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Management and Monitoring of Fish Spawning Aggregations within the West Coast Bioregion of Western Australia

Final FRDC Report – Project Number 2004/051

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Non Technical Summary

2004/051 Management and Monitoring of Fish Spawning Aggregations within the West Coast Bioregion of Western Australia

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Objectives

1. To identify species that aggregate to spawn within the WCB and to describe (e.g. location, size, timing, nature) the aggregations of key demersal species such as pink snapper and dhufish.
2. To investigate the biology, ecology and fishery for Samson fish with emphasis on the sportsfishery targeting deep water spawning aggregations west of Rottnest Island.
3. To establish methods and protocols for monitoring fish aggregations within the WCB.
4. To review relevant information and provide advice on the impact of aggregation fishing and the management of aggregating fish species in WA (with specific advice for key species within the WCB).

Outcomes achieved to date

- **Increased understanding and appreciation of the ecological and fisheries importance of fish spawning aggregations.** This study highlighted the need to properly consider spawning behaviour when managing the impact of fishing activity, and has made fishers and the public much more appreciative of fish in their natural environment.
- **Increased awareness of the tools available for studying and monitoring fish species.** In particular, this study has highlighted the need to match the tool to the budget, species ecology, and habitat. It provides an objective overview of the pros and cons of each tool as well as demonstrating new applications for them. The information gained during this study has since been incorporated into subsequent monitoring studies undertaken by the DoFWA, and enabled more critical review of other studies.

- **'Samson Science' – a highly successful research collaboration between research scientists and recreational fishers.** This widely acclaimed partnership involved a large number of well-trained anglers in a study focussed on Samson fish. It stands as a positive example of the benefits that can be gained through proper commitment to community involvement. The high level of collaboration between research scientists and fishers also extended into other areas of the study, including documentation of fisher knowledge about aggregating fish, provision of 'secret' locations for scientific sampling, and technical know-how to resolve various problems encountered by scientists when using the various equipment.
- **Greater collaboration between research bodies within Western Australia.** The level of cooperation between the DoFWA and Curtin and Murdoch Universities has been outstanding with plans for further collaboration being discussed. The study has highlighted the advantages of combining specific skills for greater mutual benefits.
- **Specific information used in new management plans for West Coast Demersal scalefish species**. This study overlapped with key stock structure and stock assessment studies by the DoFWA on dhufish and pink snapper. The information, techniques and social networks gained during this study were of considerable use in the completion of these associated studies.
- **Development of a broad range and depth of scientific expertise.** Given the formidable task of using high-tech equipment and computer software to gather information about very elusive fish aggregations, this study presented steep learning curves for the two PhD students and numerous staff that were involved. The skills, equipment and programmes developed as a consequence of this research are of significant value to the agencies involved in the study and as a reference tool to others with researchers.
- **Development of protocols for the Samson fish sportsfishery.** Based on detailed review of the fish and fishery, anecdotal evidence and experimental assessment, a handy 'how to' guide aimed at maximising survivorship of released Samson fish was produced. This was of significance given the fact that concern over the impact of this sportsfishery was the initial driver for the broader study, and also because of the growing concern over fish welfare. A number of journal and gray literature articles as well as seminars and TV documentaries have also resulted from this study.

Many strategies have evolved among fishes to maximise spawning success. One of the most striking of these is aggregation spawning, in which individuals group together, often at predictable times and locations in order to reproduce (*cf.* a school, which refers to a group of *non*-spawning fish). Aggregation spawning may enhance the capacity of individuals to select mates, synchronise spawning and optimise survival of offspring. It can also make these fish more vulnerable to capture by fishers. Nevertheless, despite the fact that numerous species of fish aggregate to spawn, it is only in recent years that the ecological and fisheries importance of spawning aggregations has become widely recognised by management agencies.

In Western Australian (WA) waters various species are known to form spawning aggregations and hence may be particularly vulnerable to overfishing. This is the case within the West Coast Bioregion (WCB), where fishing pressure is high and stocks of key aggregating species such as pink snapper and dhufish are depleted. As such, an objective of the current project was to describe the spawning strategies of these and other aggregating species of fish within the WCB, using a range of data sources including formal interviews with fishers and acoustic and video surveys. A preliminary list of 22 aggregating species of fisheries importance was compiled. The review of dhufish (*Glaucosoma hebraicum*) ecology showed that this species has a complex reproductive strategy in which size-based dominance hierarchies determine spawning success amongst individuals. In post-war years aggregations of this species containing hundreds of individuals were observed fairly regularly by fishers. These days dhufish more typically form small aggregations numbering from a few to tens of individuals. Dhufish are typically quite sedentary and individuals may not move far in order to aggregate. Nevertheless those found in southern parts of the WCB may migrate tens of miles to spawn, with the area west of Cape Naturaliste considered to be particularly favoured for spawning by this species. Dhufish are also common within the mid-west zone of the bioregion although individuals are generally smaller in size and do not appear to move as far as those living further south, possibly because of spatial differences in habitat. Whilst this review provided important information about dhufish ecology it also highlighted the poor understanding of this species.

In contrast to dhufish, pink snapper (*Pagrus auratus*) are widely dispersed across temperate and sub-tropical Australia and have been relatively well studied in WA and elsewhere. This is a schooling species that aggregates to spawn. It has been heavily targeted for many years in the West Coast and Gascoyne Bioregions, and provides a good example of the importance of managing fishing pressure on spawning aggregations in order to ensure stocks are not overfished. A particularly well-known and highly vulnerable aggregation of large-sized snapper forms each spring/summer within the shallow waters of Cockburn Sound, adjacent the Perth metropolitan coastline. When aggregated, pink snapper are unlikely to form distinct social hierarchies and males may compete to fertilise eggs by producing higher quantities of sperm rather than by physically controlling access to females. In addition to dhufish and pink snapper, the spawning strategies of mulloway (*Argyrosomus japonicus*), King George whiting (*Sillaginodes punctata*) and Bight redfish (*Centroberyx gerrardi*) were also briefly described in this report.

The research needed for the studies described above requires evidence from a range of techniques. A review of these and how they can be used in monitoring fish aggregations was a second objective of this project. Baited remote underwater and live-viewing video techniques as well as passive and active acoustic techniques are integral to this area of research and were examined in detail. All these methods have particular advantages depending on the behaviour and habitat of the fish species being examined. Each technique also has drawbacks affecting the quality and reliability of the data so gathered. For example, counts of aggregating fish are likely to be underestimated when using video techniques because of the limited camera field of view. Similarly, estimates of fish numbers from single- and multi-beam acoustic surveys can be unreliable if poor estimates of acoustic packing density or target strength are used in analyses.

The potential of passive acoustic techniques for surveys of noise producing species of fish was highlighted by the study of aggregating mulloway in the Swan River. This is a new technique that may provide a cheap and effective means of monitoring the size and dynamics of mulloway aggregations once studies to define the calling characteristics of this species are completed. The review of methods for studying fish aggregations ultimately found that the best data usually comes with a combination of techniques that are suited to the budget, species ecology and habitat.

Initially, the current project was developed in response to concerns raised by charter boat operators over the potential impact of catch and release fishing on the survival and spawning activity of Samson fish (*Seriola hippos*) aggregated west of Rottnest Island. As such, another objective of the project was to study the biology and ecology of this species, and to assess the impacts of the sports fishery that targets it. The large tagging study that was undertaken as part of this research became known as 'Samson Science' and widely acknowledged for its high involvement of recreational anglers. The 7503 Samson fish tagged during this study provided important information about migration patterns and fishing techniques for this species. Few fish visiting the Rottnest Island aggregations came from waters to the north, with most travelling from areas to the south, including two individuals recaptured in South Australia.

The study of Samson fish also showed that this species is well adapted to changes in vertical movement through the water column, having a swim bladder that can rapidly expel gas through connections to highly vascularised tissue underneath the gill plate. This adaptation is uncommon among fishes and affords a relatively high tolerance to fishing induced effects of barotrauma. For example, experimental observations showed that 93% of Samson fish captured at depths ranging from 80 to 113 m survived after capture and release. Most mortality is likely to occur as a consequence of excessive time out of the water because the fish are exhausted and highly stressed after capture. A booklet outlining protocols for catching and caring for Samson fish has been produced and distributed to fishers. Because the Samson fish aggregations are large, relatively immobile and easy to locate each spring, they were also convenient to use for trialling video and acoustic techniques, as described in the review of techniques.

The fourth objective of the project focussed on the management of aggregating species, including issues associated with undertaking stock assessments of them, in controlling fishing pressure on them, and in monitoring their populations levels through time. This review was focussed on management of relatively low value fisheries typically found in coastal waters. It highlighted the importance of considering spawning behaviour in all aspects of the management process, and provided examples of how this can be achieved. With management of fish species within the WCB undergoing major changes at present, the information obtained during this study is timely and integral to this process.

KEYWORDS: Spawning aggregation, West Coast Bioregion, Western Australia, acoustics, underwater video, dhufish, pink snapper, Samson fish, mulloway, fisheries management, recreational fishing.

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1.0 Introduction

1.1 Background

Many strategies have evolved among fishes to maximise spawning success. One of the most striking of these is aggregation spawning[1], often at predictable times and locations. This strategy may enhance the capacity of individuals to select mates, synchronise spawning and optimise survival of offspring (Thresher 1984, Colin and Clavijo 1988). However, despite being found in a wide variety of fish species it is only in recent years that the ecological and fisheries importance of spawning aggregations has been specifically addressed by management agencies (Russell 2001, Sadovy 2005, Colin *et al.* 2003).

This historical lack of focus on spawning aggregations is largely due to the fact that many are of short duration and occur in remote and/or deep locations, making them logistically very difficult to study. The high catch rates and large size of fish that may arise from aggregation fishing can also provide false indications about the health of the fishery and mislead managers into complacency. Nevertheless, the impacts of aggregation fishing became an increasingly critical issue through the 1990s with the advent of GPS technology (Colin *et al.* 2003). This was particularly so in tropical areas such as the Caribbean and Gulf of Mexico where abundances of species like the endangered jewfish and Nassau grouper have become severely depleted as a result of declines in spawning biomass and reduced population fecundity (Eklund *et al.* 2000, Sala *et al.* 2001).

Considerable resources are now being directed towards the management of aggregating species in tropical regions around the world[2]. This is increasingly the case in temperate regions as well, where aggregation spawning is a common strategy for a wide variety of fish species, including those like Atlantic cod and orange roughy that support globally significant fisheries. Indeed, conservation of spawning aggregations has become widely recognised globally as a key element of management programs, being specifically addressed at the 3rd World Conservation Congress, 2004; the 2nd Inter-Tropical Marine Ecosystem Management Symposium, and in the United Nations Food and Agriculture Organisation's Code of Conduct for Responsible Fisheries (Article 6.8).

Fisheries agencies in Australia are also paying greater attention to the aggregating phenomenon when developing management strategies. For instance, on the Great Barrier Reef (GBR) where 133 species are known to aggregate for spawning (Russel 2001), a nine-day fishing closure was implemented in 2004 to protect aggregating fish over the new moon period. Since this time the closure has been increased to three consecutive new moon periods between September and December (http://www.dpi.qld.gov.au). Similarly, protection of aggregating fish has been recommended in the management of orange roughy, eastern gemfish, pink ling and blue grenadier within the Commonwealth Southern and Eastern Scalefish and Shark Fishery

[1] In this report a 'spawning aggregation' is generally defined as a group of conspecific fish gathered for the purpose of spawning. In contrast, a 'school' is considered to be a group of fish that are feeding or migrating together. Both schooling and non-schooling species of fish can form spawning aggregations ('aggregations'). More specifically, we also use the criteria of Domeier and Colin (1997) to distinguish an aggregation: that the number of fish is significantly higher (≥ 3 fold increase) than occurs in the aggregation area during non-spawning periods. However, in some cases this definition may not be appropriate. For instance, with pink snapper it is possible for an aggregation to contain fewer fish than a school, although generally (but not always) the two are spatially discrete. Furthermore, in species such as dhufish in which individuals are typically found at low densities, an aggregation may comprise only a few individual fish loosely grouped together. The critical point being that the fish are reproductively active and grouped together in a manner that increases their vulnerability to fishing activities.

[2] e.g. SCRFA Newsletter # 8 (2005) at http://www.scrfa.org/server/educational/newsletters.htm

(SESSF; Tilzey *et al.* 2006). As a consequence, regional and area closures were enforced in 2005 to protect pink ling during the spawning season.

In Western Australian (WA) waters various species are also known to form spawning aggregations. Well known examples are pink snapper and Spanish mackerel, which are targeted and captured in large numbers when grouped for reproduction. This has previously been of concern to management and led to measures such as catch quotas for both species and, in the case of the Shark Bay pink snapper fishery, temporal closures and prohibition of traps to reduce catches during the aggregating season (Anon 1999; Mackie *et al.* 2003). There are also other examples of WA fisheries in which fish are targeted when aggregated for spawning, although there has generally been little consideration of the long-term implications of this. For instance, sand whiting, Perth herring and yellowfin bream are captured by net fishers taking advantage of their aggregating behaviour (Skepper *et al.* in prep.[3]). Large aggregations of goldband snapper have also been targeted by line fishers in recent years, with the sharp increases in catches and catch rates raising the concern of scientists. This concern is vindicated by the rapid decline in catches after just a few years (Jackson 2006). Of note, however, is the fact that catch rates in this fishery have remained constant at a high level, highlighting the unreliability of this data when used on aggregating species.

Research conducted elsewhere and anecdotal evidence suggests that many other species also aggregate to spawn in WA waters, and thus may be particularly vulnerable to overfishing. This threat is greatest in the West Coast Bioregion (WCB), extending from Kalbarri to Augusta, where the highest concentration of commercial and recreational fishers are found and where stocks of key species such as pink snapper and dhufish are already depleted (Sumner and Williamson 1999, St John *et al.* 2007). As a consequence, major changes in the management of finfish stocks in this Bioregion are now being considered (e.g. Anon 2007).

Concern over the status of finfish stocks in the WCB, along with a more holistic, ecosystem-based approach to fisheries management by the Department of Fisheries in WA (DoFWA), have provided impetus for the current project. First initiated in response to concerns by charter boat operators over the increased targeting of Samson fish aggregations by sportsfishers, this project has evolved to include a broader review of the management and monitoring of aggregating species within the WCB. It is a unique project, involving a high level of collaboration between fishers, universities and the DoFWA, a mix of cutting edge acoustic and video equipment, traditional tagging and anecdotal evidence from fishers, and a focus on ecology as much as the biology of key aggregating species. Specific objectives of this project are provided below.

1.2 Need

Many fish aggregate to spawn. Targeted fishing of aggregations can increase short-term catch rates but also lead to serious declines in aggregation biomass, reproductive output and stock sustainability. Traditional monitoring and stock assessment methods can also be compromised by aggregation fishing (Die and Ellis 1999, McAllister and Kirchner 2000). Globally, the deleterious impacts of aggregation fishing are becoming more evident and the issue is receiving increasing attention. This is highlighted by recent fishing closures to protect spawning aggregations of pink snapper (*Pagrus auratus*) in Western Australia (WA).

[3] Skepper, C. Williamson, P. and Newman, S. Spatial distribution of nearshore commercial, recreational and charter vessel catch and effort data in the North Coast Bioregion – 2002 synthesis. Department of Fisheries, Western Australia Research Report. In preparation.

Nevertheless, there is limited information about the aggregating strategy of fish species in WA waters and the affects that aggregation fishing may have on their stocks. Within the WCB of WA, where there is an urgent need to drastically reduce fishing effort in order to rebuild depleted fish stocks (Wise *et al.* 2007), it is therefore crucial that the aggregating phenomenon is properly considered in management plans.

The potential vulnerability of fish when grouped to spawn and produce offspring is a concept that fishers readily accept. As such, the current project received the strong support from the recreational anglers and their peak body, Recfishwest, due to concerns over the growing fishing pressure on key recreational species of fish. The project also received the support of charter boat operators and the WA Fishing Industry Council with similar concern over the future of fish stocks in WA waters. The project relates to the following Department of Fisheries Strategic Plan Objectives: 1) Improved sustainability of fish stocks and production,. 2) increased economic benefits to the community from fish, and 3) increased industry and community involvement in the development and implementation of management strategies. Information obtained from this study has been included in recent management initiatives by the DoFWA (St John *et al.* 2007, Wise *et al.* 2007), and is considered vital in the further development of plans to manage and monitor fish species within the WCB.

1.3 Objectives

The key objectives of this project, as stated in the original proposal, were:

1. To identify species that aggregate to spawn within the WCB and to describe (e.g. location, size, timing, nature) the aggregations of key demersal species such as pink snapper and dhufish.
2. To establish methods and protocols for monitoring fish aggregations within the WCB.
3. To investigate the biology, ecology and fishery for Samson fish with emphasis on the sportsfishery targeting deep water spawning aggregations west of Rottnest Island.
4. To review relevant information and provide advice on the impact of aggregation fishing and the management of aggregating fish species in WA (with specific advice for key species within the WCB).

These objectives have remained consistent, although the focus of Objective 2 was altered to focus on aggregating species rather than aggregations *per se* because management of aggregations in isolation is usually not sufficient or practical. Further, the methods and protocols determined during this project can also be applied to none aggregating species as well, as discussed in Chapter 5.

1.4 Report Organisation

The report chapters meet the project objectives as follows:

Chapter 3 meets Objective 1.
Chapter 4 meets Objective 2.
Chapter 5 meets Objective 3.
Chapter 6 meets Objective 4.

2.0 Materials and Methods

This project was conducted within the West Coast Bioregion of Western Australia (WCB; Figure 2.1). The data gathering component was comprised of several parts:

1. Fisher interviews to gather supplementary information about aggregating species. This component was conducted by the DoFWA and was mainly focused on dhufish.
2. Review of fisheries data for aggregating species and incorporation of the aggregation phenomenon into management. This component was conducted by the DoFWA.
3. Biological assessment of particular species. Biological data was gathered by DoFWA staff on a range of species whilst conducting other research. Target species were dhufish and Bight redfish.
4. Preliminary assessment of dhufish movement using acoustic tags – conducted as a part of a PhD project by Jason How through Edith Cowan University in collaboration with the DoFWA. This study was commenced part way through the project in an attempt to clarify dhufish movement patterns. However, the study became focussed on the technique rather than results due to low survival of tagged fish.
5. Passive and active acoustic techniques – conducted as a PhD project by Miles Parsons at Curtin University in collaboration with the DoFWA. This component focused on technological aspects as well as on individual species – particularly Samson fish and mulloway.
6. Underwater video techniques – completed by the DoFWA with input from the University of WA and the Australian Institute of Marine Science. This component focused on technological aspects whilst collecting data or validating acoustic data for individual species – particularly dhufish and Samson fish.
7. Samson fish biology, ecology and fishery – conducted as a PhD project by Andrew Rowland at Murdoch University in collaboration with the DofWA. This component also involved extensive collaboration with recreational anglers and peak bodies. In addition, a separate study of Samson fish otolith microchemistry was undertaken by the DoFWA.

These parts were overlapping and complementary, but generally required separate focus and hence are considered separately here. Field data were gathered during trips on board recreational and charter vessels, and onboard the DoFWA research vessels *RV Snipe* (7.1 m, 150 kW) and *RV Naturaliste* (21 m, 373 kW).

2.1 Fisher interviews

The ephemeral and often remote nature of spawning aggregations makes them very difficult for scientists to locate and study. As such fisher knowledge has become a cost effective and useful way of obtaining data on them, particularly in remote areas of the tropical Indo-Pacific region (Hamilton *et al.* 2005).

Fisher interviews were also considered an important means of gathering data during the current study. These interviews were conducted as an informal, one-to-one discussion in which the interviewer (always the PI) commenced with a description of the project and reason for the interview, and then asked a series of questions (Appendix 7). Answers were taken in note form. Each interview took about one hour. Where possible locations were sketched onto tracing paper overlaying a marine chart. This method of collecting data was successfully used during a stock assessment of Spanish mackerel (Mackie *et al.* 2003).

A total of 55 fishers and divers were surveyed in this fashion. The interviewees were retired/current commercial and recreational fishers/divers who ranged considerably in age and experience. They were selected because they were known to have had considerable experience and knowledge of fishing and diving within the WCB, and/or because they were known to have observed aggregations or schools of fish. In most cases the information was vague, with uncertainties in times and places, or in more specific detail such as fish colouration or behaviours. A few fishers – particularly retired commercial fishers who had spent many years at sea – provided the most useful information about fish behaviour and other information, although they could not always provide specific data on locations if they fished prior to introduction of electronic navigation aids. Data on specific locations was indeed the hardest to obtain, mainly due to an unwillingness to divulge 'secret spots' or lack of access to such data at the time of interview. The information generally focussed on dhufish because this is the species of most interest to many people (including the survey group), and because the ecology of this species is not well known and the subject of considerable debate. The interviews provided information about the following:

- List of species that form spawning aggregations
- Density of aggregating species when and when not aggregating
- Behaviour of aggregating fish
- Location and timing of aggregations
- Location of habitat suitable for research surveys

Information obtained from the interviews was important for planning field trips, obtaining ongoing assistance (e.g. in sample collection and further advice) and in supporting the findings of other components of the project.

2.2 Commercial Catch and Effort Analyses

The commercial fisheries for pink snapper and dhufish have previously been described by St John and King (2005), using data from the Department of Fisheries catch and effort system (CAES). During the current project the CAES database was interrogated for evidence of aggregation fishing. Species included for detailed examination were dhufish, pink snapper, Bight redfish and Samson fish while others (breaksea cod, greybanded cod, hapuka, King George whiting, mulloway, queen snapper and skipjack trevally) were cursorily examined for any evidence of aggregation fishing.

Initially, the data for each species was examined for each bioregion and then for the areas within the WCB (see Figure 2.1). The data were further analysed by block (1^0 square), month and method for any patterns of high catches. Where possible, the spatial resolution of the data was increased by focussing on blocks in which the fishable area was reduced because of land or water depth. Anecdotal evidence from fisher interviews assisted in this process. To calculate the effective catch per unit effort (CPUE), which allows for advances in technology over the years, the effort data (Block Day) was transformed to effective effort (Ross Marriott, *pers. comm.*). The effective CPUE data was calculated using this effective effort and was investigated as per catch data. The overall average effective CPUE was calculated for each species and any high CPUE data (3- 5 times the overall average, depending upon species) was extracted. The monthly distribution for each block of these high CPUE returns was investigated for evidence of peaks in the monthly frequency, which may indicate the regular fishing of aggregations. Finally the data were split into 5-year time intervals and the monthly averages of catch and effective CPUE for each block were plotted to display any changes in annual patterns.

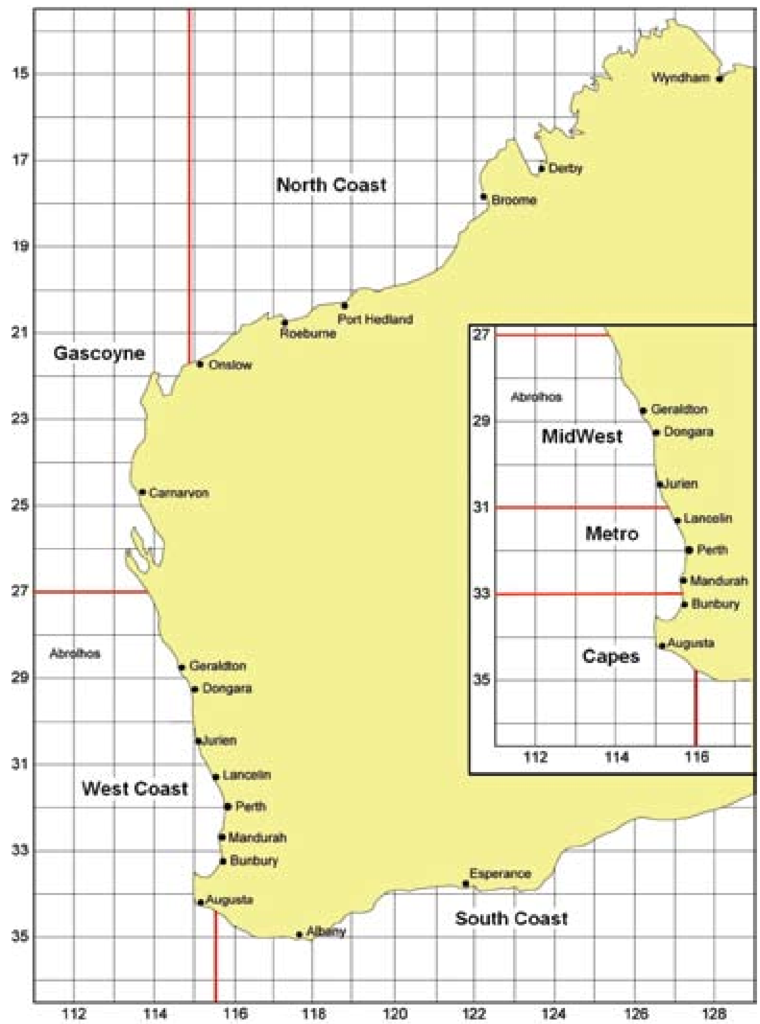


Figure 2.1. Map indicating Bioregions used in the management of Western Australian fisheries resources. Squares are catch and effort reporting blocks for the commercial fishing sector. Areas within the West Coast Bioregion are shown in the inset.

2.3 Recreational Tagging Data

Recreational tag and release data for dhufish were obtained from the Australian National Sportsfish Association (ANSA) via Andrew Rowland, coordinator of the database at the time. These data was used to investigate movement patterns between release and recapture. To plot these movements a latitude and longitude was needed for both release and recapture locations. In most instances there was no latitude and longitude information given for the release and/or recapture locations and often only a very general location is recorded (e.g. NW Rottnest Island, Port Gregory etc). In some cases, however a general latitude and longitude could be allocated (e.g. 3NM WSW MINDARIE could be allocated as Latitude-31.72° S and Longitude 115.65° E). From the information given, 67 of the 155 dhufish recaptures had sufficient information for coordinates to be allocated to both the release and recapture locations. For fish that showed some movement the release and recapture locations were plotted with the dates of each, although 5 of the 17 in the metropolitan area were missing one of the dates. The remaining recaptures were in the same general location as they were originally tagged and were plotted in different colours depending upon whether the release and recapture was in the same annual season or not. This was done to investigate any possible relationship between location and season. There were another five recaptures outside the metropolitan area that had only general location data and were not used in analyses.

2.4 Field Surveys

Data required for biological, acoustic, video and other components of the project were collected during field surveys conducted onboard research and recreational vessels (n ≈ 200 days). The DoFWA research vessels *RV Snipe* (7.1 m) being used extensively for day trips and the *RV Naturaliste* (21.6 m) used during ten extended field trips of up to 16 days duration throughout the WCB. Most of these trips utilised the whole range of sampling methods, although trips conducted with the multi-beam acoustic equipment focussed on this method. Refer to Appendix 4 for details of the surveys conducted whilst onboard the *RV Naturaliste*, and at Geographe Bay whilst onboard the *RV Snipe*.

2.5 Biological Studies

Data and biological samples for relevant fish species were collected from fish processors, recreational fishers and by research staff in the field. The numbers of samples per species varied considerably and were used mainly to gather information about reproductive activity. Otoliths were also collected from most fish sampled but not analysed as part of this project. Only samples of dhufish, Samson fish and bight redfish were specifically targeted, whilst samples of other species were taken opportunistically. Methods used in processing and analysis of gonad and otolith samples followed those of Mackie and Lewis (2001), Lewis and Mackie (2002), and Mackie *et al.* (2007).

Processing of samples

The total length (TL) and fork length (FL) of each individual was measured to the nearest 1 mm. When whole fish were sampled the whole weights of fish < 10 kg were weighed to the nearest 0.02 kg, while those > 10 kg were weighed to the nearest 0.1 kg. Whenever possible, the gutted and gilled weight was also obtained for the main species.

Reproductive biology

Where present the gonads were, macroscopically staged according to the staging system used by Mackie and Lewis (2001), for Spanish mackerel and other species:

Females: I – virgin, II – mature resting, III –developing , IV – reproductively developed, V – spawning, VI – spent. **Males**: I – virgin, II - mature resting, III – reproductively developed, IV – spawning.

If possible gonads were weighed to the nearest 0.1 g, and the whole gonad or a five centimetre cross section from the mid region of one lobe was preserved in 10% buffered formalin solution and retained for histological examination. Preserved gonads were later weighed and histologically processed (6μm transverse sections, stained with Mallory's trichrome).

The gonadosomatic index (GSI) was calculated using the equation: GSI = W1/(W2-W1) X 100, where W1 = the fresh gonad weight and W2 = the whole fish weight, i.e. W2-W1 = somatic plus gut weight. The GSI was calculated using data for female fish ≥ the estimated L_{50} at first maturity.

Where whole weight could not be measured an estimate of whole weight from the length-weight equation was used. It is acknowledged that GSI values determined using these weight estimates are approximate only. For Bight redfish, where this equation was not available, a proxy of GSI (gonad weight to fork length ratio) was used (ie GSI index = GW/FL*100). These data were considered suitable for the analyses used in this study.

Age and growth

The otoliths of all fish processed were saved in labelled envelopes. However, only those of Bight redfish and Samson fish were used during the current project. These were weighed (to 0.001g) and sectioned for ageing (see Section 2.11.4.). In addition, eight Samson fish otoliths were provided for the microchemistry component of the study (see Section 2.11.6). Dhufish otoliths collected during this study were passed on to the investigators of FRDC project 2003/52 (Spatial scales of exploitation among populations of demersal scalefish: implications for wetline management) for inclusion in relevant analyses.

2.6 Acoustic tags

Initial field trials of surgical techniques for acoustic tags implantation were completed within Geographe Bay and near Garden Island (Fremantle). Tracking of acoustically tagged dhufish was undertaken off Two Rocks, north of Perth, (Figure 2.3).

2.6.1 Assessment of surgical techniques

Surgical trials on threes species of cultured fish

Initial surgical techniques were developed and refined through surgery on six individuals from three species of fish; three pink snapper (*Pagrus auratus*), two mulloway (*Argyrosomus hololepidotus*) and a tarwhine (*Rabdosargus sarba*). Each fish was placed in a tank and anaesthetised using clove oil. A three centimetre incision was made starting approximately two centimetres from the anus, and two centimetres laterally from the midventral line (Zeller 1999). A Betadine ™ soaked dummy tag was implanted, the wound was closed with monofilament, non-absorbable sutures and an antibiotic injection of oxytetracycline was administered intramuscularly. The fish was then transferred back into a holding tank with air or oxygen bubbled underneath their gills and fresh seawater introduced periodically for recovery.

Field assessment of surgical techniques on dhufish.

Dhufish were caught on hook and line at depths of less than 30 m to reduce barotrauma related injuries. Each fish was retrieved slowly, placed in a holding tank and transported to the release site (if different to the initial capture site). Dhufish then underwent the same surgical procedure as above. Once the dhufish was showing signs of recovery (tail kicks or finning), a sling was used to transfer the fish from the tank to the sea cage. A wet towel was used with all handling and transfers to reduce stress and damage. The sea cage was then slowly lowered to the bottom.

Divers monitored fish in the sea cages recording swimming activity and cage position, stress colours and other relevant behaviour. Although monitoring was planned for several time periods; immediately after release into the cage, day one and day of release (either day two – four) this was not always possible due to weather. Some dhufish were used to evaluate various elements of the surgical procedure. They were only taken through stages of the capture, anaesthesia, surgery and recovery procedure. For example, capture and immediate release into a cage; captured, anaesthetised and then released into a cage; captured, released into a cage, cage retrieved 48 hours later when surgery was performed and returned to the cage.

Other techniques of attachment or insertion

Because of high mortality among dhufish used in surgical trials, other techniques of attachment were also trialled. These trials were initially conducted on pink snapper, with dummy tags attached externally in either the gill plate or dorsal musculature without anaesthesia (Figure 2.2). Attachment through the gill plate was done by punching a hole in the gill plate using a leather punch. The dummy tag was then cable tied through the hole to the gill plate. Attachment through the dorsal musculature was made using two threads passing through the musculature using needles. This was carried out on two pink snapper with one being anaesthetised with clove oil for seven minutes before a five minute procedure and ten minute recovery in an oxygenated recovery tank. The second pink snapper was done without anaesthesia with a procedure only lasting two minutes. It was returned directly to the holding tank with no recovery time.

Figure 2.2. External attachment of dummy tags to pink snapper through the dorsal musculature.

A wild caught dhufish was transported back to a holding tank. After being held for 132 days, it was fed a dummy tag in bait. Daily observations were undertaken to see if there was a change to behaviour whilst tagged, while also establishing retention time of the tag.

Alternative wound closure methods

Six aquaculture-reared mulloway were purchased to examine three different methods for wound closure. This was done to examine effectiveness of wound closure, but also time taken to complete surgery. This was thought to be one of the contributing factors to high mortalities among dhufish used in surgical trials (see Results). The three methods examined were absorbable sutures (Ethicon™), non-absorbable sutures (Dynek Vilene™) and surgical glue (Vetbond™). Dummy acoustic tags were inserted into two mulloway without anaesthesia, and the wounds closed using one of the above materials. They were then allowed to recover in a bath of oxygenated seawater before being returned to the holding tank.

2.6.2 Range test of acoustic transmitters and receivers

Range testing of acoustic equipment was done on two days reflecting different swell conditions. This was undertaken at Two Rocks, the same site where acoustic tracking occurred (Figure 2.3). On the 5th October 2006 swells averaged about four metres during the range test. This test ran for three time blocks of thirty minutes to provide distances 0 – 613 m before moving the zero mark with the tag on it 400 m away to get distances 492 – 1020 m for a further three thirty minute blocks (Figure 2.3). Receivers were then retrieved and data downloaded. On the 10th

October 2006 swells averaged about 2.5 m. The test ran for seven thirty minute time blocks, with the configuration not as linear as the original test (Figure 2.3) because some receivers used in the range test were left to form part of the array. As such, the range test was done over seven distances from 0 – 998 m.

Each 30 minute time block was considered an independent replicate for the number of hits received during that time period as any time periods results was not affected by the results of any other time period during the test. The number of hits per time block was standardised to the maximum number of hits recorded during this time period. This was to account for the differing number of pings that would be emitted by the transmitter due to it random timing of ping emissions between 20 and 60 seconds. Therefore, the data presented in this report is the average proportion of the maximum hits received during the range test.

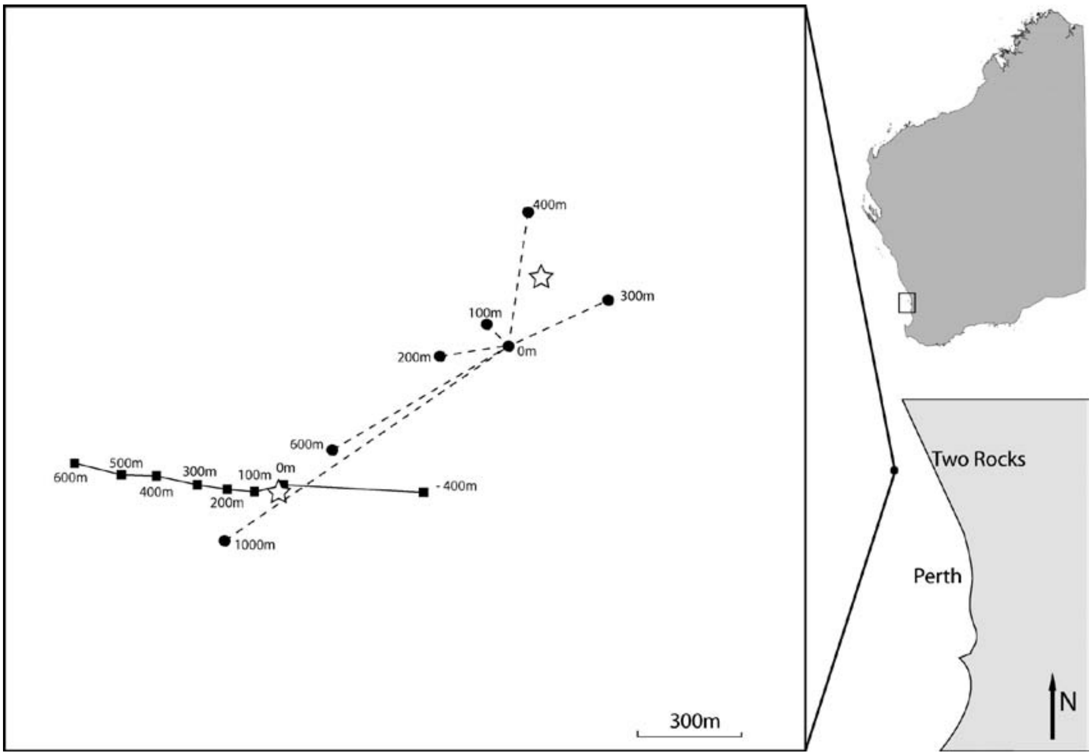


Figure 2.3. Configuration of the two range tests conducted off Two Rocks. Receivers illustrated with solid squares and solid circles and linked with solid or dashed line for high swell and low swell range tests respectively. Star indicate location of known reef areas where fish were tagged and released.

2.6.3 Array deployment and configuration

Vemco™ VR2 receivers were suspended two metres above the bottom by two subsurface floats. The system was anchored using a concrete block (approximately 25 kg) with chain linking the block and a sand anchor. An array of three receivers was initially deployed on the 14th July 2006 and retrieved on the 27th September 2006 (Figure 2.4a). With the addition of more receivers an array of 5 receivers was redeployed a week later on the 5th October (Figure 2.4b), before being adjusted 5 days later on the 10th October 2006 after analysis of initial range testing results (Figure 2.4c). The experiment was terminated on the 27th of November 2006 having a total tracking time of 129 days over the two tracking periods.

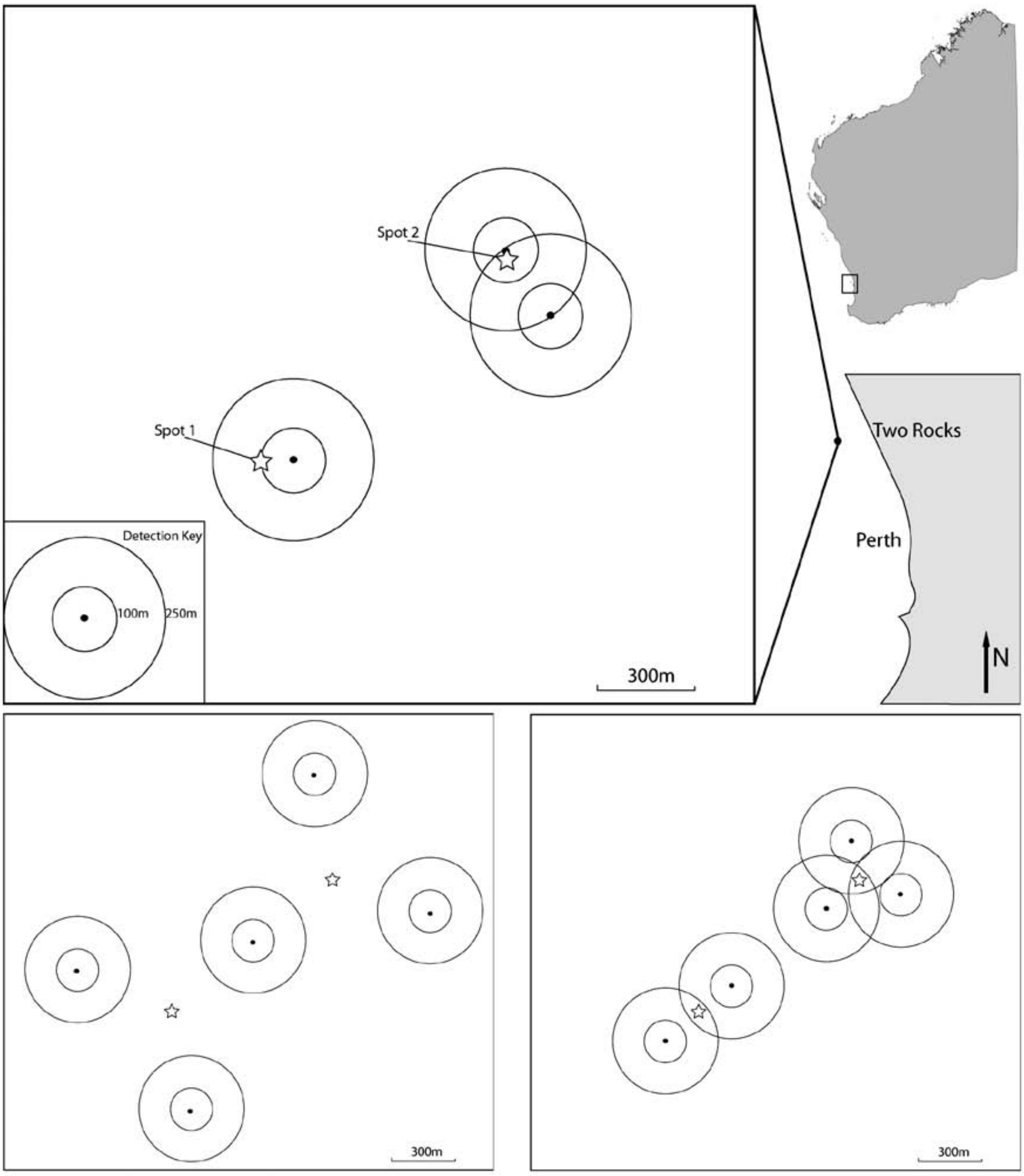


Figure 2.4. Location of the tracking site a) initial array configuration; b) larger array deployment; c) reconfigured larger array. Stars indicate reefs where fish were tagged; dots the location of the receivers in the array.

2.6.4 Tracking of dhufish using acoustic transmitters

On the 14th July 2006 two dhufish were tagged off Two Rocks with V9-2H acoustic tags that emitted a coded signal randomly between 20 – 60 seconds (Figure 2.4). Fish were tagged externally through the dorsal musculature using the no anaesthesia procedure outlined above for pink snapper. Fish were caught with circle hooks and line from 40 m of water, and brought to the surface slowly. Once tagged, they were returned with a release weight to ensure they reached the bottom as quickly as possible to mitigate any barotrauma related effects.

2.7 Single-beam Acoustics

Active acoustic techniques were employed during designated surveys to locate and assess aggregations of Samson fish (*Seriola hippos*) predominantly at sites west of Rottnest Island (Figure 2.5), mulloway (*Argyrosomus japonicus*) in Mosman Bay, Swan River, dhufish (*Glaucosoma hebraicum*) at sites along the West Coast Bio-region, pink snapper (*Pagrus auratus*) in Cockburn Sound and Bight redfish (*Centroberyx gerrardi*) at sites near Cape Naturaliste. Additional surveys were also conducted at sites within the West Coast Bioregion. Metadata files outlining data collected during these surveys are contained in Appendix 7.

Single-beam acoustic surveys employed a Simrad EQ60 dual frequency, single-beam echosounder, operating at 38 and 200 kHz. Acquired acoustic backscatter data were analysed using SonarData's Echoview software and a suite of Matlab techniques developed by the CMST, Curtin University.

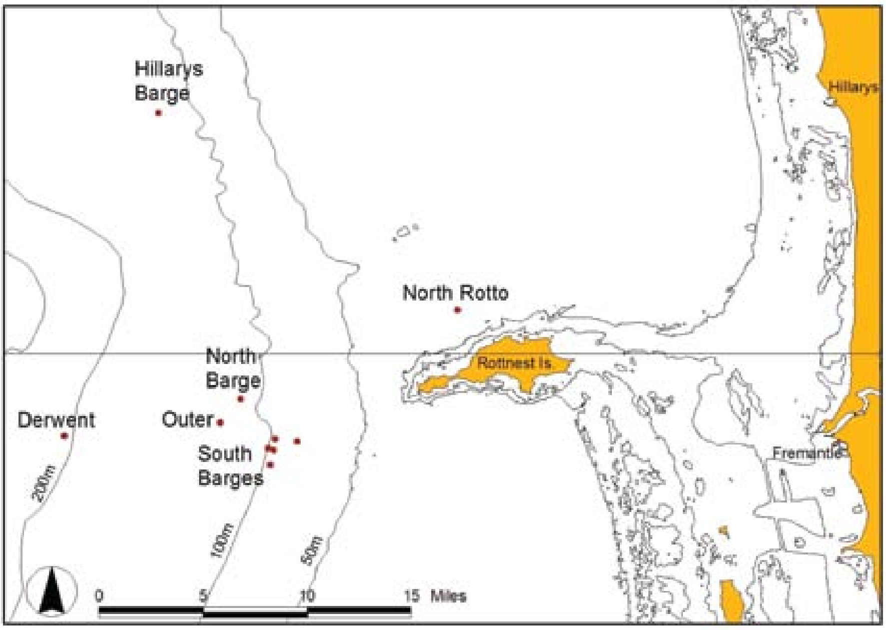


Figure 2.5. Main Samson fish aggregation sites known in the metropolitan region.

2.7.1 Calibration of Simrad EQ60

Calibration of the Simrad EQ60 single-beam echosounder took place in July 2007 at the CMST marine research site in Jervoise Bay, Cockburn Sound. A schematic of the calibration mounting is shown in Figure 2.6. A section of the experimental site comprised a 3 m high pier extending into 8 m depth of water. The EQ60 was mounted on the bow of the Curtin 4 m outboard vessel, which was in turn attached between pier supports for stability. The transducer head was located 0.8 m below the surface, directed vertically downwards. Above the water surface three 1 m poles extended horizontally from the transducer head mount at 120° angles between each pole. Along each of these poles ran a 6.2 m fishing line, of adjustable length, hanging over the end and down into the water where all three lines were combined at a depth of 5 m. Attached to the line at the inverted apex was a tungsten carbide target sphere of diameter 3.8 cm (for calibration of the 38 kHz transducer), 4.2 m directly below the transducer head.

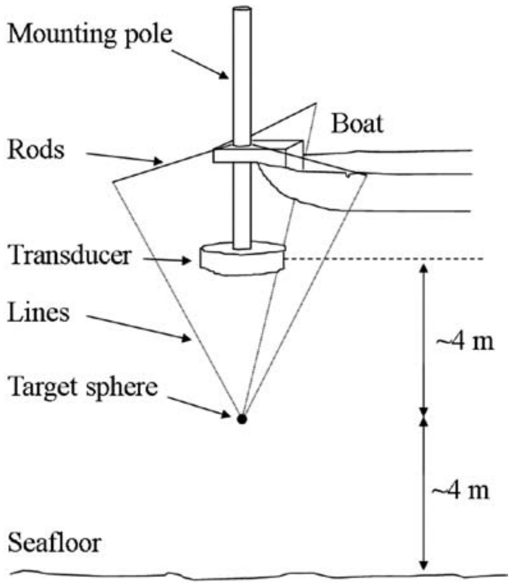


Figure 2.6. Schematic of calibration mount for Simrad EQ60 echosounder.

With the transducer in active mode the fishing lines were adjusted until a maximum backscatter reading was detected to ensure the target sphere was in the centre of the acoustic beam. Each pulse duration was tested for one minute to ensure replication of the maximum target strength value from the lowest power (100 W) to the maximum (1000W) to identify any power dependence and therefore linearity in the power settings. The 38 kHz and 200 kHz frequencies were tested separately and together to determine any interference. Data were then imported into Echoview for processing and the calibration offsets for the system for both 38 and 200 kHz beams were calculated.

2.7.2 Survey Techniques

Single-beam acoustic surveys were conducted aboard three vessels, dependent on time and location of the study. A large proportion of surveys were conducted aboard the Fisheries *RV Snipe* in waters within the West Coast Bioregion, predominantly, and at Samson fish sites west of Rottnest Island. The generator run Simrad EQ60 was pole mounted on the port side of the vessel as shown in Figure 2.7 such that whilst travelling the transducer remained above the water and during survey was located 1.6 m below the surface directed vertically downwards. Surveys were conducted with transducer settings of 512 µs pulse duration and 500 W power for the 38 kHz transducer and 1024 µs pulse duration and 500 W power for the 200 kHz (due to greater attenuation at the higher frequency).

Figure 2.7. Simrad EQ60 mounted on board the RV Snipe.

Study sites surveyed by the *RV Snipe* included 7 Samson fish aggregation sites at wreck locations, west of Rottnest Island, dhufish sites in Geographe Bay recommended by local fishermen, and pink snapper in waters off Jurien Bay. Surveys of Samson fish aggregations were conducted using a grid of transects (Kloser *et al.* 2001; Doonan *et al.* 2003) to gain the greatest coverage of the aggregation. By comparison with star formation surveys the gridded transects provide greater sampling at the expense of necessary assumptions of temporal aggregation uniformity (due to additional survey time). An example of the grid survey, together with Samson fish aggregation boundaries is shown in Figure 2.8. The grid surveys lasted approximately 30 – 45 minutes per site and attempts were made to conduct surveys at the same time of day for each survey. Vessels speeds were maintained at 2-3 knots.

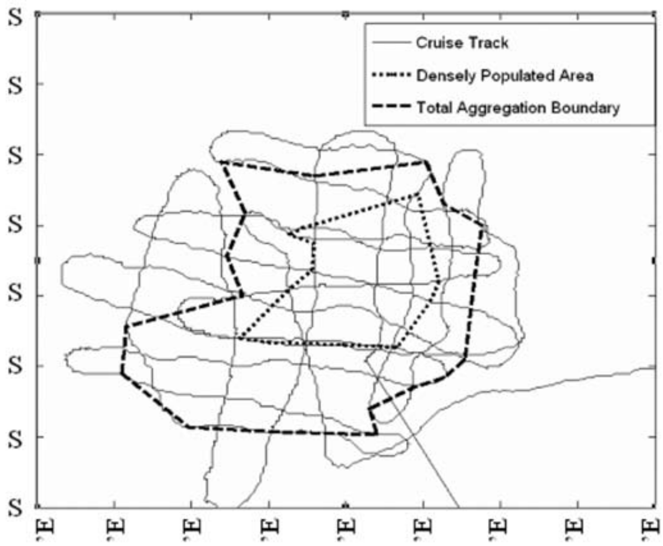


Figure 2.8. An example map of transects conducted in the *RV Snipe* over Samson fish aggregations. The cruise track is shown as a black line, and boundaries of the aggregation as dotted and dashed lines.

Surveys in Geographe Bay and adjacent Jurien Bay employed a more adaptive ‘star’ method of transects (Doonan *et al.* 2003), with the ability to survey an aggregation more rapidly before the school migrates or exhibits vessel avoidance and facilitating rapid mobilisation to ground truth either by towed video or biological sampling.

During surveys conducted aboard the *RV Naturaliste* the Simrad EQ60 was pole mounted either on the port side (in cases where it was the only echosounder present), or on the starboard side (during dual multi- and single-beam surveys). In the first case the pole mounted transducer was located 3.45 m port of ships centreline and surveyed with the transducer at a depth of 1.9 m, directed vertically downwards. In the second case the transducer was at a depth of 2.77 m and 3.5 m starboard of ships centreline. Surveys conducted aboard the *RV Naturaliste* combined grid transects and star pattern surveys dependent on weather conditions and time constraints. Over the period of this project dhufish, Samson fish, Bight redfish, pink snapper and mulloway aggregations have been surveyed between Cape Naturaliste and the Houtman Abrolhos Islands.

Acoustic single-beam data were also collected in Mosman Bay from a 4 m Curtin University vessel employing a side mounted Simrad EQ60. Speculative transects were conducted around the Mosman Bay, Blackwall Reach region of the Swan River in January 2005 in an attempt to observe spawning Mulloway.

2.7.3 Ground truthing

The conventional method of ground truthing active acoustic surveys is the use of trawlers (McClatchie *et al.* 2000; Simmonds *et al.* 1992). This is due to logistics and sample size, although even trawl samples do not provide reliable composition data (Hammond and Swartzman 2001). However, the size of the aggregations of interest, combined with logistic availability require that ground truthing of species identification in the present work be conducted through video techniques and direct sampling (line fishing). Ground truthing during surveys for Samson fish, dhufish and Bight redfish to confirm species composition and reproductive status of individuals, were conducted as per Chapters 3 and 5. This also provided the length data required for the acoustic models. Spawning mulloway in Mosman Bay for single beam acoustics were ground truthed as per Section 2.9, however, their presence in single-beam data is unsubstantiated as it is near impossible to catch the individual fish surveyed and video techniques are inapplicable at times when spawning occurs due to light and turbidity levels.

2.7.4 Data processing

Data collected with the Simrad EQ60 was imported into SonarData’s Echoview software for processing. To gain abundance data derived solely from the aggregations, transects were visually truncated from the echogram to create regions bounding only fish deemed members of an associated aggregation (Doonan *et al* 2003). The regions integrated by Echoview, yielding Nautical Area Scattering Coefficients (NASCs), were then manipulated to give an equivalent NASC for separate, whole aggregations.

Derived from the area backscattering coefficient (MacLennan and Fernandes 2000) the relationship between NASC and the biomass used within the aggregation is as follows;

$$B = \frac{NASC}{4\pi 10^{\frac{TS}{10}}} \times W \qquad (1)$$

where B = biomass (tonnes/n.mi^2), W = whole weight of an individual fish (kg), and TS = target strength (dB).

