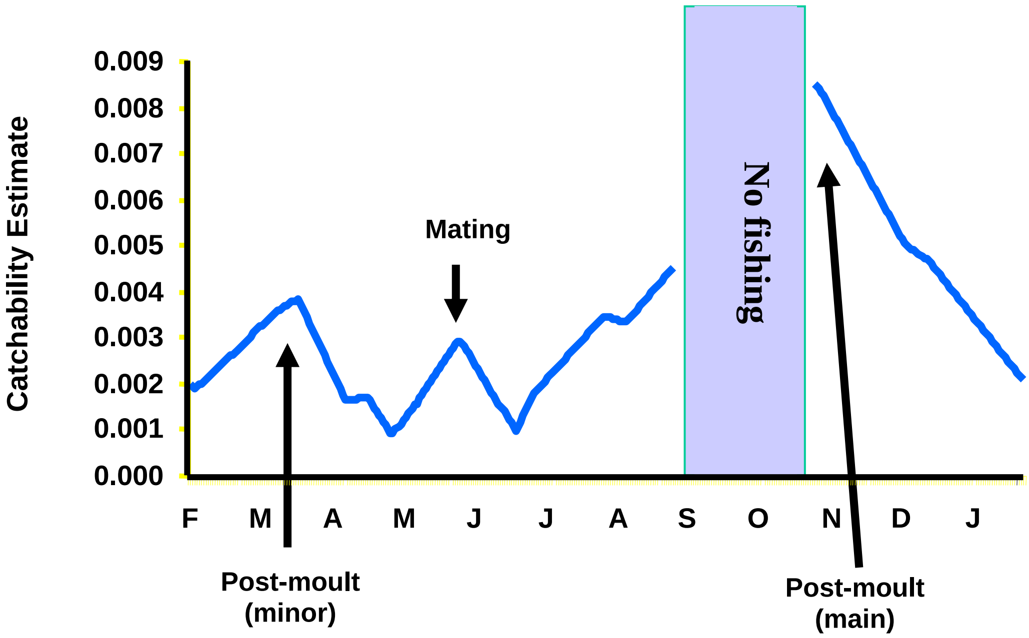


Figure 5: Relative catchability estimates for male lobsters in NW Tasmania using an exact time of recapture model.

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General discussion - Tagging and tracking

Rapporteurs - Dianne Furlani & Adam Barnett

Key discussion points

Fisheries research is being increasingly directed by the information needs to support spatial management and ecosystem based fisheries management, each requiring movement data. New tagging and tracking technologies have the capacity to generate large quantities of movement data at a range of spatial scales. Management boundaries can be more complex than simple ‘boxes’, resulting in potentially better outcomes for exploited stocks and the ecosystem in general.

Presently in Australia few fisheries assessments incorporate movement; the uptake of movement/ spatial data into management processes is an important area that requires further attention.

The lack of long-term datasets is an important issue for fish and fisheries science. We may need to look towards other disciplines to address this matter, e.g. within the physical oceanography field there is a strong culture of long-term data collection and data sharing.

Equipment that will permit long-term monitoring will effectively reduce the overall cost of individual data collection. There are also potential benefits of undertaking multi-species and multi-jurisdictional studies, such benefits need to be recognised and should be emphasised when developing research proposals.

Tagging and tracking technologies need to be appropriate to questions being asked, but will be determined to some extend by available budget. Outcomes may be enhanced by developing complementarities between the available methods. For instance, combining satellite and acoustic tagging technologies, enabling satellites to pick up signals from tagged fish as they are brought out of the water when captured, was identified. This would effectively indicate the end of acoustic transmissions and record capture location.

Apart from gene-tagging, tagging and tracking methods of wild fish stocks typically require the fish to be captured and landed. There is a need to further develop methods that enable *in situ* tagging; for instance automated underwater fish tagging systems for deep water demersal stocks.

In general adult life-stages are the primary focus of existing tagging and tracking methods, but perhaps an early life-stage focus may prove more cost effective to answer some questions. This may, however, require further development of tagging technologies and methods.

The potential benefits of establishing a national acoustic tracking network was flagged, with the need for a collaborative approach to the co-ordination of research, infrastructure and data management identified. The Integrated Marine Observing System (IMOS) initiative to establish a national network of acoustic listening stations represents an important development in this regard. It was accepted that there is a need to promote change in the way funding bodies and research organisations support such initiatives, which should include recognition of the value of effective co-ordination.

Alternative approaches to achieve the same results may be required to reduce costs, e.g. sound generation in acoustic tags using crystal technology and alternate power supply possibilities. There are undoubtedly opportunities to be more creative and borrow technologies from other fields.

As the application of particular technologies becomes more widely applied, it is anticipated that costs will fall. While ‘cheap’ necessitates volume, we also need to think outside the square and examine technologies from other fields, e.g. military, food safety and human health.

The majority of the available high tech tagging and tracking solutions identified have been applied to high value fisheries; there is also a need to monitor small-scale or low value fisheries. For less valuable fisheries where research costs need to be kept low, further application of proven methods should also be considered, e.g. PIT tags.

Conventional tags still have their uses and should not be overlooked in favour of new technologies.

Discussions noted traditional tagging methods required vast numbers of individuals to be tagged to give value to movement data and to determine mortality rates. For stock assessment applications, these parameters are ideally required for all age-classes.

Key issues

Technology

- Miniaturisation of acoustic tags through battery size reduction.
- Alternative methods of sound generation, e.g. crystal technology.
- Robotics to reduce labour costs/time.
- Lessons to be learnt from other disciplines.

Data

- Improved data management and analytical techniques are required to handle the large volumes of movement data.
- Data ownership and sharing issues must be considered.

Management

- How can we better influence management uptake of movement data?
- Promotion of collaboration, equipment sharing.
- How do we change the way management funds national initiatives.
- Need to further consider/recognise the value of co-ordination roles.

Chair's summary

Ron O'Dor

'Fish are like trees, except you can't see them and they move,' according to John Sheppard, a renowned resource manager in the UK. This Workshop focused on new technologies that actually allow us to 'see' fish and to record their movements.

Typically, with traditional tagging techniques you were only able to position the fish twice - where they were tagged and where they were recaptured. Unless a fish stock was severely over-exploited, the chance of seeing the same fish twice, and thus learning something, was generally less than 10%. This also meant that that fish were only found in places where they were fished. Modern techniques show that some fish may travel thousands of kilometres, only to be caught 100 m from where they were tagged. Traditional tagging methods, therefore, may provide very limited insights to fish movements and behaviour.

Depending on the scale of interest and size of animal, modern acoustic tag systems range from returning thousands of positions per day (accurate to meters over kilometres) to dozens of positions per week (accurate to kilometres over thousands of kilometres). For larger animals, archival and satellite tags typically return daily positions accurate to between ten and a hundred kilometres globally. Most things are knowable at a price. Crucial questions are - what do we need to know and how much is it worth?

For fisheries, the answers are not easy, but are probably knowable. For conservation, the question is much more complex. How much is it worth to save a species from extinction, say the North Atlantic Right Whale, for example? No one knows the answer yet, but it is probably the most expensive marine crusade to date requiring super-tankers to divert their routes when whales migrate into critical habitats. For comparison estimated costs for saving the Whooping Crane run to $50M for the US Fish and Wildlife Service alone. Like the whales, the cranes required two critical habitats at opposite ends of a long migration. In the end, not only did crane habitats have to be protected in two countries, but hand reared chicks had to be trained to migrate by imprinted human 'mothers'. How many marine species will we need to do this for? How many could we do it for?

One thing that becomes clear is that economies of scale are possible in the new technologies. The largest cost in most tagging programs is the tagging process - putting people in boats to catch and tag animals. Even for pop-up archival tags at $5000 each, the real cost of being where the animals are probably exceeds the cost of tags. As modern tag use increases, the prices of devices will be driven down. Perhaps never to the price of a spaghetti tag, but if we calculate the cost per position, it may already be lower for a $300 acoustic tag. There is also significant evidence accumulating that external tags not only are more prone to fall out or induce a disease, external tags also call attention to the individual and often make it a target for predators. Implanted acoustic tags have the greatest potential for long-term tracking.

On the receiving end, there was much discussion of the cost of putting out receiver arrays. Again, the cost of people and boats exceeds the cost of equipment, and, if we develop systems to track dozens of species simultaneously, the cost per position is quickly driven down. Newer technologies use automatic recording receivers that require no battery changes for over five years. Data recovery only requires that a boat pass over a receiver, so that this cost is greatly reduced, but variable, depending on the frequency of recovery required.

As we move from relying primarily on Catch Per Unit Effort (CPUE) data to direct measures of animal mortality and movement based on active tags, we will have to develop a new suite of models and statistics to minimize costs and provide reliable population information that can be incorporated into the legal framework. Once this is done, fixed monitoring systems will provide information much more economically. A major advantage of such an approach is that data recording and analysis can be essentially automated.

There is a tendency to assume that CPUE data are free because ship time is paid for by the fishers. There are, however, major fixed costs for port recorders, observers and confirmatory independent surveys. Just because industry pays, doesn’t make it free. The fuel to go out and not catch fish is an ever rising cost of CPUE data that is passed on to consumers. Why not take the next step and let a fixed monitoring system inform the fishers when there is enough of something to make a trip worthwhile? To some extent this is already being done independently on the open ocean by commercial fleets in association with Fish Aggregating Devices. If governments support the monitoring systems, they will be in a better position to decide when and where fishing is appropriate.

Ultimately, tag use depends on the questions being asked. Correct gear choices for the specific uses is needed. To improve the outcomes we need to integrate and develop complementarities between the available methods. Conventional tags, PIT tags and gene-tagging all have their place and uses, and economics ultimately dictates the methods used. However, given the economies of scale possible with acoustic/archival/satellite technologies and the increasing scale of management needed throughout the global ocean, it is time to switch our thinking from 'cowboy' oceans to permanently regulated oceans - managed routinely and continuously for the benefit of both humans and marine life. In the words of US President, George W. Bush, ‘I know that the human being and the fish can coexist.’

Australia has recently committed $55M to develop its national marine observing system through the National Collaborative Research Infrastructure Strategy (NCRIS). This will incorporate compatible acoustic tracking systems provided through a global Ocean Tracking Network supported by $45M (CAD) from the Canada Foundation for Innovation, and Canadian Natural Sciences and Engineering Research Council. These, and similar government initiatives around the world, will create permanent infrastructure in the oceans that will make entirely new approaches to ocean management possible.

Session 2: Underwater Vision And Hydro-acoustics

Simon Allen (Chair)

Developments in acoustic sensing applied to marine habitat assessment

John Penrose
Keynote speaker

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Abstract

The Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management gained supplementary funding in 2003 to support a three year Coastal Water Habitat Mapping (CWHM) Project. This project has enabled significant developments to proceed in the use of acoustic and underwater video techniques in shallow water habitat assessment. The application of high frequency multi-beam acoustic instruments to habitat assessment has been central to the CWHM Project, leading to the use of combined topography and backscatter signals in classification. Progress has been made in the use of targeted video to inform acoustically derived classifications, with an emphasis on the application of efficient video processing techniques.

There remain important challenges and opportunities for using acoustic and video techniques in habitat classification. Work on the combination of water column and related seabed acoustic returns has begun. Acoustic assessment of epibenthic flora canopy height and perhaps of some measure of plant biomass is a challenging target yet to be effectively addressed. The use of high resolution sub-bottom profiling, with the advent of newer instrumentation may yet enable useful information on the uppermost, biologically interactive component of the seabed to be gained at survey speeds.

Keywords: Habitat assessment, acoustics, backscatter, video

Introduction

The extensive use of acoustics in marine science and technology reflects the relatively low absorption experienced by acoustic waves in seawater, compared to electromagnetic waves at frequencies of interest. A very substantial literature in marine acoustics is associated with defence and seismic exploration activities, and also with biomass assessment applicable to pelagic fisheries. Acoustical techniques to provide indicators of seabed habitat type are now being used widely and are the main focus of this paper. Habitat classification necessarily has a primary focus on the optically discerned water/seabed interface and short distances above and below this boundary. In general this leads to the use of relatively high acoustic frequencies and most examples concern acoustic frequencies at tens of kilohertz or above, essentially the ranges used in fisheries acoustics generally.

As with some other techniques, acoustic methods for benthic assessment yield information on surrogate measures of habitat. Acoustic reflection and scattering from the seabed itself and from biota extending above the seabed are central to benthic assessment. Acoustic returns from biota below the seabed surface are not easily distinguished in most acoustic signals. This paper comes at a time when considerable value is seen in mapping seabed habitats such that bottom topography data and acoustic backscatter can be spatially co-located. Such conjoint data sets, informed by periodic towed video information, in particular, are currently seen as providing a workable basis for many seabed habitat requirements. Issues of spatial scales and coverage, of needed and possible spatial resolution, of the choice of classification systems and of survey costs remain as ongoing topics for consideration. It is also the case that many, if not most benthic assessment exercises are seen at present as providing baseline information, usually in map form, and that the provision of time series information, leading to indices of change, remains a task for the future.

Spatial coverage limitations associated with acoustic systems are particularly significant for, in this respect, the least satisfactory of these systems, those based on single beam echosounders. The relatively low cost of such systems has nonetheless led to significant use of echosounders in benthic classification. Such single beam systems have been the earliest developed and applied technology in the field. For successful implementation of echo sounding based benthic assessment, a high dynamic range sounder linked with suitable data acquisition and navigation technology is needed. A processing package is called for and several commercial and non-commercial variants exist. Attention needs to be given to several effects arising from varying water depth and to the influence of the host vessel.

Sidescan sonar provides extensive spatial coverage and in some cases immediately useful information on bottom type. In general, however, the interpretation of sidescan records is limited in terms of bottom biota and this technology is often seen as providing a preliminary tool to guide a suite of more detailed studies on small areas. Further work using a range of acoustic frequencies and involving texture analysis of sidescan images is warranted to seek maximum value from this technology. The advent of sidescan systems using interferometric techniques to provide linked bathymetry and backscatter information represents a developing pathway to the provision of such conjoint information.

The multibeam swath systems now available offer high performance in the provision of topographical information and are also beginning to yield linked backscatter data. This approach has been central to the CWHM Project and a number of similar ventures in Australia and overseas.

One of the many definitions of habitat is given by the Shorter Oxford English Dictionary and cited in Harden-Jones (1994) as; "The locality in which a plant or animal naturally grows or lives; habitation. Applied (a) to the geographical area over which it extends; (b) to the particular station in which a specimen is found; (c) but chiefly used to indicate the kind of locality, as the sea-shore, chalk hills, or the like". In some usages, the term habitat is extended to include the biological communities associated with a given locality. In such cases, description of a marine habitat may involve consideration of the total biomass in an area and its biodiversity. Some commentators make use of the term 'biotope' to represent the seabed physical habitat and its associated biological communities. Acoustic assessment of the seabed has commonly been employed essentially as a sediment classification technique. Considerable attention has been given (see Sternlicht (1999) for a review of this issue) to the linked parameters of sediment grain size, density, porosity, compressional and shear sound speeds and absorptions and surface roughness. This work has informed the discussion below and in part underlies the method of operation of the commercially available systems which use acoustics for seabed classification. As discussed below, the concepts of seabed acoustic 'roughness' and 'hardness' are used as seabed descriptors. Here and later 'acoustic hardness' is used as a descriptor of the acoustic impedance of the substrate type and hence of the impedance contrast offered to an acoustic wave by the water-seabed interface. The physical roughness of a surface influences the amount of sound backscattered to a receiver, so that measured backscatter values yielding estimates of 'acoustic roughness' are often proxies for physical sediment roughness. (Backscattered sound is that part of the total scattered sound that goes back towards the source). As currently employed acoustic techniques provide several surrogate descriptors of habitat. These descriptors are usually linked to more direct habitat parameters by a variety of techniques, including photography and spot sampling of sediments and biota.

For sedimentary seabeds 'hardness' in particular can sometimes be linked to sediment density and compressional sound speed, which in turn link to other sediment parameters. The roughness of sedimentary seabeds is seen as a consequence of the sources and sinks of sediment and of the kinetic energy delivered to the seabed by waves, tides and currents. However, high reflectivity and high backscatter from even a small shell content in sediments can degrade the use of acoustic 'roughness' and 'hardness' parameters for inference of geometrical seabed roughness. Additionally, epibenthic biota, particularly seagrasses and macroalgae of sufficient density can dominate acoustic returns and mask signals from the seabed itself. This paper includes some comment on acoustic backscatter from benthic biota, rather than solely from the water – sediment/reef interface itself, a topic of emerging significance. A relatively early report on this issue is due to Lyons and Pouliquen (1998)

A recent UK Government study discusses an approach to marine and coastal environments, listing seven areas of coherent action which are in turn linked to 12 guiding principles of the Ecosystem Approach as defined by the Convention on Biological Diversity. One such area of coherent action is concerned with the environment and includes a priority action item ‘Using surrogate information sources’. This appears to be a response to the need to access information on benthic habitat structure and function, amongst other factors, which can guide management and usage of the marine environment under conditions of limited understanding of ecosystem dynamics and usually, limited spatial and temporal data coverage (Davies *et al.* 1991).

In recent decades, a number of studies have linked sediment grain size with infaunal invertebrate distributions. This issue has been reviewed by Snelgrove and Butman (1994) who conclude however that ‘the complexity of soft-sediment communities may defy any simple paradigm relating to a single factor, and we propose a shift in focus towards understanding relationships between organism distributions and the dynamic sedimentary and hydrodynamic environment’. In the context however of a broader range of seabed types, including harder sediments and exposed reef structures, some generalisations appear to be justified. Thus Siwabessy (2001) has shown that certain groupings of near bottom fish species can be related to acoustically determined seabed type. This factor is associated with some developing research discussed later in this paper.

Most discussion of acoustic interaction with the seabed does not consider that benthos above the sediment or reef surface contributes to measurable backscatter. Thus most commonly, biota such as macroalgae and sea grass are treated as ‘invisible’ to acoustic sensing. This simplification appears to be a usable first approximation where low frequencies are used, and where only the dominant seabed surface return is sought. However, as shown by a number of investigators, seabed plant assemblies may be detected by appropriate acoustic techniques. Such detection may well provide a more direct surrogate measure of relevance to habitat classification than the measures currently employed, at least where substantial plant biomass areal density exists. A system known as SAVEWS (Submerged Aquatic Vegetation Early Warning System) has been developed by the U.S. Army Engineer Waterways Experiment Station to characterise vegetation in shallow water environments. SAVEWS uses a BioSonics DT4000 digital hydroacoustic sounder with a narrow-beam transducer (Sabol and Burczynski 1998). The system records the depths of the tops of vegetation, usually appearing as ‘a jagged pattern’. The pattern is interpreted visually or automatically. Koniwinski *et al.* (1999) have used this system.

Discussion of sub-surface contributions to acoustic backscatter are more common. At the high frequencies relevant to the present work, such sub-surface scattering can be expected from targets such as shell material, sediment grains, biological matter such as rhizomes, and gas bubbles. Sub-surface scattering necessarily follows in time what is usually a dominant seabed reflection/scattering signal and is mixed with off-axis acoustic returns from the major interface. Thus, for most acoustic geometries information about sub-surface scatterers is not retrievable from signals such as echosounder returns, although sub-surface scattering contributes to the received echo return. Sternlicht (1999) reviews this issue, which has received considerable attention at a somewhat deeper depth scale than is of importance for habitat description, in the context of sensing for buried munitions. However, the acoustic systems are usually very good detectors of shell beds, as these have high acoustic reflectivity and backscatter (e.g. Smith *et al.* 2001), and organisms such as horseshoe crabs and brittle stars (Magorrian *et al*., 1995).

In discussing acoustic techniques applied to seabed habitat description, it is important to note that the ‘seabed’ extends both above and below the sediment or reef interface with the water column. Biotic material above the direct interface is susceptible to acoustic detection, while that below is difficult to distinguish from signals derived from acoustic systems.

The Coastal CRC Coastal Water Habitat Mapping Project (Figure 1)

Australian applications of acoustic and other techniques in benthic habitat mapping include substantial work using single beam echo sounders, notably by CSIRO and in Tasmania, projects involving side scan sonar, and an emerging suite of surveys using multibeam sounder systems. These latter include the deep water CSIRO/NOO project off South Eastern Australia and an extensive suite of surveys in the coastal waters of four Australian States carried out by the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management. The CRC work, titled the Coastal Water Habitat Mapping (CWHM) Project has also led to extensive further work in Victorian and Western Australian waters.

THE COASTAL CRC

- From 1999, partners: Qld Govt, UQ, CQU, Griffiths, JCU, Brisbane City, CSIRO, GA
- From 2003, new partners: Curtin, IWA, GA, Reson, Fugro, DSTO, Sonardata, Georeality
- New 2003 theme- Coastal Water Habitat Mapping (CWHM); completed June 2006

Figure 1. Partners in the Coastal CRC

The CWHM Project had as its aim to 'Develop and Apply Technologies for the Rapid and Cost Effective Assessment of Shallow Marine Habitats'. The Project has thus involved a wide range of technologies, with acoustic techniques of central, but not sole importance. This is illustrated in part by Figure 2, which shows an aerial photographic view of an area off the Perth metropolitan coast which was selected for a detailed suite of acoustic and video comparison exercises.

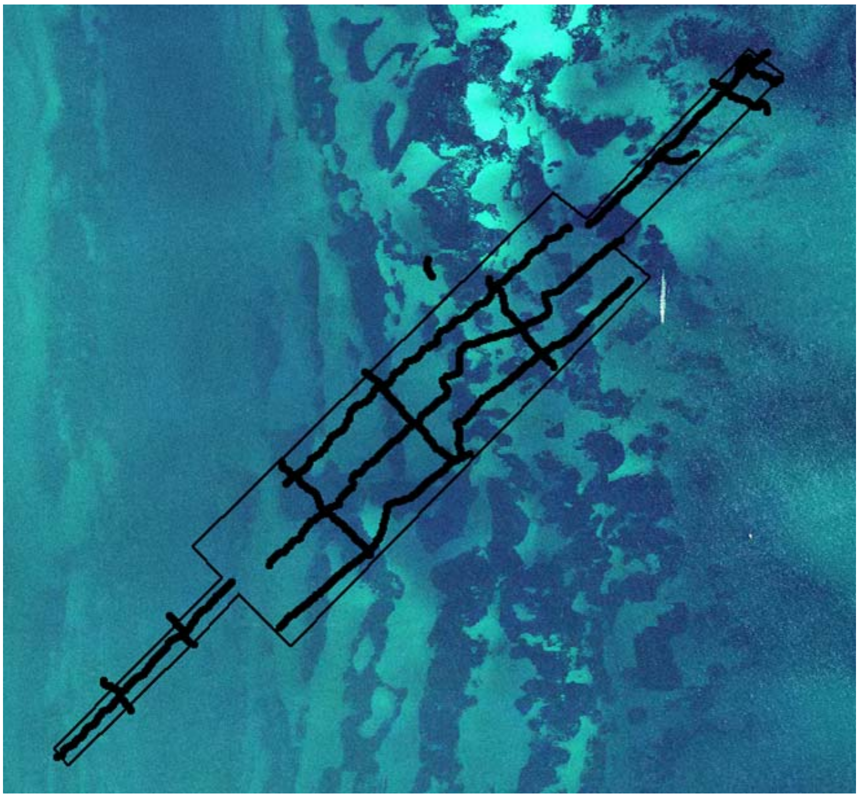

Figure 2. Hillarys region off the Perth coast, showing the area chosen for intercomparison of acoustic techniques. The test area was chosen so as to permit, in the shallower parts, comparison of the results from several acoustic techniques with aerial photographic imagery. After a variety of side scan and multibeam passes were made over the polygon shown, towed video transects were made, as shown by the heavier rendered lines. These transects were chosen, in particular, to investigate texture boundaries shown in the acoustic records.

This area was chosen in part because it allowed a comparison of visual information from aerial photography, at least over most of the area, with the results from several acoustic systems. Towed video was then used, with tracks chosen on the basis of perceived bottom type transitions from other sensors. The image also shows, in the south-west (left-bottom) corner, the reduced clarity in the aerial image associated with deeper waters there. As a result of the acoustic intercomparison here and elsewhere, the decision was made to use multibeam technology in an extensive series of Victorian surveys recently completed. At first, the multibeam unit used was linked with a towed side scan sonar system, the multibeam providing detailed bathymetry and the side scan associated backscatter images. Shortly however, the multibeam alone was used for both bathymetry and backscatter, which reduced equipment mobilization effort and substantially increased workable survey speeds.

Multibeam Sounding Systems

Figure 3 represents the beam geometry of a SeaBeam multibeam system, as fitted to the then RAN oceanographic vessel HMAS Cook. A combination of transmit and receive beam geometries provided for depth measurements to be made at, in this case, 16 positions on the seabed. It should be noted that depth estimates are made by combining time-of-flight measurements with estimates of the speed of sound. The system shared with most other acoustic systems of the time the characteristic of not retaining information on the magnitude or structure of the returned acoustic signal. It was necessary to compensate for vessel motions, notably in roll mode, a feature common to all multibeam systems.

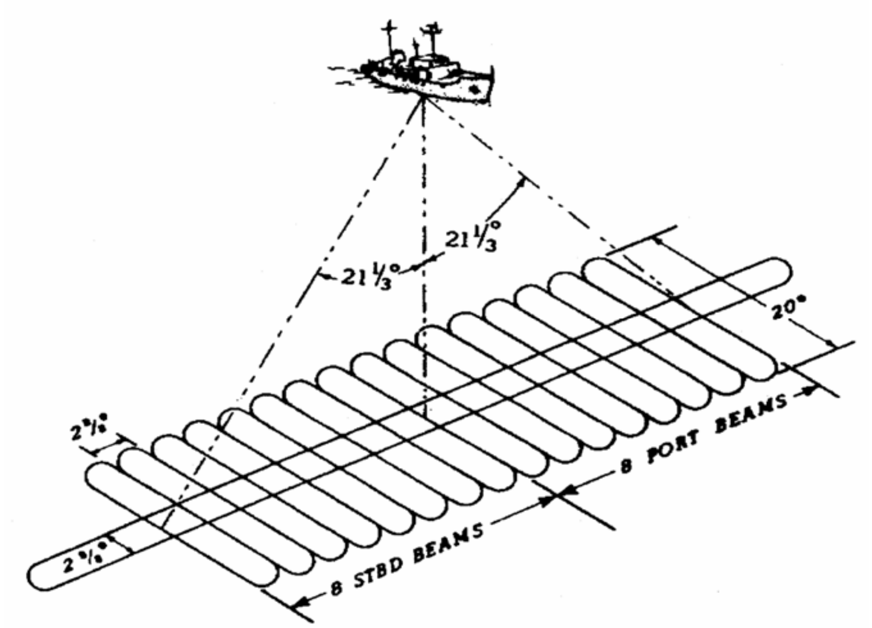

Figure 3. SeaBeam multibeam geometry

Figure 4 (Kloser *et al*. 2001) shows the footprints at 100 depth provided by a Simrad multibeam systems used on R.V Southern Surveyor in a deep water survey off South Eastern Australia in 2000. This system had 111 beams and provides spatial resolution, at the depth specified, of order metres. The figure also shows the footprint associated with one single beam sounder system carried on the vessel. The footprint geometry is represented at a stage in the insonification process when the signal trailing edge has passed through nadir. This pattern is widely used in the interpretation of single beam returns for bottom classification. In the CWHM Project multibeam systems with up to 240 beams were deployed, in waters ranging from 10m to 90m. Such systems thus provide a range of depth dependent seabed spatial resolution values. The optimum selection of such spatial resolution remains as a subject for further research.

Figure 4 illustrates the beam footprints, at depth 100m, derived from two acoustic systems used on the CSIRO/NOO study off South Eastern Australia in 2000. For this, a Simrad EM1002 multibeam sounder was used and the figure illustrates three successive footprints ensembles of most of the 111 beams provided by the instrument. Each beam is associated with a depth estimate and a measure of backscatter magnitude. These measures thus related, in both cases, to some averaging process over the footprint areas illustrated. Also, the areas involved are clearly depth dependent. The relationship between such spatial averaging and the requirements for optimum determination of acoustic surrogates for bottom classification remains an issue for further research. Figure 4 also shows one footprint pattern from, in this case, a single insonification, again at 100m, from a sounder pulse where the trailing edge of the transmitted pulse has passed beyond nadir (Kloser *et al*. 2001), yielding an insonified patch extending in angular terms from the vertical of 170 – 340 . Such pattern usages are common in single beam applications, illustrating the common practice of avoiding nadir returns for some roughness estimates. Here it is apparent that completely different scales of spatial sampling are provided by the single and multibeam systems.

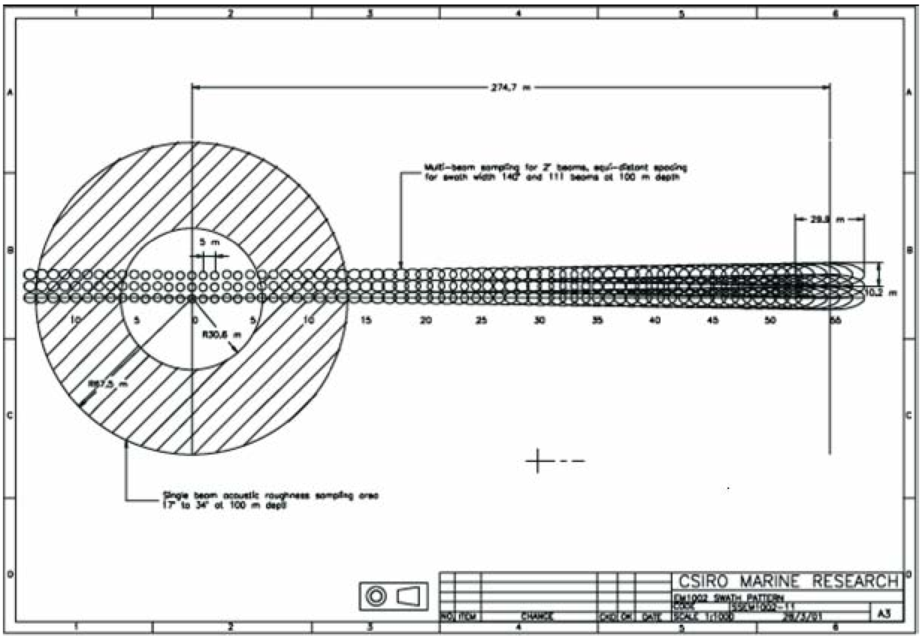

Figure 4. Multibeam and one single beam footprint at 100m as used in the CSIRO/NOO South Eastern Australia study in 2000.

Figure 5 shows a side scan style presentation derived from 240 beam Reson 8125 data taken from a site near Esperance in Western Australia. This mode of presentation composites seabed images from adjacent footprints and shows in graphic fashion differing backscatter characteristics between a sand patch and adjacent seagrass meadows. The figure also demonstrates that the two seabed types provide for significant contrast in angular backscatter dependence, notably, in the example shown at incidence angles of 30 and 60 degrees,

The upper section of the figure shows a side scan like record provided by a Reson 8125 multibeam systems and illustrates the texture contrasts associated with a bare sand surface flanked on either side by seagrass meadows. The lower figures illustrate the variation of backscatter over brief time intervals centred on incident angles of 0, 30 and 60 degrees. The seagrass backscatter varies very little with incident angle, while the sand shows strong angular variation.

This point is further illustrated in Figure 6, which shows a series of angular dependence plots from seagrass and bioturbated sediment seabeds. The area around 30 degrees incidence is highlighted as of particular value in separating the two classes. Figure 6 also illustrates the overall higher backscatter levels from the seagrass areas.

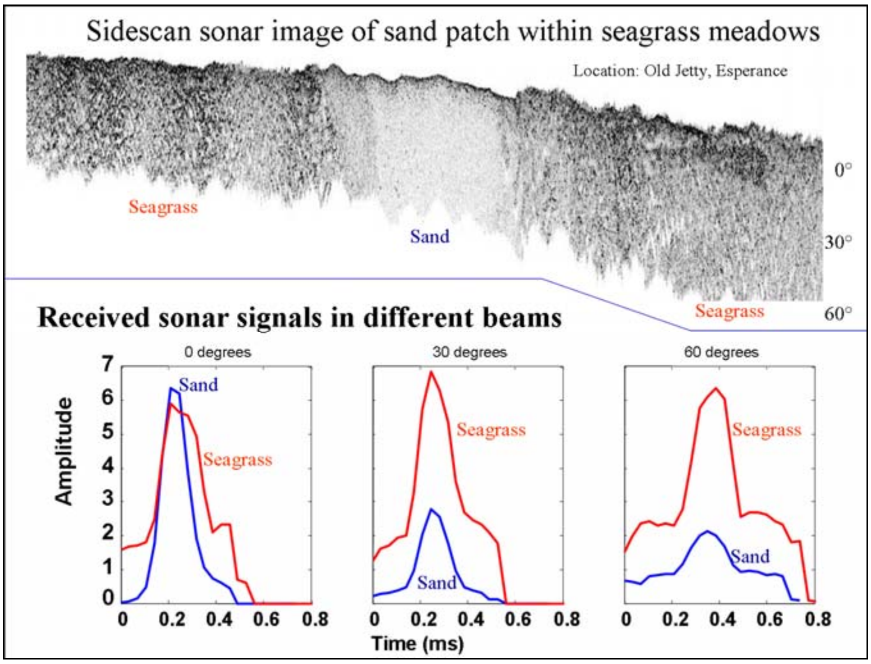

Figure 5. Sidescan representation of Reson 8125 multibeam data illustrating variations in angular backscatter from differing substrates

Figure 6 shows backscatter from two substrate types as a function of incident angle. The upper plot is from a dense seagrass target area as shown in the upper insert while the lower plot is associated with the largely unvegetated area of the upper insert. The slope of the angular dependence at around 30 degrees incident angle is significantly different for the two cases. In addition, the seagrass provides higher overall backscatter levels.

Figure 7 indicates key features of the use of multibeam data in seabed classification. The left hand image essentially represents unmodified multibeam data. Thus the centre, near nadir beams provide high signal levels and off vertical returns present at lower levels, as illustrated in Figures 5 and 6 above. The middle image results from a process of compensating for the gross angular dependence and provides a more readily interpreted image. Both images retain contrast between seagrass (red) and sand (blue) substrates. The angular dependence removed is itself, as noted above, a diagnostic tool as is shown in the right hand side image in which the dependence, between 5 and 40 degrees is seen to be greater over sand areas and less over seagrass, as illustrated in Figures 5 and 6.

A combination of detailed bathymetry, perhaps better termed topography, backscatter magnitude and backscatter angular dependence thus provides a seabed classification tool of considerable sophistication. Figure 8 shows the results of several multibeam tracks over a coral reef substrate off the Queensland coast. High on the reef itself, the multibeam derived topography reveals the bommies characteristic of such substrates. At the deeper frontal locations, where bathymetry is essentially constant, the combination of backscatter with bathymetry allows areas of sparse and dense seagrass to be separated.

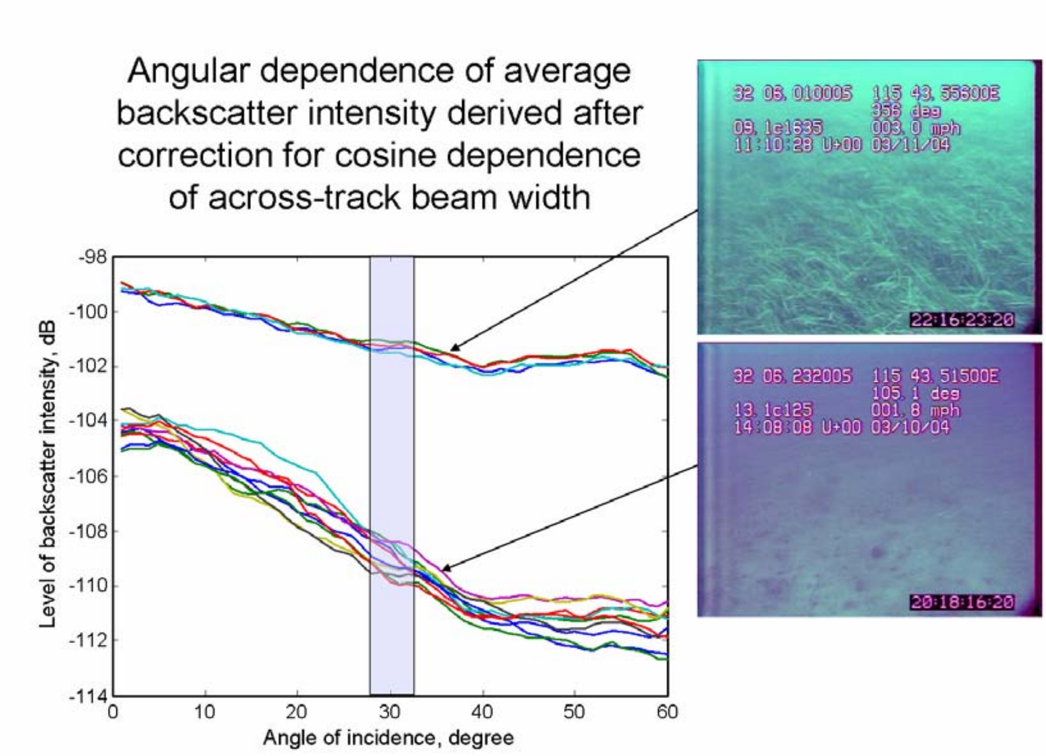

Figure 6. Reson 8125 multibeam data (one side of beam pattern) showing differing angular dependence from differing substrates.

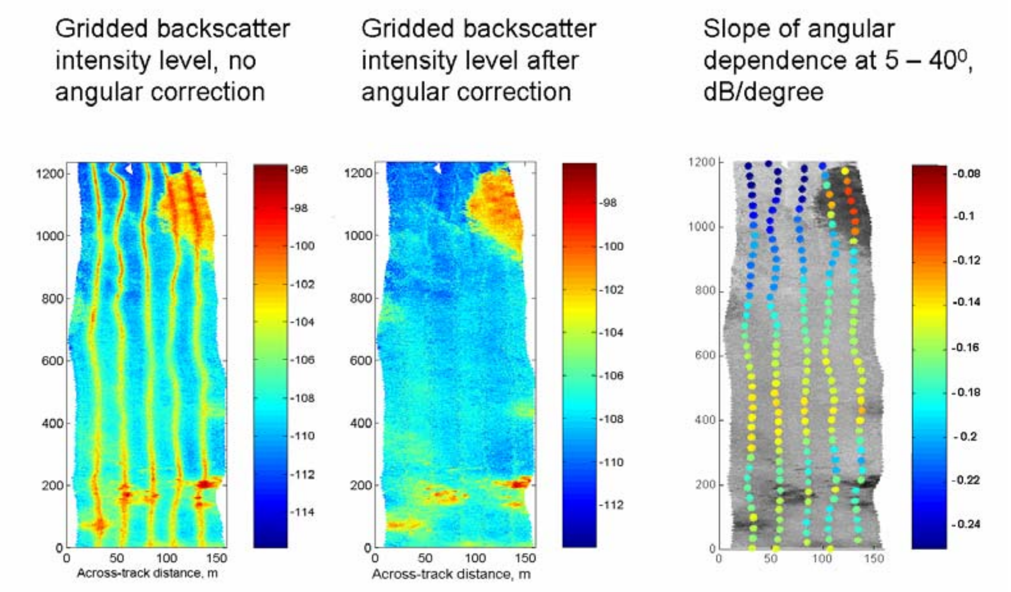

Figure 7. Removal and separate evaluation of angular dependence.

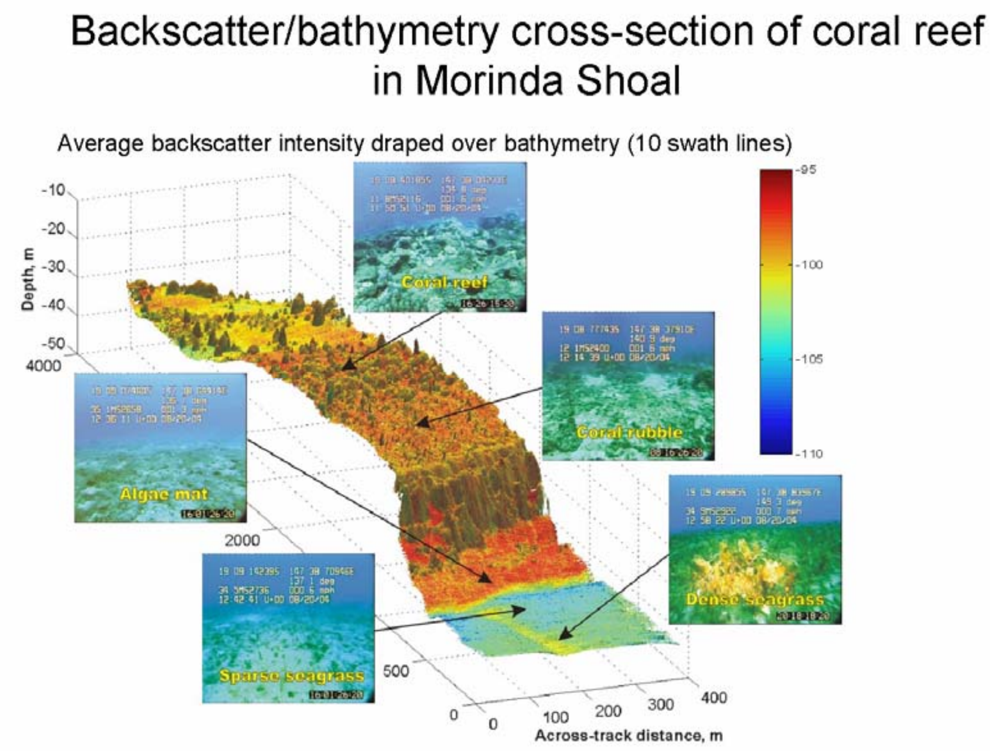

Figure 8. Bathymetry and backscatter across a coral reef substrate

Figure 9 shows an example from a temperate region substrate, and again illustrates the value of using a combination of acoustically derived topography and backscatter to discern different bottom types.

At the time of writing the combination of topography and backscatter information provided by multibeam sounders represents the most effective acoustic technology available for providing surrogate information leading to the production of seabed classification maps. The technology often allows full seabed coverage at manageable cost and resource levels. As noted above, optimizing systems in terms of spatial resolution remains an area for further development. Interferometric side scan sonars, which can offer wider swath coverage than multibeams may yet emerge as a competing acoustic technology. The long gestation associated with the development of Synthetic Aperture Sonars is now near or at its conclusion as Autonomous Underwater Vehicle systems emerge as usable platforms for such systems. Such sonars may also enhance acoustic seabed classification.

To date, all acoustic systems need to be supported by some optically derived comparison information. Towed video represents the most common approach to providing this information.

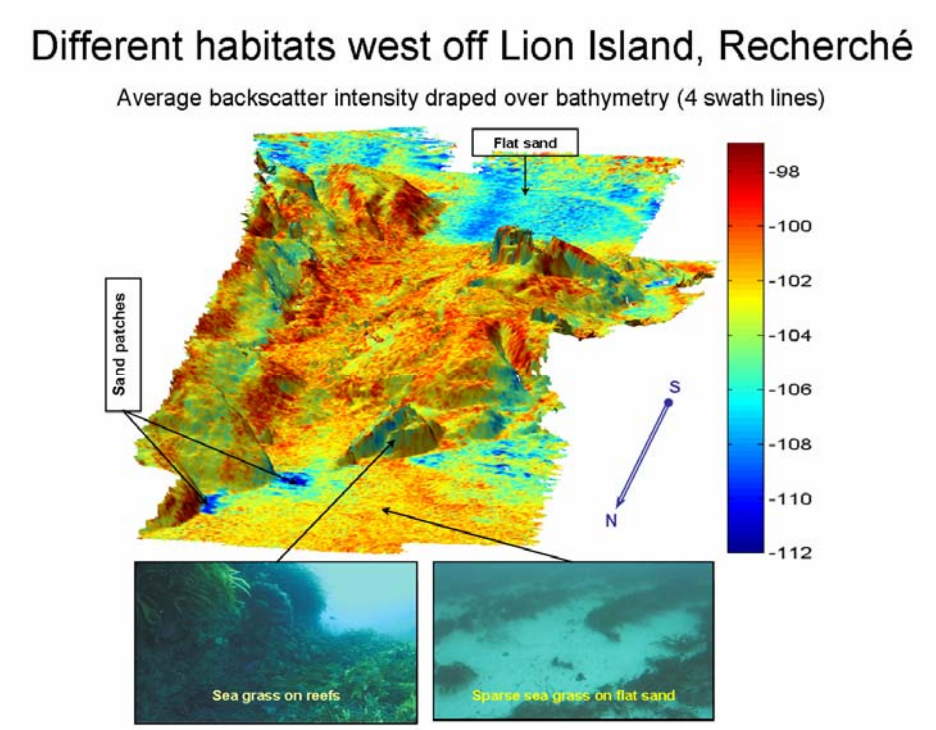

Figure 9. Bathymetry and backscatter from a temperate region substrate.

Developments in Video Technology

Some key features of towed video development are illustrated by programs carried out as part of the CWHM project and led by the University of Western Australia. During this project, the use of multibeam sounders was refined to allow optimum coverage rates. Most commonly, sounder operation and associated towed video coverage were carried out separately using separate vessels. This allowed multibeam coverage to be undertaken at relatively high survey speeds. The topography and backscatter maps produced could then be used to guide an optimum video track design, taking into account areas of apparent seabed type transition and wind and seastate conditions. The video coverage would then be carried out, usually on a smaller vessel, and at the lower survey speeds predicated by the use of a towed camera. Camera position information requires use of a USBL system coupled with Differential GPS to match the video records adequately with the acoustic data.

There remains the significant time and effort overhead associated with processing the video records thus produced. This issue is one which confronts most users of video and still imagery of the seabed environment. Imagery derived from towed, diver operated and fixed camera systems often provides very large suites of images, many of which will contain extensive amounts of information. A significant research effort has been and will continue to be directed to speeding and where possible automating information retrieval from optical images of the seabed and associated flora and fauna.