However, as there is currently no accurate target strength/length relationship for Samson fish target strength relationships for fish similar, and therefore acoustically comparable to the Samson fish, were supplemented and compared to help authenticate the data and provide some level of biomass estimate. Tuna target strength at 38 kHz can be expressed as

$$TS_{YF} = 25.26 \log FL - 80.62 \quad (2)$$

$$TS_{BE} = 24.29 \log FL - 73.31 \quad (3)$$

where TS_{YF} and TS_{BE} are target strengths of yellowfin and bigeye tuna respectively and FL = fork length (cm), (Bertrand & Josse 2000). The fork length was taken as the average of statistics collected from both sets of ground truth data.

Combining this with a relationship between Samson fish total length (TL; mm) and weight (kg) (Mackie 2005, *pers. comm.*, June 2005) where

$$W(kg) = 4.9813e\text{-}9 \times TL(mm)^{3.0924} \quad (n = 249,\ R^2 = 0.92) \quad (4)$$

estimation of biomass present at each site, on an Elementary Distance Sampling Unit (EDSU) level was possible.

Data on aggregation size, shape and position were extracted and catalogued from the echogram at the school level as laid out by Reid *et al.* (2000). Estimation of the overall scattering area of the aggregations from these data enabled the calculation of the population density of the aggregating fish and temporal comparison throughout the spawning period and across various sites.

The CMST have developed Matlab programs to analyse *in situ* recorded values of target strength which will be compared to *ex situ* data collected from an experimental site in Jervoise Bay outlined in Section 2.7.5. Visualisations of the aggregations were formed by displaying regions of an echogram determined to be backscatter from fish in a 3-D plane. These present an idea of the structure and volume of the aggregation and an idea of where outlying fish may be present.

2.7.5 Modelling of acoustic target strength

To date it has not been possible to develop a 3-D model of Samson fish acoustic target strength. An experimental site has been designed in Cockburn Sound, Perth. The site will comprise a floating pontoon, attached to a 6 x 6 x 3 m, 3/8" mesh, net cage. Individual Samson fish will be acoustically monitored within this cage using the Simrad EQ60. Positioned vertically downwards with an external trigger attached to a camera the echosounder will acquire target strength measurements from the fish whilst at a recorded location within the acoustic beam. Monitoring fish of varying lengths from numerous dorsal and lateral angles will help build a three dimensional model of the length/target strength relationship for the species to be compared with *in situ* data.

2.8 Multi-beam Acoustics

Two surveys were conducted employing RESON 8125 and RESON 7125 multi-beam sonars in October 2005 and February 2007 respectively, aboard the Fisheries *RV Naturaliste*. The October 2005 survey targeted the Samson fish aggregations west of Rottnest Island. The February 2007 survey targeted Samson fish, dhufish and Bight redfish aggregations between Perth and Cape Naturaliste. Details of data acquired during these surveys can be found in Appendix 7. Calibration of the multi-beam systems for volume backscatter was not conducted as system adherence to manufacturer's specifications was assumed (the system specifications for seabed backscatter were calibrated and found to meet manufacturer's specifications). Ground truthing for multi-beam surveys were conducted as per Section 2.7.3.

2.8.1 Surveys

Between the 18th and 21st October, 2005 a RESON 8125 multi-beam sonar was mounted on the port side of the *RV Naturaliste* 3.45 m from the centreline of the vessel and at a depth of 2.77 m, with principal axes directed vertical downwards and swath positioned athwartships. The system was operated at 455 kHz and 240 0.5° beam formed echoes generated a 120° swath. Originally designed to acquire backscatter from the seafloor, software modifications were made to the RESON 8125, as per RESON guidelines, to allow acquisition of water column backscatter data in the form of 'snapshots'. During the 18th and 19th October transects over the aggregations were used to estimate optimum settings to acquire unsaturated backscatter from the Samson fish. At the maximum range of 120 m the system settings to maintain high acoustic resolution and avoid saturation were determined as a power level of 10, receiver gain 30 dB and pulse duration 292 µs. At these settings the maximum available ping rate was approximately one ping per 4.5 seconds. Vessel speeds were maintained between 2.5 and 3.2 knots resulting in 5.8 to 7.4 m travelled between consecutive acoustic pings (excluding effects of pitch and yaw). During this survey the Simrad EQ60 was mounted on the starboard side of the vessel (see Section 2.7.1.). Ships positions were recorded using a differential GPS signal. Acoustic beam positions of the Simrad EQ60 and RESON 8125 are shown in Figure 2.9 along with an image of the RESON 8125 prior to mounting.

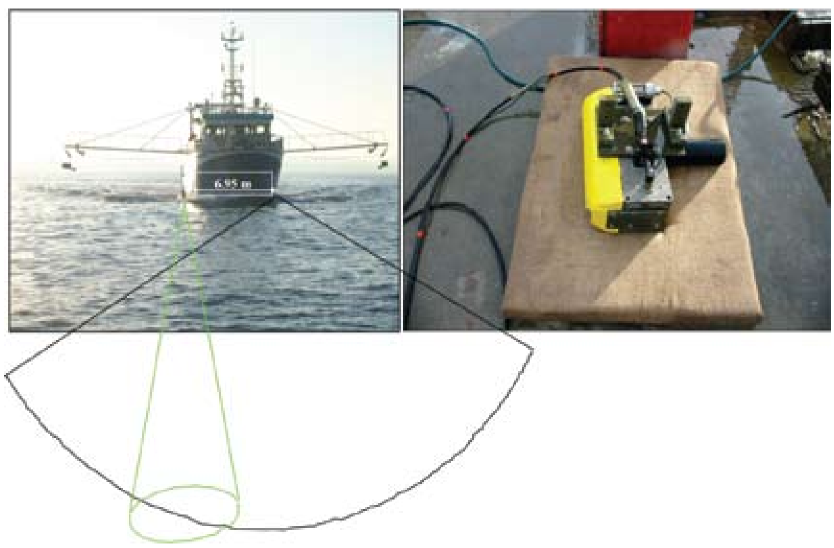


Figure 2.9. *RV Naturaliste* with schematic of acoustic beam positions for multi-beam swath (black) and single-beam cone (green), and (right) image of RESON 8125 multi-beam echosounder.

Initial transects during the February 2005 survey were conducted to obtain backscatter from the seafloor and corroborate habitat features/classifications. System settings for surface backscatter were optimised at pulse rate 92 μs, power of 220 dB and gain of 20 dB. Aggregations of Samson fish are known to be typically of a size which can be covered in a single transect encompassed in the sample volume of the multi-beam swath. Acoustic transects were conducted at varying distances from the centre of the aggregation to gain a perspective of multi-beam performance at varying positions within the sonar swath. Water column transects were conducted over the aggregations at five wrecks in north-south and east-west directions. A total of 31 acoustic transects were carried out over the Secret Spot, North Barge and Outer Patch sites.

From the 1st to 8th February, 2007 a survey aboard the *RV Naturaliste* was conducted with a RESON 7125 multi-beam sonar targeting Samson fish, dhufish and Bight redfish. Surveys were conducted at the recurring sites west of Rottnest Island and at the wreck of the Derwent as well as sites within the West Coast BioRegion noted from anecdotal fishermen evidence and previous surveys. The RESON 7125 was mounted on the port side as per 8125 directions. Beam formed echoes of 528 0.25° beams generated a 120° swath athwartships and system frequency was operated at 400 kHz. System settings for operation at 400 kHz were maintained at a pulse rate of 150 μs, power of 220 dB, gain of 25 dB, and range of 175 m. At this range and pulse rate the ping rate of the RESON 7125 was approximately 1.2 seconds between consecutive pings. Combining ping rate with a vessel speed maintained between 4 and 5 knots, consecutive pings ranged between approximately 2.29 m and 2.88 m apart in alongships direction. This separation excludes effects of pitch and yaw which can create overlap at the extents of the swath. At each site individual transects were made north-south and east-west to gain the highest possible coverage of the aggregation.

2.8.2 Data processing

Acoustic data were processed using a combination of SonarData's Echoview software, multi-beam and fish school detection modules for the water column data, and a suite of Matlab algorithms developed at the Centre for Marine Science and Technology (CMST) Curtin University for the seafloor backscatter converted from RESON 7k format data files. Initial recordings taken with RESON 7125 displayed significant interference, which while not isolated, was attributed to 'significant ships electrical interference' and not related to the multi-beam system. Figure 2.10 displays an example swath and the interference detected by the RESON 7125 (left image), relative Sv values were thresholded at 12 and 28 dB, graduated as per the colour bar. The figure includes an acoustic snapshot of an aggregation of Samson fish (right of the swath) and how the fish backscatter is visible against the interference. The right image of Figure 2.10 illustrates the acoustic response at the same threshold levels after noise removal processing. Noise removal involved subtraction in the linear domain of mean backscatter from a ping subset contained within the same transect in which individual pings did not display evidence of fish presence. Time varying gain was then reapplied to the remaining ping subset leaving only backscatter attributable to fish. Data acquired at greater range required further filtering.

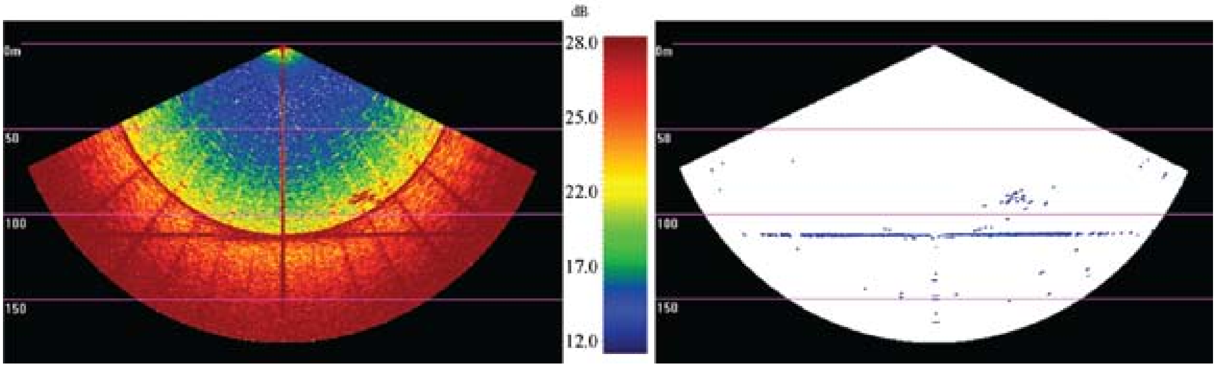


Figure 2.10. An example of electrical interference found on a multi-beam survey aboard the *RV Naturaliste*. Acoustic noise displayed as lines running away from the sonar (top of left image). Right hand image shows remaining seafloor and aggregations backscatter after processing.

Three dimensional visualisations, target detections and biomass estimations were conducted through Echoview multi-beam and fish detection modules. Regions formed from detected targets delivered volumetric information on the aggregation. Initial attempts to detect fish schools were restricted by the overlapping of consecutive swaths caused by the effects of vessel direction against strong winds. During processing a Kalman filter was applied to GPS data to limit effects of this overlap, however, targets still remained undetected and school detection was limited to within individual pings. The detected targets were then extended through an estimated length between pings to form regions, for visualisation purposes.

2.9 Passive Acoustics

Passive acoustic surveys were undertaken for: 1) mulloway in Mosman Bay which were monitored over short and long term periods, and 2) dhufish, Samson fish and Bight redfish, which were targeted for short term monitoring. Passive acoustic data were processed via CMST designed Matlab programs. Metadata files for passive acoustic surveys can be found in Appendix 7.

2.9.1 Biological/ behavioural species assessment

Biological sampling conducted as per Section 2.5 revealed anatomical characteristics such as otolith size and position, swimbladder size, position and material, and muscular proximity to swimbladder (functions and effects of which are outlined in Section 4.3). The anatomical character determined if it was thought a species was likely to exhibit vocal behaviour. Behavioural information was obtained from anecdotal evidence from recreational fishermen, previous single-beam acoustic surveys and catch data. From these data a structure and habitat within which the species formed an aggregation was inferred.

2.9.2 Survey techniques

Passive acoustic techniques to study mulloway aggregations in Mosman Bay were conducted in four variations. The research focused on the region of Mosman Bay, Swan River between Chidley Point and the Freshwater Bay Yacht Club as shown in Figure 2.11a. Here the banks descend rapidly to a 19 m channel comprising sand/silt substrate with numerous artificial reefs and several depressions, some of which reach 22 m depth. Mulloway vocalisations were recorded using HTI omni-directional hydrophones attached to either acoustic sea noise loggers (designed by the CMST, Curtin University) or D8 and D100 Sony DAT (Digital Audio Tape) recorders.

During the spawning seasons of 2005-6 and 2006-7 a noise logger was deployed in 16.9 m of water on the riverbed at the location shown in Figure 2.11c (deployment dates and times can be found in Appendix 7). The loggers recorded acoustic signals within the river at a sample frequency of 6000 Hz for 5 minutes in every 10 minutes over a period of several months.

Acoustic drift transects were conducted from a Curtin University 4 m vessel within the study region during the 2005-6 and 2006-7 seasons (dates shown in Appendix 7), ranging from 18:00, prior to sunset, to 23:00. These recordings were conducted by towing an omni-directional HTI hydrophone up current, from the vessel. Digital recordings were logged on DAT tapes with a Sony D8 or D100 DAT recorder. Signals were sampled at a frequency of 32 kHz. On each occasion grids of 5-8 minute transects were conducted repetitively throughout the evening, in a minimum of 3 m of water. Three sets of six transects conducted during the evening of the 17th January are shown in Figure 2.11d. The same transects were conducted three times approximately an hour apart to obtain data concerning the change in detectable vocalisations from that location throughout the evening. Transects conducted during the evening of the 17th covered an area of approximately 100,000 m^2; however, prior and subsequent surveys were also conducted over a more extensive area.

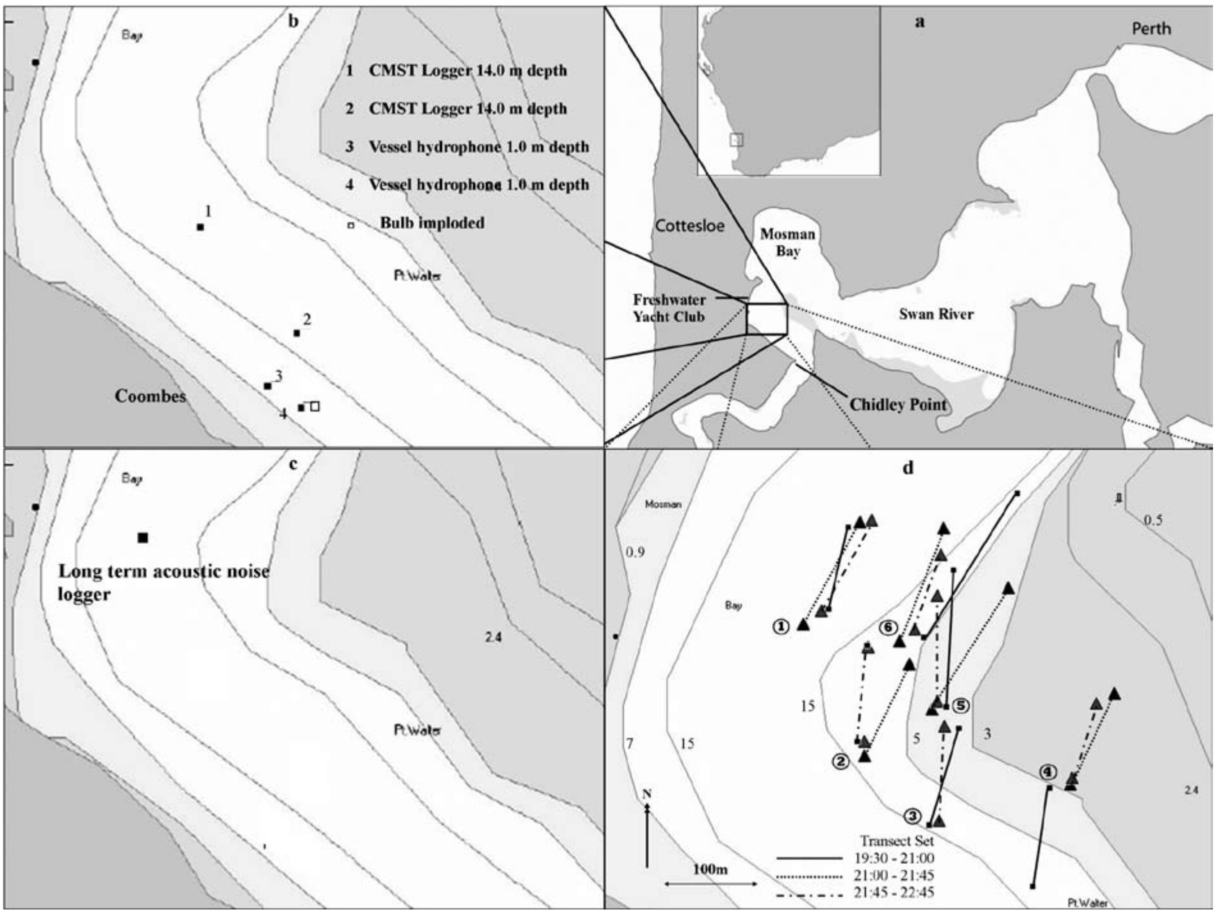


Figure 2.11. Location of study sites within Swan River and Mosman Bay used in conducting passive acoustic surveys of mulloway.

On February 13th and 15th, 2007 an array of five hydrophones (two noise loggers, two hand deployed hydrophones and the long term logger stated above) were deployed for periods of two to three hours. The locations of the February 13th deployment are shown in Figure 2.11b. Two noise loggers were moored on the riverbed at depths of approximately 19 m recording for twenty five minutes of every half hour, from 7:00pm to 12:00am, at a sample frequency of 2500 kHz (locations 1 and 2). The remaining two hydrophones (locations 3 and 4) were attached to D8 and D100 Sony Digital Audio Tape (DAT) recorders and submerged 1 m below moored vessels, at a sample frequency of 32 kHz. At 1 m distance east from the southern hydrophone and depth of 3 m a time synchronisation device (bulb implosion) was activated several times during the recording period to generate signals over all required frequencies to synchronise time on all four hydrophones. The array bounded an area of approximately 20,000 m^2, small enough to ensure detection of signals from within the hydrophones. The objective of the array was to locate individual callers and monitor behaviour throughout the spawning period of an evening.

In previous years numerous drift recordings have been taken at various sites around the Mosman Bay, Freshwater Bay and Blackwall Reach regions of the Swan River, using DAT recorders and hydrophone drifting behind the Curtin vessel.

Passive acoustic data acquired comprising Samson fish, dhufish and Bight redfish were conducted via deployment of hydrophones with either acoustic loggers or DAT recorders from the *RV Naturaliste*. Recording equipment were encased in depth rated housings and attached to hydrophones as shown in Figure 2.12. The housings were launched in a number of fashions displayed in Figure 2.13 dependent on the behavioural characteristics of the fish targeted. The housings were attached to Baited Remote Underwater Video (BRUV) frames, internal structure of craypots, attached to weighted moorings, or set floating mid water attached to a floating GPS beacon, as shown in Figure 2.13a, b, and c respectively.

Figure 2.12. Acoustic logger housing with hydrophone.

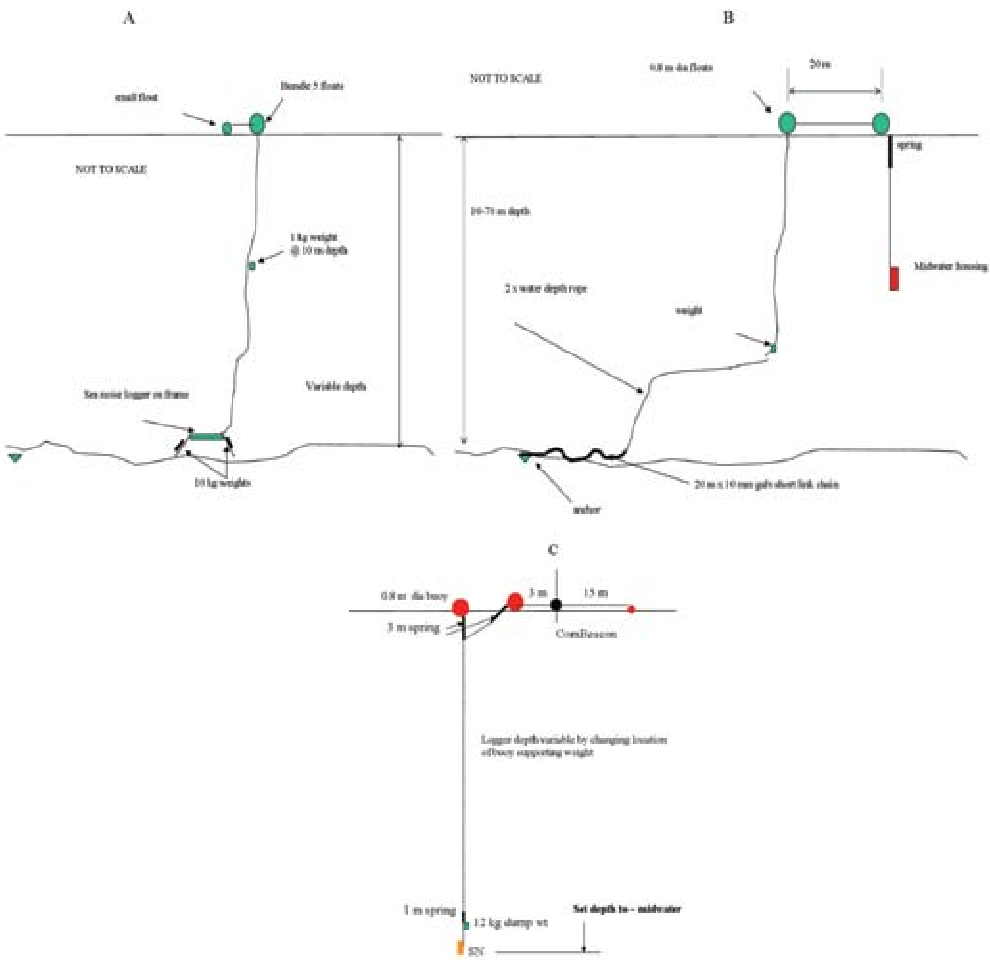


Figure 2.13. Methods used in the deployment of passive acoustic equipment.

2.9.3 Data processing

Initial audio interpretation of recorded data were conducted to intuitively reduce data to a manageable quantity. Recordings taken from DAT tapes were transferred to digital files by means of a DP430-FFT Analyser (Data Physics Corporation). The data were processed using Matlab programs developed by the Centre for Marine Science and Technology (CMST), Curtin University, and in the case of the array deployment both sets of data from loggers and DAT recorders were resampled to the same frequency of 2500 Hz. High (50 Hz) and low (1000 Hz) pass filters were applied to limit noise effects such as hydrophone movement and shrimp noise. Analyses of data were then conducted from spectrograms, power spectral densities and waveform plots, produced in Matlab. The DAT recordings are currently uncalibrated.

Data processing of passive acoustic fish vocalisations requires significant programming capabilities. A suite of Matlab programs are currently being written by the CMST, Curtin University to complete a number of functions from each of the survey methods. From single hydrophone recordings it is the objective of the developing programs to range, identify, count and categorise calls automatically. Further programs are then to be employed to analyse each of the identified calls for intensity, frequency and temporal characteristics. A separate set of functions have been designed to analyse the long term periodicity of acoustic characteristics from loggers deployed over the entire spawning season.

In processing data from the array deployment correlation of the time base of each receiver was conducted by taking leading edge sample numbers of the light bulb implosion signal recorded by each hydrophone and correcting for travel time. To assess arrival times of each recorded call the signal leading edge was located in time according to standard criteria. Estimated locations for each call were then calculated using a hyperbolic time arrival difference program. Functions mentioned earlier can then be employed to analyse behaviour of individual callers at known locations.

2.9.4 Ground truthing

Ground truthing the presence of spawning mulloway within Mosman Bay required intuitive methods. Proof of reproductive activity and location of spawning grounds have to be inferred from either the distribution of pelagic eggs or capture of ripe spawners (Hawkins 2002; Holt 2002) unless ground-truthed by video. It has been shown that spatial and temporal distributions of egg and larval abundance correlate highly to calling numbers in scianid species (Gilmore 2002). To date, no mulloway eggs or larva have been found within the Swan River, however the capture of adult females in Mosman Bay with spawning and post-spawning ovaries confirms that these fish are both present and spawning in the study area (B. Farmer, Murdoch University, *pers. comm.*).

An alternative method of ground truthing the presence of vocalising mulloway is to record signals from an isolated, known source (removing an individual from the study area and housing in an experimental site away from Mosman Bay or observing individuals in aquaria) and isolate species specific vocal parameters such as tone burst frequency and repetition pulse rates (see section 4.3 for details) in the individual's calls. The isolated parameters may then be compared to those identified on recordings from Mosman Bay, confirming the presence of vocalising mulloway.

Passive acoustic recordings to identify vocal or non vocal behaviour of dhufish, Bight redfish and Samson fish were visually correlated where possible with accompanying video data. Where video data was unavailable ground truthing was conducted via biological sampling (ie line caught fish).

2.9.5 Future field work

Confirmation of mulloway vocal behaviour and characteristics of confirmed calls are still required. Members of a spawning broodstock have been made available to researchers for observation in a 40,000 litre tank, and will be recorded during the 2007-8 season. Data processing of recorded calls in aquaria will be confounded by echoes and reverberation from aquaria walls but will still allow calling source characterisation. Other possible methods to be employed are line fishing and holding in a net cage by the side of the vessel whilst recording at a known distance from the individual. Alternatively baited video and diver video techniques may be employed.

2.10 Underwater Video

Various underwater remote and live-feed video equipment were used in this study, reflecting increased understanding of video techniques and the methods required to observe fish *in situ*. The two main video systems used, remote underwater and live-feed, are described below.

2.10.1 Remote Underwater Video

Each remote underwater video system was comprised of a MiniDV video camera housed inside a cylindrical stainless steel (rated to 250 m) or PVC housing (rated to 80 m). Different camera models enabled differing capacity for lens angle, low light function, image quality and video length. The cameras were used separately or in pairs, with the latter enabling stereo-video analyses. These stereo units were trialled at the commencement of the study with assistance of personnel from the University of Western Australia, although proper assessment of stereo video techniques were only made at the end of the study and are therefore preliminary.

Housings were fastened to metal frames placed onto the seabed and retrieved using a winch. In most cases a mesh bag containing pilchards was fastened to a pole within the camera field of view in order to attract fish to the area (Figure 2.14, single and stereo camera setups). Single-video systems were used onboard both the RVs *Snipe* and *Naturaliste*. Because of their size stereo-video systems were more cumbersome to use on smaller vessels such as the *RV Snipe*. In order to video fish located mid-water, a floated single or stereo-video system that could be set at any height off the seabed was developed (Figure 2.15). Software, hardware and training required for stereo-video calibration and analyses were provided by SeaGIS Pty Ltd for an associated project.

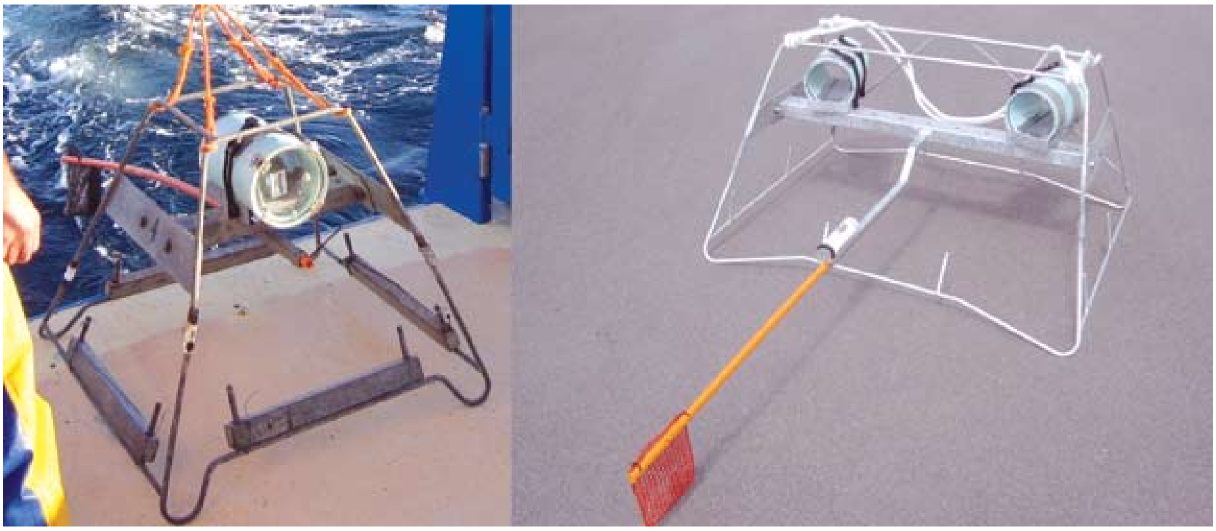


Figure 2.14. Single (left) and stereo (right) camera systems used in the project.

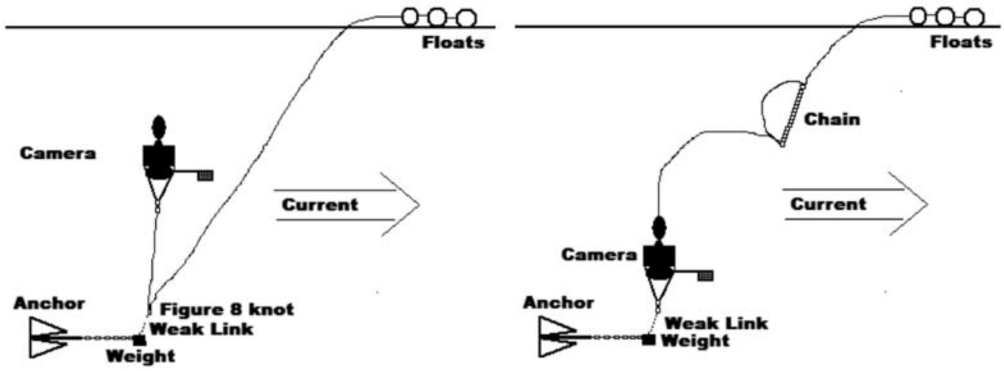


Figure 2.15. Variations of the floated camera system used to video fish located off the seabed. The picture at right depicts a floated camera system used to video fish on the seabed. Although this system can be adversely affected by currents, it is more portable and can be retrieved without winch assistance.

In the laboratory the tapes were viewed and details such as date, time, location, vessel, habitat and depth entered into a database. In analysing the tapes the arrival time of each species clearly identifiable was recorded along with the maximum number (MaxN) and time of MaxN. In the later stages of the project a collaborative agreement was entered into with the Australian Institute of Marine Science (AIMS) to use their BRUVS2.1 software to aid in the analysis of each tape. This software has sped up the processing time for each tape by entering details directly into the database as the tape is viewed, and also allows for backup images of each species seen to be captured and has a library of reference images to aid in species identification.

2.10.2 Live-feed Underwater Video

Following an initial period during which various gear from different sources were trialled, the live-feed video system developed for use in the current project consisted of two identical, single-camera units used either individually from the *RV Snipe* or together as a dual system onboard the *RV Naturaliste*. Each unit can work to depths of approximately 200 m and operate off a 12V DC power supply using either a lithium battery or a 240V AC transformer. This system provided greater flexibility although more attention and care was required when operating in stereo mode due to presence of two cables.

Both video units had GPS overlay capacity. The two colour cameras were rated to 200 m, with one having interchangeable lenses and the other a wide-angle lens with auto iris for improved low light performance. Each hand-operated reel contained 300 m of reinforced video cable. The video signal was viewed onboard the vessel using either a water resistant portable DVD player with a 7 inch LCD screen (smaller boats), or through a normal PAL television (larger vessels).

When used in dual mode onboard the *RV Naturaliste* the cameras were attached to a heavy streamlined downweight, weighing approximately 80 kg (Figure 2.16). The cameras were positioned so that their field of views overlapped by approximately 15 degrees, thus enabling wide coverage of the survey area. A pair of remote videos can also be attached to this system to obtain data for stereo-video analyses. This video system was raised and lowered using a wire hawser and hydraulic winch, and sat approximately below the stern line of the vessel. During benthic surveys the winch operator altered the height of the video system according to information received from the echo sounder and the live footage. For mid-water surveys the depth of the video system was determined using an analog depth gauge fastened to a pole in one cameras' field of view. Towing speed was usually 1 - 2 knots, but was reduced below this if approaching an area of interest.

When used in single mode onboard the *RV Snipe*, the camera was fastened to a weighted paravane and slowly towed or drifted through the study area. This system operated best in shallow water (< 30 m) and calm conditions where camera operation was less affected by cable movement. However, it was successfully used in 120 m to view the Samson fish wrecks. It was hauled by either hand or winch depending on whether a tow-rope was used (Figure 2.16).

Figure 2.16. Towed camera setups used in the current project. Left; dual camera live-feed system used onboard the *RV Naturaliste*. Right; single camera paravane system used onboard the *RV Snipe*.

2.11 Samson Fish Biology, Ecology and Fishery

The research on Samson fish required considerable involvement of recreational anglers to achieve tagging and other objectives. The large-scale collaborative research project that evolved from this requirement is described in Section 5.3.

2.11.1 Tagging

2005/06 tagging outline

Anglers participating in Samson Science were provided with a tag kit per boat and data sheets. In addition to latitude and longitude, angler, tagger, tag number and fish length the data sheets also included sections for how high the fish was lifted from the water, fishing method (i.e. jigs or baited hooks), line class, hook position, lift method, revive (release) method, release condition and a comments section where anglers could provide other details, e.g. was the fish bleeding, had the fish been previously tagged, etc.

In January 2005, Samson fish were tagged at three spawning aggregation sites in waters west of Rottnest Island (Figure 2.5) in a large scale intensive tagging program involving researchers and members of the WA recreational fishing public. All fish were caught by hook and line using either bait or artificial metal jig. Once fish were landed, the fork length was measured to the nearest cm and a nylon headed, single barbed dart tag (Hallprint PDA, 120 mm long, 3 mm diameter) with a distinctive identification number was inserted to lock under the pterygiophores of the anterior section of the 2nd dorsal fin. To assess tag loss each boat was instructed to double tag all fish caught on their first 2 days of fishing, the goal was to have at least 500 of the fish double tagged. The second tag was inserted just posterior to the 2nd dorsal fin. Once tagged the fish was then released with all efforts to ensure its descent back to the school by the spearing method or, if deemed necessary, the use of a release weight. Any fish that did not release successfully and floated were gathered for another release attempt.

2005/06 tagging outline

Tagging involving researchers and recreational fishers was conducted between May 2005 and September 2006 in the south west region of Western Australia. Although, fishers were recruited to tag Samson fish in any coastal waters between Mandurah and Augusta, tagging was concentrated in areas near Dawesville and Cape Naturaliste.

A four week intensive tagging event (*n* = 2000) involving researchers and recreational fishers within the metropolitan area was undertaken in November 2005. Tagging was again focused on the Rottnest aggregations as well as a north metropolitan aggregations known as the Hillarys Barge (see Figure 2.5). The objective of this tagging event was to investigate the length of stay at, and movement between, the metropolitan aggregations (particularly linkage between north and south metro aggregations). Furthermore, undertaking an intensive tagging event during this time increased the chance of recapturing fish tagged during the previous month in the Geographe Bay region.

During the tagging of Samson fish at the spawning aggregation sites the sex of individual fish was determined by research staff prior to release by inserting a cannula 20 to 30 mm into the gonadopore. The cannula used was a flexible vinyl tube 30-40 cm long with a small bore (2 mm inside diameter). Insertion of the tube enabled eggs or sperm to be extracted, in some cases a slight vacuum was applied by sucking on the end of the tube. Alternatively, when spawning was at its peak, slight pressure applied to the abdomen would generally expel eggs or milt.

2006/07 tagging program

During the third summer the project focused on a select group of anglers who had, during the previous summers, built up a deep interest in the project and had proven themselves as reliable taggers. The aim of the third season of tagging was to establish a core group of anglers that can “self-monitor” the Samson fish aggregations with the assistance of the DoFWA and develop of new industry-research partnerships and data collection methods.

Samson fish tagged previous to the current project at the spawning aggregations west of Rottnest Island by ANSA members (*n* = 2265) are also included here.

2.11.2 Biology

Collection of samples

Fresh samples of Samson fish were collected on regular intervals from sites near Perth (31°57'S, 115°51'E) onboard recreational, charter and research vessels from shallow coastal waters up to 200 m in depth between January 2004 and February 2007. Additional samples of Samson fish were collected from commercial fish processors and at recreational fishing competitions throughout this period and frozen frames (fillets removed) were collected from recreational fishers. Samson fish samples were also collected opportunistically from Geraldton (28°47'S, 114°37'E), Albany (35°01'S, 117°53'E), Bremer Bay (34°23'S, 119°23'E) and Esperance (33°52'S, 121°53'E).

Sampling for small juvenile Samson fish (252 to 600 mm FL) was conducted in inshore waters of the Perth region. These fish were mainly collected around channel markers and jetty pylons near the Fremantle Port, within Cockburn Sound and in the lower reaches of the Swan River estuary.

Juvenile fish, or fish of undifferentiated sex (26 to 65 mm FL), were collected on occasion from floating weed mats (predominately *Sargassum* spp.) using a fine mesh scoop net in waters west of Rottnest Island from 50 to 200 m in depth and from the near shore waters of Fremantle.

Processing of samples

Samson fish were processed following the same methods as outlined in Section 2.5. However, in addition to the standard measurements the head length (HL) and jaw length (JL) of Samson fish were also measured. The weights of Samson fish that could not be obtained prior to filleting were estimated from the regression equation that relates wet weight to fork length (see Section 5.1.1). The relationship between HL and JL with FL was calculated (Section 5.1.1) so that the FL of an individual could be estimated when only the head of the fish was available, as was sometimes the case for large fish obtained from recreational fishers.

Processing of otoliths

The two sagittal otoliths were removed by cutting vertically into the dorsal side of the skull with a bone saw slightly posterior to the brain. This action cut through the otic capsules and the fragile otoliths were then carefully removed with forceps. After removal, otoliths were cleaned, dried and stored in ependorf vials within labelled paper envelopes. Ependorf vials were perforated to allow otoliths to dry completely during storage.

Although some growth zones were visible in the whole otoliths of Samson fish these were often hard to detect and the total number was not discernable. Growth zones became far more visible after sectioning of the otolith which greatly enhanced their readability, thus, all Samson fish otoliths were sectioned prior to counting growth zones.

A single otolith from each fish was selected and mounted in clear epoxy resin. Prior to sectioning the core region of each otolith was identified under a dissecting microscope and then marked on the surface of the resin. A single 500-600 µm thick section containing the core was then cut using an Isomet Buehler low-speed saw with a diamond wafering blade. The section was then ground with fine wet-and-dry paper (1200 grade), washed, dried and mounted on a microscope slide using DePX mounting medium. These sections were then examined with transmitted light and reflected light using a compound microscope. The number of opaque zones on each sectioned otolith was counted on two occasions without any knowledge of the fork length, specimen ID or date of capture of the fish from which the otolith had been removed. A section was examined for a third time when the two counts of the opaque zones differed. When the third count agreed with one of the previous two counts it was used as the age estimate. When all three readings differed the sample was rejected. During examination each otolith section was also assigned a readability index category (1-5) and a marginal increment category (1-3), as given in Lewis and Mackie (2002).

The birth date assigned to Samson fish was determined from the approximate time of peak spawning as estimated from mean monthly gonadosomatic indices and gonadal maturity stages. The birth date was used in conjunction with the otolith annuli count, marginal increment category and date of capture to allocate an absolute age to each fish.

Samson Fish Growth

Growth curves were fitted to the individual lengths of each female and male at their estimated age of capture. The lengths at age of juvenile fish that could not be sexed were allocated randomly, but equally, to the female and male data sets used for calculating the growth curves. Samson fish growth was initially analysed using the von Bertalanffy growth equation, as is normally employed for describing the growth of most teleosts. The von Bertalanffy growth equation is:

$$L_t = L_\infty \, (1\text{-}e^{-k(t-t0)}),$$

Where L_t is the length at age t, L_∞ is the mean asymptotic length, k is the growth coefficient and t_0 is the hypothetical age at which fish would have zero length.

However, although the von Bertalanffy growth curves of each sex fitted most of the length at age data well, they passed below the points for many larger fish. The Schnute growth equation was therefore fitted to the same length at age data as the von Bertalanffy growth equation to ascertain whether it provided a significantly better fit. The Schnute growth equation is:

$$L_t = \left[L_1^b + (L_2^b - L_1^b) \frac{1 - e^{-a(t-\tau_1)}}{1 - e^{-a(\tau_2 - \tau_1)}} \right]^{1/b}$$

(Schnute 1981, Eq. 15), where L_1 and L_2 are the estimated lengths at selected reference ages τ_1 and τ_2 (years) and a and b are constants (both ≠ 0). From this equation the asymptotic length can be calculated using the equation:

$$L_\infty = \left[\frac{e^{a\tau_2} L_2^b - e^{a\tau_1} L_1^b}{e^{a\tau_2} - e^{a\tau_1}} \right]^{1/b}$$

(Schnute 1981).

The data for each equation was fitted by minimising the sum of squared deviation between observed and predicted lengths using Solver in Microsoft™ Excel.

The von Bertalanffy and Schnute growth curves derived for female and male *S. hippos* were compared using a likelihood-ratio test to determine whether there were significant differences between the curves derived for each sex using the different growth equations and between the curves derived for both sexes using the same growth equation (Kimura 1980). The hypothesis that the data in each case could be described by a common growth curve was rejected at the $\alpha = 0.05$ level of significance if the test statistic, calculated as twice the difference between the log-likelihood obtained by fitting a common growth curve for both sexes and by fitting separate growth curves for each sex, exceeded χ_α^2, where q is the difference between the number of parameters in the two approaches. (e.g. Cerrato 1990).

Mortality

The instantaneous rate of total mortality, Z, was determined for Samson fish using catch curve analysis (Hall *et al.* 2004), this analysis assumes constant annual recruitment and constant mortality after the age at which fish were considered fully vulnerable to fishing. The value for Z was estimated by maximising the log-likelihood using the SOLVER routine in Microsoft ™ Excel. The data for Samson fish were randomly resampled, with replacement, and analysed to create 1000 sets of bootstrap estimates. The point estimate for *Z* was taken as the median of these 1000 bootstrap estimates, and the 95% confidence limit was calculated as the 2.5 and 97.5 percentiles of those 1000 estimated values.

Estimates for the instantaneous rate of natural mortality, *M*, were calculated from the relationship between natural mortality, growth and water temperature as described by Pauly (1980). A regression of the same form used by Pauly (1980) was fitted to Pauly's data for 175 fish stock using Microsoft ^{TM} Excel and inserting the values of *k* (years) and L_∞ (cm FL) and water temperature for Samson fish in temperate WA. The regression was fitted in the Statistical Package for the Social Sciences (SPSS inc., Chicago) to obtain a point estimate and associated 95% confidence limits for *M*. The mean annual surface water temperature used was 22.5°C (Australian Oceanographic Data Centre, http://www.AODC.gov.au).

Natural mortality was also estimated using relationships derived from Hoenig (1983). Because the Hoenig equation for fish uses the relationship between total mortality and maximum age, this estimate of mortality equates to *M* if fishing pressure is light. As anecdotal evidence suggests this is the case for Samson fish, it was considered an appropriate estimate of *M* for this species in WA waters. A regression of the same form used by Pauly (1980) was refitted to the data provide for 82 stocks described by Hoenig (1982). The maximum recorded age was then inserted into SPSS to obtain a point estimate and associated 95% confidence limits, thereby taking into account the variation in the data around the regression line and the uncertainty in parameter estimates. These two estimates of *M* were then combined using the likelihood distribution approach of Hall *et al.* (2004). The Bayesian method described by Hall *et al.* (2004) was then used to determine the likelihood for *M*, calculated using the likelihood of *Z*, as determined from the catch curve analysis, in a procedure that assumed that, for each value of *Z*, there is an equal probability that $M < Z$. The resulting likelihood for *M* was then combined with the estimate of *M* derived from the Pauly (1980) equation.

A Monte Carlo resampling approach was used to determine the instantaneous coefficient of fishing mortality, *F*. Estimates of *Z* (derived from catch curve analysis) and *M* (derived from the Bayesian approach) were randomly resampled, with replacement, from their respective probability distributions, but were discarded when corresponding values for *M* were greater than for *Z*. These values were used to produce 5000 estimates for *F*, determined using the equation $F = Z - M$. The point estimate for *F* and associated 95% confidence limits were taken as the median value and the 2.5 and 97.5 percentiles of the 5000 estimates derived from this analysis.

Reproduction

Histological section of the ovaries of three mature female (stage IV gonads) Samson fish individuals were analysed to assess the spawning mode of this species. The maximum and minimum diameters of 100 randomly selected oocytes, in which the nucleus was visible, were measure to the nearest 1 µm. The mean diameter of each oocyte was then calculated.

The lengths at which 50 and 95% of females commenced maturation (L_{50} and L_{95}) was determined by fitting a logistic equation to the percentage of Samson fish that had commenced maturation (i.e. gonad stage III-VI) in sequential 50 mm increments. The logistic equation used to predict length at which females commenced maturation was:

$$P = 1/\{1 + \exp[-\ln(19)(L - L_{50})/(L_{95} - L_{50})]\}$$

Where: P = probability that a fish is mature, L = fork length, L_{50} and L_{95} = the lengths at which 50 and 95% of female fish reach sexual maturity, respectively.

Dietary data

The stomachs of Samson fish were removed in the field and either frozen or preserved in 100% ethanol. Stomach contents were later examined in the laboratory with the aid of a dissecting microscope. Diets of Samson fish were analysed using the frequency of occurrence and points methods (Hynes 1950, Ball 1961). The frequency of occurrence (%F) method represents the frequency with which a particular prey type is consumed by a species, whilst the points methods gives the relative contribution of each prey type to the volume of the stomach contents of the fish. Stomach fullness was estimated on a scale of zero to 10, with zero representing an empty stomach, eight representing a full stomach and 10 representing a fully distended stomach. Each prey item was identified to the lowest possible taxon. The percentage contribution of each item to the total stomach volume was estimated and identified items were allocated to one of 17 prey categories. The mean percentage volumetric contribution (%V) of each of these prey categories to the stomach contents was then calculated. Only data collected from fish collected from within the west coast region were used for analysis as many fish collected from the south coast region had been gutted at sea or had the stomachs removed during the filleting process.

2.11.3 Post-release Survival

Enclosure trials

A large cylindrical floating enclosure or ‘sock’ measuring 15 m deep x 2 m diameter was used to assess the short term post release survival of Samson fish. This apparatus was designed by the Queensland Department of Primary Industries and Fisheries to investigate the short-term post release survival of tropical demersal species. The Samson Science project was able to borrow the enclosure and secure vessel time for a brief period (10 days) in early March 2006, then again in February 2007.

Two research vessels were used during the enclosure trials. The *RV Naturaliste*, used to deploy and retrieve the enclosure and monitor fish behaviour, and the *RV Snipe*, used to catch and transport fish to be placed into the enclosure. Additional help was provided by the charter boat *NorthStar2* who also transported caught Samson fish to the enclosure or transferred fish to the *RV Snipe* for transportation. For most of the trials the *Naturaliste* drifted with the sock attached alongside, or, if the water depth was less than 60 m the *Naturaliste* was anchored.

To keep surface interval times (i.e. the time taken to transport fish and release them into the enclosure after capture) as low as possible the *RV Naturaliste* deployed the sock upwind of the fishing area while the second vessel was used to catch and transport fish (up to 3 fish at a time) to the sock. The surface interval time was therefore dependent on the drift speed of the *RV Naturaliste* through the fishing area and the catchability of the fish but was mostly kept to less than 10 minutes. Up to 11 Samson fish were placed into the enclosure at a time. The trials lasted between 2 and 31 hours as the *RV Naturaliste* drifted with the wind and current or was at anchor.

Once a fish was landed on the *RV* S*nipe* the time was recorded and the fish were measured, tagged and placed into a 200 litre esky that had been filled with fresh seawater. Each fish was tagged in a different position along the body (right/left, and 5 positions along the body in relation to the second dorsal fin) so as to be distinguishable when monitored in the enclosure. If other fish were also hooked, fresh seawater was allowed to flow into the esky and the lid closed until subsequent fish were landed. During transport the lid of the esky was kept closed and at most 3 fish were transported at a time. Once at the enclosure the time each fish went in was recorded.

During the trials fish health and behaviour were monitored continually, during daylight hours, with a live feed video camera. Each individual could be distinguished on the video by the location of the tag. Every 30 minutes the fish were assigned a 'health' score whilst in the enclosure. Observed swimming behaviour categories (1. Swimming upright; 2. Lays on side occasionally; 3. Often on side; 4. Always on side) and fish colour (1. Uniform bronze; 2. barred/ blotched) were used to generate a health score for individual fish within the enclosure. Health was assigned as: 5. Healthy (bronze and swimming upright); 4. Stressed (barred/blotched and swimming upright); 3. Sick (barred/blotched and on side occasionally or often); 2. Very sick (barred/blotched and always on side); 1. Dead. On the completion of each trial the fish were euthanized for biological sampling and assessment of barotrauma related injuries.

As the trials were conducted towards the end of the spawning season in both years, problems were encountered catching fish from the aggregations normally targeted by sportfishers (i.e. 110 m). Consistent catches of Samson fish for the 2006 trials were found on a nearby wreck (HMAS *Derwent*) located in waters of depth 195 m, see Figure 2.5.

Blood samples where also taken from a subsample of fish at the completion of the enclosure trials, in order to investigate the stress response and recovery after angling. Winching equipment aboard the Naturaliste allowed fast retrieval of the enclosure and blood samples were taken from recovering fish within 3 minutes of initial enclosure disturbance. Additional blood samples where collected from fish immediately after capture by angling. A 2 to 4 ml blood sample was taken from the caudal vasculature of each fish with a 22 gauge hypodermic needle. Blood was transferred immediately into heparinized vials and placed on ice. Blood plasma was separated in all samples by centrifugation within 10 minutes of collection then frozen and stored at -80°C to await analysis.

Plasma cortisol was measured by a competitive chemiluminescent assay using a Bayer Advia Centaur® analyser. Plasma lactate was determined by the amperometric method using the ABL800 FLEX blood gas analyser (Radiometer Medical ApS, Copenhagen, Denmark).

As blood sampling during this study was opportunistic and logistically difficult the number of samples collected was small. Thus, levels of each cortisol and lactate where combined to produce a mean level (± S.E) of these parameters for each recovery interval.

Swim bladder investigations

The release of gas by *S. hippos* on ascent when hooked was noticed during the early stages of this project. Almost all *S. hippos* observed during capture at the spawning aggregation sites released large quantities of air into the water, particularly during the last 10 to 20 m before reaching the surface. Investigations into this phenomenon started with the collection of anecdotal evidence from fishers and divers who had witnessed such gas release. Samples of fish that had vented gas during capture were collected for external and internal examination. Several fish were frozen at sea soon after capture in order to keep the vented swim bladder in situ for examination by x-ray imaging. Images of these frozen fish were taken with an X-ray machine at the radiology laboratories in the School of Veterinary Biology and Biomedical Science at Murdoch University. In the laboratory a combination of careful dissection, and the introduction of water or latex under slight pressure was used to determine the morphology of the swim bladder and thus the route of escaping gas. In particular was gas released due to rupture/damage to the swim bladder and tissue above the gills and beneath the operculum or was gas released in some non destructive manner?

2.11.4 Otolith microchemistry

Sample preparation

The otoliths were removed from three Samson fish shortly after capture, then stored dry until just prior to sectioning as recommended by Milton and Chenery (1998). The otolith was set in a resin block and cut into sections using a Buehler Isomet saw broadly according to the method of Jenke (2002). Starting from the anterior end of the otolith three transverse sections, each approximately 250 µm thick were removed in close proximity to the primordium. We endeavoured to include the primordium in the middle section of each otolith (i.e. Sections 2, 5 and 8). Each section was separated from the next by the thickness of the cutting blade (approximately 400 µm), resulting in a distance of approximately 1.6 mm from the anterior surface of the first section to the posterior surface of the third.

The sections were not treated with dilute hydrochloric acid, nor mounted onto a glass slide with cover slip as described by Jenke (2002). Instead, each section was polished on both surfaces using graded aluminium oxide slurry coated onto a polyester film backing lapping paper (3M, 261X, 9 µm nominal grade), presenting six polished surfaces of each otolith for analysis. Each surface was appropriately labelled and the section stored in a paper envelope. Just prior to analysis, each section was mounted onto a glass block using adhesive tape, taking care to not obscure the otolith surface with the tape.

LA - ICPMS

Each section was analysed using LA-ICPMS techniques with a New Wave model UP213 Nd:YAG deep ultraviolet (213 nm) laser coupled with an Agilent 7500 CS ICPMS. The abundance of the seven elements was determined, namely strontium-88 (^{88}Sr), manganese-55 (^{55}Mn), barium-138 (^{138}Ba), calcium-44 (^{44}Ca), magnesium-24 (^{24}Mg), potassium-39 (^{39}K) and lead-208 (^{208}Pb). For each analysis, the otolith section was moved through the laser beam by means of a moveable stage so that the surface was ablated in one of four patterns, namely: a straight line, a segmented line, discrete spots, or a moving track (raster). The pattern for each otolith section is summarised in Table 1, with the location of straight line tracks shown in Figure 2.17.

Table 1. Summary of LA-ICPMS analyses of otoliths from three Samson fish.

Sample ID	Section ID	Surface	Laser parameters		
			Pattern	Width (μm)	Speed (μm/sec)
R1060201(1)	S1	Anterior	Straight line x4, Seg. line x2	100	20
R1060201(1)	S1	Posterior	Straight line x4, Seg. line x2	100	20
R1060201(2)	S2	Anterior	Straight line x4, Seg. line x2	100	20
R1060201(2)	S2	Posterior	Straight line x4, Seg. line x2	100	20
R1060201(3)	S3	Anterior	Straight line x4, Seg. line x2	100	20
R1060201(3)	S3	Posterior	Straight line x4, Seg. line x2	100	20
R1051217-5(1)	S4	Anterior	Raster, 75 μm vert.spacing	50	20
R1051217-5(1)	S4	Posterior	Raster, 75 μm vert.spacing	50	20
R1051217-5(2)	S5	Anterior	Raster, 75 μm vert.spacing	50	20
R1051217-5(2)	S5	Posterior	Raster, 75 μm vert.spacing	50	20
R1051217-5(3)	S6	Anterior	Raster, 75 μm vert.spacing	50	20
R1051217-5(3)	S6	Posterior	Raster, 75 μm vert.spacing	50	20
R1051119-30(1)	S7	Anterior	Straight line x2, Seg. line x1	100	20
R1051119-30(1)	S7	Anterior	Spots x 16	100	20 (sec)
R1051119-30(1)	S7	Posterior	Spots x 15	100	20 (sec)
R1051119-30(1)	S7	Posterior	Straight line x2, Seg. line x1	100	20
R1051119-30(2)	S8	Anterior	Straight line x4, Seg. line x2	100	20
R1051119-30(2)	S8	Posterior	Raster, 75 μm vert.spacing	50	20
R1051119-30(3)	S9	Anterior	Raster, 75 μm vert.spacing	50	20
R1051119-30(3)	S9	Posterior	Spots x 8	100	20 (sec)

Starting from the distal edge of the section, straight line ablated tracks 100 μm in width were directed along a transect on the dorsal side of the surface usually used to determine the age of the fish (the ageing transect), and along another transect closer to the sulcus on the dorsal side. A track described by segmented lines was directed approximately parallel to the distal edge, then approximately parallel to the sulcus on the dorsal side of the section. Tracks following these transects were replicated on the ventral side of the surface of the section, ensuring that material form the primordium if present in the section, was included in each track.

Discrete spots 100 μm in diameter were ablated following these tracks. Where appropriate, the tracks were aligned on both surfaces (i.e. anterior and posterior) of each otolith section.

The raster pattern consisted of a series of ablated lateral (ventral / dorsal) tracks 50 µm in width, alternating in direction and separated at the end of each lateral track by a vertical track 75 µm in length. The rectangular shape of the raster pattern extended beyond the otolith section in both directions so that none of the vertical tracks impinged on the surface of the section.

Additional analyses (April 2007)

The sectioned otolith R1060201(2) was re-analysed using four lines of discrete spots aligned adjacent to tracks T2 and T5 on the anterior surface, and T8 and T11 on the posterior surface. This section was chosen since it was closest to the centre of the otolith, where normalised abundances from previous analyses of both surfaces were similar.

Each spot had a diameter of 25 µm, with the centres of adjacent spots separated by 40 µm. The laser was operated at 75% power, with each spot ablated for 30sec. Photographs of the two ablated surfaces showing the alignment of the line of spots relative to the continuous line of ablation are shown in Figure 2.17.

In addition to the previously determined elements (i.e. ^{24}Mg, ^{39}K, ^{44}Ca, ^{55}Mn, ^{88}Sr, ^{138}Ba and ^{208}Pb), chromium-52 (^{52}Cr), chromium-53(^{53}Cr), copper-63(^{63}Cu), zinc-66(^{66}Zn) and cadmium-111(^{111}Cd) were also determined.

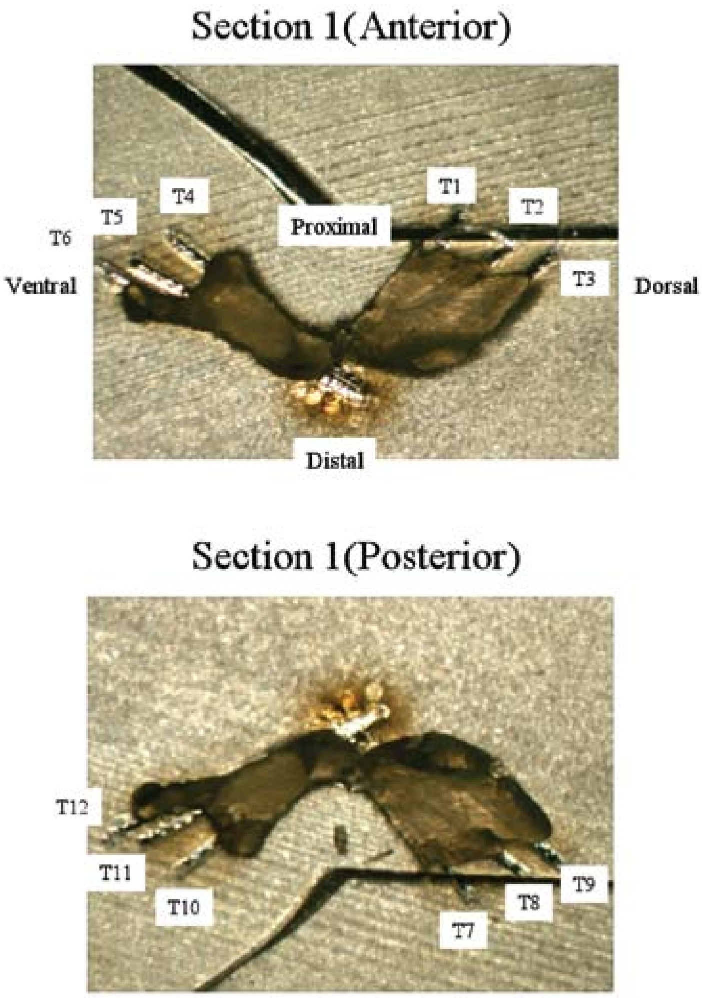


Figure 2.17. Photographs showing the anterior and posterior surfaces of Section 1 removed from the Samson fish otolith R1060201 and analysed using LA-ICPMS techniques. The labels T1–T12 denote the ablated laser tracks.

3.0 Examples of Fish Species that Aggregated to Spawn within the West Coast Bioregion

Michael Mackie and Paul Lewis

Although the majority of aggregating species are pelagic spawners (Claydon 2004), they exhibit a wide variety of life history strategies. Many typically school for feeding or shelter, and when aggregated for spawning do so in multi-male, multi-female groups. These polygamous species include pink snapper, Spanish mackerel, orange roughy and tropical snappers (F. Lutjanidae). Males of these species have relatively large testes and attempt to maximise spawning success by releasing large volumes of sperm during group spawning events (Stockley *et al.* 1997). Other species are less gregarious when not aggregated for spawning. These include various species of grouper (F. Serranidae), in which individuals often spawn in pairs. Males of these monogamous species attempt to maximise spawning success by competing physically for access to spawning females or favoured spawning sites. As such, smaller less competitive males have decreased spawning success. Because there is less need to produce large volumes of sperm when pair spawning, males of these species have relatively small testes.

Numerous monogamous and polygamous aggregating species are found within the West Coast Bioregion, including those shown in Table 3.1. This list is not comprehensive because identification of aggregating species is hampered by a lack of knowledge of their reproductive biology and behaviour. Nevertheless, the list highlights the biological and ecological diversity of fish species that aggregate to spawn. It also highlights the range of aggregating species that are targeted by fishers, and which therefore are potentially more vulnerable to overfishing. In order to discuss this more, and to direct focus, a review of the biology and ecology of several key aggregating species within the West Coast Bioregion is given below.

Table 3.1. Preliminary list of aggregating species within the West Coast Bioregion. Sources of information include fisher interviews, literature, and research observations made during the current study.

Baldchin groper (*Choerodon rubescens*; Nardi *et al.* 2006, interview data)
Bight redfish (*Centroberyx gerrardi*; interview data, research observations)
Blue groper (*Achoerodus gouldii* ; interview data)
Bass groper (*Polyprion americanus*; Peres and Klippel 2003, interview data)
Bream (*Acanthopagrus butcheri*; interview data)
Chinaman leatherjacket (*Nelusetta ayraudi*; interview data, research observations)
Common coral trout (*Plectropomus leopardus*; Samoilys and Squire 1994, interview data)
Dhufish (*Glaucosoma hebraicum*; interview data, research observations)
Gemfish (*Rexea solandri*; Tilzey *et al.* 2006)
Grey-banded cod (*Epinephelus octofasciatus*; interview data)
Hapuka (*Polyprion oxygeneios*; interview data)
King George whiting (*Sillaginodes punctata*; interview data)
Mulloway (*Argyrosomus japonicus*; interview data, research observations)
Pink snapper (*Pagrus auratus*; Jackson and Cheng 2001, Jackson 2006, interview data)
Queen snapper (*Nemadactylus valenciennesi*; interview data)
Red snapper (*Centroberyx australis*; interview data)
Samson fish (*Seriola hippos;* interview data, research observations)
Sea mullet (*Mugil cephalus*; interview data)
Silver trevally (*Pseudocaranx dentex*; interview data, research observations)
Sweetlip emperor (*Lethrinus miniatus*; interview data)
Trevalla (*Hyperoglyphe antarctica*; interview data)
Yellow tail kingfish (*Seriola lalandi*; interview data, research observations)

3.1 Dhufish (*Glaucosoma hebraicum*)

Dhufish belong to the Family Glaucosomatidae that includes just four species collectively called the pearl perches. Dhufish have a restricted distribution confined to the southwest of Western Australia, but within this range they are a prominent component of the ecosystem and heavily targeted by fishers. Various studies have focussed on aspects of dhufish biology and physiology (e.g. Hesp *et al.* 2002, Cleary and Jenkins 2003). However, little is known about the ecology of this species. Because of this, and because it is arguably the most important scalefish species within the West Coast Bioregion and a priority species in the current study, a comprehensive review of dhufish ecology is provided here. This review uses information from a range of sources, including aquaculture projects and the current study, to provide insights into the reproductive strategies of dhufish and how this may be affected by fishing activities.

3.1.1 Biology and Ecology

Dhufish are slow growing and long lived, reaching ages of at least 41 years. However, fishing activity appears to have significantly reduced the maximum age and proportion of old fish in the population in recent times. Growth rates and maximum size of males are greater than those of females (Hesp *et al.* 2002, St John *et al.* 2007), and the largest fish in a social group is typically male (Table 3.2, Plate 3.1).

Little is known about the early life history of dhufish. Their eggs are buoyant and after hatching their eyes are adapted to daylight (Pironet and Neira 1998, Shand *et al.* 2001), indicating a pelagic habitat. After about three weeks the eyes become adapted to low light and the fish actively avoid bright light (Shand *et al.* 2001), indicating that settlement to a benthic habitat occurs at that time. The number of juvenile fish recruiting to an area (cohort strength) will therefore be influenced by both the spawning output of adults and oceanographical conditions during the planktonic stage. As such, the size of each juvenile cohort may vary spatially and temporally, and a relatively large cohort can play a significant role in the fishery for years. This has been observed in dhufish, with four relatively strong consecutive years of recruitment (1993 – 1997) dominating the fishery in recent years (Wise *et al.* 2007).

Individual dhufish are gonochoristic (non-sex changing), and reach sexual maturity at around 30 cm length (Hesp *et al.* 2002). The testes of mature male dhufish are notably small, weighing less than 1% of body weight during the spawning period, compared to 5-10% of other species such as black bream and pink snapper (Cleary and Jenkins 2003, Hesp and Potter 2003). Histological examination indicates that the volume of sperm released during spawning events is also small relative to other species (M. Mackie, *unpubl. data*). As found in the epinepheline serranids (groupers), a group which share morphological and ecological characteristics with the dhufish, small testes and large male body size are indicative of energy commitment to body growth rather than sperm output. This demonstrates strong intra-sexual competition for pair spawning opportunities and a complex social system (Mackie 2003, Stockley *et al.* 1997).

Ovarian development commences as water temperatures start increasing from the seasonal low, with spawning occurring between November and April (Hesp *et al.* 2002, St John *et al.* 2007). The fact that there is little variation in the timing of reproductive activity throughout the Bioregion indicates that spawning is influenced by other factors besides environmental cues such as water temperature, which vary with latitude. Therefore, unlike spawning by pink snapper, which does vary according to latitude (St John *et al.* 2007, see below), it is possible that other factors such as social cues have an important role in the timing of spawning by dhufish.

During spawning females release batches of eggs, with the number of eggs per batch increasing considerably with body size. For instance, a female newly recruited into the fishery (ie 50 cm TL) will spawn, on average, about 36,500 eggs (± 5,425 SE) whereas a female 80 cm long will spawn about 192,500 eggs (± 78, 406 SE) per batch (Jill St John pers. com.). However, the error estimates also highlight the variability in batch fecundity of similar sized fish. This may be due to a range of biological and social factors, including frequency of spawning, since histological examination of ovaries during this study shows that female dhufish are capable of spawning over consecutive days, and the number of eggs per batch is likely to decline as oocytes reserves are expended.

Spawning frequency is also dependent on body size in dhufish, as shown by the high incidence of oocyte atresia in ovaries throughout the spawning season, particularly in smaller females (Figure 3.1). This high incidence of ovarian atresia was consistent over two consecutive years, and is in contrast to gonad maturation cycles of other species in which the incidence of ovarian atresia generally peaks at the end of the spawning season (M. Mackie *pers. obs.*). This observation, that ovarian atresia may be common among smaller female dhufish, is supported by examination of the developmental status of the gonads of individuals within two social groups (Table 3.2). Lack of spawning opportunity is a plausible reason for this pattern, with smaller females being less competitive than larger individuals, as found in other species such as the chinaman cod, *Epinephelus rivulatus* (e.g. Mackie 2006). Nevertheless, histological evidence confirms that small females also spawn, and thus it is likely that these atrophied ovaries redevelop again in readiness for further spawning during the same season.

Sex ratios of dhufish in samples obtained for biological samples indicate an overall slight bias towards males, but no seasonal pattern in relative numbers of either sex (St John *et al.* 2006). However, video data shows that female biases of up to 5:1 occur among localised social groups (average 2.4, n = 17; Table 3.3), at least during the spawning period when all except one of the video samples were taken. This is supported by line caught samples taken during the spawning period, which show that social groups can be female biased (Plate 3.1.). These samples also show that the largest individual is typically male. Fisher interviews also indicate that the sex ratios of dhufish can vary substantially, at least in the lead up to spawning in the Cape Naturaliste area. These interviews indicate that prior to the commencement of spawning activity (~ October/November), sex ratio of dhufish catches can actually be highly skewed towards males, apparently because of migration by them into coastal waters ahead of the females. However, following migration by females into the same area (~ December), the sex ratio of catches generally becomes female biased. Although these observations need more verification, the fisher observations are considered reliable and corroborated by other data (e.g. CAESS – see below). Size related differences in migration patterns for spawning purposes have also been observed in whitemouth croaker (Sciaenidae; Norbis and Verocai 2005).

This information about seasonal changes in demography provides further evidence of complex social behaviour by dhufish, and indicates that the relative vulnerability of males and females to fishing pressure can vary seasonally. Sexual dimorphism is also a feature of animals with complex social behaviour and, unlike most fish species, is a feature of dhufish as well, with males having a distinctive elongation of the dorsal fin filament that is not found in females (Plate 3.2.). These male features may portray mating and dominance qualities, with size being a defining character (Emlen and Oring 1977). In dhufish it is possible, therefore, that growth in the male filament (Figure 3.2.) is indicative of social status.

Colouration is another means of showing male qualities. In dhufish it may have some function in this because males tend to have a greater amount of black colouration in their body scales than do females (Table 3.4). However, dhufish colouration is likely to function in a much broader capacity, exhibiting ontogenetic changes (e.g. the distinctive juveniles stripes that fade in adults) and spatial/temporal differences that appear to be habitat or socially induced. For instance fishers typically consider colouration to be related to habitat, with darker fish found on reef and/or out deep whereas lighter (silver) fish inhabit sand/more shallow waters. Nevertheless, video observations of both dark and light coloured fish at the same location indicate that other factors may also be involved.

Table 3.2. Reproductive details of dhufish shown in Plate 3.1. FL; fork length. POF; Post-ovulatory follicle.

	Sex	FL (mm)	Gonad Reproductive Stage	Gonad Weight (gm)	Comments regarding gonad condition
Social Group 1 (left photograph)					
1	M	807	Spawning	17.6	Few reserves of spermatozoa, but capable of spawning
2	M	480	Spawning	3.7	Central sperm sinus full of spermatozoa.
3	M	407	Spawning	2.9	Central sperm sinus full of spermatozoa.
4	F	776	Spawning	245.9	Hydrated oocytes and old POFs indicate imminent as well as recent spawning.
5	F	714	Spawning	222.0	As above.
6	F	520	Spawning	54.9	As above.
7	F	488	Atretic	24.2	Large amounts of vascular tissue in lamellae. Few oocytes left.
8	F	423	Spawning	149.8	Hydrated oocytes and old POFs indicate imminent as well as recent spawning.
Social Group 2 (right photograph)					
1	M	929	Spawning	28.6	Few reserves of spermatozoa, but capable of spawning.
2	F	724	Spawning	147.2	Hydrated oocytes and old POFs indicate imminent as well as recent spawning.
3	F	640	Spawning	97.6	Hydrated oocytes and old POFs indicate imminent as well as recent spawning.
4	F	553	Atretic	36.8	Large amounts of vascular tissue. Old POFs indicate has spawned recently.

Table 3.3. Number of males and females, and gender of the largest fish observed in underwater baited video surveys.

Date	# Fish	# Male	# Female	Largest fish
1-Dec-05	2	1	1	M
2-Dec-05	2	2	0	M
2-Dec-05	2	0	2	F
4-Dec-05	3	0	3	F
23-Feb-06	4	1	3	M
21-Mar-06	3	1	2	M
23-Mar-06	4	1	3	M
14-Jul-06	2	1	1	M
28-Sep-06	4	1	3	M
5-Oct-06	6	1	5	M
9-Nov-06	2	1	1	M
12-Dec-06	3	2	1	M
16-Dec-06	3	1	2	M
10-Feb-07	2	1	1	M
23-Feb-07	8	2	6	M
23-Feb-07	3	0	3	F
25-Feb-07	4	1	3	M
Mean Ratio		1	2.4	

Table 3.4. Colouration of dhufish observed in the vicinity of baited underwater videos. Colours refer to dominant colouration, since this sometimes changed or more than one colouration was present. For instance, a faint striped pattern was observed on many fish. The blotched pattern is due to black colouration on the scales. Sizes indicate relative size of fish only.

Colour	Females			Males		
	Small	Medium	Large	Small	Medium	Large
Striped[1]	14	1	1	5		
Silver[2]	1	7	13		2	1
Blotched[3]		1	5			19
Dark[4]		2			2	
Total	15	11	19	5	4	20

[1] Horizontal dark stripes ('juvenile colours')
[2] Overall light colour with little or no black on scales
[3] Considerable black on scales
[4] Overall dark colour

Plate 3.1. Dhufish social groups, captured in February 2007. Fish in each group were captured at the same location after being observed together on baited underwater video cameras. The group on the left is comprised of three males (marked with M) and five females (one not shown). The group on the right is comprised of one male (top) and three females. In both pictures the largest fish is a male.

Plate 3.2. Male dhufish showing elongate filament on the dorsal fin and 'blotched' colour pattern.

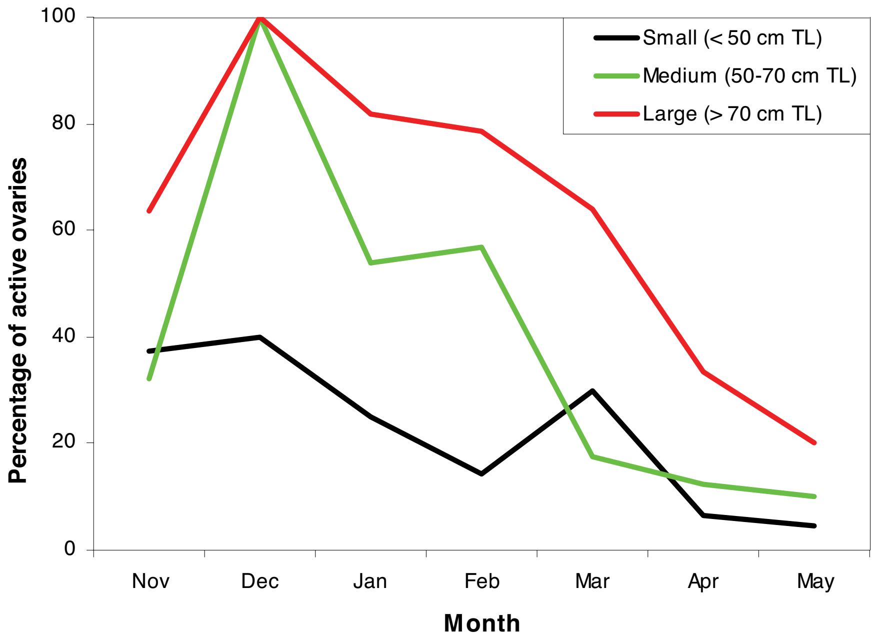


Figure 3.1. Percentage of females in three size classes spawning each month during the spawning season (*n* = 269). Data is based on histological assessment of ovaries during the current study.

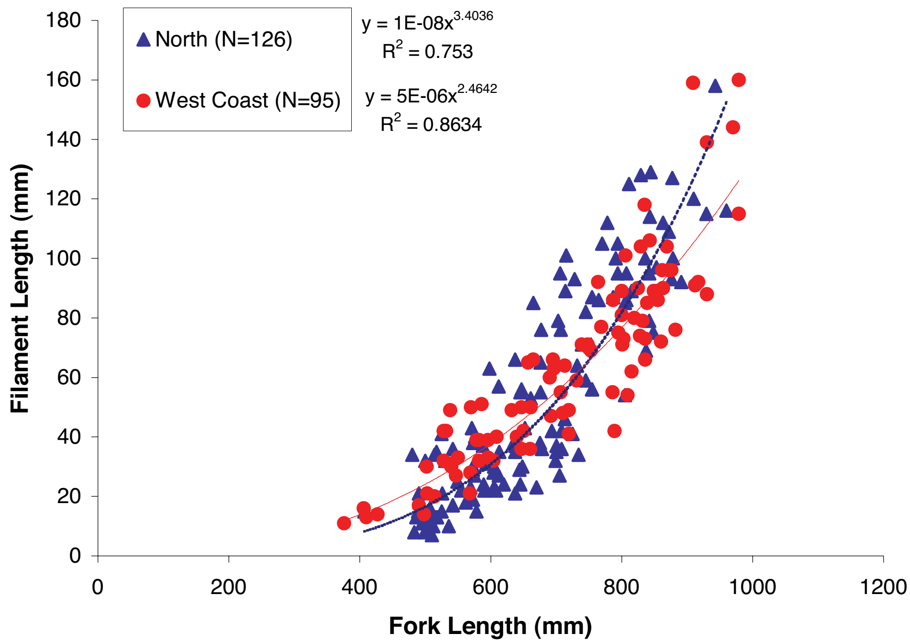


Figure 3.2. Relationship between body and dorsal fin filament lengths in male dhufish.

3.1.2 Social and Spawning Strategies

Aggregating behaviour

Interviews with divers and fishers, and observations by research staff indicate that dhufish typically occur in numbers of up to three fish. However, at times they are present in larger numbers – usually ten or less, but occasionally more than this and, on rare occasions, in their hundreds (Plates 3.3 – 3.5; Table 3.5). Plate 3.4 shows a catch of 51 dhufish taken by a charter boat in an area south of Mandurah during November 2001 (year uncertain). According to interviewed fishers, about 800 dhufish were taken from this area over a three month period, indicating that the fish were aggregated (or at least more densely concentrated than normal within the area) prior to spawning. Aggregating dhufish have been found throughout the West Coast Bioregion (Table 3.5), with the Cape Naturaliste area noted by two ex-commercial fishers who once fished grounds from Cape Naturaliste to Shark Bay, as being the main aggregating area within the species range. Indeed, the largest reported aggregation was found off Cape Naturaliste by a commercial fisher in November 1966 (year uncertain), and nicknamed the 'ghost patch'. The fish in this aggregation were densely packed and filled an area approximately 40 feet high and up to 400 feet long. It was estimated by the four retired fishermen who independently mentioned this aggregation that it contained thousands of fish. This aggregation was fished constantly by four boats until catches declined and it disappeared in February the following year. Of note is the frequent observation by interviewed fishers that dhufish aggregating in the area west of Cape Naturaliste (and other areas) do so over relatively flat habitat covered by a particular type of seagrass, and that the aggregations typically do not form at the same specific location each year.

Whilst dhufish aggregations in other areas of the west coast may not be as big as those that can form in the Cape Naturaliste area, they nevertheless do occur (Table 3.5). Other areas in which aggregations are reported include the Abrolhos Islands and Geraldton area, the Dongara to Two Rocks area, and the Perth to Myalup area.

The largest aggregation observed during the current project was found during a survey of benthic habitat in April 2006. It was located in 42 m off Lancelin and included at least twenty dhufish. The location was revisited in February 2007 and eight dhufish were present (8 F: 2 M; Plate 3.1). A smaller aggregation was also surveyed south of Mandurah in December 2006 and again in February 2007 using live-viewing video, acoustic (see Section 4.2.2) and fishing methods. During the first survey at least ten dhufish were present (along with pink snapper and other species), whereas up to eighteen dhufish were observed during the second survey. In the latter survey the fish were distributed as a fairly tight aggregation comprised of about twelve fish along with about eight dispersed males. Both of these locations have contained good numbers of dhufish on multiple surveys, and are ideal for ongoing monitoring of dhufish (and snapper) abundance (see Chapter 6.3). Other recent reports of aggregations include one found by recreational anglers in Geographe Bay during 2005. This aggregation was targeted by these fishers on eight different occasions between May and August before it disappeared, and was estimated to contain about 200 dhufish (Table 3.5).

Nevertheless, few fishers have seen an aggregation numbering more than a few fish. For example, one male and three females with spawning gonads were captured from an area near Cape Naturaliste during the current study. These fish appeared to be only loosely aggregated because they were caught within tens of metres of each other, even though they were clearly ready to spawn. Collection of samples during the current study indicates that these small aggregations commonly occur amongst dhufish. Given the significant overfishing of this species (Wise *et al.* 2007), it is also possible that declines in population densities have reduced the frequency of larger aggregations. The consequences of this, in terms of decreased genetic diversity, spawning output and social interactions, may be considerable since these factors are likely to be enhanced as fish numbers within aggregations increase (Sadovy and Domeier 2005).

As detailed above, dhufish do not only aggregate during the spawning period (Table 3.5). For instance, two separate aggregations containing up to 40 individuals were observed by divers in June 2005. In both cases the aggregation was mobile, although in one the fish were wary whereas in the other the fish swam within one metre of the diver (possibly because in the first case two of the fish were speared using spearguns). The first aggregation was located in 46 m of water off Two Rocks, whilst the second was found at a depth of 20 m in the Abrolhos Island area. Given that the observed fish were unlikely to be spawning, they could technically be called a 'school'. The aggregation at the Abrolhos Island has been reported by several other fishers and researchers as well and appears to be quite resident to the area, thus making it potentially useful for monitoring numbers through time.

In addition, between late autumn and early spring (April to September) many fishers report higher densities of dhufish in shallower coastal waters that may not necessarily be associated with schooling or aggregating behaviour. This apparent inshore movement is often considered by fishers to be associated with movement by rock lobster, although dhufish rarely seem to eat this prey as they are rarely found in the stomachs of dhufish (fisher and research personnel observations). Nevertheless, this inshore movement does appear to be associated with feeding since fishers have also reported seasonal changes in diet of dhufish. For instance, local ex-commercial fishers note that the inshore movement into shallower (< 30 m) waters off Leeman coincided with increased numbers of octopus and cobbler in the diet. This is supported by the study by Lek (2004), which indicated a change in diet during autumn, and by data presented in the next section on dhufish movement.

Movement

Formation of aggregations and seasonal increases in densities requires movement, since diver observations show that the fish are not in the aggregating areas in similar numbers at other times of year. However, this is a topic of some debate amongst fishers, because it is unlikely that dhufish move large distances or do so very quickly given their sedentary, demersal life style, rounded body shape, and low physiological tolerance to rapid changes in environmental parameters such as water temperature and pressure (Stephens *et al.* 2002, Cleary and Jenkins 2003). Tag and release data from recreational anglers also indicate that many recaptures are often made at the same location in which the fish had originally been tagged (Figure 3.3), noting that these data are primarily for fish that were below the legal size limit of 50 cm (TL).

The tag and release data nevertheless also shows that dhufish do at times move distances of tens of kilometres, generally in an offshore – onshore fashion (Figure 3.4). This is supported by fisher observations, including Cusack and Roennfeldt (1987), and by catch and effort data (see below). For instance, ex-commercial fishers with many years of experience believe that dhufish migrate into the Cape Naturaliste for spawning, and they move inshore during winter in areas such as Bouvard Shoals and Leeman. It is also likely that the amount of movement is dependent on where each fish resides outside of the aggregating period, and hence how far the fish must move to reach the aggregating area.

In addition to migratory movement to and from an individual's normal home range, it is likely that home range size varies considerably between dhufish and that they may encompass more than one reef. Variable home range size is common among fish and may reflect gender, density of con-specifics and habitat quality (e.g. Mackie 1998). Evidence of short-term movement away from a particular reef was found during the current study. For instance, monitoring of a small reef off Two Rocks using baited underwater video showed that individuals were not consistently in the area. Acoustic tagging of a dhufish at this same location provides further proof of this (see Chapter 4.5.1). This tagged fish moved away from the small reef where it was captured immediately after release, but returned in twenty days and remained there for at least 46 days until the tag was dislodged. Interestingly, the pattern in acoustic signals indicate that this fish remained further from the reef at night, suggesting nocturnal foraging away from the immediate vicinity of the reef.

Although data for catch and effort by the commercial sector is too broad scale to provide detailed information about dhufish movement and abundance patterns, it does provide some general evidence. For instance, as shown in Figure 3.5, the incidence of high catch per unit effort (> 100 kg/day) in the commercial fishery peaks in spring between Jurien Bay and north of Bunbury. This high CPUE (approximately twice the average as reported by St John and King 2006) is likely to reflect increases in general fish densities and/or vulnerability that may be associated with aggregating behaviour. In particular, the data for Block 3015, which covers a relatively small area of coastal water from Jurien Bay to Lancelin, confirms a consistent peak in CPUE from July to September, the period when dhufish are more abundant in inshore waters (Figure 3.6).

Catch data also shows an increase in Block 3015 during the latter half of the year (Appendix 5), noting that this data does not reflect changes in fishing effort due to other factors such as weather. Similarly, catch data for Block 3214 which, because of its location, includes only a small portion of dhufish habitat north of Cape Naturaliste (the rest of the block being deep water), exhibits consistent peaks before and after summer, when peaks in catches occur within the adjacent Block 3314 (which covers the main Capes spawning grounds; Appendix 5). The patterns in these data are particularly obvious between 1975 and 1990 but become less apparent in recent years. This is also evident when comparing the historic data for Block 3314 by itself (Figure 3.7). The incidence of high CPUE provide further evidence of increased abundance and vulnerability that may be associated with aggregating behaviour (Figure 3.5).

Various hypotheses have been developed to explain why fish migrate to particular areas to spawn. One that may apply to dhufish is enhancement of egg and larval dispersion and survival by ocean currents, since the wind driven Capes Current generally only occurs during summer (Pearce and Pattiaratchi 1999) to coincide with the dhufish spawning period. This current is likely to have a strong and variable influence on the transport of eggs and larvae released in the Cape Naturaliste spawning area. When in the aggregating area, the behaviour of dhufish may also be influenced by oceanographical conditions. For instance, as found in other species, formation of aggregations can be affected by water temperature, storm activity, and swell (Clayton 2004, Chauvet 2005, Peres and Klippel 2003).

Mating and Social Strategies

Information provided above indicates that dhufish have a complex social structure that is based on intra-sexual competition and inter-sexual selection of mates. The greater investment by males into body growth (rather than gonad size), and the fact that they spawn in pairs rather than multi-male groups, is characteristic of species in which large males gain extraordinarily high reproductive success by dominating other males and attracting larger and/or more mating partners (Bekkevold *et al.* 2002). Among fish, these male characteristics are more typical of protogynous (female-first, sex-changing) species rather than gonochoristic (non sex-changing) species (Molloy *et al.* 2007) such as dhufish. However, in common with protogynous species (e.g. many groupers species), the relatively low output of sperm by males could lead to sperm limitation, and subsequent incomplete fertilisation of released eggs, if large (predominantly male) fish are selectively removed from the population (Vincent and Sadovy 1998).

The distinctive dorsal filament that becomes longer and more obvious with size is also likely to play a role in defining social and mating status, in a similar manner to the distinctive male plumage found in bird species that have a polygynous mating strategy (Emlen and Oring 1977). Capture of males dhufish with scrape-like wounds, particularly during the spawning period (fisher obs. and *pers. obs.*), and aggressiveness of males towards each other in aquaculture facilities (Cleary and Jenkins 2003) further highlights strong intra-sexual competition. This is supported by the fact that the largest fish in groups observed by baited underwater video or captured for biological sampling is always a male.

Heightened aggression between males has also been observed in grouper species such as the chinaman cod (*Epinephelus rivulatus*) which, like dhufish is typically sedentary and has a complex social system (Mackie 2003). However, males in grouper species typically defend territories from each other whereas male dhufish are often found co-habiting an area (e.g. Plate 3.1; fisher obs. and *pers. obs.*). This indicates lekking behaviour whereby males congregate to establish dominance hierarchies, and attract and court females. Lek systems have been described in a range of animals (Emlen and Oring 1977) as well as in other species of fish, and are a focus of increased attention by fisheries ecologists (Donaldson 2005). This type of mating system, in which males do not directly defend females but instead form a hierarchy used by the females to select an appropriate mate, is called a 'male dominance polygyny' (Emlen and Oring 1977).

A social hierarchy is also likely to occur amongst females as well, as seen in grouper species (e.g. chinaman cod, Mackie 2003), due to male preference for larger, more fecund females during spawning. This is evidenced by the lower frequency of spawning among smaller females compared to larger fish (Figure 3.1). These data again highlight the significant contribution that large dhufish make to reproductive output, and the associated need to ensure that they are adequately represented in the population.

Table 3.5. Descriptions of dhufish aggregations reported by commercial and recreational fishers and divers.

Year	Time of year	Estimated size (# of fish)	Location	Depth
1980	August?	~ 70	Abrolhos Islands	
2005	June	30-40	Abrolhos Islands	20
~ 1992	Summer	68 caught	Abrolhos Islands	60
1980s	October	> 90 caught	Abrolhos Islands	
early 1960s	April?	128 caught in one day	Abrolhos Islands	
early 2000s	October?	22	Abrolhos Islands	
	September?	20	Abrolhos Islands	7
2006	November	30 m diam. 100s of fish (30 caught)	Beagle Islands	38
~1980	February	145 caught	Beagle Islands	38
1991	January	900 kg caught	Bunbury	~ 50
1971	January	Not much on sounder but 113 caught	Cape Naturaliste	~50
1994	January	100s	Cape Naturaliste	50?
2005	April - May	4 x 4 metres	Cape Naturaliste	25
~ 1970	January	75 caught	Cape Naturaliste	
~1990	January	~ 200	Cape Naturaliste	
~1999	March	20 m diam x 6 m high	Cape Naturaliste	44

1966?	November	40 ft high x 3-400 ft long (1000s of fish)	Cape Naturaliste	45
	March	~ 12 females, 2 males	Cape Naturaliste	35
	December	17 caught but a lot more there	Cape Naturaliste	~ 50
	Sept - Oct?	30	Cervantes	6
		20 +	Direction Bank	30
	March	15-20	Dongara	
2005	May-Aug	~ 200	Geographe Bay	35
~ 1980	Summer	~ 60	Geraldton	
1975?		~ 110 fish caught in 2.5 hrs	Geraldton	
early 1980s	Summer	22 but disappeared next day	Geraldton	
~ 1985	Aug-Sept	~ 15 (5 caught)	Greenhead	5
2001	January	hundreds? (50 m diam x 20 m high)	Gregory	43
2004 + 2005	October	12 (2004), 24 (2005)	Gregory	50
2005	November	~ 20	Hamelin Bay	17
2005	November	~ 14	Hamelin Bay	17
	March	40 - 50 (caught 14)	Jurien Bay	48
2003	January	12 caught in ~ 45 mins	Lancelin	30?
	Jan - Feb	200 + (caught 24 one day, 17 the next)	Lancelin	48
early 1990s	Aug-Sept	127 caught	Leeman	
~ 1994	November	~ 200	Mandurah	22
1980s	Wint/Spring	50-60	Mandurah	25
2001?	November	51 caught in one day	Mandurah	
early 2000s	May	1.5 x 1.5 m (9 caught)	Mandurah	26
late 1980s		~ 45	Moore River	10
1999	January	7	North Perth	34
2002	April - May	30 m diam. 100s of fish	Perth	45
1970s	February?	27 caught in 90 mins	Perth	100?
since 1999	Oct - Nov	small numbers’	Perth	45-50
	Jan - Feb	~ 50 - 60 (caught ~ 15)	Perth	40
1979	June-July	~ 20	Perth	18
1994	~ August	10	Two Rocks	11
1997	Winter	~ 15	Two Rocks	16
2005	June	30-40 (speared 2)	Two Rocks	46
early 1990s	December	Used to be ~ 100 but no longer	Two Rocks	38
		~ 100	Two Rocks	18
late 1980s	March-April	~ 20	Wedge Island	20
	Sept/Oct and Feb/Mar	4-20	Yanchep	20 - 29
1991	~ July	45 caught		80
	Jan-Feb	120 (Day 1), 80 (Day 2)	Jurien Bay	
1987	Feb - Mar	57 (Day 1), 50+ (Day 2), 40+ (Day 4)	Jurien Bay	55
2007	July	30-40 aggregated – filmed on video	Abrolhos Island	20
2004	~ August	20 caught on dropline. More there.	Two Rocks	~ 50

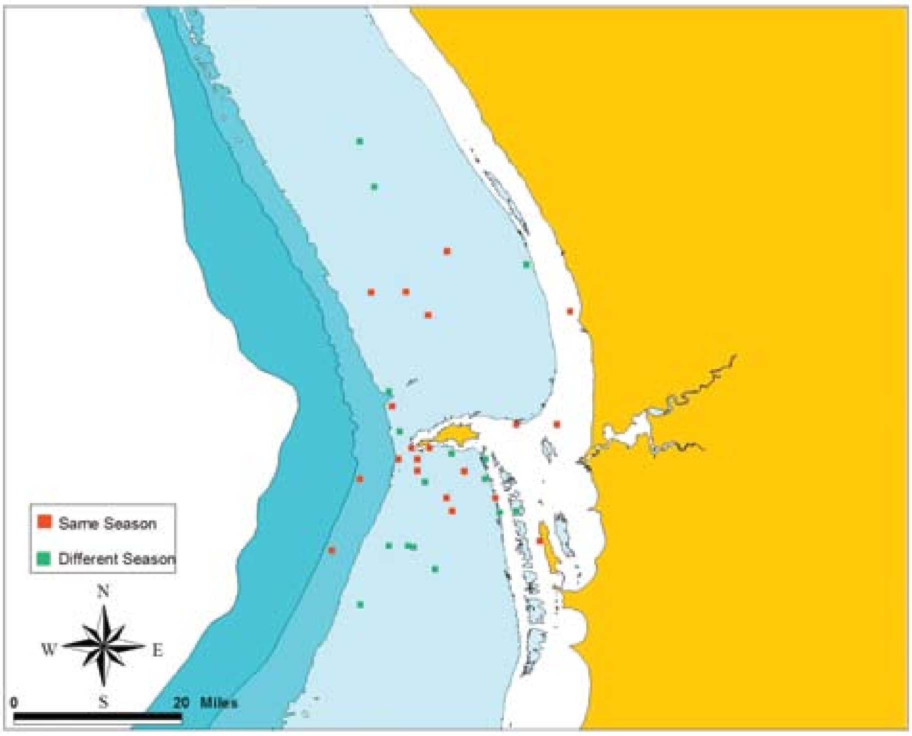


Figure 3.3. Locations where dhufish have been tagged and recaptured at the same location. Black and blue circles indicate recaptures during the same and different season as initial tagging, respectively. Data were derived from the Australian National Sportsfishing Association database and are for undersized dhufish tagged by recreational anglers.

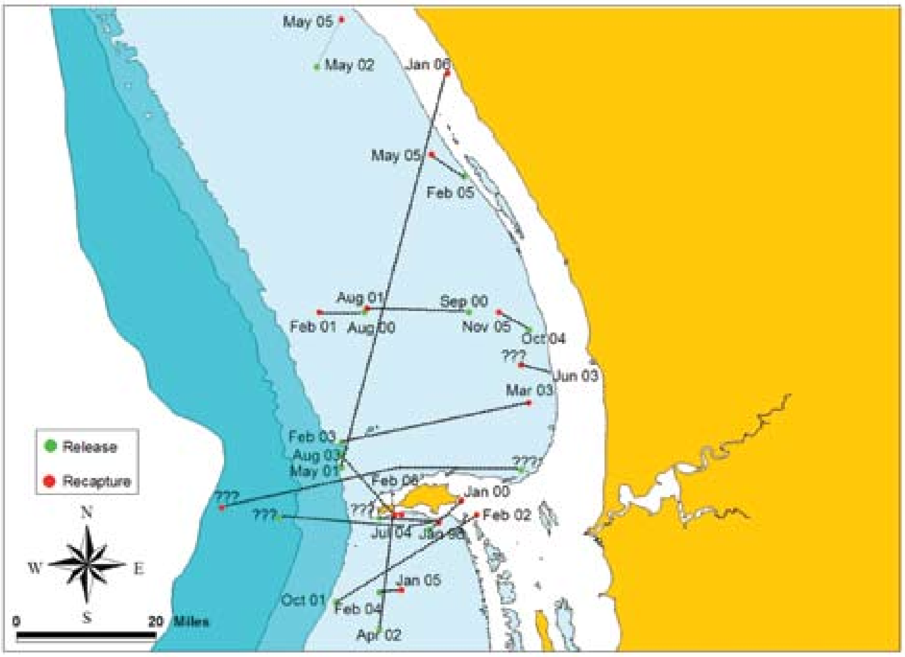


Figure 3.4. Locations where dhufish have been tagged and recaptured at different locations. Green and red circles indicate release and recapture locations, respectively. Question marks indicate unknown release or recapture dates. Data were derived from the Australian National Sportsfishing Association database and are for undersized dhufish tagged by recreational anglers.

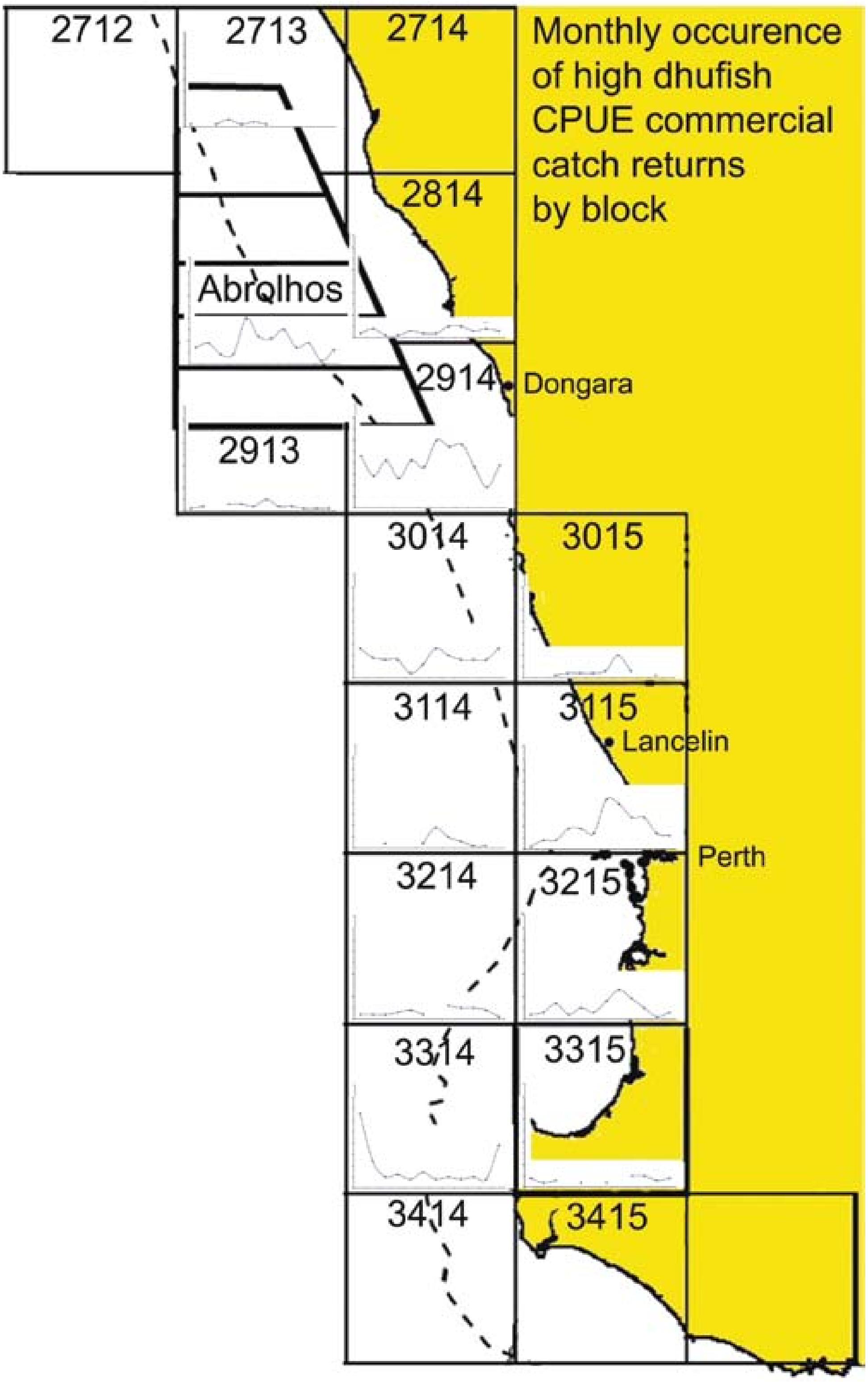


Figure 3.5. Monthly occurrence of high dhufish catch per unit effort (> 100 kg / day) by commercial fishers within the West Coast Bioregion. For each graph the x-axis indicates month from January to December, and the y-axis indicates frequency of each high CPUE.

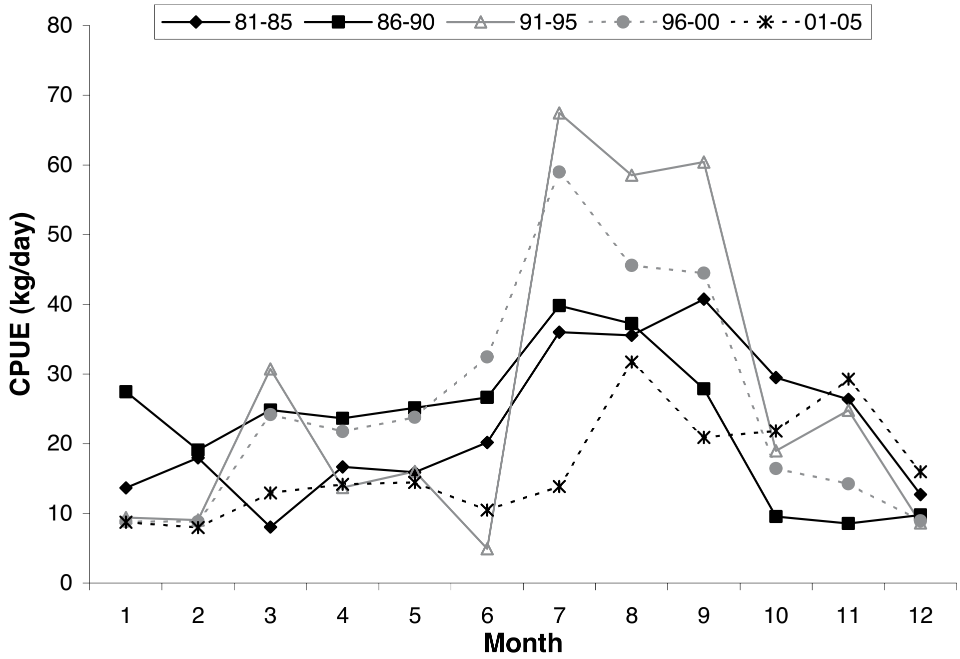


Figure 3.6. Effective catch per unit effort of dhufish by commercial line fishers within Block 3015 (Lancelin to Jurien Bay). Data are pooled by five-year blocks as indicated in the legend.

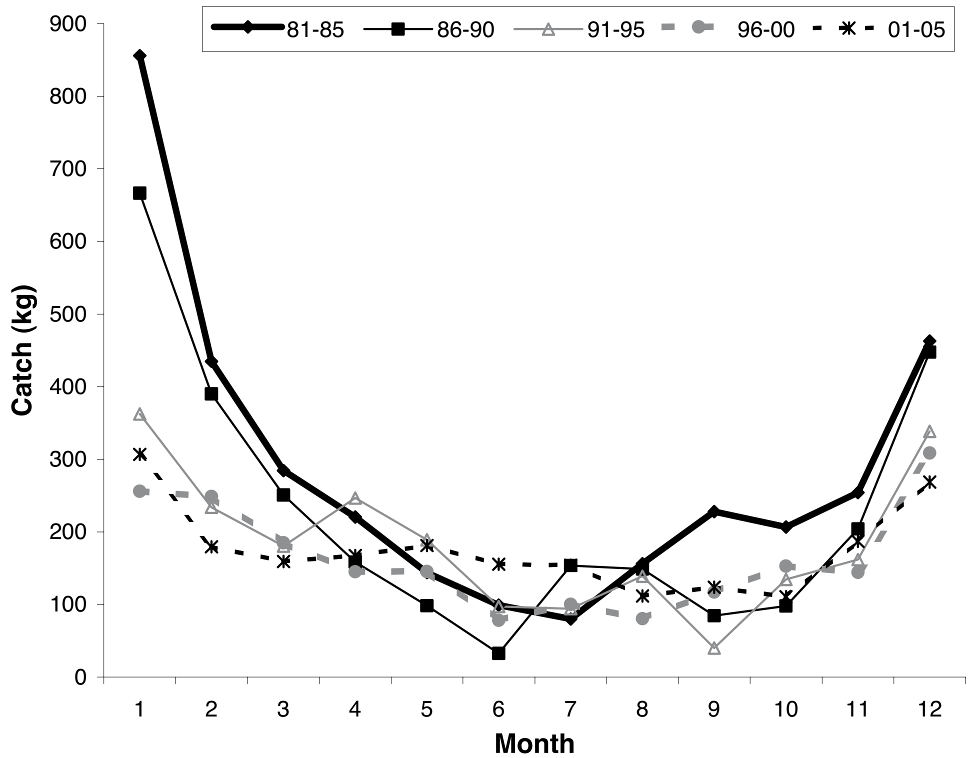
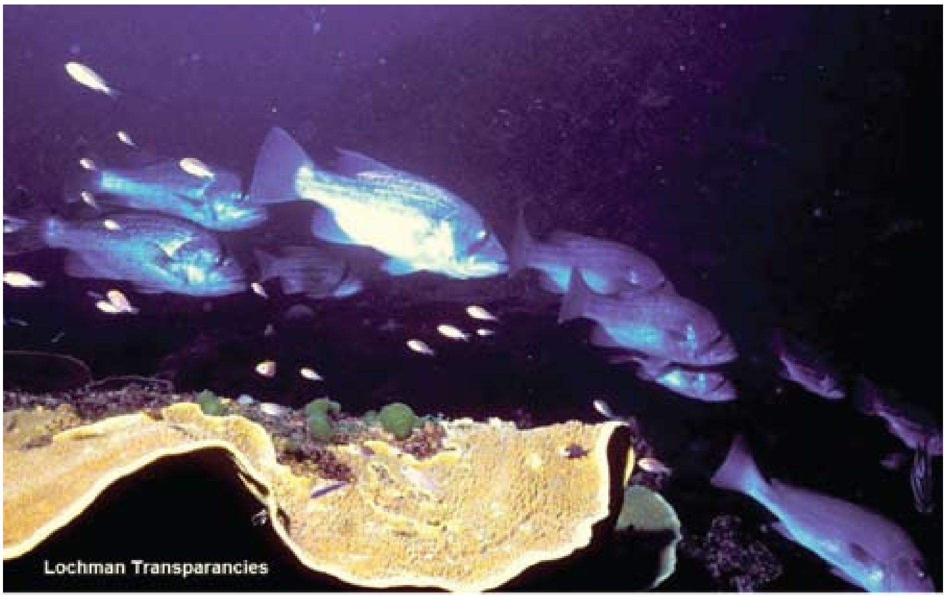


Figure 3.7. Commercial catches of dhufish within Block 3314 (Cape Naturaliste). Data are pooled by five-year blocks as indicated in the legend.