Figure 10 illustrates several features of the image processing tool JEHP. One feature, the use of a menu of organism types, allows ready data entry of, in this case, descriptions of fish type. The system also offers a number of image processing capacities to assist the viewing operator. Figure 11 illustrates the use of JEHP in length measurement mode on a benthic organism. This is a two-dimensional measurement process, suited in this case to the organism shown. Figure 12 shows images provided by a bottom mounted stereo camera pair. The associated software enables fish length measurements to be made from operator selected measurement points on the targets. The 3D stereo approach enables length determination to be made at a variety of fish orientations to the camera axes.

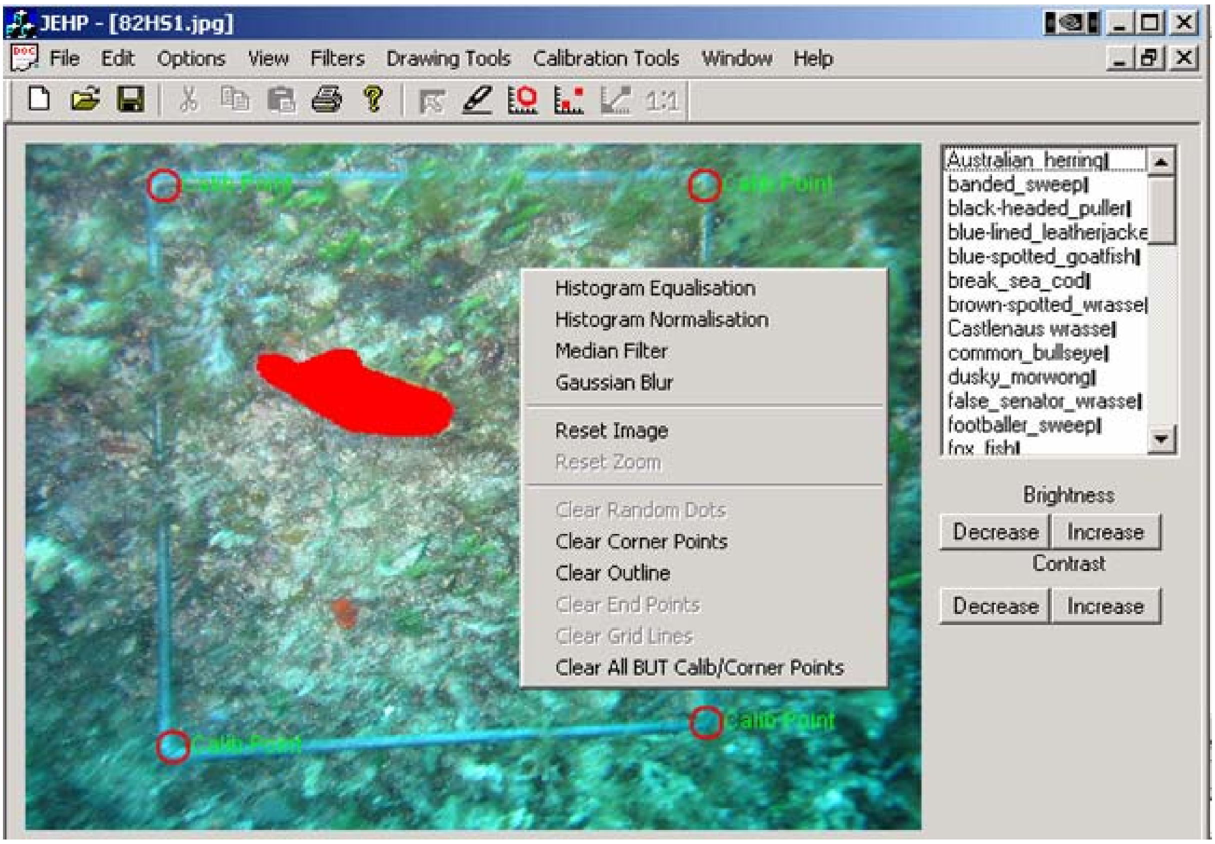

Figure 10. JEHP, an image processing tool

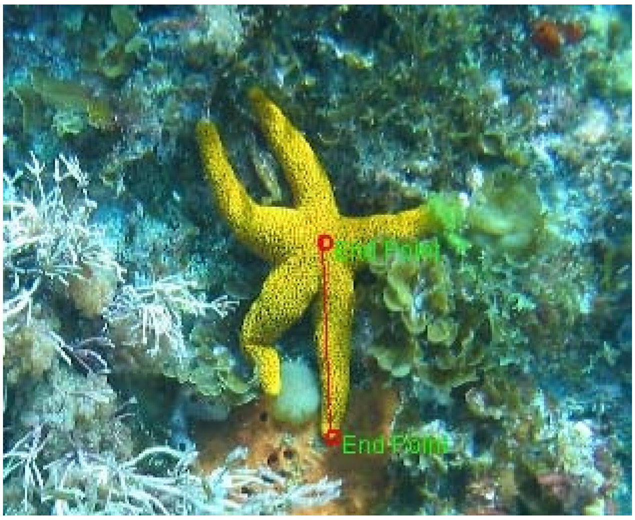

Figure 11. Length measurement using JEHP

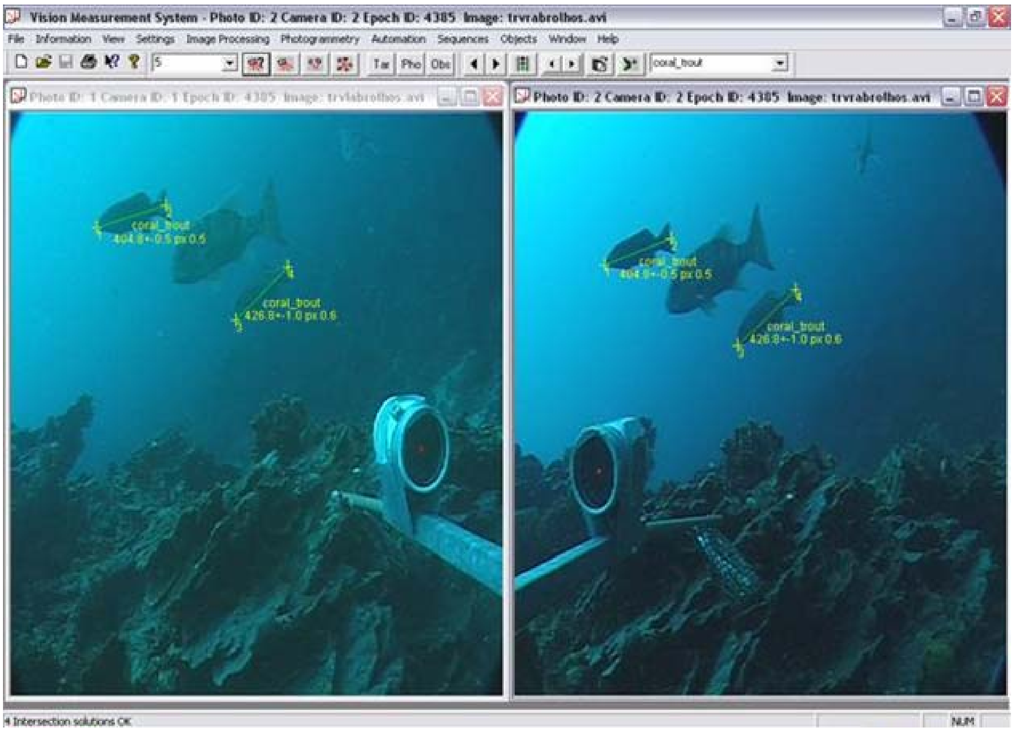

Figure 12. Fish length measurements from stereo images

The concept of moving towards automating image processing to further reduce operator involvement represents a continuing research challenge. Work undertaken at the University of Western Australia as part of the CRC program illustrates three approaches towards meeting this challenge. Identifying information associated with target contours, colour and texture, each of which contributes to the human target identification process, may yet be derived from automated pattern recognition data processing.

Linking Water Column and Seabed Sensing

A characteristic feature of multibeam sounder systems is the extensive amount of data produced. As with other data intensive technologies, this can pose difficulties in terms of the processing speeds required to adequately acquire the data available and concerning data storage. At the time of writing, the former issue has most currency. Multibeam systems most commonly acquire only the signals scattered from the seabed, leaving any backscatter arising from midwater targets unused. The multibeam coverage of the water column does however offer the possibility of using such technology to map, and in principle, assess the biomass of pelagic organisms. Fig 13 shows a quasi 3-D representation of a fish school from work being carried out at Curtin University in Western Australia and using software from Tasmanian company Sonardata. Also, if the multibeam technology can be configured to acquire both midwater and seabed derived signals, the possibility exists to provide linked acoustic characterisation of seabed properties and bentho-pelagic biota. As newer multibeam systems emerge, it is likely that such facility will become available.

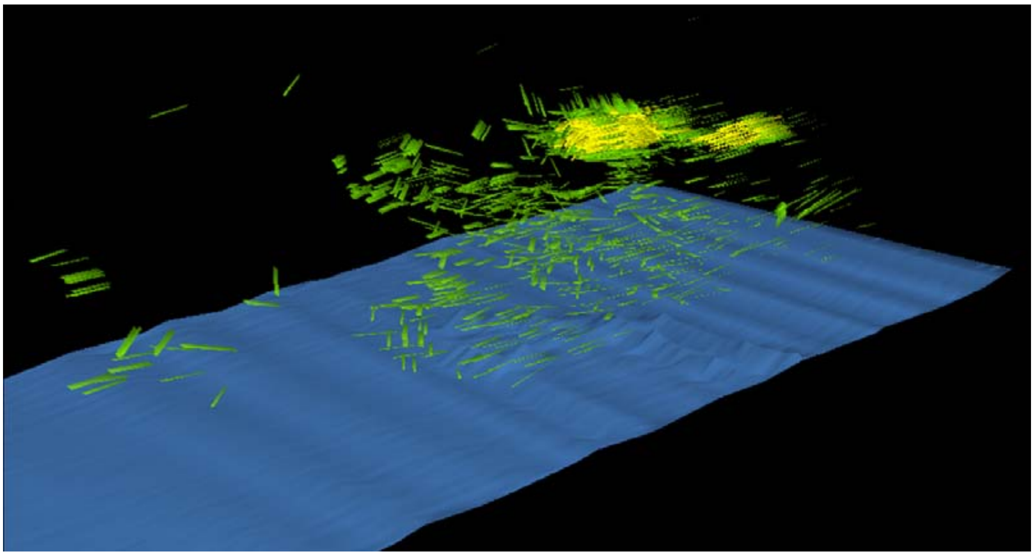

Figure 13. 3-D Visualisation of a fish school derived from multibeam data

Sub-surface Sensing

Reliable and effective sensing of the immediate sub-surface nature of the seabed remains a significant challenge. Sub-bottom profiling technology, particularly using chirp techniques, now offers finer vertical resolution than that earlier available. Figure 14, from work undertaken by Geoscience Australia in Keppel Bay in Queensland, shows results from such a survey. The centre sub-bottom image illustrates the nature of the vertical resolution available from this survey, while the lower image shows the presence of mobile sand waves and the gross direction of their movement. A challenge facing acoustic sub-bottom sensing is to determine if it will become possible to provide techniques which would give useful information on subsurface structures and in-benthos within, say, the top metre of sedimentary seabeds.

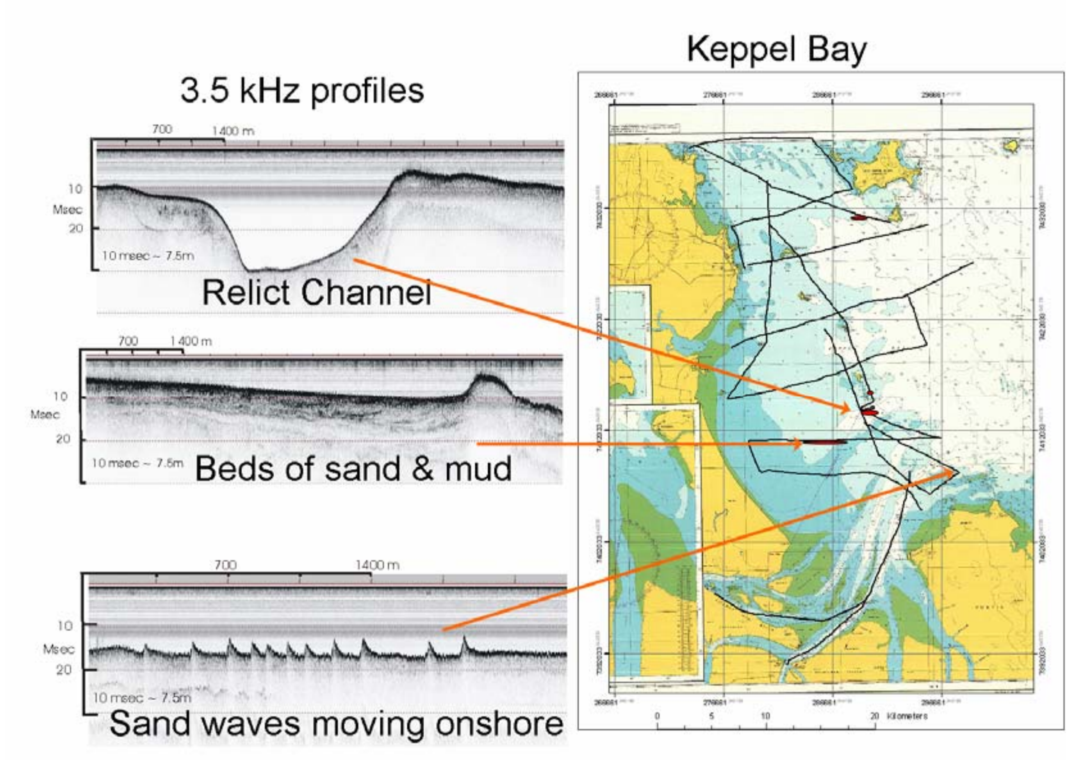

Figure 14. Sub-bottom profiling results in Keppel Bay, Queensland

Autonomous Platforms

A feature common to most field oceanography, and to most of the examples of acoustic deployment cited here, is the need for surface vessel support to deploy the acoustic or video equipment. The concept of deploying seabed sensing equipment from an autonomous underwater vehicle (AUV), is now a reality. Such vehicles can now carry, and support in on-board energy terms, a variety of acoustic sensors for extensive mission durations. Autonomous vehicles of this sophistication are expensive and require vessel support. The extent to which the required mother vessel can be utilised on other science tasks while its AUV, or indeed several such AUV's are deployed will require further development. Another pathway concerning AUV technology is to further develop smaller, cheaper units and the possibility of using shore based and/or small boat deployment techniques.

Passive Acoustics

A substantial body of knowledge has been developed within the international defence community concerning the propagation of acoustic signals in both deep and shallow waters. Particularly in shallow water propagation studies, a number of techniques have been developed which allow estimation of seabed properties from the detailed nature of propagation between a signal source and a listening station. The frequencies and propagation ranges involved generally do not support the development of seabed models which are of value in environmentally useful benthic assessment. In principle however, the techniques developed for low frequency, long range propagation inversion to yield models of the seabed could be used at higher frequencies and at shorter ranges to provide seabed assessment more applicable to environmental applications. Passive acoustic systems, using listening devices to record sounds from noise producing biota, do have application in assessing such noise generators and in some cases such signals may be linked to seabed types.

Looking Forward

There is currently an active program internationally directed to mapping seabed characteristics, often associated with the definition of marine parks and protected areas. Much of the seabed areas of interest, because of a combination of water depth and quality do not allow the use of satellite based or airborne optical sensors. The advent of acoustic systems allowing enhanced coverage rates is leading to increased use of such sensors to provide surrogate measures of seabed characteristics. Such measures are usually supported by towed video or similar technology deployed over features of interest as assessed from the acoustic record. Currently multibeam systems are the acoustic systems often preferred for such surveys and a combination of detailed topography and backscatter parameters used to delineate surrogate bottom classes. Further refinement of this technology is to be expected and variants using interferometric side scan techniques may emerge as systems of choice. The need to improve data processing speed, real time processing and the ability to incorporate mid water scattering information with seabed data is likely to lead to increasingly sophisticated acoustic systems offering new dimensions in marine environmental sensing. Issues associated with the spatial scales sampled by acoustic systems, and their relationship to scales of ecological significance call for further research.

It is unlikely that the use of towed video and similar technologies will not continue to be required. This calls in turn for the development of techniques to provide rapid and efficient data retrieval from seabed images, with some measure of automated image processing increasingly likely to emerge. A challenging and valuable field of research development is concerned with understanding the nature of acoustic backscatter from seabed biota, particularly in shallow waters and from bottom flora. The refinement of acoustic sensing capability to yield improved data on shallow sub-surface sediments, including in-benthos, is a challenging research task.

In many fields of marine science and technology, autonomous platforms of various kinds are prompting a review of the role and cost of conventional surface ships. The balance between small and large vessels and AUV systems will be impacted by AUV and other developments. Passive acoustic systems are emerging more strongly as understanding grows concerning natural noise sources in the ocean.

Acknowledgements

This paper has drawn on the work of the CWHM Project of the Coastal CRC and on a number of international contacts. The support of the CRC partners shown in Figure 1 is gratefully acknowledged. Particular thanks go to Rob McCauley and team, to Gary Kendrick and team, to Brendan Brooke and team, to Des Lord and to Rudy Kloser of CSIRO.

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Hydro-acoustics for fish biomass assessment

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Extended Abstract

Hydro-acoustics is a tool that has been used for many years to obtain biomass estimates of marine and freshwater fish (Simmonds and MacLennan 2005), and works by projecting acoustic pulses into the water and then listening for echoes from fish and other organisms.

Effective use of the technique requires an understanding of the physics that underlie the generation, propagation, and behaviour of sound in water. Of note are the frequencies that are usually used in biomass estimates (3 kHz to 2 MHz), the speed of sound in water (nominally 1500 $m.s^{-1}$), the rate at which sound is absorbed by water (higher in saltwater than fresh), the reduction in sound pressure levels due to spherical spreading, the inverse relationship between beam angle and transducer size, and the maximum range at which fish can be detected, which depends on many factors, but in general the higher the frequency the shorter the detection range (e.g., 1 m to 10 000 m at the frequencies typically employed in biomass assessment). The one factor that distinguishes hydro-acoustics, when used for biomass estimation using the echo integration technique, is the need to calibrate the system to a high precision.

There are two main types of hydro-acoustic equipment used for fish biomass estimation – conventional single- or split-beam echosounders, and the more recent multi-beam echosounders. Single- and split-beam systems operate with a relatively narrow acoustic beam (3° to 40°) and can accurately measure the magnitude of the acoustic echoes from fish. They are easily calibrated and are good for quantitative biomass estimation. A multi-beam system consists of many (often over a hundred) very narrow (0.5° to 3°) beams aligned in a fan shape. This significantly increases the volume of water than can be seen compared to a single- or split-beam system. However, they can be difficult and tedious to calibrate and for a number of reasons are poor for quantitative biomass estimation, although recent and ongoing work is improving this situation.

Single- and split-beam systems are typically used with systematic survey designs, are structured to adequately sample the survey area, and give relative or absolute biomass estimates. The technique works best on fish which form single-species, well defined pelagic aggregations. To convert the acoustic data into biomass, knowledge of the fish target strength is required, which is a measure of how strongly the fish reflects sound, and varies with size, behaviour, morphology, composition, orientation, and acoustic frequency.

Obtaining positive identification of the source of acoustic echoes is important for quantitative biomass estimates. As the acoustic technique does not directly give the species for each echo, other techniques are used, and typically involve catching a sample of the fish. The difficulty of this should not be underestimated – e.g., the selectivity of the various catching methods must be taken into consideration when matching acoustic echoes to fish caught.

Hydro-acoustics has the one great advantage of being able to see underwater where no other technique can, especially in turbid water and at long ranges. The equipment is well developed, readily available, portable, and reliable. However, due to how sound propagates in water, there are some range/resolution trade offs. As the operating range increases, the resolution at that range decreases. To obtain valid results one must be fully aware of the various limitations of the equipment and technique and work within them – it is a field where attention to details is important.

Hydro-acoustics for fish biomass estimation is a developing field. The use of multiple frequencies is increasing, as fish reflect different amounts of sound at different frequencies, and this can be used to improve target identification (Kloser *et al*. 2002, Logerwell and Wilson 2004). As well as discrete frequencies, broadband techniques for target identification are also under development (Reeder *et al*. 2004). The use of multi-beam systems improves spatial coverage and allows the sampling of a much higher proportion of the fish in an area. Work is ongoing to develop techniques to enable the use of multi-beam systems in a quantitative sense (Cochrane *et al*. 2003), including procedures for calibration (Foote *et al*. 2005). Much modelling of how fish reflect sound is being carried out so as to better understand the target strength of fish, how this can vary, and the impact this has on the biomass estimate (Foote and Francis 2002, Gauthier and Horne 2004, Reeder *et al*. 2004). Commensurate with the echosounder equipment becoming smaller and requiring less power, it is also becoming available on other platforms (such as commercial fishing vessels, e.g., O'Driscoll and Macaulay 2005), and the potential for collecting more data over a wider spatial and temporal scale is increasing. The use of hydro-acoustic equipment from autonomous systems is also increasing.

The developments in the use of hydro-acoustic techniques for fish biomass estimation leads, in general, to improved survey precision and coverage, with the eventual result of providing better inputs to the fish stock management process.

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Application of a Dual-frequency Identification Sonar (DIDSON) to fish migration studies

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Abstract

Observing fish in their natural environment is often difficult, especially in turbid water or at night. Traditional sampling methods generally require scientists to interact with the fish in some way to obtain biological information. Disturbing or handling fish may alter their behaviour, so it is difficult to know how ‘natural’ such observations are, especially for short-term studies. Recently developed sonar systems are currently being assessed in North America and their non-invasive application to fish migration studies is extremely promising. One such device, the Dual-frequency Identification Sonar (DIDSON), uses sound-distorting lenses to create high quality video-acoustic images. When operating in high frequency mode, the DIDSON creates images from sound beams that can show the outline, shape and even the fin details of target fish. In addition, the unit’s software can count and measure fish automatically. With such features, DIDSON has enormous potential to improve scientific understanding of fish migrations and behaviour in Australian aquatic systems. The DIDSON has several characteristics that could enhance monitoring programs, including directly observing behaviour, species identification, counting, recording fish length, estimating sampling gear efficiency and permitting direct observation of fish in extremely turbid conditions or at night. It is recommended that the capabilities of this technology should be further explored and developed to enhance existing research programs and to provide a new sampling tool for future projects.

Keywords: DIDSON, Sonar, fishways, migration, freshwater fish

Introduction

Why develop new techniques to study fish migrations?

The requirement for fish to move within and among different habitats is a well-established paradigm for many freshwater fish species (Lucas and Baras, 2001). Mechanisms that obstruct migrations, such as constructing dams and weirs, have led to worldwide declines in fish populations (Baxter, 1977; Cortes *et al*, 1998). Although the adoption of various management strategies has improved fish populations in many parts of the world (such as weir removal and fishway construction), the success of any rehabilitation project relies heavily on a fundamental understanding of the biological requirements of fish (Pitcher and Pauly, 1998). Such information is important to ensure that any effects of human disturbance can be adequately mitigated.

The ability to observe fish in their natural environment is often difficult to achieve, especially in turbid or low visibility situations (Tiffan and Rondorf, 2004). Although many recent advances in technology have been developed, traditional methods generally require biologists to interact with fish (through trapping or handling) to obtain biological information. Whilst in some cases this is the only practical method to obtain data, it is largely unknown whether handling fish can alter their ‘natural’ behaviour; a phenomenon that is almost impossible to control for (Hubert, 1985).

Trapping or netting fish during upstream or downstream movements is commonly employed to obtain data during migration studies (See for example Mallen-Cooper, 1996; Mallen-Cooper, 1999; Fievet, 2000; Stuart and Mallen-Cooper, 1999; Stuart and Berghuis, 2002; Baumgartner 2005). In Australian systems, information on fish migration is usually collected from two sources; fishway trapping (Mallen-Cooper, 1996; Stuart and Berghuis, 2002; Baumgartner 2005) or tag-recapture studies. Such studies provide important quantitative information on timing of migrations, distances traversed and species composition. However, fish are often trapped or recaptured in the process of migrating and little information can be deciphered about the ecological reasons behind observed migratory patterns

(Pusey *et al*, 2004). Subsequently, little is known about fine-scale fish behaviour or even the proportion of migrating fish that are actually sampled.

Electronic monitoring of fish

In more recent times, the development of electronic monitoring devices such as hydroacoustics (Johnson *et al* 1994; Steig and Iverson 1998; Frear 2002), infrared (Halfdanarson, 2000), sonar (Eggers, 1994; Eggers *et al*, 1995; Williams *et al*, 2003; Belcher and Matsuyama, 2003) and transponder (Castro-Santos *et al*, 1996; Zydlewski *et al*; 2001; Hockersmith *et al*, 2003) technology has greatly improved the ability of researchers to gather information beyond trapping and tagging studies. Such technologies allow fish to be observed with little or no interference.

Recent research has focused on hydroacoustic technology (Berghuis and Matveev, 2004). ‘Hydroacoustics’ is a term applied to the use of echo sounding, which detects and records the return signals of frequently transmitted sound waves. The result is an integrated image known as an echogram, which can be interpreted into biological information by trained researchers (Berghuis and Matveev, 2004). This technology is widely used in North America for quantifying migrations of Atlantic salmon (*Salmo salar*) (Ransom *et al*, 1998; Thorne and Johnson, 1993; Yule, 2000) and shad (*Alosa* spp) (Schael *et al*, 1995; Vondracek and Degan, 1995). In some cases, extremely accurate estimates of migrating fish numbers have been obtained (Ranson *et al*, 1998) and the technology is advancing rapidly. Hydroacoustic systems have had some application in Australia but its widespread use is limited by a high capital cost and usually poor species recognition capability (Berghuis and Matveev, 2004).

The use of transponder technology has also increased rapidly in more recent times (Lucas and Baras, 2000). Passive Integrated Transponders (PIT) comprise a coil and an integrated circuit that is programmed to transmit a unique code to a remotely-stationed reader (Prentice *et al*, 1990). The tags are encapsulated in glass or plastic and implanted into the musculature or stomach cavity of the fish. It is important to note that PIT tags do not contain a battery. Therefore, once a tag has been implanted into a fish, it is theoretically tagged for life (Lucas and Baras, 2000). The two major disadvantages of PIT technology are that fish must be handled to implant the tag and that automated detection systems have a very limited read-range (often <1 m). The strategic placement of PIT detection systems, such as in fishways or migratory bottlenecks, however, can provide excellent point-source data on fish movements (Armstrong *et al*, 1996). Details about more generalised movements of fish are much more difficult to determine because of physical limitations on the number of antennas that can be installed at automated detection sites.

The development and operation of sonar systems

Recently developed sonar systems are currently being assessed in North America and their application to fish migration studies is extremely promising (Eggers, 1994; Eggers *et al*, 1995; Williams *et al*, 2003). The Dual-frequency Identification Sonar (DIDSON; Figure 1) uses acoustic lenses to transform sound waves into high quality video images that are captured on a laptop (See examples in Moursund *et al*, 2003 and Baumgartner *et al*, 2006). When operating in high frequency mode, the DIDSON uses 96 acoustic beams that can define the outline, shape and even fins of target fish. Importantly, the technology is particularly effective in dark or turbid conditions where visibility is otherwise extremely poor. The software, which operates the unit, can also count and measure fish automatically. Therefore, this technology can potentially allow the observation of fish behaviour such as migration, spawning and feeding. Previous applications of DIDSON technology have primarily focused on quantifying migrations of commercially important species, such as Atlantic salmon (Eggers *et al*, 1995, Moursund *et al*, 2003; Maxwell and Gove, 2002).

Figure 1: A standard unibody DIDSON transducer which weighs approximately 7kg and measures 171mm x 307 mm x 206 mm; b) A standard DIDSON accessory kit containing data cable, set-top box, Ethernet cables and the transducer. The operator additionally requires a laptop running DIDSON software to operate the unit.

Operation of the DIDSON unit is straightforward and requires minimal training. The DIDSON unit comprises the sonar, a set-top control box, a data cable, control software and an associated laptop computer. The DIDSON is directly connected to the set-top box, which is linked to the laptop via an ethernet connection. The image is transferred from the unit to the laptop via the control software, which displays the data as a streaming image. Image files can then be either directly viewed using the control software or saved onto a hard drive and reviewed manually at a later date.

The DIDSON operates in either high (1.8 MHz) or low frequency (1.0 MHz) modes (Table 1). In high frequency mode, image resolution is greatest but the unit cannot generate images from greater than 12m away. In low frequency mode, image resolution is compromised for a greater operational range (>40 m). High frequency mode is considered the most useful for fisheries-based applications as image quality enables a much better determination of fish behaviour, including morphological features that could enable species recognition (Maxwell and Gove, 2002; Figure 2).

Table 1: Technical specifications of the DIDSON unit (From Moursund *et al*, 2003).

High-frequency mode	
Operating frequency	1.8MHz
Beamwidth (two-way)	0.3º horizontal by 12º vertical profile
Number of beams	96
Low-frequency mode	
Operating frequency	1.0MHz
Beamwidth (two-way)	0.6º horizontal by 12º vertical profile
No. of beams	48
Both modes	
Field-of-view	29º
Power Consumption	30 W typical (24 volts)
Weight in air	7.0 kg
Weight in water	-0.61 kg
Dimensions	171mm x 307 mm x 206 mm

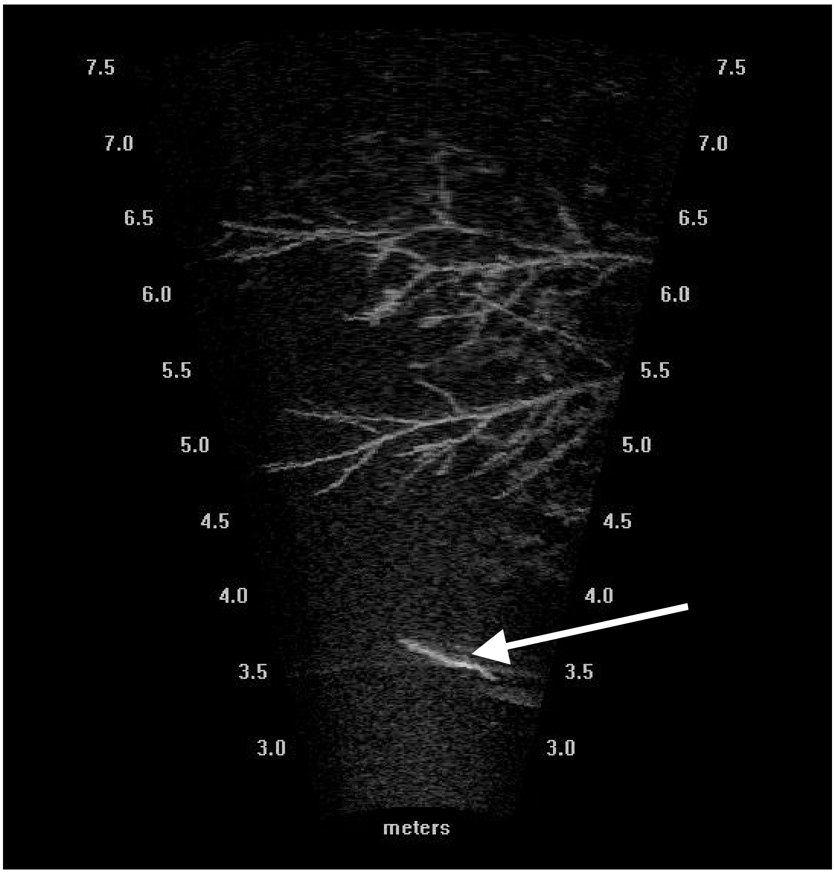

Figure 2: An example of a DIDSON generated acoustic image showing a longfinned eel (*Anguilla australis*) (arrowed) seeking refuge under a snag on the Williams River, NSW, Australia.

DIDSON applications in Australia

Recent deployment of a DIDSON unit in the Murray-Darling Basin explored the advantages and limitations of the technology for wider application in fisheries research. The unit was assessed for its ability to collect specific ecological data. Subsequent field tests included quantifying escape and trap avoidance within a fishway, assessing the effect of altered entrance conditions on passage through a vertical slot fishway and determining entrance and exit efficiencies of a fishlift (Baumgartner *et al*, 2006).

The results indicated that the DIDSON is a powerful tool for observing freshwater fish populations. When used in conjunction with conventional trapping equipment, the DIDSON consistently provided additional data on fish behaviour that could not be otherwise obtained. For example, at fishways on the Murray River, the DIDSON demonstrated that many more fish were approaching and entering the fishways than were trapped as they passed through. In many cases, fish actively avoided traps or displayed a behavioural reluctance to entering the fishway. In addition, several fish were observed to migrate downstream through the fishway when no traps were in place. The DIDSON also provided useful observations of non-migratory activity and non-finfish fauna. In particular, predatory birds and fish were observed to use fishways to actively hunt prey. Such observations are not possible through conventional sampling, especially in turbid conditions.

Despite these apparent advantages, the unit had some limitations, which could narrow the suite of potential field applications. Specifically, the unit was unable to provide an accurate image of small bodied fish (<75 mm). This limitation prevented the ability to obtain accurate counts or classifications for these species. In addition, the automated counting and measuring functions were quite variable in some instances, especially when fish were present in high densities. New software is now available, which may overcome these problems. Field trials will commence in late 2006 to evaluate the capabilities of this new software. If it performs up to expectation, substantial value will be added to future programs that use DIDSON technology.

Future applications and possibilities

Despite its limitations, the capacity for the DIDSON to contribute to increased ecological understanding is becoming widely recognised. In North America, DIDSON is now widely used to replace existing hydroacoustic monitoring stations because of its increased capabilities and resolution (Maxwell and Gove, 2002; Table 2). The technology can permit direct observations of fish behaviour in fishways, fish traps and in open water. Observations of fish under these conditions will lead to new hypotheses which, when tested, will improve the collective understanding of fish behaviour. For example, researchers could investigate the efficiency of different trapping systems and use DIDSON-generated data to develop a design that maximises catches (by minimising avoidance and escape) for future trapping studies. The technology could also be applied to determine the optimal placement of fishway entrances by investigating areas of fish accumulation downstream of weirs.

Table 2: Advantages and disadvantages over other methods of DIDSON electronic monitoring based on the results of the present study and Maxwell and Gove (2002).

Task	DIDSON attribute
Advantages	
Imaging	The production of clear images that are easier to detect with a static background
Angle	A wide viewing angle (29°)
Depth	Good vertical coverage of the water column with few background noise issues
Operation	The unit is simple to aim and calibrate. Very little training is required.
Directionality	Upstream and downstream movement can be defined easily at ranges as close as 0.8m from transducer
Image Quality	Sound waves are transformed into high quality video images (1300 frames/sec) and a background subtraction feature can eliminate unwanted noise
Fish length	The operator can manually determine approximate fish length up to 12m away from the unit in manual high frequency mode
Data	The unit is capable of revealing complex behavioural information with no interference of the researcher. Observations of feeding, spawning and migration are all possible.
Disadvantages	
Data handling	Large data files are produced which create storage concerns
Automated software	Improvement of automated counting and measuring capabilities are required for remote operation
Small fish	Presently unable to permit accurate assessments of fish under 75mm
Damage	Most electronics are deployed underwater and increase the probability of debris strike or vandalism
Vertical profile	The 12º vertical profile can limit some applications in particularly deep water. This can be partially overcome through strategic placement of the unit to maximise field of view.

The results of previous studies (Baumgartner *et al* 2006) suggest that the immediate deployment of a DIDSON to monitor fish migrations in Australian systems is feasible and could be used to supplement existing assessment programs. Although currently limited to larger-bodied fish (>75 mm) the technology enables the continuous collection of data without physical interactions with target species. No other sampling technique can boast the same advantages and provide continuous data at such a high resolution. The capabilities of this technology will be further explored by the NSW Department of Primary Industries in collaboration with the Murray-Darling Basin Commission with the aim of providing an additional tool for assessing the health of fish communities in Australian systems.

Acknowledgments

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Towed camera platforms for deepwater seabed surveys

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Extended Abstract

Vessel-towed camera platforms are being used in Australia and elsewhere to acquire imagery of the seabed in depths beyond those accessible to divers. Imagery enables ‘unseen’ seabeds to be visualized, and, if calibrated, permit quantitative data on physical and biological attributes to be taken. These data, qualitative and quantitative, contribute to understanding fine-scale habitat distributions and habitat associations of biota, and may be applied to management processes such as risk assessment (e.g. impacts of fishing) and spatial planning (e.g. inventory within marine protected areas or fishery closures). Towed systems provide fine spatial scale data along transects up to several km long, are able to cover broad depth ranges and traverse steep and rugged seabed types, and have an operational simplicity that allows deployment from a wide variety of commercial and research vessels. These characteristics make them the platform of choice for large-scale, visual benthic habitat studies in Australian waters.

This talk outlined aspects of the technology incorporated into towed platforms being used by CSIRO for deepwater fishery and biodiversity surveys on the deep continental shelf and continental slope (in ~50 to 1 500 m depths). Details of the following components were discussed:

Cameras (see Figure 1):

- navigation camera - forward looking to reduce the risk of collisions
- paired PAL cameras (720 x 576 pixel) with precise in-water (pool) calibration and re-calibration at working depth using 16-laser array to enable quantitative data extraction (x,y,z and area)
- 8 mega pixel digital SLR to record species/ habitat features of interest at high resolution; this has surface control (operator triggered shutter) and dual strobes with ‘smart’ metered exposure to increase the proportion of useable images.

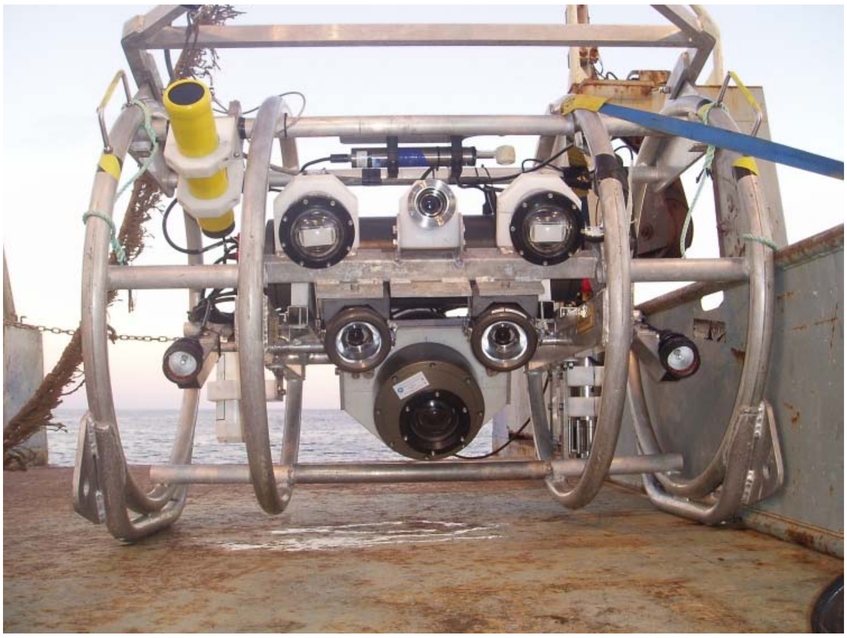

Figure 1: Vessel-towed camera platform system.

Data transmission and telemetry:

Transmission is via optic-fibre tow cables of 1 000 m on a portable system for use from small research vessels or fishing vessels, and 3 000 m for use from a large vessel platform. Fibre-optics enables:

- navigation using the forward looking camera
- real-time capture of both PAL video streams to DVCAM tape at the surface, and
- preview of digital stills to verify image capture and in-water upload of still images (see Figure 2 for output image).

Telemetry is regulated with an electronic control and monitoring package, sensors measuring at 2 Hz:

- depth
- altitude above seabed
- pitch/ roll
- CTD (salinity/ temp/ pressure), and
- system diagnostics (power, internal temperature etc).

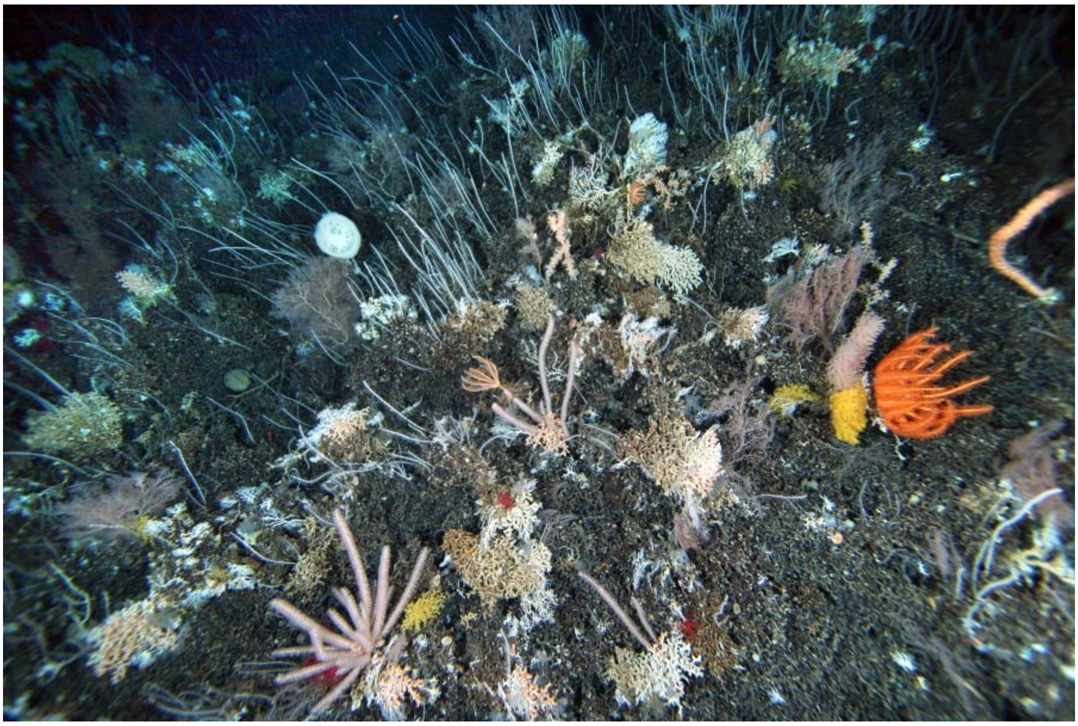

Figure 2: An image taken from the camera platform showing a diverse coral community with echinoderms, at 1106 m water depth.

Geolocation

The camera platform is usually at some considerable distance behind and below the vessel in deep water, making it critical to fix its position so that data can be accurately geo-referenced, e.g. in relation to seabed maps. Platform position is reported to the vessel by acoustic transmission using a Sonardyne ultra short baseline (USBL) beacon. Accurate position estimation requires minimizing errors from several sources:

- vessel position – using DGPS
- vessel pitch and roll – have good motion reference and compass data
- transmission time – applying a sound velocity profile and acoustic ray tracking
- vessel-beacon calibration - static and dynamic corrections
- knowledge of camera platform dynamics – based on its own pitch and roll sensors

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

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Abstract

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

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

Introduction

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

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

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

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

Table 1: Continued

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

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

The general benefits of the technique lie in three main areas. Firstly, baited video approaches are non-extractive and do not cause major disturbance to the substrata and its epibenthos. This means they can be used in marine reserves and rugose seabed topographies, and to gather information on numbers and size of animals of special conservation significance. Secondly, large, mobile animals that avoid SCUBA divers and extractive fishing gears are included in samples (Figures 2 & 3) (see Cappo and Brown 1996 for review). All animals passing though the field of view, in response to the effect of bait or not, can be recorded (see Armstrong *et al*. 1992). This lack of size selection, and the powerful sampling replication afforded by multiple camera units, avoids 'false negatives' (Tyre *et al*. 2003) and allows standardised sampling at any depth, time of day and seabed topography. Thirdly, the acquisition of a permanent tape record removes the need for specialist observers to conduct all fieldwork, allows impartial, repeatable measurements, enables standardised data collection and training in association with remote taxonomists (via emailed imagery), and provides a remarkably popular format to communicate science to the public.

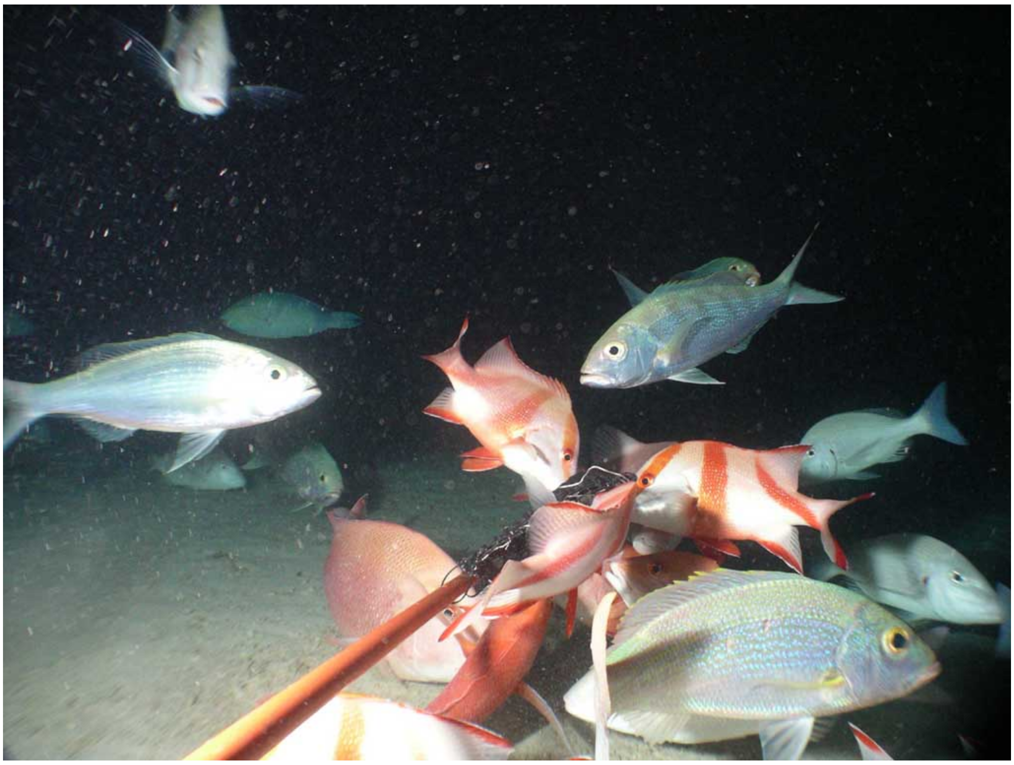


Figure 2: Digital still image with strobe flash showing activity around a BRUVS bait canister at 92m depth on the north-western Australian shelf, showing predatory *Lutjanus sebae*, *Pristipomoides typus*, *Lethrinus lentjan* and the parrotfish *Scarus ghobban*. Image courtesy A. Heyward AIMS.