Plates 3.3. Schooled or aggregated dhufish – probably at the Abrolhos Islands (copyright Lochman Transparencies).

Plate 3.4. Catch of fifty-one dhufish taken by a charter vessel south of Mandurah during November 2001.

Plate 3.5. Catch of fifty-two dhufish taken by a commercial fisher during January, early 1990s, in 45 m of water near Naturaliste Reef (north of Cape Naturaliste; courtesy of T. Faulkner).

3.2 Pink Snapper (*Chrysophrys auratus*)

Like dhufish, pink snapper ('snapper') are targeted by commercial and recreational fishers throughout the West Coast Bioregion (WCB). In contrast though, snapper are distributed and also targeted across Australia and New Zealand, and have therefore been studied in much greater detail than dhufish. Along the WA coast, considerable research on snapper has occurred in the Shark Bay area of the Gascoyne Bioregion (e.g. Moran *et al.* 2003, 2005, Jackson *et al.* 2005), where the bulk of the commercial catch is taken (Figure 3.8). Only recently has this species been the focus of research within the West Coast Bioregion (e.g. St John and Syers 2005, St John *et al.* 2007, Wakefield 2006), where commercial catches are relatively low and recreational catches are likely to comprise a greater proportion of the total catch. Because of the large amount of literature already available on snapper biology and ecology, these were not a primary focus of the current project. Only a brief synopsis of snapper reproductive and aggregating strategies is therefore provided here.

In WA waters, snapper biology is strongly influenced by environmental parameters, particularly water temperature. As a consequence, snapper exhibit latitudinal differences in growth, with fish in the southern waters maturing at a larger size/age, and reaching a larger maximum length than fish in the north. Because snapper tend to spawn within a small range of water temperature (19 - 21°C) the timing of spawning also shows a latitudinal trend, with peak spawning occurring between July and September in the north, October and December in the central, and about December and January in the south of the West Coast Bioregion (St John *et al.* 2007, Wakefield 2006).

Snapper are a schooling species that also aggregate in large numbers for spawning, often at specific locations requiring considerable movement by participating fish (Moran *et al.* 2003, Wakefield 2006). The unbiased sex ratio, similarities in growth patterns of males and females, and large testis size of males (> 8% of body weight; St John *et al.* 2007) indicate that fish within these aggregations spawn together in multi-male multi-female groups, in contrast to the pair-spawning strategy of dhufish. Because snapper are pelagic spawners (like virtually all aggregating species; Clayton 2003), and have neutrally buoyant eggs, the scale of recruitment and hence catches can also vary considerably. This is demonstrated by temporal variation in the incidence of very high catch rates, presumably as a result of fishing schooling and/or aggregating snapper (Figure 3.9).

Much of the commercial catch in WA waters (ie in the Carnarvon area) is taken when snapper are aggregated for spawning, prompting management action since 1986 to reduce fishing mortality on the stock (Anon 1999). Because snapper spawning aggregations are spatially and temporally predictable, they have also been targeted by recreational anglers, particularly in Shark Bay and Cockburn Sound. Cockburn Sound, along with the adjacent Warnbro Sound, is thought to be the most important aggregating site within the WCB. This appears to be due to the unique spawning and nursery conditions that are favoured by snapper (Lenanton 1974, Wakefield 2006), and may not occur to the same extent elsewhere in the bioregion due to the lack of similar embayments. For instance, information from fishers indicates that Geographe Bay, a more open coastal feature to the south is not a significant aggregating area. Fisher interviews further show that whilst snapper migrate and school in shallow waters adjacent to Jurien Bay, this occurs around May each year and therefore is unlikely to be associated with spawning.

Nevertheless, the available evidence is not sufficient to make definitive statements about the spawning strategy of snapper in most areas of the WCB, and it is certainly the case that snapper in spawning condition are found throughout the bioregion (Table 3.6). This indicates that snapper in the WCB may include two distinct components – one comprised of relatively large fish that migrate into Cockburn and Warnbro Sounds (see below), and another comprised of fish that spawn in more open waters along the coast. These 'open-water' aggregations may comprise smaller-sized fish than those in the Sounds, but they may also be more abundant and therefore potentially contribute more to spawning output as a whole, particularly if eggs released by fish in the Sounds have limited dispersal (as discussed below). At the same time, recruitment success from these open-water aggregations may also be much lower. Clearly more research is needed into this issue.

The annual migration of snapper into Cockburn Sound is a striking phenomenon. The participating fish are significantly larger than those caught in adjacent waters, and are not commonly captured outside the Sound, possibly because they disperse widely and comprise only a small proportion of the oceanic population (Wakefield *pers. comm.*). As batch fecundity increases with length in this species (Mackie *et al.* 2007), these Cockburn Sound snapper also play an important role in production of recruits. However, the proximity to Perth also makes this population very vulnerable to overfishing and coastal development.

The study of the Cockburn Sound snapper by Wakefield (2006) highlighted the close relationship between spawning and environmental conditions in this species. The presence of an eddy within the Sound during the spawning period (mainly October to December) may maximise retention in accordance with the dual role the Sound plays as both a spawning and nursery area. Spawning was also correlated with tidal regime, peaking on the new and full moons, as well as during the three hours following high tide. As found elsewhere, the spawning season was also timed to occur when water temperatures were between 19 and 21° C. This strong correlation with environmental conditions may enable fish to synchronise spawning activities, and may ensure that eggs are released at times suitable for dispersion and survival (e.g. fast growth) to optimise subsequent recruitment.

The commercial line fishery exhibits considerable spikes in annual/monthly CPUE of snapper, particularly in northern areas of the WCB where the majority of the snapper catch in this bioregion is made (Appendix 6). This is indicative of targeted fishing of snapper when they are either schooled or aggregated. However, there is little evidence of a seasonal trend in most of the data blocks. This is contrasted by the strong summer peaks in commercial catch rates within Cockburn Sound by fishers targeting the spawning aggregation (Figure 3.10). Similar peaks in catch rates are not evident for adjacent open waters (ie Blocks 31150 and 31250; Figure 3.11) where, as found elsewhere, catches and catch rates tend to fluctuate considerably without clear trends.

Table 3.6. Number and location of spawning pink snapper sampled during recent DoFWA studies (present study and St John *et al.* 2007).

Month	Location (North-south)							
	Kalbarri	Abrolhos	Port Gregory	Dongara	Geraldton	Bunbury	Geographe Bay	Cape Naturaliste
Jan				2			1	2
Feb		2					1	1
Mar						1		1
Apr								
May	7							
Jun	6		1					
Jul	5							
Aug	62							
Sep	58	5			2			
Oct			1				3	
Nov		4				1	1	
Dec								7

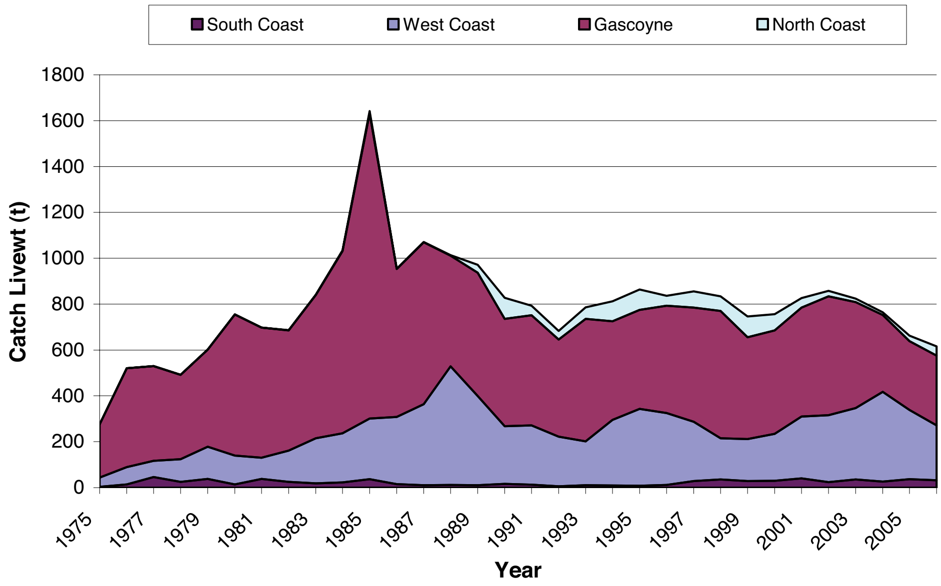


Figure 3.8. Annual commercial catch of pink snapper within the Gascoyne, West Coast and South Coast Bioregions.

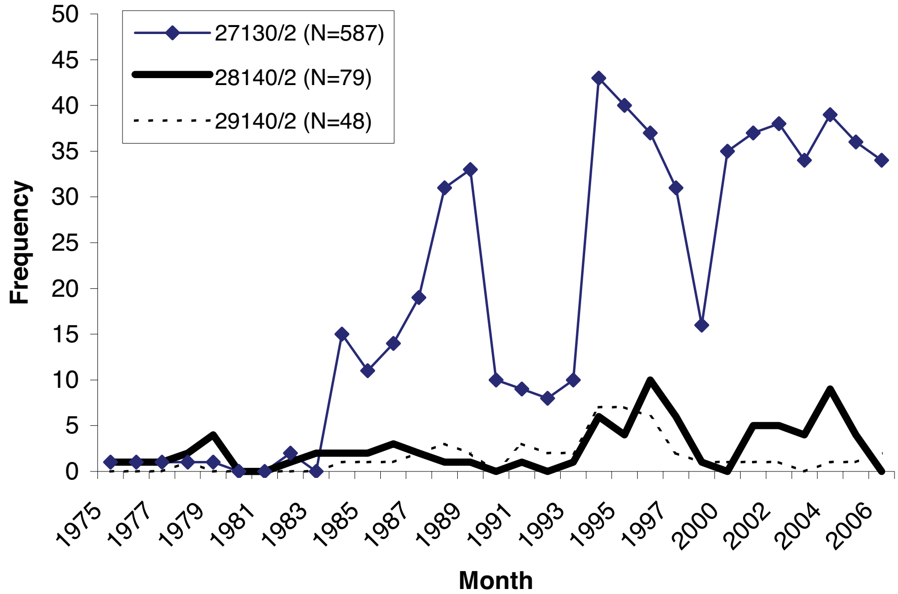


Figure 3.9. Frequency of high pink snapper CPUE (> 150kg/day) each year since 1975, for select reporting blocks within the West Coast Bioregion (refer to Figure 3.5 for the location of these blocks).

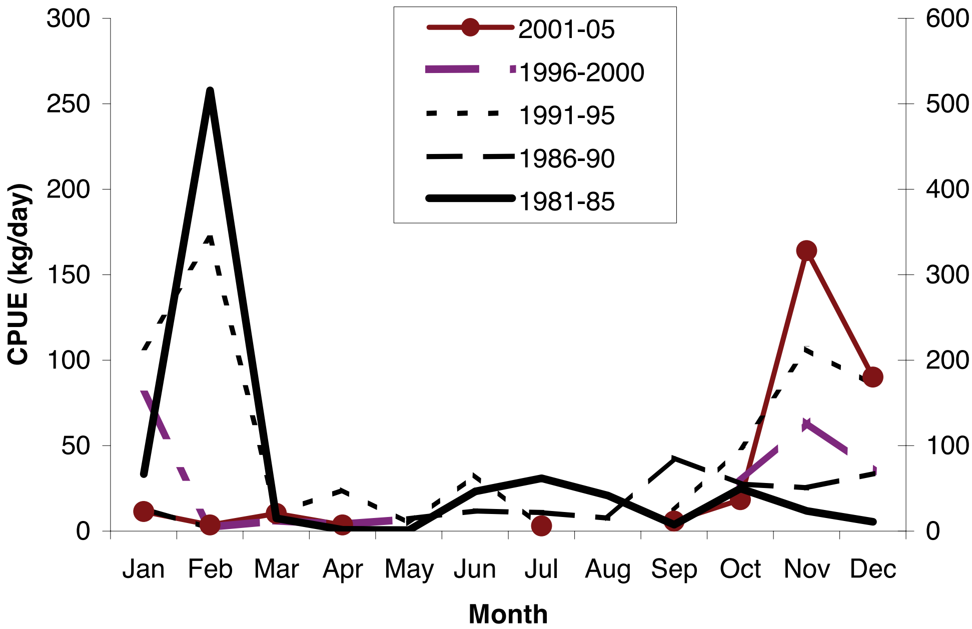


Figure 3.10. Monthly catch per unit effort of pink snapper within Cockburn Sound. Data is average CPUE per five-year block. Data for 1981-1985 is shown on the right axis (data for all other years shown on the left axis).

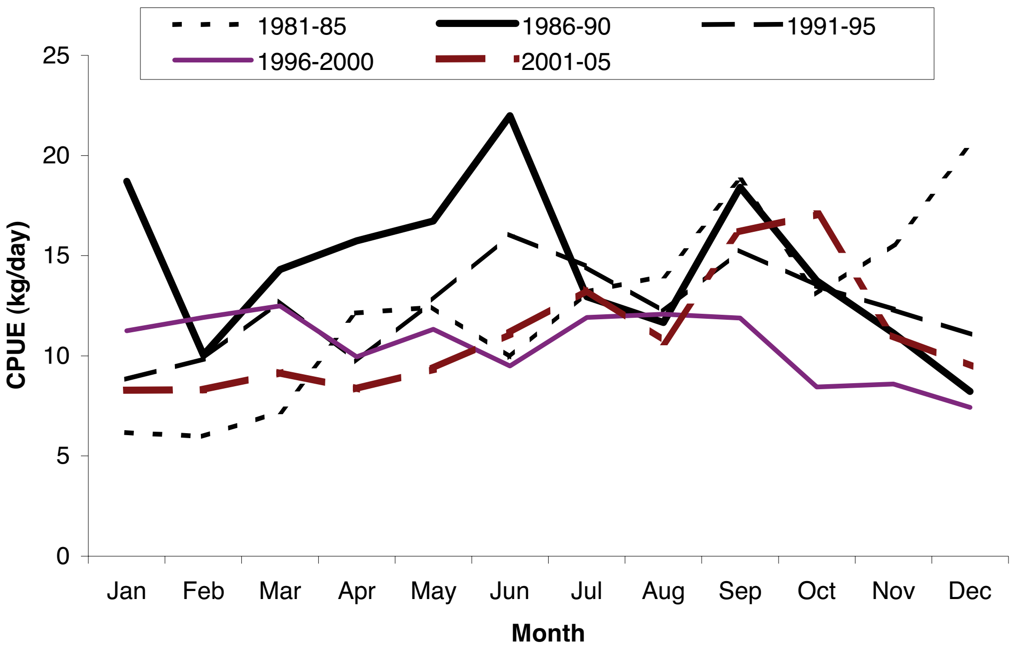


Figure 3.11. Monthly catch per unit effort of pink snapper within Block 31150 (Perth to north of Lancelin). Data is average CPUE per five-year block.

3.3 Bight Redfish (*Centroberyx gerrardi*)

Bight redfish are broadly distributed across southern Australia where they mainly inhabit deep waters along the edge of the continental shelf. Most of the commercial catch of this species is taken within the Great Australian Bight Trawl Fishery operating at depths of 200-500 m in the vicinity of the WA – SA border (Lynch and Garvey 2003). In WA waters Bight redfish are considered the most economically important demersal scalefish in the South Coast Bioregion (R. Lenanton, DoFWA, *pers. comm.*). The species is also prominent in the lower West Coast Bioregion, where commercial catches have risen seven-fold since 1998 (Figure 3.12). Recreational and charter fishers are also increasingly targeting this previously remote resource as technology and knowledge increases (fisher interviews and discussion on the Western Angler website at www.westernangler.com.au). Smaller-sized congeners, particularly *C. australis* (yelloweye redfish) and *C. lineatus* (swallowtail), are also caught in the WCB, with all often reported simply as 'redfish' in fisher logbooks. However, discussion with fishers and research sampling show that these other species comprise only a small proportion of catches. Thus, whilst the description of catch and effort provided below refers to redfish it is expected to consist almost entirely of *C. gerrardi*.

In 2005, the total commercial catch of redfish in WA waters was 114 tonnes, and by weight redfish were the most important scalefish in the South Coast and the fourth most important in the West Coast Bioregions. Redfish were also the highest catch of charter operators in the South Coast Bioregion (Penn *et al.* 2005). There is little information on recreational catches, although the 2000/01 National Survey data indicated that almost 22,700 redfish were captured by this sector during the survey year. Interviews with fishers has identified that a considerable proportion of the Bight redfish catch is taken when the fish are aggregated for spawning (see below). Because of its relative abundance and prominence in temperate ecosystems, this species is also considered by the DoFWA to be of ecological significance. As such, the need for biological data on Bight redfish in WA waters has been formally acknowledged (Penn *et al.* 2005).

Most (~ 70%) of the commercial catch of redfish within the WCB is taken by line fishers from waters west of Cape Naturaliste (Figure 3.12), with small amounts taken as far north as Kalbarri (these northern catches are unlikely to be *C. gerrardi*). Catches in the Cape Naturaliste area peak in February and March, with smaller peaks towards the end of the year around October (Figure 3.13; note that because of the small number of fishers targeting Bight redfish the catch data is sometimes skewed by high individual catches, such as that shown for July in Block 32140). Peaks in the frequency of high CPUE, indicating aggregation fishing, also occur around March and October (Figure 3.14). Information from fishers indicates that these peaks coincide with an inshore movement by Bight redfish into areas where they are not caught at other times of year. The decline in catches over winter is due to inclement weather at this time coinciding with an offshore distribution of the fish.

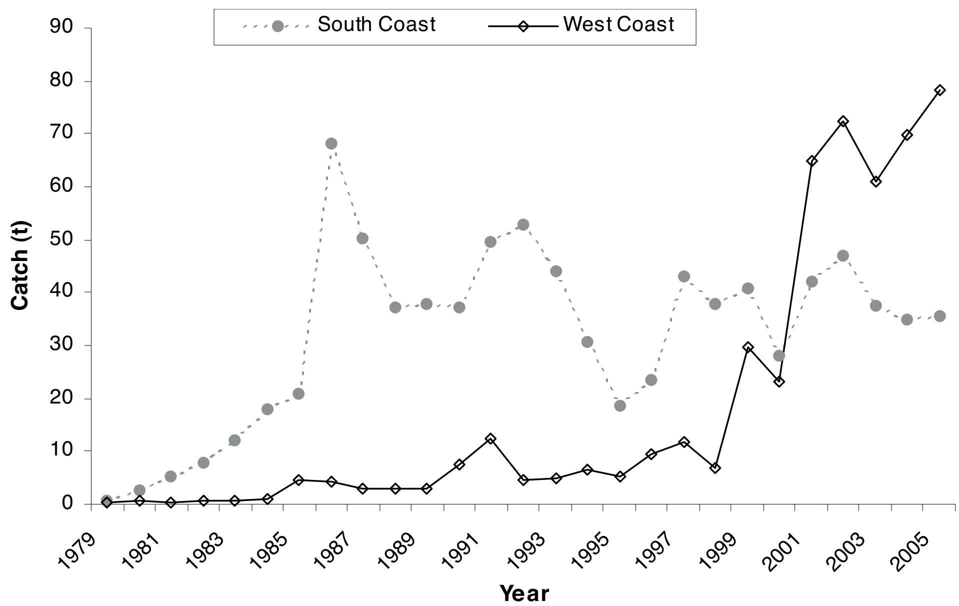


Figure 3.12. Annual commercial catch of redfish in the South and West Coast Bioregions. The majority of this catch is Bight redfish.

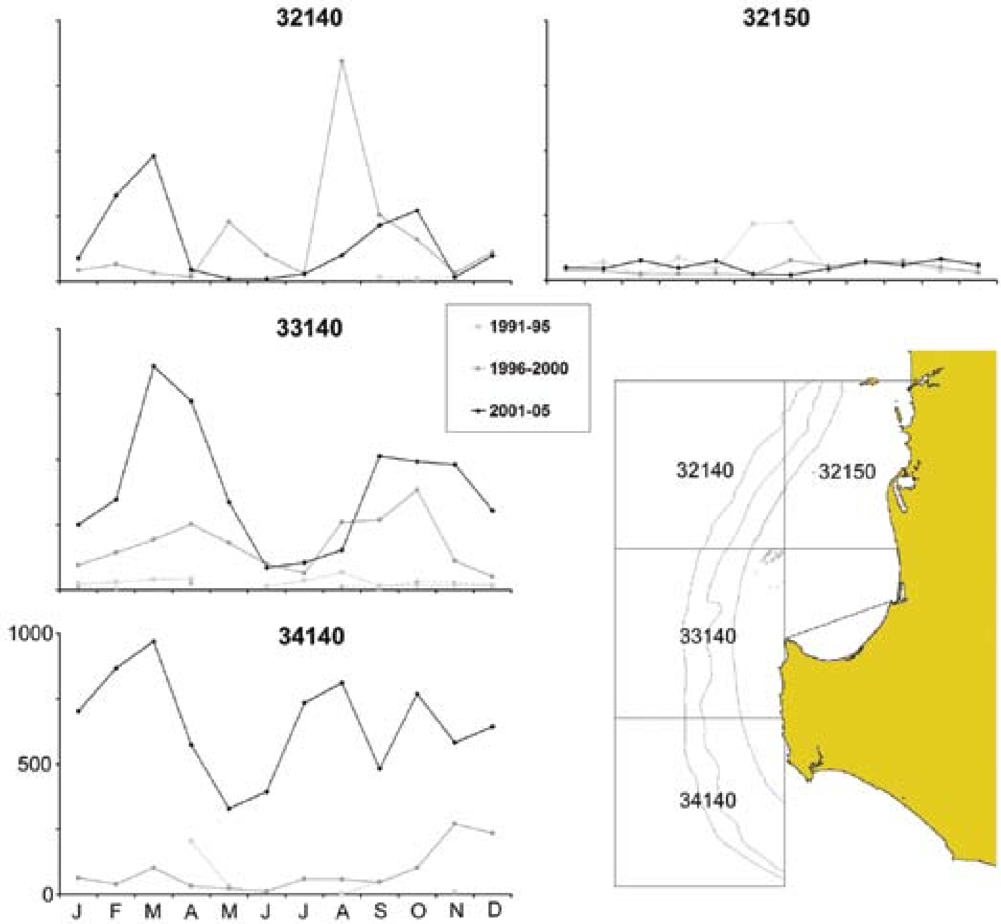


Figure 3.13. Average monthly catch of redfish (mainly Bight redfish) in the Cape Naturaliste area. Data for each fishing block is grouped by five-year periods. Depth contours shown are 100, 200 and 500 m.

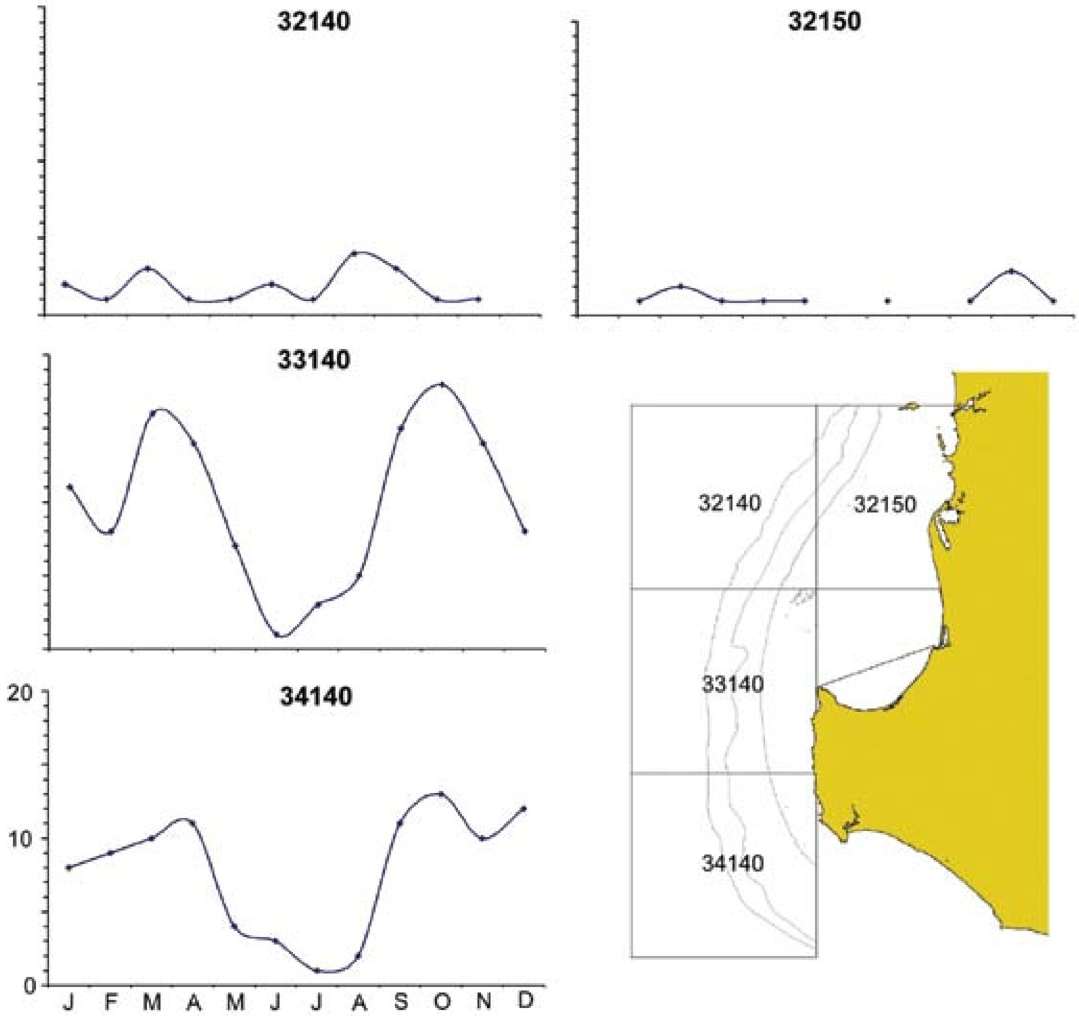


Figure 3.14. Monthly frequency of high redfish (mainly Bight redfish) commercial catch per unit effort (> 50kg/day) in the Cape Naturaliste area. Depth contours shown are 100, 200 and 500 m.

3.3.1 Biology and Ecology

Research conducted in the GABTF shows that Bight redfish live to at least 64 years (Stokie 2004) and have fairly low rates of productivity and natural mortality (Wise and Tilzey *et al.* 2000). Preliminary ageing of fish obtained from the Cape Naturaliste area during the current study shows that the otoliths of this species have a clear ring structure and that ages of at least 56 years are reached (assuming annual formation of growth rings). The congener, *C. affinis*, is also long lived (> 35 yrs) and slow growing. This species is targeted by the Southern and Eastern Scalefish and Shark Fishery, and has experienced a significant decline in biomass between 1970 and 1990 (Tilzey *et al.* 2006).

Samples obtained during the current study from the Cape Naturaliste area show that male and female Bight redfish have similar growth patterns (Figure 3.15). A preliminary length-weight relationship is:

Whole Weight (g) = 0.0001 (Fork Length (mm))$^{2.758}$

Although there is little difference in the length frequency distribution of male and female Bight redfish in a particular area, there appears to be marked differences in mean size between areas (Figure 3.16). The Cape Naturaliste stock also appears to have a larger mean size than stocks targeted by the GABTF, in which it is reported that up to 80% of the catch is below 300 mm (the possible size at maturity; Brown 2004). In contrast, the majority of Cape Naturaliste fish were above 400 mm. These differences in mean size suggest that there is little mixing between the spatially separated stocks.

The co-occurrence of oocytes at all stages of development within the ovaries shows that female Bight redfish release eggs in batches, although macroscopic inspection of spawning ovaries suggests they have a low batch fecundity. Spawning testes weigh more than 3% of body weigh, indicating that individuals spawn in multi-male, multi-female groups.

Macroscopic staging of Bight redfish ovaries shows that spawning occurs from February through to at least April, with peaks in March and April when virtually all sampled females were spawning (Figure 3.17). This high proportion of spawning fish, coupled with the apparently low batch fecundity, indicates that females spawn a relatively small number of eggs at frequent intervals whilst aggregated. No samples were obtained in May because of a lack of commercial samples during the study period, as appears generally to be the case in previous years (Figure 3.13). It is possible, therefore, that Bight redfish abruptly stop spawning in April and move offshore during May away from the inshore fishery. This pattern in spawning was confirmed by data for gonadosomatic indices, which highlight the rapid gain in weight by ovaries in March and April as they become reproductively active (Figure 3.18). The fact that the error bars around the mean values during these two months are similar to those at other times of year further suggests that batch fecundity is low and hence there is less variation in ovarian weight as a consequence of spawning. This contrasts with other species such as pink snapper and dhufish, in which there is typically considerable variation in batch fecundity during the spawning period (e.g. St John *et al.* 2007).

The ovaries of Bight redfish are non-reproductive and have low GSIs from August through to December. Through this time period a good proportion of the annual catch is also taken and a high incidence of high catch rates occur (Figure 3.14), indicating that the fishery is also targeting this species when it is schooled up. Information from fishers indicates that the fish may be hunting squid at this time.

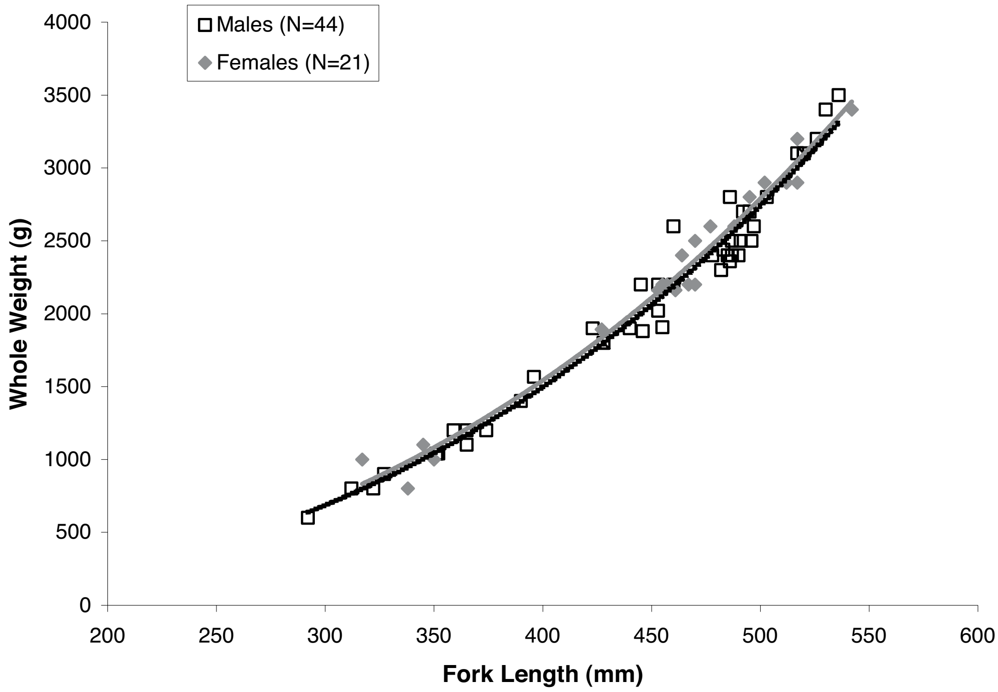


Figure 3.15. Relationship between whole weight and fork length for Bight redfish sampled from the Cape Naturaliste area.

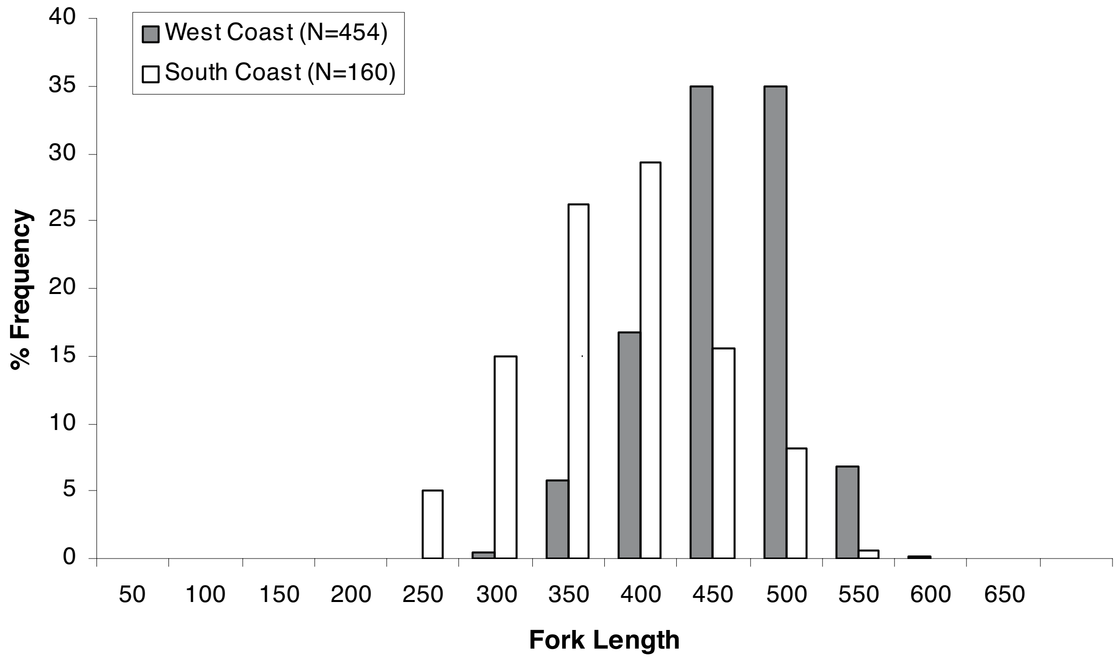


Figure 3.16. Length frequency of Bight redfish sampled from the West Coast (Cape Naturaliste) and South Coast Bioregions.

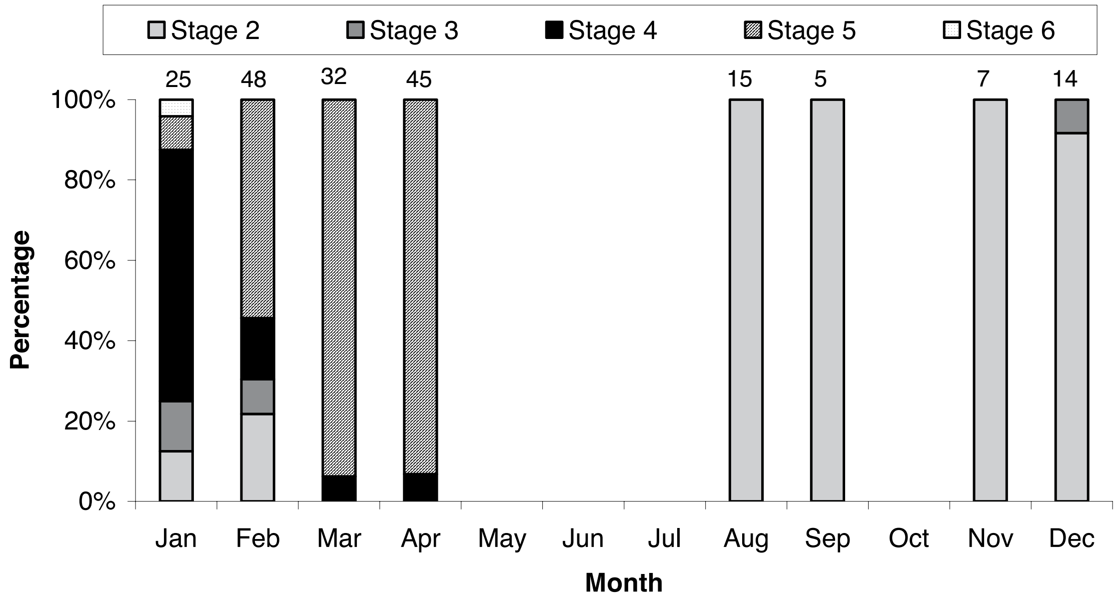


Figure 3.17. Monthly frequency of Bight redfish ovarian stages in the Cape Naturaliste area during 2006. Samples sizes are indicated above each column.

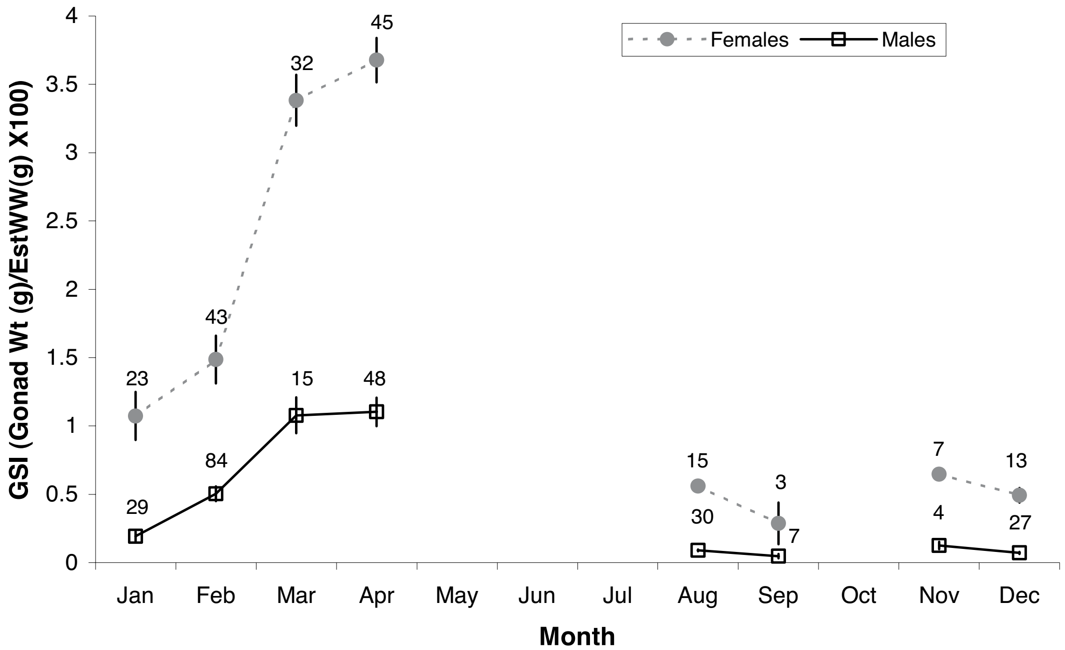


Figure 3.18. Mean monthly gonadosomatic index (± SE) for Bight redfish in the Cape Naturaliste area during 2006 (based on estimated whole weights). Sample sizes are also shown.

3.4 Other species

3.4.1 King George whiting (*Sillaginodes punctata*)

King George whiting is the largest of the 31 species belonging to the Sillaginidae, with maximum reported lengths and ages of 596 mm and 14 years for females and 555 mm and 13 years for males, respectively (Hyndes *et al*. 1998). In southwestern Australia, individuals of this species attain 50% maturity at about 410 mm and four years of age and spawning occurs from June to September (Hyndes *et al* 1998). Individuals of this species exhibit ontogenetic changes in habitat, involving progressive movement into deeper offshore waters. With a current size limit of 280 mm, individuals become vulnerable to capture (and are most heavily fished) whilst inhabiting marine embayments and estuaries when 1.5 to 2.5 years of age (Hyndes *et al.* 1998). Hyndes *et al.* (1998) further noted that once through this period, the fish have moved further offshore where they mature and are less susceptible to capture due to reduced number of fishers and less fishing pressure over winter when the fish are spawning.

However, information obtained from fishers during the current study indicates that large spawning adults are targeted by fishers when aggregated for spawning in the metropolitan area between about June and August. These fish reach over 600 mm (TL), as verified by samples obtained for research analyses, which also confirm that the fish are aggregated for spawning purposes. These aggregations are located in about 30 metres of water, are easily accessible to fishers, and the fish are very susceptible to capture (e.g. captures of more than ten fish per drift have been reported). Most of the commercial catch is obtained within estuaries and of that outside the majority is taken in the South Coast Bioregion, with catches in all areas relatively low (Figure 3.19). Seasonal patterns in the King George catch rates outside of estuaries suggest that commercial fishers don't target the winter spawning aggregations of this species (Figure 3.20).

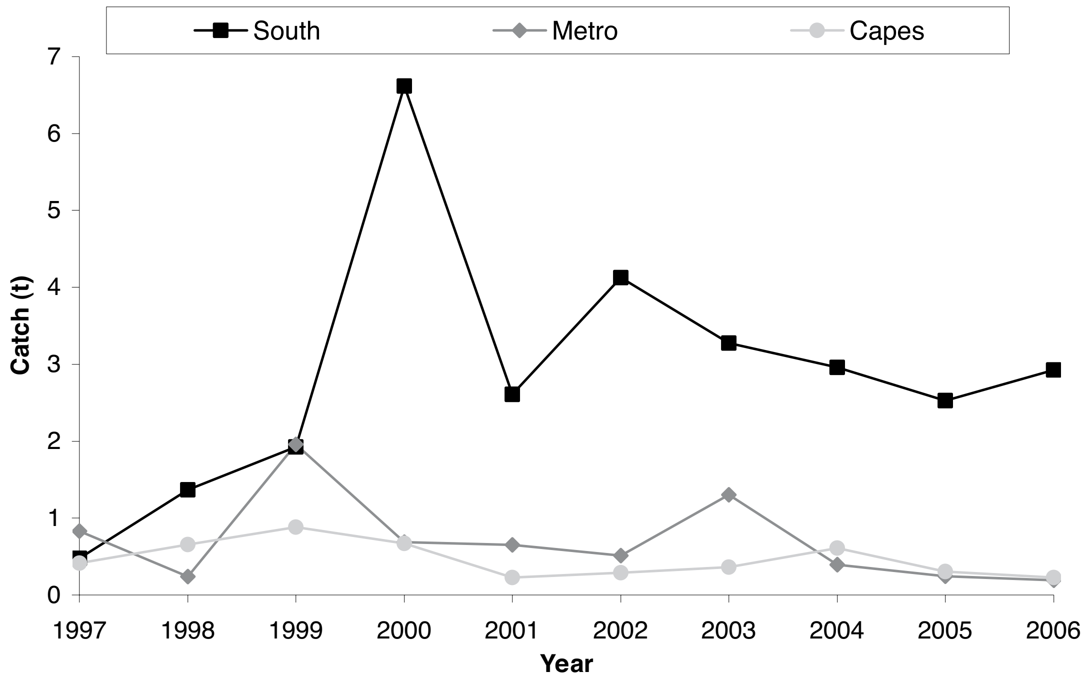


Figure 3.19. Annual commercial catch of King George whiting outside of estuaries for each area of the West and South Coast Bioregions.

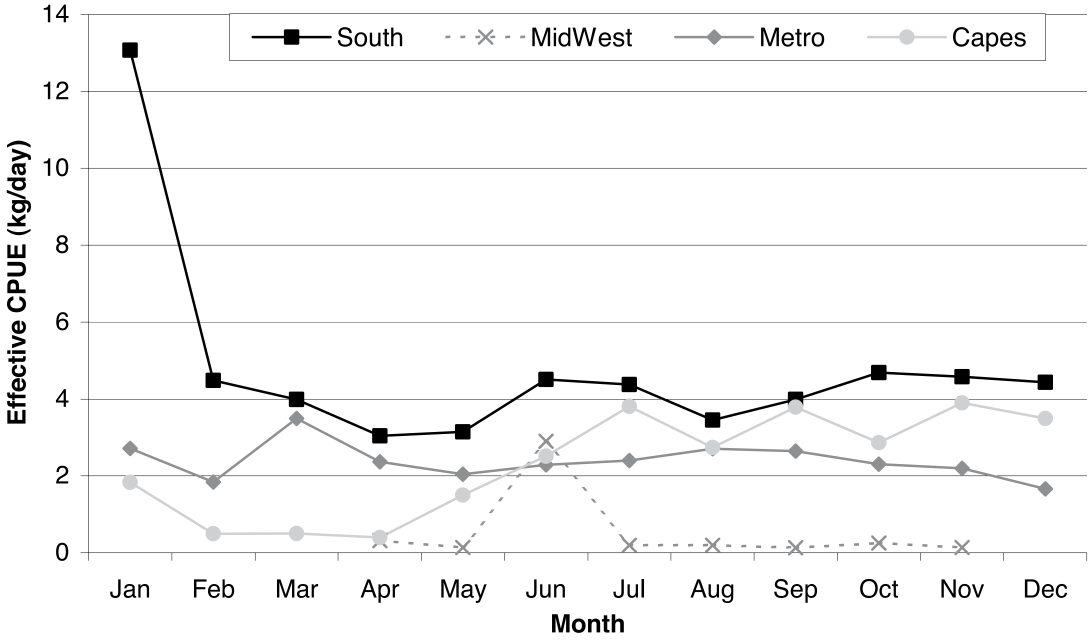


Figure 3.20. Average monthly effective CPUE of King George Whiting for each area of the West and South Coast Bioregions.

3.4.2 Mulloway (*Argyrosomus japonicus*)

Mulloway is a coastal/estuarine species that is broadly distributed in temperate and subtropical waters of Australia. Individuals grow rapidly during their first two years, with females growing faster and attaining larger sizes and ages than males. They also aggregate to spawn, typically in or around the mouths of estuaries. The timing of spawning varies spatially and is probably related to water temperature and oceanography, particularly fresh water outflow from rivers (Hancock *et al.* 1990, Silberschneider and Gray 2005). In WA waters there is little information about the reproductive biology of mulloway. The Swan River is considered to be an important spawning area for this species, with large individuals migrating up river during summer to form aggregations in areas such as Mosman Bay (Hancock *et al.* 1990, Farmer *et al.* 2005, Section 4.3.1.).

Information from fishers indicates that the mulloway aggregating in the Swan River are generally targeted by catch and release fishers. However there is concern over the survivorship of these fish because of the effects of barotrauma and stress during capture. This was confirmed by the experience of research scientists whilst trying to acoustically tag individuals in Mosman Bay during the current project (M. Mackie, *pers. obs.*). The related black jewfish (*Protonibea diacanthus*) is similarly highly prone to catch and release mortality due to the effects of barotrauma and stress (Semmens 2006[4]). Individuals are also captured in Cockburn and Warnbro Sounds, probably whilst migrating to and from these aggregations in the Swan River (as indicated from fisher interviews).

[4] Semmens, J. (2006). Understanding the dynamics of aggregations of black jewfish (*Protonibea diacanthus*) in the Northern Territory. Australian Society for Fish Biology 2006 Conference Abstracts and Official Program. 28 Aug – 1 Sept 2006, Hobart, Tasmania.

Commercial catches of mulloway are greatest in the West Coast Bioregion (Figure 3.21). Within this bioregion, annual catches have varied considerably. Since 1989 most of the catch has been taken within the Midwest region, with peaks in 2001 and 2002 before a considerable drop in more recent years (Figure 3.22). Targeted fishing of a mulloway aggregation by commercial fishers in the Kalbarri area was reported during the current project. According to the report, three commercial line boats each caught approximately one tonne per night of spawning mulloway off a particular reef in early February, 2005. The overall catch by these boats was estimated to be in the tens of tonnes. An aggregation or school of mulloway was also observed by video off Dongara during a research trip in April 2005.

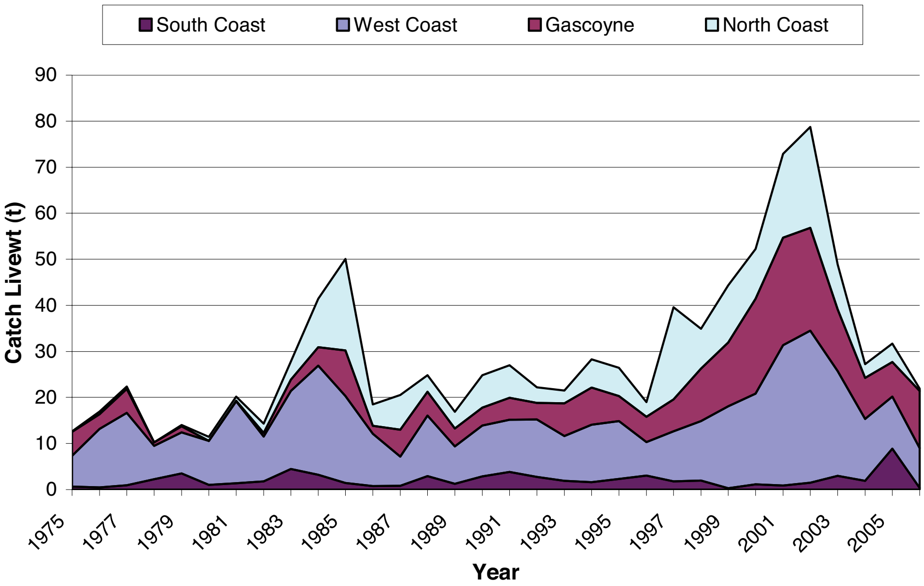


Figure 3.21. Annual commercial catch of mulloway in each bioregion.

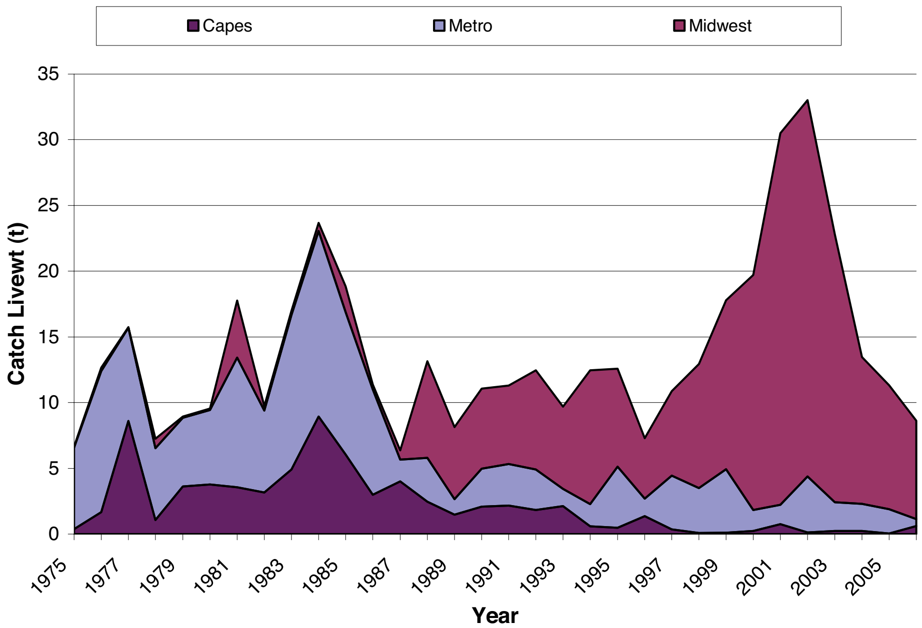


Figure 3.22. Annual commercial catch of mulloway in the West Coast Bioregion.

4.0 Assessment of Techniques for Monitoring Aggregating Fish Species

Various methods have been used to monitor fish aggregations, ranging from diver based underwater visual surveys that are commonly used in shallow tropical waters (Sadovy *et al.* 2005), to industry based acoustic surveys that are used on deeper temperate water species such as orange roughy (*Hoplostethus atlanticus*) and blue grenadier (*Macruronus novaezelandiae*) (Honkalehto and Ryan 2005, Tilzey *et al.* 2006). The methods used are based on logistics and characteristics of the species, with no single method appropriate in all situations.

In undertaking these monitoring programs the key issue is how to obtain a measure of fish abundance, with an acceptable degree of precision so that the data is spatially and temporally comparable and meaningful. Direct counts of all fish in an aggregation may be possible if the number of fish is small enough, such as may be the case with smaller aggregations of dhufish or mulloway. However, it is more likely that the dynamics and size of the aggregation require a less direct means of estimating fish biomass, or an index of this biomass. Although it is often difficult to assess the accuracy of these estimates, if designed and implemented with proper consideration of methods and error sources, a valuable source of monitoring data can be developed, as described in Chapter 6. This chapter provides a review of techniques assessed directly during this study or from information available in the literature.

4.1 Single-beam Acoustics

Miles Parsons, Rob McCauley, Michael Mackie and Paul Lewis

The use of acoustic techniques to detect aquatic organisms is a centuries old process, dating from Chinese fishermen following the sound of soniferous fish through the hulls of their wooden boats (Moulton 1964). Acoustic waves propagate extremely efficiently in water, potentially detectable kilometres from the source (dependent on environmental and source characteristics). Due to characteristics such as turbidity and attenuation, the propagation of light is limited to tens of metres in coastal waters, and hence is less attractive as a large scale sensing technique. Therefore, acoustics, offers an efficient means of 'viewing' underwater communities.