General Approaches and Applications

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

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

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

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

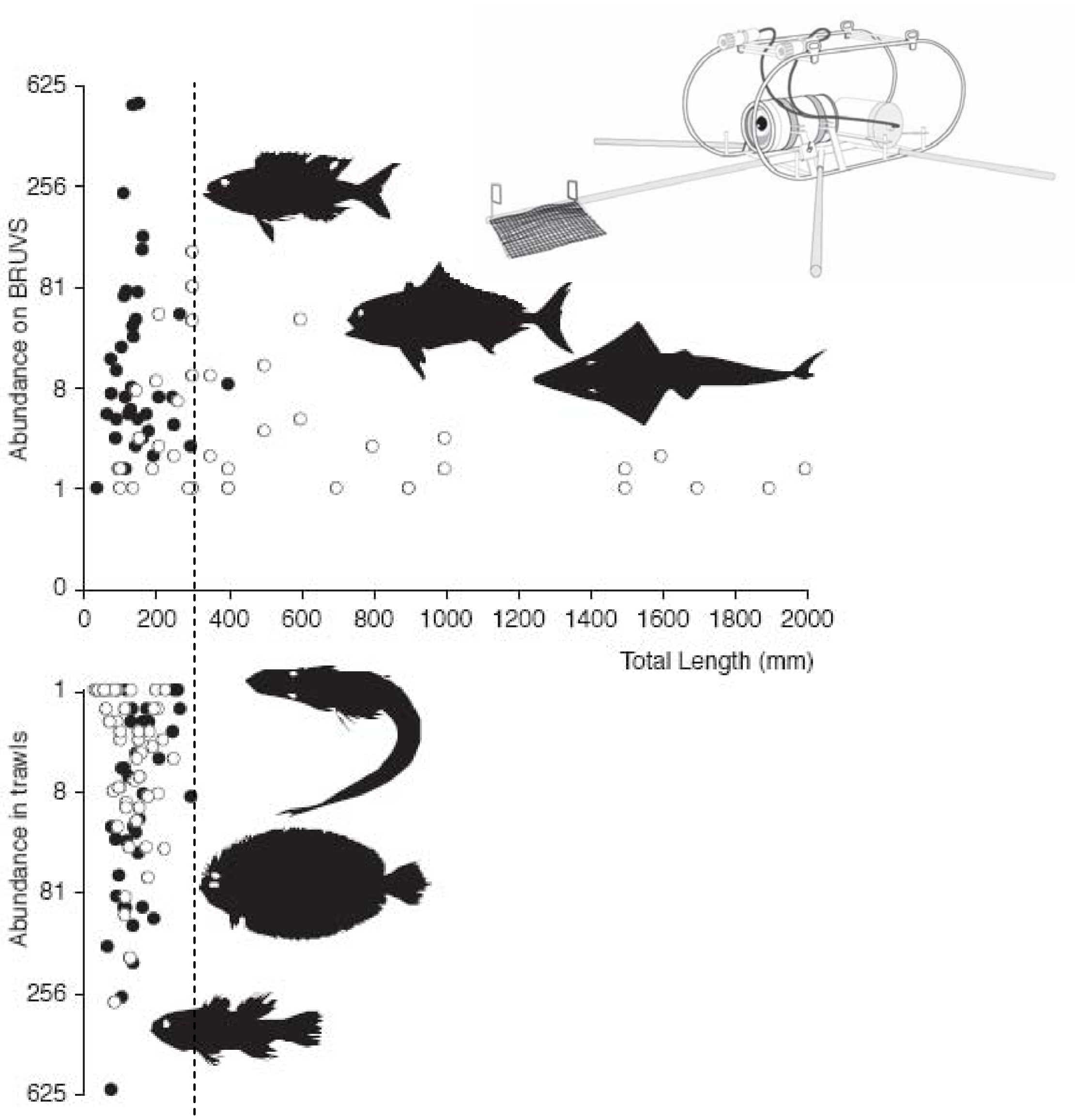


Figure 3: Differences in vertebrate size and form recorded by baited video techniques and trawls, adapted from Cappo *et al*. (2004). Each symbol represents the average total length of one species of vertebrate. Filled symbols are species recorded by both techniques. Open symbols are species recorded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

There are a number of measures of the timing and magnitude of sightings of vertebrates that can be derived from tapes to produce counts and indices of abundance. The first type concern the time elapsed before arrival and departure of species in the field of view. The difference between the two times is the duration on tape. The second type comprises the counts of maximum number of individuals (*MaxN* or *npeak*) within particular short segments [usually 30 seconds or 1 minute] or frames of video. In some applications, the sediment, topography and epibenthos in the field of view is classified before tape reading begins, and measurements of targets are made by comparison with simple scale bars, between paired lasers targets falling on the fish, or anywhere in the field of view with stereo-video (see below).

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

Deepwater density estimation

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

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

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

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

where N is the density of fish per square kilometre, t_{arr} is the time delay between the bait landing on the seafloor and the arrival of the first fish in seconds;

$$\mathrm{C} = 0.3848(1/Vf + 1/Vw)^{2}$$

The constant C depends on the water velocity in (Vw ms^{-1}) dispersing the bait plume down-current, and swimming velocity of the fish toward the bait (Vf ms^{-1}).

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

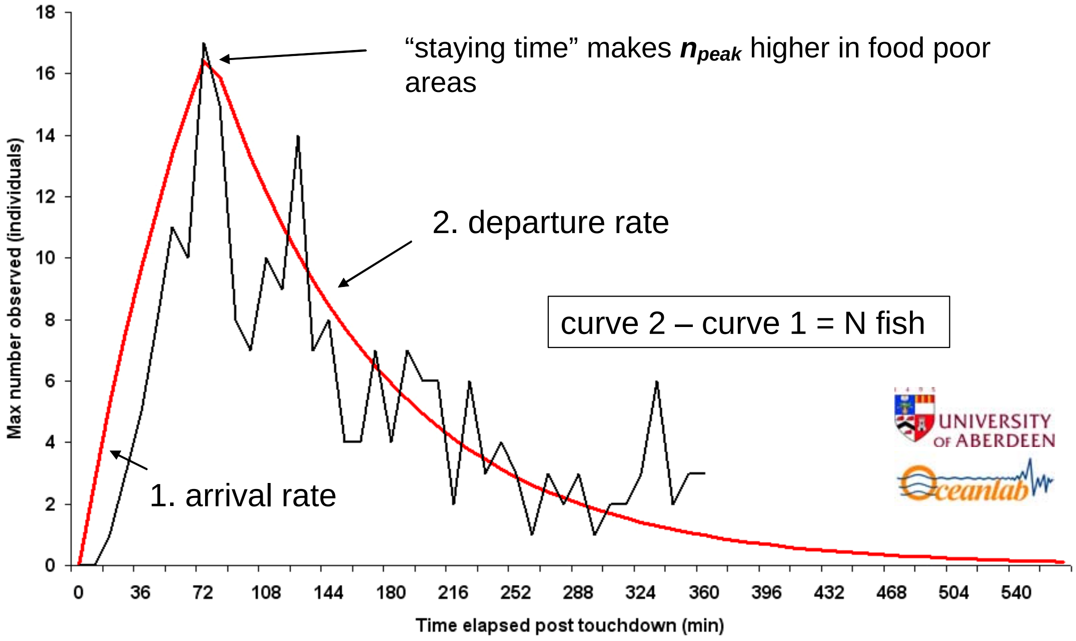


Figure 4: An application of the Priede *et al*. (1990) method of estimating the absolute number of an abyssal scavenger *Coryphaenoides* (*Nematonurus*) *armatus* visiting a bait station for a deployment of ROBIO by King *et al*. (2006). The number of fish present at time *t* (minutes) post touchdown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

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

$$N_t = \alpha_0/\ \chi(11- e^{-\chi t}) \text{ if } t \leq \beta$$

where α_0 is the initial arrival rate of the fish (individuals min^{-1}), β is the mean staying time of the fish (minutes) and χ is the bait decay constant. The model produces a characteristic ‘shark’s fin’ curve (courtesy of Dr Nikki King, OceanLab, University of Aberdeen).

Relative abundance in shallow water

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

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

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

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

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

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

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

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

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

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

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

The effect of bait

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

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

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

$$AR = 60 \text{ x } (St) \text{ x } ((V_f \text{ x } V_c) - Vc^2)/\ V_f$$

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

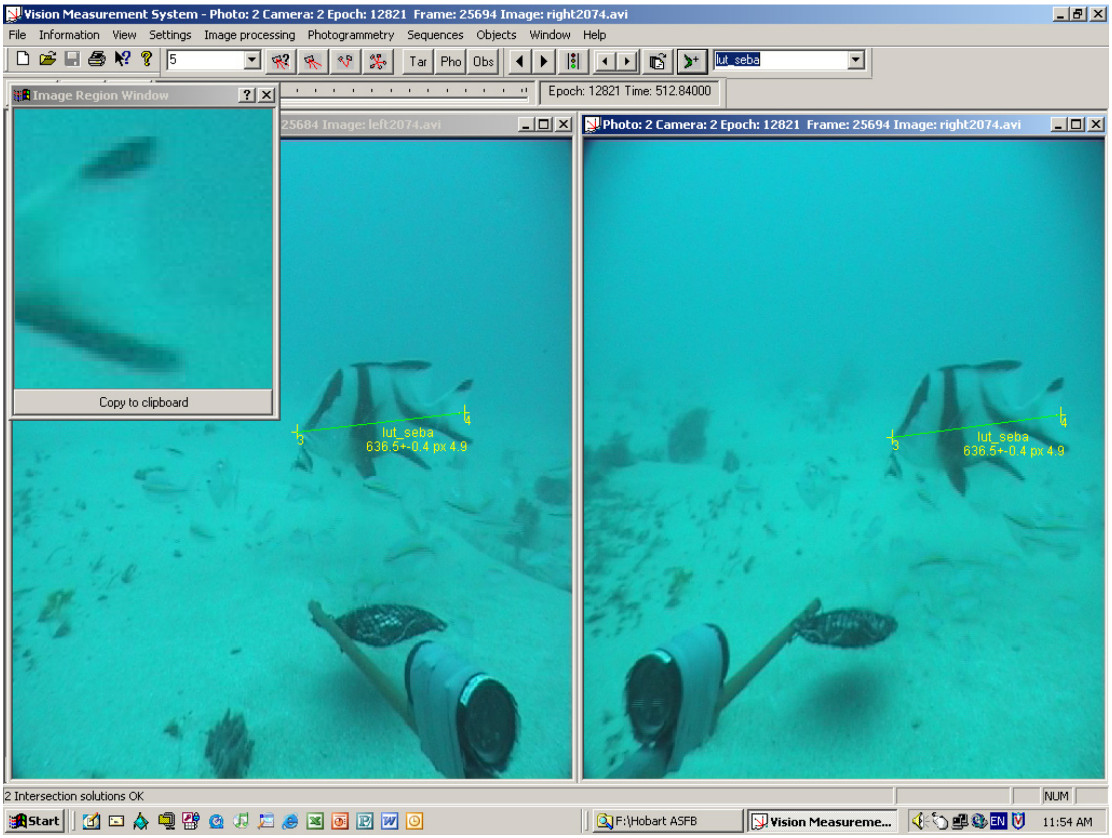
Target Measurement

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

Stereo-video systems

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

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


Vision Measurement System - Photo: 2 Camera: 2 Epoch: 12821 Frame: 25694 Image: right2074.avi

Epoch: 12821 Time: 512.84000

25684 Image: left2074.avi

Photo: 2 Camera: 2 Epoch: 12821 Frame: 25694 Image: right2074.avi

lut_seba
636.5+-0.4 px 4.9

2 Intersection solutions OK

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

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

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

Future advances to overcome limitations

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

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

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

Algorithms for motion detection and pattern recognition are being adapted to the task of reducing the amount of tape to be viewed and to automatically identify targets for measurement (J. Seager pers comm.). Further automation of fish identification is probable in the future, given recent advances in computer vision and applications to aquaculture and fish processing lines (Storbeck and Daan 2001, White *et al*. 2006). These developments will continue in a market dominated by demand for cheap, reliable systems and approaches from scientists involved in fish biology and fisheries science.

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Low-cost autonomy for visual verification of acoustic data sets

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Abstract

Visual verification of acoustic data sets could greatly increase the understanding and management of fisheries. Many challenges exist in obtaining this visual benchmark including technological, operational and cost effectiveness. Making the task of obtaining high density visual benthic habitat information affordable, logistically simpler, and reducing the operational cost, will improve both the spatial and temporal distribution of collected data sets. Autonomous Underwater Vehicles (AUVs) offer potential for mid-water and benthic camera ground truthing. This paper outlines current AUV technology for marine science applications as well as the challenges and operational issues associated with their use. It also describes an alternate approach to AUV development and operation with focus on recent advances in technology and methodologies to achieve low-cost autonomy for remote visual data collection.

Introduction

Despite the great advances in acoustic benthic mapping available today, there is still a general need to ‘visually’ verify the data set. The numerous approaches to marine visual benchmarking include drop cameras (monocular and stereo), towed camera systems, Remote Operated Vehicles (ROVs), and diver-based video transects. Other methods include remote (satellite) sensing and airborne LIDAR systems but these are limited to relatively shallow, non-turbid water.

Current implementation of these technologies generally requires high logistical support in terms of equipment and vessels which makes the task of going to sea very expensive. Therefore, to allow more widespread use of remote sensing technologies, there needs to be a step change in the cost-risk-reward equation; that is a significant reduction in the cost associated with data collection to the point where the risk of losing the equipment is considered negligible. Table 1 summaries three emerging technologies -- towed camera, ROVs and Autonomous Underwater Vehicles (AUVs) -- in terms of their current operational requirements and limitations (the light grey squares highlight the primary limitations of each of the technologies).

Table 1: Requirements and limitations for three current and emerging technologies for visual benchmarking of marine habitats. The light grey squares highlight current limitations, with dark grey squares showing current limitations but with future trends.

	Towed Camera	ROV	AUV
Tether	Yes	Yes	No
Communication bandwidth	High	High	Limited
Ship support	High	High	High (Low targeted)
Endurance	Unlimited	Unlimited	Limited
On-board sensing/processing	Low	Medium	High
Controllability	Low	High	Medium (currently)
Proven Technology	Yes	Yes	No (But will be!)
Cost	Low	Medium	High (Low targeted)

Given the recent advances in robotic (autonomous) systems and image processing from the robotics and computer vision communities, there is potential to reduce the operational and capital costs associated with marine visual benchmarking. Using advanced robotic techniques, AUVs are becoming more reliable as oceanographic observation tools. Advances in AUV technology and application are overviewed by Whitcomb, Yoerger, Singh and Howland (1999), however, this study looked at the early AUV hardware which is relatively expensive. These AUVs are considered too expensive, both in capital and operating costs, for general marine science community use.

In response to an emerging need within the marine science community for cheaper, logistically simpler technologies, Hydroids REMUS AUV (www.hydroidinc.com) is a successful relatively low-cost torpedo style AUV that is used by an increasing number of scientists. However, the use of current AUV designs is not considered appropriate for reliable use within coral reef environments. Therefore, new vehicle design philosophies and operating procedures are required to ensure that automated vehicles can provide true benefit in increasing data collection rates at significantly reduced cost.

AUVs as man-power multipliers

There is significant potential for advanced robotic tools, AUVs, to act as man-power multipliers. Correct application of the technology will mean that an AUV can be used as a tool which enables collection of more information per person than is currently achievable. Further potential for AUV technology includes the ability to:

- Collect data from surface to well below diver depths.
- Perform extended duration observation
- Conduct ultra-long transects
- Allow accurate underwater positioning and repeat surveys
- Cooperatively collect data using multiple AUVs working in unison
- Free the operator/s to conduct other tasks when vehicle is operating (e.g. post processing results or performing fine-scale diver surveys).

This potential has been recognised by the military and offshore oil and gas industries through extensive use in acoustic survey and recognisance tasks being conducted. Limited studies have been conducted using AUVs for general marine observation typically at significant depths such as the Autonomous Benthic Explorer (ABE) developed by WHOI for the study of deep water hydrothermal vents. However, in the sense of man-power multipliers, current vehicles and applications require more than one person to deploy and operate a single vehicle. In practice, tens of people can be required per AUV. In order to become true man-power multipliers, this ratio needs to be reversed, preferably to a number like 4; that is a single scientist can operate four AUVs.

To achieve this ratio, and for widespread acceptance as a marine science tool, step changes are required in:

- Decreased vehicle cost
- Reduced vessel support
- Smarter fusion and processing of on-board data
- Mission reliability
- Design for ‘real world’ environments (including size and weight)

The key points here are to significantly reduce the cost of the vehicle, and designing for challenging environments such as coral reefs. Having a vehicle capable of realising the above has enormous potential for cost effective autonomous visual benchmarking.

Challenges for applied low-cost autonomous visual benchmarking

The primary challenges in the development of a low-cost autonomous vehicle capable of collecting visual benchmarking data are; technological, operational, data collection and conservatism within the marine science community.

The technical challenges are associated with traditional robotics which include localisation and autonomy. In all mapping situations, accurate position estimation is required. However, there is a trade off between accuracy and cost. Operationally, the vehicle size and support infrastructure needs to be significantly reduced, as well as the need for easy programming out in the field. The challenges for data collection using an autonomous vehicle are related to the ability to follow standard operating procedures for image collection, ensuring appropriate camera calibration and lighting. The final significant challenge is associated with the general conservative nature of the marine science community in the adoption of the technology as a useful tool which will require demonstration and validation of the technology against existing methods.

The consideration of all these challenges in realising widespread adoption of AUVs as useful, cost effective tools requires at least the following paradigm shifts in mindset in AUV design and utilisation:

1. Considering the real needs for marine scientists, not the military and petroleum industry.
2. Designing platforms where the vehicle and operating costs are less than the cost of the on-board observation sensors.
3. Moving away from multiple ‘expensive’ single use sensors, to smarter use of observational sensors for navigation (e.g. using vision to collect data as well as to navigate).

The Starbug AUV

As a first attempt in delivering a low-cost autonomous platform that considers the above paradigm shifts, the Starbug AUV as shown in Figure 1, was developed by the CSIRO ICT Centre.

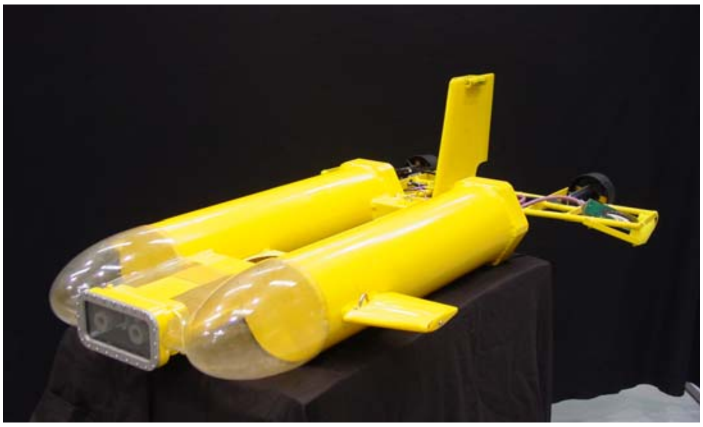

Figure 1: The low-cost Starbug AUV which uses stereo vision (forward and downward cameras) for navigation and data collection.

The ‘Starbug’ AUV is a small, untethered, highly manoeuvrable platform designed to complete a range of reef monitoring tasks (English *et al.* 1994). These tasks require the vehicle to navigate over unstructured surfaces at fixed altitudes (down to 500 mm above the sea floor), knowing its position during linear transects to within 5% of total distance travelled. The vehicle’s design combines characteristics for endurance and manoeuvrability, and provides a platform for manipulators and scientific payloads. It is small enough to be deployed from small boats, jetties or from the foreshore, and, due to its size and simplicity, it is possible for a single person to operate more than one vehicle simultaneously. Details of the vehicle performance and system integration are given in Dunbabin *et al.* (2005a,b).

Combining observation with navigational sensors

One of the biggest expenses in AUV development is the navigational and observational sensors. Traditionally, navigation sensors consist of high-end and generally high cost acoustics, pressure and inertial devices. These can be very expensive depending on the accuracy required and typical practice is to have all these sensors just for navigation, then add scientific instruments. Given that scientific instruments are generally high resolution in nature, the question can be asked, why not just use the observational sensors as the navigational sensors? Furthermore, visual benchmarking requires image collection, therefore, using vision as a primary sensor for navigation and control becomes a logical option. It's what humans and fish typically use to navigate, so why can't a robot (AUV) use it!

Vision was chosen as the primary sensing component for Starbug's navigation due to its relatively low cost (compared with acoustics), and its suitability for use in clear water, terrain-rich, reef environments. Furthermore, using the same sensor for navigation as well as observation allows more efficient utilisation of the sensor suite. Starbug's vision system consists of two stereo heads: one looking downward to estimate altitude above the sea-floor and odometry, the other looking forward for obstacle avoidance. Stereo imagery not only allows high-resolution colour images to be collected, it can be viewed or processed to 'see' the 3D structure of the surrounds. Figure 2 shows example stereo images taken by the Starbug AUV.

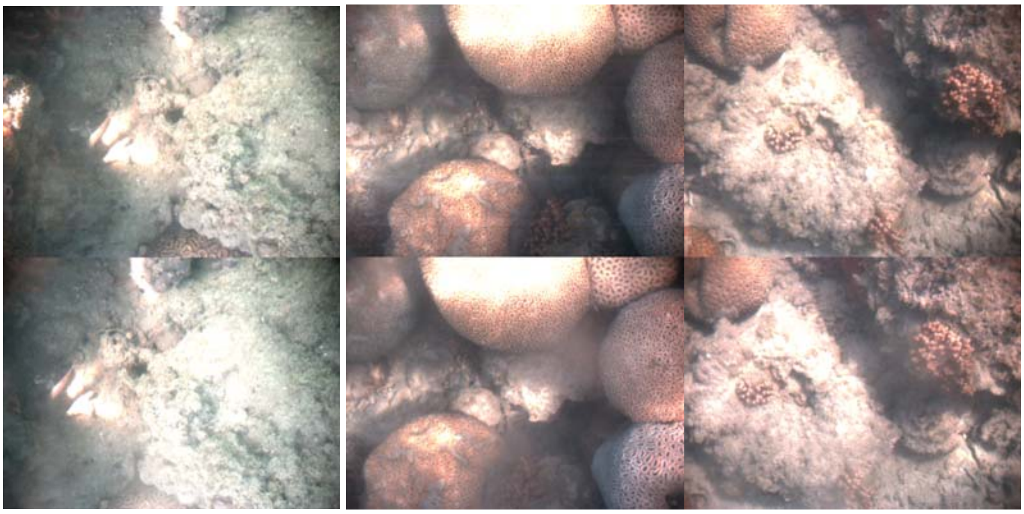

Figure 2: A set of three stereo images taken from the Starbug AUV at an altitude of approximately 1m over a coral reef off Peel Island. Upper image is from the left camera, lower image is from the right camera.

A key challenge is the 'ground truthing' for the AUV position estimation. In low-cost autonomy, high-end acoustic positioning systems are not considered cost-effective. Therefore, alternate methods are required to ensure the AUV knows where it is, as well as to ensure that repeatable transects are conducted. Methods used to 'localise' the Starbug AUV include surfacing periodically to obtain a GPS position, simple acoustic pingers and vision-based target identification used to reset position when sighted. The performance of the Starbug vision-based navigation system is described by Dunbabin *et al* (2005b).

Methods for visual benchmarking and habitat classification

Visual benchmarking can be performed in a number of ways. In terms of using AUVs, there has been a number of studies that consider combining vision with other sensing modalities to build a map by mosaicing of images as well as predicting the location of the vehicle. One example by Williams and Mahon (2004) constructed a mosaic of monocular images over a map generated by side-scanning sonar. More recent and advanced research by Eustice *et al.* (2005) and Singh *et al.* (2005) developed and applied their Simultaneous Localisation and Mapping (SLAM) algorithms to a set of ROV images taken of RMS Titanic in which a detailed reconstruction of the seafloor was conducted. The application of SLAM not only allows accurate map generation but also allows the vehicle's position to be accurately determined, however, there is a requirement that the vehicle passes over a pre-observed point at least once. Both these examples applied their algorithms on post processed data, with no indication as to their ability to be applied in real time.

In many of the applications considered for the Starbug AUV, the vehicle typically does not return to or cross the path during the transect. Therefore, some alternate approaches for automatically obtaining visual benchmarking information have been investigated without the need to generate detailed maps of the environment. Through processing of the images taken by the Starbug AUV during navigation, it is observed that they contain vast amounts of additional information that could be used as indicators for visual benchmarking and habitat classification. A few examples of the application of novel processing from the colour stereo images include bathymetry, surface roughness to indicate seafloor characteristics, and night time fluorescence. Being able to determine these ‘information’ indicators in real-time allows:

- the AUV to adapt its path in real-time to traverse a certain type of structure (e.g. seagrass beds, edge of coral reefs)
- on-board pre-processing of the logged images which during post processing can ‘point’ the researcher to regions of logged data that contain certain characteristics.

Combining the distance from observed features within an appropriately calibrated set of stereo images with the vehicle’s depth (typically obtained from an onboard depth sensor or reading a CTD sensor), bathymetry of the seafloor can be estimated. Figure 3 shows an example of real-time image processing on the Starbug AUV, commanded to perform an autonomous survey 0.6m above the seafloor.

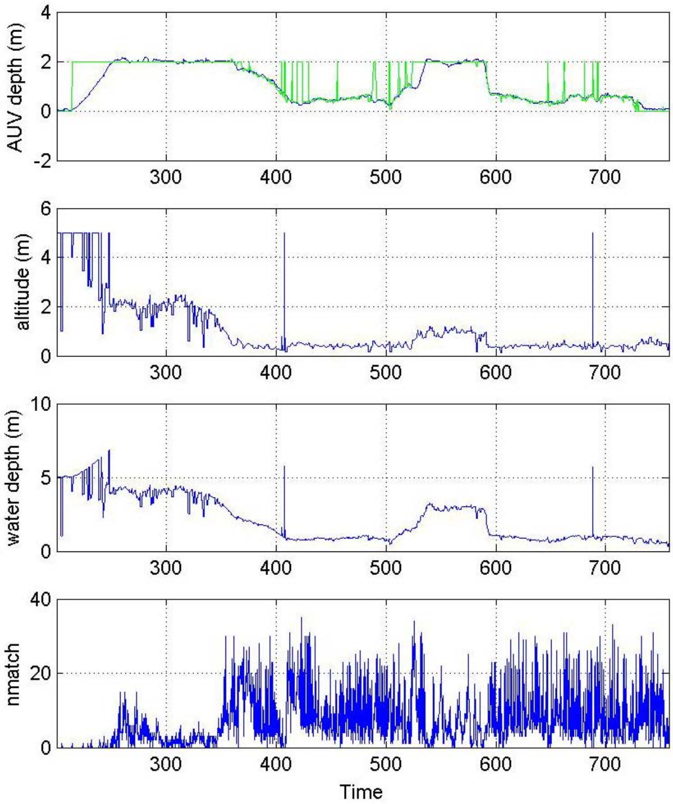

Figure 3: Results from an autonomous terrain following survey at Heron Island. The top trace shows the vehicle’s demanded and actual depth, the second trace shows the vehicle’s visually estimated altitude above the seafloor, the third trace shows the estimated water depth (bathymetry) during the transect. The final trace is the number of tracked features in the images.

An interesting aspect of Figure 3 is the number of ‘strong’ features tracked in the images as the vehicle moves. At approximately 350s the AUV travels from a sandy base to the coral reef edge which shows a marked increase in features tracked due to the increased texture. Therefore, further investigation of the number of features tracked as seafloor roughness indicators have been considered for autonomous classification. Figure 4 shows example results from an autonomous transect where seafloor statistics are used in an attempt to classify the surface. The key statistic used here is the standard deviation of the tracked feature distance from the camera (*h*std).

During this transect, the seafloor consisted of sparse seagrass (t=10-80 s), denser seagrass (t=80-110s), mud and fine silt (t=110-130 s) and coral similar to Figure 2 (t=130-185 s). As seen, there is a loose correlation between this 'roughness' measure and the seafloor type. The large spikes at t=50, 130 and 155 s are a result of the AUV getting too close to the seafloor and collecting unfocused images leading to large errors in image processing. Further research is being conducted to obtain more robust measures to autonomously correlate seafloor type with simple statistics that can be obtained from real-time image processing.

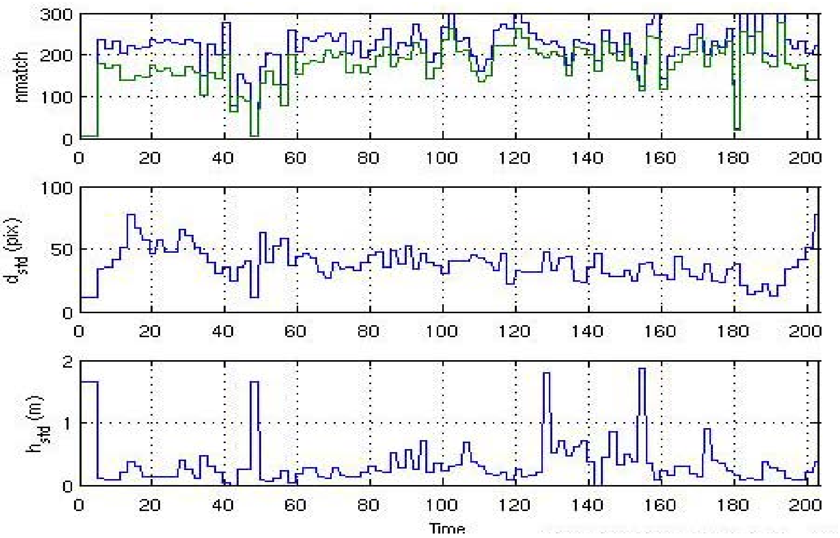

Figure 4: Image processing results from an autonomous transect at Peel Island. The top trace shows the number of features tracked in the stereo images (both before and after outlier rejection), the middle trace shows the standard deviation of the feature disparity, and the lower trace shows the standard deviation of tracked image height.

A final example of image processing is the use of alternate lighting sources to navigate as well as quantify various seafloor types. A particular problem with vision-based navigation at night is the large amounts of power required to ensure adequate illumination of the seafloor. If illumination is poor, the images generally contain insufficient clarity for accurate localisation. However, if the structures in the image fluoresce, then they typically stand out from the rest of the image and can be readily identified and tracked. Figure 5 shows a typical result from an image taken using low-power UV light in which the coral is fluorescing. Not only does the fluorescing coral stand out, it can also be automatically segmented from the rest of the image and its size quantified by counting the segmented pixels.

These few examples show the potential of how further processing the images collected by the AUV navigation system can be used in visual benchmarking and habitat classification. Current research is investigating further indicators that can be used for classification of the habitat, for example texture and colour.

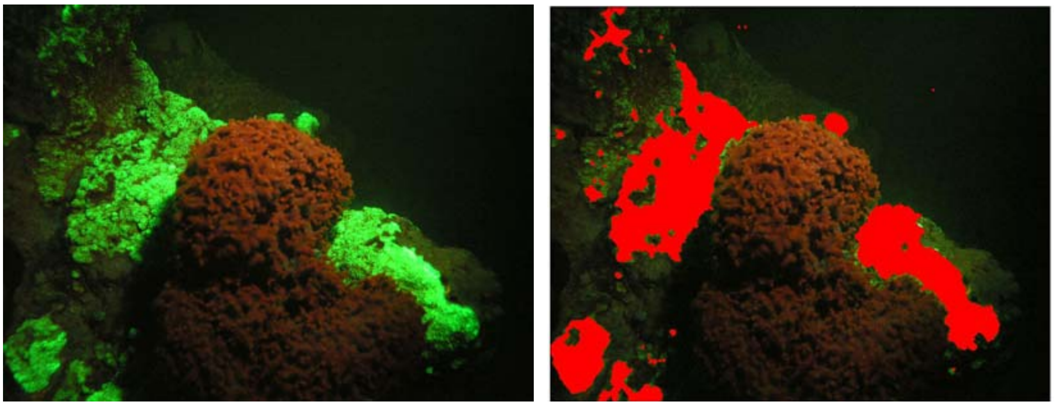

Figure 5: Example image of green fluorescing coral taken using low-power UV light (left), and after automatic segmentation (right).

Summary

Next generation low-cost AUVs and related technology are expected to be a valuable tool for marine researchers and authorities allowing remote and dense (both spatially and temporally) data collection at a significantly reduced cost per data point collected.

Current trends in AUV development have targeted off-shore oil and gas industry and the military. This generally means that vehicles are expensive and are designed for operation at considerable depths. This puts these technologies out of the reach of the general marine research community. To this end, the Starbug AUV has been designed by considering the minimum requirements for visual benchmarking marine habitats. To significantly reduce the size and cost of the vehicle the vision system required for observation is also used for navigation. This reduces the number of sensors required and allows more efficient use of the captured data.

As a result of this precursor technology, it is envisaged that in the near future AUV’s will become commonplace as a tool for visual benchmarking acoustic data sets. The technology will become logistically simpler to operate from the shore or a small boat (e.g. as shown in Figure 6) and allow autonomous operation in real unstructured environments. As onboard processing becomes more efficient, real-time data processing can be conducted with denser mapping and classification becoming feasible (e.g. as shown in Figure 7). The ultimate goal will be the availability of AUV technology where the cost of the scientific sensors added to the vehicle dominates the cost of the platform itself.

Figure 6: Images of the Starbug AUV being deployed from the shore, and from a small (logistically simple) boat.

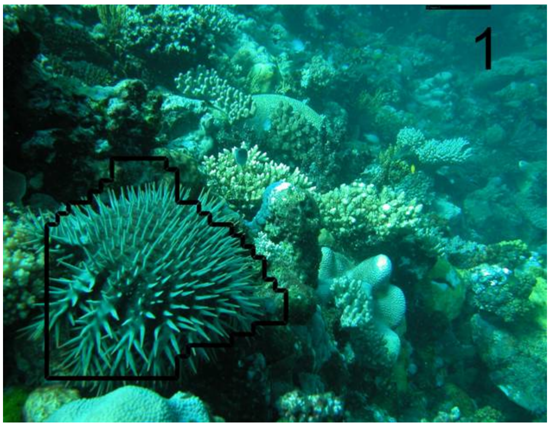

Figure 7: Example of Crown-of-thorns starfish segmentation from a digital image (from Clement *et al* 2005).

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General discussion - Underwater vision and hydro-acoustics

Rapporteurs - Gary Jackson & Michael Mackie

Key discussion points

Modern hydro-acoustic systems are able to account for the noise of the moving vessel using automated and manual processes to filter and validate the data. In conducting acoustic surveys, movement of fish schools was flagged as an issue that could result in double counting. By completing passes as quickly as possible and, where feasible, surveying in the general direction of school movement were identified as solutions.

The application of passive hydro-acoustics techniques, for instance spectrograms of demersal fish through isolation of vocalisation patterns and volume was raised. It was noted that many fish and mammals vocalise and there has been considerable work on whales and there appears to be potential for using this technique for fish.

Dual-frequency Identification Sonar (DIDSON) technology can be used to identify and count fish with reasonable accuracy, especially where species have different body shapes. It is also feasible to determine the size of individuals to 2-3 cm accuracy. Shadowing effects and schooling behaviour can, however, represent limitations in resolving targets.

There are at present at least three DIDSON units in Australia - NSW DPI, Murray Darling Basin Commission and Pacific Diving Supplies. Units are available for commercial hire.

The potential of underwater video technologies has not been fully developed as yet. Baited remote underwater videos (BRUVs) are being increasingly used in biodiversity studies whereas there has been slow uptake of stereo camera techniques to gather information such as fish size structure. Gear costs can be kept low, being as simple as standard video cameras with housings and frames made from cheap hardware materials.

A key bottleneck in the use of video technology relates to the time taken to review data; there is considerable potential to develop automated species recognition and fish size calculation software. There is also a need to further develop statistical techniques for analysing underwater video data. Best data to use at the moment seems to be a combination of max *N*, time of arrival and total *N*, though the significance of these metrics will vary with species. It was noted that NOAA are doing considerable work in this area at the present time.

The possibility of incorporating some form of automated or semi-automated tagging device, including ‘gene-tag’ options, with BRUVs was identified as an opportunity.

It was noted that there have been significant advances in autonomous ground vehicle technology that could have implications for Autonomous Underwater Vehicles (AUVs).

Chair’s summary

Simon Allen

The session looked at a variety of study areas that used acoustic or visual imagery to remote sense the marine environment.

John Penrose gave a comprehensive overview of the methods developed for benthic habitat mapping within the CRC for Coastal Zone, Estuary and Waterway Management. This was followed in rapid succession with presentations on hydro-acoustics for (pelagic) biomass assessment, the use of DIDSON in fish migration studies, towed camera systems, baited in-situ camera systems and finally visual navigation based Autonomous Underwater Vehicles.

Overall the workshop tried to cover too much ground with resources spread too thinly. This seems to be the modus operandi of our research too. It was noted, however, that where technical solutions were developed by biologists, the emphasis was on basic functionality and low cost, where a solution was proposed by an organization with a technical bent the Rolls Royce approach was put forward.

The eternal struggle between wishing to get the best data possible whilst on site because of the operational cost of getting there versus the need for greater spatial distribution achieved by driving capital costs down was highlighted. The autonomous vehicle, Starbug, perhaps offered a glimmer of a future where this struggle is less pronounced.

Multi-frequency acoustics for fish biomass estimation have the potential to replace catch per unit effort related stock assessments. This opens up the path to monitor the recovery of closed fisheries in a remotely sensed manner. Currently the errors within the translation from acoustic signals to fish numbers or biomass are high, but the work presented showed how rapidly the errors are being chased down and refined.

From fish stock size to individual fish movements, acoustics currently represent the only technology to observe fish in a relatively undisturbed environment. The work presented by Lee Baumgartner on the initial use of the DIDSON to examine individual fish behaviour around structures sparked renewed interest in this sensor.

When species identification is important as well as contextual information about the surrounding habitat, you cannot beat a pair of eyes. This was still considered true, and when it was too deep or to expensive to deploy the eyeball, high quality digital stills and stereo video imagery was considered the next best thing. Alan Williams presented the current state of play of the CSIRO towed benthic observation platform, together with imagery that had contributed to significant decisions in the management of our marine resources.

Mike Cappo had a different approach to Alan, whilst Alan was keen to take the camera to the fish, Mike advocated bringing the fish to the camera as a lower cost mechanism that enabled greater spatial coverage. Mike also was advocating the use of stereo imagery to add quantitative remotely sensed information. Mike’s presentation sparked rigorous debate on the transfer of observations to population densities, and the spike effect of larger predators on observations.

As Mike had advocated lower cost per observing platform as an enabler to deploy more platforms and increase synchronous spatial distribution of observations, the last presentation by Matthew Dunbabin showcased the potential capabilities of new low cost observation platforms that take the camera’s to the seabed, with his review of the Starbug AUV. The AUV offered quantitative (stereo) imagery from two pairs of stereo camera, together with a low deployment overhead and low capital cost. The project is transitioning from proof of concept to prototype operational tool. John Penrose and others saw the potential of this technology to significantly impact current work methods.

The session closed on an optimistic note with all present looking forward to increased access to remotely sensed quantitative underwater imagery, both acoustic and visual. Mike Cappo added the final cautionary note suggesting we should now increase our efforts in developing automated analytical techniques for baseline parameters and compressing the analytical process.

Session 3: Chemical Techniques

Greg Jenkins (Chair)

Overview of chemical techniques as applied to fish ecology and fisheries science

Bronwyn Gillanders
Keynote speaker

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Abstract.

A variety of chemical techniques have been used in fisheries science to answer questions relating to stock structure and identification, migration and environmental histories, and trophic interactions. Chemical techniques have also been used for age determination, as pollution indicators, and for batch or mass marking. Several of these applications rely on naturally occurring signatures, whereas others use artificial marking methods. In this paper I provide a brief overview of the broad range of technologies before focusing on artificial marking methods including novel advances in mass marking techniques and transgenerational marking. I then provide a further section on natural chemical signatures in calcified structures for addressing questions related to movements, population replenishment and stock structure of invertebrates and fish. Huge scope exists for many of the applications to be expanded further, for a wider range of organisms than just fish to be investigated, combinations of techniques to be used and as instrumentation is further developed for additional elements and isotopes and finer spatial scale sampling to occur.

Key words: Chemical techniques, LA ICP-MS, otolith chemistry, statolith chemistry, stable isotopes, natural signatures, artificial marking

Introduction

A variety of chemical techniques are available for use in fish ecology and fisheries science. In this brief overview, I will focus on the various applications and the chemical techniques that are available, and the range of issues that each address. The key applications that have to date been addressed include age validation and ageing, an indicator of pollution, tracing prey of organisms and food webs, tracing origins and migration of organisms, and stock identification. Since a number of the subsequent papers will focus on tracing prey of organisms and food webs (e.g. Connolly, Nichols, and Jarman in this Workshop Proceedings) and Ovendon (also in this Proceedings) will focus on molecular approaches, I will not cover these areas. I will briefly cover validation of increment periodicity using chemical approaches, but the majority of the review will focus on mass marking approaches and use of natural elemental and isotopic tags.

One of the most rapidly growing areas of fisheries science is the use of elements in calcified structures, such as ear bones (otoliths), to answer ecological questions related to origins and movement. Most research in this area has focused on otoliths although it is by no means limited to just this structure. Two features of otoliths make them particularly amenable for recording aspects of the environment in which the fish have lived. First, the acellular and metabolically inert structure of otoliths ensures that any chemicals accreted onto the growing surface are permanently retained (Campana 1999). Second, the otolith continually grows (from prior to hatching to time of death) ensuring that the entire life of the fish is recorded (Campana 1999).

Validation of increment periodicity as part of age validation

A variety of chemical approaches exist for validating the frequency of formation of growth increments. One of the most robust methods is the release of known age and marked fish, where fish may be marked using a variety of approaches including chemicals (Campana 2001). Other chemical approaches include bomb radiocarbon, mark-recapture of chemically-tagged wild fish, and radiochemical dating. Campana (2001) provides an excellent review of these methods, but a brief description including examples of their use is provided here. After atmospheric testing of thermonuclear bombs, a dramatic increase in radiocarbon in the atmosphere and oceans occurred. This radiocarbon provides a chemical mark on fish otoliths that can be used to validate the age of long-lived species (Kalish 1993; 1995; 1996; 1997; Kerr *et al*. 2005). Wild fish may be marked, via immersion, injection or feeding, with calcium-binding chemicals (e.g. oxytetracycline, calcein, alizarin). These chemicals then provide a permanent mark, visible under fluorescent light that represents the time of tagging. Fish are then left at liberty for a period of time and the number of increments distal to the chemical mark should represent the time at liberty after tagging (e.g. Fowler 1990). Radiochemical dating, where radioactive decay of radioisotopes is determined based on a known radioactive decay series, has also been used to validate ages of long-lived fish (Campana 2001). Usually the otolith core is extracted and analysed (Campana 2001). A number of studies have used 210Pb:226Ra or 228Th:226Ra in fish otoliths (Fenton *et al*. 1991; Cailliet *et al*. 2001; Stevens *et al*. 2004; Andrews *et al*. 2005), but similar methodology has also been used to validate increment formation in invertebrates (e.g. gorgonians, Andrews *et al*. 2002).

Mass marking approaches involving chemicals

Many of the chemicals applied to fish have been used to validate increment formation (see above). However, there have been several studies that have used fluorescent compounds as a tag and to distinguish different groups of fish or determine connectivity (e.g. Jones *et al*. 1999; 2005). For example, in a novel application Jones *et al*. (1999) marked over 10 million embryos in the field with tetracycline, and then examined 5000 juveniles to determine how far larvae disperse. Their results suggested that 0.5-2% of embryos were marked and therefore that between 15 and 60% of juveniles returned to the natal population (Jones *et al*. 1999). Clearly, a lot of fish need to be marked to get any sort of meaningful return. Another possible limitation is the need to kill fish to examine the otoliths.

A further application of mass marking using chemicals is to be able to distinguish between different groups of fish, for example, between hatchery produced and wild produced fish. This is necessary to formulate effective stocking and management strategies, but also if fish are to be used as indicators of environmental health in monitoring and assessment programs. Here cost-effective and practical methods that are suitable for marking a large number of fish are required. Although immersion of fish in fluorescent dyes has been used to mark fish internally (e.g. otoliths, van der Walt and Faragher 2003) and externally (e.g. Mohler 1997), it has often been time consuming (a few hrs to 48 hrs). The development of an osmotic induction technique for marking fish in as little time as 10 mins involves placing fish in a hypersaline solution for a short period of time prior to exposure to the fluorescent chemical (Mohler 2003). The rate of dye uptake is then greatly increased. Recent work on golden perch (Macquaria ambigua) has shown that both calcein and alizarin red S can be successfully used to mark otoliths and external structures (e.g. head, anal fin, caudal fin) (Crook *et al*. 2006; Crook *et al*. In press). The major advantage is that marks can be easily detected on live fish. Trials are, however, required at the hatchery scale. Osmotic induction is a novel technique that results in significantly better mark quality in calcified structures, but to date has only been used to mark freshwater species and therefore further work is required to determine whether the technique is also applicable for marine fish since freshwater and saltwater species differ in their osmotic regulation (see Hickman *et al*. 2006). Other chemicals may also be useful for osmotic induction marking.