In the past century, technological advancements in the remote detection of submerged bodies have been evolving rapidly. The first technological application of hydro-acoustics was to detect fish in a tank (Kimura 1929). Transferring these techniques to detect fish in the marine environment, trials were conducted in the Barents Sea, Norway (Sund 1935) and later (Balls 1948) to show the qualitative abundance and distribution of fish life.

Since then, single beam echosounders and the echo integration method have become an established technique in biomass stock assessments. Where levels of fish density are such that they do not impede acoustic penetration of a school echo integration is linear, thus acoustic and real density are linearly related (Foote 1983). The echo integrator output can be converted to biomass estimates, over a required depth, by use of the Target Strength (TS) of fish within the integration region, given as;

$$TS = 10\log_{10}\left(\frac{\sigma_{bs}}{1m^2}\right) \qquad (1)$$

where σ is the backscattering cross section of the fish (Urick 1983). It has been shown that the swimbladder of a fish can contribute in excess of 90% of the overall target strength (Foote 1980) and that the back scattering cross-section increases by approximately the square of the fish lengths, leading to variations in up to 25dB of the target strength (Nakken and Olsen 1977). It is this length relationship on which most *in situ* regression target strength models have been based, in the form of;

$$TS = a \log L - b \qquad (2)$$

where a and b are constants specific to each species and frequency, while L is the length of an individual fish (cm), (Johannesson and Mitson 1983; Urick 1983).

It is also known that the target strength varies considerably with swimbladder tilt angle, in some cases up to 30dB at a 45° tilt (Foote 1980). When combined with other biological factors such as spawning maturity and physical factors such as feeding (Ona 1990) or multiple reflectance (Johannesson and Mitson 1983), it is paramount to develop an accurate target strength model when estimating aggregation biomass.

Fisheries single-beam echosounders typically operate with beam angles of 7-15° (Simrad EQ60 produces a 3 dB beam angle of 13° major axis and 21° minor axis), which sample a relatively small volume of water. Resulting transects over a school of fish obtain backscatter from only a portion of the school, thus requiring several transects to determine the extents and shape of the aggregation. The time taken to perform transects leads to requirements for assumptions of uniformity of the aggregations as a whole. However, the ease of mobilisation and survey, the ability to replicate surveys in the long term, ease of data processing, extremely high resolution in alongships direction and inexpensive purchase and running costs indicate that single-beam systems are an excellent tool in monitoring aggregations which are stable over extended periods of time.

While operating, echosounders emit an acoustic pulse of determined duration. This duration, combined with the speed of sound in water define the signals water column vertical resolution for a single object, the acoustic shadow zone near the seabed or the ability to resolve two objects in the water column. The vertical resolution of a single target in the water column is defined by the pulse duration times the speed of sound in water. The acoustic shadow zone near the seabed or the ability to define two closely spaced objects in the vertical plane is determined by:

$$x = \frac{1}{2} c \tau \qquad (3)$$

where c is the speed of sound in water, τ is the pulse duration and x is the minimum distance between two objects at which they discernible. This is because when the vertical distance between two objects positioned on the central axis of the acoustic beam (for example two fish, or a fish and the seabed) is equal to half the pulse length then as the rear of the pulse leaves the fish, but is still moving towards the bottom, its echo starts moving towards the transducer. However, the leading edge of the pulse has already been to the bottom or reflected from the target and its echo has travelled by half the pulse length back to the transducer. The two signals, ie. the return from the pulse leading and trailing edges for an in-water target, arrive simultaneously at the receiver thus limiting its ability to discriminate targets. If the fish were any closer to the bottom than half the pulse length, the rear edge of the pulse would not have left the fish before the wavefront of the bottom echo arrived back at the fish position. The fish and the bottom echoes would therefore be merged. This is known as the acoustic dead zone. Targets located away from the central axis of the beam are also influenced by the wave front curvature of the acoustic beam, increasing the acoustic dead zone. When considering fish inhabiting the seafloor at the time of survey such as dhufish and mulloway, the performance of the system and height of the acoustic dead zone determine whether a target is discriminated from the seafloor. For further information on the theory of echosounding see Johannesson (1983) and Urick (1983).

4.1.1 Samson Fish

Acoustic backscatter data from Samson fish were collected from seven sites west of Rottnest Island with the Simrad EQ60, dual frequency, single-beam echosounder (approximate positions shown in Figure 4.1). Data were acquired predominantly from three of these sites know as Site 1 ('Secret Spot'), Site 2 ('North Barge') and Site 3 ('Outer Patch').

The results from the Rottnest sites illustrate the advantages and disadvantages of using a single beam echosounder to study the spawning aggregations. A sample echogram from a transect at Site 2 on the 2nd February, 2005, is shown in Figure 4.2 including some outlined school parameters. Some image metrics outlined are vertical and horizontal, beginnings and ends of the aggregation. Most of the images obtained, however, were not conducive to the image analysis protocols set out by Reid *et al.* (2000), suggesting typical school parameters to catalogue. Those techniques are more amenable to discrete, densely populated schools, as opposed to the Rottnest aggregations, which also contain a significant area that is sparsely populated by dissociated members of the aggregation. It should be noted that this response is enhanced by the reduced speed of the surveys (~3 knots) relative to usual biomass surveys (~10 knots), (Johannesson and Mitson 1983).

Densely populated areas within the aggregations were defined with Echoview v4.1 fish detection algorithms, combining fish linking distance with a maximum detection threshold of 60dB. However, due to a high level of spatial variability of the fish, parameters of the sparsely populated areas were visually inferred from the echograms. The sparsely populated areas could not be easily dismissed, as they contributed a significant proportion of the biomass and provided additional information that may be characteristic to that particular aggregation. Several of the catalogued school parameters from these images at Sites 1 and 2 during two surveys are shown in Table 4.1. This demonstrates the variability of aggregation characteristics between different sites and throughout the spawning period.

The grid formation of transects allowed determination of the aggregation boundaries in three dimensions. Table 4.1 also highlights the difference in scattering area between the densely populated portion of the aggregations and that enclosed by the disassociated members which can be visualised more easily in Figure 4.2. In this example 72.5% of the area occupied by the aggregation is sparsely populated, a characteristic typical of the other survey sites, confirming that this dissociation contributes a significant proportion of population area.

Figure 4.3 illustrates north and south views of visualisations of Samson fish aggregations at Site 1 from surveys throughout the 2004-5 spawning season with the accompanying cruisetrack to illustrate the level of coverage obtained during the survey. Areas of high acoustic backscatter are displayed as per the colour bar. The seafloor is displayed at the bottom of each image with extruding areas of lower backscatter illustrating the acoustic reflectance of the wrecks. Aggregation backscatter is visible above each wreck at varying acoustic intensities. This displays the opportunity to visually compare aggregations either at the same site over the season, or varying sites at the same time.

Figure 4.4 displays two 3-D images, produced from the echograms of Sites 1 and 2, together with their respective cruisetracks. A surface has been interpolated (shown in blue) from acoustic backscatter to represent the seafloor bathymetry at each site. This figure visually illustrates the difference between backscatter strength, aggregation structure and estimated fish numbers between sites. Densely populated areas of the aggregations can be seen at the centre of each while sparser areas lie closer to the seabed.

Table 4.2 illustrates the variations in estimated biomass numbers (based on a target strength model of yellowfin tuna). The three predominantly surveyed aggregations display distinct differences in site preference over the three year period as well as between successive seasons. Relatively lower numbers of Samson fish were surveyed at Site 1 (Secret Spot) in all three years indicating it is not a preferred site of the majority of Samson fish (easily discernible from 3-D visualisations. Sites 2 and 3 ('North Barge' and 'Outer Patch' respectively) displayed a far greater biomass in comparison to remaining surveyed sites over the project duration. Figures show that in the 2004-5 season more Samson fish aggregated at Site 2 in comparison with those at the Site 3, however, in the 2005-6 season these roles where reversed and more fish were present at the Site 3. These results correlate with the anecdotal evidence from recreational fishermen and biological sampling conducted during the project.

Figures in Table 4.2 also demonstrate the season trends at each of the sites. Although surveys were limited by weather, equipment, vessel and personnel constraints, coverage over the spawning season illustrate an increase in biomass at the sites between October and November to a season height in December and January. Numbers then dwindle as Samson fish begin to migrate south in February and March. It has been recorded at this time in data from two of the seasons (notably data displayed in section 4.6.2 acquired with a Reson 7125 multi-beam sonar) that the Samson fish aggregations at the end of the season have been less stable and more mobile. In both circumstances the survey was conducted in the days following a full moon. It is possible that either the full moon, or phase in the spawning period, or a combination of the two affect the Samson fish behaviour. There is currently insufficient data to conclude the cause of the change in behaviour. Discussion about causes for the early migration of the Samson fish are included in section 4.2. A more comprehensive analysis of acquired single-beam acoustic backscatter from Samson fish over three spawning season will be found in a paper currently under preparation.

Table 4.1. Echogram metrics of Samson fish aggregations at Sites 1 and 2 taken 20/01/2005 and 02/02/2005.

	20/01/2005		02/02/2005	
Site	**1**	**2**	**1**	**2**
Survey Start Time	10:19:08	9:23:04	10:31:14	09:23:47
$AB_{v\ Max/Min}$ (m)	96.17/76.81	87.55/66.62	85.52/75.56	100.40/58.40
$AE_{v\ Max/Min}$ (m)	101.93/97.93	106.17/99.97	99.10/93.56	105.66/94.41
$SB_{v\ Max/Min}$ (m)	90.77/84.45	83.85/66.95	81.01/75.56	105.40/72.78
$SE_{v\ Max/Min}$ (m)	98.56/92.17	93.61/83.73	93.56/89.04	105.17/93.92
$AM_{h\ Max/Min}$ (m)	13.67/7.38	38.63/12.37	22.80/11.49	47.797.67
$SM_{h\ Max/Min}$ (m)	9.22/5.86	28.43/7.59	12.71/12.51	21.48/14.32
Total Aggregation Area ($m^{2)}$	17,663	38,133	16,292	36,186
Dense Area (m^2)	13,204	10,481	2,744	12,863

Table 4.2. Aggregation characteristics from three sites of Samson fish, (biomass based on yellowfin tuna target strength model).

Survey Date	Average Aggregation NASC (m^2/n.mi.-^{2})	EDSU Density weight (kg/n.mi^2)	Aggregation Area (m^2)	Estimated number of fish	S_v Max (dB)	S_v Mean (dB)
Site 1						
23/11/2004	4,317	3,282,164	20,213	1,078	-41.75	-46.03
20/01/2005	1,334	4,046,555	21,821	1,434	-26.51	-43.82
2/02/2005	2,287	2,886,003	16,431	1,660	-27.70	-46.76
26/02/2005	2,072	3,630,233	32,085	1,892	-23.07	-44.80
18/10/2005	5,475	5,530,620	10,000	950	-33.21	-45.25
20/10/2005am	4,035	5,917,666	15,000	1,100	-20.59	-45.43
20/10/2005pm	3,217	4,390,390	12,000	900	-29.56	-49.43
21/12/2005	5,234	6,546,263	10,572	1,124	-31.20	-43.69
15/01/2005	4,575	4,686,484	16,776	1,277	-26.90	-43.09
13/02/2005	391	939,087	15,708	240	-34.01	-52.18
13/09/2006	7508	8,198,068	15,471	2,326	-25.85	-43.56
15/11/2006	489	533,945	17,168	168	-38.62	-48.65
Site 2						
23/11/2004	7,475	8,447,617	50,010	6,862	-29.60	-34.61
20/01/2005	7,005	13,845,780	47,422	10,665	-36.08	-44.29
2/02/2005	10,358	9,160,659	35,400	5,268	-16.20	-41.46
27/02/2005	1,752	2,127,918	23,389	808	-40.67	-46.36
21/12/2005	5,559	13,725,096	70,820	15,789	-11.76	-41.73
15/01/2006	7,354	18,734,397	35,597	10,833	-20.62	-41.31

13/02/2006	16,419	28,498,911	32,418	15,007	-18.32	-40.78
21/03/2006	672	673,384	20,273	222	-30.60	-52.29
13/09/2006	1842	2011374	9,378	346	-35.65	-47.86
15/11/2006	10596	11569971	36,211	7,682	-31.36	-38.89
Site 3						
23/11/2004	1976	2157543	66,576	2,634	-29.11	-33.87
20/01/2005	8041	8780593	38,472	6,194	-24.06	-35.21
29/01/2005	2696	2944052	43,857	2,368	-24.61	-37.85
2/02/2005	9362	10222895	23,390	4,385	-16.28	-30.96
26/02/2005	900	982720	21,660	390	-33.01	-47.87
21/12/2005	15165	16558831	75,880	23,040	-17.35	-32.76
15/01/2006	35872	39169033	52,098	37,418	-9.44	-31.64
13/02/2006	4535	4951545	54,747	4,971	-25.11	-37.98
13/09/2006	4587	5008596	21,419	1,967	-12.46	-38.37
15/11/2006	5846	6383312	13,863	1,623	-26.27	-39.26

The results shown here have assumed all acoustic backscatter has been generated by Samson fish. Examination of the video data confirmed that the aggregations are not completely homogenous throughout the spawning season, with other species such as skippy present at times. Although their presence was small it could not be quantified, thereby affecting the uncertainty levels of the data. Further analysis of variation between backscatter at 38 kHz and 200 kHz of single targets may assist in differentiating between species, this will be difficult to detect within the dense aggregation.

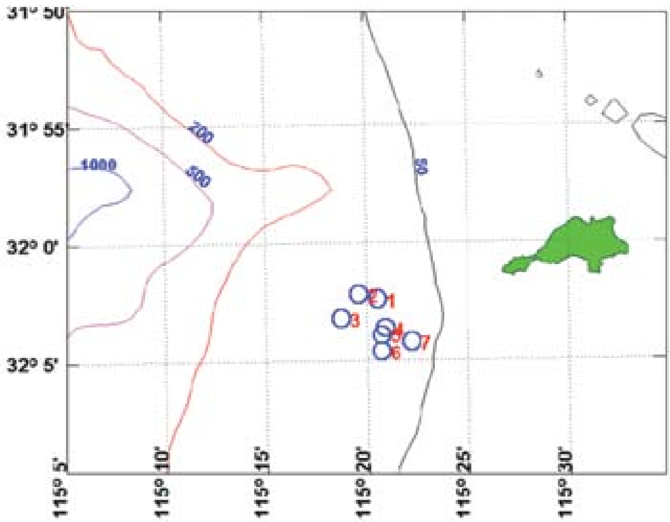


Figure 4.1. Approximate locations of seven study sites west of Rottnest Island, Western Australia.

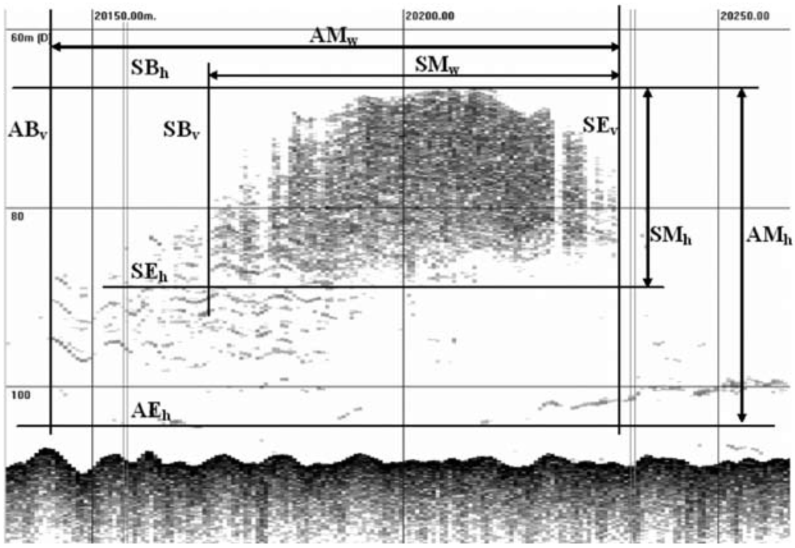


Figure 4.2. Echogram image of a Samson fish aggregation, showing morphological parameters. SB_v and SE_v are the vertical beginning and end of the densely populated school while AB_v is the vertical beginning of the aggregation. SB_h and SE_h are the horizontal school beginning and end while AE_h is the horizontal aggregation end. SM_h and SM_w are the maximum school height and width respectively, while AM_h and AM_w are the aggregation equivalent.

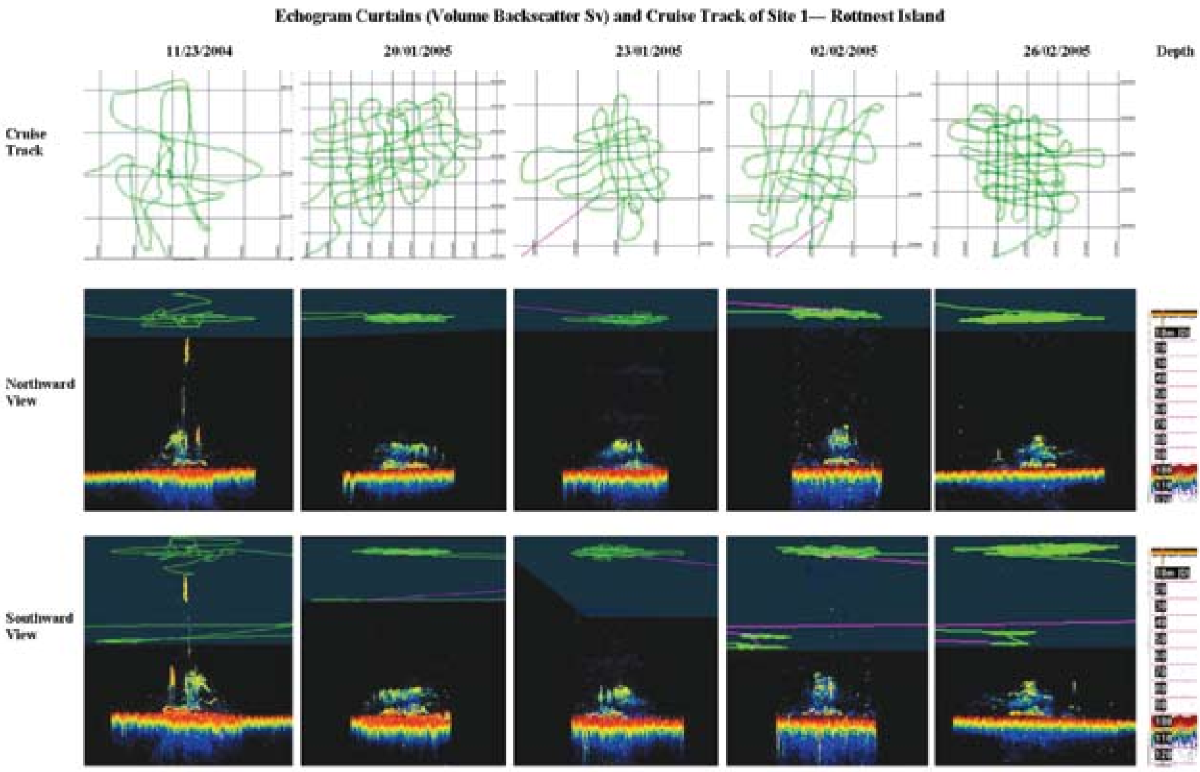


Figure 4.3. Northward and southward views of an aggregation visualisation at Site 1 from various surveys with associated cruisetracks.

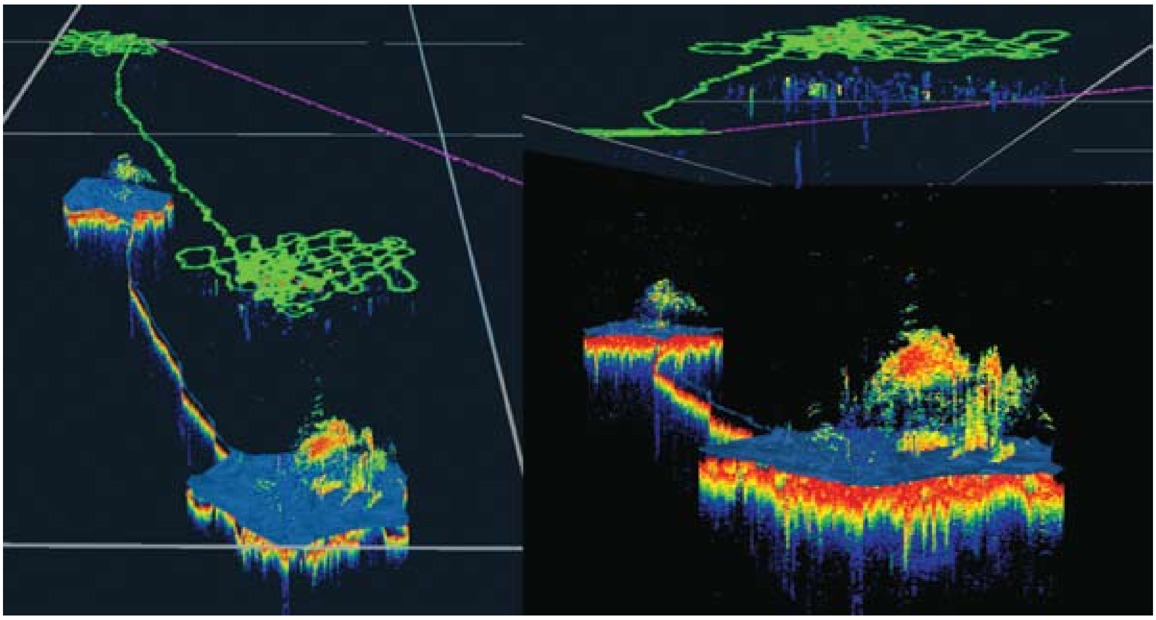


Figure 4.4. 3D visualisations of Samson fish aggregations and seabed, with associated cruise tracks of Sites 1 (right of images) and 2 (left of images) at 20/01/2005 (left) and 02/02/2005 (right). The cruise track is shown in green, seafloor in blue and fish backscatter in varying colours.

4.1.2 Dhufish

Description by fishers indicates that single-beam acoustic techniques may be appropriate for surveys of dhufish aggregations. The large size of the swim bladder in this species makes it likely that individuals could also be discerned with this method. However, during the current study no single-beam acoustic data where acoustic targets have been confirmed as dhufish by video techniques or biological sampling were acquired. More research on the use of single-beam acoustics (and passive acoustics – see Section 4.3) is therefore required to determine the full potential of this technique in monitoring dhufish stocks.

4.1.3 Bight Redfish

Acoustic surveys of Bight redfish were conducted with the Simrad EQ60 from the *RV Naturaliste* in December 2006 and February 2007 at sites close to Cape Naturaliste. Figure 4.5 illustrates the most compact star pattern transects employable from the *RV Naturaliste* in the given weather conditions (right image). The echogram (middle image) displays a tightly packed school of small fish hovering above a lump as well as scattered Bight redfish around and above the school. These individual fish can also be seen in the 3-D picture (left image) at varying distances and directions from the other school. Discriminating the number and species using this method required towed video confirmation as there is no target strength/ length relationship for redfish, although once qualified the data provides information on the particular school structure. In the case shown it is possible to count individual targets to obtain an estimate of numbers present, however, in other cases echo integration is required.

These surveys occurred at a time when there were few Bight redfish on these inshore lumps. At other times of year, particularly around April during the main spawning period for this species, it is likely that the abundance of Bight redfish on these lumps is greatly increased (as indicated by fisher interviews). Acoustic surveys at this time should may therefore be more effective at providing information about stock abundance of this species.

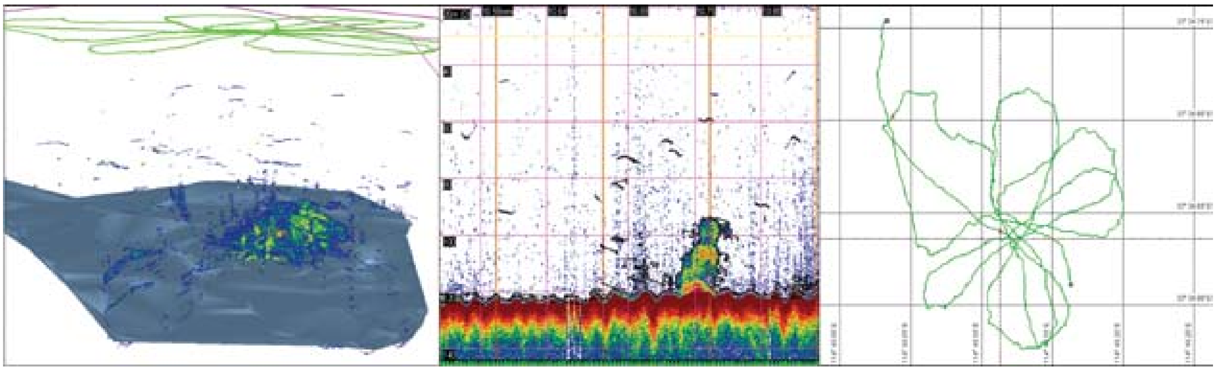


Figure 4.5. 3D visualisation of Bight redfish (left) together with a segment of the associated echogram (middle) and cruisetrack (right).

4.1.4 Pink Snapper

There are currently no acquired single-beam acoustic data where acoustic targets have been confirmed as pink snapper by video techniques. Attempts at acoustic surveys of a pink snapper aggregation in Cockburn Sound were not successful because of the mobile and wary nature of the aggregation. This shows that single-beam acoustics are unsuitable for pink snapper when aggregated in shallow water for spawning. Aggregations of this species in deeper waters were not located during this study, however it is possible that acoustic techniques may be appropriate, particularly in the Carnarvon area where most of the commercial catch is taken. The main issue is likely to be mobility of the school.

4.1.5 Mulloway

Single-beam surveys conducted in the Swan River revealed one possible instance of a single mulloway on the echogram, although this was not backed by video or other evidence. This lack of success probably reflects the dispersed nature of individuals during the survey periods, difficulties in discriminating fish within the acoustic dead zone (i.e. too close to the riverbed to be detected), and avoidance behaviour. Greater success may be achieved in the future if individuals can be more accurately located using passive acoustic techniques, although it is unlikely that single-beam acoustics will be effective for monitoring these shallow water aggregations. It is possible that this technique would be suitable for aggregations reported by fishers in deeper water, although more research is needed on the nature of these aggregations to determine if this is so.

4.1.6 Conclusions

Single-beam acoustics is potentially a useful tool for long term monitoring of aggregations. It provides a permanent record and when used in conjunction with other techniques such as video, can be used to gather unique information about fish species and benthic habitats. Surveys of Samson fish aggregations showed consistent estimates of Samson fish stock levels at individual sites during the spawning period, and distinguishable differences between stock levels and aggregation structure at separate sites. However, whilst single-beam acoustics is logistically simple, enables high coverage of aggregations, and allows easy relative comparison of biomass, the usefulness of this technique for absolute estimation of biomass is hindered by accuracy-related limitations, primarily a lack of reliable estimates of target-strength.

As demonstrated by the effects of the tuna target strength model on estimates of Samson fish abundance, it is vital that a species-specific and reliable model of individual target strength

(TS) is determined before accurate estimates of absolute abundance can be made. Additionally, *a priori* knowledge of species ecology and reaction to external stimuli are also a necessity. Several techniques (empirical and theoretical) are available for the determination of TS (Foote 1991), however it is likely that adapted *ex situ* methods, such as used by Gauthier and Rose (2001), will require sufficiently comprehensive biological and behavioural data to generate accurate regressive models on which to base future abundance estimates. These models can be clarified further by theoretical analysis of acquired *in situ* data.

The accuracy of single-beam acoustic surveys will also be dependent on the amount of movement by the aggregation during the survey. This can lead to spatial aliasing of the aggregation, an issue partially resolvable through geostatistics or the use of a multi-beam system. Nevertheless, with some very mobile aggregations, such as those of pink snapper in Cockburn Sound, this technique is unlikely to be appropriate.

4.2 Multi-beam Acoustics

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The use of multibeam echosounders in place of single-beam echosounders for future bioacoustic surveys is warranted by their increased coverage, which can improve acoustic estimates of biomass and abundance and better characterize spatial distributions of organisms (Gallaudet and de Moustier, 2002). Multibeam systems generate a swath of single beams across the vessel tracks with athwartships coverage in excess of 90° (e.g. Reson 8101 generates a swath of 150°, Reson 8125 of 120° and Simrad SM2000 up to 180°) and minimal fore-aft beam angle, thus covering a footprint width typically between two and eight times the depth of the water, whilst maintaining high directional accuracy. In view of this particular project, the swath geometry creates the possibility of surveying an aggregation of fish in a minimal number of transects, removing several assumptions required with single beam surveys regarding the temporal uniformity of the aggregation.

Primarily introduced for acquiring bathymetry data and more recently seabed backscatter data, multibeam systems have been inhibited in collecting water column backscatter by the sheer volume of information entailed and the data processing capabilities available. As a result, in the last twenty or so years since their inception, the systems have been designed to record only the returns from the seafloor. Rapid advances in processing technology alleviated this and allowed the introduction of multibeam systems as a fisheries assessment tool, recording the complete water column (Mayer *et al.* 2002). However, protracted speed of data acquisition is still a common concern with many fisheries surveys and an unfortunate characteristic of the system resulting in lower than optimal along track resolution determined by ping rate. While the ping rate allowed by systems hardware can be a limitation in along track resolution, it must be remembered that ping rate is inherently limited by the desired maximum sample range. A minimum listening time of twice the travel time to the maximum range must be used for object discrimination. Thus high resolution multibeam surveys may need to be carried out at slow travel speeds to account for hardware limitations or required listening time (desired sampling range) between pings.

With the addition of a third dimension in the multibeam data, quantifying fish schools is no longer a comparatively simple procedure (Buelens *et al.*, 2005). Visualisation of multibeam fisheries data is a challenging computational task. However, once fish schools and targets are detected, they are located in 3D space and time, allowing visualisation within a four dimensional environment, providing more detailed data on school avoidance or migratory characteristics than any other fisheries tool (Wilson *et al.*, 2005). In addition to water column data, multibeam systems vastly increase knowledge of species-specific aggregation habitats from comprehensive bathymetry and seabed classification data, contributing to the predictive location of unknown spawning sites. This information creates the possibility of identifying aggregation locations outside the spawning season.

The geometry of the multi-beam swath in comparison with that of the single-beam has significant impact on the sample volume and therefore the fish detected. Figure 4.6a shows a schematic of the comparison between the volume ensonified by four multi-beam swaths (white) of a Reson 8125 and one ping from the single-beam Simrad EQ60 (green). The single-beam (approximately 13° in fore-aft direction and 21° athwartships) extends fore and aft such that it includes sections of the water column sampled by multi-beam pings before and after the equivalent single-beam ping. Conversely the multi-beam swath samples a much wider volume of water column either side of the single-beam. Figure 4.6b and c displays how the multi-beam detects schools (or sections of an aggregation) missed by the single-beam, by comparing three multi-beam swaths with their equivalent position in time on the single-beam echogram. The fish missed by the single beam may be due to avoidance behaviour (implying an underestimation of the population), another school (such that the single-beam is missing interaction between two schools), or simply that the aggregation is wider than the single-beam.

The drawbacks to multi-beam systems are their expense, volumes of data and inherent processing requirements, in comparison with single-beam techniques. Indeed, even within the range of multi-beam systems capable of processing water column data there is a distinct difference between the trade off from acquiring high sample resolution within an individual swath at the expense of remarkably high volumes of data (compared to those usually collected in a fisheries survey) and ping rate. The ability to maintain sufficiently high beam sampling resolution while restricting data volumes to manageable levels has become a significant design objective in multi-beam water column backscatter acquisition.

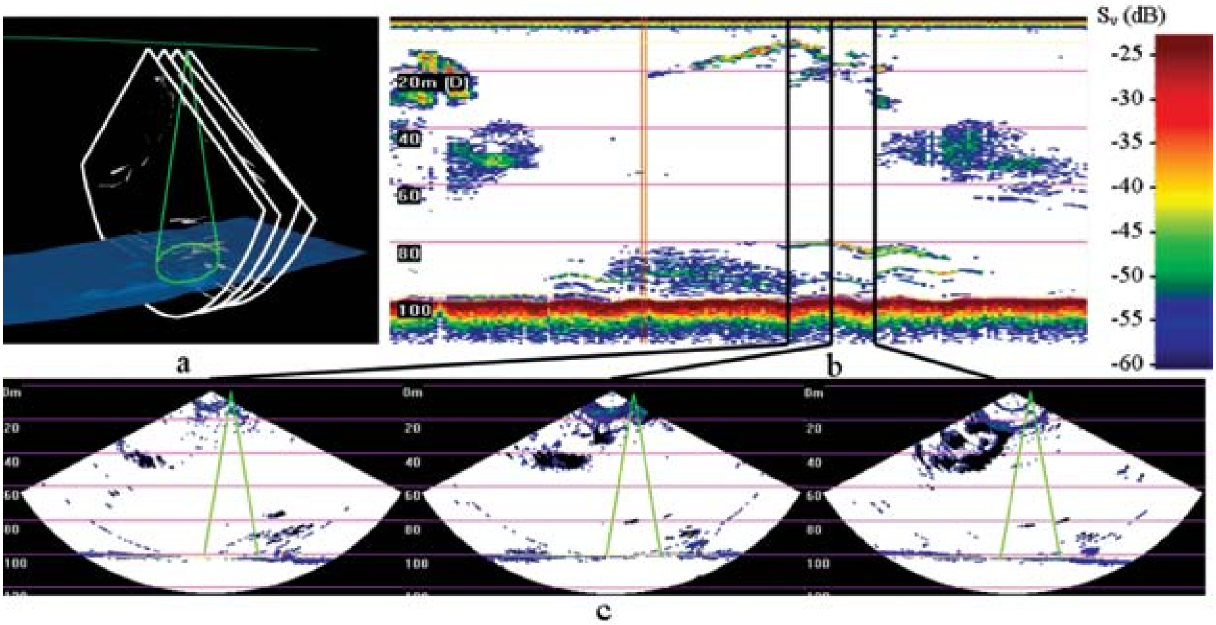

Figure 4.6. Schematic of single-beam footprint (cone) overlapping four multi-beam snapshots corrected for roll (wedge) and the samsonfish detected by the multi-beam (rectangular regions) from a transect conducted on the 18th October (a). Corresponding section from the single-beam echogram (b) and three snapshots (c) taken at 11:52:04, 09, and 14 am (left to right) with the ideal single-beam minor axis shown.

4.2.1 Samson Fish

Reson 8125 data

Data collected from the multi-beam RESON 8125 and single-beam Simrad EQ60 in October 2005 provided an insight into surveying of a relatively stationary aggregation such as Samson fish. Initial transects were conducted to obtain accurate bathymetry of the wrecks to obtain possible information on the structures effect on the aggregation formation. Figure 4.7 illustrates the bathymetry of sites 1, 2, and 3, known as 'Secret Spot', 'North Barge', and the 'Outer Patch', respectively.

During transects conducted at the Outer Patch acoustic backscatter from the aggregation was visible with both single- and multi-beam systems. Figure 4.8 displays a single snapshot taken with the RESON 8125 using maximum power and gain settings and processed in Echoview software. The relative backscatter Sv values have been thresholded at 9 and -21 dB re 1 µPa. The multi-beam detected individual targets at a sufficient spatial resolution and signal to noise ratio to permit target counting of fish to estimate numbers. Samson fish, estimated 0.80 to 1.40 m in length can be seen distinctly as targets ranging from roughly 60 to 95 m depth. To the left of these targets is a school of smaller fish (likely baitfish) ranging from 60 to 70 m depth and 15 m width. However, in this snapshot many of the targets' backscatter (both Samson fish and smaller species) were saturated. The image also displays some of the artefacts possibly created in the near-field of the 8125 at the top of the swath. These artefacts are visibly discernible only at the highest power and gain settings and fade into noise with reducing power.

Figure 4.9 illustrates the aggregation as a 3-D representation by connecting detected targets in consecutive pings. This displays the Samson fish as individual regions (green) and the smaller fish as a tight school (yellow) forming above the north end of the wreck and allows visualisation of the aggregation structure and determination of its boundaries. However, due to the ping rate and vessel distance travelled between pings these regions are considerably elongated. This demonstrates the ability to visualise the entire aggregation from a single transect with a multi-beam system and gain significant information on school structure of both Samson fish and other species they may interact with, as well as estimate the numbers within the school. Spatial aliasing within RESON 8125 data, however, is still an issue due to distance travelled between consecutive pings.

Simultaneous recording with multi-beam and single-beam systems provided an impression of the difference between biomass covered by each technique. Figure 4.10 illustrates data acquired from each system and a 3-D visualisation of how they compare. Images on the right show the eastern view of regions generated by each technique. This displays how both systems acquired similar data, however, it should be noted that in this transect the vessel passed directly over an aggregation of medium size. If the transect line had been offset to the east or west the single-beam may have detected no fish at all, or if the aggregation was larger than the single-beam footprint dimensions, considerable data would have remained undetected.

During the course of the survey, several consecutive transects were conducted over the same aggregation to assess the temporal behaviour (Figure 4.11). Six consecutive transects were conducted between 8:30am and 9:45am before the aggregation was line fished for two hours by six fishermen, from two boats. A further seven (six are shown) transects were then conducted to assess impact on the aggregation. It is clear that in this case that movement of the aggregation as a whole was not significant, though the afternoon transects (post fishing) displayed more compact behaviour. Figure 4.12 illustrates this limited movement in a composite of each transect, displaying considerable overlap in position of the aggregation. Overall movement of the aggregation in metres can be seen in Table 4.3, along with the plan area variation and numbers of detected targets.

Table 4.3 also highlights the stability of the aggregation size on this day and a comparison between the number of targets detected by the single-beam and multi-beam systems. The numbers of single targets detected illustrates that in several transects the single-beam system left many fish undetected while the spatial aliasing of the multi-beam also created a loss in fish numbers detected. It should be noted that in neither case have detected targets accounted for spatial aliasing or multiple detections of the same target.

Reson 7125 Data

Much of the acoustic data collected during the February 2007 survey has yet to be processed. However, several conclusions have been drawn from the results shown below. As stated in section 2.7.2 and shown in Figure 2.7.2, electrical interference from the *RV Naturaliste* created significant processing issues for the acoustic data collected. Despite the interference, post processing analysis of acoustic swaths revealed the detection of Samson fish at various depths as individual targets within the aggregation.

Figure 4.13 displays plan views of regions formed from detected targets in six transects over the Outer Patch aggregation. The six transects displayed some interesting behavioural information on movement by the aggregation. Initially, it was thought that the Samson fish aggregations remained fairly stationary over long periods of time (Parsons *et al* 2005). A recent survey, the morning after a full moon, towards the closing stages of the spawning season has shown that this assumption is not always correct and in some circumstances the school is mobile, around the wreck above which it is located. Figure 4.13 illustrates movement of the aggregation over a fifteen-minute period. The aggregation moves visibly from the northern end of the wreck to the east side, approximately 91 m over the survey period. Although this is not a significant distance it may compromise surveys conducted with single-beam echosounders where assumptions of temporal uniformity have been made. Also of note is the difference between 10:11am (run south to north) and 10:14 (run north to south) transects where a distinct increase in area and target numbers was detected. The detected increase of this size is unlikely to have occurred from a change in fish numbers that implies either a change in vertical density (i.e. individuals becoming more spread out over a flatter area), or movement by fish in tandem with the vessel (possibly avoidance behaviour). Either outcome illustrates the advantage of multi-beam coverage to allow such observations.

A significant limitation of echo integration from multi-beam data is the anisotropic nature of backscatter from fish swimbladders. Figure 4.14 displays a 3D visualisation of the 10:14 am transect. Each image illustrates regions formed from target acoustic backscatter of varying intensities, above the seafloor and wreck (shown as the blue surface). The separation of detected targets relative to target strength and beam position provides significant information in the development of a target strength/angular dependence relationship. Detection of targets has been conducted in sections of detected Sv values to analyse distribution of backscatter strength across the beam angles. The target colours shown reflect relative Sv values as per the colour bar.

Figure 4.15 displays a 3-D visualisation of the detected targets as a composite of regions varying in intensity to represent the overall acoustic backscatter of the aggregation. Targets range in backscatter by up to 15 dB, a variation greater than attributable to that created by a target strength/length relationship and possibly due to the ensonification of anatomical regions other than swimbladder and the stochastic nature of fish target strength. Analysis of video ground truth data will help determine fish orientation to compare with detected TS values. This image illustrates the capability to acquire significant quantities of backscatter data from individual targets throughout the aggregation.

An example of the Reson 7125 ability to acquire habitat and water column acoustic data is shown in Figures 4.16 and 4.17. The axes in Figure 4.16 mark east and west distance in metres, while bathymetry and acoustic backscatter are displayed as per the colour bars. During acoustic transects the multi-beam system acquired bathymetric data (figure 4.16 left image) and seafloor backscatter data (Figure 4.16 middle image). Processing of the seafloor backscatter by removing mean and standard deviation trends provided images of corrected backscatter (Figure 4.16 right image) and the classification of the area around which Samson fish spawn. Three areas of note are easily discernible from the corrected backscatter image and are highlighted in Figure 4.17.

Once combined with water column acoustic data it is possible to develop a more comprehensive image of the aggregating Samson fish and the habitat around which they spawn. Figure 4.17 displays the Samson fish, the wreck, sand, and an area of sand to the south west of the wreck possibly scoured by current from the north east.

Table 4.3. Metrics of detected targets, plan area and movement of the aggregation from data collected in 12 transects conducted with RESON 8125 over the Outer Patch Samson fish aggregation in October 2005.

Transect Start	No. Targets Detected		Plan Area (m^2)	Variation of areal backscatter centroid from initial transect (m)
	Multi-beam	Single-beam		
08:39:18	1415	925	8962.80	0
08:44:29	2061	2594	8975.22	22.3
09:04:00	2049	4434	12959.43	20.71
09:12:46	1849	1638	9533.02	11.71
09:21:12	791	1628	10342.83	10.8
11:58:56	738	374	7890.39	9.26
12:06:44	799	768	6049.82	9.97
12:15:21	657	589	6180.82	3.7
12:22:07	979	280	5056.79	20.71
12:30:09	1817	711	9582.63	18.89
12:38:11	1152	1052	9895.74	3.7
12:45:31	784	704	8617.91	11
12:54:01	866	971	8956.46	10.8
13:05:51	1137	711	6183.40	18.52
13:09:47	721	716	8396.62	34.8

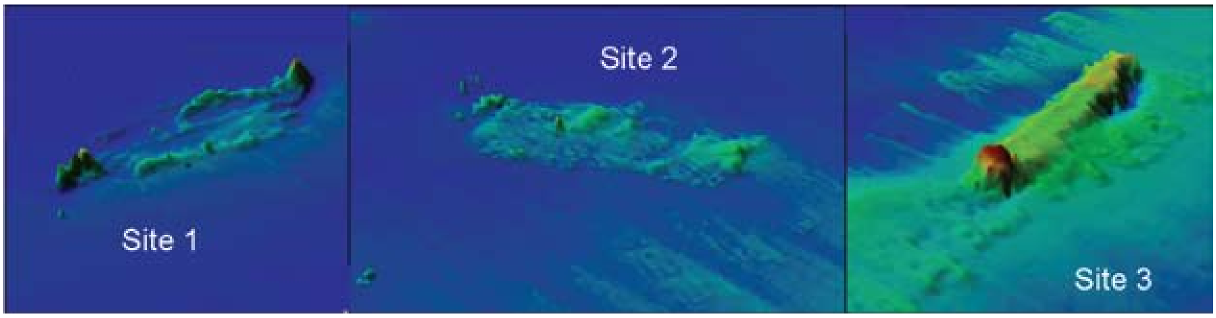

Figure 4.7. Bathymetry of wrecks at sites of three Samson fish aggregations acquired with the RESON 8125 multi-beam system.

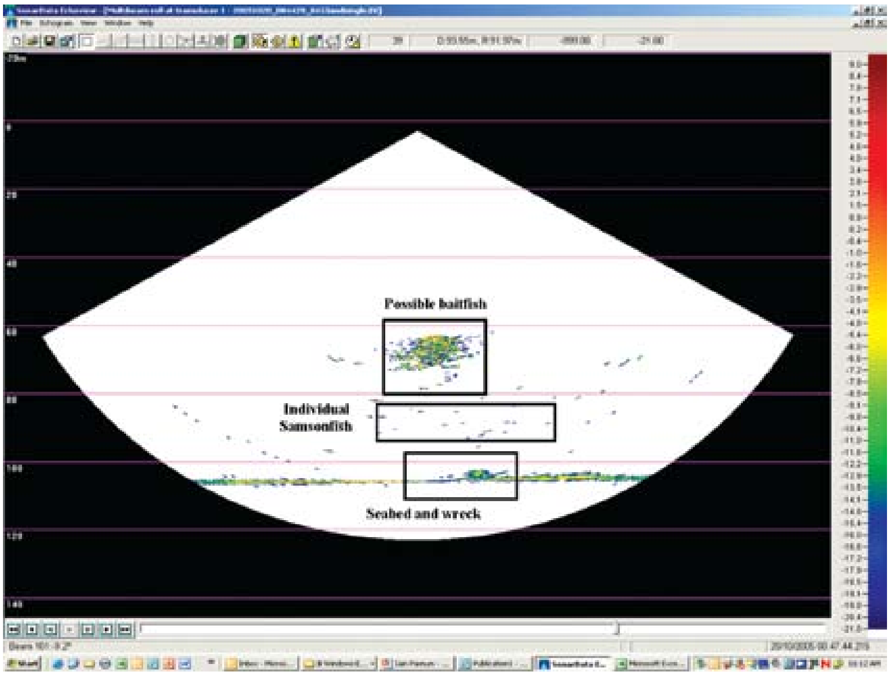

Figure 4.8. A single snapshot of a Samson fish aggregation taken with the Reson 8125. The snapshot displays the seafloor with wreck, individual Samson fish targets and a school of possibly baitfish.

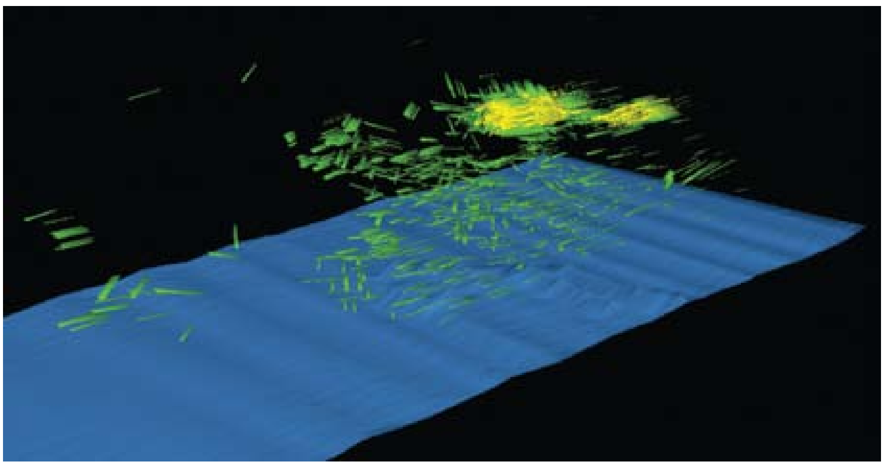

Figure 4.9. 3-D visualisation of the aggregation from the southeast created with Echoview software. The seafloor (with wreck) is displayed in blue, Samson fish aggregation in green and school of smaller fish shown in yellow.

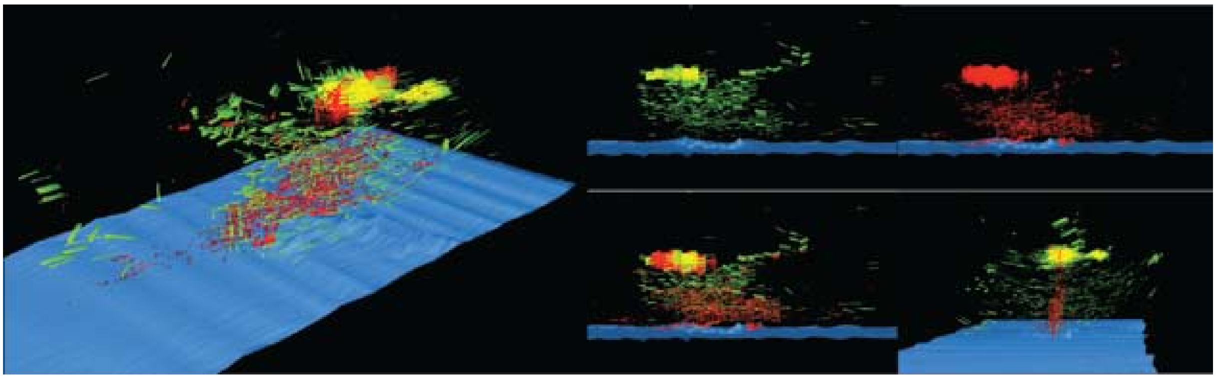

Figure 4.10. Three dimensional visualisation of the aggregation from the southeast with both single- and multi-beam backscatter and regions shown. Multibeam regions are shown in yellow and green (as per previous figure) and single-beam regions are shown in red. Right hand images display comparison of multi- and single-beam data acquired from a single transect, viewed from the west and south.

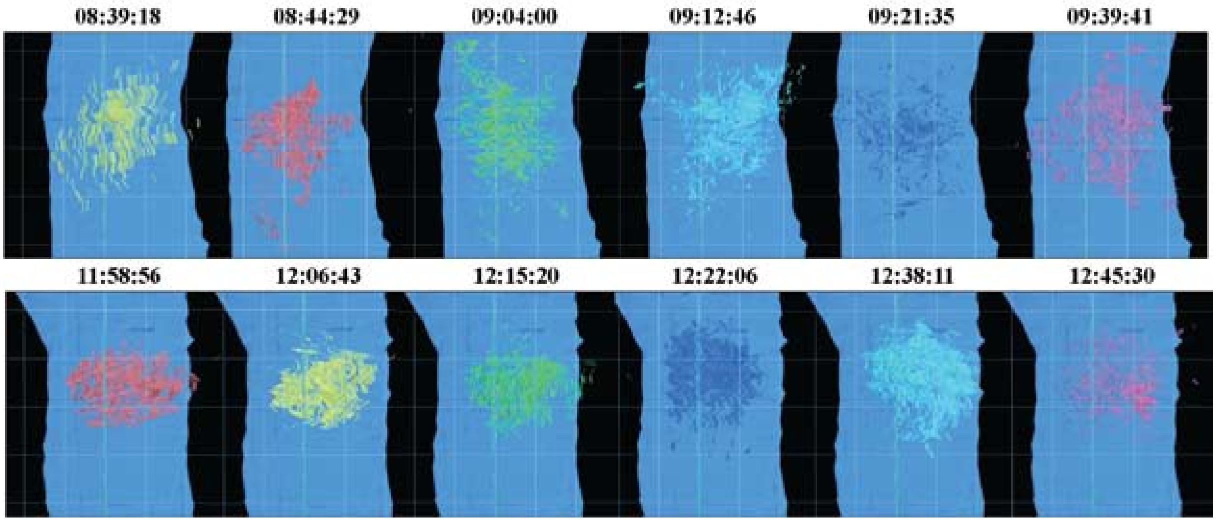

Figure 4.11. Plan views of regions formed from 12 transects conducted with the RESON 8125. Seabed shown as a blue surface and Echoview formed target regions shown in various colours.

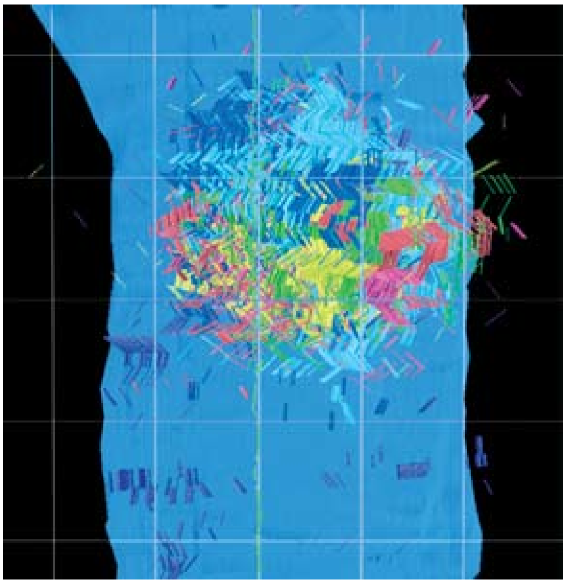

Figure 4.12. A composite plan view of the 12 transects shown in Figure 4.11.

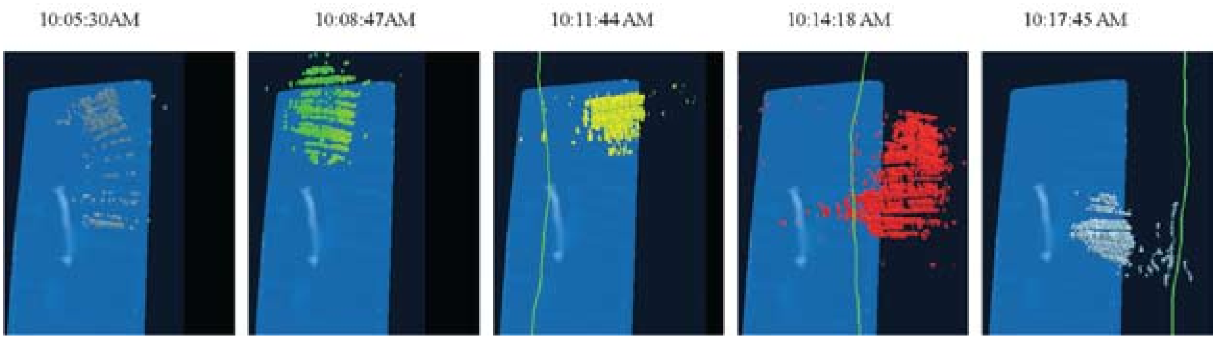

Figure 4.13. Plan view from five consecutive acoustic transects displaying movement of the Samson fish aggregation during a fifteen-minute period, with transect start times noted above. Seafloor shown in blue and fish regions generated from backscatter shown in various colours.

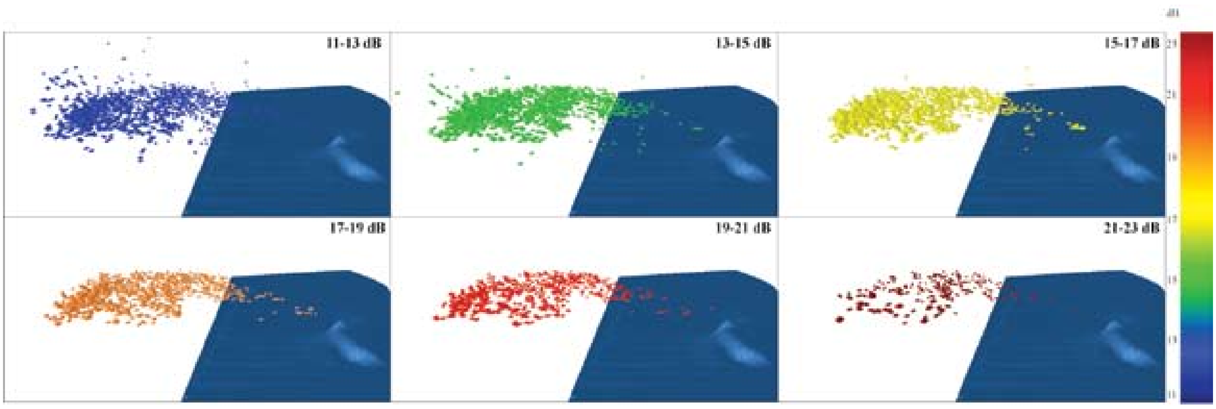

Figure 4.14. 3-D visualisation of regions generated from varying Sv bands of backscatter of the acoustic backscatter acquired from Samson fish aggregation during the 10:14am transect 3rd February, 2007.

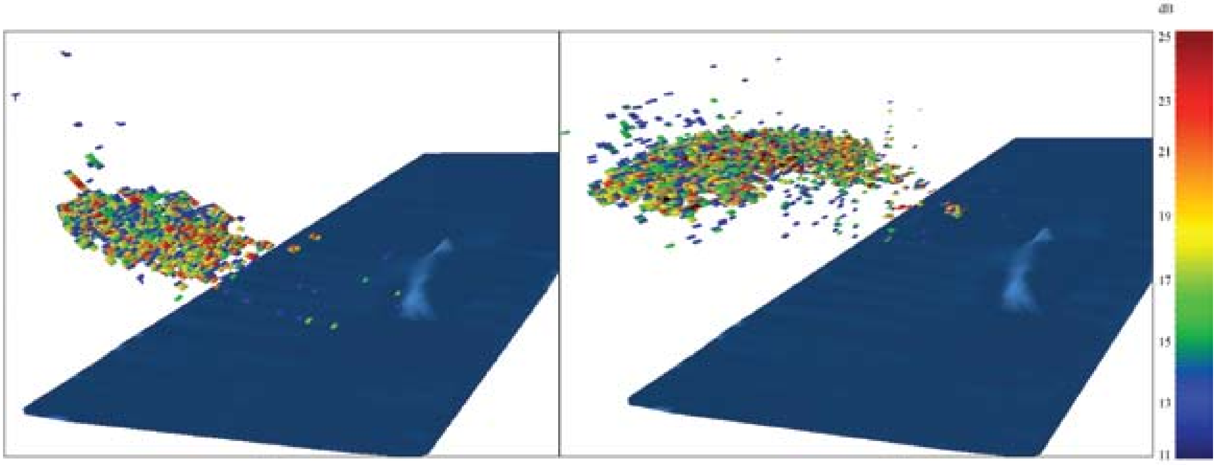

Figure 4.15. 3-D composite of regions generated from detected regions formed from the acoustic backscatter acquired from Samson fish aggregation at the Outer Patch during the 10:14am transect 3rd February, 2007.

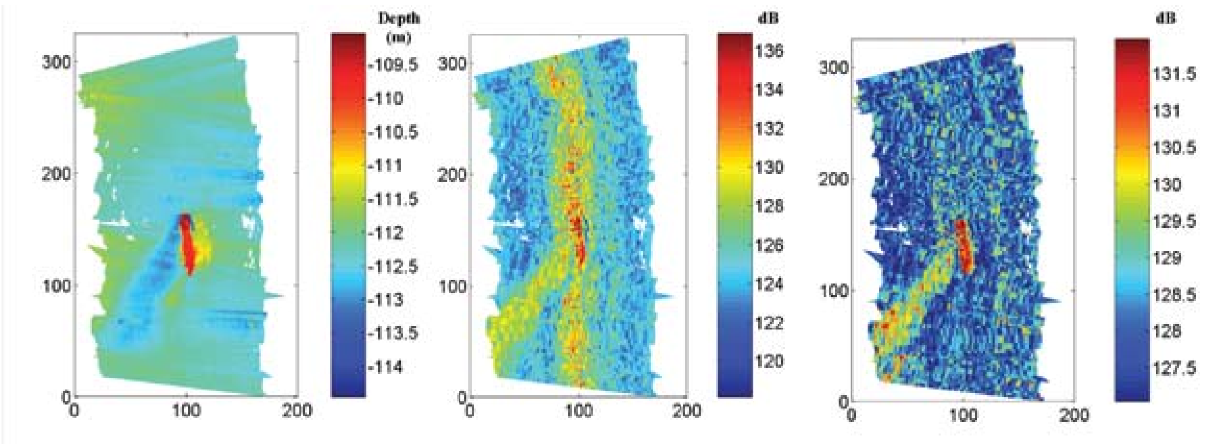

Figure 4.16. Bathymetry, uncorrected backscatter, corrected backscatter, from left to right respectively acquired from a single acoustic transect of the Outer Patch site. Depth and relative backscatter are shown as per the respective colour bars.

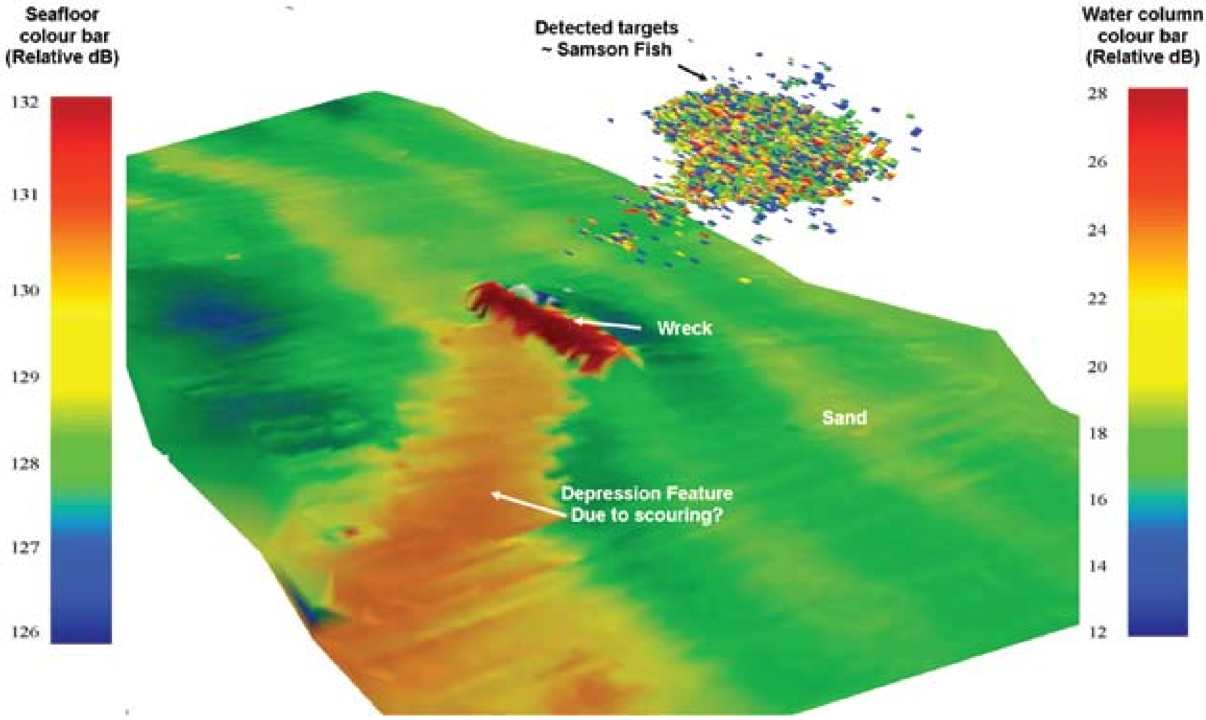

Figure 4.17. A 3-D visualisation of the habitat and Samson fish aggregation at the Outer Patch with colouring of surface and volume backscatter as per the respective colour bars.

4.2.2 Dhufish

During the February 2007 survey of a suspected spawning site north of Bunbury, an aggregation consisting of tens of dhufish was observed on towed video. The video GPS stamp confirmed the location of the dhufish aggregation, as well as another of baitfish to its southwest, as shown in Figure 4.18. Following the towed video tow an acoustic transect was conducted minutes later. A 3-D image of the possible dhufish (red) and baitfish (grey) is shown in Figure 4.18.

Acoustically derived groupings of this aggregation data suggest dhufish (sparsely populating an area to the north west of a seabed lump), and baitfish hovering above the seabed lump. The acoustic transect was conducted five minutes after a towed video transect, which displayed a tight group of dhufish and 5 larger separated dhufish to the north of the aggregation. Pink snapper were also observed in the video, although weather conditions at the time of the survey made it difficult to accurately count individuals.

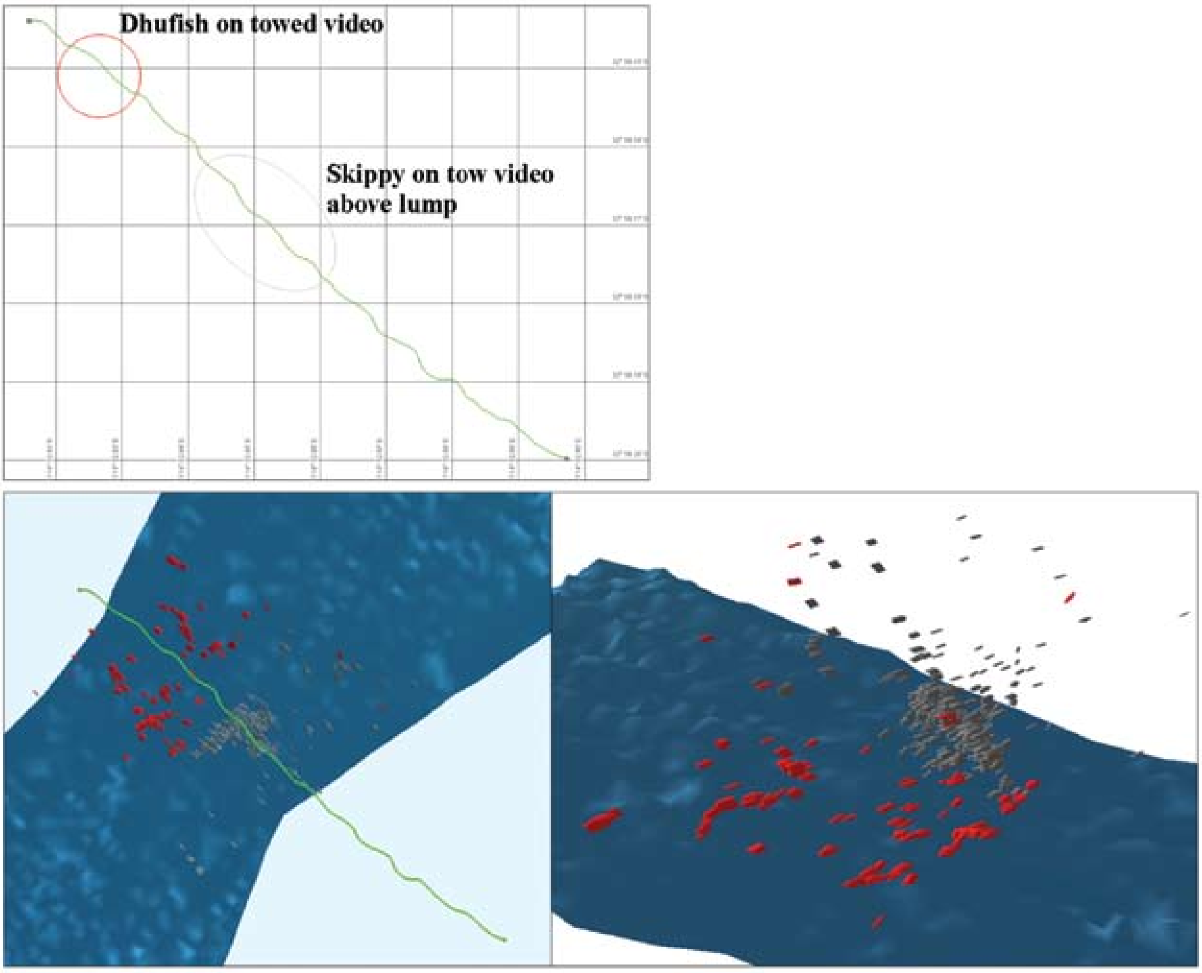

Figure 4.18. Map outlining locations of dhufish and baitfish confirmed by towed video (top image). Plan view and aerial view of 3-D visualisation of detected targets speculated to be mainly dhufish (red) and baitfish (grey).

4.2.3 Bight Redfish

During the February 2007 survey aboard the *RV Naturaliste* several small multi-species aggregations that included Bight redfish were located and surveyed with the RESON 7125 multi-beam sonar. This survey highlighted the need to ground truth using video data, since the aggregations were initially thought to comprise mainly Bight redfish based on samples obtained by line fishing. However, subsequent towed video transects showed that in fact there were relatively few Bight redfish scattered amongst individuals from at least two other fish species. Nevertheless, information from fishers indicates that large aggregations dominated by Bight redfish would occur at these sites during the spawning period for this species.

An example of an acoustic swath over the 'redfish' aggregation and the successive 3-D visualisation are shown in Figure 4.19. The detected targets displayed visible school structure and target strength differences from those aggregations of Samson fish surveyed with the same system. Whether these characteristics are species specific or attributable to the size of aggregation, fish size or environmental conditions has yet to be determined.

This smaller-sized aggregation also displayed possibilities for future developments in school analysis. Coverage of the towed video transect included the entire aggregation (when compared to multi-beam images). This facilitates confirmation of a comparison between detected multi-beam acoustic targets and the actual number of fish observed on the towed video. Detected correlations between the two will confirm density packing of actual targets compared to that of acoustic targets.

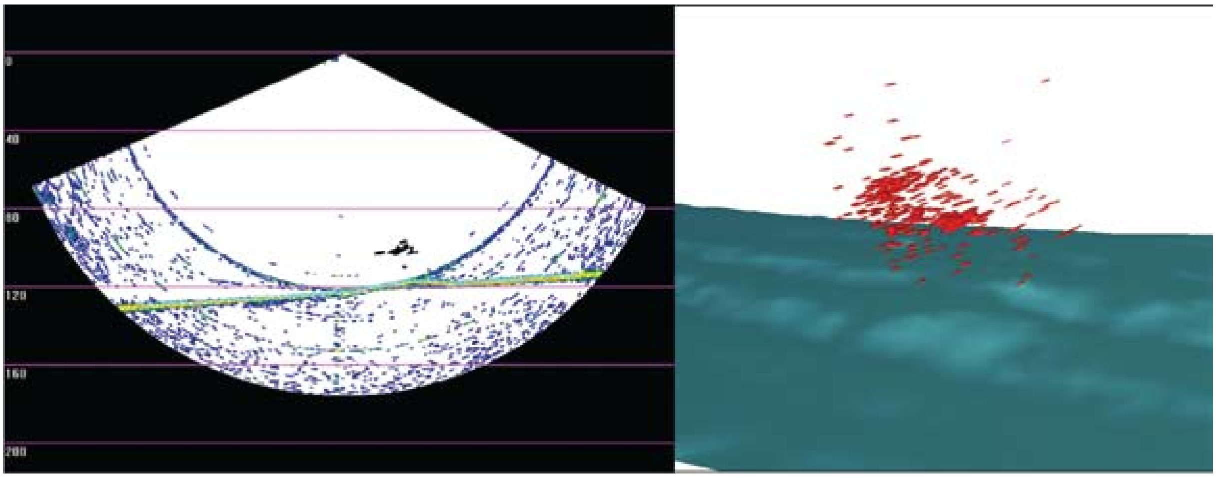

Figure 4.19. Acoustic multi-beam swath of detected ‘redfish’ targets (left), and 3-D visualisation of a small aggregation of ‘redfish’ (right).

4.2.4 Pink Snapper

During the RESON 8125 survey, on the 20th October, 2005, a survey to estimate fish in an aggregation of pink snapper was conducted in Cockburn Sound. A second vessel was employed to assist in locating the aggregation. Unfortunately, although the pink snapper were located on several occasions, by the time the *R.V. Naturaliste* had arrived the fish had moved on. This may have been simply the mobility of the aggregation or avoidance behaviour as a reaction to the approach of either vessel in such shallow water (max. 14 m). A possible solution to this reaction is the mounting of the multi-beam system. During the October survey the multi-beam was mounted with principal beams directed vertically downwards, however, other studies (Gerlotto *et al.*, 1998) have employed principal beams directed to port or starboard sides. Such mounting facilitates the observation of an aggregation at the side of the vessel at a greater distance, thus reducing avoidance effects. Figure 4.20 displays an example of this mounting from Gerlotto *et al.*, (1998).

Video evidence and fisher information also shows that pink snapper often aggregate or school in large numbers in deeper water, and that the aggregations are mobile. For the reasons of mobility and aggregation size multi-beam sonar therefore holds good potential for monitoring of this species in deeper water, particularly compared with single-beam systems where fish mobility is a problem.

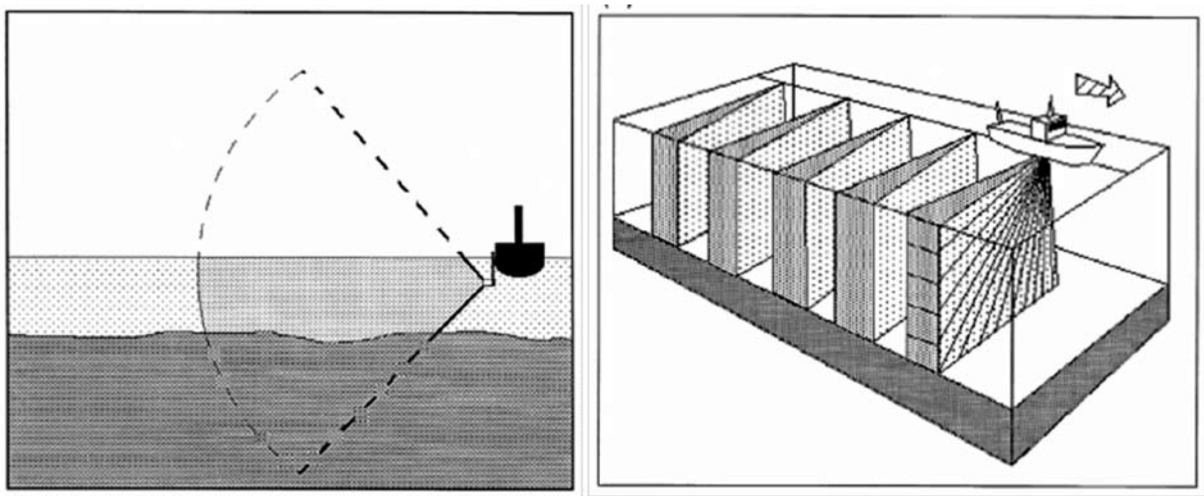

Figure 4.20. Side mounting of a multi-beam sonar in shallow water.

4.2.5 Other Species

An example of the coverage of baitfish has been shown in Figure 4.16 illustrating the capability of detecting fish of small target strength. In addition Figure 4.6 displays the ability of the multi-beam system to detect mobile schools of unknown species around the boat. Once the system has been mobilised to cater for the environmental characteristics (vessel speed or mounting direction for example) the multi-beam system should be able to gain coverage of typical fish aggregations.

4.2.6 Conclusions

Backscatter collected by the RESON 8125 multi-beam system provided unsaturated, highly resolved athwartships spatial data of Samson fish aggregations at a high signal to noise ratio, allowing target counting to estimate numbers of fish present. It displayed volumetric backscatter from schools of smaller fish. Snapshot data also provided information on mobile aggregations as they travelled around the aggregating area (not detected by the single-beam), and evidence that Samson fish do not exhibit excessive avoidance behaviour to survey vessels. However, such estimates are limited by two primary constraints. Firstly, alongships resolution was restricted by ping rate when using the RESON 8125, creating spatial aliasing and requiring assumptions of school uniformity between snapshots, an issue alleviated by the performance of the RESON 7125. Secondly, an accurate biomass estimate of any fish using multi-beam echo integration techniques requires a species-specific, length dependent 3-D target strength model, due to anisotropic backscattering (stochastic nature of fish reflectance) and large quantities of acoustic survey.

Despite significant electrical interference the RESON 7125 detected individuals and groups of fish at high resolution in depths of approximately 100 m covering the aggregation in a single transect. The 1.2 s ping interval available for acquiring backscatter at depths up to 175 m greatly reduced effects of spatial aliasing found with data processing of backscatter collected with the RESON 8125 in previous surveys. The system simultaneously acquired significant backscatter data from the seafloor. The ability to collect such quantities of detailed acoustic backscatter simultaneously from both water column and seafloor is extremely advantageous to fisheries management.

The data acquired with the RESON 7125 provides significant behavioural information on Samson fish aggregations in addition to that of biomass present and characteristics of the habitat. Five transects conducted during a 15-minute period have confirmed evidence that the Samson fish aggregations are not always stationary. The rapid coverage of the entire aggregation allows recording of this movement, otherwise estimated from data acquired with single-beam techniques. Anecdotal evidence from charter and recreational fishermen suggest that during the 2006-7 spawning season the aggregations of Samson fish dispersed earlier than previous years and so by early February fewer fish were aggregating above the wrecks than expected. As a result the survey occurred towards the end of the spawning season by comparison to previous years when it would have been close to the height of the season. This suggests that the level of movement exhibited by the aggregation may increase as the end of the spawning period approaches and the fish prepare to migrate. As such, multi-beam surveys may also be used to assess when the aggregation is likely to break up.

High resolution multi-beam systems will acquire significant behavioural and biomass related data from species which aggregate in large numbers, such as Bight redfish and pink snapper. It has been shown that surveys using the Reson 7125 of mobile aggregations in shallow water have limitations, whereas considerably more acoustic data can be collected on mobile aggregations in deeper water. It should also be noted that some of the limitations discovered in shallow water (such as avoidance) may be alleviated through alternative mounting positions of the sounder, resulting in the increased possibilities of surveying aggregations in areas such as Cockburn Sound.

The ability of the Reson 7125 to capture such high resolution (to a sample resolution of 21 cm) acoustic data in a swath as well as maintain a ping rate capable of one or more pings per second indicates the possibility of surveying aggregations of mulloway as they spawn close to the riverbed. Further research would be required into the capability of discriminating between riverbed and fish as it is currently thought that mulloway remain in areas close to the acoustic dead zone while spawning. Assessment of multi-beam performance in such conditions has inferred implications for the study of fish exhibiting other such benthic behaviour. For example, once a possible habitat for spawning dhufish has been located, multi-beam surveys may provide significant, non invasive data on behaviour and population as well as the ability to classify essential fish habitat (EHF) and possible spawning sites from future speculative surveys.

The Reson 7125 has also demonstrated the capability of detecting variation in aggregation structure which, after further investigation, may facilitate species discrimination during each survey. Examples of such variation can be seen in comparison of Samson fish aggregations (Figure 4.9) where individual targets have a large nearest neighbour distance, Bight redfish (Figure 4.19) where relatively smaller targets display smaller nearest neighbour distance and baitfish (Figure 4.18) where many fish are detected as a single volume. Further analysis of data may help in the determination of whether these characteristics are species or size related.

Simultaneous acquisition of acoustic seafloor and water column backscatter from aggregating fish and their preferred spawning habitat provides invaluable data for evaluating and monitoring variations in both biomass and habitat. Retaining high resolution acoustic backscatter, whilst maintaining manageable volumes of data is paramount for future broad scale acquisition of fisheries and habitat classification data. Acoustic surface and volume backscatter collected from the Samson fish aggregations at Rottnest Island have shown the capabilities of the Reson 7125 to acquire such high resolution data, and future developments (Malzone 2007) are planned to facilitate manageability of data from large scale surveys.

Although the sampling volume of the single-beam system does not provide accurate spatial resolution of targets, the high alongships resolution offers invaluable data for biomass estimates. Single-beam technology is also likely to be the most effective acoustic survey tool in terms of cost, ease of operation and convenience, particularly when monitoring immobile fish aggregations. When combined with the athwartships spatial coverage of the multi-beam, single-beam backscatter can provide accurate biomass estimates as well as structural and behavioural information. In comparison, multi-beam systems acquire extensive, high resolution (both beam resolution and ping rate) acoustic backscatter data from entire aggregations in a single transect, and exhibit the ability to discern fish at distances of as little as 21 cm from the seafloor.

4.3 Passive Acoustics

Miles Parsons, Rob McCauley and Michael Mackie

Many species of fish aggregate to spawn in habitats or at times where communication through visual stimuli is greatly inhibited by turbidity or lack of light (for example nocturnal spawning). Thus such species have developed alternative methods to vision for communicating, in this case, acoustic communication.

Winn (1964) and Fine *et al.* (1977) summarised sounds produced by fish as associated with one of several categories including; aggressive encounters (usually territorial), reproductive, echolocation, schooling, recognition, feeding, migration, exploration, distress and not-understood. Several species are characterized by their specialisation in acoustic communication, such as the sciaenids (drums or croakers) (Fish and Mowbray 1970), signified by their well-developed muscles associated with the swimbladder (Moulton 1963), and utilise sound as part of their reproductive behaviour (Guest 1978; Mok and Gilmore 1983; Saucier and Baltz 1993; Connaughton 1996; Luczkovich *et al.* 1999; McCauley 2001).

Sound production by fishes can eventuate from a number of methods, including bubble release from the mouth, or vibration of bubbles at the anal cavities (Wahlberg and Westerberg 2003). However, the two chief mechanisms are via stridulation (high frequency, wide-bandwidth, usually of short duration) or the application of vibration patterns to the swimbladder (McCauley 2001). Contraction of the swimbladder muscle creates vibrations in the swimbladder chamber. The swimbladder is an efficient sound generator in water due to the high acoustic impedance difference between the gas in the swimbladder and surrounding sea water.

Hearing in fishes involves the inner ear, peripheral structures such as the swimbladder, and the auditory portion of the central nervous system (Popper and Coombs 1980). Located within three sac-like otolithic organs of the teleost inner ear, otoliths are calcareous structures associated with acoustic (sound detection) functions (Popper and Fay 1993). The otolithic organs contain a sensory epithelium, which surrounds the otolith and comprises a large number of vertebrate type II sensory hair cells. Differential movement of the otolith and hair cells result in a nervous which is decoded as impinging sound.

Spawning fish are known to produce sounds (Mok and Gilmore 1983), and techniques have been employed to locate aggregations from these calls (Holt 2002; Luczkovich *et al.*, 1999; Saucier and Baltz 1993). However, the production of sound by aggregating fishes may serve several functions. The male haddock *Melanogrammus aeglefinus*, for example, produces sounds of varying characteristics in the lead up to, and during courtship (Hawkins and Amorim, 2000). McCauley (2001) speculated these functions in Terapontidae and Sciaenidae may be one or more of: increasing the 'catchment area' of the aggregation; to 'prime' nearby fish for spawning; and to assist in mate selection and mediate gamete release. However, as spawning in these species is invariably after dusk, specific confirmation is difficult to obtain. By comparison, correlations have been shown between calls and spawning related events for several species which can be observed by diver or video, with simultaneous acoustic monitoring, either *in situ* (Lobel 1992; Mann and Lobel 1995, 1998; McCauley 2001) or in aquaria (Allen and Demer 2003).

Many fish sounds contain species-specific pulse rates or dominant frequencies (Lobel and Macchi 1995; Mann and Lobel 1998) and are stereotypical, allowing the identification of a sound by simple parameters, such as duration, peak frequency, repetition frequency and bandwidth (Mann 2002). It is often the case that a single call type is used by spawning fish (Luczkovich *et al.* 1999; Hawkins 2000, 2002; McCauley 2001; Sprague and Luczkovich 2002).

Once the species-specific call parameters are identified, the intensity of the call within a time averaged scene of many callers can be estimated (Gilmore 2002; Sprague and Luczkovich 2002). Together with the localisation and/or ground truthing of the caller it is possible to evaluate the attenuation characteristics for the given aggregation area (Urick 1983; Forrest *et al.* 1993) and so the distance over which a call may be detected. By combining this with the calling: non-calling ratio and the population calling sex ratio (estimated from sampling), it may be possible to estimate the number of members within a spawning aggregation.

Recently techniques have been employed to locate aggregations of fish from their vocal behaviour (Gilmore 2002), however, little research has been conducted to locate and monitor individual fish within an aggregation. Three-dimensional location of fish using passive acoustic tracking has rarely been reported, due largely to the requirement of a sufficiently large hydrophone separation in the third dimension of depth (Watkins and Schevill 1972). Within a rigid array, containing two hydrophones located in the horizontal plane and a third offset in the vertical plane, it is possible to locate a sound from arrival time differences. The system can be calibrated for distant arrival times by the creation of an acoustic source at a known location (Watkins and Schevill 1972), preferably from within the array dimensions. From this the acoustic properties of the area (such as attenuation and spreading losses) can be calculated.

Thus the deployment of hydrophones and passive recording of fish vocalisations facilitates the identification of fish habitat by providing relatively inexpensive remote, non-invasive, unbiased (e.g. compared to video techniques), continuous and comprehensive coverage of an aggregation site. This offers data on a macro scale from a census of marine life down to micro-management of anthropogenic impacts and specific species behaviour, e.g. inferred daily spawning patterns.

4.3.1 Mulloway

Information from fishers has long suggested that aggregations of mulloway form in the lower regions of the Swan River, Western Australia, during summer months. Although previous extensive sampling of the Mosman Bay region of the Swan River did not reveal eggs and larvae of mulloway (Gaughan *et al.* 1990), individuals at stage V and VI reproductive maturity were caught between October and January (peaking in December) during a recent study (Farmer *et al.* 2005), confirming spawning activity within Mosman Bay. Mulloway are thought to usually reside on the river bed of the Swan River, apart from when spawning, which, due to acoustic 'dead zones' make them unconducive to active acoustic techniques.

Mulloway have sonific muscles in a narrow longitudinal band (one on each side) along the inside of the ventrolateral wall of the body cavity, which are not connected to the swimbladder, typical of some members of the Sciaenid family (Griffiths 1995). Confirmation that the vocal samples from Swan and local waters were from mulloway was made using individuals from this species held in aquaculture facilities at TAFE, Fremantle. These fish are often heard vocalising prior to spawning (Jenkins, 2005, *pers. comm.*). Previous passive acoustic recordings taken from Mosman Bay (McCauley, unpublished data) suggest that like other Sciaenids, mulloway vocalise over consecutive evenings for extended periods commencing prior to sunset and continuing for several hours into the night.

Recordings acquired from Mosman Bay broadly illustrate the advantages and disadvantages of passive acoustics in the fine-scale study of spawning aggregations within a relatively enclosed, shallow environment accessible to human activity. Some sections below summarise findings by Parsons *et al.* (2006, 2007).

Analysis of a mulloway call

The analysis detailed below has been derived from transects conducted on the 17th January, 2006 as per Figure 2.8.2 in section 2.8.2. Figure 4.21 is a spectrographic display of 25 s recording taken at the beginning of transect 1, approximately in the middle of the channel (15 m depth). Areas in red show an increase in detected sound pressure levels at particular frequencies. Aural examination of the recordings suggest these data comprise predominantly fish calls, similar to those sounds produced by other Sciaenids, and to a minor extent, shrimp clicks not removed by filtering. In this section, three calls stand out in particular at approximately 11, 14 and 24 s. Figure 4.21 displays spectral intensity at various frequencies and an estimation of the call length. To the right of Figure 4.21 is a magnified display of the call at 24 s, highlighting sidebands of amplitude modulation of the signal (Watkins 1967) discussed later, and providing an idea of the call structure, signified by the intense areas slightly below spectral lines at the start of the call (23.75 s). Typically spectrographic images displayed that call modulation frequencies of approximately 55 Hz were still visible as spectral lines from 50 Hz up to 1000 Hz, though tone burst carrier frequencies always remained between 250 and 300 Hz. These tone burst carrier frequencies and modulation frequencies can be employed to determine which population an individual is likely to belong to. Figure 4.21 also displays variation in the call types detected, for example the calls at approximately 1, 5, 9 and 16 s differ from those at 11, 14 and 24 s. This call variation will be discussed later.

The data also show a large number of calls at differing spectral densities. If it is assumed that fish call at similar intensities over a short period of time this suggests that the calls of differing intensity are coming from varying distances from the hydrophone and probably from different fish. Anecdotal evidence from divers suggest that during the vocalising period mulloway ‘nest’ in the substrate for prolonged periods of time, possibly in the same way that weakfish form ‘leks’ (Gilmore 2002) corroborating the assumption that calls originated from different sources.

Waveforms of the hydrophones’ detected voltage provide significant data on amplitude and structure of each signal. Figure 4.22 illustrates the waveform produced from filtered data of 50 s recorded during transect 1, the first 25 s of which are displayed in the spectrogram in Figure 4.21. Calls mentioned above are visible with the highest response amplitudes in the first half of the top waveform. Sections of the waveform (bordered by dotted lines) have been expanded to demonstrate the structure of the individual call at 24 s (also magnified in the spectrogram of Figure 4.21). This figure highlights the tone bursts generated during the call, and below, the structure of a single burst. These features are characteristic of amplitude modulation (Watkins

1967) and typical of muscular modulation of a swimbladder. The call comprised 22 bursts over 39.80 ms, typical of a particular type of call discussed later. Signals with lower amplitudes, corresponding to calls from fish thought to be a greater distance from the hydrophone are also visible throughout Figure 4.22 (top image).

Separation of individual callers

Visual comparisons of individual calls often detected marked similarities between waveforms. Figure 4.23 illustrates the waveform of bursts from three different signals. Calls 1 and 2 are expanded waveforms from signals also shown in Figure 4.23 (31 and 36 s respectively), while Call 3 was recorded approximately half an hour later at a location approximately 250 m away. The similarities in structure between Calls 1 and 2, combined with their proximity in time and location suggest that these calls originate from the same caller. It is possible that minor changes in the waveform could be interference caused by vessel drift. The marked difference in burst structures shown in Figure 4.23, particularly the initial response amplitude where an extra cycle can be seen in the tone burst, imply that Call 3 originates from a different source.

The waveforms of individual bursts within signals at 11, 14, 43 and 49 s were also similar to the structures of Calls 1 and 2, suggesting that all these calls originated from the same fish. The detected voltage amplitude over the course of these calls varied from a maximum of 0.35 V in the first call to a maximum of 0.0175 V in the last call, 38 s later. During this time the vessel had drifted 7.14 m. Further analysis of the three calls in Figure 4.23 showed that the modulation frequencies and the structure of the overall call displayed variations. Figure 4.23 shows spectrograms of the three calls. The structure of Calls 1 and 2 display similar carrier and modulation frequencies and also the same intensity at fractionally lower frequencies at the start of the call. Call 3 displays spectral lines lower than those of the other two calls and also less change in frequency over time.

Temporal analysis of spectrograms and waveforms revealed that for some periods individuals repeated calls with regular intervals. Figure 4.24 illustrates some examples of this regularity with three callers exhibiting repetitive calls. It also displays areas where multiple callers result in a signal that cannot easily be split into individual contributions (dashed line). Callers 1 and 2 appeared to have approximately 4 s between calls. A third caller may have exhibited similar behaviour, however, at that point multiple vocalisations were recorded (approx. 35 s) and were difficult to confirm. Periods of repetitive calling by suspected individuals has been detected throughout the recordings, however, analysis of their occurrence has not yet been conducted.

Thus, during periods of vocalisation where detected call signals do not overlap to a great extent it is possible to separate callers from a single hydrophone by each or a combination of periodicity of calls, intensity, tone burst frequency. These characteristics also supply information on the fish themselves as tone burst frequency is related to swimbladder volume and therefore length (this relationship has yet to be investigated). Once a typical sound pressure level for a mulloway call has been determined this data will also provide an estimated range of caller from the hydrophone (based on the assumption that individuals call at the same or similar sound pressure levels). However, the relationship of the above characteristics to fish size has not been investigated, and it is possible that the calls of similar sized individuals are particularly difficult to separate.

Categorisation of mulloway calls

Preliminary analysis of individual calls throughout recordings resulted in general classification of identifiable fish calls into four types: Type 1 (Baaarp), a single audible signal consisting of many tone bursts in which the amplitude of the initial burst are lower than that of those succeeding them; Type 2 (Ba-baarp), comprising two (occasionally three) preliminary bursts followed by an interval equal to one burst and then many bursts of increased amplitude; Type 3 (Bup), a short signal consisting of two or three bursts, generally of lower amplitude than the longer calls; Type 4 (Bup), a short signal similar to Type 3 with an apparently prolonged impulse and period between pulses. Examples of waveforms for each of these call types can be see in Figure 4.25.

Variations in vocal behaviour throughout the evening calling cycles were apparent from the changes in call types heard. In late afternoon (sometimes several hours before sunset) calls have been recorded comprising predominantly of type 3. Typically, as the cycle proceeds these calls are replaced by types 1 and 2 with increased regularity and number of callers. Several hours after the cycle commenced calls of type 1 and 2 dwindle in number and those of type 4 become more prevalent. Some examples of call types and their properties from data recorded on 17th January are shown in Table 4.4.

Localisation of an individual caller

Localisation of callers was conducted using signal time arrival difference method (Parsons *et al.*, 2007) as per section 2.8.2 using the array detailed in Figure 4.26. Initial processing illustrated that during periods of calling where the presence of vocalising individuals was less prevalent, signals could be distinguished by all four hydrophones. Figure 4.26 displays a spectrogram and waveform for a bulb implosion and successive mulloway calls detected by each of the four hydrophones. Signal 1 represents the detected voltage amplitude after the bulb implosion has occurred. The remaining selected signals are detected mulloway calls generalised into two of four categories outlined in section 4.3.1.3. Signals 2, 4, 5, 6, 7, 8, and 11 are of one call type while 3, 9 and 10 are of another. Initial examination of relative intensities inferred that calls 2, 5, 8 and 11 originated from roughly the same location and inspection of waveforms suggested the same source. Analysis of call power spectral density, linked to swimbladder volume, correlated with this inference. Calls 3 and 9 also appeared to originate from the same position. However, call 10, although of the same call type comprised larger voltage amplitude at the vessel hydrophones, implying a more southerly location. Also displayed in Figure 4.26 are areas where signal to noise ratios for one or more of the hydrophones drastically reduced the accuracy of detecting the sample number for the signal leading edge. This limits the ability to locate the call from 3 dimensions to 2. It should be noted that a fifth hydrophone was retrieved from Mosman Bay, in May 2007. Analysis of data from this hydrophone should improve localisation of mulloway in the area.

The ten example calls described above are displayed in Figure 4.27 in a 2-D map of the Coombe waterfront. This illustrates how CMST localisation programs confirmed groupings of calls to specific areas and to a degree that the callers remain stationary while vocalising. Calls 2, 5, 8 and 11 have all been located together. The program also illustrates that most detected signals were located in the deeper regions of the river. Examination of successive calls after the implosion revealed that many of the callers, particularly of the preparatory call remained stationary. However, many other calls were individual, possibly from a moving source. There are also periods of calls where a signal leading edge is indeterminable from the decay of a previous call and so localisation of such signals would require further investigation.

There are also several factors, both permanent and variable, which affect the localisation from these datasets and need to be addressed. GPS accuracy, mooring drift on deployment and redundancy are all contributing factors to confidence levels in location of individual call origins, although they are permanent offsets from start to finish of a recording session and would not affect the relative location of consecutive calls. In contrast vessel movement due to wind and current are variable factors throughout the session, though it is noted that variations were less than 2 m. When considering relative displacement between call sources, these variable factors do not affect the ability to distinguish between callers.

Long-term temporal patterns of vocalisation

The sea noise logger set at 16.9 m depth in Mosman Bay operated at the sampling settings described in Table 4.5. Once call types and associated behaviour have been identified the sea noise loggers are particularly powerful at determining temporal patterns in animal behaviour since the sampling definition is so high. An example of this is shown by stacking the power spectra of several days samples through time. This is shown in Figure 4.28 where several power spectra from each sample are combined to present the frequency content on a logarithmic scale and are shown stacked through time with colour representing signal intensity. The increase in evening mulloway calling behaviour over a five-day period is clearly evident on Figure 4.28.

Once the frequency content of a call structure has been ascertained then an average spectral density across some frequency band can be used as a proxy for estimating calling intensity for a species. For mulloway the 250 Hz 1/3 octave spanning the frequency band 223-281 Hz acts as an indicator of calling levels. By zeroing the time of each days recording to the time of local sunset and averaging each evenings fish chorus level in the 250 Hz 1/3 octave across the entire recording period we can see the daily pattern of calling, as shown on Figure 4.29. When averaged across the full recording sets a consistent pattern of calling peaking around an hour after sunset is shown by this analysis. The curves shown on Figure 4.29 are different in levels reached, this will be either due to differences in the number of individuals calling biasing the averaging, or some system calibration error between each season. It is believed set 2689 had a calibration error, which will affect measures involving sound levels but will not affect counts of calling fish.

As a further indication of daily calling trends across the recording set duration each evenings 250 Hz 1/3 octave level, zeroed to time of local sunset, has been stacked through time for set 2689 and is shown on Figure 4.30. Although the full recording set average 250 Hz 1/3 octave level shows a peak at 1 hour post dusk as in Figure 4.29, there is clear evidence of a shift in highest calling level through the season from near dusk early in the season to 1-2 hour post dusk mid – season and back to near dusk at the end of a season. A lull in calling behaviour is evident through January to mid February. These variations are illustrated in Figure 4.30 by spectrographic dark patches displayed around dusk from October that defer to more concentrated, darker areas, from mid November. Throughout January and February a light area is visible where little calling was recorded, and calling times return to a peak around dusk as the spawning season moves into late March.

By averaging the 250 Hz 1/3 octave each evening across a time period spanning the evening calling activity and plotting this with time, longer term temporal patterns can be studied. This is shown for the Mosman Bay recordings sets on Figure 4.31 where the 250 Hz 1/3 octave each evening has been averaged from one hour pre-dusk to 2.5 hours post dusk and plotted against season day. A three-day running average has also been included. Calling activity was present across the full recording period of each set but clear differences in the levels of activity occurred across the summer season. Again a significant difference between the overall levels reached occurred between seasons suggesting a problem with the calibration of the 04-05 season's data. It is suspected that the set 2689 has a calibration error, although this will not affect the in-season data comparisons. Each recording set shows a jump in levels towards late summer, this occurring approximately 12 days earlier in 2004-05 than in 2005-06 while the longer set 2689 shows a January to mid February lull in calling and, by proxy, spawning behaviour. The longer set over 2006-07 shows a sharp rise in calling activity in late October. All data sets show a cyclic pattern in levels with periodicity approximating a half lunar cycle. These temporal aspects are to be further investigated and correlated with moon and tide. While using the 1/3 octave level as a proxy for mulloway calling allows a quick comparison of data sets, using counts of calling fish will be more accurate. The CMST is currently building software to scan the large data sets to provide such counts. It is intended to deploy sea noise loggers in the Swan River indefinitely to allow a much larger and more powerful seasonal comparison with the ability to detect long-term trends in mulloway visitation.

Effects of biological and anthropogenic noise

Evidence of biological noise unremoved by the filtering process was present throughout recordings. The most predominant of which were shrimp clicks. During surveys evidence of dolphin clicks was also present though this has not been detected in the current analysis. Figure 4.32 displays the effects of noise created by a passing vessel and their distortion of mulloway signals, in this case at a distance of approximately 100 m. During this recording (probably due to the late stage in the vocalising period) the detected fish signals were weak. Vessel noise is visible in the spectrogram as horizontal dark lines, and in the waveform as increased background voltage amplitude in comparison with Figure 4.24 where no audible vessel noise was detected. During surveys vessel noise was found to be sporadic, though of considerable interference to data. Removal of this noise requires further processing. Other noise known to be present, but as yet undetected in analysed data, is the presence of scuba divers. The breathing and bubble release of scuba diver contributes considerable noise around the frequencies of mulloway calls, although they are much more infrequent than other noise sources, and generally restricted to the Coombe and Freshwater Bay yacht club areas of the river.

What is believed to be train and road traffic noise are distinguishable from the Swan River passive acoustic data. The potential train data can be linked to the train schedules at the nearest station, Mosman Park, whereas the road traffic noise shows a clear increase at peak hour times and a lull on Sundays. It is not clear how this noise reaches the logger, be it via an airborne or ground borne path radiated into the water or some combination.

Table 4.4. Mean values and standard deviations of example call characteristics of four identified types of call.

Call Type	Mean Peak Frequency (Hz)	Mean No. Bursts	Mean Burst Length (ms)	Mean Call Length (ms)
1	261.3 (± 42.82)	20.96 (± 3.36)	18.5 (± 1.44)	390.9 (± 61.2)
2	264.0 (± 41.76)	17.55 (± 2.98)	19.4 (± 1.32)	399.2 (± 54.6)
3	277.1 (± 52.89)	2.20 (± 0.41)	19.6 (± 3.67)	50.6 (± 15.4)
4	250.9 (± 27.56)	2.00 (±0.00)	28.2 (± 0.61)	56.4 (± 7.82)

Source: (Parsons *et al.*, 2006)

Table 4.5. Long-term passive acoustic deployment in Mosman Bay.

Set	Valid samples / Days recorded	First sample	Last sample	Sample rate	Sample schedule
2662	3-3608 / 25	11-Jan-2005 12:00	05-Feb-2005 12:50	6 kHz	300 s every 10 minutes
2689	2-9409 / 98	06-Dec-2005 18:00	14-Mar-2006 17:45	6 kHz	300 s every 10 minutes
2730	4-2,400 / 223	11-Oct-2006 17:00	22-May-2007 14:00	4 kHz	300 s every 15 minutes

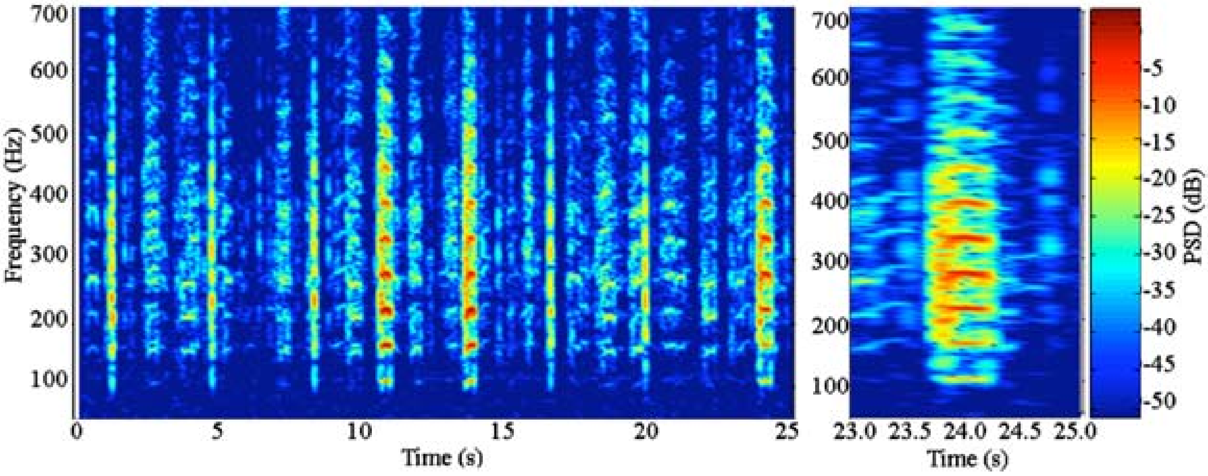

Figure 4.21. Spectrogram of signals recorded during the first 25 seconds of transect 1, 19:35:07 17th January in Mosman Bay, Swan River. The right image shows a close-up of a single call speculated to originate from Mulloway between 23 and 25 seconds into recording.

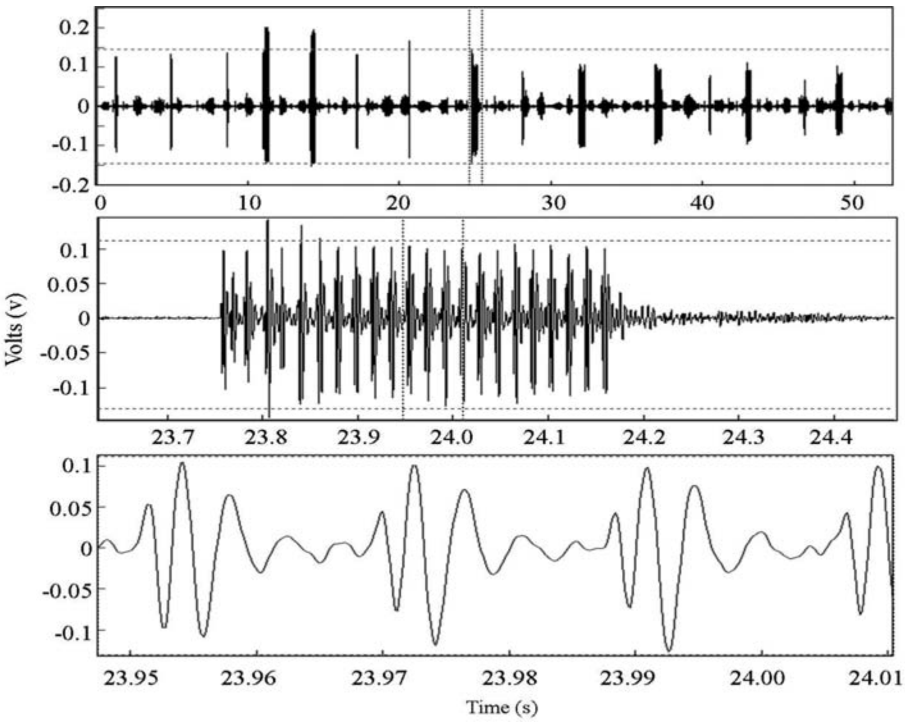

Figure 4.22 Waveforms from 50 s recording of transect 1 taken at 19:35 pm 17/01/06. Borders of magnified sections are highlighted by dotted lines in the prior image.

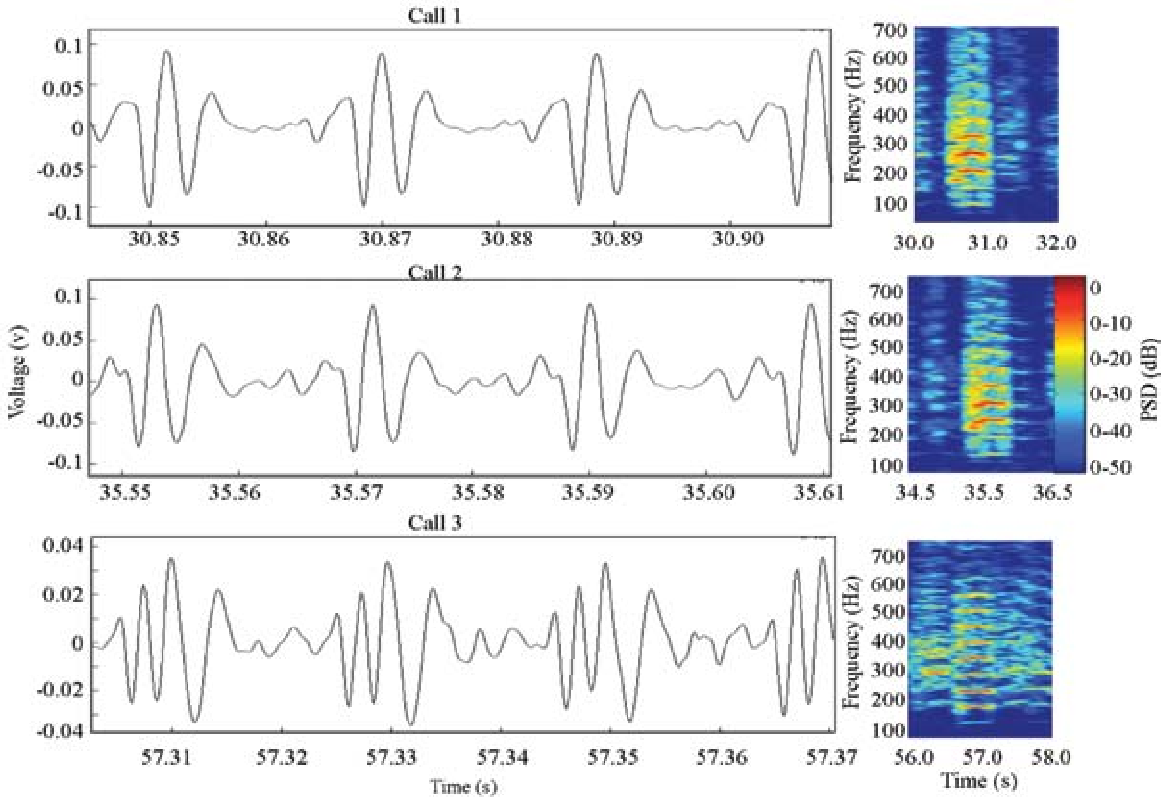

Figure 4.23. Waveforms and spectrograms from three individual calls recorded during the first two transects on 17/01/2006.