Several studies have also suggested enhanced diffusion of fluorescent compounds (e.g. calcein) into calcified structures of fish using ultrasound (Bart *et al*. 2001; Frenkel *et al*. 2002). For example, Bart *et al*. (2001) reported a several fold increase in calcein uptake when fish were treated with cavitation level, low frequency ultrasound, although background autofluorescence also increased. Besides representing a method for distinguishing hatchery-produced fish in both aquaculture and stock enhancement programs, the method could also be beneficial for mass administering compounds into fish (Frenkel *et al*. 2002). I am not aware of any similar studies undertaken in Australia.

Besides fluorescent compounds, a range of elements (e.g. Sr, rare earth elements, Ennevor and Beames 1993; Giles and Attas 1993; Ennevor 1994) and isotopes (e.g. enriched isotopes of Ba and Sr, Munro *et al*. submitted) have also been used to successfully mark fish via immersion. Strontium is the element most commonly used to mark fish (Brown and Harris 1995), but Sr:Ca ratios of freshwater can be as much as that of marine waters or higher (Kraus and Secor 2004) and therefore potential exists to confuse natural Sr signatures with artificial Sr marks. Other elements occurring in low concentrations (e.g. rare earth elements) have had variable success in producing marks in fish especially over short time scales (Munro *et al*. unpublished data). Enriched stable isotopes can be used to create unequivocal marks that cannot be mistaken for a natural signature since there is no way that a wild fish could have a similar signature (Munro *et al*. submitted). There are a number of other advantages to enriched stable isotope marking including that it is stress-free to the fish, the isotopes are naturally occurring and are stable (i.e. non-radiogenic) and therefore pose no environmental or human health risks, the method can be applied to any life history stage, and standard equipment (e.g. laser ablation ICP-MS) can be used to analyse the otoliths since the isotope ratios are shifted so drastically (Munro *et al*. submitted). Whilst enriched stable isotopes are expensive, small concentrations (e.g. 15 μg/L Ba and 100 μg/L Sr) are required to produce clear shifts in isotopic ratios (Munro *et al*. submitted). The work of Munro *et al*. (submitted) was focused on fingerlings of golden perch (*Macquaria ambigua*), but there is potential for the technique to be used on golden perch larvae, which are maintained in closed systems for about 5 d. Trials are about to commence on larvae. Further work is required before this method could be used at the hatchery scale. Other species have also been marked by immersion in stable isotopes (unpublished data).

The previous techniques described all require marking of thousands of fingerlings via immersion. A potentially easier method may be to mark the mother in an effort to mark the offspring. Recently, a new technique for artificially mass marking fish larvae, that of transgenerational marking, has been described (Thorrold *et al*. 2006). Briefly, fish larvae are marked after gravid females injected with enriched isotopes transfer the isotope spike to the embryonic otoliths of their offspring (Thorrold *et al*. 2006). Thorrold *et al*. (2006) demonstrated that both a benthic-spawning and a pelagic-spawning fish had unequivocal isotope signatures over a range of dose rates and that marked larvae were found for at least 90 days after a single injection. Several research groups in Australia are currently trialling this technique as a means of marking larvae, which would then enable a range of questions related to metapopulation dynamics to be addressed. To date, this method has been utilised on fish, but it may also have potential for use on other organisms (e.g. cephalopods).

Natural elemental and isotopic signatures

Due to the metabolically inert structure of otoliths and that fact that they continue to grow throughout the life of the fish, otoliths are able to record an accurate chronology of exposure to environmental conditions, including salinity, temperature and composition of ambient water. The underlying premise is that dissolved trace elements within ambient waters are taken up through branchial uptake by the fish and incorporated into the otolith, although there is some elemental discrimination (e.g. at the water/gill, blood/endolymph and endolymph/crystal interfaces). There has been limited testing of this assumption especially across a range of species (but see Bath *et al*. 2000; Elsdon and Gillanders 2003; 2004). Information on environmental conditions that the fish has lived in can then be coupled with the age (either annual or daily) of the fish to provide unprecedented information on the timing and frequency of movement, as well as the relative importance of different habitats. Thus, otoliths provide an ideal natural tag. Other calcified structures from fish (e.g. scales, vertebrae, spines) as well as other organisms (e.g. statoliths of molluscs, vertebrae or spines of sharks) may also be useful as a natural tag, although assumptions particularly related to the structure not being reworked through time (i.e. metabolically inert) may not be satisfied. Some structures may also not provide age information (see Campana and Thorrold 2001).

Analysis of strontium concentrations has been widely used for tracing salinity history and reconstructing past environmental histories of fish (e.g. Kalish 1990; Limburg 1995; Kimura *et al*. 2000; Secor and Rooker 2000; Rooker *et al*. 2004) largely because it is widely assumed that there is a positive relationship between otolith Sr and ambient salinity (see review: Secor and Rooker 2000). Despite this assumption a number of experimental studies have found mixed results with respect to the relationship between otolith Sr and salinity (see examples in Gillanders 2005a). Despite potential difficulties of reconstructing environmental histories of fish using otolith Sr:Ca researchers have used this methodology to address a wide range of questions, especially for diadromous fish (see Table 2 in Gillanders 2005a). More recently, Elsdon and Gillanders (2006) identified different migratory contingents of black bream (*Acanthopagrus butcheri*) by combining otolith Sr:Ca with temporal collections of ambient Sr:Ca concentrations. Briefly, temporal variability in ambient Sr:Ca ratios was examined at the scale of days, weeks, months and seasons. Correlations between otolith and ambient Sr:Ca from experimental laboratory studies (e.g. Elsdon and Gillanders 2003) and field-collected fish were then used to predict otolith Sr:Ca of a 'resident' fish (Elsdon and Gillanders 2005; 2006). Finally, fish were classified as either resident or migratory based on the percentage of time that otolith Sr:Ca matched the predicted concentrations for each site, which was based on ambient Sr:Ca values (see Elsdon and Gillanders 2006 for further details). Fish were resident during winter, but migratory during summer. This study demonstrates that otolith chemistry can be used to address questions on life history diversity, such as whether different migratory contingents exist, as well as the proportion of resident versus migratory fish in a population or the proportion of time individual fish are migratory or resident in a water body.

The migratory history of fish along a growth axis can also be reconstructed using other elements/isotopes besides Sr:Ca (hereafter referred to as elemental profiles). These analyses can then be linked to the age of the fish. For example, stock structure of adult snapper (*Pagrus auratus*) and the extent that this was influenced by adult movement was investigated by analysing elemental profiles across the otolith for 9+ fish (Fowler *et al*. 2005). Elemental profiles were then related to the age and average elemental concentration calculated for fish from different regions. Using this approach, both Ba and Sr showed similarities among regions in the otolith signature for the first 3 years, then diverged between the ages of 3 and 5 years and continued to differ for the remainder of the fish life. These results suggested that all fish, regardless of where captured, originated from one or two nursery areas, then dispersed throughout the different regions between the ages of 3 and 5 before becoming resident in their new regions of occupancy (Fowler *et al*. 2005). This example demonstrates the utility of otolith chemistry for addressing questions related to management.

Both of the above examples rely on analysing elemental profiles across the otolith in search of common life histories or ages/dates at which they diverge. Further studies have sampled juvenile (or larval) fish and used the otolith elemental data as the baseline data of known origin. Adult (or juvenile) fish can then be sampled to determine where they spent their juvenile (or larval) life. Many studies have shown that spatial differences exist for juvenile fish collected from different areas (e.g. Gillanders and Kingsford 1996; Thorrold *et al*. 1998a; 1998b; Gillanders 2002; Gillanders and Kingsford 2003; Hamer *et al*. 2003). Since different elemental signatures are found among the baseline samples, a number of further questions, such as the relative importance of different areas of habitat, can then be addressed. For example, Gillanders (2002) analysed adult snapper collected from the commercial fishery to determine which estuaries they spent their juvenile life in. She found that for adult fish collected near Sydney the majority (89%) had spent their juvenile life in local estuaries. Similarly, Hamer *et al*. (2005) found that the contribution of Port Phillip Bay (Victoria, Australia) juveniles to coastal populations of snapper (*Pagrus auratus*) decreased with distance from the bay. Data can be compared for one cohort of fish across many locations, among cohorts across many locations, and among age classes for varying cohorts and locations (Gillanders 2005b). However, it is important to note that several further assumptions underlie these analyses, for example either the temporal stability of the elemental signatures must be known or adult fish must be matched to juvenile signatures of the same year class in which case ageing errors need to be minimal. In addition, a further assumption is that all possible groups contributing to the group mixture must be characterised (see Gillanders 2005b for further details).

Otolith chemistry has also been widely used for stock identification, although it is not always clear at which spatial scale stocks can be identified since frequently samples are collected from several locations spanning the range of the species (or the area of interest). If differences are found among the groups of fish then different stocks are assumed. However, if groups of fish had been collected at smaller spatial scales then differences may still be found suggesting finer scale population structuring. To date, a large number of studies have focused on population structure of fish via otolith chemical analysis (e.g. Edmonds *et al*. 1989; 1991; 1992; 1995; Edmonds and Fletcher 1997; Edmonds *et al*. 1999), but there are fewer studies on other organisms (e.g. statoliths of cephalopods, Arkhipkin *et al*. 2004). Scope exists for further research on other organisms (e.g. vertebrae or spines of elasmobranchs).

Conclusion

Although chemical analysis of structures of fish has been conducted for many years (e.g. Radtke 1983; Radtke and Targett 1984; Morales-Nin 1986; Kalish 1989), it is only since the 1990's that a wide range of non-physiologically regulated elements have been investigated. Many of the applications listed above have not yet reached their full potential (see also Campana 1999). In addition, many of the mass marking approaches have huge scope to be used to answer field-related questions including source-sink dynamics (e.g. larval dispersal). Further areas for development include using combinations of techniques to address questions and thereby help verify techniques. For example, there is scope to combine chemical approaches with more conventional tagging approaches or acoustic tagging methodologies or to combine both molecular and chemical approaches for stock identification questions. As always, developments will continue in terms of instrumentation enabling a wider range of elements and isotopes to be analysed that occur in even lower concentrations than those we routinely analyse these days (although caution that samples are not contaminated will always be an issue) and allowing even finer scale spatial resolution within a structure than that currently available (e.g. NanoSims). However, there will always be a need to use appropriate methodology to address the different questions. This review has by no means covered every application that is possible, but has provided an overview of some of the recent applications and considerable scope exists to answer even more novel questions.

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Use of otolith chemical analysis to trace the migrations of diadromous fish

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Abstract

Diadromy is a general term describing the migration of fish between freshwater and marine environments. There are several recognised types of diadromy that are distinguished by the life history stage at which migration occurs, including anadromy (adults migrating to freshwater to spawn), catadromy (adults migrating to estuaries or the sea to spawn) and amphidromy (larval or juvenile stages migrating between freshwater and the sea). Species representing all of these strategies occur in Australian rivers and streams. However, whilst there is a good understanding of the diadromous strategies of some species, evidence for other species is circumstantial or almost entirely lacking. Seawater typically contains higher concentrations of strontium and lower concentrations of barium than freshwater and, thus, it is possible to determine the occurrence and timing of diadromous migrations based on analyses of the concentrations of strontium and barium incorporated into the otoliths (earstones) of diadromous fish. In this presentation, I describe the use of laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) and Proton Induced X-ray Emission (PIXE) as methods for tracing the diadromous migrations of several coastal fish species. The results are discussed with regard to the potential of otolith chemical analyses for developing our knowledge of the life histories of Australian diadramous fishes.

Introduction

Diadromy is a general term describing the migration of fish between freshwater and marine environments. There are several recognised types of diadromy that are distinguished by the life history stage at which migration occurs, including anadromy (adults migrating to freshwater to spawn), catadromy (adults migrating to estuaries or the sea to spawn) and amphidromy (larval or juvenile stages migrating between freshwater and the sea) (McDowall 1988; Lucas and Baras 2001). Species representing all of these strategies occur in Australian rivers and streams. However, whilst there is a good understanding of the diadromous strategies of some species, evidence for other species is circumstantial or almost entirely lacking.

The otoliths (earstones) of fish grow continuously throughout life and are comprised of a calcium carbonate matrix that is not re-metabolised once deposited (Campana 1999). Dissolved trace elements in the surrounding water become incorporated into the otolith matrix as it accretes and, although rates of uptake are influenced to some degree by factors such as diet and temperature (Elsdon and Gillanders 2002; Buckel *et al*. 2004), the concentrations of trace elements in otoliths have been widely used to reconstruct the surrounding water chemistry at different stages of life (e.g. Tsukamoto *et al*. 1998; Limburg *et al*. 2001). This type of analysis is particularly valuable for examining diadromous migrations because seawater and freshwater are chemically distinct, and as a consequence, material accreted onto the otolith during marine and freshwater residence is also chemically distinct (Campana 1999). Strontium (Sr) tends to be present in much higher concentrations relative to Calcium (Ca) in seawater than in freshwater (Campana 1999), whilst the opposite has been shown for Barium (Ba) (Pender and Griffin 1996). Accordingly, otolith material accreted by a fish living in seawater should be characterised by relatively high Sr:Ca and low Ba:Ca, and vice versa for fish resident in freshwater. In this study, we analysed Sr:Ca and Ba:Ca concentrations in otoliths to examine the occurrence of diadromous migrations in two native Australian fish species, the Australian grayling *Prototroctes maraena* and Australian bass *Macquaria novemaculeata*.

Methods

Study sites and fish collection

Otoliths of 25 Australian grayling and 18 Australian bass from rivers in coastal Victoria were obtained from collections held by the Arthur Rylah Institute for Environmental Research in Melbourne. The Australian grayling were collected in 1997 from the Bunyip (n=8), Tambo (n=7) and Barwon rivers (n=10), and Australian bass were collected in 1995 from the Snowy (n=8) and Albert rivers (n=10).

Chemical analysis

The Sr:Ca and Ba:Ca ratios of water in a sub-set of the study rivers were examined to ensure that generalisations regarding the concentrations of Sr and Ba in water of varying salinities were valid in this study (Table 1). Water samples were collected in March 2004 from sites in freshwater, estuarine water and nearby coastal seawater at the Barwon, Bunyip and Tambo rivers. Water samples were also collected in January 2005 from freshwater, estuarine water and nearby coastal seawater at the Snowy River. The results of the water analyses confirmed that Sr:Ca was generally high in marine water, intermediate in estuarine water and lower in freshwater, whilst Ba:Ca tended to show the opposite pattern (Table 1).

The sagittal otoliths of the Australian grayling and Australian bass were removed and prepared for chemical analysis using the methods described by Crook *et al*. (in press). The Australian grayling otoliths were embedded in epoxy resin (sulcus surface facing up) on a microscope slide and polished down to the core using a graded series of aluminium oxide lapping films. The Australian bass otoliths were embedded in epoxy resin and sectioned transversely through the core using a low speed saw. After cleaning, two-dimensional scans of the Sr:Ca structure in the otoliths were produced using proton induced X-ray emission (PIXE). Linear transects across the otolith were also conducted using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to measure the concentrations of a suite of elements including Sr, Ba, Mg and Mn. Details of the analytical methods are described by Crook *et al*. (in press) and Macdonald and Crook (2005).

Table 1: Sr:Ca and Ba:Ca of water samples from sites ranging from freshwater reaches to coastal seawater from the study rivers. Modified from Crook *et al.* (*in press*).

River	Site	Salinity (ppt)	Sr:Ca (mmol mol^{-1})	Ba:Ca (μmol mol^{-1})
Bunyip	Iona	0.1	3.4	1546.5
	Koo-Wee-Rup	1.8	9.5	315.4
	Western Port Bay	34.3	11.1	6.0
Tambo	Tambo Upper	0.3	4.6	534.9
	Swan Reach	20.9	10.4	65.1
	Rasherville	22.2	10.5	40.5
	Lake King	24.1	10.5	27.0
	Lakes Entrance inlet	29.2	10.8	12.9
	Lakes Entrance beach	33.5	11.4	6.6
Barwon	Inverleigh	1.6	7.4	388.0
	Geelong	1.9	8.9	407.1
	Lake Connewarre	32.1	10.6	50.4
	Barwon Heads estuary	35.6	10.9	32.4
	Barwon Heads beach	36.8	10.6	11.4
Snowy	Orbost	0.2	3.5	552.8
	Upstream Brodribb River	0.4	5.0	341.7
	Inlet near entrance	9.0	8.4	40.9
	Marlo beach	28.3	10.0	9.3
	Cape Conran beach	36.0	10.4	5.0

Results

Australian grayling

The PIXE and LA-ICP-MS analyses showed that the core regions of the otoliths had high Sr:Ca compared to the adult regions for all 25 fish examined, with Sr:Ca typically 2-3 times higher in the core than in the adult growth region (Figure 1a,c). These results are consistent with marine residency during the larval and juvenile phases. Peaks in Sr:Ca within the adult region were also apparent for some of the fish using LA-ICP-MS. If such structuring in Sr:Ca represents alternation between freshwater and marine residency, one would expect a negative relationship between Sr:Ca and Ba:Ca in the adult region. This does not appear to be the case, however, as Sr:Ca in the adult region was not negatively correlated with Ba:Ca

Australian bass

The patterns of Sr:Ca and Ba:Ca in Australian bass otoliths were extremely complex in comparison to Australian grayling and high levels of variation were evident within and between river systems. Some Albert River bass were characterised by a strong inverse relationship between Sr:Ca and Ba:Ca in the early life stages, with Sr:Ca peaks approaching 4 mmol.mol^{-1} close to the otolith cores (Figure 1b,d). The negative relationship between Sr:Ca and Ba:Ca tended to be less evident or absent in the later life stages of these fish, although there was often marked cycling in Sr:Ca and Ba:Ca in the adult growth region. By contrast, several Albert River fish exhibited no inverse relationship in Sr:Ca and Ba:Ca near the otolith core, with Sr:Ca levels remaining relatively stable throughout their entire lifetimes. The results may be indicative of a large amount of individual life history flexibility. However, without further detailed work, interpretation of such complex patterns in otolith chemistry is difficult and conclusions drawn from these data are only preliminary at this stage.

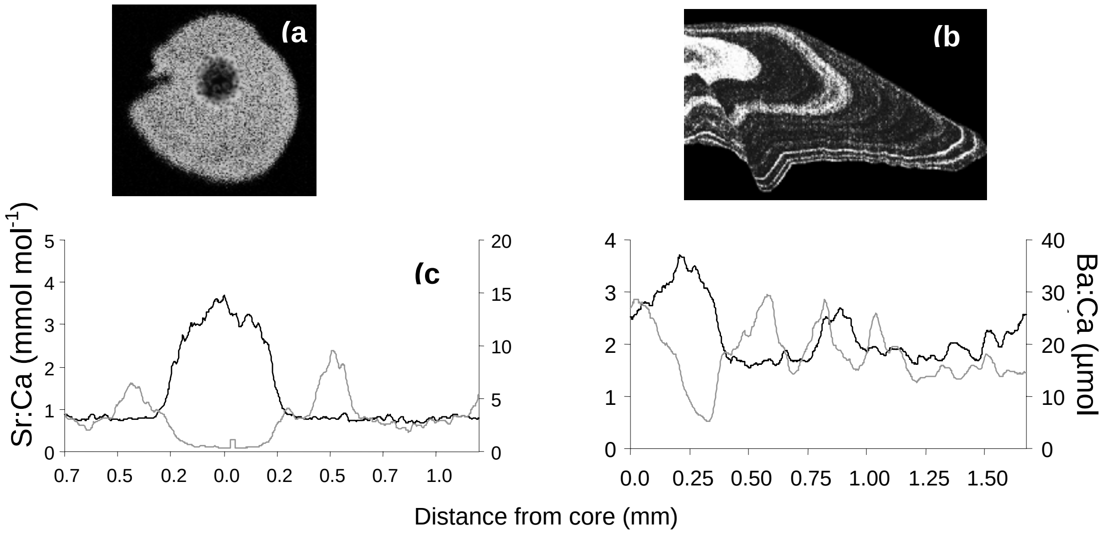

Figure 1: Examples of otolith chemical analyses for Australian grayling from Tambo River (a, c), and Australian bass from Albert River (b,d). This figure shows PIXE scans (a, b), with dark areas representing high Sr:Ca and light areas representing low Sr:Ca, and (c, d) laser ablation transect across the otoliths. The transect runs from edge to edge of the otolith through the core. The Australian grayling otolith was dorso-ventrally sectioned and the Australian bass otolith was transversely sectioned. Black line represents Sr:Ca (mmol.mol^{-1}), grey line represents Ba:Ca (µmol.mol^{-1}). Modified from Crook *et al.* (*in press*) and Crook and Macdonald (2005).

Discussion

The otolith chemistry results appear to confirm the suggestion of Berra (1982) that Australian grayling exhibit an amphidromous life history (see Crook *et al*. in press). The core regions of the otoliths of all 25 fish examined had substantially higher Sr:Ca values compared to the adult growth areas. The Sr:Ca values in the core are similar to values used to infer marine residency in previous studies (Radtke and

Kinzie 1996; Tsukamoto *et al*. 1998; Limburg *et al*. 2001), and evidence for a marine larval/juvenile phase is further strengthened by the finding that Ba:Ca values in the otolith core were low in all cases. These results are also well supported by the analyses of water chemistry at the study sites.

Interpretation of the variation in Sr:Ca and Ba:Ca in the adult region of the Australian grayling otoliths is more difficult than for the core regions, as consistent correlations between Sr:Ca and Ba:Ca did not occur in the adult region. Similarly, the results for Australian bass were highly complex. If one assumes positive and negative relationships between conductivity and Sr and Ba respectively, the observed high Sr:Ca and low Ba:Ca in several Albert and Snowy River bass during the first months of growth are consistent with the hypothesis of larval habitation in brackish tidal and estuarine areas proposed by Harris (1986). Laboratory experiments suggest larvae form schools around at around 45 days old, and juveniles are thought to begin upstream dispersal 2-3 months after hatching (Ehl 1980). A slight reduction in Sr:Ca and simultaneous increase in Ba:Ca identified in several fish, also provides evidence for an upstream dispersal movement to less saline water during the juvenile phase. By contrast, however, several other fish displayed positive relationships between Sr:Ca and Ba:Ca throughout their entire lifetimes.

The marked cycling of Ba:Ca ratios evident particularly in the adult growth region of Snowy River individuals is possibly related to downstream movements to the estuary to spawn (Harris 1986). The Australian bass has been classified as ‘marginally catadromous’ (Jerry and Baverstock 1998), and Harris (1986) suggested that individual fish may not undertake a spawning migration each year, although they may also undertake several migrations in a single year. This complexity and flexibility in migration strategies may partially explain the variability in otolith chemistry patterns between individuals sampled from the same river in this study. The otolith chemistry techniques presented here potentially offer a cost-effective method for determining the timing and frequency of diadromous movements and migrations over the whole lifetime of a fish. However, the results also show that for some species there can be a large amount of individual variation and complexity in otolith chemistry patterns and that further work is required to refine the techniques to allow for more definitive interpretation of the data. Ways forward might include: laboratory experiments to determine the details of relationships between water and otolith Sr and Ba; the use of multi-collector ICP-MS to use isotopic ratios in defined regions of otoliths to detect diadromous migrations; and the use of radio- and/or acoustic tracking data to validate interpretation of otolith chemistry data.

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New sources of biological data - derived from DNA - for modelling harvested fisheries populations

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Abstract

Genetic markers such as allozyme loci, mitochondrial DNA and microsatellite loci have provided excellent tools for resolving population dynamics of exploited freshwater and marine species for conservation purposes. Recent advances in biotechnology and theory have widened the range of fisheries genetics applications to include (1) harvest rate estimates using genotypes as indelible tags, (2) age and hence growth information for invertebrates using the rate of decay of telomeric DNA and (3) genetic estimates of the number of animals successfully participating in spawning. The new data sources provide an excellent means of increasing the accuracy of fisheries population models and hence the predictions made by the models for various exploitation scenarios. Although the future of fisheries genetics is promising much research is needed into the details of these new methods. This would include biological and *in silico* studies involving active collaborations with a range of fisheries scientists.

Keywords: fisheries genetics, review, stock assessment modelling

Introduction

Australian federal and state governments are responsible for managing the exploitation of fisheries species that occur within the Australian Fishing Zone. Their objective is to maximise the economic return from fisheries resources to businesses without jeopardising future harvests or damaging marine ecosystems. The Australian Fishing Zone extends 200 nautical miles from shore and has an area of about nine million square kilometres. Australian fisheries species are diverse and unique as they occur across a large spatial area in a wide range of habitat types and they are relatively isolated from the fauna of other continents. Australia's fisheries resources are not abundant or productive as marine habitats are low in nutrients due to little run off from the dry Australian continent, the continental shelf is narrow except in the north and the region lacks permanent upwellings (Caton and McLoughlin 2004).

Since the Fisheries Management Act 1991 came into effect the Bureau of Rural Science in Canberra has reported each year on the status of a consistent set of 74 species whose management is the responsibility of the federal government. In 2004, 17 species were classified as overfished compared to five in 1992. Furthermore, the status of 40 of the 74 species is listed 'uncertain' due to the lack of sufficient biological information to determine status (Caton and McLoughlin 2004). However, Australia leads the world in advanced fisheries management methods relying to a large extent on 'fisheries stock assessment'. This process uses mathematical models to predict abundance through time under various management scenarios (Hilborn and Walters 1992). The models can be used to evaluate various management actions such as setting a total allowable catch, restricting the type of fishing gear and temporal closures prior to implementing those methods.

DNA data can provide data for the process of fisheries population modelling, potentially improving the accuracy of those models by providing unique information that is difficult or impossible to obtain elsewhere. Regions of DNA are targeted that are subtly different between individuals, populations or species (Hallerman *et al*. 2003). Nucleotide sequence is analysed directly or indirectly with restriction enzymes, allozymes or molecular probes. Genetics data is generally independent of other biological measurements, is cost effective and complementary to other sources of biological data on fisheries species. Genetics can provide measurements of fisheries populations that are not available elsewhere and multiple types of genetic data can be obtained from a single set of tissue samples.

This paper explores five ways in which DNA can contribute unique data to the fisheries modelling process and discusses their limitations, and how the methods may be developed and improved in the future. This is not an extensive review of the fisheries genetics literature relating to these methods, but is a personal glimpse into the future with examples drawn largely from the work of our laboratory.

Species identification

The DNA sequence of certain regions of the mitochondrial genome (mtDNA, Box 1) has long been known to vary between, but not within species. The regions involved are the more slowly evolving mtDNA genes that code for proteins or RNA. Once the sequence of the region has been determined for a species, the sequence can then be used to provide identification for animal products that cannot be identified using conventional methods. Fish eggs and larvae and fish body parts can be identified in this way.

Shark fin is a popular product in Asian markets. They represent numerous elasmobranch species sourced from a variety of fisheries. Shark fin is often seized from foreign fishing vessels within the Australian fishing zone. Information about species composition of the seized fin would assist with the sustainable management of tropical elasmobranch species. However, the salted, dried and skinned product is difficult to identify to species level by visual inspection. In our laboratory mtDNA sequences from seized fins are revealing the species composition of illegally harvested fins. Regulators will use this information to monitor the relative harvest pressure experienced by northern Australian elasmobranch species.

The use of mtDNA sequences to identify species is the approach being taken by the BarCode of Life consortium, which plans to establish an internet database of mtDNA sequences from all animals. Ward *et al*. (2005) have made a start on collecting sequences from some Australian fish species. There are problems associated with applying this method across a wide range of taxa, including inability of mtDNA to describe all biodiversity, the resultant bias towards species that can be defined with mtDNA sequences and the need for species identity to be worked out beforehand (Rubinoff 2006).

However, the use of mtDNA sequences to identify commercial fisheries species is unlikely to experience these problems. Generally, the taxonomy of fisheries species is clear, and close cooperation between geneticists using DNA as an identification tool and museum-based taxonomists will ensure accuracy. The establishment of a sequence database for commercial fisheries species across the biogeographic regions in Australia will require considerable coordination between laboratories and, as Rubinoff (2006) says, its important to remember that the collection of DNA data is a tool, and not an end in itself. In the future it may be possible to perform DNA-based identifications in the field using a ‘dip-stick’ test where coloured dyes differentiate between species, or by means of a hand-held sequencer that can generate sequence data in the field.

Box 1

Mitochondrial DNA (mtDNA): Mitochondria are organelles found in the cell cytoplasm outside the cell nucleus. Mitochondria have their own 'mini' genomes that produce proteins essential to cellular respiration and which cannot be transported in from the cytoplasm. The genomes are small (about 16,000 base pairs), double-stranded, circular and maternally inherited. They are composed of protein and RNA genes (tRNA, rRNA) and a region that controls genome replication (control region or D-loop). Mitochondrial DNA (mtDNA) generally has a rapid rate of sequence evolution, making it ideal for highlighting differences between groups of conspecific individuals. Some regions, such as some protein and RNA genes have a slower rate evolution making them ideal for studying differences between species. The polymerase chain reaction (PCR) is commonly used to target specific gene regions. Pairs of PCR primers are readily available that focus on mtDNA regions. PCR products can be directly sequenced or sequence characteristics can be indirectly inferred using restriction enzymes (Ovenden 1990).

Population Structure

Management actions need to be scaled to match the pattern of population structure. For example, a spatially sub-divided species needs finer scale management than a well-mixed species. Genetic analyses of population structure can identify isolated or partially-isolated populations within the range of a species and have been used extensively to resolve fisheries management issues. A rapidly evolving region of the mitochondrial genome is commonly used, such as the control region or D-loop (Box 1). Its sequence is analysed directly or indirectly and population structure is inferred following statistical and phylogenetic analyses. Nuclear loci, such as microsatellites, are often used in conjunction with mtDNA. It is assumed that patterns in the data are caused by movement of genes within the range of the species, and not by the other forces of evolution – genetic drift, natural selection or mutation.

Spanish mackerel (*Scomberomorus commerson*) are large predatory fish distributed across tropical Australia and the Indo-Pacific region. They grow rapidly and reach maturity in about two years at a length of around 80 cm (FL). They frequently reach 10 (males) or 14 (females) years of age. Fecundity is presumed to be high with a short larval duration of two to four weeks. The total Australian recreational and commercial catch is between 200 - 3000 tonnes. Several types of mtDNA control region sequence were found among Spanish mackerel collected from the east, north and west Australian coasts. The 'A' type was present on the east coast at a frequency of 25%. In the northeast it was present in 10% of the samples, and on the north and west coast it was present in much lower frequencies - 0 to 1%. Spanish mackerel collection locations with similar frequencies were inferred to belong to the same population. A single population or stock was described from the east coast, a second stock was proposed for Torres Strait and a third stock on the north and west coast (Buckworth, *et al*. in prep).

Tests for genetic population structure have the ability to discern separate populations, but they have low power when it comes to accepting the null hypothesis of no population structure. This is because analyses of population structure cannot rule out the possibility of uncovering population structure if the study was repeated with more extensive population sampling, or if a different array of genetic markers was used. However, as genetic markers become more sensitive and where studies often use large numbers of genetic markers, this issue is becoming less common.

Users of genetic data also need to be aware that the concept of a population is often different between fields such as ecology, evolution and statistics. For example the definition of a fisheries stock is often ‘a group of fish that maintains itself over time in a definable area’ which may or may not be the same as an ecological definition of population – ‘a group of organisms of the same species occupying a particular space at a particular time’ or an evolutionary definition – ‘a group of interbreeding individuals that exist together in space and time’ (Waples and Gaggiotti 2006).

The limitations of relying on genetic population structure analyses only are circumvented by studies that also include data from otolith chemistry and parasite loads to discern population structure (Buckworth, *et al*. in prep; Welch, *et al*. in prep). Otolith chemistry reflects the geographical location occupied by the individual for the majority of its life, while parasite load reflects the location most recently occupied. In comparison, genetic information reflects the location occupied by numerous past generations of the individual. It is also important to recognise the sophisticated behavioural adaptations of fish, such as mating behaviour and social structure (Hoarau, *et al*. 2005), that should be incorporated, if possible, into the interpretation of genetic analyses of population structure.

Age and growth data

Populations of slowly growing species cannot be harvested at the same rate as species that grow rapidly, so age and growth data are important to fisheries population models. Vertebrates such as fish have hard structures that can be examined for evidence of incremental growth. Fish ear bones (otoliths) and vertebrae are sectioned and each ring is inferred to correspond to a check in a period of growth associated with environmental fluctuation such as daily or seasonal temperature or food availability. Invertebrates rarely have equivalent hard structures showing incremental growth.

Consequently, no satisfactory method is currently available for estimating the age of individuals of these species.

Recently, Vleck *et al*. (2003) and other have suggested that the telomeric DNA (Box 2) could provide a tool for aging animals. Telomeric DNA undergoes shortening during cell divisions over an animal's the life-span. A correlation of 0.6 - 0.7 has been observed between age and telomere length for species such as humans and birds (Nakagawa, *et al*. 2004). I am not aware of published studies that have used this aging method in an ecological context, although work is under way to use the method to age humpback whales (Dennis 2006).

In the most comprehensive study to date, Ying (2005) measured telomere length in relation to chronological age in two marine fish species. For mangrove jack (*Lutjanus argentimaculatus*) telomere lengths shortened significantly in whole blood, dorsal muscle and brain tissues in captive-bred individuals from 2.5 months to 3 years of age. A similar result was obtained for black seabream (*Acanthopagrus schlegeli*) except that blood telomeres increased in length, possibly due to increased levels of an enzyme (telomerase) that restores degraded telomeres. Ying (2005) also reported that telomere length was highly variable among individuals, which may be associated with the relatively inaccurate method used to determine telomere length (Southern blotting). The rate at which telomeres shortened in a wild population of black seabream from Hong Kong harbour was significantly faster than for the captive-bred individuals. Tests for fluctuating asymmetry showed that the harbour population was experiencing environmental stress and this may have explained the more rapid rate of telomere degradation in the wild population.

Preliminary work in our laboratory has found a relationship between telomere length and carapace width (as a surrogate for age) in spanner crabs (*Ranina ranina*). Growth rate data is currently missing from spanner crab population models, but its addition could considerably refine management of the species in south-east Queensland. But, to use telomeric DNA as a tool to age spanner crabs, the relationship between the rate of telomeric degradation and age would have to be determined in this species. There are several problems that must be overcome here. Spanner crabs are difficult to maintain in captivity, so known age animals would be difficult to obtain. Even if the species can be maintained in captivity, the results of Ying (2005) suggest that the relationship may be different between captive and wild populations. Confirming the relationship in wild populations may be difficult, as it would rely on taking successive DNA samples from tagged animals during their life span. Tagging crabs is challenging, although genetic tagging may be possible.

The use of telomeric DNA as an aging tool has potential, particularly for invertebrate species, where no feasible alternative is available. It is likely that the relationship between telomeric degradation and age will have to be determined for each species, and perhaps for each type of tissue sampled and in each type of environment. Obtaining known age animals to use in this process may be challenging. This research area is set to expand rapidly in the next few years and time will tell whether or not predictions are realised for this new method.

Box 2

Telomeric DNA: Telomeric DNA is a component of DNA from the cell nucleus and is located on the ends of chromosomes. Telomeres are several thousand repeats of a single sequence - often 'TTAGGG'. This sequence assists in preventing the 'unravelling' of chromosomes during chromosome replication during cell division (Tsuji *et al*. 2002). During an animal's lifetime and successive cell divisions, telomeres become shorter until chromosomes are deleteriously affected and death occurs. The most common method for determining the length of telomeres in an individual is to use Southern blotting to hybridise genomic DNA with a labelled probe whose sequence is homologous to the telomeric sequence. Genomic DNA is digested with restriction enzymes prior to hybridisation so that telomeric DNA, that does not contain restriction sites, is resolved as large fragments in an agarose gel after electrophoresis (Nakagawa *et al*. 2004).

Harvest Rate Estimates

The process of fisheries population modelling can be imprecise and data-hungry. A simpler, more direct method of fisheries management is the season-to-season adjustment of harvest rates based on the proportion of the resource harvested each season. Tagging individuals and recording how many tagged individuals are found amongst the harvest at the end of the season can be used to estimate harvest rate. For example, if 50% of the tagged fish are caught, then roughly 50% of the available fish were caught. If this is too high, then the harvest rate for the following season is reduced by management actions and the tag-recapture process is repeated until a stable and appropriate proportion is harvested each season (Buckworth 2004). However, tagging of fisheries species has many problems. Fish need to be caught, brought on board, injected with a plastic tag and released. Mortality is high, and fish that do survive may loose their tags before they are recaptured. Tagged fish in commercial harvests may be undetected or under-reported.

Genetic tags are being used for a Spanish mackerel population in the Northern Territory adjacent to Darwin (Ovenden, *et al*. 2002) as an alternative to plastic tags. This species is particularly susceptible to tagging mortality and requires sound management to safeguard it for the future. Specially designed fishing lures take a small tissue sample from mackerel at liberty in the population. These fish are then genotyped with seven microsatellite loci (Box 3). Gene-tagged fish can be recognised by this genotype for the rest of its life. Fins are taken from Spanish mackerel in the commercial harvest and genotyped. If a previously gene-tagged fish is identified it is then 'recaptured', and harvest rate estimates can be made for this fishery.

Genetic tagging studies have many of the same limitations as regular tagging studies. Gene-tagged individuals need to distributed evenly across the spatial extent of the population and the population re-sampled later at an appropriate time and place. Recovering sufficient recaptures for statistical significance is a numbers game, depending on the size of the original population, the number of tagged individuals and the number of individuals that are re-sampled. Genetic tagging studies need to be able to genotype large numbers of individuals in the laboratory, which often requires specialist high-throughput equipment and expertise. Considerable computer power and dedicated software is required to make the many millions of pair-wise comparisons between genotypes necessary to find recaptures. Methods need to be developed to account for genotype matches when the number of shadows (Box 3) is likely to interfere with reporting of recaptures (Broderick *et al*, in prep).

Estimates of Numbers of Breeders

Many stock assessment models are based on the stock-recruitment relationship, which is a positive correlation between the number of recruits and the size of the spawning stock (or population) in the previous generation. Many fisheries species are Type III species that have large fecundity and large variance in family size. In other words, while a large number of individuals in population participate in spawning, only a few will successfully contribute offspring to the next generation. These individuals are called breeders (N_b). The number of breeders is an essential link in the stock-recruitment relationship, where N_b is a function of the stock size, and recruitment is a function of N_b. We maintain that if Nb was known then the accuracy of stock assessment models that are based on the stock recruitment relationship would improve.

Recently, it has been demonstrated that the effective population size (N_e) of type III species is equivalent to N_b (Hedrick 2005) and that N_e can be determined with genetic methods under certain circumstances for fisheries species. Ovenden *et al*. (In press) estimated N_e for a population of tiger prawns (*Penaeus esculentus*) in Moreton Bay in southeast Queensland, Australia. They measured the amount of allele frequency change across two temporal intervals of one generation for eight microsatellite loci. Allele frequency change was converted to effective population size estimates assuming that it was equivalent to genetic drift at each generation, and that drift was proportional to effective population size (Waples 2002). For instance, allele frequencies change from generation to generation depending on which adults successfully reproduce and which juveniles survive and become recruits. In the most extreme case, allele frequencies would be severely affected if only a single male and female successfully produced the next generation of recruits. Ovenden *et al*. (In press) also showed that N_e was about three orders of magnitude less than the number of prawns in spawning condition.

The practicality and usefulness of N_e estimates for improving population models of fisheries species remains to be demonstrated. For the tiger prawn population of Moreton Bay, the measurement of N_e was conducted under the best possible conditions. The population was relatively small, genetically isolated from surrounding populations and had non-overlapping generations. It remains to be seen whether repeatable, statistically valid estimates can be generally obtained from other commercial populations of fisheries species. Hauser *et al*. (2002) and Turner *et al*. (2002) have successfully measured the parameter in less numerous commercial fish populations, which is encouraging. The importance of knowing the parameter N_b in stock assessment modelling is also unknown at the present. This could be addressed by incorporating N_b estimates into existing population models, or by using simulation studies.

Box 3

Microsatellite DNA: Microsatellite loci are found in nuclear or chromosomal DNA. A locus is a specific location in a chromosome, at which alternate alleles, or genes, may be found across individuals in a population. In diploid species, two alleles are found at each locus. Alleles at microsatellite loci are discrete numbers of repeats of a specific sequence, such as 'CTG'. This sequence is called a tri-nucleotide repeat. Microsatellites also exist as di- and tetra-nucleotide repeats (Li *et al*. 2002). A species may have three tri-nucleotide alleles; the first having say, one repeat (CTG), the second having two (CTG CTG) and the third having three repeats (CTG CTG CTG CTG).

Microsatellite loci are found in all species - animals and plants. For species whose nuclear genome has been entirely sequenced, it is easy to find them and develop PCR strategies to amplify them from extracted DNA. This is not the situation for the vast majority of fisheries species. However, methods exist that can target, isolate and characterise these loci in the absence of complete genomic sequence (Zane *et al*. 2002).

The alternate alleles at a microsatellite locus can be the same, in which case the fish is said to be homozygous for that locus. A heterozygote fish has two different alleles at a locus. The genotype of a fish is its allelic state for several loci, where an individual can be heterozygous for one locus, but homozygous at others. The number of different genotypes in a population is a function of the number of polymorphic loci used and the frequency of alleles in the population at that locus. When microsatellite loci are used as genetic tags, combinations of loci are chosen such that each individual in the population is likely to have a different genotype, even if the population size is in the billions. Individuals that have the same genotype by chance in such as study are called ‘shadows’, assuming they are not identical siblings (Waits *et al*. 2001). The incidence of shadows is of great importance in a genetic tagging study. When two samples have identical genotypes, it is either the recapture of the same individual or two different individuals that are shadows. As the aim of a genetic tagging study is to identify recaptures from the total pool of individuals sampled, it is essential to have statistical methods that are able to identify shadows from recaptures.

Conclusion

As well as providing new biological knowledge, the impetus for the development of new fisheries genetics methods is to provide new sources of data for the process of fisheries stock assessment modelling, which is instrumental in providing advice on sustainable levels of harvesting. This paper has presented the rationale for five applications of population and molecular genetics in fisheries science accompanied by examples. Apart from tests for genetic population structure, all the methods discussed here are relatively new, having been developed in the last 10-15 years. In the future it may be possible to design research projects that collect more than one type of genetic data from tissue samples collected from individuals in the population, as the raw data for all of these methods is contained in DNA. For instance, telomeric DNA may provide information about age, and hence growth, in a population, while microsatellite loci from the same sample can be used to estimate the number of breeders in a population.

To balance this optimistic assessment of the usefulness of molecular and population genetics in sustainable fisheries management, it is important to remember that all of the methods presented here have limitations. The potentially rich source of data provided by genetic methods must be continually benchmarked against results obtained by other methods. For instance, genetic population structure results should be compared to population structure assessed with other methods, such as otolith microchemistry and parasite distribution and abundance. Other particularly promising areas, such as the use of telomeric DNA for aging, need to be tested by a considerable amount of further research. Validating existing genetic results, and extending new genetic methods depend to a large extent on sound and active collaboration with fisheries scientists from a range of disciplines.

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DNA as a dietary biomarker for fish

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Extended Abstract

The diet of fish and many fish predators can be hard to estimate accurately because of biases in methods for identifying prey items. The most common method for studying fish diet is to morphologically identify prey items recovered from stomach samples. This method is also frequently used to identify fish prey of other predators, where fish are identified by bones or scales that survive digestion.

A common goal of dietary studies is to estimate quantities of food items consumed by populations of a predator. The biases in identifiability caused by differential digestion of morphologically identifiable items can lead to inaccurate estimates of food composition.

DNA has the advantage as a potential dietary biomarker of being universally present in food organisms and all food organisms having unique DNA sequences. The biological function of DNA is to store information. Some of the information contained in DNA molecules can be used to identify individuals, species or higher taxa. Most prey tissues contain DNA and only small amounts of DNA are needed for analysis. DNA is also easily detectable even in very small quantities, making it suitable for dietary studies that rely on digested material.

DNA has previously been used to determine fish diet with examples including species identification of krill consumed by whale sharks (Jarman and Wilson 2004); larval cod in the stomach of predatory fishes (Rosel and Kicher 2002); and diverse items from the stomach of several large pelagic fishes (Smith *et al*. 2005). DNA has additionally been used to examine fish as prey items some examples include: species identification of fish consumed by giant squid (Deagle *et al.* 2005); salmonids eaten by harbour seals (Purcell *et al*. 2004); grey seals (Parsons *et al.* 2005); and identification of nototheniid fish consumed by Adelie penguins (Jarman *et al.* 2004).

DNA in dietary samples begins with the isolation of prey DNA from stomach contents or faecal material. The DNA purified from stomach contents or faeces is a mixture of bacterial DNA, eukaryotic microbial DNA, predator DNA and the target prey DNA. The DNA from prey is highly degraded due to digestive processes.

Species-specific DNA markers can be designed by identifying short DNA regions unique to a given prey species. Then for a few target species, PCR primers specific to two regions are made. For many target species, hybridisation probes specific to each species have also been made and all results are interpreted as simple presence or absence of prey.

A taxonomic ‘group-specific’ approach can be used to look at the presence or absence of a wider range of prey items. Two short DNA regions unique to a given prey group are identified and PCR primers specific to these regions are used to amplify DNA only from this group of prey. Further detail about the species within the group may be obtained either by cloning and sequencing as described later or with gel mobility methods.

Broad dietary information can be gained by DNA cloning and sequencing ('clone library') analysis. In this approach a short but informative DNA region from the dietary sample is amplified with universal PCR primers. The DNA region chosen should include a highly conserved sequence for the binding of the universal primers as well as an internal and variable region to facilitate the taxonomic identification of prey species. Often to achieve these requirements a DNA region is chosen based upon available sequence information in international databases. Clones taken from the library can be analysed individually and compared with sequences in databases to give a semi-quantitative analysis of prey DNA represented in the sample. This method is very laborious, however, and is only really feasible for small sample numbers.

Strengths and weaknesses of DNA as a dietary biomarker need to be understood for any new dietary study. DNA is bad for: 'What does animal x eat' type studies, integration over time and individual level diet estimation. DNA is good for: very specific questions and obtaining high taxonomic resolution. Presently DNA is difficult to use for quantification. There are many technical difficulties in exploiting the potential of DNA for animal diet estimation, but good progress is being made in overcoming these issues.

When planning a DNA diet study it is important to ensure that questions are well defined and to consider whether DNA is an appropriate system for the question. If so it is recommended that the study group employs a molecular biologist to develop the methods, obtain moderately substantial funding and is patient in waiting for results.

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Signature lipid and fatty acid profiling in food web studies

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Abstract

The application of signature lipid methodology for East Australian and Southern Ocean fish and squid is demonstrated for selected species, with protocols provided for representative methodology. Case studies are used to highlight the application of this approach with *Dissostichus eleginoides* (Patagonian toothfish), *Lepidocybium flavobrunneum* (escolar) and the onychoteuthid *Moroteuthis ingens*. Comparison of fatty acid profiles of toothfish, including for size and location sub-groups, with those of prey species, showed that the diet of the toothfish varied to a far greater extent, relative to size increases, than is suggested by stomach content analyses. Escolar and rudderfish are often mixed up or substituted for each other or other species in Australia; both species contained exceptionally high oil content which is unusual for Australian species and escolar was clearly distinguished from rudderfish using lipid profiles. Digestive gland (DG) fatty acid profiles indicated that *M. ingens* was reliant on a myctophid-based diet. It is also possible to examine the effect of regional, temporal and other differences including maturity on diet and the overall role of lipid in these and other fishes and squid. Consideration of the use of signature lipid data for the determination of the diet of higher predators is also discussed.

Keywords: *Dissostichus eleginoides* (Patagonian toothfish), *Lepidocybium flavobrunneum* (escolar), *Moroteuthis ingens,* signature fatty acids, diet, higher predators, chemotaxonomy

Dedication: This manuscript is dedicated to Prof David Cleaveland White (1929-2006), a pioneer, colleague and mentor in the field of signature lipids in environmental microbiology and microbial ecology.

Introduction

The application of fatty acids as dietary tracers in the marine environment has occurred since the 1960's (Ackman and Eaton 1966, Sargent 1976), with the technique used to explore dietary relationships in a number of diverse marine organisms (Mourente and Tocher 1993, Graeve *et al.* 1994, Kirsch *et al.* 1995, 1998, Cripps *et al.* 1999, Navarro and Villanueva 2000). The approach is based on the assumption that many fatty acids in the marine environment, particularly polyunsaturated fatty acids (PUFA), can only be biosynthesised by certain phytoplankton and macroalgae species and become essential dietary components to higher trophic levels. Phytoplankton and macroalgae species are often characterised by very distinct ratios of fatty acids, and these ratios influence the fatty acid profiles of higher organisms and are thus useful tools for providing information on food webs (Graeve *et al*. 2002). Fatty acid profiles can therefore be used at the various trophic levels in marine food webs.

It may be more difficult to interpret the influence of diet on fatty acid composition in a tissue where biosynthesis and modification of fatty acids occurs, such as in the muscle or blubber tissue of marine vertebrates. Conflicting evidence exists in the literature about the effectiveness of deriving dietary information of marine vertebrates, principally pinnipeds, from fatty acid analyses (Grahl-Nielsen and Mjaavatten 1991, Grahl-Nielsen 1999, Smith *et al.* 1997, Smith *et al.* 1999). However, over the past decade the signature lipid approach has been increasingly applied to dietary studies of these and other animals in both the northern and southern hemispheres, as at-sea foraging data is very difficult to obtain from conventional methods. Analyses can be conducted for mammals on small milk or blubber samples, so intrusive techniques such as stomach lavage and lethal sampling are no longer required.

In this report we provide an overview of signature lipid methodology in applications with Australian and southern ocean fish and squid, and in addition provide selected case study findings for *Dissostichus eleginoides* (Patagonian toothfish), *Lepidocybium flavobrunneum* (escolar) and the onychoteuthid *Moroteuthis ingens*.

Methods

Specimen collection

Fish, squid and potential prey items were collected using standard trawling or fishing gear with full sampling details provided elsewhere (Phillips *et al*. 2001, Wilson 2004, Nichols *et al*. 2001). For lipid profiling, all samples were frozen after collection at -20° C and returned to Hobart for dissection and analysis.

Lipid extraction and fatty acid analysis

An overview of the protocol used is provided in Figure 1. A small tissue sample (approximately 1g) taken typically from the right shoulder in fish and from the ventral mantle of squid was collected from most specimens, and the whole Digestive gland (DG) of squid was collected where possible. These were stored frozen at -20°C and retained for lipid and fatty acid analysis. Whole DG were homogenised in a hand-held blender and a 0.25-0.5g subsample was taken for lipid extraction. Mantle tissue samples were ground in a mortar and pestle prior to extraction.

Tissue samples were extracted overnight using a method modified from Bligh and Dyer (1959) in a one-phase methanol:chloroform:water solvent mixture (2:1:0.8 v/v/v). Phases were separated the following day by addition of chloroform and water (final solvent ratio, 1:1:0.9 v/v/v methanol:chloroform:water). Lipids were recovered in the lower chloroform phase, and the solvent removed under vacuum to give the total solvent extract (TSE); these were weighed to obtain lipid content (% wet mass). Samples were made up to a known volume in chloroform and stored at -20°C. An aliquot of the TSE was analysed with an Iatroscan MK V TH10 thin layer chromatograph flame ionisation detector (TLC-FID) analyser to determine the proportion of lipid classes. A polar solvent system (60:17:0.1 v/v/v ratio of hexane:ether:acetic acid) was used to resolve triacylglycerol (TAG), free fatty acid, sterol (ST) and phospholipid (PL), while a non-polar solvent system (96:4 v/v ratio of hexane:ether) was used to determine diacylglyceryl ether and wax ester. Peaks were quantified with DAPA Scientific Software.

An aliquot of the TSE was transmethylated at 80°C for 2 hours in a 10:1:1 v/v/v mixture of methanol:hydrochloric acid:chloroform to produce fatty acid methyl esters (FAME). FAME were partitioned by the addition of water and extracted with 4:1 hexane:chloroform v/v under nitrogen, then silylated at 60°C overnight in N,O-bis-(trimethylsilyl)-triflouracetamide. FAME were then reduced under nitrogen and stored in chloroform at -20°C. FAME were analysed by gas chromatography (GC) using a Hewlett Packard 5890A GC equipped with a HP-5 cross-linked methyl silicone fused capillary column, an FID, a split/splitless injector and a HP 7673A auto sampler. Helium was the carrier gas, and pressure was maintained at 65kPa. Samples were injected in splitless mode with an oven temperature of 50°C, and temperature was ramped to 150°C at 30°C/minute, then to 250°C at 2°C/minute, and finally to 300°C at 5°C/minute. Confirmation of component identification was achieved by gas chromatography-mass spectrometry (GC-MS) analysis using a Finnigan Thermoquest GCQ GC-MS fitted with an on-column injector. Peaks were quantified with Waters Millennium or Agilent Chemstation software. Statistical treatment of fatty acid data sets is as described in Phillips *et al*. (2001).

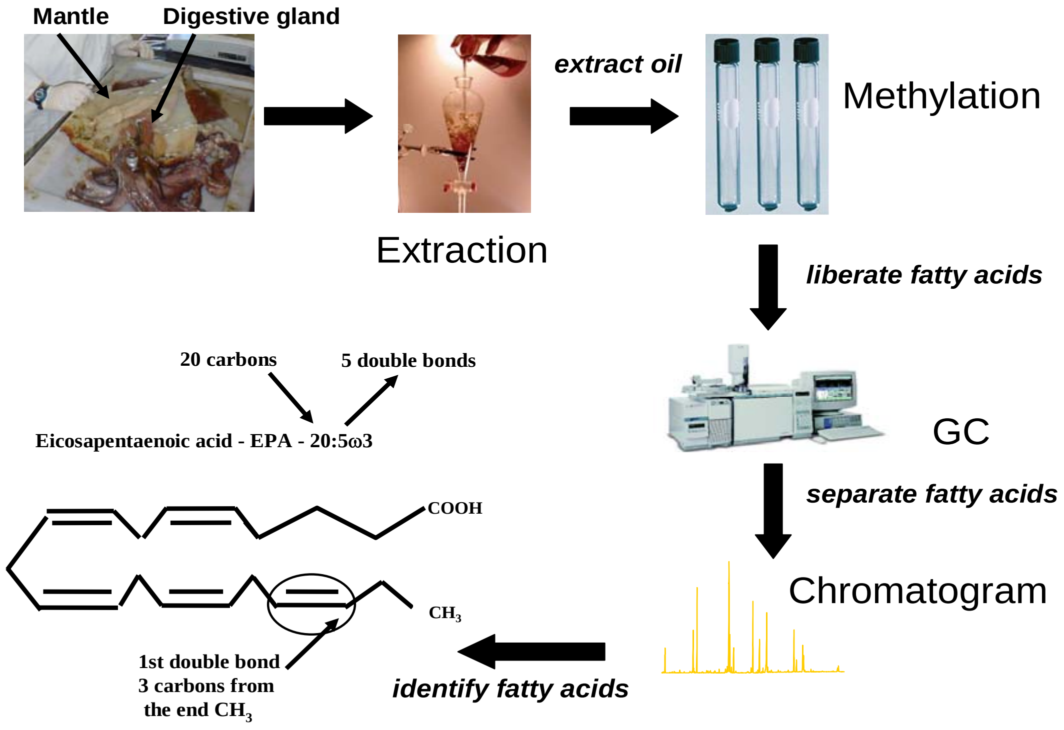

Figure 1. Overview of lipid extraction and fatty acid profiling protocol. The structure for EPA is shown.

Results and Discussion

Patagonian toothfish

Recent commercial interest in the Patagonian toothfish in the Macquarie Island region has heightened the need for a better understanding of this species. Of particular interest are dietary considerations. However, despite the importance of toothfish in the deep-sea food web at this and other southern ocean locations, relatively little had been known of their diet. Current knowledge is based on examination of stomach contents, a technique that fails to identify with any certainty long-term dietary composition. The determination of lipid and fatty acid composition provides an effective means of determining the diet of toothfish, one that complements traditional techniques.

As part of a broader study of the species, the lipid and fatty acid composition of the toothfish was investigated in relation to physical (sex, age/size) and fishing parameters (region, season, depth, time of day) (Wilson and Nichols 2001, Wilson 2004). Each parameter was compared using a variety of statistical treatments. Significant variations occurred in total lipid content, lipid class composition and especially fatty acid composition between fish of different sizes (ages), pointing to a potential shift in diet as fish mature (Figure 2). Eicosapentaenoic acid (EPA, 20:5ω3, Figure 1) and docosahexaenoic acid (DHA, 22:6ω3) were those fatty acids most responsible for the observed variation with size. The influence of other parameters on lipid composition was less pronounced.

To determine whether these variations in fatty acid composition with size were due to possible variations in diet, a comparison with profiles for prey species was undertaken. This involved the examination of 21 species of midwater fish, including 8 species of Myctophidae, and 6 species of squid. Many of these species are known to contribute to the diet of toothfish in the Macquarie Island region. The results of statistical analysis suggest that the diet of Patagonian toothfish at Macquarie Island may vary to a far greater extent, relative to size increases, than is suggested by stomach content analyses. For instance smaller toothfish are more closely linked to squid, based on fatty acid composition (Figure 3a) than are larger toothfish. In regards to potential fish prey, the fatty acid compositions of Myctophidae are more closely related to larger rather than smaller toothfish (Figure 3b), consistent with a shift in dietary preference as toothfish mature.

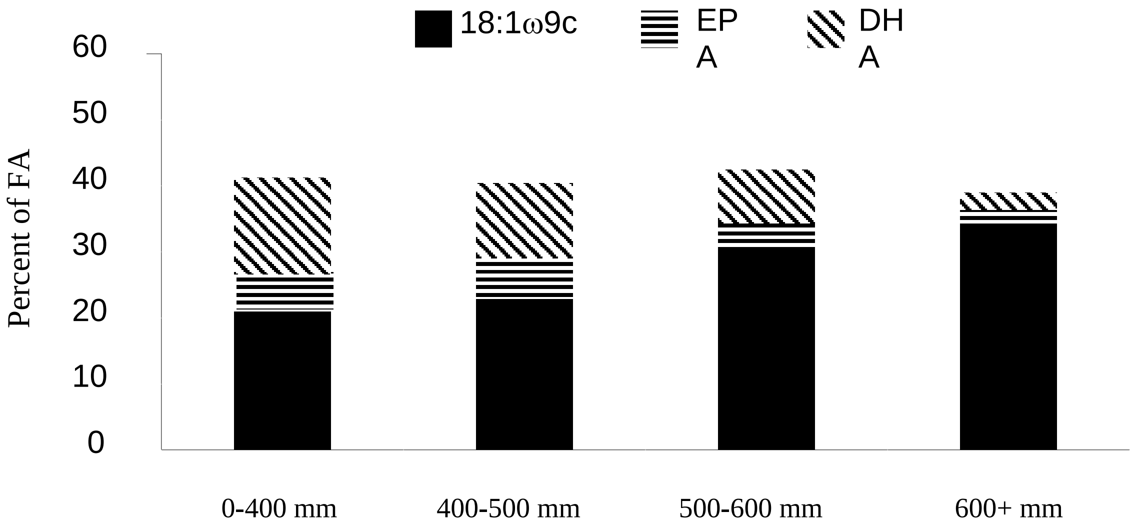

Figure 2: Composition of major fatty acids (percent of total fatty acids) in Patagonian toothfish from the northern fishing ground at Macquarie Island, showing changes with fish size.

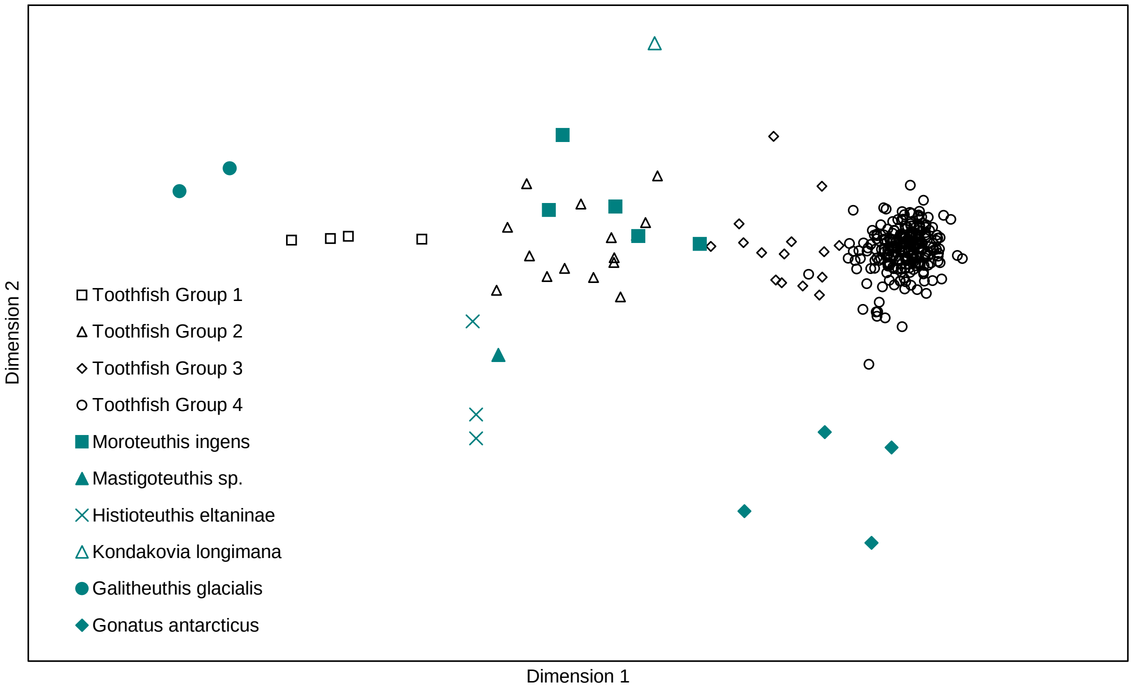

Figure 3a: Scatterplot of multidimensional scaling (MDS) based upon the total fatty acid composition of *Dissostichus eleginoides* (size groups: 346±18 mm, group 1; 363±29 mm, group 2; 423±64 mm, group3; 681±159 mm, group 4) and various squid species included in this study from the Macquarie Island region.

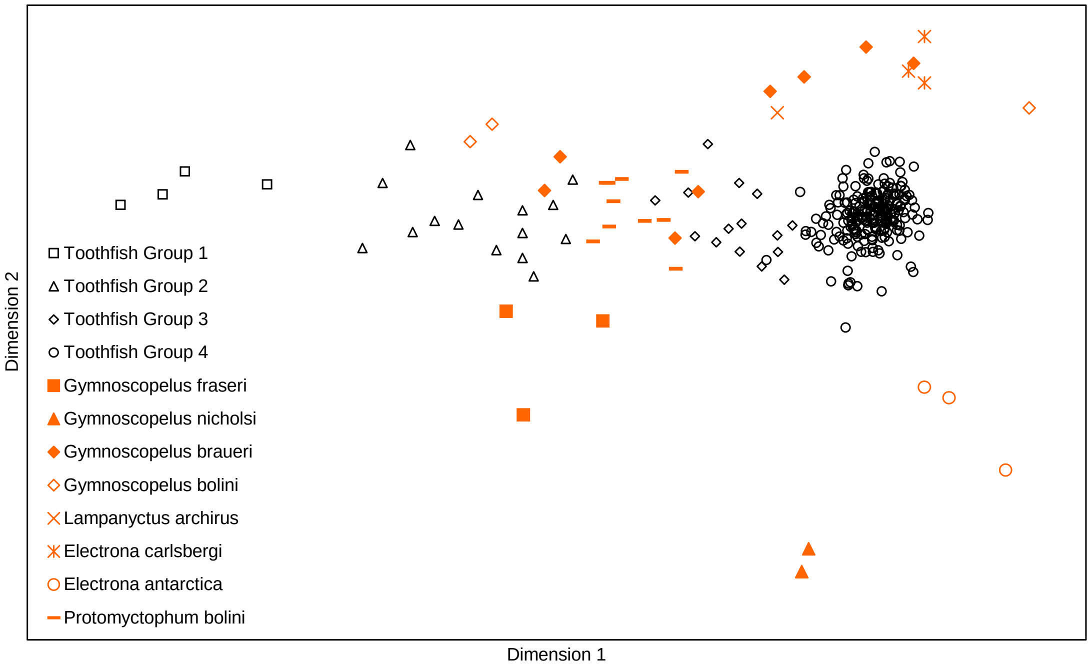

Figure 3b: Scatterplot of multidimensional scaling (MDS) based upon the total fatty acid composition of *Dissostichus eleginoides* (refer to Figure 3a for details of size groups) and Myctophidae included in this study from the Macquarie Island region

Escolar versus rudderfish?

Analysis of the lipids of the fishes *Lepidocybium flavobrunneum* and *Ruvettus pretiosus* (escolar), and *Centrolophus niger* and *Tubbia* spp (rudderfish) has been performed (Nichols *et al*. 2001). The analyses were used to clarify the cause of recent reports of illness (diarrhoea) in Australia from consumption of purported rudderfish.

Both escolar and rudderfish contained unusually high levels of oil (between 14 to 25%, as % wet weight) in the fillet. In comparison most Australian fishes are low in oil content (average 1%, Nichols *et al*. 2001 and references therein). The oil compositions were also different to most seafood. Escolar oil contained mainly wax ester (>90% of oil) (Figure 4). The oil from five specimens of rudderfish contained mainly diacylglyceryl ether (DAGE, >80% of oil) or hydrocarbon (> 80% of oil, predominately squalene). One rudderfish specimen contained mainly polar lipid (PL).

Major differences in oil content and composition, including fatty alcohol and glyceryl ether diols (derived from DAGE), were observed between purported individuals of the same species or related species of rudderfish, raising the possibility of geographic or seasonal differences affecting the oil composition.

The oil composition of fish fillet samples (sample X, Figure 4) associated with the health issues was consistent with the profiles for escolar, rather than rudderfish species. These oil class findings, in particular the lipid class and fatty alcohol profiles (Nichols *et al*. 2001), were supported by general protein fingerprinting results and were consistent with the samples originating from individuals of the escolar species *Lepidocybium flavobrunneum*. The high wax ester content of the escolar group clarifies the reported diarrhoeal effects to consumers. Purgative properties of high wax ester containing fish oils have been reported for escolar and other species. The results highlight the potential for lipid class and non-saponifiable lipid profiles to be used for identification of fish fillets and oils to at least group level.

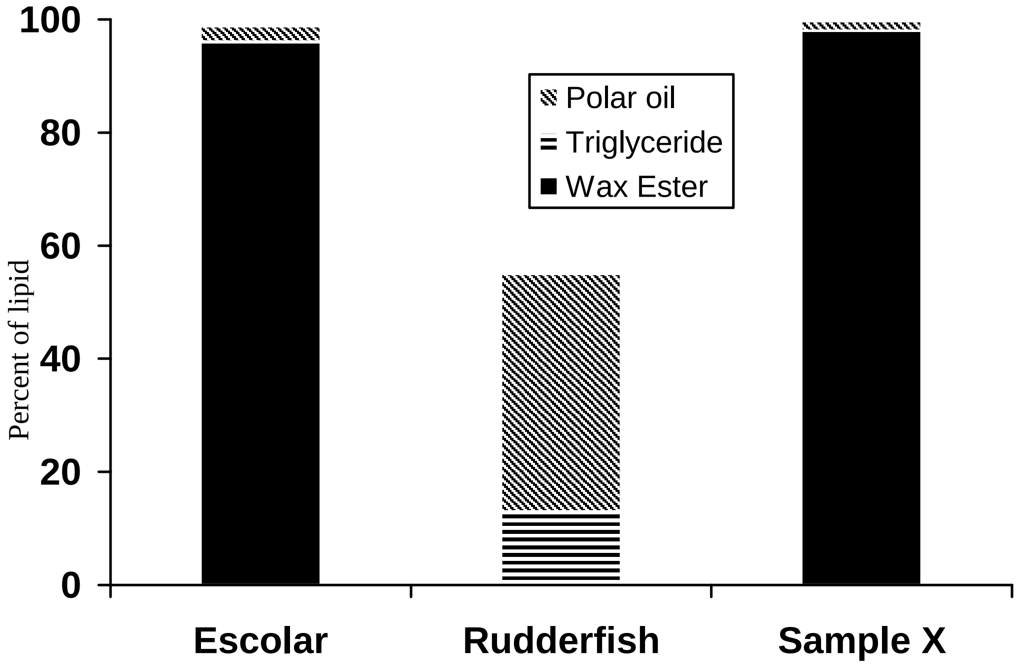

Figure 4: Lipid class composition (as percent of total lipid) of escolar and rudderfish, and an unknown specimen (sample X) supplied as rudderfish.

Moroteuthis ingens – the digestive gland (DG) as a source of fatty acid dietary tracers

Squid occupy a key ecological niche in the Southern Ocean (Rodhouse and White 1995). However, we currently know little about the parameters required for their adaptation to these polar waters. Lipid analysis of cephalopods provides insight into biochemical, physiological and ecological requirements of these animals. While many marine vertebrates (including pinnipeds) prey on cephalopods, very few data are available on the fatty acid composition of squid for inclusion in such predator-prey comparisons.

Analyses of total lipid and lipid class composition of the digestive gland of selected cephalopods revealed that lipid stored in this organ is unlikely to be mobilised during sexual maturation (Blanchier and Boucaud-Camou 1984, Clarke *et al.* 1994) or long-term starvation (Castro *et al.* 1992). Recent studies have investigated the relationship between cephalopod lipid content and diet. The DG of cephalopods are an ideal source of fatty acid dietary tracers, as dietary lipid is deposited in this tissue with little or no modification (Phillips *et al*. 2001). Using this knowledge DG lipid, in particular fatty acid, profiles have been used therefore to identify important prey groups of the Southern Ocean squid *Moroteuthis ingens* (Phillips *et al*. 2001).

Mantle tissue was low in lipid, with lipid content 1.5 ± 0.1% wet mass in *M. ingens* samples from Macquarie Island. The major lipid class was PL, present at 83.1% of total lipids. ST (12.3%) represented the only other lipid class with values greater than 3% of total lipid. PUFA were the most abundant class of fatty acids in mantle tissue, with a sum value of 53.1 ± 1.6%. PUFA were largely comprised of EPA and DHA; no other PUFA were at values exceeding 5% of total fatty acids. Saturated fatty acids (SAT) were dominated by 16:0, with a sum of SAT of 31 ± 0.7%. Monounsaturated fatty acids (MUFA) comprised 15.5 ± 1.4%; represented largely by 20:1ω9.

In comparison to mantle, the DG lipid content (26.8 ± 12.9%) was generally an order of magnitude greater than the mantle. Triacylglycerol (TAG) was the major lipid class (75.0 ± 17.5% of total lipid). Major fatty acids in the DG were 16:0, 18:1ω9 and 20:1ω9, with MUFA as the major class.

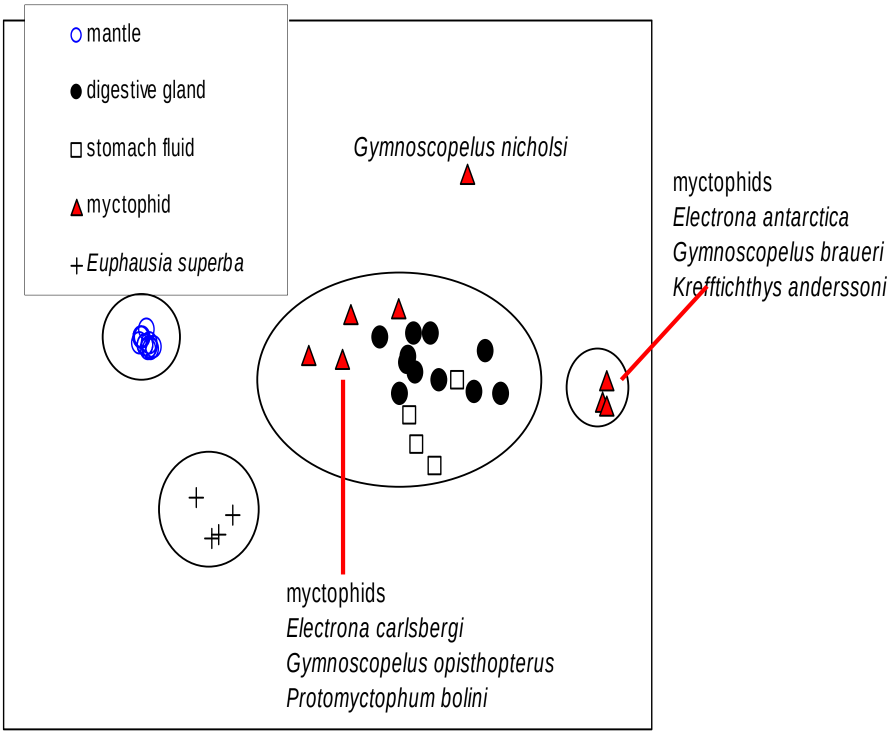

Figure 5. Multidimensional scaling (MDS) of FA data from *M. ingens* - mantle, digestive gland and stomach fluid, myctophids and antarctic krill. Axis scales are arbitrary in MDS and are omitted. From Phillips *et al*. (2001).

The fatty acid profiles of the DG of *M. ingens* grouped with those of the stomach fluid and selected myctophid species in multivariate analyses (Figure 5), indicating that the DG is a source of dietary fatty acids. For *M. ingens*, the application of the signature lipid approach has been used further to examine temporal, spatial and size-related variations in diet (Phillips *et al*. 2002, 2003a, 2003b). As the lipid content of the DG of *M. ingens* greatly exceeds that of the mantle, the fatty acids in the DG derived from this sub-Antarctic squid are therefore in greater absolute abundance than fatty acids in the mantle. A squid predator would ingest more lipid from secondary prey items, which has been stored in the DG of the squid, than from the mantle tissue of the squid itself.

Implications for the use of squid lipid data with higher predators

In the context of dietary lipid studies of higher predators, blubber, milk and muscle samples from a range of species have been analysed with the aim of identifying prey groups (Horgan and Barrett 1985, Iverson 1993, Kirsch *et al.* 1995, Smith *et al.* 1997, Raclot *et al.* 1998). When squid data have been included in these analyses, it is often unclear whether fatty acid data were obtained from whole homogenised squid, flesh tissue only, or from squid remains retrieved from the stomach contents of a predator. If squid is low in lipid content (around 1% wet mass) and dominated by PUFA (Iverson 1993, Iverson *et al*. 1997), it is likely to have been extracted from flesh tissue only. Based on our findings for *M. ingens* and other species of Southern Ocean squid (Phillips *et al*. 2002), squid flesh data alone is not suitable for inclusion in these analyses. Such data does not represent the overall lipid composition of a squid as ingested by a predator, and consequently it is highly likely that squid will be interpreted as having little importance in the diet.

When whole, homogenised squid are used to represent potential prey items in fatty acid studies of higher predators, it will be important to consider the large amount of ‘secondary’ fatty acids stored in the DG. Squid may not be effectively represented as a distinct prey group in analyses as their lipid signature may be very similar to (or in the case of lipid-rich species, masked by) other potential prey items such as myctophid fish. Therefore, the dietary importance of squid as a prey group may be difficult to interpret and isolate from other prey groups. These implications could constrain the use of fatty acids to assess the importance, or inclusion over space and time, of squid prey items in the diet of higher predators. Given the fact that our general knowledge of squid trophodynamics in the Southern Ocean is poor, it is important to identify and attempt to understand such biases associated with food-web studies. A combination of techniques, such as fatty acid analysis of blubber or muscle, and DNA analysis of stomach contents or faecal remains, may provide a more robust representation of the inclusion of squid in the diets of higher predators.

In summary, we have demonstrated in this brief overview that lipid and fatty acid profiling can be used in food web and taxonomic studies to complement other traditional and ‘chemical tracer’ approaches. Recent developments with fast GC technology and statistical packages suggest that the approach may be further embraced in future fisheries research. To this end, applications with swordfish, rattail and selected tuna species are presently underway.

Acknowledgments

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Stable isotope analysis in fisheries food webs

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Abstract

Stable isotope analysis has been used as a technique to analyse fisheries food webs for a quarter of a century, and remains the principal method for determining energy and nutrient pathways from primary producers to consumers in aquatic ecosystems. Carbon isotope analysis has been used to distinguish autotrophs at the base of inshore and offshore fisheries food webs. The combination of nitrogen and carbon isotope analysis has established the contributions of different food items to the energy and protein requirements of fish. Methodological issues with stable isotope analysis are being solved using new laboratory and mathematical modelling techniques. For example, compound-specific isotope analysis of phytol (the side-chain of chlorophyll), can be used to obtain a carbon isotope signature of benthic microalgae without interference from contamination. Advanced mixing models help distinguish among sources even in situations such as estuaries where potential sources are numerous. The addition of sulphur analysis can help to separate the contribution of sources indistinguishable using carbon and nitrogen. Ultimately, when natural abundance isotopes cannot separate sources, the addition of enriched isotope material in pulse-chase tracer experiments is effective in testing among alternate food web models.

Keywords: Stable isotopes, food webs, fish diets

Introduction

Analysis of fish diets is a necessary part of fisheries science for two reasons. Firstly, knowledge of the dietary requirements of harvested (wild or cultured) species is important for management of harvestable stocks. Secondly, the provision of organic matter to food webs and its assimilation at different trophic levels is fundamental to sustainable management of fisheries in an ecosystem context (Connolly *et al*. 2005a). From both these perspectives, it is often more important to know what is assimilated, rather than what is merely ingested, and these are mostly not the same thing.

Stable isotopes provide an efficient and useful means of analysing assimilation of energy (carbon) and nutrients in fisheries food webs. Stable isotope analysis is based on the ratio of naturally occurring isotopes of key elements such as carbon, nitrogen and sulphur that are ubiquitous in aquatic environments and are essential to the nutrition of all animals. These elements all have a common, light isotope and a rarer, heavier isotope, in which the atom has an additional neutron (i.e. $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{34}S/^{32}S$). Different autotrophic sources (often) have different ratios of the heavy and light isotopes, because they use different sources of nutrients (e.g. water for algae, air or sediment for mangroves) or have different photosynthetic pathways (e.g. saltmarsh grass, mangroves). The signatures of different autotroph sources are taken on by primary consumers, and ultimately animals at higher trophic levels. Diets and food web structure can therefore be determined by collecting and analysing plant and animal isotope ratios and using the isotope signatures as tracers (Lajtha and Michener 2006; Fry 2006).

Although analysis of stomach contents of aquatic animals can provide information useful in the interpretation of isotopes, as a stand alone technique its limitations are that it: a) demonstrates ingestion of plant or animal material but does not demonstrate assimilation; b) underestimates or fails to detect consumption of food items that leave no conspicuous presence (e.g. soft-bodied prey such as nematodes, microbes too small to observe, and plant material that is difficult to identify once consumed); and c) cannot be used on very small organisms, such as microbes (e.g. only chemical analysis of bacteria can determine nutrient sources).

In this paper I first provide examples of harvested marine species for which stable isotope analysis have proven effective at determining food web structure, including distinguishing utilisation of different food items for energy and protein requirements. I then provide potential solutions to the key challenges for aquatic isotope analysis of: 1) measuring inconspicuous sources, 2) analysing contributions from multiple sources using mixing models, and 3) overcoming lack of differentiation among potential food sources.

Effective stable isotope analysis

Carbon isotopes in an offshore food web

Growth rates of larval *Macruronus novaezelandiae* (blue grenadier) in waters offshore of western Tasmania are higher after periods of strong southerly winds. Thresher *et al*. (1992) used stable isotope analysis to demonstrate that although adult blue grenadier rely on a pelagic marine food web driven by plankton, larvae depend on seagrass detritus. The stable isotope evidence helped Thresher *et al*. (1992) develop a model explaining the correlation between larval growth and wind patterns. Periods of strong southerly winds drive detrital mats of seagrass matter from the shallow waters of Bass Strait into western Tasmanian waters. Blue grenadier larvae feeding on microbes associated with the mats grow faster than larvae unable to access seagrass, and ultimately contribute a greater proportion of juveniles recruiting to inshore waters.

Energy and protein sources for fish in artificial waterways

Massive canal developments built to provide waterfront living opportunities in southeast Queensland provide hundreds of kilometres of artificial estuarine habitat, either replacing or in addition to natural coastal wetlands (Waltham and Connolly 2006). Several harvested species occur in the canals, including *Arrhamphus sclerolepis* (snub-nosed garfish). In natural wetlands, snub-nosed garfish feed on live seagrass material during the day and on crustaceans at night. Seagrass is absent from canals, and garfish instead consume microalgae and macroalgae, although during the night rather than the day (Waltham and Connolly 2006). They prey on a variety of animals during the day, including terrestrial insects accidentally entering the water. Garfish obtain the bulk of their energy (carbon) from algae, and the carbon isotope signature of their tissue therefore matches that of algae (mean -19‰). The nitrogen isotope signature of garfish, however, does not match that of algae (after adjusting for fractionation), but sits approximately where it would be expected if the majority of nitrogen is obtained from animals. Isotope analysis therefore provides evidence of the different roles food items have in the nutrition of this species, and demonstrates a plasticity in feeding strategies that allows garfish to flourish in artificial and natural waterways.

Nutrition of wild juvenile prawns

Stable isotopes have been used successfully to investigate the relative importance of mangrove and seagrass organic matter in the nutrition of juvenile penaeid prawns in Queensland (Loneragan *et al*. 1997). Although in theory mangrove leaf litter can form the basis of food webs in adjacent waters (Lee 1995), isotope analysis of prawns show that they derive their nutrition from organic matter in seagrass meadows. The transfer might be either through direct consumption of epiphytic algae and seagrass or via animal intermediaries in a detrital pathway. The study by Loneragan *et al*. (1997) also provides an excellent example of the extent of spatial and temporal variation in isotope signatures, and how to measure variation at multiple scales.

Measuring isotopes of inconspicuous sources

Potential sources that have low biomass, and are therefore inconspicuous, but have high productivity are often overlooked in isotope studies. For example, even the best studies in estuaries (e.g. Loneragan *et al*. 1997) have difficulty obtaining enough benthic microalgae from sediment to obtain an isotope signature. Attempts to extract microalgae from the matrix of sediment, algae, detritus, meiofauna and microfauna usually lead either to a degree of contamination or a failure to extract all algal types (e.g. depends on motility, cell size and density). Centrifuge extraction relies on algae having different densities to other particles in the sediment (Hamilton *et al*. 2005) and is particularly useful where algal biomass is high relative to detrital load. Where algal biomass is relatively low, however, a stable isotope signature for algae is best obtained using a novel compound-specific method (Oakes *et al*. 2005). Phytol (the side-chain of chlorophyll), in marine sediments derives almost exclusively from microalgae, and the compound-specific analysis of carbon isotopes of phytol therefore provides an accurate isotope signature of microalgae without the need to physically extract cells from the sediment matrix.

Advanced mixing models to analyse multiple sources

The commercially important sillaginid fish, *Sillago schomburgkii* (yellowfin whiting), of southern Australia inhabits sheltered, shallow waters supporting large areas of seagrass, mangroves, saltmarsh and unvegetated intertidal flats. Although yellowfin whiting sometimes occurs over seagrass it is more common over unvegetated habitat (Connolly 1994), and the highest densities have been recorded in tidal creeks surrounded by extensive stands of mangroves and saltmarsh (Connolly and Jones 1996). Stable isotopes were used to determine whether yellowfin whiting production was supported by a food web based on seagrass, mangroves and saltmarsh, or algae.

In situations such as these open embayments, where potential autotroph sources are numerous, attempts to use isotopes to distinguish among sources have been hampered by the lack of a unique result in mixing models. Recently developed mathematical modelling of source mixtures helps elucidate important sources in such situations. The IsoSource model of Phillips and Gregg (2003) calculates feasible combinations of autotrophs that could explain the consumer signature. The method examines all possible combinations of each autotroph's potential contribution (0 - 100%) in defined increments (e.g. 1%). Combinations that add almost exactly to the consumer signature are considered feasible solutions. Results are reported as the distribution of feasible solutions for each autotroph. For yellowfin whiting, modelling of feasible source mixtures showed that seagrass and epiphytes were the most important contributors to the nutrition of fish, but their relative importance varied between seasons (Figure 1). The median contribution of other sources was < 10%.

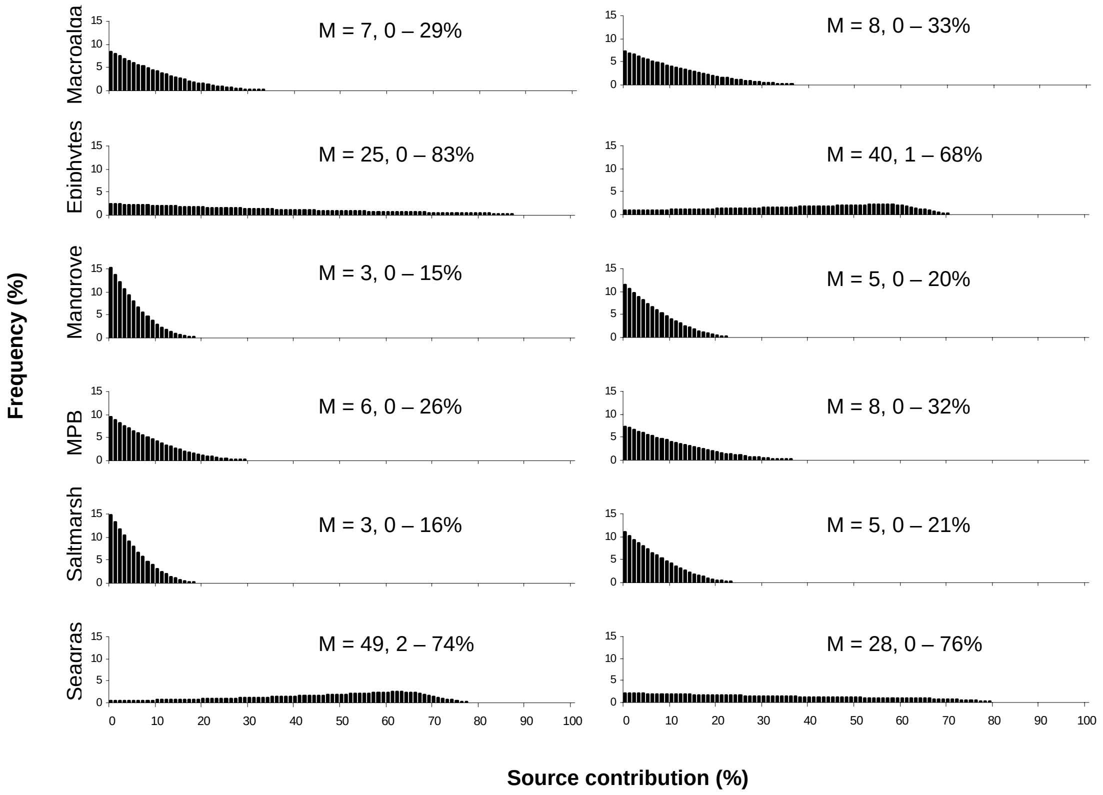

Figure 1: Distributions of feasible contributions of the 6 potential autotrophs to yellowfin whiting based on IsoSource modelling of stable isotope data (after Connolly *et al*. 2005). M = median, the ranges are 1%ile and 99%ile values.

In many cases, sources can logically be pooled into natural groupings (e.g. saltmarsh succulents and mangroves both occur high on the shore and have depleted carbon isotope signatures). Output from the initial IsoSource analysis can be re-processed using the smaller subset of grouped sources (Phillips *et* *al*. 2005). This pooling has been used to generate a more informative, narrower range of possible contributions for the grouped sources (Melville and Connolly 2005).

The spatial variability in isotope signatures of fish and potential sources can provide further evidence of source contributions. Correlation between site to site variation in isotope signatures of a consumer and site to site variation in isotope signatures for any of the sources, implies a contribution from that source. For most studies this is best done as a single test on carbon and nitrogen isotopes together, for which a two-dimensional correlation test in Euclidean space has been developed (Melville and Connolly 2003). For yellowfin whiting, the spatial correlation test combined with IsoSource showed that seagrass and epiphytic algae provided most nutrition, and that other algae made a minor (< 10%) contribution. Yellowfin whiting rely on inwelling of organic material from seagrass meadows rather than outwelling from mangroves and saltmarsh (Connolly *et al*. 2005b).

Overcoming lack of differentiation among potential food sources

Where isotopes of the most common elements cannot separate potential sources, additional elements can be used. Sulphur is the most likely candidate in marine systems, since the source and therefore the isotope signature of sulphur utilised by different autotrophs varies strongly. In a review of marine isotope studies that use the three elements (C, N, S), Connolly *et al.* (2004) showed that the mean difference in isotope signature between any two pairs of autotrophs was greatest for S, followed by C and N (Figure 2). The automation of S isotope analysis of ecological samples is increasing both the breadth of food web studies in which S can be employed and the levels of replication that can be used. However, sampling and analysis artefacts are less well understood for S than for C or N. Improved preparation and analytical techniques (e.g. Hsieh and Shieh 1997; Fry *et al*. 2002) are being developed but need to be more widely tested and used to give rigour to the use of sulphur in food web studies.

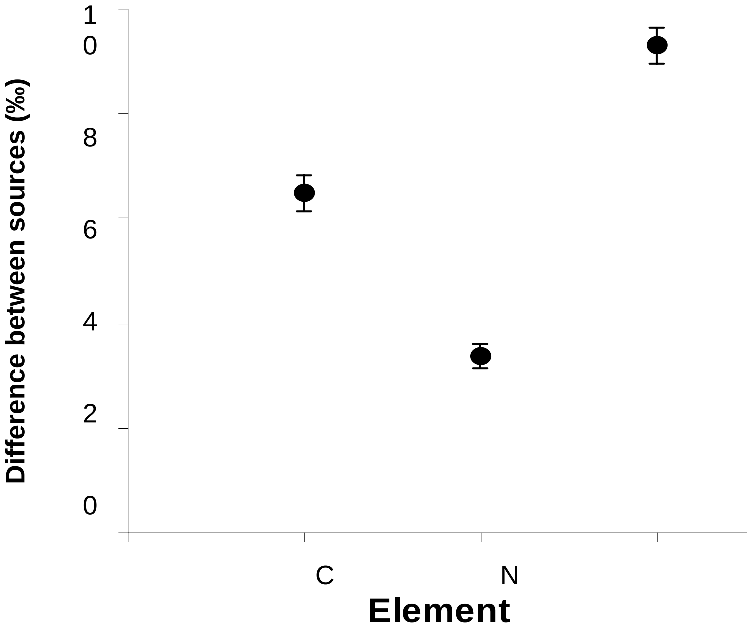

Figure 2: The average isotopic separation between any pair of potential autotrophic sources in all marine food web studies using the three elements carbon (C), nitrogen (N) and sulphur (S), drawn from data within Connolly *et al*. (2004).