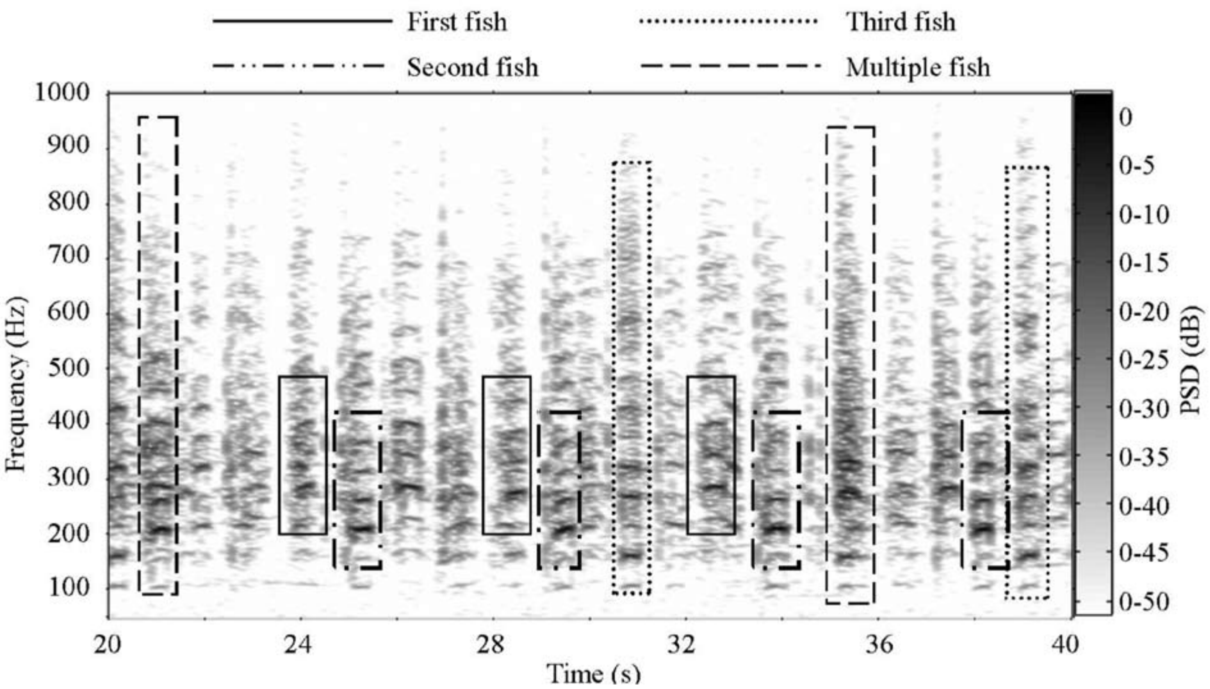

Figure 4.24. Spectrogram of fish vocalisations highlighted for periodicity of individual callers.

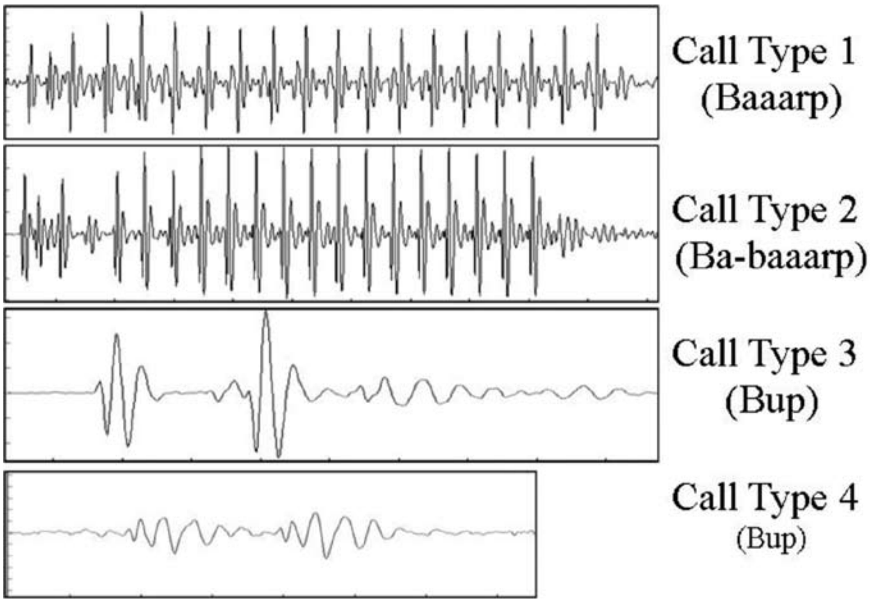

Figure 4.25. Waveforms of four classified types of detected fish calls thought to originate from mulloway.

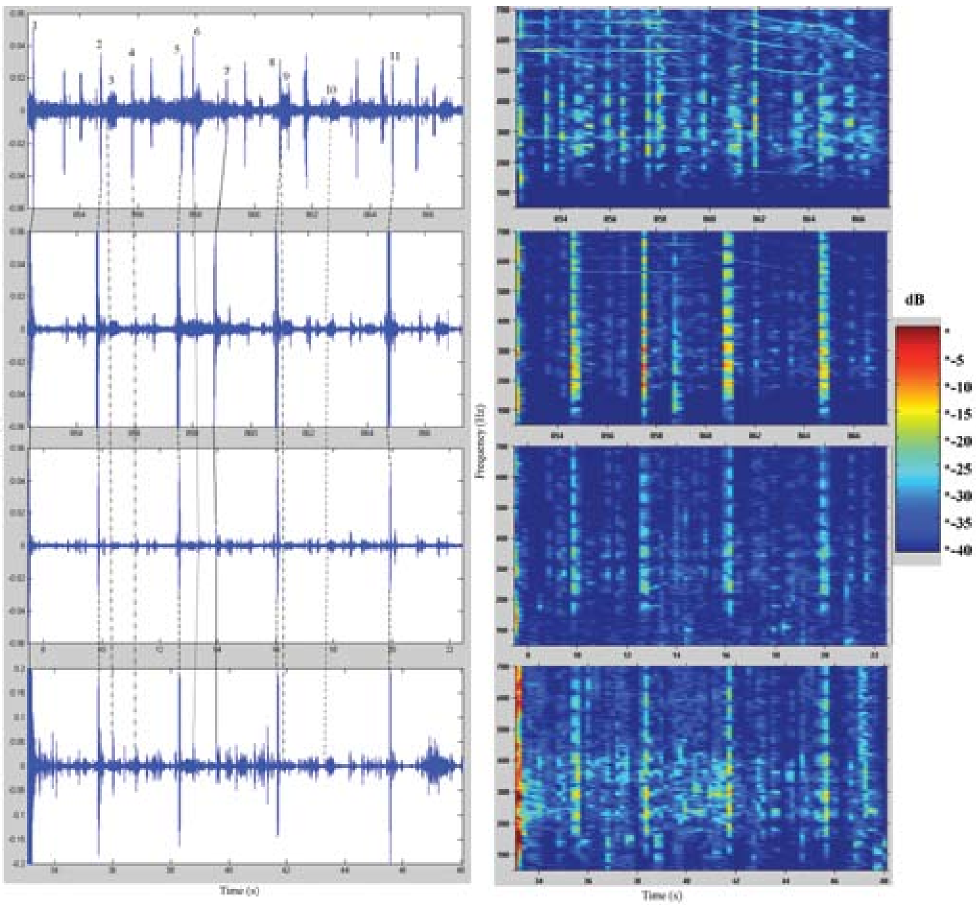

Figure 4.26. Spectrograms and waveforms from hydrophone recordings, displaying time synchronised signals from an implosion and ten highlighted mulloway calls.

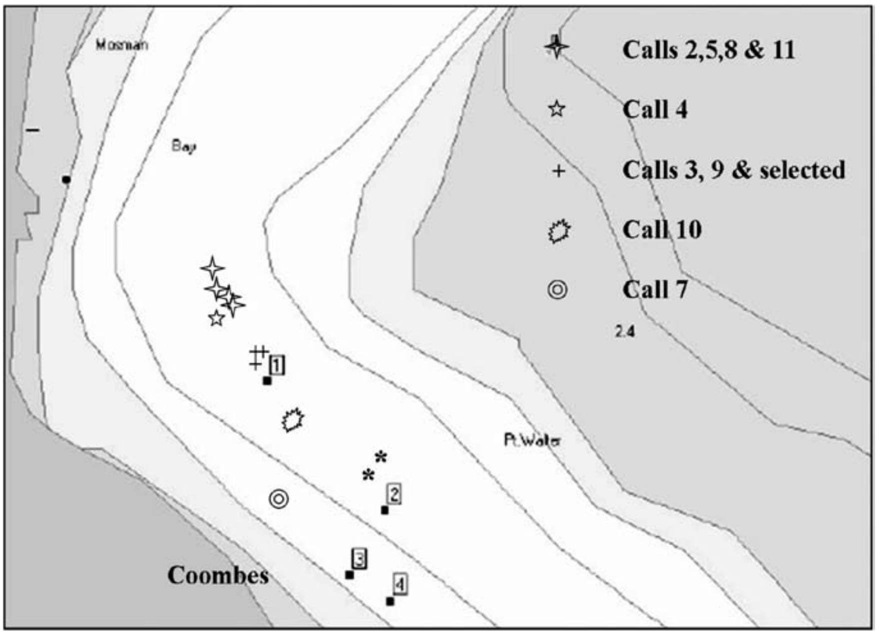

Figure 4.27. Map of the mulloway calls, linked to waveforms shown in Figure 2.8.1.

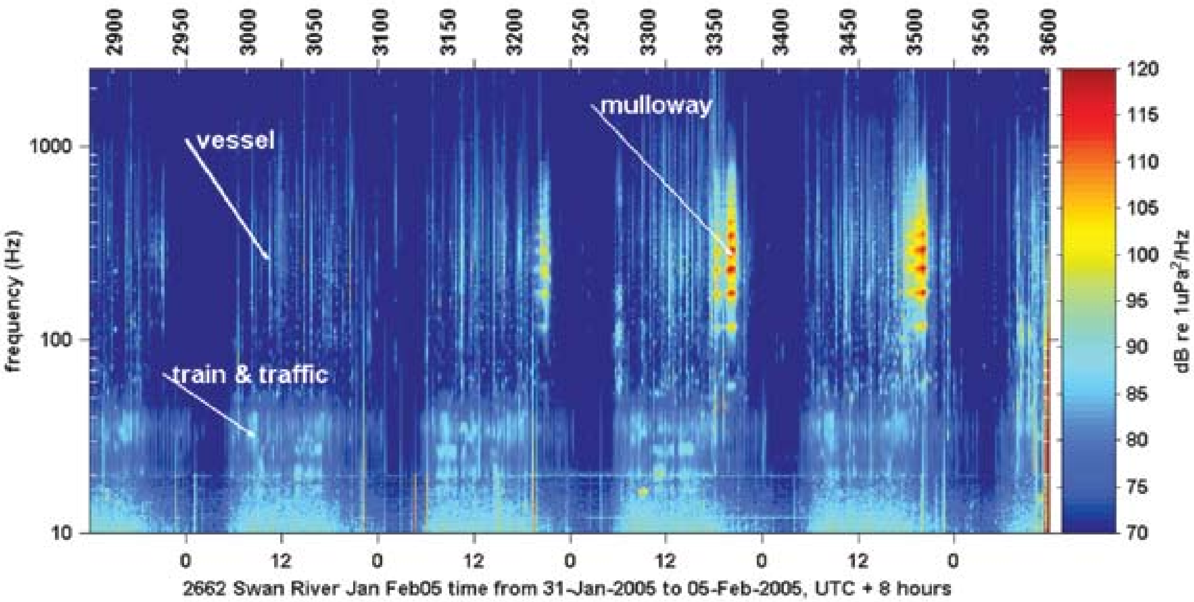

Figure 4.28. Stacked power spectra of sea noise from Mosman Bay recorder in summer 2005 showing an increase in evening calling behaviour of mulloway over a five-day sample period. Vessel, train and vehicle traffic noise are also highlighted.

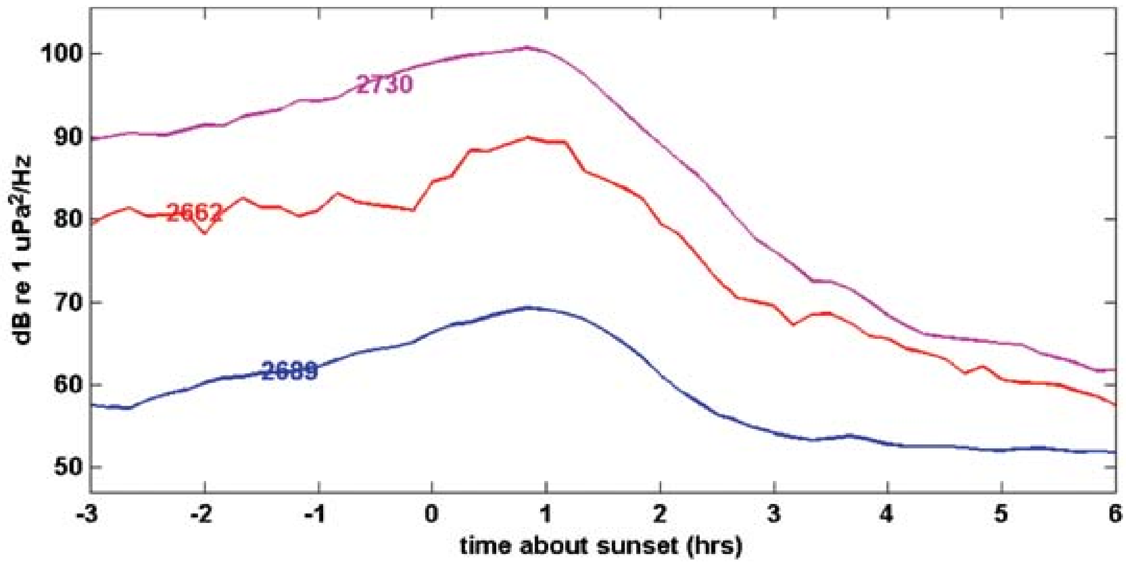

Figure 4.29. Time of evening mulloway chorus from Mosman Bay, with time zeroed to that of local sunset and the chorus level in the 250 Hz 1/3 octave averaged each evening over the full recording period.

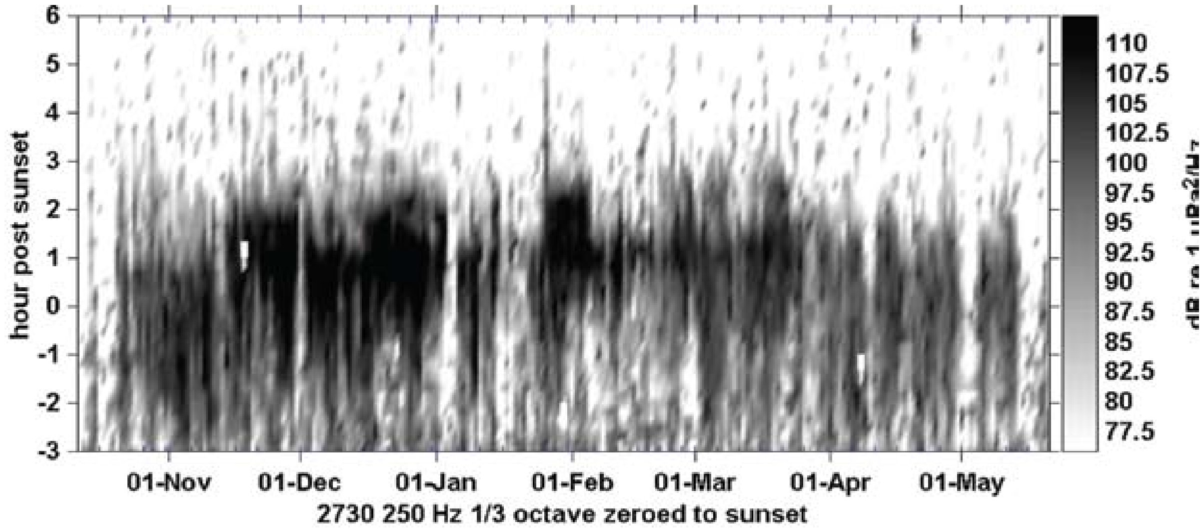

Figure 4.30. Level in the 250 Hz 1/3 octave as indicative of mulloway calling, shown stacked for each evening with time zeroed to time of local sunset, for recording set 2689. Minor ticks are five days, spectral levels are shown.

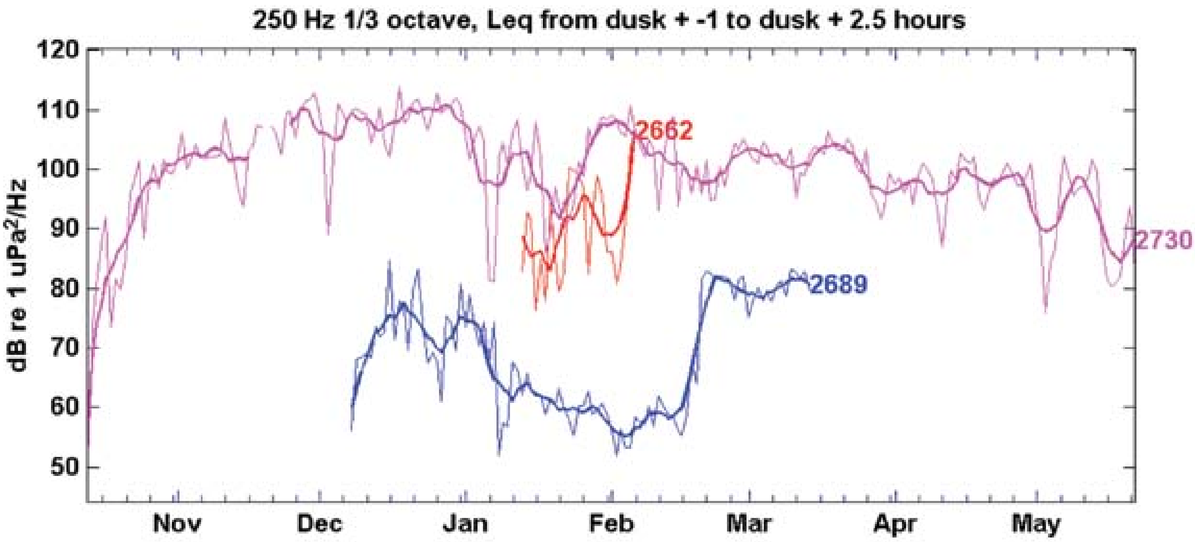

Figure 4.31. Evening mulloway calling activity as given by each evening's average 250 Hz 1/3 octave across dusk to dusk plus 2.5 hours. A three-day running average is shown for each curve. The minor ticks are five days.

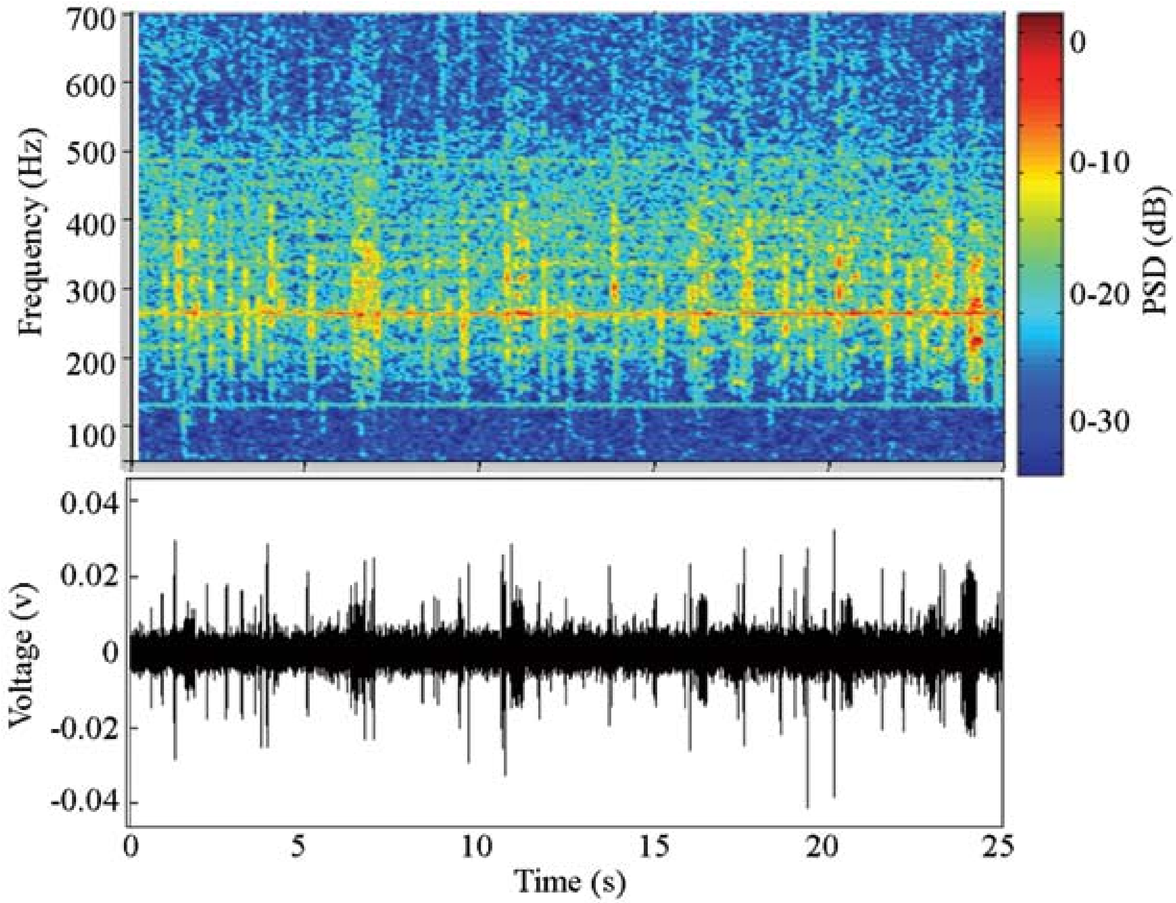

Figure 4.32. Spectrogram and waveform of a recording taken at approximately 21:30, January 17th, 2006, illustrating the effects of contributing vessel noise at frequencies similar to that of the signals produced by fish. Horizontal dark lines in the spectrogram result from passing vessels.

4.3.2 Other Species

Samson fish

Biological sampling of Samson fish swimbladder muscles and otoliths suggests that the species is unlikely to exhibit vocal behaviour. The tendency to form aggregations of up to thousands of fish, within close proximity in waters of relatively high visibility supports this inference. An acoustic sea noise logger was deployed in January 2004 to acquire passive acoustic data from a location close to one of the Samson fish aggregations. Aural analysis of these data displayed no sign of vocalisation from the species.

Dhufish

Dhufish possess relatively large otoliths, suggesting the ability to detect underwater sound, and have paired, fast acting muscles attached to the anterior part of the swimbladder (McCauley unpublished). The possession of these anterior muscles strongly suggest the fish actively vocalises at some stage of its life cycle. The sealed swimbladder, sedentary lifestyle and nocturnal activity also imply the possibility of communication through means other than visual stimuli. In addition, anecdotal evidence from researchers has shown vibration from the swimbladder of a captured dhufish during an acoustic tag study (M.Mackie *pers. comm.*). Therefore, whilst attempts during the current study to obtain evidence of dhufish vocalisation were unsuccessful, this is considered to be due more to inadequate sampling rather than the species being non-vocal. Further research into the potential of using passive acoustic techniques to monitor dhufish stocks, is therefore required.

Bight redfish

Fish from the order Beryciformes, such as *C. gerradi*, are nocturnal, coastal species which show inter-specific differences in sound production (Cruz and Lombarte 2004). The Bight redfish preferred habitat of a light limited environment would suggest acoustic communication is utilised (Cruz and Lombarte 2004).

The swimbladder of the Bight redfish (*Centroberyx gerradi*) is a relatively large and specialised organ, which extends through the majority of the length of the abdominal cavity. Extracted otoliths have been found to be proportionately large in comparison with overall body size. Since there is a positive relationship between hearing sensitivity and large swimbladder with acoustical communication (Ladich and Popper 2000), it could be hypothesized that Bight redfish are soniferous fish. The x-rays (Figure 4.33) portray the shape of the swimbladder (Salgado and Vu, *pers. comm.* 2007).

During December 2006 DoFWA staff on the *RV Naturaliste* deployed a bottom mounted sea noise logger for four days adjacent to a rock pinnacle that was identified as having small numbers of Bight redfish. The logger was intended to capture any sounds that may emanate from Bight redfish. The noise logger collected 'clean' samples (immediately after deployment to immediately prior recovery) from 12:15 hours on 11-Dec-2006 to 09:00 hours on 15-Dec-2006. The logger collected signals of regular evening choruses, a few isolated fish calls and pygmy blue whales. An example of stacked power spectra for the second day of deployment is shown in Figure 4.34.

The evening fish choruses recorded are widespread, recorded almost everywhere in deep water where samples are taken, and are believed to be produced by small fishes of the deep scattering layer, probably myctophids. They occur immediately following dusk and either drop away in late evening, as here, or carry through at a low level through the night, have a small pre-dawn peak then disappear during daylight. The choruses are not believed to be associated with Bight redfish. A few isolated fish signals were recorded although these were sparse through the recording set. The signal type has been recorded before but is also not believed attributable to Bight redfish.

Pygmy blue whale calls, as shown on Figure 4.35 were recorded, primarily on the 12th December 2006. These calls were associated with a southerly pulse of whales known to pass around Cape Naturaliste in November and December each year.

Therefore, although biological and behavioural characteristics of Bight redfish suggest the species is soniferous, this was not confirmed during the current study. Nevertheless, samples to date have only been obtained during the non-spawning period. As individuals are most likely to vocalise during the spawning period (e.g. see previous discussion on mulloway), it will be of interest to conduct further passive acoustic sampling of Bight redfish at this time.

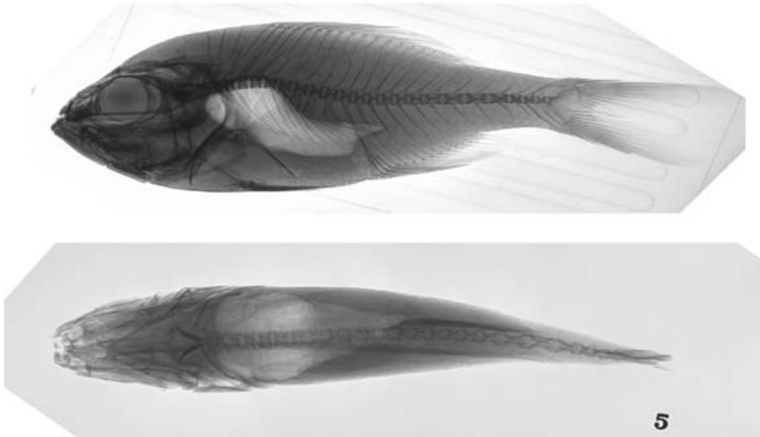

Figure 4.33. Lateral and dorsal *in situ* view of the swimbladder of a Bight redfish (image from Vu and Salgado, *pers. comm.*). Dark areas indicate radio-opaque structures, such as bones or otoliths, whereas lighter areas outline radiotranslucent structures such as air-filled cavities (Coombs and Popper 1981).

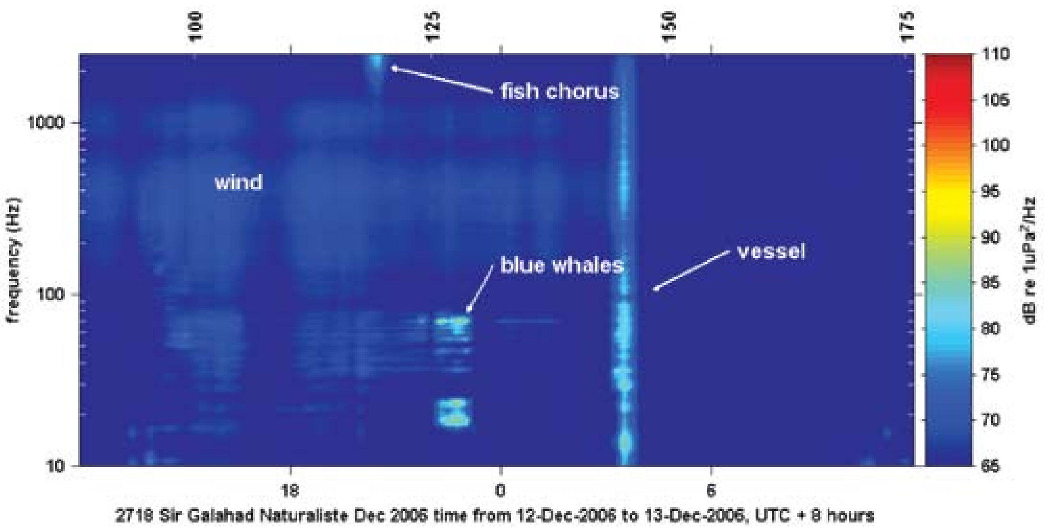

Figure 4.34. Stacked power spectra from sea noise logger deployed off Cape Naturaliste showing pygmy blue whales, fish, a passing vessel and wind noise.

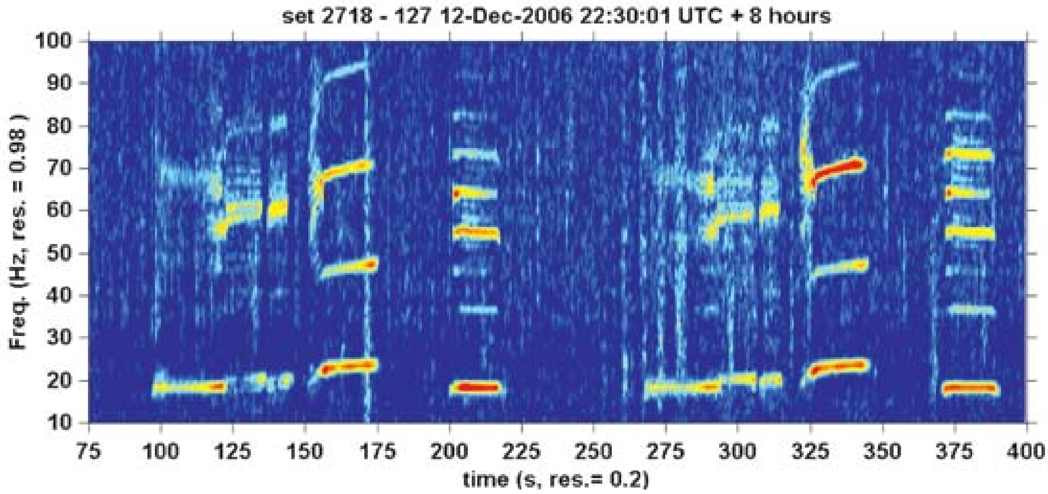

Figure 4.35. Spectrogram of two sets of a pygmy blue whale call recorded off Cape Naturaliste.

4.3.3 Conclusions

It has been possible to identify individual fish calls, originating from mulloway in Mosman Bay, and to separate these from biological and anthropogenic noise. However, further data processing is still required to reduce remaining noise levels, in particular those originating from passing vessels. Callers have been identified from characteristic waveforms, frequencies and call structures, though significant variation has been determined in an individual's call structure. Further analysis is required to determine cause and effect of this call variation. Discrimination has also been applied through variation in detected voltage amplitude facilitating the estimation of range from the hydrophone. Significant variations have been detected in the aggregation's vocal behaviour throughout the course of an evening calling cycle. Future ground truthing data are required to confirm that the use of different call types is employed by individual fish. More comprehensive datasets will reveal the extent and hopefully the cause of this behaviour.

Deployment of long term stationary sea-noise loggers, recording five of every ten minutes, continually throughout the spawning seasons provided comprehensive data on vocal behaviour of callers within the detectable range of the logger. Further analysis of these datasets should reveal any annual, lunar, diel and tidal aggregation formation, as well as mobility data of vocalising fish.

The discrimination of callers means that it may be possible to determine the number of vocalising fish within the range of the hydrophone by counting calls during periods of vocalisation when overlapping signals do not inhibit discrimination. Once calibrated, the acoustic hydrophone array data will also be able to estimate numbers of fish in the Mosman Bay during these periods from their contribution to the overall sound pressure levels.

Localisation of individual calls during periods of relatively sparse calling has been conducted in the Coombe region of Mosman Bay. Individuals have been detected as relatively stationary to within a few metres while vocalising, however, issues remain in the processing of acquired acoustic data affecting accuracy of source positions. Signals have also been detected where relative voltage amplitudes suggest a different location from localisation programs. Analysis is required to confirm whether localisation or sound pressure level assumptions are correct.

Verification of the origins of signals detected in the Swan River remains an issue. Turbidity and nocturnal behaviour inhibit visual confirmation of signal sources as that of vocalising mulloway. Future plans to correlate calls are: recording signals produced by captive mulloway to compare waveforms with signals recorded in the river; underwater video to confirm 'nesting' behaviour of mulloway to compare with vocalisations at a known location. Data acquired from a hydrophone array will also confirm calling strength of individual fish and density packing of the aggregation as a whole.

Passive acoustic data collected from vocalising mulloway in Mosman Bay provide significant information on fine scale (minute, hourly and daily cycles) to broad scale (lunar and seasonal cycles) movement and activity patterns during the spawning months. Once analysis is complete this facilitates a simple, cheap and effective means of monitoring the mulloway spawning population for any variations caused by anthropogenic, environmental or biological impacts. It also provides opportunity to determine preferred habitat and spawning sites for mulloway within the West Coast Bio-region. Longer term monitoring of the Mosman Bay spawning site will also provide information relevant to the management of mulloway and the Swan River ecosystem.

Passive acoustic techniques may also provide important information on the behaviour of species whose biological and behavioural characteristics are not conducive to monitoring via active acoustic or other techniques. In particular, it is considered that there is potential to gather further information about dhufish activity via passive acoustics, with the possibility of developing a low cost, long term monitoring program of populations at key locations.

For the efficient use of resources, confirmation of soniferous behaviour by species thought to be vocal is more readily attained during periods when fish are most likely to be communicating (such as during the spawning season). Replicated surveys, or deployment of long term sea noise loggers at known spawning locations verified with biological sampling should provide substantial evidence of possible vocal behaviour. If confirmed, the initial deployment alone could offer information on the timing of spawning by Bight redfish and the number of participating individuals. In such an open environment, however, ground truthing of recorded signals as originating from Bight redfish is paramount.

Recordings from the December 2006 DoFWA Cape Naturaliste survey have displayed the opportunity to acquire significant acoustic data from additional marine life in conjunction with fisheries surveys. The long-term deployment of acoustic loggers in locations adjacent to whale migratory paths will offer considerable information pertinent to research other than the immediate study.

4.4 Underwater Video

Paul Lewis and Michael Mackie

4.4.1 Introduction

Visual observations provide a wealth of information that greatly enhance the ability to study animals and the environment they live in. The difficulties associated with observing animals in the marine environment has meant that underwater research has suffered in the past from an inability to properly observe aquatic species in their natural habitat. It is not surprising therefore, that improved video technology has gone hand in hand with an increase in the number of scientific studies that utilise it. Underwater video provides a permanent record of the observations and allows environments beyond the limits of SCUBA divers to be investigated. This chapter reviews the development of underwater video, the types of systems that are available, and their application to scientific research. Particular attention is focussed on the use of underwater video in studying and monitoring fish species that aggregate to spawn.

4.4.2 History of Underwater Video Equipment

The first use of underwater video footage in fisheries science can be traced back to observations of seafloor habitats during the early 1950s (Barnes 1952). Since then a series of advances in technology have contributed to the increased use of underwater video as a research tool. The advent of SCUBA diving in the 1950s revolutionised the study of shallow water environments by extending the duration and depth at which observations could be made. This was followed by the development of vertical helical scan (VHS) during the 1970s, which made video cameras freely available and allowed scientists to utilise them as a permanent record of observations for further analyses. Further advances in technology during the 1980s led to increased availability of video and a substantial increase in the number of studies that used it as a sampling tool (Harvey and Mladenov 2001). These studies predominantly used underwater video for monitoring the behaviour of fish and invertebrates, for examining fishing equipment, and for surveys of epibenthic flora and fauna. Since then advances in closed circuit television (CCTV) technology have allowed remotely operated systems to record footage in waters beyond depth limits of SCUBA. Studies have surveyed benthic habitats down to 1150 m below sealevel **(**Lauth *et al*. 2004**),** and have used AUDOS freefall vehicles fitted with cameras to record footage of benthic fishes at 4800 m (Armstrong *et al.* 1992). The ongoing miniaturisation of both handheld video and CCTV has increased the range of uses for video as a research tool. Smaller size has allowed the attachment of video "crittercams" to large marine animals such as whales, seals, sharks and turtles giving insights into the behaviour of these species. The smaller size also allows cameras to be fitted to smaller operating equipment that can be used from smaller vessels.

The progression towards digital video technology and advances in computing power has changed the way footage is stored and enabled the analysis of digital footage without loss in quality. This digitalisation has contributed to the development of stereoscopic video systems that can be analysed by specialised computer software to give measurement data from the synchronised footage. Prior to this the placement of reference objects such as a grid or cube of known dimensions in the field of view or alternately the use of scaling lasers consisting of parallel beams to give a scale had been utilised to estimate measurements from video footage. Other factors, including increasingly stringent safety regulations and costs of SCUBA diving, have contributed to the greater use of remote and CCTV systems in marine research.

Video technology is still evolving and there are marked differences between the types of handheld video cameras currently available - from miniDV, DVD or hard disk, 600 kbyte to three megapixel charged coupling device (CCD), single or 3 CCD, continuous to progressive scan, and night shot to super nightshotplus being just some of the options available. These advances result in better quality footage that enable more information which, ultimately will exceed that achievable by divers collecting data in situ (Heyward and Rees 2001). The restrictions are price and storage media. Similarly, there are distinct differences in film quality obtained from basic live feed video systems and of the more advanced setups that include other options such as ability to operate in almost no light (0.0001Lux), moveable cameras, multiple cameras, optic fibres, controllable lighting, depth, temperature and position indicators.

4.4.3 Diver Operated Underwater Video Systems

Video equipment in this category usually consists of video cameras inside commercially available housings with full external controls. This equipment is relatively easy to use and obtain, although cost of the cameras and housings varies considerably depending upon the specifications. Standard camera housings are restricted to diving depths of 40 m or less and the footage quality is influenced by the experience and capabilities of the diver operating it. The use of video on diver underwater visual census (UVC) surveys provides a record of the survey that can be examined in detail at a later stage by experienced personnel. There has been some use of diver held stereo-video setups with full-face mask and microphone recording commentary to tape to get details of the survey. Stereo-video footage also enables accurate measurement of both fish size and transect width, greatly enhancing the population information provided by the survey (Harvey *et al.* 2002).

4.4.4 Remote Underwater Video Systems

Equipment in this category consists of video cameras in custom made housings, with little or no external controls, that are used in a range of circumstances where it is not possible or desirable to use divers. Typically, these units are used in baited or unbaited benthic frames or floated systems, in either single- or stereo-video configurations (see Chapter 2.10. for details). Single-video units are considerably cheaper, smaller and easier to deploy. During the current study they have been used extensively to describe benthic habitat, to search for and identify fish species, to describe fish behaviours and colouration, and to obtain visual imagery for dissemination to target audiences. The floating system is particularly easy to transport and use off small recreational vessels (< 6 m) without winch assistance. This system can also be set to record at any height above the seabed, thus making it ideal for visualising mid-water fish schools. As the floating system is not held rigid it can be both adversely (e.g. unstable picture) and favourably (e.g. greater field of view) affected by water movement. Measurements of objects (e.g. fish) can also be made with single-video units by using two or more laser lights to project a 'scaling beam' of known width (Colin *et al.* 2003). Despite the fact that estimates by lasers of fish that are orientated at an angle to the camera will be less accurate, the considerable advantage of portability with single-video units makes lasers an attractive option that is currently being investigated by the DoFWA.

To date, the most accurate means of measuring objects or distances underwater is with the use of stereo-video configurations (Harvey and Shortis 1996), thus enabling greater statistical power in detecting changes in mean length of a group of fish (Harvey *et al.* 2002). Stereo-video is therefore becoming more widely used in fisheries and ecological research, and has recently been adopted for use in monitoring of fish communities by the DoFWA. However, stereo-video units are more expensive and more cumbersome to use than single camera systems (a floating unit is more useable off smaller vessels but can be adversely affected by currents, and requires the use of progressive scan technology). Furthermore, stereo-video also requires specialised analytical and calibration software and hardware, as well as considerably more pre-and post-data collection calibration and analysis.

A further refinement on the stereo video system is the perspective-based stereo system (Dubrack 2006). This is less sensitive to minor changes in camera positions, is relatively easy to calculate sizes and, when used from above, may obtain more accurate size data than horizontal setups as it allows for the swimming motion of individuals.

The experience gained during the current study has shown that remote video systems can provide visual imagery of considerable worth to scientists. However, when this imagery is used for collection of specific information such as species diversity and fish numbers it can be misleading, being affected by a variety of factors including camera orientation, predator presence, water clarity and current strength. It is not clear that sufficient focus has been given to the impacts of these factors on the results of many studies reported in the literature.

4.4.5 Live-viewing Underwater Video Systems

Underwater live-viewing video or CCTV systems have been developed relatively recently, and use security cameras in waterproof housings and specialised underwater connectors and cables to transmit live images to the surface. These systems range from the basic units with only a single power and video line to reinforced cables with 4 or 5 power and optic fibre cables plus other options such as controllable lights, acoustic position indicating beacon and depth/temperature indicators. Live-viewing video has a range of uses including towed or drifted benthic surveys, positioning of equipment and monitoring experiments. These systems have the advantage of giving instant results and thereby allow for initial analysis or decisions to be made whilst the survey or equipment is in progress. They avoid problems associated with diver-operated equipment and reduce the occurrence of 'failed deployments' that can occur with remote video units. The capabilities of the more expensive systems extend to fully movable and focusing cameras, controllable lighting systems, position-indicating equipment and, in the case of Remotely Operated Vehicles, thrusters to manoeuvre the unit. However, live-viewing systems are more expensive and prone to malfunction than remote systems, are bulky and therefore not suitable for use off small vessels, require additional electronics and operator skills, can be greatly influenced by surface conditions, and typically provide an inferior quality recording and adversely influence fish behaviour more than remote systems.

The live-viewing system used during the current study whilst onboard the *RV Naturaliste* – essentially a heavy streamlined weight fitted with cameras that was lowered by winch (see Chapter 2.10) – reduced any affects of surface conditions and allowed quick alterations to height to steer over structures or through schools. Because of its weight the system sat almost vertically below the stern of the vessel, thereby enabling the camera location to be known without the use of expensive positioning equipment. Remote underwater cameras in stereo configuration can also be attached to obtain additional data. The live-viewing system was useful for habitat surveys and to verify species compositions of schools viewed on the echo sounder, particularly in circumstances where other systems were less likely to be successful. For instance, if the school was small, located in deeper water and a distance off the bottom, and current flow was strong such that it would be difficult to properly position the remote system, then it was usually more productive to deploy the live-viewing system, even if multiple passes were needed to properly pass through the school. However, in many situations, particularly if the school was mobile (e.g. snapper) or the fish were dispersed/cryptic (e.g. dhufish), the towed system was less useful than the baited remote underwater system.

4.4.6 Ancillary Equipment

Light sources for operation at night are available to be used in conjunction with the above video equipment. These can be independent or in the case of the advanced live-viewing systems also controlled from the surface through connections to the main cable. The use of artificial light at night can have the advantage of defining the survey area, in the case of a video survey, but can also alter the behaviour of fish to the camera. The ability of many digital video cameras to detect infrared light allows it to be used at night without affecting the behaviour of the fish as infrared is outside the visible spectrum of most species. However, infrared light is absorbed quickly in water and the range of even a powerful light source is low.

GPS overlay systems are routinely used in conjunction with live-viewing systems to permanently record the ships location onto the footage. However, in order to obtain an accurate position of the camera unit an acoustic position indicating beacon is typically required.

A depth sensor may also be important – for example when positioning a towed live feed system in the water column to pass through a school of fish lying mid-water. A cheap solution for this is to secure an analog SCUBA diving depth gauge to a pole within the field of view of the camera such that the needle can be seen (even if the actual depth cannot). Although these depth gauges are typically not rated below 80 m they will in fact go beyond that depth.

4.4.7 Application of Underwater Video Systems

Biodiversity studies

All three types of video have been used for biodiversity studies. Handheld video cameras are regularly used with SCUBA underwater visual census (UVC) surveys to reduce some of the bias of diver experience, producing a permanent record of the survey that enables more accurate fish identification and counting of all individuals (Parker *et al*. 1994). Stereo-video allows the transect width to be defined, lengths to be estimated and positive identification made of most fish encountered. However, comparison of results by Watson *et al.* (2005) showed that the baited remote video required fewer replicates, particularly in low relief situations, to detect a 25 percent change in mean total number of individuals (possibly due to diver avoidance). It also recorded the rarer, larger, predatory fish that appeared to avoid SCUBA in areas where spearfishing was likely to occur. Similarly, alterations in fish behaviour in response to diver presence have been documented for red emperor and pink snapper, leading to both under- and over-estimates of numbers by divers (Brown and Cappo 2001).

The use of remotely operated underwater videos in either baited (BUV or BRUVs) or unbaited frames for surveys of fish diversity and abundance has numerous advantages over diver UVC surveys. These include standardisation of methods, and removal of the effects of diver experience and fatigue, and diver avoidance or attraction by certain species (Willis and Babcock 2000). As the results of Watson *et al.* (2005) show, BRUVs also reduce field time and personnel, and therefore field costs, making the technique more efficient than UVC for repetitive studies. However, stereo BRUV systems and associated analysis and calibration software are expensive to purchase, and analysis of data is time consuming. In addition, there is a considerable amount of time involved in the analysis of footage particularly for the acquisition of length data, although digital video and various software have been developed to speed up the analysis and backing up processes. Robson *et al*. (2001) have investigated the possibilities of developing semi-automated image analysis and emphasise the need for high image quality to allow such analyses. Previous diversity studies have reduced the analysis time by only processing the first 10-30 minutes of the BRUV drops, but this is dependant upon the goals of the study, as the highest diversity is usually encountered in this initial period.

Baited video systems may also be used in combination with other survey methods to improve overall results. For instance, Cappo *et al*. (2004) recommended that BRUVs and prawn trawls in combination should be used for comprehensive assessment of fish biodiversity on soft sediment. The BRUVS detected the larger mobile species from a wider range of families (38 species only in BRUV) while the trawls caught sedentary cryptic species (52 species only in trawl). Comparison of the results showed the species accumulation curves were similar.

A number of studies have utilised live-viewing underwater video techniques for monitoring biodiversity, particularly beyond the limits of SCUBA. The Australian Institute of Marine Science (AIMS) has developed a dual camera ROV to deliver image quality at depths up to 100 m that are comparable to that of SCUBA surveys, and are currently developing a system that operates to much greater depths (Heyward and Rees 2001).

Population estimates and recruitment studies

There has also been considerable use of towed live-viewing systems and ROVs to conduct benthic fauna population surveys. A number of these studies have been conducted at night, using lights (Adams *et al.* 1995) or scaling lasers (Morrison and Carbines 2006) to define the transect width. These studies compared the results with traditional methods, with Adams *et al.* (1995) showing that video produced higher estimates of abundance and lower coefficients of variation than trawl, along with additional information on species-habitat associations. These authors concluded that video was better for environmental assessments of benthic species as it can detect smaller changes. Morrison and Carbines (2006) found that towed video detected snapper above five centimetres in size better than trawl due to evasion. Additionally, the towed video provided seafloor habitat mapping and images of sleeping snapper. Spencer *et al.* (2005) used a simple towed live-viewing camera sled to estimate flat fish densities on sand, providing similar estimates to divers and better results than fish trawl surveys. These authors noted that the limits and costs of diving make the towed sled's ability to sample larger areas and greater depths from small boats a distinct advantage.

Towed video surveys are not restricted to live-viewing systems, with Lauth *et al.* (2004) using a remote video on a towed 500 kg sled in depths from 450-1150 m. This technique is suited to benthic, sedentary species that are ubiquitous on flat featureless sedimentary floor.

Due to difficulties in estimating the area over which fish are attracted to BRUV systems, this method generally provides a relative index of abundance, rather than an absolute estimate. Ellis and DeMartini (1995) used baited camera surveys as a recruitment index for snapper and compared results with a traditional longline set. The video data showed less variation and greater diversity. Thus, it was concluded that if samples were not needed, video is ideal for spatial and temporal indices of abundance, as well as providing important information on habitat-species associations. However, Morrison and Carbines (2006) showed that BRUVs did not detect small snapper, and concluded they were not attracted to the bait or were avoiding the larger individuals that were.

Habitat description

All three types of video systems have been used extensively to conduct benthic surveys for the description of habitat and the production of habitat maps. The towed video equipment or ROVs required for detailed habitat mapping are expensive as there must be a correction for the camera position in relation to the ships GPS position, thus requiring an acoustic position indicating beacon at the camera. The live-viewing footage must also be sent over many metres of cable (Pitcher *et al.* 2001). Mapping of benthic habitats has often used a combination of methods. In other less detailed surveys a combination of diver operated video tows (manta tow), remote camera drops and SCUBA surveys have been used to map broad habitat types, often in conjunction with acoustic and aerial photographic surveys (Kendrick *et al.* 2001). In addition, video observations are being used to assess the environmental impact of salmon farms (Crawford *et al.* 2001).

Ground-truthing of acoustic studies

Towed live-viewing and fixed point remote camera drops have been used in conjunction with acoustic surveys to ground truth acoustic information. The need to identify which species and habitat type are being surveyed is an important consideration of an acoustic survey, and it is recommended that a number of methods including remote video be employed (McClatchie *et al.* 2000). To achieve this, deepwater studies have used manned submersibles with video and verbal observations of species and habitat associations (Nasby-Lucas *et al.* 2002), while others have used expensive towed video systems that include a tracking beacon to indicate the position of the camera in relation to the vessel, and altimeter and depressor weights to negate the effects of surface conditions (Barker *et al.* 2001). Shallow water surveys have relied upon SCUBA observations or remote camera footage to ground truth the acoustic information (Cole *et al.* 1981, current study).

Acoustic data for each fish species can be further refined by developing an orientation based acoustic echo in an experimental situation. This requires the use of live-viewing video to monitor the orientation of individuals passing through the acoustic beam.

Behavioural studies

Behavioural observations of fish by SCUBA has been the principal use of diver operated video systems (e.g. Mackie 2006). The use of remotely operated live-viewing systems have allowed researchers to monitor fish behaviour around the clock from fixed cameras that relay the signal back to the research vessel or even laboratory. Further development of an autonomous freefall vehicle (AUDOS) fitted with time lapse cameras has observed the behaviour of fish to 5000 m (Armstrong *et al.* 1992).

Monitoring field studies

Live-viewing and remote video systems have been used to assess the efficiency of fishery sampling methods and monitor the progress of experiments. These include using remote cameras to monitor the performance of bycatch reduction device in trawl nets (P. Stephenson, DOFWA, *unpubl. data*), the efficiency of fish traps (Travers *et al.* 2006), and the survival of caged deepwater species after capture (Lloyd 2001). These systems have also been used to observe predation (Hindell and Jenkins 2001) and monitor fish interactions with nets of varying mesh size **(**Grant *et al.* 2004).

4.4.8 Use of Underwater Video in Studying Aggregating Species

There has been limited use of video to directly study spawning aggregations, with it mainly being used to document behaviours. For instance, Whaylen *et al.* (2003) used video to record the evening spawning events of the Nassau grouper and other species at spawning aggregations, but relied on diver visual surveys for abundance and behavioural estimates. One exception is Koenig *et al.* (2000), who used video from a ROV and manned submersible to record reef fish communities at an aggregation site in depths greater than SCUBA limits. These authors documented the absence of a gag (*Mycteroperca microlepis*) aggregation that had previously been recorded at the site, as well as a dramatic reduction in the abundance of aggregating scamp (*M. phenax*) to just a few individuals. However, it is important to note that fish abundance in aggregations can vary considerably over a small time frame, and the results of improperly timed surveys can be misleading (see Section 6.3). Sadovy *et al.* (2005) emphasised the repeatability of UVC surveys and suggested that wherever possible video should be used as an independent means of validating the accuracy of the UVC results.