Where natural abundance isotopes cannot separate sources, even when using an additional element such as sulphur, pulse-chase tracer experiments are required to distinguish the contribution of different sources. Stable isotope analysis of marine food webs has made major advances through the manipulative enrichment of source signatures using the addition of artificially enriched isotopes (e.g. Gribsholt *et al*. 2005). Such experiments increase discrimination between the roles of potential sources and can therefore provide more rigorous tests of hypotheses about food webs. Although some of these experiments have been on large scales, there has not yet been a focus on fisheries species.

Winning *et al.* (1999) showed how sources that cannot be separated naturally might be distinguished using manipulative experiments. Loneragan *et al.* (1997) had been unable to separate seagrass and its epiphytes using natural abundance isotopes of carbon (both -11‰) and nitrogen (both 4‰). Working in the same system, Winning *et al.* (1999) added potassium nitrate artificially enriched in ^{15}N to seagrass mesocosms. After just 15 minutes of exposure to enriched nitrogen, the two sources were able to be easily separated. After enrichment, seagrass nitrogen isotopes values averaged about 100‰, while epiphytes values averaged about 400‰ (Figure 3). This separation was maintained for up to a month, enough time to show that prawns added to the system relied on seagrass material itself and not just, as theory would predict, the productive epiphytes (Winning 1997).

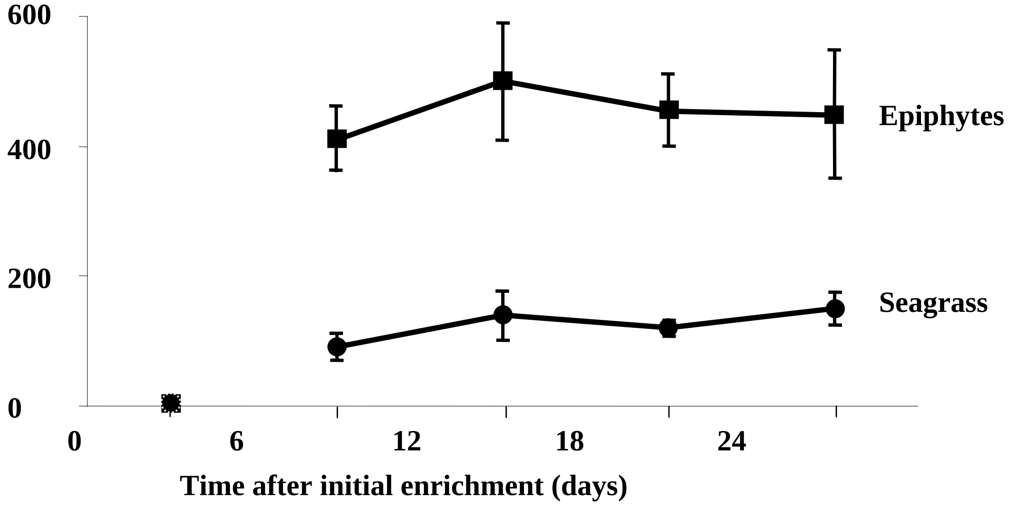

Figure 3: Separation of source (seagrass, epiphytic algae) isotope values using manipulative enrichment, prior to pulse-chase tracer experiment to determine prawn nutrition (data redrawn from Winning *et al.* 1999). Values for seagrass and epiphytes prior to enrichment (time = 0) were both 4‰.

Conclusion

When used well, stable isotope analysis allows rigorous testing among different food web models. Recent developments in the laboratory and in modelling procedures have advanced isotope analysis rapidly, making the technique suitable for many fisheries related situations.

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General discussion - Chemical techniques
Rapporteurs - Jayson Semmens & Zoë Doubleday

Key discussion points
The question about how chemical techniques could be applied to address ecosystem based fisheries management (EBFM) was discussed. It was noted that there are a range of techniques available that can address different ecosystem questions, the most appropriate technique being determined by the specific questions. In relation to EBFM, however, it was observed that ecological information requirements have tended to be vague and there was a need to work with managers to further refine the questions.

It was noted that emerging chemical techniques complement existing approaches, though a considerable amount of calibration/validation work is still required - the new techniques need to be conducted along with traditional methods to allow their validation, as well as to address gaps/limitations of traditional approaches. This will require collaboration between researchers and consideration of multi-species ecological studies.

There was general recognition that many of the chemical techniques considered in the session are complementary, and when applied in combination have the capacity to address weaknesses or limitations of individual methods. To some extent, differences between techniques are largely a matter of scale (temporal and/or spatial).

There was recognition that chemical techniques would increasingly be applied in fish movement studies:

- Stable isotope and fatty acid techniques in combination are showing great promise, yielding an understanding of movements of large fish predators.
- Stable isotopes and otolith microchemistry can be combined to answer questions about movement and habitat usage.

Chemical approaches have the capacity to overcome some of the logistic problems of working with larvae and juveniles, e.g. through the use of chemical markers.

It was noted that with fatty acid analysis that is was possible to discriminate between species of the same genera.

Genetic techniques have expanded rapidly and there a many novel applications for genetic data, e.g. genomes.

A concluding comment highlighted that the fact that many of the key management questions have not changed, for instance stock structure remains a fundamental issue, yet we struggle to answer it. There is a need to refine the questions, and seek better ways to incorporate the science into management outcomes. To this end it was acknowledged that managers need to become co-investigators in research.

Chair’s summary
Greg Jenkins

The Chemical Techniques session highlighted a range of chemical-based methods that have exciting potential. Although many of these techniques are not completely ‘new’, that is, they have a history going back a couple of decades, they are generally evolving rapidly as technology advances. These techniques build on traditional techniques that have been around much longer. For example, stable isotope, DNA biomarker and signature lipid/fatty acid techniques build on traditional gut analysis methods of analysing diet and food chains. Similarly, otolith microchemistry and genetic techniques build on traditional analysis of stock structure and movement using external tags. In the latter case these innovative techniques are crucial for the study of small larvae and juveniles that cannot be tagged by traditional methods. Generally, the new methods do not replicate information provided by traditional methods, but instead provide different and complementary data recorded at different spatial and temporal scales. For example, traditional gut analysis provides information on diet at a very fine temporal scale (i.e. hours) whereas stable isotope analysis provides food chain information at a scale of months. This emphasises one of the points from the panel discussion that these new techniques should not be seen as a replacement for old techniques but rather as complementary. It is still necessary to select the appropriate method, whether cutting-edge or traditional, to answer the question at hand.

There is considerable scope for more than one of these techniques to be combined in an overall study. For example, the combination of microchemistry and genetic techniques can provide information on stock structure at different time scales that together can provide enhanced information for managers. Another example is the combination of otolith microchemistry and the acoustic tagging techniques outlined in Session 1, providing information on movement and migration at different but complementary time scales. Combining methodologies will require significant collaboration amongst research institutions because the expertise and infrastructure for a particular technique is often housed in only a few institutions. The combination of more than one of these innovative methods, or of these methods and traditional techniques, may be very important in terms of validating and calibrating the methods. As discussed in the panel session, new technologies can be seductive and the pace of change can be rapid, however, there is a danger that the validation and calibration of the methods will lag considerably and therefore the conclusions derived from data collected may be questionable.

An interesting point of discussion with the panel was related to the uptake of these new techniques by management and industry. Although there are specific examples where results from these new chemical methods have resulted in new or changed management actions, in general it was felt that the take up to date has been relatively limited. In part this may represent a lag between the rapid change in scientific methods and the ability of management to take on board the implications of the research results and translate this into changed management actions. In part the onus is on researchers to work with managers so that the implications of results from these new research methods can be understood and integrated into management. There would be significant merit in involving managers in the research project at an early stage to encourage management understanding and ownership.

Uptake of results from these techniques may change in the near future in parallel with changes currently underway in fisheries science. In traditional fisheries management the results of these techniques can be used to supplement the overall information on which stock assessments are based, and management decisions are made. An example here is where chemical techniques provide information on stock structure and movement that can influence decisions on the spatial scales of management. There is, however, limited scope for the incorporation of ecological information into traditional stock assessment models. The modern movement towards EBFM will lead to a requirement for ecological information that is unprecedented in fisheries science. Ecological models are data hungry and innovative techniques will be required to provide the information to populate them. Fisheries management is also becoming more spatially based and this trend will continue into the future. Results from innovative chemical techniques in relation to stock structure and movement will therefore become increasing relevant. Overall, given the current trends in fisheries science, it seems likely that the uptake of results of these innovative chemical methods will be much greater in the future.

Session 4: Data Capture And Management

Ian Knuckey (Chair)

Vanquishing the 'data-poor fishery' using electronic smart tools

Bruce Wallner
Keynote speaker

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Abstract

In the past, fisheries management in Australia and around the world relied heavy upon information posted in by fishers after they arrived home, data collected at the wharf when the boat unloaded, scientific information collected aboard research vessels and a frighteningly small amount of independent data from observed fishing. The focus was on the target fish species and the fishing operation in order to quantify catch and fishing effort.

Today technology advances allow an incredible spectrum of data to be collected. More data can be collected faster, with greater precision and transmitted to analysts and decision makers in real time if required. Some electronic tools such as VMS to track vessel positions and electronic sampling aids to weigh and measure fish are embedded into our data processes. Other emergent use of video and sensor logging apparatus are providing abundant, new and unfamiliar data about fishing. These new types of data capture systems come with some attendant problems that are yet to be overcome.

This presentation provides a brief overview of 'smart' approaches to monitoring fisheries. It examines and compares electronic systems that are used by people at sea to improve data capture and fully automated electronic data capture systems that require no human assistance. Can these approaches be used to meet our fisheries management needs?

Introduction

This time on earth is being dubbed the information age. Technology is allowing a vast array of data to be collected, communicated and processed to assist in making management decisions. With specific reference to fisheries applications of technology today, there are some broad generalizations:

- the assessment and management of fisheries is information intensive due to computer power and modelling capability,
- technology convergence is permitting greater access and use,
- costs of technological solutions are now much lower,
- there has been good uptake of technology by industry to catch more fish, but application by regulators for management has lagged, and
- technological applications are now developing rapidly in every jurisdiction but there is little collaboration.

The collection of information to support sustainable fisheries management can often be one of the main costs in managing commercial fisheries. For example, in the Commonwealth's Eastern Tuna and Billfish Fishery, the main information sources come from a catch and effort logbook program, an observer program (at only 5% of fishing shots), a catch disposal recording system, and a size monitoring program for just target species. The total cost for these programs is in excess of $1.5 million per year. Hence, harnessing technology to make cost efficiencies is very attractive.

I examine three examples of technological solutions for information capture that have been developed by the Australian Fisheries Management Authority. Two of these are 'enabling tools' in that they assist people with data collection work, and the third is a fully automated data collection tool:

1. Electronic catch and effort logbooks – enabling fishers
2. PDA – paperless data capture on the deck – enabling observers
3. Integrated electronic monitoring

Electronic catch and effort logbooks – 'e-Logs'

Catch and effort logbooks are completed are completed at sea by all Commonwealth fishers on a daily or 'shot-by-shot' basis. They are a diverse, complex and spatially and temporally referenced data source. They attempt to collect data on vessel details, fishing gear, catch, effort, bycatch, discards, bycatch mitigation methods, wildlife interactions, environmental conditions, processing methods and tagged fish. Paper logbooks require printing and circulation and they are returned by mail relatively slowly. In addition, they require time and labour for processing, follow-up and tracking. They are subject to transcription errors and need physical storage space.

There have been a number of initiatives toward e-Logbook development to address the shortcomings of paper logbooks. These include Queensland's Electronic Catch and Effort Recording System that used the Inmarsat C satellite vessel tracking system as the communication medium (Good and Peel, unpublished); the 'SHEEL' project sponsored by the European Union to develop a Secure Harmonised European Electronic Logbook for about nine participating European countries (http://fish.jrc.cec.eu.int/sheel/sheel.htm); several north American initiatives; and a simple spreadsheet-based solution for Australian vessels fishing in the sub-Antarctic to report to CCAMLR. However, to date few of these initiatives have resulted in industry wide adoption of electronic reporting.

AFMA first commenced development of E-log options in 2002 following *Electronic Transactions Act 1999*. A strategy was developed (http://www.afma.gov.au/industry/logbooks/guide_vendors.htm) that initially comprised the following features:

- existing legislative requirements conformity by designing electronic 'equivalence to paper logs';
- collaboration with third party software developers;
- development of an 'open standard' based on XML, electronic signature and encryption using public key infrastructure; and
- flexible medium of transmission for data.

The overall data flow of the e-Log approach is shown at Figure 1.

To date, two companies have developed e-Log software that meets AFMA's standards. Both products provide vessel management features as well as an electronic reporting facility. There has been some use of one of these products in the Commonwealth Northern Prawn Fishery (NPF) (http://www.catchlog.com/). The use of this product has demonstrated that technical problems have been largely overcome and that e-Logs are both feasible and reliable. In particular, the data from e-Logs is of high quality, especially the spatial accuracy of fishing position. In addition, there are significantly fewer transposition errors, missing values and misinterpretations. Despite these apparent benefits, adoption of electronic reporting by the fishing industry generally has been disappointing, with fewer than 20% of NPF vessels choosing to use e-Logs routinely and little interest in other Commonwealth fisheries. AFMA is now pursuing a new project to re-examine its e-Log strategy to promote more rapid and complete adoption of e-Logs as a standard method of catch reporting by fishing vessels.

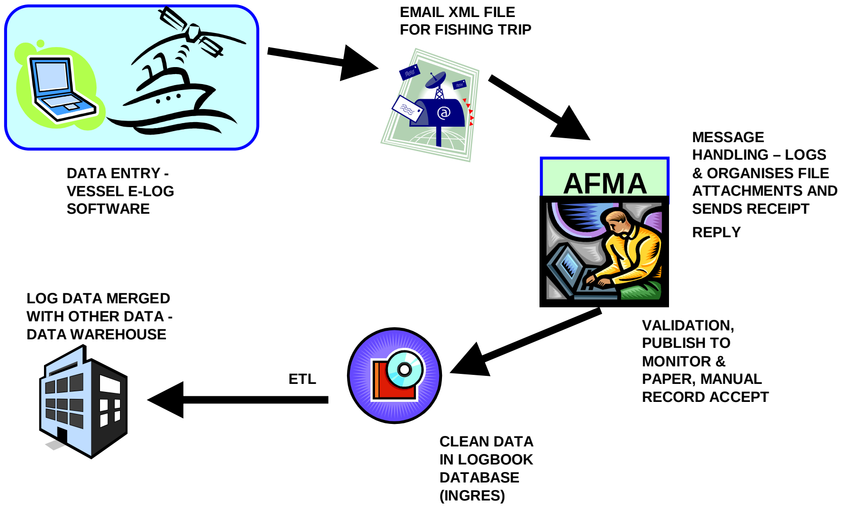

Figure 1: Schematic diagram of e-Log data flow.

PDA-based paperless data capture

The advent of compact but powerful computers – Personal Digital Assistants or PDAs has enabled AFMA to harness this technology to develop a new, cutting-edge data collection tool for use by fisheries observers working at sea on the deck of fishing boats. This tool facilitates accurate real-time data capture and has wide potential for any remote data recording application. The approach is to use available off-the-shelf products.

The PDA toolset consists of a laptop computer, a PDA (HP iPAQ hx2100) selected on the basis of price and reliability of test model) and an independent GPS receiver (GlobalSat BT-338). The PDA and GPS are housed in standard water proof plastic cases made by Otter Products LLC (http://www.otterbox.com/). The PDA case comes with a membrane face to allow view of the screen and operation of the unit and an elastic security strap on the back of the case that can slide over the operator’s hand (Figure 2). On the GPS case, a magnet is affixed to allow the housed GPS unit to be attached to any steel part of the vessel’s superstructure that allows a clear view of the sky.

Figure 2: PDA and GPS in water proof ‘Otterbox’ cases.

The PDA was programmed simply to create a series of ‘electronic forms’ that could be used to capture digital data directly rather than the usual method of pencilling on waterproof paper and later key-punching data into a data base. Simple button menus are used to navigate through forms. Dropdown pick-lists are used for coded fields and a ‘power-pick’ facility is used for fields where there is a long list with numerous values to choose from, for example, fish species names. The position (latitude and longitude) and time (UTC) is captured for each relevant event at the click of a button. These values are sourced from the GPS unit via a ‘blue-tooth’ link. Parameter ranges are provided for key fields and an initial validation check is performed at the point of data entry.

Data captured on the PDA is periodically exported to the laptop securely housed in the vessel’s wheelhouse via bluetooth link. The export creates an XML file and a PDF forms file. These are stored on the laptop and then emailed to AFMA in Canberra periodically or at the conclusion of a fishing trip. The communications medium is either satellite or mobile phone networks.

Email file attachments received by AFMA are then treated with some file handling software that receipts the messages, applies further validation checks and downloads the data into AFMA’s generic Observer database. The data flow is essentially the same as for e-Logbook data (see Figure 1). Clean data is able to be downloaded into the central database often before the vessel ties up in port and the observer disembarks.

There are several benefits from use of the PDA tool:

- It is efficient and very cost-effective. The price of the basic kit including the laptop computer is about $3200. This price is repaid in less than a year from data entry savings.
- All data are accurately time- and geo-located. Latitude and longitude fields are normally associated with significant recording inaccuracy and higher data-punching error rates than other fields.
- Data are validated at the time of the event. Memory is not required to ‘fix’ illegible or missing data fields and there are no transposition errors
- Automated data handling avoids problems of seasonal data entry loads.

Despite these clear benefits, the PDA is a battery-powered electrical device being operated in a hostile environment. It does need to be charged regularly and kept secure and dry. Loss or failure of the PDA unit necessitates carriage of paper forms as a backup. In addition, use of the tools requires a much higher level of operator skill and more disciplined workflow planning to ensure that the PDA is charged and that data is periodically downloaded to minimize the risk of data losses arising from equipment loss or failure. Significant additional training is required for operators.

Integrated Electronic Monitoring (e-Monitoring)

Integrated electronic monitoring, or e-Monitoring, describes an array of digital video cameras and electronic sensors that are combined with a programmable data logger to provide a powerful automated data collection tool (Figure 3). This technology has been steadily maturing over the past decade.

A Canadian company, Archipelago Marine Research Ltd (http://www.archipelago.ca/) has developed an integrated system with specific controls to monitor and collect information on board fishing vessels. They are routinely monitoring a number of Canadian fisheries using this technology combined with other more standard data collection approaches such as fishing logbooks, observers and dockside monitoring. Similar systems are now being implemented in some American and New Zealand fisheries. To date, Archipelago Marine’s system logs all data to a secure, high capacity, removable hard drive that is mounted on board the vessel. Data is retrieved manually by swapping the full hard drive for an empty one when a vessel docks. Hence, e-Monitoring is not yet ‘real-time’.

AFMA has trialled e-Monitoring systems in five Commonwealth fisheries over the past two years:

1. Small pelagic fishery – a mid-water trawl fishery with significant marine mammal bycatch risk (McElderry *et al*. 1995a).
2. Southern shark fishery – a gillnet fishery targeting gummy shark but with significant interaction with other stocks (McElderry *et al*. 1995c).
3. Northern prawn fishery – a trawl fishery with a large volume and diversity of bycatch (Stanley 1996a).
4. Eastern tuna and billfish fishery – a pelagic longline fishery with a requirement to monitor interactions with seabirds and marine turtles (Stanley 1996b).
5. The exploratory Antarctic longline fishery – a demersal longline fishery where 100% of fishing activity must be monitored by an observer (McElderry *et al*. 1995b).

Australian fisheries are characterized by remote ports and logistical difficulty in attending vessels when they dock. Hence, AFMA has also undertaken developmental work to transmit some data to AFMA from vessels at sea in close to real time using either mobile phone or satellite communications networks. Transmitted data consists of sensor data and information about the status of the hard disk and operating system. Video data files are very large in comparison and while technically feasible to transmit video imagery it is cost-prohibitive at present.

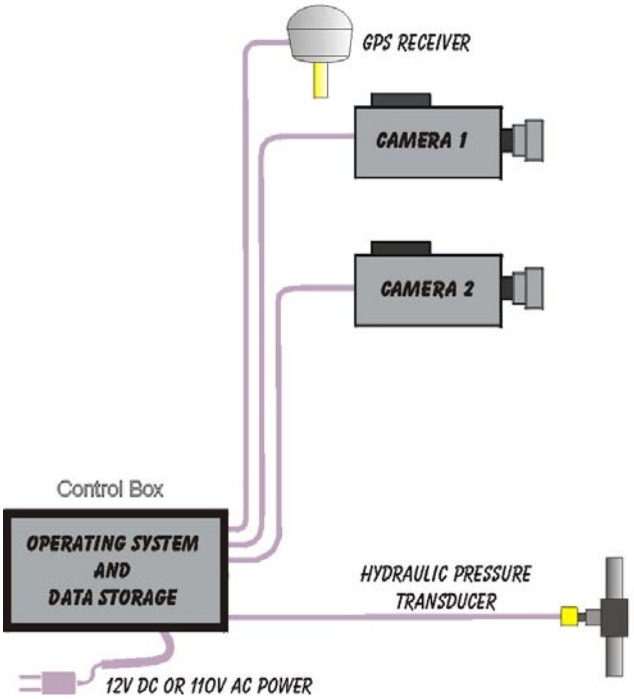

Figure 3: Diagram of e-Monitoring system.

AFMA's e -Monitoring trials have demonstrated the utility of e-Monitoring systems for validating other forms of monitoring and reporting; determining fine scale fishing effort and quantifying the type and amount of fishing gear used; measuring industry compliance with regulations and codes of conduct; enumerating catch including identification of species; quantifying bycatch; and rates of discarding and protected species interactions. Not every fishery or type of monitoring data can be collected using e-Monitoring systems. There is a need to define cost-effective targets and test the application of the technology, analysis and interpretation of the data and imagery gathered using an e-Monitoring system. However, in general the key benefits of e-Monitoring approaches are:

- They can provide high sampling intensity at relatively low cost and hence are good for detection and monitoring of rare events, and
- They are tireless and able to sample where humans would be at risk.

In designing a targeted e-Monitoring strategy for a fishery, there is a need to consider two ‘philosophies’ of monitoring:

1. Monitoring for ‘event’ detection - focus electronic data gathering on identifiable events of interest, e.g. catch of a protected species or deployment of fishing gear inside closed area.
2. Monitoring by data ‘logging’ - a wide range of signals is continuously recorded at short time intervals and data is subjected to analyses to find indicative patterns.

These two philosophies of monitoring are characterised by a number of positives and negatives (Table 1). Most monitoring strategies will usually involve a mix of the two philosophical approaches.

Table 1: Positive and Negative features of two approaches to monitoring.

	Positive Features	**Negative Features**
‘Event’ monitoring	- Collects only selected data - Informs about target events - Storage and transmission demands low - Little data post-processing required	- Need to understand target event well - Usually involves expertise to tune - Relies on many assumptions - Harder to interpret ambiguous events - Tampering may be harder to detect - Signal to noise ratio is high but subject to interpretation, false positives and missed events
‘Logging’ approach	- Target events inferred - Information rich - Can be implemented with only basic assumptions - Tampering is more evident - Less likely to make interpretive errors	- Collects vast amount of data – signal to noise ratio is low - Post-processing or sifting of data is required - Storage, transmission and analyses demands high

E-monitoring systems may be highly cost effective for some fisheries monitoring applications. The price of a basic system including a pair of video cameras, a GPS unit, a control unit, and pressure sensors to detect winch activity is around $7,000. This equates to around two weeks of observer time. A more significant cost is the cost of analysing sensor data and video imagery and managing the data thereafter. Based upon the trials to date, there are variable efficiencies across fisheries depending mostly upon the monitoring targets. For example in the small pelagic fishery, a fishing season’s video imagery and sensor data can be analysed for just dolphin bycatch in around two to three days. While in the exploratory Antarctic longline fishery, data analyses can only be reduced to about half of the elapsed time of a longline haul where the monitoring targets are catch enumeration and monitoring for bycatch and discarding.

The technical feasibility of e-Monitoring has now been proven, however this technology now raises new questions that require answers before e-Monitoring can take its place alongside standard monitoring approaches for commercial fisheries. Some of the questions that AFMA are now working on are:

- Who can supply and maintain e-Monitoring systems?
- How should e-Monitoring systems be accredited?
- What do new types of data mean and how can to integrate them with conventional fisheries data?
- How best to integrate all the new ‘smart tools’ e.g. e-Monitoring with e-Logs?
- What constraints may be imposed by the Privacy and Electronic Surveillance Acts?
- How to secure the data?
- Will industry accept e-Monitoring?
- Will a court accept electronic data as evidence of a fisheries breach?
- How best to meet the logistical demands of data and imagery analyses. Do we outsource or build capacity?

- What are the best solutions for storage and archiving large data volumes?
- Who can access e-Monitoring data?

Conclusions

The availability and competitive cost of technology is allowing rapid evolution of new approaches to monitoring commercial fisheries. 'Data poor' fisheries should indeed be vanquished in years to come by the application of such technologies. However, it is easy to be seduced by the technology- making the equipment work is generally the easy part of any new technological development. The hardest parts of implementing such technologies are getting the policy settings right, managing the information and delivering an output to fisheries managers in a form that can be readily used for informed decision making. In addition, a critical element for successful implementation is ensuring industry support for these 'smart' systems. Industry behaviours and attitudes need to be influenced using a mix of incentives and regulation, such as financial benefits or increased operational flexibility.

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Determination of cost effective techniques to monitor recreational fishing participation and catch in Western Australia

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Abstract

The traditional methods for estimating recreational fishing participation and catch in Western Australia have been creel and phone surveys, each of these methods has a relatively high cost. Whilst there is little doubt that an intensive survey method will need to be completed at periodic (e.g. five year) intervals, having information at a lower precision between these intervals (i.e. annually) to provide an indication of whether recreational fishing participation and catches are remaining steady, increasing or declining, will be of great benefit for the effective management of recreational fisheries.

Given management of multi-species recreational fisheries is likely to be focused on a relatively small number of key species, ongoing indicator surveys may need different sampling strategies to those used in standard surveys. In addition, alternative methods of data collection are now more readily available. These include the use of remote monitoring technology (e.g. video cameras) and the use of catch rate data collected by the Department of Fisheries, Fisheries and Marine Officers in a more directed fashion.

Understanding the relative accuracy and precision of each of the various standard and innovative approaches along with their relative costs, benefits, limitations and integration is essential for the development of the most appropriate, cost effective ongoing monitoring scheme for this system.

Introduction

A community survey conducted in 2005 showed that an estimated 537,000 individuals or 31.1% of the total population in Western Australia participates in some form of recreational fishing annually (Baharthah, 2006). Accordingly there is an ongoing need for monitoring of recreational fishing activity in Western Australia. Moreover there is an increased requirement for better data to enable the management of those fish stocks where recreational fishing takes a major component of the catch. In addition, these data will also be needed to assess whether the outcomes of management are meeting the explicit sectoral allocations that will be determined through the Integrated Fisheries Management processes.

Integrated Fisheries Management (IFM) is aimed at addressing the issue of how fish resources can be best shared between users within the broad context of Ecological Sustainable Development. The IFM process allocates resources between the commercial, recreational and indigenous sectors and promotes continued monitoring of the total catch, ensuring sustainable harvest levels and catch shares are maintained.

Currently, the recreational sector in Western Australia has no ongoing system for recording fishing participation and catch data on a frequent basis from a client base, which is extremely large and variable. In contrast the commercial and charter sectors, unlike the recreational sector, have a known client base due to the licensing structure and the mandatory reporting of catch and effort data which provides long-term trends, thus aiding towards better management decisions. This further highlights the growing importance to gather recreational fishing participation and catch trends on an ongoing basis, enabling those management decisions to be made using the best possible data available.

The traditional methods for estimating recreational fishing participation and catch in Western Australia scalefish stocks have been creel surveys however due to their high costs are only completed periodically (e.g. seven to 10 years). Whilst comprehensive creel surveys will continue to be used for estimating recreational fishing participation and catch, an indication of what is occurring between these surveys is crucial. Effective alternative survey techniques such as phone, diary and mail surveys can be used for estimating recreational fishing participation and catch, however, they have inherent biases and can be costly. The use of remote monitoring technology (e.g. video cameras) and the potential to use data collected by the Department of Fisheries, Fisheries and Marine Officers (FMOs) offers alternative approaches and potentially resolve the cost benefit viability that surrounds traditional methods for assessing the recreational sector.

Creel, phone diary, remote and FMO surveys, targeting boat-based demersal scalefish fishing, was undertaken on the West Coast Bioregion of Western Australia. The use of these different and relatively independent survey approaches has been undertaken to provide cross-validation of the West Coast Bioregion recreational fishing participation and demersal scalefish catch estimates and to assess cost-benefit issues.

Methods

During a 12-month period between July 2005 and June 2006 various surveys and remote monitoring methods were carried out in the West Coast Bioregion of Western Australia, to estimate boat-based recreational fishing participation and catch of demersal scalefish resources (Figure 1). These surveys included a creel survey, a phone diary survey, a remote monitoring survey and a Fisheries and Marine Officers Survey.

Creel Survey

The bus route method (Robson and Jones 1989, Jones *et al*. 1990) was used to estimate the recreational fishing participation and catch of individuals fishing from boats launched at boat ramps along the West Coast Bioregion between July 2005 and June 2006. The bus route method is where interviewers travel from boat ramp to boat ramp during a survey day as described by Pollock *et al.* (1994). The interviewers followed a pre-determined schedule specifying the boat ramp to visit and the sampling time for each boat ramp. More days were allocated to the locations where more recreational fishing participation occurred based on prior information obtained from a similar creel survey conducted in the same area in 1996/97 (Sumner and Williamson 1999). Refer to Sumner and Williamson (1999) for the calculations used to estimate recreational fishing participation and catch for boats launched from boat ramps.

Each boat ramp is grouped into a district (e.g. Hillarys district includes three ramps, Mindarie, Ocean Reef and Hillarys boat ramp) according to their location. These districts are subsequently combined into zones (Kalbarri, Midwest, Metro, South) in the West Coast Bioregion (Figure 1). There is no creel survey data for the Abrolhos zone since most boats visiting the Abrolhos Islands are kept in marinas or on moorings rather than launched at boat ramps on the mainland. Analysis of the collated data provided estimates of recreational fishing participation, catch and catch rates of dhufish and pink snapper.

Phone Diary Survey

A phone diary survey of the West Coast Bioregion was conducted between July 2005 and June 2006. A phone diary survey was used in preference to the less reliable telephone recall survey. Phone numbers were randomly selected from the Department of Planning and Infrastructures registered boat owner’s database. The survey was stratified by the place of residence, which enabled a higher level of sampling in the West Coast Bioregion. Furthermore, the survey stratified by boat size (small <4 m, medium 4-8 m, large >8 m). Monthly interviews recorded participation in recreational fishing, catch and fishing districts (Henry and Lyle 2003) which were grouped into West Coast Bioregion zones. Analysis of the data produced estimates of total recreational fishing participation for each zone (Kalbarri, Abrolhos, Midwest, Metro and South) in the West Coast Bioregion (Figure 1). Refer to Henry and Lyle (2003) for calculations used to estimate recreational fishing participation and catch.

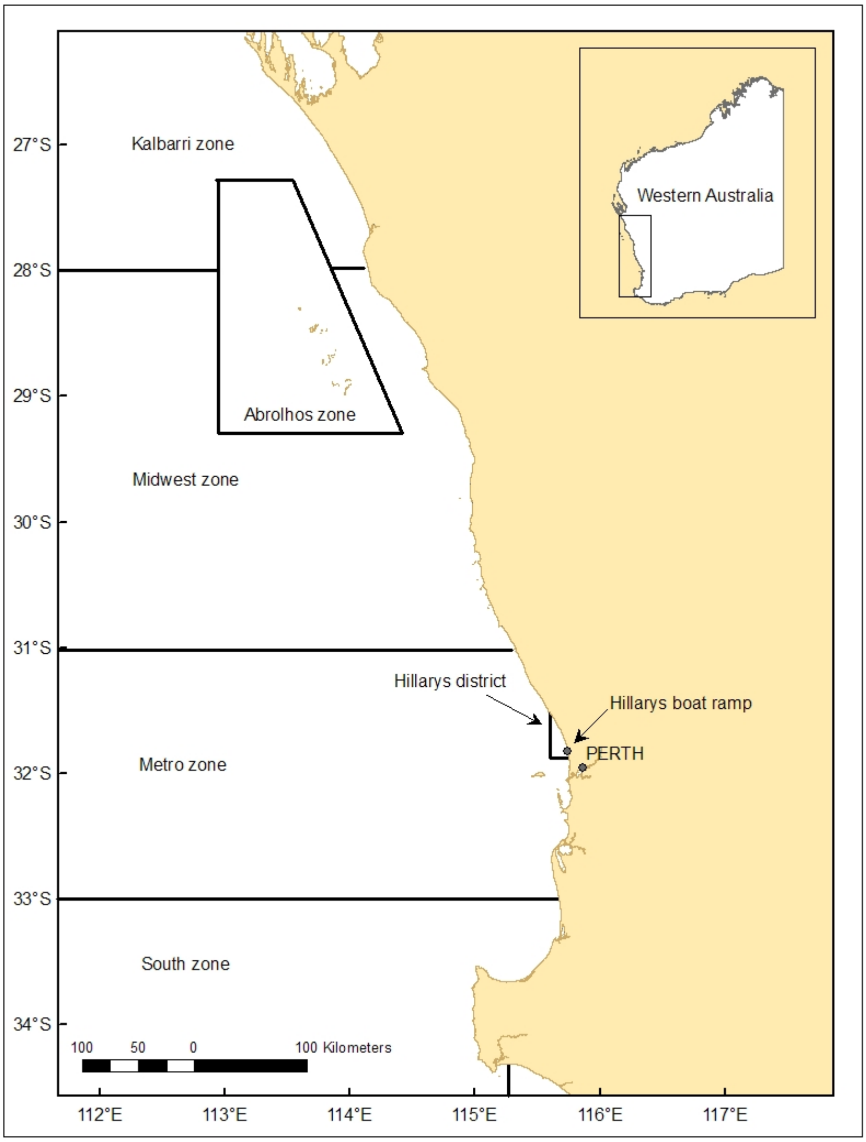

Figure 1: The West Coast Bioregion showing the Kalbarri, Abrolhos, Midwest, Metro and South zones, Hillarys district and Hillarys boat ramp.

Remote monitoring survey

From August 2005 to July 2006 a video camera was installed and monitored the Hillarys boat ramp (Figure 1), which is one of the busiest boat ramps in the metropolitan area. This video camera recorded activity on the boat ramp 24 hours a day for the 11 month period. Boat launch and retrieval times based on boat size categories (small <4 m, medium 4-6 m, large >6 m) were extracted by someone visually reviewing the captured video information. The extracted data was analysed to provide estimates of the number of launches and retrievals by month, season and time of day. Further analyses provided an estimate of total recreational fishing participation in boat hours for Hillarys boat ramp.

Fisheries and Marine Officers surveys

The Department of Fisheries, Fisheries and Marine Officers (FMOs) conduct ongoing routine marine and safety inspections in the field. In addition they record on an ad-hoc basis recreational fishing data. During these surveys the FMOs record the number of individuals interviewed, ascertain whether they are/will be fishing and the catch (if any) of the key species in a district based on the location of the inspection. The FMO survey data was analysis for the 12 month period between July 2005 and June 2006 for the Hillarys district (Figure 1) to calculate the number interviewed, the proportion fishing, catch and catch rate for dhufish and pink snapper.

Results

Creel survey

A total of 15,812 interviews were carried out at boat ramps in the West Coast Bioregion between July 2005 and June 2006. The majority of these were in the Metro zone followed by South, Midwest and Kalbarri zones (Table 1). Overall 82% of those interviewed were fishing the Kalbarri zone had the highest proportion fishing (Table 1). The total cost of the 12 month creel survey was approximately $350,000 including salaries and resources.

Table 1: Creel survey interviews carried out at boat ramps in the West Coast Bioregion between July 2005 and June 2006.

	West Coast	Kalbarri	Midwest	Metro	South
Interviews	15,812	692	2,409	10,397	2,314
Fishing	82%	91%	86%	81%	82%
Non-fishing	18%	9%	14%	19%	18%

Phone diary survey

A total of 55,354 registered boats reside in the West Coast Bioregion. A stratified random sample of 504 boats was taken and their owners interviewed by phone every month between July 2005 and June 2006. Overall there were 419 (83%) active boat owners/skippers interviewed during the survey, however, sample sizes in the Abrolhos and Kalbarri were very low (Table 2). Most boats were launched from boat ramps except in the Abrolhos and Midwest zones where a considerable number of boats launched from other locations including beach and moorings (Table 2). The total cost of the 12 month phone diary survey was approximately $85,000 including salaries and resources.

Table 2: Phone diary survey interviews of registered recreational boat owners carried in the West Coast Bioregion between July 2005 and June 2006. Boats launched from other locations including beach and moorings.

	West Coast	Kalbarri	Abrolhos	Midwest	Metro	South
Active boats	419	4	6	52	273	84
Launched from boat ramps	76%	100%	17%	58%	77%	86%
Launched from other locations	24%	0%	83%	42%	23%	14%

Comparison between the creel and phone diary surveys

The creel and phone diary surveys produce comparable estimates of recreational fishing participation, however a t-test indicated that all estimates are significantly different ($P<0.05$) between the two surveys (Table 3). The phone diary estimates of boat hours are lower than the creel survey estimates; in contrast the phone diary estimates of fisher hours are higher than the creel survey except in the South zone (Table 3). The standard error associated with the phone diary survey is much higher than the creel survey (Table 3).

Table 3: Creel and phone diary survey estimates for boat based recreational fishing participation rates on the West Coast Bioregion. SE is the standard error.

Bioregion	Survey	Boat hours	SE	Fisher hours	SE
West Coast	Creel	851,289	17,246	1,661,488	34,016
	Phone diary	744,861	52,014	1,962,748	299,791
Kalbarri	Creel	10,723	620	25,667	1,483
	Phone diary	4,969	2,226	11,154	5,675
Abrolhos	Phone diary	6,529	3,682	19,426	11,558
Midwest	Creel	113,275	6,165	212,720	11,578
	Phone diary	107,530	18,801	236,665	45,803
Metro	Creel	538,711	12,638	1,035,190	24,285
	Phone diary	443,438	33,275	1,264,786	247,318
South	Creel	188,579	9,965	371,455	19,628
	Phone diary	149,419	27,417	334,059	60,193

Fisheries and Marine Officers survey

Fisheries and Marine Officers (FMOs) carried out a total of 2,284 interviews in Hillarys district between July 2005 and June 2006. Overall 57% of individual on the boats interviewed had been or were fishing while another 18% were planning to go fishing, with the remaining 25% did not fish. A total of 36 dhufish and 10 pink snapper were caught between July 2005 and June 2006. The cost of ongoing surveys carried out by the FMOs is unknown as it forms part of their marine safety inspections but additional costs to the Department of Fisheries is assumed to be minimal.

Catch rate comparisons between the creel and Fisheries and Marine Officers surveys

Catch rates differ between the creel and FMO surveys where the creel survey provides substantially higher estimates (Table 4). However the FMO survey data could not distinguish between fishers that had been fishing and those that were currently fishing and thus these data provide underestimates of the catch and catch rate.

Table 4: Creel survey and Fisheries and Marine Officers (FMOs) survey catch rates for dhufish and pink snapper in the Hillarys district between July 2005 and June 2006. Released information is not collected by FMOs.

	Dhufish catch rate		Pink snapper catch rate	
	Kept	Released	Kept	Released
Creel (fish/hour)	0.016	0.017	0.011	0.022
Creel (fish/trip day)	0.076	0.081	0.056	0.105
FMOs (fish/trip day)	0.027		0.008	

Remote survey

The video camera monitoring of Hillarys boat ramp was carried out between August 2005 and June 2006. Overall there were 25,743 boats launched and 24,849 retrievals observed during this period with 90% of the time recorded (Table 5). Monitoring was occasionally interrupted due to camera problems/power failures (9.3%) or poor visibility (0.7%) as a result of the weather. The latter was not considered a threat to the accuracy of boat counts as bad weather results in nil or very limited boating activity.

The number of launches and retrievals were highest between December and April corresponding to the summer-autumn seasons, which includes the Christmas and Easter holidays (Figure 2). There were more medium sized boats (45%) compared to large boats (36%) with least number of small sized boats (19%) launched or retrieved (Table 5). Median launch times were between 8-9am while median retrievals occurred between 12pm and 2pm (Figure 3, Table 5). Launch times were earliest in summer and latest in winter (Figure 4). Retrieval times were bimodal in summer and autumn corresponding to the rock lobster season with many fishers returning early after catching their bag limit of lobsters (Figure 4).

The approximate cost of the remote survey over 12 months was $20,000 for initial setup such as the camera, computers and networking and $15,000 costs for salaries and ongoing monthly costs such as internet access.

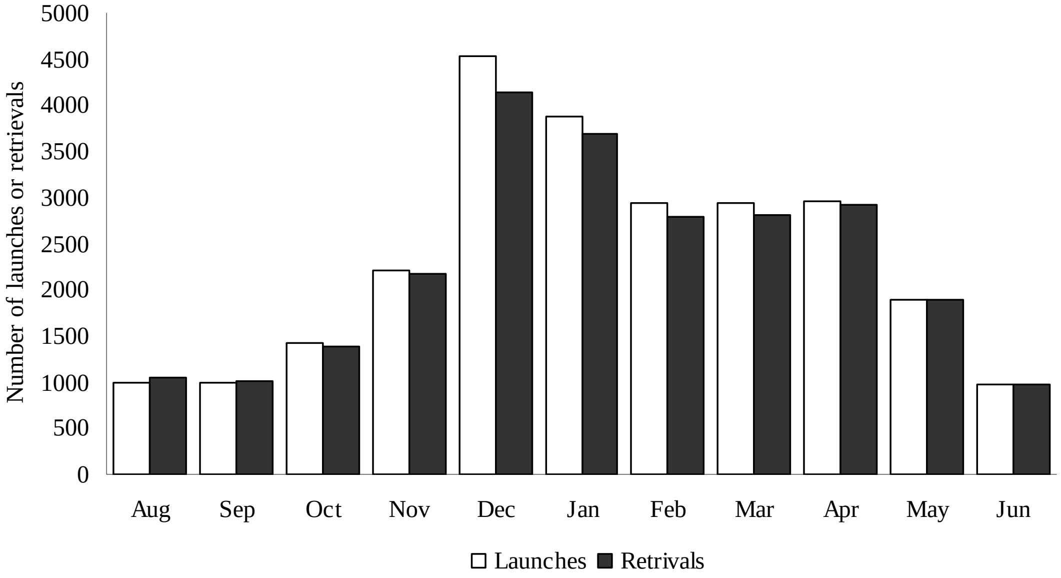

Figure 2: Monthly number of launches and retrievals counted at Hillarys boat ramp from August 2005 to June 2006.

Table 5: Launches and retrievals monitored at the Hillarys boat ramp from August 2005 to July 2006.

	Small boats	Medium boats	Large boats	Total
Number of launches	4,812	11,439	9,492	25,743
Number of retrievals	4,677	11,548	8,624	24,849
Median launch times	8:29am	8:14am	8:51am	
Median retrieval times	12:06pm	12:26pm	1:24pm	
Difference between median launch and retrieval times	3.62 hours	4.20 hours	4.55 hours	
Boat hours based on number of retrievals	16,931	48,502	39,239	104,672

Comparison between the creel and remote surveys

The total recreational fishing participation estimated for the Hillarys district by the creel survey was 156,772 (SE=7,801) boat hours with 81,210 (SE=4,526) boat hours from Hillarys boat ramp. The estimated average time boats spent fishing from the creel survey was 4 hours for both the Hillarys district and Hillarys boat ramp, and was similar to that estimated (3.62-4.55 hours) in the remote survey (Table 5).

After allowing for 8.6% of time that was missing (camera problems/power failure and nil data for July 2005) for the equivalent 12 month period between July 2005 and August 2006 the total boats hours estimated from the remote survey was 113,673 (Table 5). Using information from FMO and creel surveys for Hillarys district estimates of boats actually involved in recreational fishing were 75% and 82% respectively. Applying these to the remote survey, the estimates of recreational fishing participation ranged between 78,504 and 85,853 boat hours, which was similar to that estimated in the creel survey (81,210 boat hours) for Hillarys boat ramp.

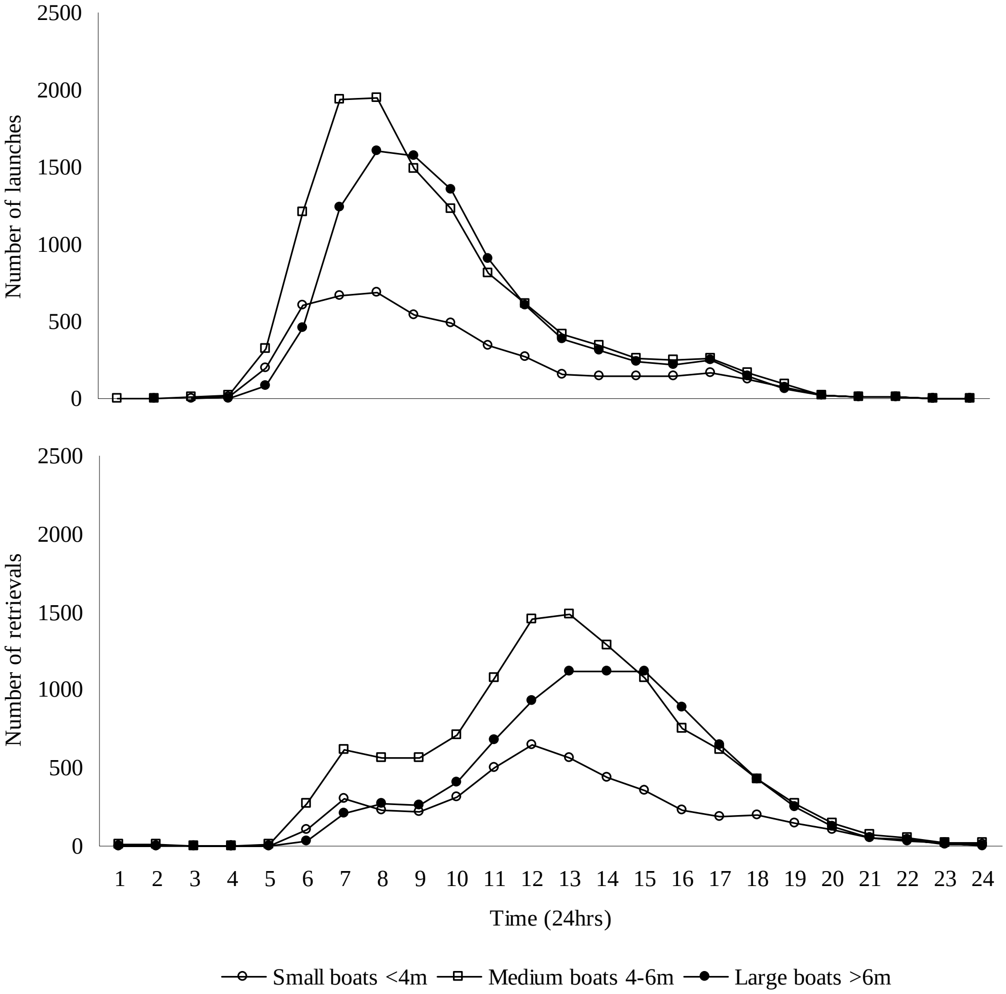

Figure 3: Number of launches and retrievals by boat size at Hillarys boat ramp between August 2005 and June 2006.

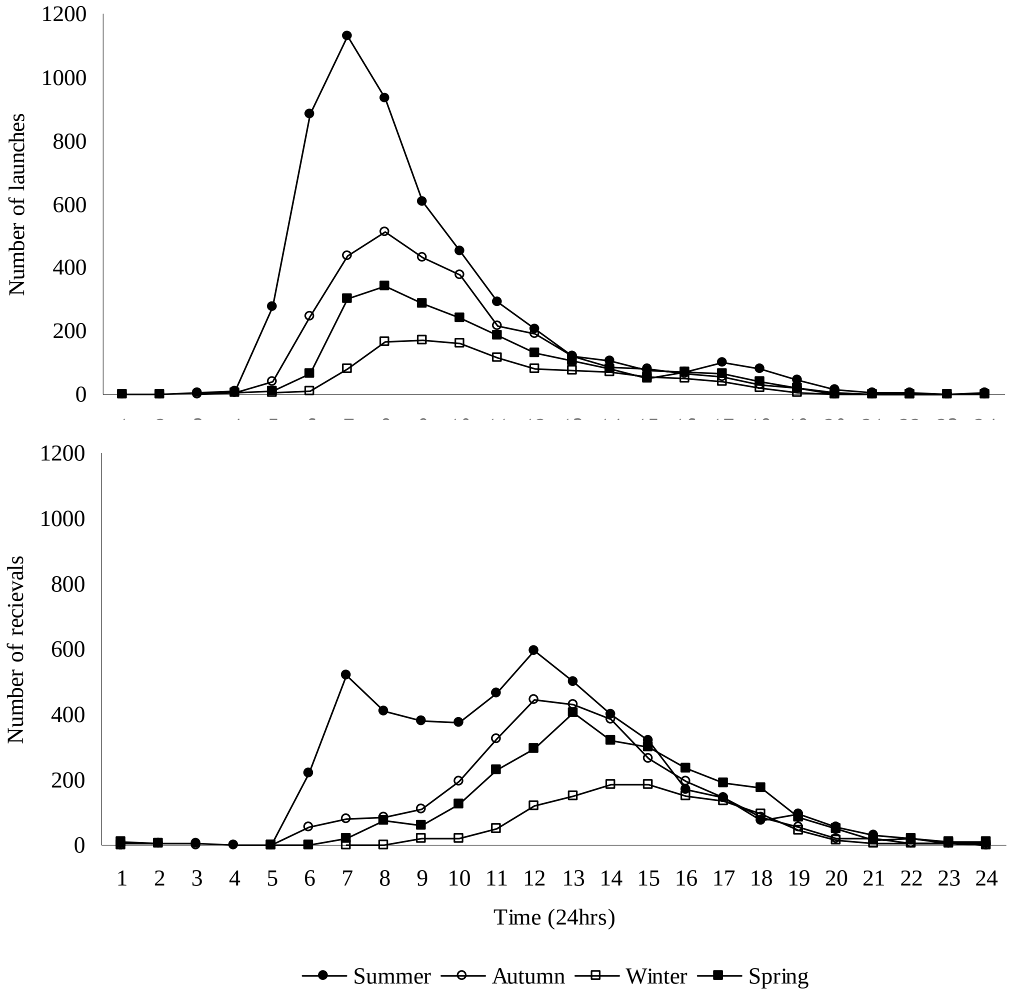

Figure 4: Number of launches and retrievals of medium sized boats by season at Hillarys boat ramp between August 2005 and June 2006.

Discussion

Understanding the relative accuracy and precision of standard and innovative approaches for estimating recreational fishing participation, catch and catch rates, together with their relative costs, benefits, limitations and interactions is essential for the development of the most appropriate, cost effective ongoing monitoring scheme for the recreational sector in Western Australia.

To determine what may constitute a cost effective approach for ongoing monitoring of recreational fishing participation and catch rates in the West Coast Bioregion a creel survey, phone diary survey, remote survey and Fisheries and Marine Officers (FMOs) survey were compared during the same time period between July 2005 and June 2006.

The creel survey, while the most expensive method, provides more precise estimates of recreational fishing participation and catch rates for districts, zones and the whole bioregion. The bus route method is not designed to provide estimates at individual boat ramps. Since the method is based on face to face interviews the cost inhibits the ability to cover the 24 hour period per day for an entire year. Another limitation of this creel survey was that it only estimates fishing from boats launched from boat ramps and access points surveyed.

A less expensive phone diary survey provides a comprehensive fishing data for a sample of fishers. Phone surveys rely on the fisher to remember when and what they caught and while the diary improves their recall ability the method may still be subject to recall bias or under reporting. The approach also relies on the fisher to correctly report time spent fishing, the fish species and number caught. In addition the sample size is limited by cost and as a consequence the standard errors are large as demonstrated by the estimated recreational fishing participation in the West Coast Bioregion and each of the zones compared to the creel survey. However this method estimates all boat based fishing regardless of where the boat was launched or moored.

The FMO survey provides limited information on catch rates as the survey is part of a larger routine marine and safety inspections. In addition as a consequence of the compliance focus the interviews are usually localised to areas such as marine protected areas and carried out on an ad hoc basis rather than a random survey design. The impact of these limitations resulted in lower recreational fishing participation and catch rate estimates compared to the creel survey. Given that this information is gathered with negligible additional costs and that these interviews are ongoing state-wide, with small improvements over time it is hoped this data will provide better information on catch rates. Moreover, this survey provides estimates from all boats launched or moored and provide ‘true’ catches as the FMOs have the authority to conduct searches of the boat unlike creel survey interviewers.

Remote surveys using video cameras provide very detailed information of launches and retrievals over the entire year at individual boat ramps. When comparing the remote survey with the creel survey the estimated average time boats spent fishing and the estimated total boat hours involved in fishing was similar. The initial setup costs of the survey are considerable however ongoing costs are relatively low and may possibly be reduced further through automation using digital recognition of registration numbers as boats are being launched and retrieved. Currently the limitation is the intensive data extraction from the video and costs rise rapidly as more ramps are monitored. This information only provides boat ramp usage and would need to supplement with catch rates from another approach. However the remote survey provides useful information for designing future creel and FMO surveys.

Other alternative approaches have been investigated including traffic counters, trailer counts and parking tickets/fines for trailers, however these approaches proved problematic. Traffic counters provide numbers of axels however there is a requirement to discriminate between vehicles with trailers and those without. Counts of boat trailer in car parks provide some indication of boats on the water however during peak times car parks overflow and many boats were launched and the vehicle and trailer returned home. The ticketing, issuing of fines and seasonal pass data collected by local government officers (e.g. Hillarys boat ramp car park) was problematic as the total number of users and how regular the seasonal pass users visited the boat ramp could not be calculated.

In addition, catch rate information comes from alternative resources such as Department of Fisheries Volunteer Fisheries Liaison Officers (VFLOs) who interview mainly shore-based recreational fishers, and also a recreational angling program (RAP) which provides voluntary anglers logbooks to recreational fishers and fishing clubs.

Further analysis of the data aimed at integrating the various approaches is underway to determine what might constitute a cost effective ongoing monitoring scheme for the recreational sector in Western Australia. Each approach has its advantages and limitations and all become very costly when used as an intensive survey method for the entire West Coast Bioregion. Whilst there is little doubt that an intensive survey method will need to be completed at periodic (e.g. five year) intervals, having information at a lower precision between these intervals (i.e. annually) to provide an indication of whether recreational fishing participation and catches are remaining steady, increasing or declining, will be of great benefit for the effective management of recreational fisheries.

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Vessel Monitoring System (VMS) data: a cost effective alternate to logbook data

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Abstract

Western Australia fisheries in general consist of valuable invertebrate fisheries but small low productivity scalefish fisheries. In the largest invertebrate fishery for western rock lobster, an estimate of the temporal and spatial distribution of retained and discarded lobsters is required. This necessitates a logbook programme. In the prawn fishery, detailed spatial and temporal information on the productive areas and breeding grounds is required for maximising the yield. This requires detailed logbook information to be collected initially, with possibly scaling down data collection after 3-4 years. In less valuable fisheries, the expense of maintaining a logbook may be justified where it is the mechanism for reporting the temporal and spatial distribution of captures of protected species (e.g. Pilbara Trawl Fishery) or where the operators fish over extensive areas each trip (e.g. mackerel fishery). In addition, on occasions decisions are made to introduce logbooks without the costs and benefits being analysed. Small fisheries in WA, where trips are short duration and the vessels range over a small area each trip, could be managed using VMS polling and trip unloads. Two fisheries are examined to determine the cost savings and the resolution of the catch and effort using this method rather than logbooks.

Introduction.

When deciding on a monitoring programme, I feel that too often the decision is made to introduce a shot-by-shot or daily session logbook without due consideration of the benefits and shortcomings of such a decision. The reasons for introducing a system with the maximum detail may be justified or may be made on the basis that more detail must be better.

The theme of this paper is that careful consideration should be given to current management arrangements, the spatial scale of the stocks, the scale of data needed for stock assessments, together with the current and anticipated future needs for information necessary to make decisions on the effects of fishing on the ecosystem, introduction of marine protected areas, spatial or temporal closures, location of spawning aggregations, and location of nursery areas.

Once these deliberations have concluded, funds need to be secured for additional costs if more detailed data collection is considered necessary. These costs could derive from data entry, modifying exiting databases or building a new database, data entry, costs of adjusting the data to unloaded catches or processors data, increased analysis, contact with industry to ensure data quality and timely data transfer is maintained over time. Only after these deliberations should the decision be made to shift to a more detailed monitoring data collection regime.

In Western Australia, in the 1980’s, licence holders generally reported catches in the form of statuary monthly catch and effort returns with a spatial resolution of 60 by 60 nautical miles. This had been satisfactory in the past for generating reports to Bureau of Rural Resources, Australian Bureau of Statistics, and local government agencies and Department of Fisheries reports to Parliament. Since then, smaller blocks have been introduced for areas of interest (e.g. estuaries) and logbooks have been introduced in some fisheries to make the spatial scale of the data match the assessment requirements.

In this paper, I will consider three fisheries and discuss the reasons for the introduction of more detailed data collection.

Methods of data collection.

When data is reported on monthly returns, typically the fisher will fish in multiple 1^o blocks but will not report the catch in every block fished. Consequently the catch is apportioned evenly among the blocks. Thus the spatial resolution is not even at a resolution of 1^o by 1^o. A sensible refinement would be to divide the catch between blocks in accordance with the known spatial distribution of the species (Watson and Kitchingman 2006), but this is a task for the future.

The trip duration in several fisheries is weekly. If the catch is reported on this scale, immediately the spatial and temporal resolution of the data is improved simply because they fish in fewer blocks per trip than per month.

Many fisheries in Western Australia have a Vessel Monitoring System (VMS) used by the compliance division to monitor closed areas and seasons. The hourly pollings of the vessel give detailed information of the location of the vessel and consequently the effort of each vessel is available. In addition, if the vessels fish in a confined area each trip, the unloaded catch can be allocated to each polling position to give a more reliable spatial distribution of the catch.

Vessels without VMS where the vessel ranges over a wide area each trip will need to rely on monthly or trip catch returns or change to paper logbooks. If these vessels take on a VMS then there is the potential to change to e-logbooks, where the skipper fills in the catches on an electronic form which is transferred to the Department of Fisheries via satellite, or more cheaply via wireless and email when the vessel comes to port.

The Spanish Mackerel Fishery in the Kimberly.

One licence holder in the Kimberly Spanish Mackerel Fishery indicated on a chart the ground he covered in a 17 day trip in 2004. He commenced fishing off Broome and travelled north for 17 days fishing (Figure 1).

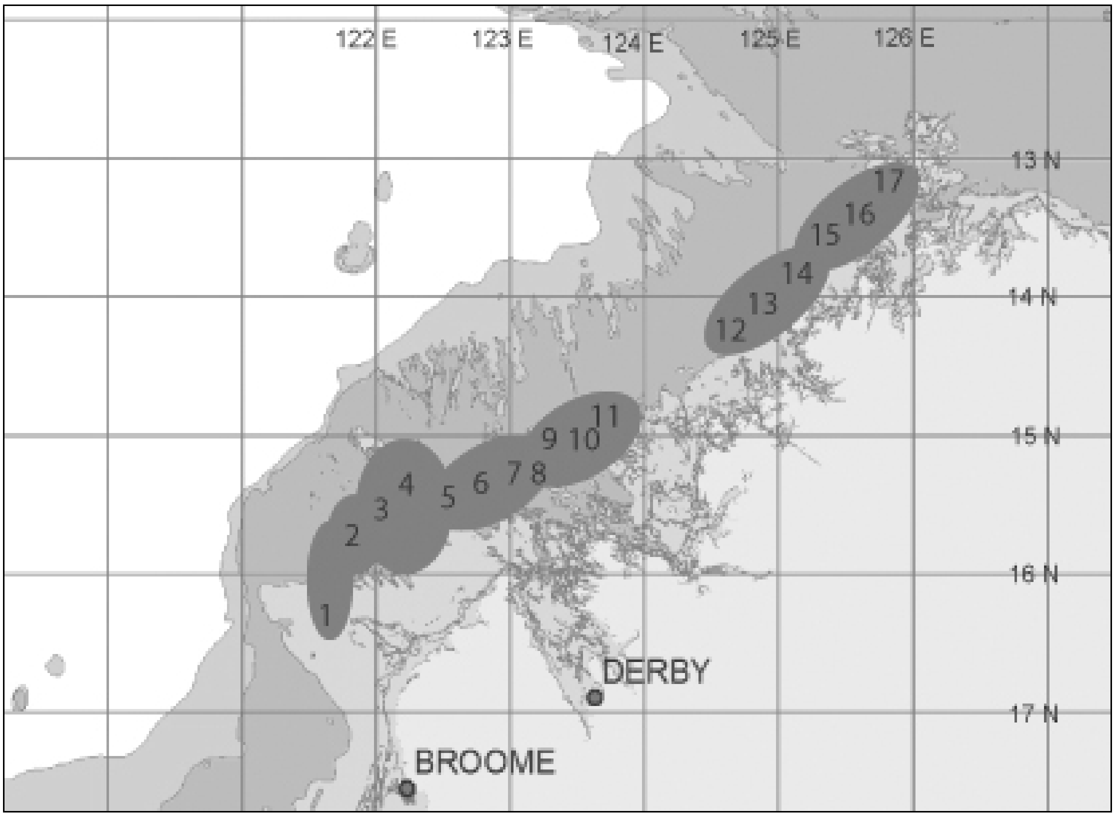

Figure 1: Distribution of effort for one trip by a single operator in the Kimberly Spanish mackerel fishery in 2004. The ellipses bound the fishing locations for each of the numbered days of the trip from day 1 to day 17.

In 2007, VMS will commence for all vessels in this fishery. If the unloaded catch for this trip is distributed across the pollings, the result will be little better than distributing the catch across the eight 1^o by 1^o blocks.

In this fishery, the current poor spatial resolution of catch data could not be improved by VMS so logbooks were introduced with the fisher required to record the catch for each session each day. In 2007, the effort distribution can be confirmed from the VMS pollings.

Pilbara Trawl Fishery.

This fishery extends from 116°E to 120°E (shaded polygon in Figure 2) being a subset of the Pilbara trap and line fishery which extends from 114°10' to 120°E (unshaded polygon in Figure 2). The Pilbara Trawl Fishery came under new management arrangements in 1998 with effort being allocated to each licence holder in management areas 1, 2, 4, and 5 shown in Figure 2. Area 3 was closed to fishing to reduce the fishing mortality on some long-lived species and Area 6 is a research only area that has not been trawled since 1998. A VMS was used to determine the effort used in each management area.

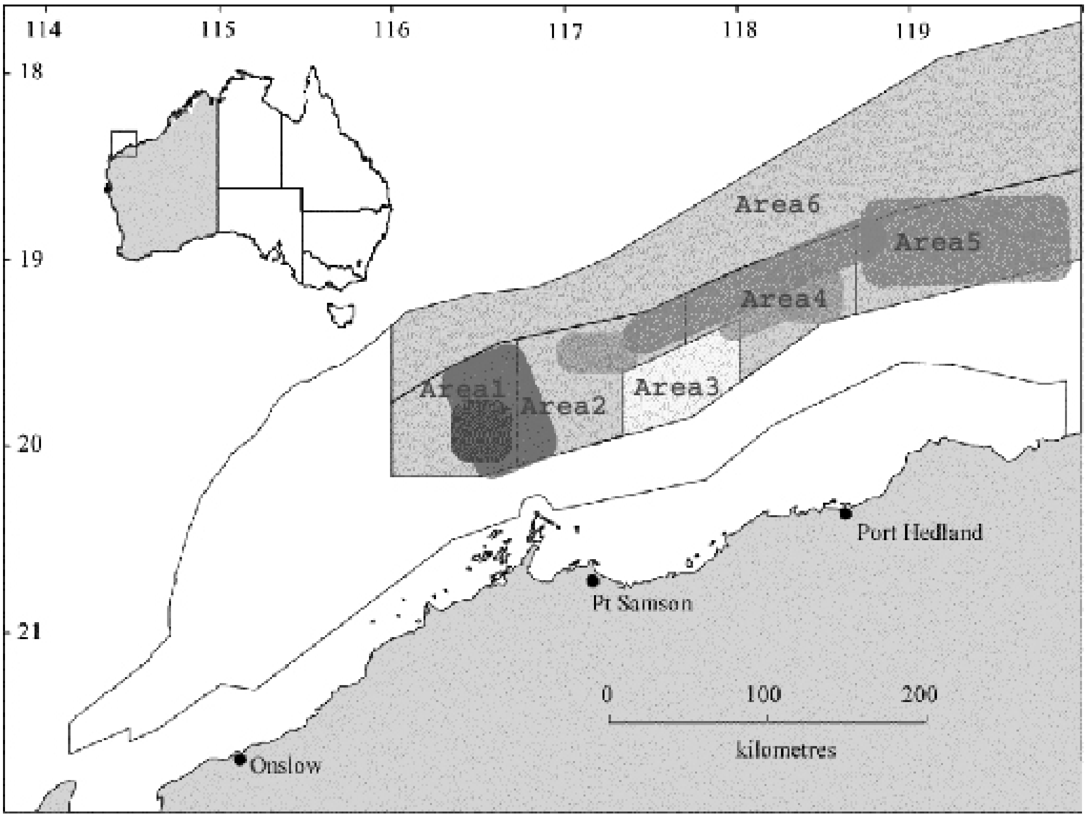

Figure 2: The shaded areas 1 to 6 between 116°E and 120°E are the management areas of the Pilbara Trawl Fishery. The rounded rectangles show the distribution of effort of one vessel in this fishery from four separate trips in one month.

The fishers trawl over a wide area each trip. An example of the distribution of effort by one vessel in a month, determined from VMS pollings, is shown by rounded rectangles of different shades in Figure 2. Of the four trips for the month shown, only one was confined to one management area (Area 1). Two trips extended over two management areas, and one trip extended over 3 management areas. The assessment models used to determine stock status require inputs of catch from each management area in order to adjust the effort in each area, if necessary. If the catch data is determined from trip landings and the effort from VMS, the resolution will be insufficient for the currently required model inputs.

Consequently the skippers' logbook system continues in this fishery whereby the skippers' estimate of the shot catch for each species is cumulated for the trip and multiplied up to the unloaded catch of that species.

Northern Demersal Scalefish Fishery

This trap fishery has effort allocated to each licence holder with no restriction on where the operator fishes. The effort used by each fisher is determined with VMS. The distribution of effort (from VMS pollings) for 11 trips on various vessels in 2005 is shown in Figure 4. Each trip the fishers work in a very restricted area. If the trip unload catch is distributed amongst the 1 hourly VMS pollings, the spatial resolution of the data is about 0.2^o by 0.2^o.

In the past, vessels have fished in the area of the old coastline approximating the 100 m depth contour (shown in grey in Figure 3). Recently there has been a shift into shallower water by some operators and there is potential for the fleet to move into deeper water, especially if catch rates decline in the area currently being fished. The species catch in these new areas needs to be monitored in the future to determine changes in catch rates.

In this fishery, logbook data is not required from the skippers because, with the current pattern of fishing small areas each trip, the unload catch together with VMS pollings will give sufficient data resolution to manage the fishery.

The Pilbara Trap Fishery operates in a similar manner, with the area covered in each weekly trip being small (about 0.2^o by 0.2^o). As with Northern Demersal Scalefish Fishery, trip unloads are allocated to VMS pollings to determine the spatial distribution of catch in the Pilbara Trap Fishery.

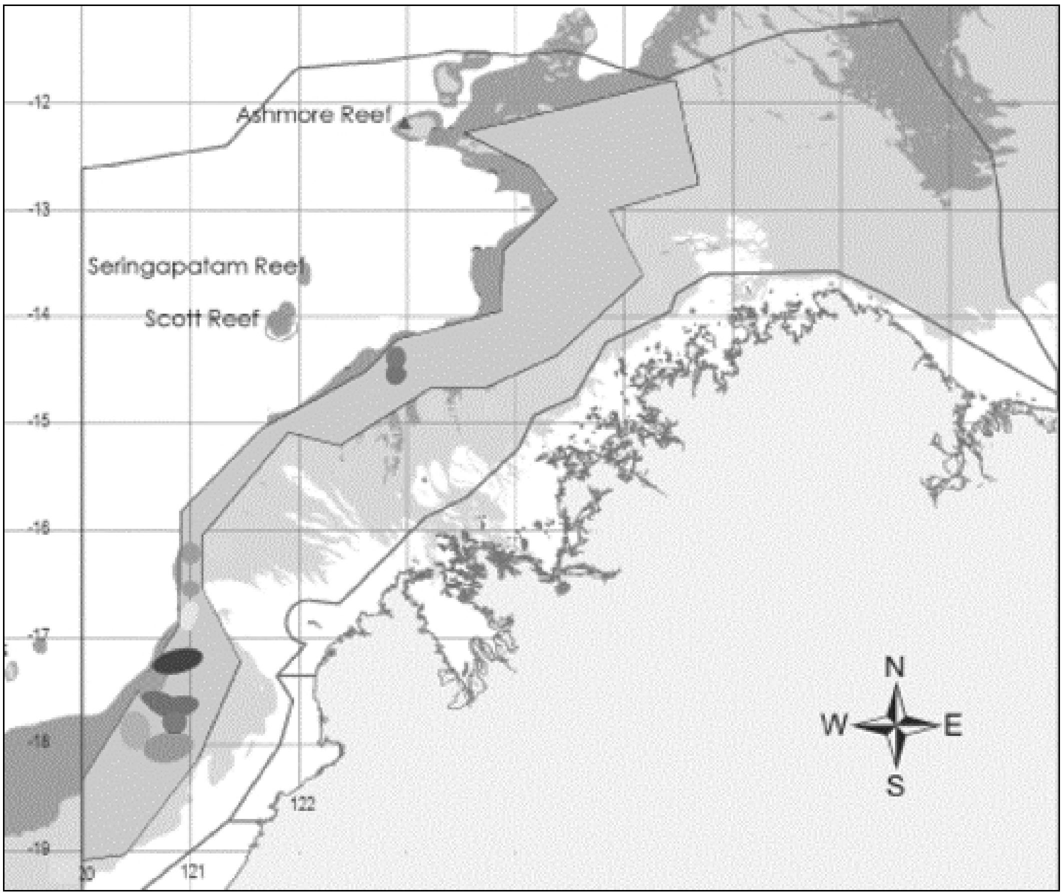

Figure 3: The large polygon is the boundary of the Northern Demersal Scalefish Fishery (provided by Stephen Newman, Department of Fisheries WA) with the current fished area shown as a shaded polygon. The area fished in each of 11 weekly trips, determined from VMS pollings are shown as ellipses, 9 close to 121^{o}E and two south-east of Scott Reef.

Conclusion

In some fisheries, shot-by-shot or session logbook data is required from fishers so that the catch and effort data has sufficient resolution to detect localized depletion. However, where VMS is used to manage the fishery, there is potential for significant cost savings by using trip unloads in conjunction with VMS pollings, provided the resulting resolution of the data meets the needs of management. The Pilbara Trap Fishery and the Northern Demersal Scalefish Fishery both operate with this mode of data collection.

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Electronic data capture in abalone fisheries: facing up to reality

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Abstract

Data concerning fishing activity in the Tasmanian abalone fishery has primarily been captured as a component of the fisheries management and fishing license and compliance process. As a consequence the type and accuracy of data, and scale at which fishing effort is reported is limited by that process. In 2004, we recognised that the limiting factor in assessment of the Tasmanian abalone fishery using CPUE data was not that CPUE is a poor measure of fishery performance as is widely stated, but a limitation due to the scale and quality of the data collected. Despite the concerns, nothing much as changed in terms of scale and accuracy of reporting in the 20 years since the quota system was introduced in Tasmania. It seems the problem is not the ‘tyranny of scale’ but the tyranny of inertia. At TAFI, by practical application of new technology and the assistance of both DPIW managers and abalone industry members, we have set about developing a new process for collecting the data on fishing activity at the scale and quality we desire, to achieve a more precise assessment of our fishery. This is a big change, and requires a cultural shift in a large part of the industry, as well as managers and researchers. Nearly two years on from the germination of the original idea, the concept is still alive and improvements continually made. Rather than inertia we now have momentum, but will it last?

Key Words: Abalone, GPS, data logger, catch, effort

Introduction

Catch and effort indices are widely used as an indicator of stock abundance or for assessing fishery performance. Although CPUE data are considered an unreliable estimate of abalone abundance (Karpov *et al* 2000), the use of CPUE for abalone stock assessment persists because fishery independent estimates of abundance are logistically difficult and considerably more expensive to obtain. The dominant view for highly structured fisheries such as abalone is that the only solution is to empower the divers with the skills to assess and manage fisheries on a reef by reef basis (Prince 2003).

The adequacy of CPUE as a proxy for stock abundance is dependent firstly on the type of relationship between CPUE and stock abundance (assuming there is one), and secondly on the quality and spatial resolution of the catch and effort components. There is little robust data on the relationship between CPUE and stock abundance for any fishery, but is unlikely to be linear over the full range of stock levels and requires further research for abalone fisheries. Data quality and spatial resolution of fishery dependent data is however, readily addressed with currently available technology, and is the focus of this project.

The issue of quality of the fishery dependent catch and effort data while acknowledged is rarely the focus of research. The poor quality of CPUE data in abalone fisheries is due to two primary issues. The first and most important is that the scale at which fishing effort is reported (block, map code etc) is much larger than the area fished by a diver on a given day (reporting at 1 – 10 kms vs. fishing at100’s of metres). The mismatch between scale of unit stocks and scale of data collection on fishing effort is recognised as a key management weakness for most fisheries (Hilborn et. al 2005). The second issue relates to quality of CPUE data and that catch and/or effort are rarely recorded accurately. In Australian abalone fisheries it is normal practice to obtain an accurate weight of each divers catch. The effort recorded however is estimated, and may vary from the true effort by as much as 25% (Mundy unpub. data). Consequently CPUE data in abalone fisheries are likely to provide a fuzzy picture of stock trends, and mask the onset of declines in fishery performance or stock abundance. CPUE data also fail to incorporate spatial components of the diving/fishing process, and are ineffective at capturing changes in diver behaviour which may precede changes in CPUE when stocks are spatially structured.

The objectives of the TAFI E-data project are to improve the quality and spatial resolution of catch and effort data in the Tasmanian Abalone Fishery using GPS receivers connected to data loggers, and automatic time/depth/temperature recorder (DTR). A number of Tasmanian abalone divers have been assisting TAFI with this project since 2004.

Methods

Spatial resolution of fishing event

In order to improve the quality and spatial resolution of the dive event data, a GPS data logger unit is attached to the abalone diver's catching vessel. In Tasmania, most divers work either from small aluminium dinghies without onboard power (approximately 5m length), or from larger vessels such as Shark Cats. For this reason, the GPS loggers (SciElex GPS data logger) needed to have a small footprint with minimal power requirements. The GPS data logger records standard NMEA data including latitude, longitude, date, time, and vessel speed at 10 second intervals. Capacity of the data logger is approximately 10^6 records (Figure 1).

Increasing quality of effort data

The current approach to recording effort in all Australian abalone fisheries, is by estimation of hours (daily total) spent diving. Many divers wear dive computers, and some use the logbook function of the dive computer to assist with calculation of hours dived. In order to automate this process, a small depth/time recorder (Sensus Ultra – www.reefnet.ca) that commences recording automatically when the diver enters the water and stops recording on exit was attached to the divers harness. The Sensus Ultra stores depth, temperature, date and time at 10 second intervals for the duration of the dive, and can store 1500 hours of diving data (Figure 1).

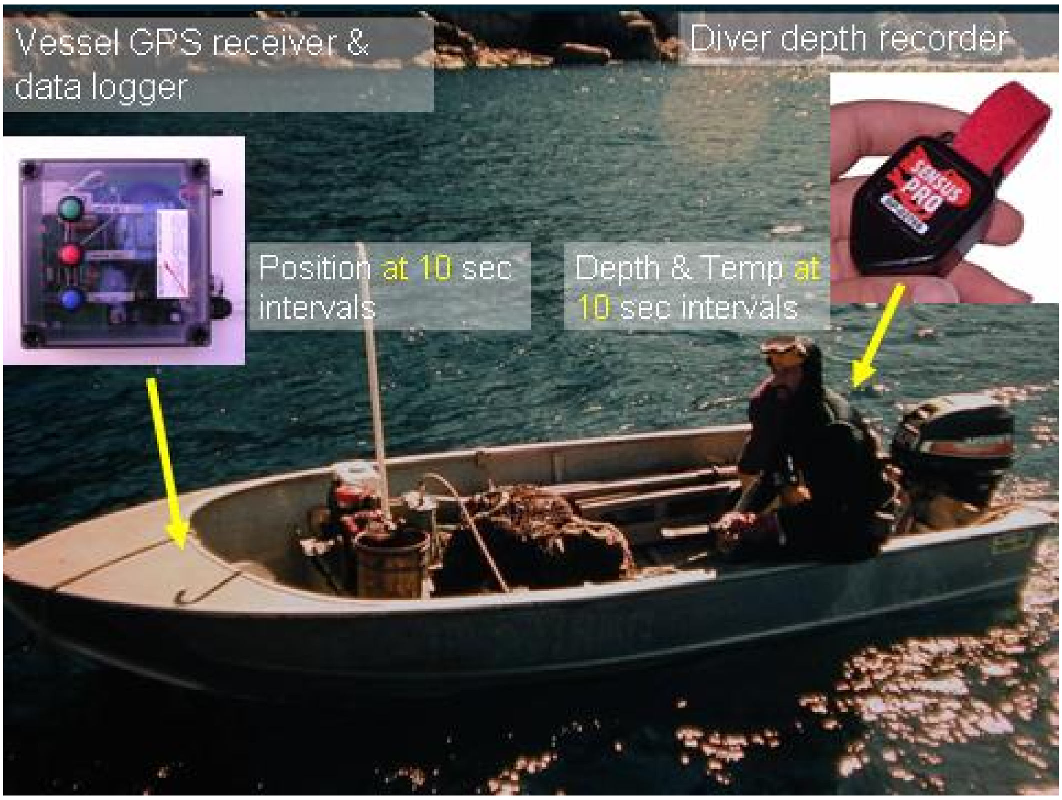

Figure1: Electronic data collection system for Tasmanian abalone divers.

Results and Discussion

Electronic data capture: can it work

The combined GPS data logger and depth/temperature/time logger approach to recording fishing activity at high resolution has proven to be very effective. By mapping the depth data onto the GPS position data, the location of the catcher vessel is recorded at a high level of accuracy, with minimal imposition on the diver/deckhand team. The data are amenable to a broad range of spatial analysis with GIS software. This expands the opportunity to derive valuable additional information from fisheries dependent data that was not previously possible.

A comparison between effort data captured electronically and effort data recorded through traditional paper docket records highlights the scale of inaccuracy of recording of effort, and the variation in accuracy of recording among divers (Figure 2). The level of variation in effort recoding among and within divers further emphasises the need for a standard, accurate effort capture system.

In addition to accurate recording of total daily effort, the depth/time data logger approach accurately records the number of dives per day, and allows researchers to calculate additional parameters such as fishing effort within particular depth bands. The ability to dissect effort data in this way enables researchers to track local changes in the way divers are accessing stocks. For example the depletion of shallow water populations of abalone has been alluded to at King Island for some years, although CPUE has remained unchanged as divers move into deeper water.

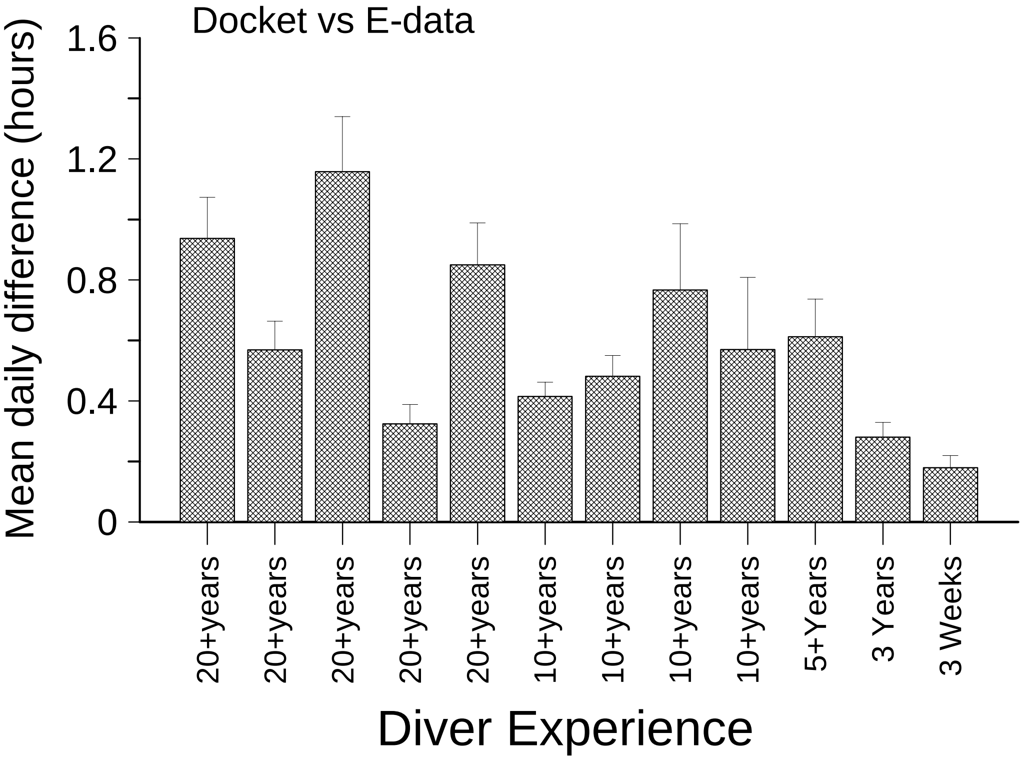

Figure 2: Comparison between daily effort (hours) recorded by the automatic Sensus depth data logger and the effort (hours) recorded on the divers official catch docket. Data are the average of the absolute difference in hours between depth and docket data.

The electronic data capture approach in abalone dive fisheries using GPS data loggers allows fishery dependent data to be focused on each dive event. For each dive event, there are a number of unique parameters – date, time, diver, location, area fished, effort, depth, catch, and habitat type (Figure 3). However, in most dive based fisheries, fishery dependent data (catch, effort, location) is recorded on a daily basis, with data from multiple locations pooled for each day and consequently a loss of information. For example, a common approach by Tasmanian abalone divers is to fish initially in deeper water and then shift into shallow water later in the day to avoid decompression issues. Under standard fisheries dependent data capture approaches based on daily reporting any variation in stock abundance, spatial location and ease of fishing associated with these practices is lost. The electronic data capture approach developed for the Tasmanian abalone fishery enables researchers to easily capture data and derive parameters for each dive-event. Dive event data enables researchers to undertake more robust analyses of data, and to calculate meaningful performance indicators.

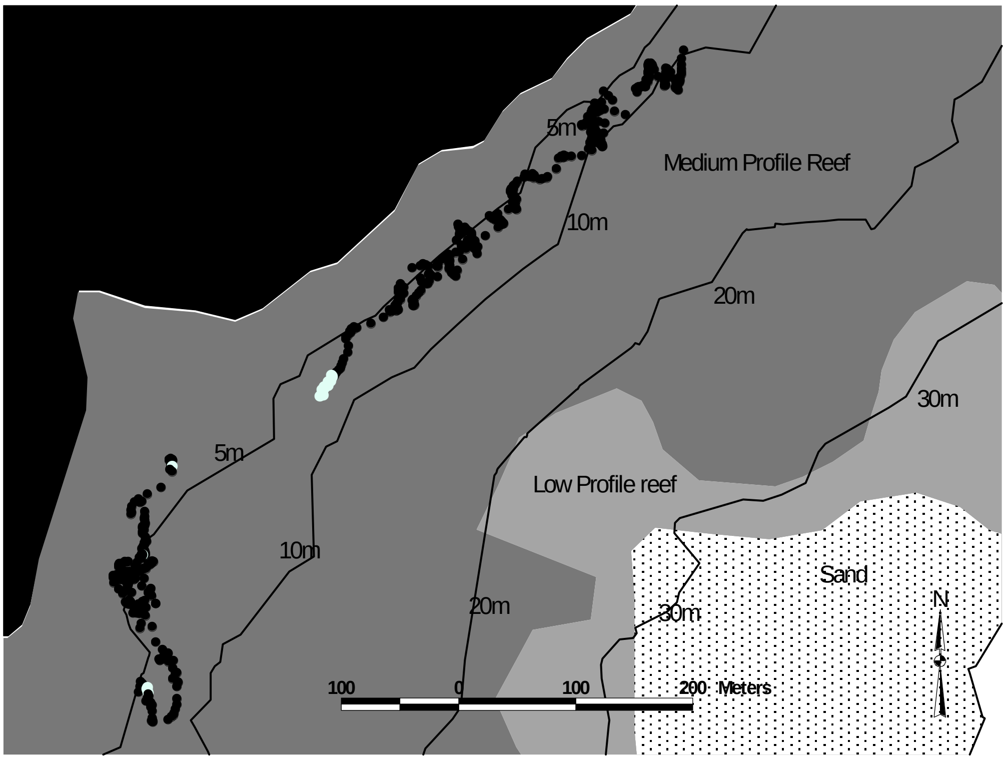

Figure 3: Example of detailed data obtained from the GPS data logger placed on the abalone divers vessel. Black dots indicate path of abalone divers vessel during dive events. Three habitat types are evident – Medium profile reef, Low profile reef and Sand. Note that the dive was entirely within medium profile reef, in the 5m to 10m band, and the area fished can be identified at a very fine scale in comparison to that possible with a traditional effort reporting system.

The challenges ahead

There are several technical and cultural challenges involved in adopting an electronic fishery dependent data collection system. The key technical challenges include a redesigning of research database systems to allow a shift to a dive event based data capture process, and the ability to handle and process enormous amounts of data on an annual basis. In 2006, the total effort required to catch the Tasmanian abalone TAC was 26,139 dive hours. If all of this effort was recorded with depth and GPS loggers, each data set (GPS and depth) would contain in excess of 9.5 million records. In comparison, the total record set for 2006 in the current fishery dependent data capture system is 6,669. The cultural challenges are predominantly associated with adoption of electronic recording by the abalone divers, specifically, the high resolution information provided by the GPS units. Many divers have expressed concern about how we will use the information, and who will have access to the data. For some divers, it is access to the information by other divers that is of concern, while for others it is the fear that the data will be used by Government, or by researchers to make changes without understanding spatial variability in the structure of stocks. This requires a high level of responsibility by the research provider to ensure confidentiality is maintained at all times, but also to provide feedback and demonstration of the benefits of the data to the catching sector. This is a key challenge, as new initiatives require demonstration of benefit, both to stakeholders and funding agencies in order to gain wider acceptance.

The primary benefit of the electronic data capture process described here is for stock assessment and research, but not compliance. Convincing the catching sector that access to this information will benefit divers in the long term, and that the e-data approach is not designed or destined to function as a compliance tool is also an important component of diver acceptance of new technology involving GPS.

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Turning video into information

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Abstract

Video can be a relatively low impact and effective tool for collecting fisheries-related information. As more studies employ video data, it is essential to have an efficient system for managing the ensuing hundreds or thousands of hours of video and the associated video annotation information. Video Annotation and Reference System (VARS) is a working example of a system for managing large amounts of video data.

The Monterey Bay Aquarium Research Institute (MBARI) uses high-resolution video equipment to record over 300 remotely operated vehicle (ROV) dives per year. Over the past sixteen years, 16,000 videotapes (equates to over 13,500 hours) have been archived and managed as a centralized institutional resource. MBARI has developed a custom software and hardware system, VARS, to facilitate the creation, storage, and retrieval of video annotations based on ROV dive tapes. The VARS components reference a knowledge database of over 3500 biological, geological and technical terms. This hierarchical information allows for consistent and rapid classification, description, and complex querying of objects observed on video. MBARI currently has over 1.8 million annotations stored in the VARS system. These annotations have been used in over 200 professional publications and presentations, in addition to numerous education and outreach projects. These publications span multiple sub-disciplines within biology, geology and chemistry.

An operational VARS suite consists of a relational database, a videotape recorder (VTR) that supports the Sony 9-pin protocol over RS-422, and the three VARS applications: Knowledgebase, Annotation, and Query. The relational database is used as a centralized repository for storing the knowledgebase data and annotations. Each VARS application is responsible for different aspects of the information stored in the database. The Knowledgebase application is used for managing the controlled vocabulary for creating and searching for annotations. Annotations and images captured from the video are added to the relational database through the Annotation application. The Query application provides simple, convenient access to the annotations, video images, and related ancillary data.

VARS was expressly designed so that other institutions could easily adopt it and in 2005 was released as open-source software. This presentation will give an overview of the capabilities of the VARS system and showcase examples of video analyses that could be applied to fisheries research. More information about VARS as well as a VARS demonstration application can be obtained at http://vars.sourceforge.net.

Keywords: video, annotation, knowledgebase, software

Introduction

As technologies have improved and the costs of deploying systems capable of collecting underwater video have declined, video has become a common method for data acquisition in ocean sciences. For example, a search on Google Scholar (Google 2005) for ‘video fish’ returns over 46,000 references. Video has a number of appealing qualities as a tool for collecting fisheries data; most notably, it is a non-destructive method for assessing both target and non-target species in fisheries (Harvey and Cappo 2000). It is also a very effective tool for communicating complex information to researchers, policy makers and the general public. Video does have some drawbacks; one of which is that, if a video collection grows beyond a certain size, locating events or objects of interest becomes a challenge. One technique for managing a video collection is to create video *annotations.* A video annotation is primarily composed of three pieces of information: a reference to the video source, an index to locate an object in the video source and a description of the object of interest. Most video is currently recorded onto videotapes, so the video source is a unique identifier for a particular videotape; the index is typically a time code.

The Monterey Bay Aquarium Research Institute (MBARI) uses high-resolution video equipment to record over 300 remotely operated vehicle (ROV) dives per year. More than 16,000 videotapes (equates to over 13,500 hours) have been archived and managed as a centralized institutional resource since 1989. MBARI's mission emphasizes a peer relationship between engineers and scientist. Through this relationship, MBARI has developed a software system, Video Annotation and Reference System (VARS), to manage its video collection. VARS allows researchers to create, store and retrieve video annotations based on the ROV videotapes.

Overview of VARS

About VARS

In 2005, MBARI released VARS as a freely available open-source software project [MBARI 2005]. Any individual or organization is free to set-up and use VARS to manage video collections. An operational VARS system (Figure 1) typically requires a relational database server, a web server, a professional-grade videotape recorder (VTR), an optional video-capture card and the three VARS applications: Knowledgebase, Annotation and Query. For smaller video collections or for organizations with simple video management requirements VARS can be run with only the three VARS applications, a small database server that comes bundled with the VARS software, and a professional grade VTR.

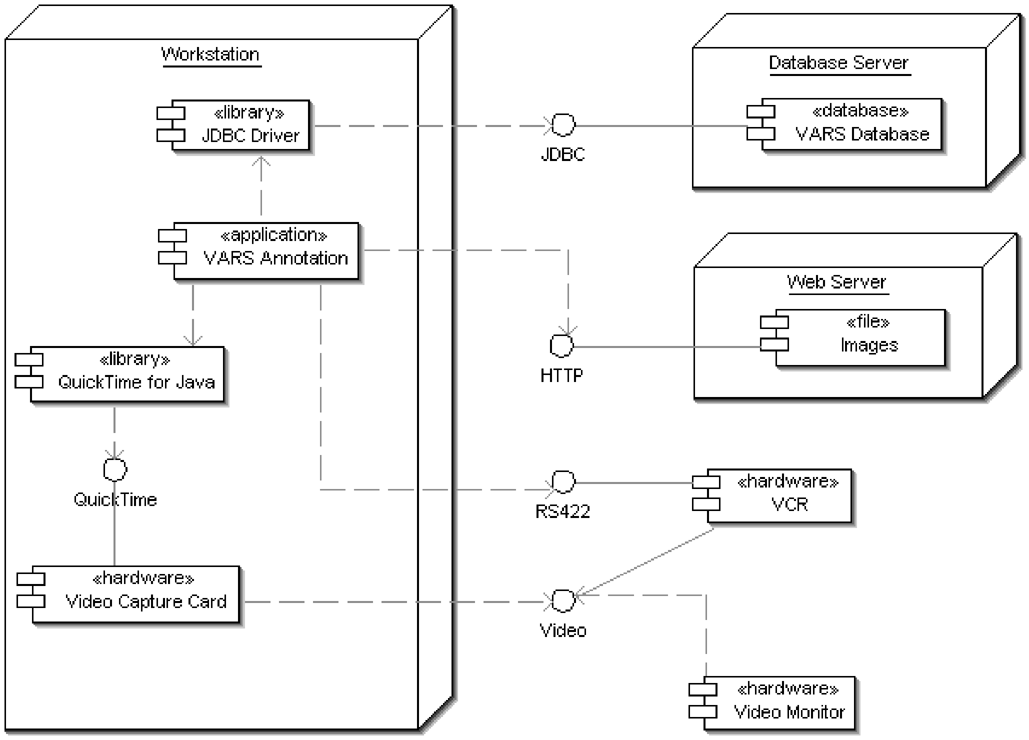

Figure 1: VARS Deployment Diagram

The relational database server is the centralized repository for storing all data created and used by the VARS applications including the annotations, user settings and the knowledgebase data. The knowledgebase data is the core of the VARS system. It consists of a hierarchical tree of *concepts,* where a concept is a single node in the knowledgebase hierarchy, which can be used to create annotations. The shared knowledgebase provides several benefits when used to create annotations. First, annotations are always correctly spelled, greatly increasing the reliability of searches of the annotation database. In addition, the knowledgebase allows several names or terms to be applied to a particular concept. This allows annotations to be created using terms that are familiar to an individual researcher. For example, the terms ‘market squid’ and ‘*Loligo opalescens*’ are equivalent in MBARI’s version of the knowledgebase and can be used interchangeably in the VARS applications. Finally, the hierarchical structure of the knowledgebase allows for modelling of phylogeny. This greatly extends the power of searchers and allows observed organisms to be annotated down to species level while still preserving the ability to retrieve them in more generic searches. For example, a search for the term ‘squid’ can be extended to return all species of squid stored in the knowledgebase.

VARS is currently designed to annotate videotapes, although we expect to add the ability to annotate video files in 2007. In order for VARS to associate an annotation with a particular frame on the videotape, a method of communicating with a VTR is essential. The most common protocol for communicating with a VTR is the Sony 9-pin protocol over RS422. This protocol is supported by many professional-grade VTRs. VARS uses this protocol for: controlling the VTR operations, reading time code information, and for reading and writing UTC time and date to a track on the video tape. When a video is annotated after being recorded, VARS can read the time from this track and use it to note the moment in time when a video frame was recorded. Annotations that have date and time information can be linked to other scientifically relevant data, such as latitude, longitude and depth.

MBARI researchers have found that associating images captured from the video with an annotation is very useful. VARS supports image capture with any QuickTime [Apple Computer 2003] compatible frame capture card. Captured images can be uploaded to a web server by VARS. By hosting the images on a web server, images can be retrieved using the Query application.

VARS User Interfaces

The VARS applications, Knowledgebase, Annotation, and Query, each perform a distinct function for interacting with the relational database server that stores the knowledgebase and annotation data. These applications are cross-platform and can be run on a variety of computer operating systems.

The Knowledgebase application is used to create and modify the knowledgebase data. The knowledgebase data functions as a dictionary of terms and defines the relationships between concepts. The knowledgebase also stores detailed descriptive information for each concept such as physical descriptions, taxonomic history, references and images.

The Annotation Application is used for creating annotations and capturing images. Annotations can be created using only the concepts found in the knowledgebase. One of the design goals of the Annotation application was to allow users to create annotations in both real-time and after the video has been recorded. To facilitate this goal, the Annotation application features a customisable user interface; concept can be dragged from the knowledgebase onto tabbed panels allowing the user quick access to frequently used terms.

Annotations can be retrieved using the Query application. The Query application allows for complex querying and sub-setting of the annotations. Researchers can search using common names or synonyms and retrieve ancillary data, such as position, salinity, and temperature, which are associated with an annotation. At MBARI, the Query application is available using Java Web Start (Sun Microsystems 2002). This allows the Query application to be deployed throughout an institute without requiring the end user to manually install any software applications. The results of a query, including textual data and images, can be saved to a local computer. MBARI makes a subset of the archived video annotations available to the public; the public Query application can be launched from http://varspub.mbari.org/webstart/varsquery.jnlp.

Obtaining VARS

VARS was released as open-source software in 2005 under the LGPL license (Free Software Foundation 1999] and is free for anyone to use. The VARS software can be downloaded from http://vars.sourceforge.net (MBARI 2005). Directions for installing and modifying VARS can also be found at that web site. The download comes with a database server suitable for small deployments and testing. It also includes Knowledgebase data that can be extended and modified to suit individual needs.

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Compiling a data archive for a research voyage.

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Abstract

A scientific research voyage generates a variety of data sets. These data sets need to be accessible to scientists to analyse the data, but also form a valuable resource as a compiled entity. There is a need to be able to create a compilation of these data sets that allow them to be visualized in the context of each other; to be accessible to all users, and to form a reference available into the future. I will look at the advantages and requirements of creating a usable data archive of the results of a scientific research voyage. In particular I will look at how one program, DataView, attempts to solve many of these issues.

Introduction

A research voyage collects a wide variety of data sets. Often these data sets provide a context for each other and the collation of data is more significant than the individual parts. Compiling these data sets into an ‘archive’ of a voyage, in a format that is useful, creates a valuable resource. Basically, there are three target audiences for the data collation - researchers wanting to investigate the data, stakeholders that would like to view the data, and future users requiring the data for other purposes.

These three groups have different, and sometimes conflicting, requirements for an archive of data. These differing requirements have guided the choices we have made in developing a format for maintaining voyage archives. Researcher's requirements include:

- timely access to the data,
- the ability to drill down into the data, and
- the ability to view multiple data sets in context.

Other stakeholders, such as funding bodies, require:

- ease of use,
- scenes of interest, and
- use on computers we have no control over.

Future users are similar to external stakeholders, but have some additional requirements:

- the data has to be accessible on computers that do not currently exist,
- users must have the ability to read the data a long time into the future
- meaningful metadata must be available, and
- complete archives.

At CMAR, the Marine Acoustics group have approached this problem by writing our own data visualisation program, called DataView. DataView is a basic GIS system where the program is written to match the data, unlike commercial GIS systems where the data has to be massaged into a format the GIS can handle. This can provide significant advantages when the data set is still being created or edited in its original format, allowing DataView to be useful during the data acquisition and early in the data processing and quality control cycle.

Researchers

Timely access to data

DataView provides a framework where each different type of data set is handled by a distinct bit of code (known as a DataLoader). There are a number of generic DataLoaders, for datasets such as:

- comma separated text files,
- NetCDF files,
- MapInfo Interchange Format (MIF) files

- ESRI shape files,
- SQL database queries, and
- common raster formats such as PNG, GIF, JPEG, TIFF and GMT grids.

Data that is already in a suitable format can just be loaded into DataView, as it can with most GIS systems such as MapInfo and ArcInfo.

In addition to the generic DataLoaders, DataLoaders can be written to read data sets in their native format. Writing a DataLoader takes some time, usually about two to four weeks, but once the DataLoader is written new data sets of that type can be loaded into DataView as they become available.

Drill down in the data

In DataView the user can select a data point from the display and the details of that point can be viewed, like most GIS systems.

However, since the DataView code is customised to the data, the display of the data is also customised. For example clicking on a CTD location in the map display will bring up the CTD profile for that cast; clicking on a point in the profile will display the water temperature and salinity values for that depth in the profile (Figure 1).

View multiple data sets in context

One of the primary goals of DataView is allow multiple data sets of different scales to be viewed in context.

DataView has a modular structure and the program can be configured so that the DataLoaders needed for a particular archive are visible in the program. This allows the same software to be reused to generate a variety of archives, involving not just research voyages on a variety of vessels and instrument configurations, but also archives related to particular areas or subjects of interest.

Stakeholders

Other stakeholders, such as funding bodies, can be given copies of the voyage data on DVD as an appendix to a voyage report.

Ease of use

The stakeholder is generally not interested in spending any time learning yet another computer program. So the program needs to have a basic set of functionality that is fairly easy to use.

However, ease of use is subjective and difficult to deliver. It requires a significant amount of programming effort and user feedback. DataView does not yet perform particularly well against this criterion.

Scenes of interest

DataView has the ability to save its current display as a scene which can later be loaded by this or other user. The scene is also supported by a scripting language which allows tutorials or commentary to be included.

Use on computers we have no control over

The preparers of a data archive have no control over the computer system that external users will use to view the data, nor can they expect the user to purchase licenses for third party software to run the applications.

Since funding bodies are often government agencies some assumptions can be made as to the likely platforms, e.g. Windows XP without administrator rights, but they may use other platforms which we should also support, such as Windows 2000, Mac OS X, Linux and Solaris.

DataView addresses this by being written in pure Java. Java runtimes for Windows and Linux are usually included, so the application can be run directly off the disk on those platforms, without the need for any installation.

Other platforms require that Java is installed for DataView to work, but this is not an unnecessarily harsh restriction as Java is freely available for most platforms and many already have Java installed. DataView was written on a Linux system, but has been used on Windows, Solaris, Mac OS X and even a super computer.

Future users

Use computers that do not currently exist

All of the issues dealing with having users on computer platforms we don't know or control are the same. In many ways dealing with computers of the future is just a case of inter-temporal platform portability.

Using Java as an intermediary is again a good solution to the problem. Future Java runtime systems are likely to be able to run our code long after the computers that support the current Java runtimes are obsolete.

Ability to read data a long time from now

We don't know what computers of the long term future will look like, but we can make some guesses. Any data formats which are closed and undocumented, such as Microsoft Word, Excel and Access are unlikely to be readable 10 years from now. As far as the future is concerned any data held in only those formats can be considered lost.

On the other hand, simple formats, such as comma separated text, are the most portable into the future, with well documented standards such as NetCDF also likely to be readable for a long while.

While the requirement to store documents in accessible formats may seem at first glance to contradict the researcher's requirement that data be in its native form, in practice this is often not the case. The need to share data between scientists has already ensured that much of the data are in accessible formats. Much of the data we deal with, e.g. CTDs and bathymetry grids, are already in NetCDF format.

We use an open source Java DBMS, HSQLDB, which allows us to use SQL to query data that are stored in comma separated text files with column headers. While this is not as efficient as its binary cache format, or the closed formats of other DBMS such as ORACLE, it is good compromise as the data will always be readable into the future, even if the application itself is no longer runnable.

Meaningful metadata

Data alone can be meaningless if there are not adequate meta data to describe it.

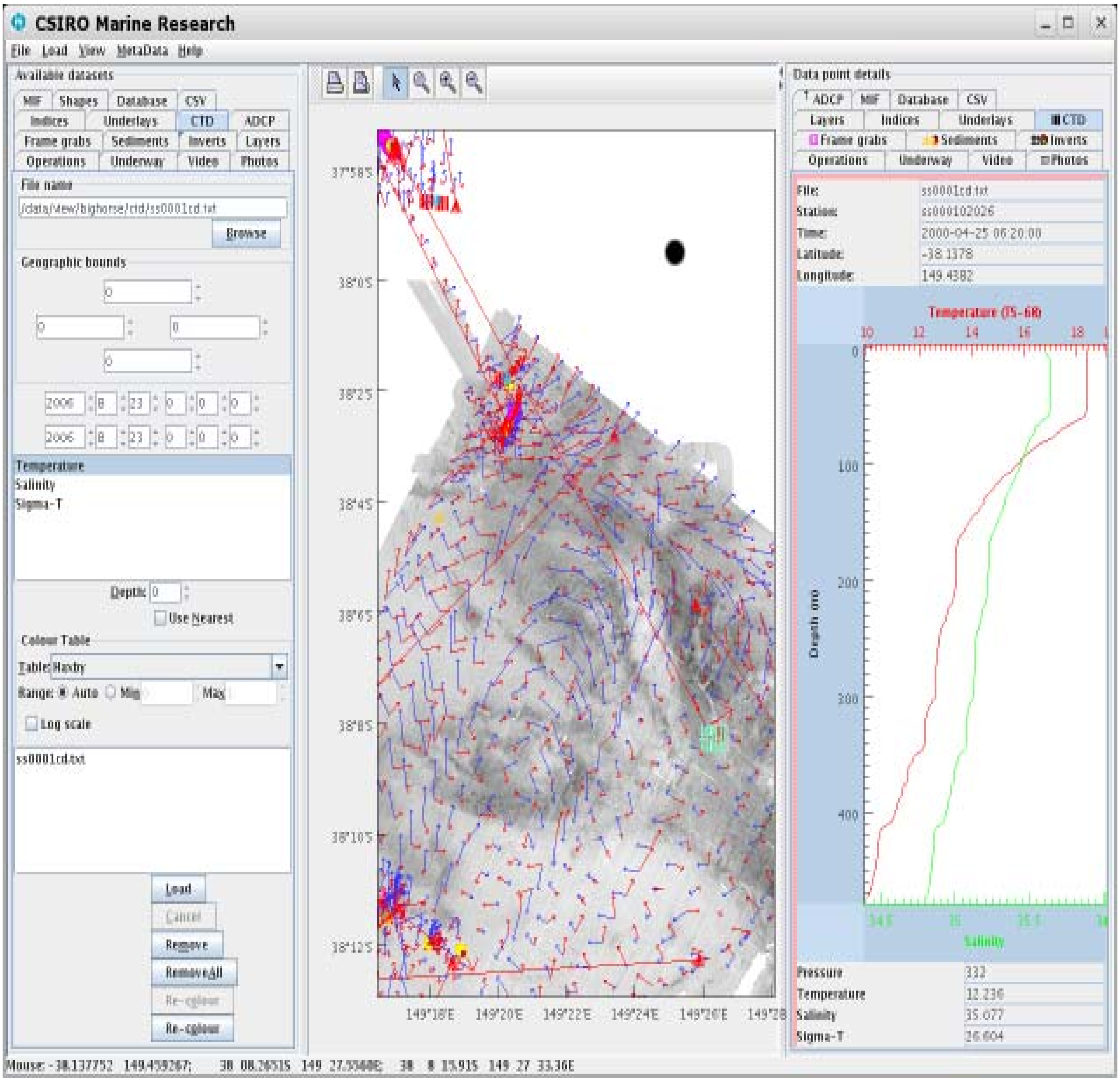
I mostly envisaged that DataView would be included as part of a Voyage Report, where the other parts of the report will provide the context and meta data for the archive. Nevertheless, DataView does have a basic ability to display text and HTML documents containing metadata.

Complete archives

The complete voyage data set may include many hours of digital video and gigabytes of acoustic data. It is currently impractical to store all this data on a medium suitable for general distribution, or running software. So at this stage DataView archives are not complete.

Conclusion

There are real advantages to using customised software to create data archives. This software needs to have cross platform portability and the data needs to be stored in open and documented formats. The DataView program we have written addresses most of these requirements.



File name: /data/view/bighorse/ctd/ss0001cd.txt

Geographic bounds: 0 / 0 / 0 / 0

2006 8 23 0 0 0

2006 8 23 0 0 0

Temperature

Salinity

Sigma-T

Depth: 0

☐ Use Nearest

Table: Haxby

Range: ● Auto ○ Min Max

☐ Log scale

ss0001cd.txt

File: ss0001cd.txt

Station: ss000102026

Time: 2000-04-25 06:20:00

Latitude: -38.1378

Longitude: 149.4382

Pressure: 332

Temperature: 12.236

Salinity: 35.077

Sigma-T: 26.604

Mouse: -38.137752 149.459267; 38 08.26515 149 27.5560E; 38 8 15.915 149 27 33.36E

Figure 1: DataView screen grab showing CTD location in the map display, and water temperature and salinity profile for the depth at that sampling location.

General discussion - Data capture and management

Rapporteurs - Alan Williams & Bruce Barker

Key discussion points

Advances in data capture technologies have contributed to spatial management initiatives, improving the ability to delimit areas of interest and providing the opportunity to manage them explicitly as well as monitoring the fleet and fishing activity. Although small scale fishery dynamics relevant to harvesting/ sustainability can be captured, such information tends to be below the scale of relevance to present management regimes.

Vessel monitoring systems have an obvious role in fisheries enforcement and in describing fine scale fleet movements but could be further developed to provide more detailed operational and catch information. On board cameras, automated logging of operational data (e.g. winch monitors, load cells on trawl wires) can contribute to better defining fishing activities, though it was acknowledged that while technological solutions may be cheaper, on board observers bring in a lot of other data.

Management processes move slowly compared to the rate at which there is opportunity to acquire and understand data, with lags in translating information into management action. However, management agencies are becoming increasingly responsive to spatial management issues.

IP and confidentiality issues associated with collecting, distributing and sharing data were flagged as an issue in certain situations. Depending on the user, solutions include the provision of different levels of access/disaggregation or data versions.

The benefits of developing centralized archives/databases to house data (especially environmental and biological data) was supported, noting that funding for archiving and on-going database maintenance tends to be overlooked. The current BlueNet initiative to establish an Australian marine science data network represents a good example of how to address this issue. It was also noted that in other disciplines there are examples of data sharing that could be investigated.

There is considerable need to invest in the development of automated processing techniques, including software, to reduce the time required taken to analyse spatio-temporal and video data. While data collection is relatively simple, data analysis is considerably more complex. Development of capacity and skills in GIS techniques, and database management was recognised as a challenge.

Chair’s summary

Ian Knuckey

The speakers in this session provided a broad range of presentations on the different issues associated with data capture and management in fisheries. The Keynote address by Bruce Wallner and Panel presentations by Brent Wise, Peter Stephenson, Craig Mundy and Brian Schlining largely focussed on the technical capabilities and ‘electronic smarts’ that are presently being trialled and implemented over a range of different commercial, recreational and research situations. It was clearly apparent that digital video technology is providing a unique opportunity, whether it is for onboard monitoring and surveillance of commercial vessels, monitoring and quantifying recreational fishing effort, or surveying the oceans benthic communities, and will continue to develop as one of the most important data capture tools. Equally, it was apparent that no one single data capture tool will suitable for all situations and it will be some combination of video monitoring, VMS, electronic data capture and logbooks that will form the data capture foundation of future fisheries management. If combined correctly, these tools could make fishing vessels one of the most valuable data collection sources of the estuarine and marine environment.

Conspicuously, it was much less clear how these data could be managed and utilised. Gordon Keith gave a good specific example of what can be done and the capabilities of user-friendly GIS interface to access and query data collected during a research voyage. The discussion on this session revealed that in general there was still a long way to go in the data management and integration side of the issue despite the fact that adequate tools already seem to be available. Much of the difficulties in this area relate to the need for clear objectives as to what information is needed, how it will best be collected and how it will be used.

It was obvious that the suite of current data collection technologies have the capacity to collect information on very small spatial and temporal scales but fisheries tend to be managed on much broader scales. Some 'meeting of the minds' needs to occur on this level to ensure that adequate information is available at an appropriate scale for good fisheries management and there is not just wholesale and unnecessary data collection 'because we have the technology'. The importance of who has access to different information collected and the potential Intellectual Property of this information was also highlighted as an issue for data collection and management. The need for standards on data collection and a central or national archive for marine data was highlighted. A metadata 'warehouse' would be a good step in the right direction and the Blue-Link system was given as an example that could be expanded in scope.

A final point made during this session was that, regardless of what technologies are used, ultimately someone has to pay for the data collection and management and this needs to be an important consideration in determining an appropriate data collection and management regime for a fishery. Presently, Australia's commercial fisheries are striving to achieve and demonstrate their ecological sustainability whilst competing in an open market with seafood products that may not meet these same criteria. Whilst this goal is commendable and will bring benefits in the longer term, it is coming at a significant cost to industry in the short-term. This needs to be recognised.

New technologies in data collection and management have huge potential to assist in cost-effective fisheries research and management but a holistic approach to their adoption and a realistic evaluation of their short- and long-term cost/benefits and how they will be funded must be undertaken before they are implemented.

Wrap-Up Session

Colin Buxton (Chair)

Wrap-up discussion

Rapporteurs - Sandy Morison & Cathy Bulman

Ron O'Dor: Lots of good ideas have been presented but one thing that did not come through is the use of tracking to understand how fish interact with each other and their environment, e.g. pH monitoring in gut to tell us about feeding, tail beat monitoring to tell us about swimming metabolism.

Greg Jenkins: Many of the emerging technologies are complementary to traditional methods and there remains a need to use both - it is necessary to select appropriate methods for each question.

New developments are driven by technological innovations and there is a need to keep abreast of them. Attention should be directed at getting management to understand the complexity of the methods and at the better incorporation of information into assessments and spatial models.

Combining techniques represents an important opportunity, e.g. acoustic tagging with microchemistry.

Ecosystem based fishery management (EBFM) and ecological modelling are increasingly important but they are data intensive and this will drive the collection of large quantities of ecological data.

Collaboration among groups was highlighted as a need, e.g. listening stations, sharing of environmental data. High tech methods can be seductive but they can get ahead of basics that underpin them and attention must be given to validating methods.

Ian Knuckey: Transfer of technology from research to industry is important. Fisheries are dollar and data-hungry but how well do global markets realise the hurdles that are being imposed on the fishing industry? Our sustainable fisheries are competing on world markets against others that may not be sustainably managed and there are few examples where there have been cost savings as a result of technology. How to support industry through this phase until benefits accrue represents a challenge and the real cost-benefits need to be realised in the short-term, not only the long-term.

Pamela Mace: EBFM is a good place to start because it is the 'umbrella' for a lot of the technologies that have been discussed. Since the concept of EBFM came into fashion it has necessitated, and justified, the development and application of a diversity of technologies. However, single species and multi-species stock assessments are still part of EBFM.

Malcolm Haddon: We have been exposed to an array of different methodologies providing technological solutions to problems. People tend to be enthusiastic advocates for their methods, and there is a clear need for collaboration, however, competition tends to get in the way.

Ideally, we need the managers to identify strategic questions and directions. Only once key issues have been identified is it time to argue about the most appropriate technologies to address them. Major investments on listening curtains may not be the best strategic investment on clearly identified problems.

Kim Holland: The fuzziness in defining EBFM is universal. As biologists it highlights the need for us to understand trophic linkages and energy flows through the system and, consequently, the knock-on effects of perturbations.

We have already successfully tested a chat tag in sharks that allows stored information to be transferred between tagged fish, a stomach pH tag to gauge feeding periodicity and bio-acoustic probes which record sounds in fish environment, including internal sounds such as heartbeat and external sounds such as boat noise. 'Business card' tags are also in train. These are all part of EBFM and the need to understand how systems work. Acoustic telemetry questions are limited by imagination, not technology.

Alistair Hobday: What's wrong with the old technology? Competition for funding is forcing us to use the more innovative techniques to attract the money, rather than filling in the gaps or using established technology. We need to more critically appraise methods and decide if new technologies really are the best way forward.

Jock Young: In open ocean ecosystems, albacore are a non-targeted species yet are following a similar pattern of decline to species such as bluefin or yellowfin tuna. We do not understand why and are probably missing important questions. Oceanographers have good datasets, yet we struggle with long-term datasets and 'short-termism' in biological projects. Long-term climate questions are going to become increasingly important yet we are not monitoring the basics and need place more focus in this area.

Colin Buxton: Support for long-term datasets may not come from FRDC, it is the responsibility of research agencies. Unfortunately very few invest in the long-term data collection.

Matt Barwick: It is agreed that responsibility for long-term datasets doesn't just lie with FRDC. But there is a pivotal interchange of innovation and cutting-edge technologies and we need better ways of doing things not just new things.

Bruce Wallner: Do have some long-term datasets but not environmental data. New technology may fill the gap, there is a need to invest in on-going data collection.

Elkana Ngwenya: Do we need central coordination/inventory of what equipment is available and a common pool of resources?

Stewart Frusher: Equipment is expensive and nationally there is limited coordination between research providers. Maybe need coordinated demonstration of equipment and then decide on where they need to be applied.

Rick Officer: There is a need for integration of the work. The key assessment questions have not changed but we now have new ways to look at them, so we need to integrate the old with the new to answer the questions. Australia is leading the way in integration but there are good examples overseas of the way data series are being collected and managed because of legal requirements to collect data.

Alan Jordan: Most state agencies are using hydro-acoustic techniques to undertake habitat mapping, with very small teams of people involved. However, many more skills are required to make the best use of the data generated. The challenge is to recruit appropriately multi-skilled people, improved coordination of expertise nationally is desirable.

Ron O'Dor: Have the fundamental questions not changed? The Census of Marine Life project looked at the history of a trawl fishery in Australia and at least 6 species went commercially extinct. The fishery is constantly moving from traditional to new species, and questions are changing. Development of new technologies is being pushed to help keep up with this demand.

Bruce Wallner: Same old questions? If so, then the assessment questions may not be the right questions anymore. Industry asks how to run their business profitably and an overwhelming majority of fishers have tendered to leave fishery. The economics are no longer viable because of high fuel prices and competition with cheap imports. Fisheries are low on stock abundance but high in diversity. Fishers are facing a major decline of commercial fisheries and turning to small-scale niche fisheries to survive. New technology may help in ways to manage these new fisheries.

Gary Jackson: There has not been much emphasis outside of commercial fisheries, but recreational fisheries are likely to become more important as commercial fisheries decline. Recreational fishers will move into the gaps left by the commercial fishers and there is, therefore, a need to improve the datasets relating to the recreational sector. We need to look at the bigger picture and beyond commercial fisheries, many of which are in decline.

Matt Barwick: FRDC represents all sectors of industry and needs to demonstrate benefits to all sectors. Work is underway to ensure that mode of collection of funds matches where it is spent.

Innovation is biologically based but we also need to focus on areas that will help the economics of industry. There is a pressure to be innovative in the use of data to answer more than just one question and this type of research would be supported by FRDC. Unfortunately, this is not necessarily interesting to research agencies so it becomes important that both funding and research providers are aware of the value of data.

Patrick Coutin: One of benefits of new technology is to promote science to the public and stakeholders. Use of video is a valuable way to sell the benefits of the science.

Chair's summary

Colin Buxton

The stated outcomes of the workshop were identified as:

- emerging science-industry opportunities
- opportunities for collaboration
- cross-theme linkages
- future needs and directions of fisheries science

Emerging science – industry opportunities

Some of the salient points for me were:

- New technology is providing very large data sets (spatial and temporal). This leads to particular challenges in storage and visualisation. There are opportunities for industry to assist in handling this data. For example, we are working with a local SME, Sonardata, to develop 4D visualisation software to combine and handle our acoustic tagging and SeaMap data.

- We heard that technology for catching fish was evolving faster than the technology for assessing stocks. Also that parameterisation of models is not keeping up with the model development.

- I really liked Pamela Mace's view that science must pay dividends – perhaps easy for fisheries but not so easy for biodiversity conservation and other public good aspects of what we do.

- Those that know me also know that I equate the terms 'industry' and 'stakeholder' – so I like another of Pamela Mace's suggestions:- that we must promote a greater public awareness of marine science – get them involved in promoting the need for good science to underpin conservation and utilisation of resources. This is easier said that done – fisheries scientists are second only to weather forecasters in consistently getting it wrong but staying employed!!

- I liked Craig Mundy's reality check – the suggestion that electronic data doesn't substitute for interaction with fish – he was clearly telling us not to lose sight of the real world, something that is easy to do in this age of technology.

Opportunities for Collaboration

These are enormous. If you can't see them you must have been sleeping through the performances!

Perhaps we should rather contemplate the barriers to collaboration because the benefits are obvious. I think it was Geoff Garrett (CSIRO CEO) that said the age of publish or perish has been replaced by partner or perish.

Cross Theme Linkages

My take on cross theme linkages was that the four themes discussed were very clearly linked. Tagging, tracking, hydro-acoustics, and underwater video methods are often used together. There appeared to be opportunities for cross linkage between acoustic and chemical methods used to determine movement. We also listened to several examples of how new technologies not only compliment each other, but also some of the more established methods.

One thing's for sure - technology is producing more data, much more data.

This demands better methods of data management, better data manipulation skills (GIS, data base management and visualisation methods) and methods of sharing data.

I believe that the time is right for the biological sciences to change their culture – from data hoarding to data sharing. Dave Griffin provided wise counsel, to look to the physical research disciplines as an example of how data sharing works to maximise the use of our investment in research.

This takes us back to collaboration because data sharing is just another form of collaborating. I see the challenge as follows:

- How do we climb out of our silos – both geographic and discipline?
- How do we remove the barriers of our system of government, where the State and Commonwealth fiercely protect their turf? Fish don't follow political boundaries!
- How do we work more collaboratively and effectively across the Tasman when so many of our structures promote competition?
- Is competition a useful construct in science?

Future Needs and Direction

Our discipline is facing enormous challenges in the area of EBFM or Integrated Fisheries Management (IFM) – call it what you will – as we move towards the management of fisheries in the context of the environments in which they operate. Stock assessment is hard enough without having to consider the complexity of the environment, and the interaction and effects of fishing on the target and other by-catch species. We have heard much in the last few days that illustrates we can use technology to help us in our quest.

Turning back to the workshop outcomes – the acid test will be an evaluation before the next ASFB of what this workshop has delivered:

- New science industry links
- New collaborations
- More and real cross-theme linkage
- Greater clarity of direction

That is a challenge for the committee.

In closing I would like to thank all who contributed to the past few days, the speakers and the contributions from the floor, and would like to leave you with these thoughts:

- invest in innovation
- improve data management
- share data
- improve data visualisation
- educate and communicate
- partner or perish.

K. Radway Allen Presentation

Paper delivered at the 2006 ASFB Conference in Hobart by Norman Hall,
recipient of the K. Radway Allen Award (2005) for outstanding contributions to fish and fisheries science in Australia

Hooked by the bottom line!

Norman Hall

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Abstract

In reflecting upon the changes that have occurred over the past forty years in Australian fisheries, and in their research and management, it is very apparent that economics has been and continues to be a major driving force. Australia's strong economy has facilitated improved access and greater opportunity for recreational fishers, and has placed increased pressure on commercial fishers to maintain or improve their catches in the face of (often) diminishing stocks, greater competition, increased costs, and more stringent regulations. These latter economic pressures have driven an increase in exploitation through improved fishing efficiency and additional fishing effort. Recognition of escalating exploitation has required fishery managers to introduce more responsive and effective management to address a broader range of issues, bringing more fisheries under the 'umbrella' of control and introducing regulations or incentives to constrain further effort increase or to reduce current levels of fishing. Increasingly, with greater demand on governments to direct funds towards other priority areas and, as a consequence, reduce funding for fisheries management, the costs of research and management for many of the higher-valued commercial and some recreational fisheries are now recovered from fishers. Temporal and spatial closures, which have a low management cost, are increasingly being used to protect spawning aggregations of fish and to maintain biodiversity. The growth in levels of exploitation and greater demands for more effective fisheries management have required the use by fisheries scientists of more sophisticated approaches, with a change in emphasis from population biology of fishes to studies of stock and risk assessment, management strategy evaluation and exploration of the ecosystem impacts of fishing. Increasingly, research funding provided through competitive grants is being required to be innovative and to produce outcomes with tangible, direct benefits to fishers. There is little doubt that this trend towards increased demand for more sophisticated management advice, combined with increasing pressure by governments to reduce direct funding and to ensure an economic return on research investment, will continue. However, in some cases, the data to resolve the management questions that are now emerging are proving inadequate and, increasingly, our ability to undertake core research is constrained by the funds that are available. Inevitably, research funding must be targeted towards high-valued fisheries or 'key indicator species' rather than towards lower-valued species and/or fisheries or studies, such as frequent recreational fishing surveys, that are inherently expensive. The challenge that we face is to ensure that, with reduced research funding for studies of these lower-valued species or fisheries and/or the diverse range of fish species in the multi-species fisheries that are exploited by recreational fishers, adequate research information will be available to ensure their effective management. The risk is that, like dominoes, one after another of these species will become overfished without appropriate action being initiated to ensure that their stocks are sustained.

Introduction

It was a very great honour to be selected last year to be the recipient of ASFB's Kaye Radway Allen award. I'm most grateful to those who nominated and selected me. Thank you!

Selection for this award brings the recipient the opportunity to talk on a topic of his/her own choosing at the following year's annual conference. Usually, the overall theme of a presentation is prescribed by the conference organizers. It is therefore an interesting challenge to be asked to choose your own subject and to identify a topic that is likely to be relevant to the broad range of interests of society members. I considered a review of the methods currently being used for stock assessment and the emerging trends in this area, but rejected this topic as it was far too focused and technical. I thought also of focusing the presentation on the need for developing the quantitative skills of our current fisheries scientists and of providing the training necessary to ensure that people with the necessary skills in fisheries and ecosystem modelling will be available for recruitment by fisheries agencies to meet the emerging needs of those agencies. Once again, however, I rejected the topic as it was of too narrow a focus.

Finally, on reflecting on the very considerable changes that I had seen during my career in fisheries science, I decided that it is these changes that should be the topic of my talk today. Accordingly, I present below a personal perspective of the changes that have occurred, the factors involved, the emerging trends and implications of these to our younger scientists.

Fisheries science in Australia three decades ago

It was a very different environment 37 years ago, when I commenced my career in fisheries science. Mainframe computers ran programs in batch mode from punched cards and the state-of-the-art in personal computing was a 64-step programmable calculator with four memories. Fisheries management in those days was through benign dictatorship and was very much influenced by the fisheries models of the day, which were simple and deterministic. Virtually all research funding was provided by the State and derived from consolidated revenue (i.e. income to government from taxes, etc.) and funding agencies such as the Fisheries Research and Development Corporation (FRDC) were yet to be established. Research funds were more readily available and the pressure to produce immediate research results was far less than today. At that time, one of the legends in the field of fisheries stock assessment was Kaye Radway Allen.

When I commenced my career, Kaye Radway Allen was directing research at Nanaimo for the Canadian Department of Fisheries and Oceans. He was well respected for his work in the field of population dynamics and stock assessment and we were extremely pleased when he accepted a position with CSIRO as chief of its Division of Fisheries and Oceanography.

I was fortunate to have had the opportunity to interact with Kaye when he became established in his new position with CSIRO as he then became a regular visitor to Perth to help in guiding our research activities through his role in what was known as the Western Fisheries Research Committee. He later retired to Cronulla, but continued his involvement in research with NSW Fisheries and I met him again at numerous workshops. Along with others, I recall that, at that time, Kaye had developed the practice of occasionally closing his eyes as people talked, but thoughts that he had fallen asleep were always quickly dispelled when he would open his eyes and make an astute comment that inevitably demonstrated that he had been following the discussion closely. He invariably made an invaluable contribution, often by applying simple approaches that he had developed or used in earlier years to provide huge insight into the dynamics of the fishery or biological process that was being discussed. Kaye’s passion for fisheries science remained undiminished through the years, although he is now no longer actively involved. At the age of about 95 years, he is still occasionally seen by New South Wales fisheries staff as he drives around in the Cronulla region.

The changes that have occurred

Comparing the current situation with that experienced thirty to forty years ago, one is immediately struck by the changes that have occurred in technology, the experience and skills of the research staff, the approach to research and the ways in which research is now funded. I’ll discuss each of these below.

The changes in technology are extremely obvious and are reflected in the computing hardware and software now available, and particularly in the presence of personal or notebook computers on virtually every desk. Our ability to maintain the extensive sets of fisheries data that are now being collected and stored has been enhanced by the storage capacity of today’s hard disk drives and the database software that we can now access. The internet has created new opportunities for us to collaborate, communicate and interact and to share and access data. Technology has improved the effectiveness of fishers in finding and catching fish. While it has also brought opportunities to improve our research techniques, e.g. through remote sensing, smart tags, etc., these improvements are less rapid than those relating to improving fishing efficiency, probably as a result of the larger market for the latter.

The levels of skills and experience possessed by the staff of today's State fisheries agencies far exceed those of thirty years ago. We also see a broader range of disciplines represented among today's scientists, including specialist staff with skills in fisheries management, information technology, statistics, economics, social science, and ecology. Staff have greater experience and, even among the technical support staff, possess far higher qualifications than in earlier years. Another very evident change is the far greater number of fishery managers and research scientists in most fisheries agencies.

Changes in the ways in which scientists in our fisheries agencies are now required to operate are evident in the greater requirement for fisheries scientists to focus on specific priority issues and essential tasks. There now appears to be considerably less flexibility in the research that is undertaken and considerable pressure to deliver timely advice. In addition there is a requirement to produce more records and reports and an increased demand for accountability and transparency in the research that is undertaken. Indeed, many senior research scientists in fisheries agencies are now so committed to reporting that little time is available for them to undertake research themselves.

Funding is very much less flexible and the research to be undertaken is constrained by the limited funds that are available to meet far greater research demands and thus must be directed by priorities. Again, a requirement for greater accountability is evident and there is an increasing reliance among fishery scientists on external funds.

Commercial fishing has clearly been driven by and responded to economic pressures. Increasing costs (e.g. for fuel) and greater competition both among and within fishing sectors have led to increasing effort and/or increasing efficiency of that effort (i.e. capital stuffing). The catch share of commercial fishers has been eroded by increases in recreational fishing and catches have responded to often diminishing stocks, becoming further reduced through management controls imposed on exploitation or access. Many fishers are finding the current economic climate difficult.

Recreational fishing has also grown, in part because leisure activities reflect Australia's strong economy and recreational fishing is 'subsidised' by income from other activities. We've seen a greater participation rate, an increase in boats and in 4 wheel-drive vehicles, an increase in technology (e.g. GPS, colour sounders, etc.) and improved access to fishing opportunities through construction of boat ramps, roads, etc. There has also been an increase in the number of charter operators. These changes to the recreational fisheries have been reflected in an increased spatial distribution of fishing activity and an increased range of species that are now targeted and caught by recreational fishers.

The inevitable consequence of these changes in commercial and recreational fishing has been increased exploitation of stocks. The additional fishing effort and improved fishing efficiency have been driven by economic pressures. The result of the increased exploitation has been declining stocks or fisheries, increased demand for stock assessment and management advice, and imposition of further regulations to control the levels of exploitation.

In addition to the need for managers to respond to increasing exploitation of fish stocks, there is now growing pressure from international and national agencies to ensure responsible fishing and conservation of biodiversity. This change in responsibilities requires that fishery managers now must consider the ESD implications of management plans and take into account economic and social objectives. They are required to consider the ecosystem impacts of fishing and respond to competition among different users by considering how available catches should be allocated among those users. Fisheries managers have had to become more responsive, effective, accountable and strategic, respond to a broader range of issues and recognise a broader range of management objectives. For the fisheries scientist, the result of these increased management responsibilities has been an increased demand for advice.

The demand for fisheries science has increased with increased exploitation and declining stocks. Increasingly, there are demands for more sophisticated evaluations of multispecies interactions, ecosystem implications of fishing, and bycatch issues. Scientists are now required to account for the spatial distribution of fishing and/or fish, to undertake management strategy and risk evaluations and to demonstrate greater accountability for the advice that they provide. These increased demands for scientific advice require appropriate resources, including scientists with the necessary skills and experience, research funding and time, all of which are often in short supply.

Most fishery agencies are faced with reduced funding for core research as consolidated revenue is increasingly directed by State Governments towards police, health and education. With reduced agency funding for research, there is a greater reliance on external research funding. However, increasingly and, very understandably, external funding agencies are requiring that research must be innovative, broadly applicable, and produce tangible outcomes, and, of course, that benefits must justify costs. External research funding is thus not available for core research activities. In addition, there is increasing competition for funding and the ability to attract grants is often influenced by an applicant’s track record of peer-reviewed publications and research grants. Thus, to increase the chance that an application for research funding will succeed, experienced senior staff with greater chance of obtaining grants put forward applications rather than early-career scientists. Unfortunately, this impedes career development opportunities for early-career scientists as they have less opportunity to develop a track record of successful grants. The reliance on external research funding has a more severe impact on the careers of these early-career scientists, however, as project-based funding lacks continuity. Most externally-funded research projects have a lifetime of about three years. Thus early-career scientists are often employed on three-year contracts and must chase further employment at the end of each contract. The consequence of this is that, at our universities, we begin to find that prospective postgraduate students are less attracted to pursue a career in fisheries science and choose other fields of study with more secure employment prospects.

Another aspect of fisheries science that has been affected by economic forces is the publication of results in peer-reviewed journals. These journals must have a high impact if library subscriptions are to be maintained. As a consequence, editors now require that papers must be innovative, address hypotheses, and are likely to be relevant to an international audience who will cite the papers and thus raise the journal’s impact factor. These changes constrain publication of papers of local interest, or that are not innovative, unless their authors are adept at presenting their results in a form that is acceptable and of interest to the broader scientific community. Thus, the results of much basic research, such as stock assessments and baseline biological studies or fishery surveys are now more difficult to publish and thus receive the necessary peer review. In addition, editors are now requiring reduced but more tightly-focused content in order that the number of papers in each issue might be increased. Accordingly, there is now little opportunity to publish research data in detail, only the results of the analyses. This hinders duplication of research and comparison of data from different studies.

Funding agencies fund research and delivery of outcomes, not publication, and most fishery agencies place little emphasis on the need to publish research results. Failure to recognize the importance of publication encourages the production of grey literature and, again, failure for research to be adequately peer-reviewed. It also hinders broad communication of research results through the scientific community and encourages the development of data silos, which are viewed by their custodians as ‘levers for future research funding’.

We see trends towards increased cost recovery and co-management (with the potential for influence by vested interests) and levels of management and research that are more closely aligned with the value of the resources. Thus, there is now reduced subsidizing by fisheries agencies of the costs of research and management for low-valued stocks. We note also the increasing use of marine protected areas and areas closed to fishing, which have a relatively low management cost. However, the effectiveness of these areas in achieving the objectives of conserving biodiversity and sustaining fish stocks is often inadequately assessed.

With limited research funds and an increased demand for research, fisheries agencies have no choice but to prioritise proposed research studies and approve only those projects of higher priority. Thus, it is not surprising that research studies of low-valued fisheries or of species of low recreational/commercial importance have low priority. Similarly, research with high cost, e.g.

recreational fishing surveys, is undertaken only rarely and at low frequency. The implication of these funding limitations is that many low-valued species or fisheries will attract little research attention and the species will face an increased risk of becoming overfished. Faced with inadequate data, it would be appropriate to manage such fisheries more conservatively, yet the precautionary approach is seldom applied. The emphasis of management appears to be to maintain current stock status, reflecting an attitude that 'because we don't know that the stock is being overfished, we'll take the precautionary approach of not changing current management arrangements'.

The future

The economic forces present over the past three to four decades will persist over future decades. Economics and the need to consider the 'bottom line' will continue to drive fisheries, fishery management and fisheries science! Thus, we may expect increasing exploitation, an increasing need for appropriate management and demand for more sophisticated management advice, reduced expenditure on low valued species and resources and increased focus on high-valued fisheries and key indicator (important) species and regions, coupled with reduced funding for core research or expensive surveys and an increasing trend towards publication in grey literature rather than peer-reviewed scientific publications. With the increasing demand for research but constraints on research funding, we will have to find ways of doing more with less if we are to meet the demands for the research advice required to manage adequately our lower-valued fisheries.

Challenges for the ASFB

The challenges to the ASFB and its members are

- How should we respond to these trends?
- How can we provide adequate research advice and management to ensure sustainability of species in low-valued fisheries?
- How can we bring science back into the fisheries scientists' responsibilities?
- How can we ensure continuity of employment for early-career scientists?

There is a need to lower the cost of research such that we may provide advice for the lower-valued fisheries. One possibility of achieving this is to ensure that research tools and methods that are developed may be readily applied to other fish stocks in other fisheries. Increased communication of research results, collaborative research and establishment of processes to share expertise, tools, methods and data among fisheries scientists throughout Australia would assist in reducing costs of research. Costs of data collection might be reduced through the involvement of fishers or use of technology. Similarly, opportunities for research synergy by engaging PhD and Honours students in research should be considered whenever such studies are appropriate. There is a need to develop low-cost, robust methods of assessment and management approaches for data-poor fisheries and species.

While it's unlikely that the need for reporting can be reduced such that senior fisheries scientists can spend greater time on research, it may be possible to ensure that the quality of the science undertaken within agencies is enhanced through the development of methods of peer review for baseline scientific reports and stock assessments that are no longer accepted by journals. The internet offers opportunities for communication of results and there is sufficient scientific expertise in Australian fisheries agencies to establish a system of peer review. By publishing (only) such peer reviewed documents on the Internet as, for example, an ASFB series of online papers, results could be readily accessed both nationally and internationally.

Continuity of employment and career development are essential for early-career scientists. The ASFB and its members may be able to assist these scientists by using their network of contacts to ensure that good scientists are retained and their skills are picked up at the end of contracts and by mentoring to ensure that those young scientists gain experience in preparing grant applications. However, there is also a pressing need to re-focus research projects such that we ensure that publication of results and research quality will drive those studies. Early-career scientists must be encouraged to publish as their future employment prospects and promotion will depend on their publication records.

While we cannot change the economic forces that drive our system, we can change the way in which we respond! The question that I pose to you is ‘how should the ASFB and its members respond to these challenges’?

Finally, thank you all once again for honouring me with the Kaye Radway Allen award. Surely a lapse of judgement by the Society, but one which is most appreciated!

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