In their manual for the study and conservation of reef fish spawning aggregations, Colin *et al.* (2003) suggested that the underwater video camera is the single most useful tool for documenting aggregations, including the number of species and individual fish present, and their behaviour. The methods recommended for documenting spawning aggregations include video as a permanent record of the size and structure of the aggregation. Colin *et al.* (2003) emphasised the use of survey methods, which are "repeatable with precision" for future comparable monitoring. As a possible method they suggest a remote eye in the sky approach whereby a remote or live feed camera is suspended above the aggregation area so as to view a large portion of the aggregation, to sample the aggregation at various times of the day and to address the issue of fish avoidance associated with other survey methods. This system also has advantages if setup as a dual camera perspective system for the measuring of individuals, as discussed by Dunbrack (2006). This perspective based dual camera setup allows more individuals to be accurately measured because the orientation of fish relative to the camera and swimming motion are negated. This setup also appears to be less sensitive to any minor changes in the positioning of the cameras compared to stereo-video systems, which need to be regularly calibrated to ensure that knocks during deployment do not affect the accuracy of fish measurements.

During the current study remote underwater and live-viewing video systems were used to:

- Assess fish diversity and abundance at potential aggregation sites using BRUVS.

To assess areas suspected to hold fish aggregations we have predominantly deployed BRUVs to determine species presence and individual abundances in an area. This method brings the fish to the camera and usually gives a better idea of fish communities present at a given location than conventional methods, such as line fishing or fish trapping (Table 4.6.). It also gave better fish abundance results than the towed live feed surveys, which can miss some fish species, presumably through avoidance. Additionally, we have used the remote housings in the floated setup to observe the composition and behaviour of midwater schools at the Rottnest Island aggregation sites.

- Search for fish aggregations with towed live-viewing surveys of potential aggregation sites

We have surveyed numerous areas of good habitat and/or catches, given to us by fishers, using the towed video system. These surveys enable the habitat to be properly described and to quickly determine the presence and identity of species that may be present in significant numbers. However, it was often the case that the towed system would not reliably sample cryptic species such as dhufish.

- Ground-truthing acoustic surveys

Acoustic surveys of aggregations are of limited use unless the species composition is known. To achieve this we have used towed or drifted live-feed video, and/or floated or benthic BRUV systems to ground-truth the acoustic data. This has shown that aggregations on the wrecks west of Rottnest Island vary in species composition depending on the time of year. For instance, skippy and/or snapper may dominate during spring whereas Samson fish are the main or only species present later in spring and summer. The video imagery is also important for determining whether aggregations of different species are spatially discrete or mixed, spread out or compact. It is also useful for determining the acoustic signatures of individual species to help with subsequent surveys. Similarly, aggregations over isolated reefs that were initially thought to be mainly Bight redfish, based on fisher information and line fishing, were instead shown by towed video to consist of a variety of species that were numerically dominant to Bight redfish.

- Monitor experiments

During the short-term post-release survival study of Samson fish (Chapter 5) the live-viewing video system was used to monitor the behaviour of line caught Samson fish being held in a recovery enclosure. The camera was suspended in the centre of the enclosure and could be raised or lowered so each individually tagged fish could be monitored. The live-viewing video allowed hourly observations on the health and colouration of each individual to be made and recorded.

Table 4.6. Comparison of dhufish and snapper numbers obtained by different sampling methods.

Sample #		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Snapper	BRUV	1	4	1	-	0	0	0	0	0	-	-	-	-	-	0	3	3	3	0
	Tow Vid	-	-	-	0	-	-	-	-	-	0	0	6	8	6	0	-	-	-	-
	Fishing	1	0	0	0	0	0	0	0	0	2	1	9	16	1	0	2	1	0	1
Dhufish	BRUV	4	0	1	-	-	1	3	6	0	-	-	-	-	-	6	0	0	4	3
	Tow Vid	-	-	-	0	0	-	-	-	-	0	0	10	15	0	1	-	-	-	-
	Fishing	0	0	0	1	1	0	0	0	1	0	0	1	1	0	8	0	0	4	4

4.4.9 Conclusion

Underwater video systems are becoming increasingly used as a low impact, repeatable sampling method that provides a permanent record of marine communities and their habitat. Their advantages over other methods and the range of applications in which they can be used are increasing as technology improves, to the point where they have become a fundamental component of marine research, often best in combination with other techniques. In particular, baited underwater systems have the broadest range of applications for studies of fish species, whether they be cryptic or common, benthic or pelagic, although uncertainties over sampling area and estimates of parameters such as species diversity and fish numbers are key issues to address, as are the associated problems with data storage and analyses. Nevertheless, the advantages are many, and the crucial role of visual imagery in conveying important messages to stakeholders and the general public should not be underestimated.

4.5 Other Techniques

Michael Mackie, Jason How (Edith Cowan University) and Paul Lewis

4.5.1 Acoustic Tags

Surgical trials on cultured species

Most of the fish held in aquaria survived surgical procedures required for implantation of acoustic transmitters. One pink snapper also survived well after surgery and was subsequently used for an external tagging experiment. The tarwhine died after 78 days and two other pink snapper died after 15 and 62 days. Post mortems on the dead fish found that the pink snapper that died after 15 days had an infection (skin was a red colour and swim bladder was very bloated). Note that the body cavity was full of fat, as is common in cultured fish (S. Kolkovski, DoFWA, *pers. comm.*). In contrast, the snapper that died after 62 days may have starved because the intestine was inadvertently stitched during surgery and the fish had no fat reserves. There was no obvious cause for the death for the tarwhine after 78 days. The wound in the tarwhine showed good repair and was completely covered with a new layer of scales 40 days post surgery.

Field trials on dhufish

Surgical methods developed using the cultured fish did not translate successfully to wild caught dhufish. Field surgery was attempted on nine dhufish. Three of these were in poor condition after capture and handling, and were not deemed well enough for release into the holding cage after surgery. Of the five fish that were implanted with dummy tags, two survived surgery and were released from the cage after either two or four days. The other three dhufish died with no obvious explanation and despite showing good initial recovery following surgery. Surgery on the final and smallest fish (31 cm TL) was aborted due to the stitches pulling through the flesh. Trials were subsequently made on four additional dhufish to test various stages of the surgical process. To determine if catch mortality was responsible for some of the deaths, two fish were held on board for 6 and 18 minutes respectively, before being released back into the cage for 4 days and four hours respectively. Both fish are still alive, surviving caging, cage retrieval and transportation to DoFWA tanks at Hillarys. To determine the effects of the anaesthesia one fish was held on board for 6 minutes before being anaesthetised and placed in a holding tank for recovery. No surgery was performed and this fish was released into a cage. However, the fish was subsequently stolen from the cage. One dhufish was caught and returned to a cage after 17 minutes on board. The cage was then retrieved two days later to perform surgery on the fish. This was done to reduce any compounding stress effects of capture and surgery on the same day. The fish then underwent the same surgical procedure as outlined above and showed good initial recovery and swimming motion. However, this fish was found dead four days after surgery.

It is possible that the high stress levels from capture, combined with surgery and recovery in a relatively exposed cage, may cause a number of sub-lethal stresses that in combination are deadly due to the poor capacity of dhufish to transport oxygen in their blood (Stephens *et al.* 2002). Low survivorship requires further trials on captive fish to establish a more suitable protocol. The use of glue to close the wound after surgery (see below) is seen as an important step towards improving survival of acoustically tagged dhufish.

Other techniques of attachment or insertion

Attachment of the tag to the gill plate of pink snapper was not successful as it was shed after several days. Attachment through the dorsal musculature had longer retention times (126 days) but resulted in inflammation. The tag ingested by the dhufish was expelled after eleven days but had no visible effect on the behaviour of the fish and is a useful method for short-term studies.

External attachment was also used for the field trials of dhufish movement after the successful trials on cultured pink snapper (see below). This procedure enabled the fish to be returned to the water quickly without subjecting it to anaesthesia or more invasive surgery. However, both field and tank experiments show that this procedure may require modification to reduce tearing around the insertion point.

Alternative wound closure methods

Of the three methods trialled for closing the wound after surgery, glue was the most successful, reducing the surgery time and post-surgery survival (Table 4.7). It also showed similar, if not better wound recovery than the sutured wounds.

Range testing of acoustic equipment

Testing under two differing swell regimes showed that there were differences in close proximity detection rates. Under calmer conditions, there was no discernable reduction in the number of receptions up to 90 m (Figure 4.36.), possibly due to decreased amounts of suspended matter interfering with the signal. However, for both calm and higher swell conditions the maximum detection distance was 250 - 300 m. Using a linear range of 250 m this would indicate that the VR2 receivers each had a detection area of about 0.196 km^2.

Movement patterns of acoustically tagged dhufish

Acoustically tagged dhufish 1 (515 mm TL female) was recorded 31 times for a period of 1.5 hrs after release. It was not recorded again for the remainder of the study. No conclusions can be made from these data.

Dhufish 2 (410 mm TL female) was recorded 14225 times from the date of release until the 18th September 2006 (129 days). During this period, dhufish 2 was present within the detection area of the array for 47 days. This fish was only recorded by the receiver at the location in which it was initially captured. It moved out of the detection area of this receiver around three hours after release and returned 20 days later (Figure 4.37), and then remained in the detection area for 46 days straight. Recordings for this fish stopped ten days before the array was initially retrieved and despite a larger array being deployed eight days later it was not detected again. However, video evidence from a baited camera deployed 51 days after the last recording showed that dhufish 1 was in the same location that it had previously been detected in but it had lost its acoustic tag.

There were patterns in the number of receptions recorded for dhufish 2 when it was within the detection area of the array. During daylight hours (0600 to 1800), there were significantly more receptions than during the night ($p < 0.001$; Figure 4.38). However there wasn't a corresponding pattern in the time of the day that the fish was either in the array or not being detected by it. This indicates that the fish was moving closer to the receiver during the day and moving to the outer limits of the arrays detection area at night – possibly as a result of foraging behaviour since dhufish are generally considered to be more active in this behaviour at night (Shand *et al*. 2001, fisher interviews).

In summary, the data for dhufish 2 is of interest because it suggests a movement away from the area in response to capture and release. It also shows a return by the fish to the capture location and subsequent limited movement for at least 46 days, and it shows differential activity patterns that may be due to nocturnal foraging away from shelter.

Finally, this study highlights the valuable and unique data that may be obtained about movement and activity patterns of dhufish and other species using acoustic tags. Although barotrauma related injuries will always pose a problem, particularly with species such as dhufish and mulloway, the expertise obtained during this study will be important for undertaking further studies of fish movement and behaviour in the future.

Table 4.7. Details of alternative wound closure methods as trialled on culture reared mulloway.

Fish No	Closure Method	Total Length (cm)	Surgery Time (min)	Day Survived
1	Glue	41	2	85+
2	Glue	41	2	85+
3	Non Absorbable	42	6	40
4	Non Absorbable	43	4	104+
5	Absorbable	44	4:46	11
6	Absorbable	49	5:16	28

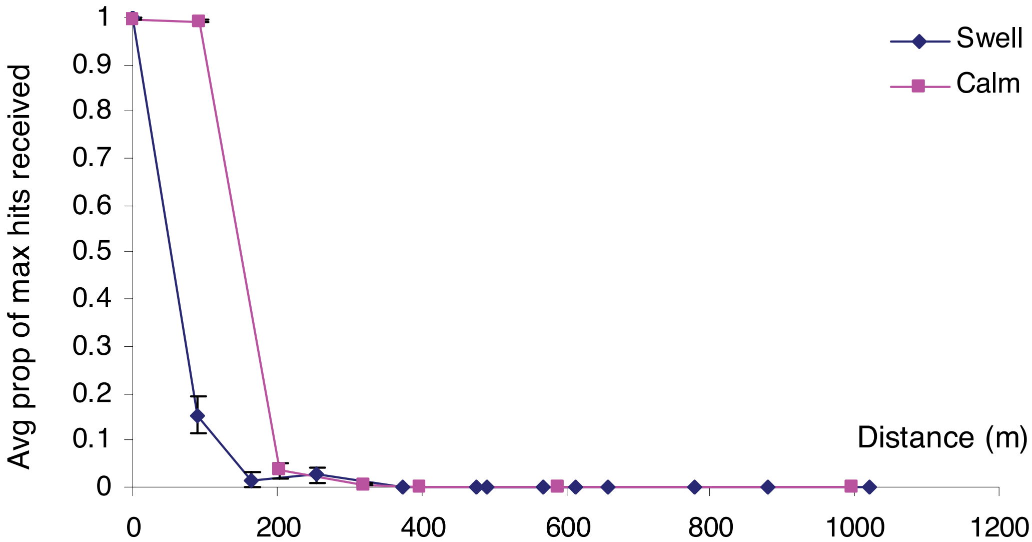

Figure 4.36. Average proportion of the maximum hits received for the two range tests conducted under high swell and calm conditions. (±SE bars).

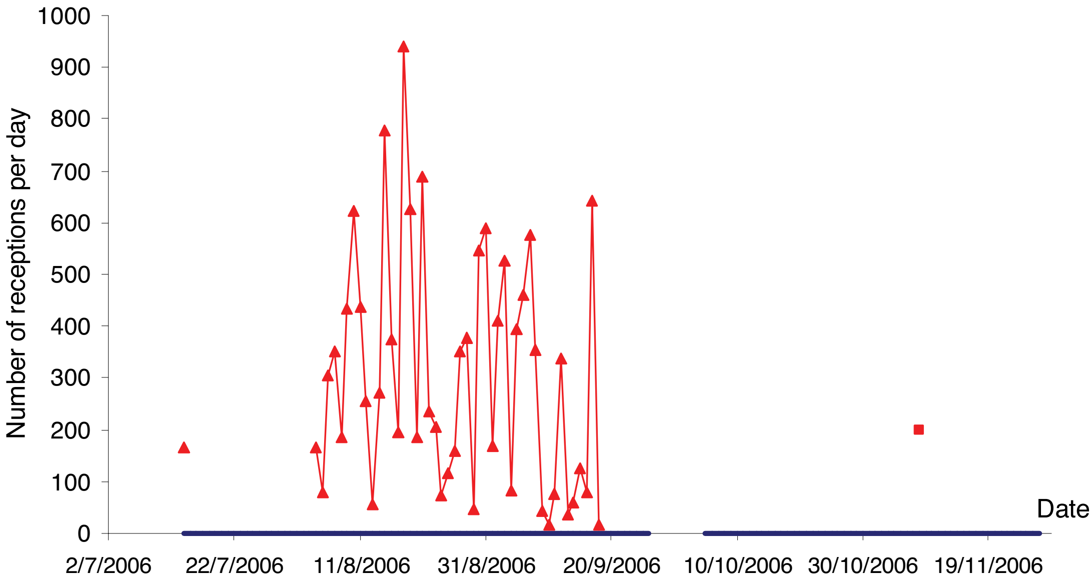

Figure 4.37. Acoustic recordings within the study area (triangles) and subsequent video recording (square) of acoustically tagged dhufish 2.

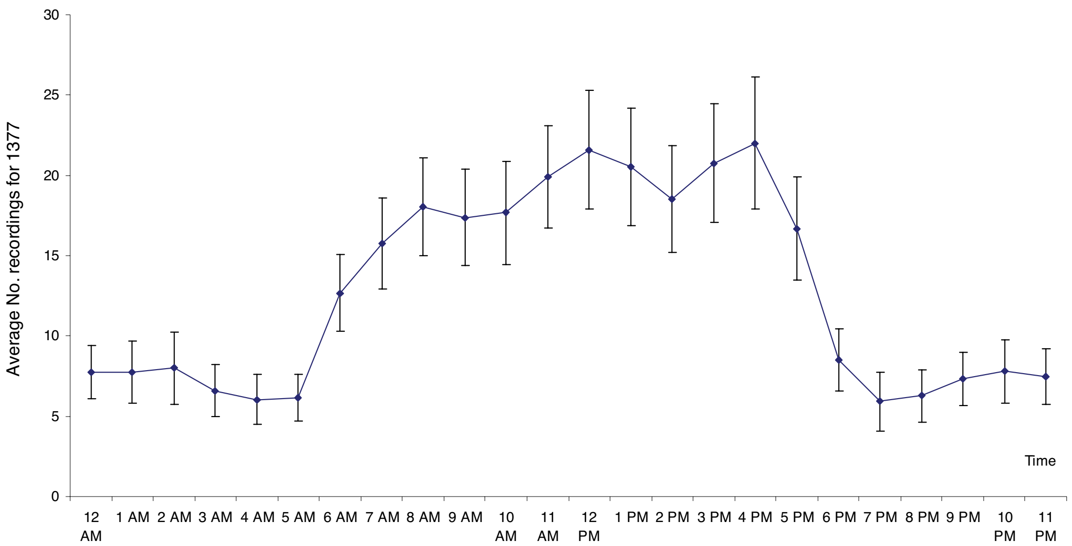

Figure 4.38. Average number of recordings per hour (±SE) for all days when dhufish 2 was detected within the array (*n* = 47).

4.5.2 Conventional Tags

Attaching conventional (e.g. dart, t-bar anchor) tags to fish in order to gain information about population dynamics including rates of movement and growth has been an integral part of scientific research for over a century. More recently, fish tagging has become popular among recreational fishers (Lenanton 1995). In the current study, it was intended to use dart tags to estimate numbers of Samson fish within aggregations west of Rottnest Island, mortality rates associated with the capture and release of these fish within the sports fishery for this species, and movement patterns of individuals to and from the aggregations.

Estimation of fish numbers was to be achieved using the Petersen mark-recapture method (see Krebs 1998 for details). The accuracy of this method depends on several assumptions, including random mixing of tagged fish and no recruitment, migration or tag/capture induced mortality between tagging and recapture. However, it was soon apparent from short-term recaptures during the initial Samson Science tagging event (summer 2004) that fish were not remaining within the aggregations very long, thereby violating the key assumption for this method that the population is 'closed'. As such, this method could not be used to estimate the number of aggregating Samson fish.

Similarly, estimates of sportsfishing-related mortality of Samson fish have not been achievable with sufficient confidence from tagging and recapture data. This is because the number of recaptures to date from the aggregations (*n* = 203, about 2% of tagged fish) is insufficient for detailed analyses (see Chapter 5). Nevertheless, despite the inability to achieve these project aims, the tag-recapture data has proven to be very useful in understanding general movement patterns of Samson fish to and from the aggregations - showing, for example, that individuals migrate large distances to attend the aggregations and that virtually all fish within these aggregations inhabit waters to the south of this area, with only limited participation by fish found in waters to the north. Furthermore, the tagging study provided an ideal opportunity to incorporate recreational anglers into the research project, with this component evolving into 'Samson Science' – a community-based research project that has been widely acclaimed as an excellent example of cooperative research between anglers and scientists (refer to Chapter 5 for more details).

The above discussion probably provides a good example of the utility of conventional tags in studying and monitoring aggregating species of fish. It is a relatively cheap technology that can be used in collaboration with stakeholder groups. However, the limitations and appropriateness of this methodology need to be properly assessed in each circumstance.

4.5.3 Catch and Catch Rate Data

Monitoring of catch and catch rate (fishery-dependent) data is essential for understanding the characteristics of a particular fishery, and for assessing the impacts of fishing pressure and the effectiveness of management strategies. With aggregating species, it may also be useful for identifying seasonal peaks in catches and catch rates that may be attributable to targeting aggregations, and in identifying potential aggregation sites. However, the usefulness of catch and catch rate data are largely dependent on the spatial and temporal scale at which it is collected. If too broad, as is the case with DoFWA data (e.g. Chapter 3), the usefulness of the data is greatly diminished. The introduction of daily logbooks in which data are recorded into 10 x 10 mile grids, along with implementation of a satellite vessel monitoring system, is expected to improve the usefulness of catch and catch rate data in future monitoring of finfish fisheries in WA.

Catch and catch rate data are also influenced by other factors. For instance, in fisheries where much of the annual catch is taken from aggregations, these data can exhibit hyperstability, meaning that catch rates no longer reflect stock abundance and remain relatively stable despite drastic declines in the overall number of fish in the stock. In severe cases, the aggregation can be decimated until catch rates suddenly plummet (Colin *et al.* 2003), and this is thought to have occurred with Nassau grouper (*Epinephelus striatus*) stocks in Cuban waters (Sadovy and Domeier 2005).

Increases in fishing efficiency due to introduction of GPS, faster vessels, improved fishing equipment and techniques, and greater access to fishing knowledge, must also be accounted for when analysing trends in fishery data. This can be done by standardising the data in some manner, such as done for Spanish mackerel catch rate data where a multiplication factor was used to allow for the increase in effective effort through time due to the introduction of GPS and other efficiencies (Mackie *et al*. 2003). In the case of aggregating species, these changes in fishing efficiency may have particular impact, because they can enable even novice fishers to easily locate known aggregations, to identify habitat that would otherwise not have initiated interest, to increase the number of fish taken whilst fishing, and to travel greater distances in order to maintain catch rates.

Other changes in fishing behaviour can also influence catch and catch rate data. This can be due to changes in target species due to market demands (Colin *et al*. 2003) or to species availability. For instance, commercial finfish fishers operating in the Cape Naturaliste area have historically focussed more on dhufish during summer months when they are aggregated in shallower waters for spawning, and will target Bight redfish during autumn for the same reasons (fisher interviews, M. Mackie, *pers. obs.*). Weather can also have a significant influence on catches and catch rates, by impacting the number of fishing days and the ability to fish effectively whilst on the fishing grounds. Although attempts can be made to account for weather in analyses, it is very difficult to determine how to do this, particularly with broad scale logbook data. In addition to the influence on fishing capacity, weather can also affect the feeding behaviour of fish. For instance, several fishers made note of the relationship between catchability of dhufish and changes in weather patterns (fisher interviews).

4.5.4 Daily Egg Production Method

The daily egg production method (DEPM) is a fishery-independent method of estimating spawning biomass that was originally developed for northern anchovy *Engraulis mordax*, and since applied to other species (Parker 1980, Alheit 1993). The DEPM requires information on spawning area, egg production (number of eggs before losses to mortality), the weight of adult fish, the proportion of females that spawn each day, sex ratios, and batch fecundity. The method has a number of drawbacks, including a requirement for considerable research resources. It is also critical that the timing of a DEPM survey coincides with the period of peak spawning, that the plankton samples are collected quantitatively and with sufficient proximity to detect concentrations of eggs within the spawning area, and that a large number of adult samples be obtained for biological analyses.

These drawbacks make the DEPM unsuitable for widely dispersed, oceanic spawning species such as scaly mackerel (*Sardinella lemuru*) and Spanish mackerel (*Scomberomorus commerson*) that occur along the WA coast, due to difficulties in defining the spawning area and because of variability in the timing of spawning and in population parameters such as spawning fraction (Gaughan 2000, Mackie *et al.* 2003). This is also likely to be the case with other aggregating species that typically spawn in open oceanic waters and for which there is insufficient understanding of reproductive biology and ecology. Nevertheless, the DEPM has been used with success on pink snapper in Australia, including at Shark Bay and Cockburn Sound (Jackson and Cheng 2001, Wakefield, 2006), where spawning occurs within discrete locations (embayments) and resources can be focussed sufficiently to gather the required biological data and undertake appropriate egg surveys. Given the difficulties to date in monitoring the Cockburn Sound aggregation with video and acoustic methods (although forward viewing multi-beam sonar is considered a possibility; see above), it is likely that the DEPM will remain the most viable means of monitoring pink snapper in this area. The biggest issue in this case is the gathering of sufficient biological samples without impacting this relatively small stock. Further, it is unlikely that the DEPM will be appropriate for pink snapper aggregating in more open oceanic waters because of difficulties in defining spawning areas.

4.5.5 Underwater Visual Census

Underwater Visual Census (UVC) is the most commonly used method for gathering data on aggregating species in tropical waters. The summary presented here has been extracted from Colin *et al.* (2003), Sadovy and Domeier (2005) and Sadovy *et al.* (2005), and these should be consulted for more detail on this method. This method is usually done by divers and thus generally confined to shallow waters less than thirty metres deep. Video is often used to supplement direct visual observations, that are typically based on strip or point transects. Although the use of divers complicates safety and logistical considerations, it does enable more thorough, accurate and diverse data to be obtained on both aggregating fish and the surrounding environment. Aside from estimates of fish abundance, these data include observations on courting and spawning behaviour, habitat use and other species present that can be very useful for management purposes.

It is important with UVC to have a preliminary understanding of the aggregation area including currents, depths and habitat so that surveys of the aggregation can be properly conducted.

Estimates of fish abundance are usually made by counting fish in the whole aggregation, if practical, or in part of it and then estimating total numbers from estimates of the area of the aggregation. Consideration needs to be made of the size, number, placement and deployment method of transects used for UVC. Potential sources of error that are common to other methods include multiple counting of individual fish, missed counts due to substrate complexity or visibility, and short term variability in fish numbers within the aggregation. A key disadvantage to dive-based censuses is the effect of diver presence on fish behaviour, between-diver differences in counts and observations, and limits imposed by light and diving conditions.

4.5.6 Other

Recently developed techniques suitable for monitoring fish populations include:

Dual-frequency Identification Sonar (DIDSON)

The DIDSON is a new technology that uses sound-distorting lenses to create video images (www.pcds.com.au). At high frequency, the system creates images from sound beams that can show the outline, shape and even fin detail of target fish. In addition, the integrated software can enable fish to be counted and measured automatically, and it is ideal for direct observations of fish behaviours in low visibility water or at night. The DIDSON has a limited range (40 and 12 metres at low and high frequency, respectively), is expensive, and the low resolution makes it difficult to distinguish species. It is currently being used by the Narrandera Fisheries Centre, NSW, to study migration patterns of freshwater species of fish (Baumgartner *et al*. 2006), and has been used in a variety of situations where video cameras will not work (Rose *et al*. 2005, Mueller 2006).

Ocean Acoustic Waveguide Remote Sensing (OAWRS; Makris et al. 2006)

This method enables continuous monitoring of large fish shoals within an area of thousands of square kilometres through the use of remote sensing technology involving ocean acoustic waveguide propagation. It has been used to describe minute-to-minute changes in the behaviour and abundance of fish in large shoals containing millions of fish (possibly Atlantic herring and other species) and covering tens of kilometres. For monitoring at this large scale the technique avoids problems associated with using relatively slow, highly localised line-transect acoustic methods. However, the spatial resolution (and probable cost) of this technique clearly limit its use along the WA coast, and there is still the need to validate the identity of species using video or some other method.

4.6 Conclusions

There are a variety of tools available for gathering information about fish. Some of the more widely used ones have been trialled and adapted during the current study, on a variety of species and in a variety of habitats. These trials and literature research have shown that each of these tools works well in some situations but not in others, and that a combination of tools may be required. For example, the visual image obtained by BRUVS provides a wealth of information on fish behaviour, species composition and habitat that is difficult to obtain by other means, particularly for wary and less densely populated species. However, the small field of view provided by BRUVS can lead to biases, and uncertainty about events happening in the area surrounding the camera. During the current study the main issues encountered with BRUVS were the underestimate of fish numbers derived from the ‘MaxN’ parameter, particularly when dealing with large schooling species such as pink snapper, and the uncertainty with sampling area due to vagaries of bait plume dispersion. Nevertheless, with the adaptations made to this system that enable BRUVS to be set at any height in the water column, and to be hand-hauled off small vessels, this technique is the single most useful tool for gathering a range of data, in a range of circumstances, on fish species and aquatic communities. In certain circumstances, such as when undertaking general habitat surveys or pinpointing aggregations in deep water and strong currents, a towed live-feed system may be more appropriate. Similarly, in other situations, such as when studying an aggregation in which the fish are spread across a broad area of the seabed or are mobile, a handheld video may provide better data. However, logistics, costs, and biases of these techniques place limits on their usefulness compared to BRUVS.

Acoustic techniques include those based on listening (passive) and those based on a picture derived from reflected wave emissions (active). The latter utilise technology used in widely available echo-sounders. Single-beam systems are relatively cheap, simple, and easy to deploy, and require limited technical knowledge for field operation. Hence they are more amenable to cost-effective monitoring programs. They enable a very useful 3-D appreciation of the aggregation from which a range of data including biomass estimates and aggregation dynamics can be obtained. The main drawback with this data is the critical need for a good model of target strength and, even with this, knowledge of the orientation of fish relative to the acoustic beam, and of the identity of species within the survey area. The last two requirements can usually be obtained using video techniques. The issue of target strength is difficult to resolve. Instead, it may more beneficial to focus on relative measures of biomass, such as aggregation volume. With the use of associated video and catch data to obtain information about packing density, fish size and species composition, it may then be possible to derive a reasonably accurate and reliable measure of biomass.

Multi-beam systems greatly improve the amount of data gathered during surveys, and are less affected by spatial dynamics of the aggregation during the survey period. They are therefore more suitable for monitoring species that form mobile aggregations than are single-beam systems. This is a significant issue to consider. Multi-beam systems are therefore better for detailed studies of group spawning behaviour and the affects of the environment on this and on general group behaviour. However, these benefits come at a significant cost in term of budget, time, logistics, convenience and technical requirements. As such multi-beam techniques are more suitable to longer-term, less frequent and larger scale monitoring programs. Like single-beam systems they are best used in combination with video techniques.

Passive acoustics is a comparatively new tool for monitoring sound producing species of fish. In particular, it holds good potential for monitoring mulloway aggregations within the Swan River but may also be applicable to species such as Bight redfish and WA dhufish. Nevertheless, whilst acoustics and video techniques provide the most scope for gathering information about fish species, other techniques are preferential in certain circumstances. For example, the daily egg production method has thus far proven to be the best method for monitoring pink snapper aggregations within Cockburn Sound.

In summary, effective monitoring of fish populations using fishery independent monitoring techniques requires an understanding of the fish and of the biases and limitations of each monitoring tool. Examples of the most appropriate methods to use for monitoring key aggregating species in particular habitats within the West Coast Bioregion are provided below.

Samson fish west of Rottnest Island: Single-beam acoustic system attached to the 7.5 m research vessel conducted in a grid or petal shaped manner, with repeat surveys over a four day time period in consultation with recreational anglers fishing the area. This should be combined with multiple deployment of housed-video camera systems adjusted to float at varying depths to confirm species composition and orientation of individual fish. Multi-beam acoustics is a better alternative if the larger vessel and appropriate equipment are available. In this case a towed live-feed video system may also be effective, and possibly provide better information about fish density and numbers.

Pink snapper in Cockburn Sound: This aggregation(s) is typically too mobile for single-beam, and the depths too shallow for multi-beam acoustics. Forward facing or side mounted multi-beam may be an option but has not been trialled to date and is expensive. Similarly, video methods are not suitable in the often turbid waters especially when the fish are large and present in a swirling, confusing mass as pink snapper usually are when aggregated. Ultimately, it is likely that the more conventional daily egg production method that has previously been used to estimate biomass of this species in Cockburn Sound and elsewhere, remains the best means of monitoring in this particular circumstance.

Mulloway in the Swan River: These fish appear to form a low density aggregation in murky river waters, are usually most active in dark light levels, and are usually located near the substrate. Neither active acoustics nor video are likely to provide anything but ancillary data in this circumstance. Instead, passive acoustic techniques offer a low cost and information rich means of monitoring this species.

Dhufish: For monitoring this species in its typical habitat and density, BRUVS are likely to provide the most useful and reliable data set on fish abundance, sex and size ratio, habitat and behaviours. A towed video system and/or active acoustics may be useful with large aggregations, although these are rarely encountered. Passive acoustics may be useful for this species, although further research is required into the vocalising capacity of this species.

Bight redfish: As per Samson fish. Preferably multi-beam although single-beam should provide reasonable data, combined with towed live feed (or floated) video.

The strategies listed above for gathering data on key species within the WCB require an understanding of the species, its habitat, and the capabilities of each technique. Typically, there is a requirement for preliminary research prior to commencement of proper monitoring and, for some species, none of the techniques described in this report may be appropriate.

5.0 Samson Fish Biology, Ecology and Fishery

Andrew Rowland, Michael Mackie, Howard Gill and Paul Lewis

5.1 Biology

Between January 2004 and February 2007 a total of 714 Samson fish from three regions of Western Australia were collected and processed for biological analyses (Figure 5.1). Fork length (FL) of fish collected ranged from 26 (1.2 g) to 1470 mm (47 kg). The majority of these fish were collected from spawning aggregations west of Rottnest Island (*n* = 317) and inshore waters in the Perth metropolitan area (*n* = 168). Other samples were sourced from throughout this species' range in WA, including 89 fish from the Geraldton region in the north and 129 fish from southern coastal waters. Small juvenile fish (< 100 mm FL, *n* = 22) were commonly associated with floating debris and jellyfish in offshore (> 20 km from the coast; 56%) and inshore (44%) waters.

5.1.1 Age, Growth and Mortality

Description of Samson fish sagittae

The sagittae of Samson fish are small and fragile. They have a long narrow pointed rostrum with a shorter pointed anti-rostrum and a straight ventral margin with a rounded posterior. The otolith is laterally compressed with a concave distal surface and the edges are generally smooth or have fine growth projections ventrally. A deep, prominent sulcus traverses the proximal surface longitudinally. A series of translucent and opaque zones are often distinguishable on the posterior section of the distal surface of whole dried otoliths when viewed under reflected light. These were validated as being laid down annually (see below). Although the first and second annuli were usually discernible, the total number were not in the whole otoliths of most fish, particularly larger specimens.

When viewed with transmitted light in cross section the sagittae of most adult fish also revealed a distinct series of narrow opaque and wide translucent zones. The distance between the first two opaque zones was typically wider than the distance between subsequent opaque zones, however, the first annulus was generally less distinct and often hard to distinguish.

Validation of otolith increment periodicity – calcein injection

One hundred and forty six Samson fish captured from the Rottnest Island spawning aggregations were injected with calcein solution and tagged with specific tags informing anglers to retain recaptured fish. Although five of these fish were recaptured by recreational fishers, only one fish was recovered for analysis. This specimen was a 940 mm FL male tagged and injected on the 2nd February 2006 and recaptured during the following summer on the 17th December, the time at liberty was 319 days. A calcein mark was observed on the sectioned sagittae of this fish between the two most recent opaque zones (Figure 5.2). Delineation of a translucent zone can be seen on the sectioned otolith soon after the time of calcein deposition. This translucent zone is then followed by a partly formed opaque zone at the otolith margin. The information obtained by this recapture revealed that a single annulus is formed during summer, as confirmed by marginal increment analysis (see below).

Validation of otolith increment periodicity - marginal increment analyses

Marginal increment analysis of sectioned Samson fish otoliths (Figure 5.3) demonstrated that

September through to March was the time of annulus formation, with otoliths in this category (opaque margin) most abundant between November and January. Those with category 2 margins (1-50% of previous translucent zone), present from January to October, were most abundant from March to July whilst category 3 (51-100% of previous translucent zone) were present from March to December and most abundant in August to October. Thus, the marginal increment categories demonstrate a logical progression throughout the year with each category peaking once for 3-5 months. A single opaque zone is therefore formed annually in the otoliths of Samson fish during spring/summer which becomes surrounded by a translucent zone during autumn. As the spawning of Samson fish occurs in summer (see below) the first opaque zone formed on the otoliths of 0+ Samson fish occurs towards the end of the first year of life.

Analyses of the precision between counts and the readability of otoliths

Fifty seven (12.7%) of the 450 sectioned otoliths were rejected as being unreadable at the completion of the first two reading (Table 5.1). Of the fish rejected for aging 83.9% were less than 1000 mm FL. The agreement between the initial two counts for the remaining 393 otoliths was 80.7%. Otoliths for which the age differed between readings were re-examined and, in all cases, except one, the third reading corresponded to one of the previous readings. Although the otoliths of Samson fish were not easy to read, with the males having lower readability than females, most otoliths, could be read with only 58 being unreadable (Table 5.1).

Age and growth analysis

Trends exhibited by reproductive variables (see section on Reproduction) demonstrated that the spawning period for Samson fish occurred in late spring/early summer peaking in November and continuing into January. The approximate mid-point of this period, i.e. 1st December, was therefore assigned as the birth date of this species.

The age distributions of female and male Samson fish aged from sectioned otoliths overlapped considerably (Figure 5.4). The oldest fish aged was a female at 29 years, with the oldest male being 28 years, 97% of fish aged were less than 20 years old and 68% were less than 10 years old. Female and male Samson fish are almost equally represented in fish greater than 20 years old contributing 55% and 45%, respectively.

The Likelihood ratio test demonstrated that the Schnute growth curve significantly improved ($P < 0.001$) the fit for the length at age data for female and male Samson fish compared to that obtained using the von Bertalanffy equation (Figure 5.5). The Schnute growth curve overcame deficiencies at the upper end of the age range for each sex (Figure 5.5a). The improvement of fit by using the Schnute curve is emphasised by the fact that the coefficient of determination increased from 0.906 to 0.929, and 0.930 to 0.943, for females and males respectively (Tables 5.2 and 5.3). It also resulted in a marked increase in the L_∞ for both females and males from 1279 to 1594 mm, and 1139 to 1210 mm, respectively. The Schnute growth equation also provided a more realistic estimate of asymptotic length as the largest female and male individuals encountered in this study had fork lengths of 1470 mm and 1280 mm, respectively.

The lengths derived for female and male Samson fish, using the Schnute growth equation, demonstrate that the growth of both sexes was rapid and similar during the first 5 years. However, even at this early age females are bigger, with estimated lengths at ages 2, 4 and 5 for females being 608, 800 and 867 mm, respectively, compared to 566, 767 and 834 mm for males. Growth slowed markedly in both sexes after this period, particularly in males as growth trajectories diverged with females becoming noticeably larger at age. Thus, by 10, 15 and 20 years of age, the predicted lengths for females were 1088, 1221 and 1311 mm, respectively, compared with 1035, 1124 and 1167 mm, respectively for males (Figure 5.5a). The maximum fork length and age recorded for female Samson fish was 1400 mm and 29 years, respectively, while, for males it was 1280 mm and 28 years, respectively. Female and male Samson fish both attained the minimum legal length for retention after capture (MLL) of 600 mm TL (equivalent to 533 mm FL) within the second year of life.

Length – weight relationships

The likelihood-ratio test demonstrated that the relationship between caudal fork length (FL, in mm) and whole weight (WW) for the two sexes were not significantly different ($p > 0.05$) (Figure 5.6). Therefore the data for males and females were combined giving a relationship between FL and WW of:

WW (kg) = 0.0001497 x $FL^{2.982}$ (mm) ($n = 264$, $R^2 = 0.99$),

The relationship between total length (TL) and WW is shown below. Only fish with a FL > 700 mm were used to develop this relationship and associated conversion table (Table 5.4) as the inclusion of smaller fish tended to underestimate the weight of fish typically caught in the sportfishery (i.e. 900 to 1300 mm FL, see Figure 5.7):

WW (kg) = 0.00000000498 x $TL^{3.09}$ (mm) ($n = 249$, $R^2 = 0.92$)

The relationship between TL and FL for Samson fish was:

TL = 1.09FL + 17.84 ($n = 443$, $R^2 = 0.998$)

Head length (HL and jaw length (JL) to FL relationships were investigated to determine whether these could be used to provide FL estimators for the head only samples collected in this study. The relationship between HL and FL of Samson fish was:

FL (mm) = 4.34HL (mm) – 52.45 ($n = 248$, $R^2 = 0.981$)

The relationship between JL and FL of Samson fish was:

FL (mm) = 10.22JL (mm) – 19.0 ($n = 248$, $R^2 = 0.957$)

The HL based equation was used for FL conversion for the head only samples as there was less variance with this measurement . Head length is also generally easier to measure and is less influenced by individual variation in the augmentation and shape of the jaw.

Length frequency distributions

Lengths of Samson fish tagged by recreational anglers and researchers at the Rottnest Island aggregations ($n = 6886$) during the summers of 2004/5 and 2005/6 ranged from 550 to 1600 mm FL, with a median length of 1070 mm FL (Figure 5.7a). The sex of 2596 of these fish was determined before release. Males ($n = 1150$) ranged in length from 605 to 1380 mm FL while females ($n = 1446$) ranged from 780 to 1520 mm FL (Figure 5.6b). Female fish dominated the larger size categories (Figure 5.7b) and had a median length of 1100 mm FL while males had a median of 1040 mm FL.

Mortality

Age frequency distributions of Samson fish sampled in this study had a modal peak at 6 years of age (Figure 5.8). Age at full recruitment was thus considered to be 7 years and catch curve analysis was undertaken on data for 7+ and older age classes (Ricker 1975). The resulting point estimate for the instantaneous rate of total mortality, Z, was 0.21 $year^{-1}$ (Figure 5.10b, Table 5.5).

The point estimate for the instantaneous rate of natural mortality, *M*, derived by refitting the relationship of Pauly (1980) was 0.40 $year^{-1}$ (Figure 5.9a) a value greater than the point estimate of *Z* determined by catch curve analysis. The point estimate of *M*, derived when the maximum age of Samson fish was inserted into the refitted Hoenig relationship for fish was 0.20 $year^{-1}$ (Figure 5.9a). The combined point estimate of *M*, derived using the method of Hall *et al.* (2004), which combined the separate likelihood distributions for the two estimates of *M*, produced a point estimate of 0.22 $year^{-1}$ (Figure 5.9b, Table 5.5). The resultant posterior probability distribution for this point estimate of *M*, the point estimate of *Z* (catch curve analysis), and the requirement that $M \leq Z$, yielded a point estimate for *M* of 0.16 $year^{-1}$ (Figure 5.10a, b, Table 5.5) (Hall *et al.* 2004). The resultant 95% confidence limits for this estimate of *M* for Samson fish was narrower than those for *M* derived from refitting the relationships of Pauly (1980) and Hoenig (1983) (Table 5.5).

The point estimate of the current level of fishing mortality, determined by Monte Carlo analysis, was 0.04 $year^{-1}$ (Table 5.5).

Table 5.1. Percentage of sectioned Samson fish otoliths within each readability category.

Sex	n	Readability Categories				
		1 (unreadable)	2 (poor)	3 (fair)	4 (good)	5 (excellent)
Female	195	11.3	13.3	53.3	21.0	1.0
Male	149	16.1	17.4	57.7	8.7	0
Unknown	106	10.4	15.1	66.0	8.5	0
Overall	450	12.7	15.1	57.8	14.0	0.4

Table 5.2. Von Bertalanffy growth parameters for female and male Samson fish derived from lengths-at-age of individuals (L_∞ asymptotic length; *k* growth coefficient; t_0 hypothetical age at length 0; R^2 coefficient of determination; *n* sample size).

	k ($years^{-1}$)	L_∞ (mm)	t_0 (years)	R^2	*N*
Females	0.188	1279	- 0.900	0.906	207
Males	0.240	1139	- 0.563	0.930	167

Table 5.3. Schnute growth parameters for female and male Samson fish derived from lengths-at-age of individuals (L_1 and L_2 lengths at selected reference ages τ_1 (1 year) and τ_2 (10 years); *a* and *b* constants (both $\neq 0$); L_∞ asymptotic length; R^2 coefficient of determination; *n* sample size).

	L_1 (mm)	L_2 (mm)	*a*	*b*	L_∞ (mm)	R^2	*n*
Females	435.3	1089.1	0.044	2.748	1594	0.929	207
Males	400.3	1034.5	0.136	1.971	1210	0.943	167

Table 5.4. Reference for the conversion of length to weight for Samson fish of the size typically targeted by sportfishers.

Total Length (mm)	Whole Weight (kg)	Total Length (mm)	Whole Weight (kg)
900	6.8	1300	21.2
950	8.0	1350	23.9
1000	9.4	1400	26.7
1050	11.0	1450	29.8
1100	12.7	1500	33.0
1150	14.5	1550	36.6
1200	16.6	1600	40.3
1250	18.8		

Table 5.5. Estimates and their 95% confidence limits for total, *Z*, natural, *M*, and fishing mortality, *F*, for Samson fish in Western Australia, calculated using catch curve analysis, life history models (Pauly 1980, Hoenig 1983) and Bayesian analysis.

Method of analysis	*Z*, *M* or *F* (year^{-1})	Estimate	Lower 95%	Upper 95%
Catch curve analysis	*Z*	0.21	0.18	0.23
Refitted Pauly (1980)	*M*	0.40	0.14	1.24
Refitted Hoenig (1983) fish equation	*M*	0.20	0.05	0.42
Combined Pauly (1980) & Hoenig (1983)	*M*	0.22	0.10	0.44
Combined M (Bayesian method)	*M*	0.16	0.09	0.22
Monte Carlo	*F*	0.04	0.00	0.12

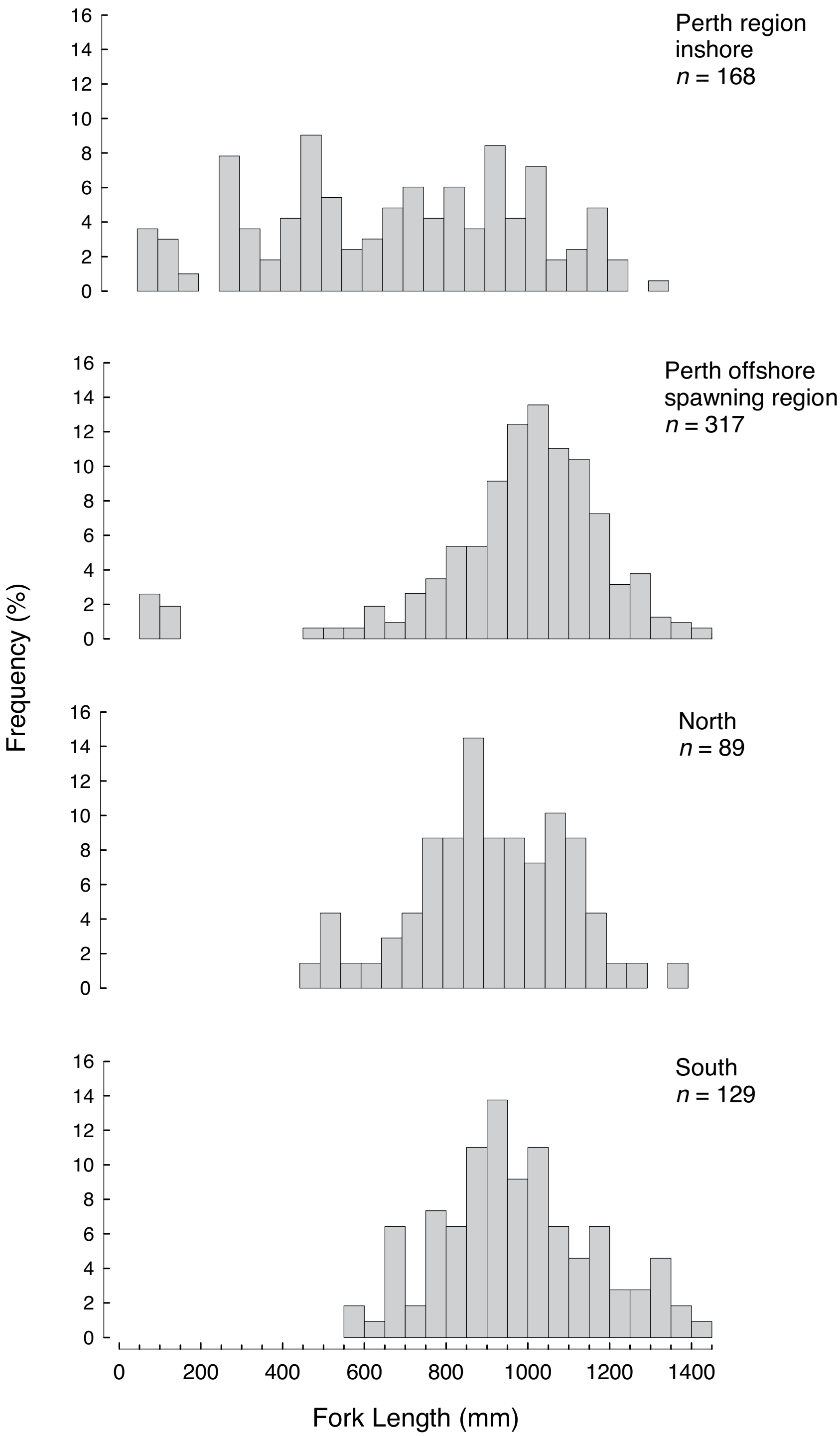

Figure 5.1. Length frequency distributions for Samson fish collected for biological analysis from inshore metropolitan, offshore metropolitan, northern and southern regions of Western Australia. *n* = sample size.

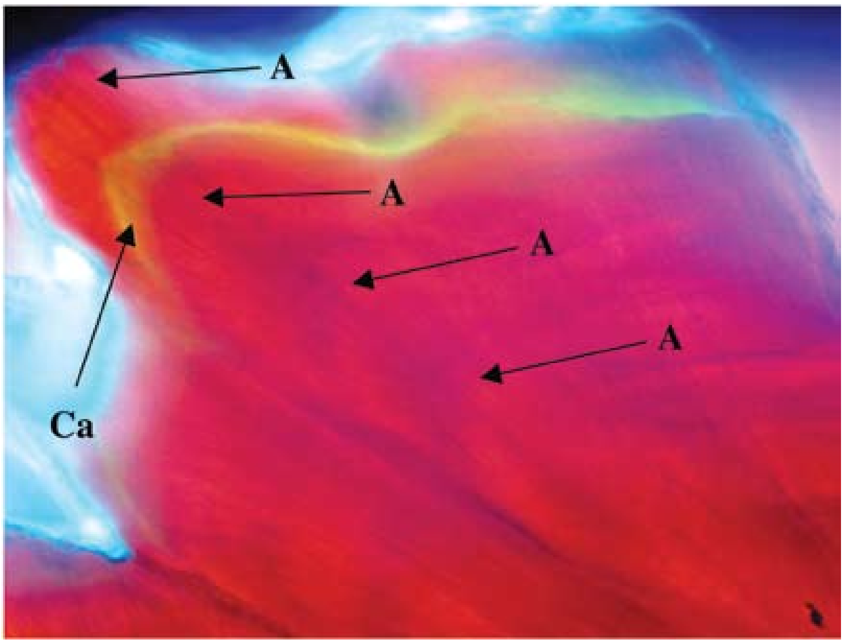

Figure 5.2. Sectioned otolith of a tagged and recaptured Samson fish after injection of calcein observed under ultraviolet light. Fish was at liberty for 319 days. Ca = calcein mark, A = annulus.

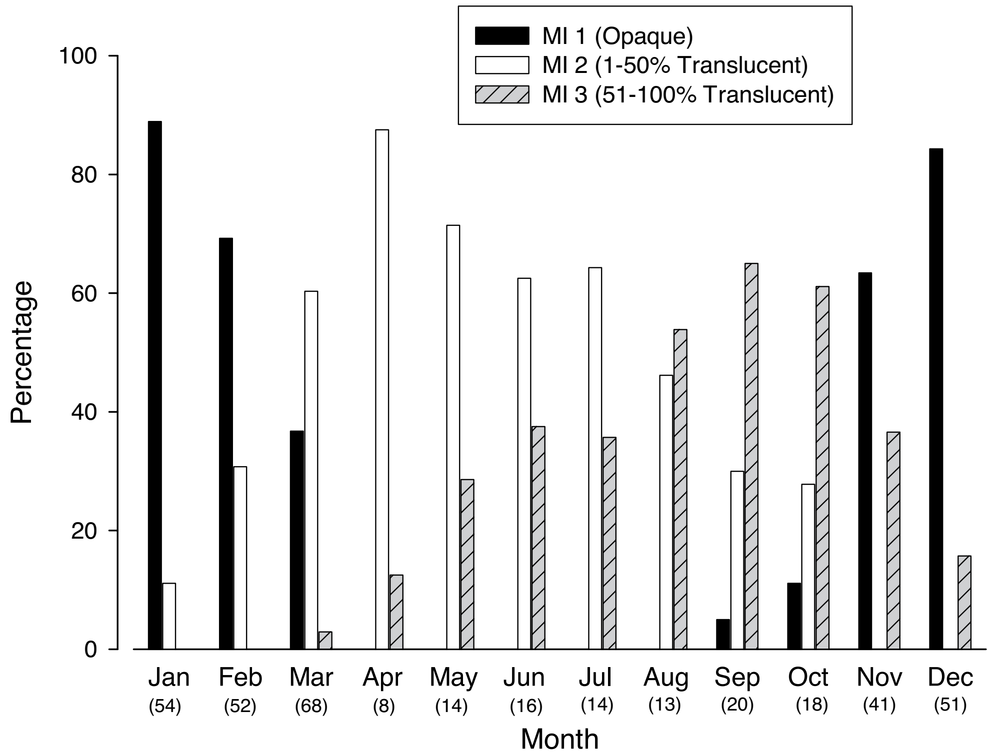

Figure 5.3. Monthly percentages of each otolith marginal increment category for Samson fish. Data pooled by region, sex and age-class with the number samples for each month given in parentheses.

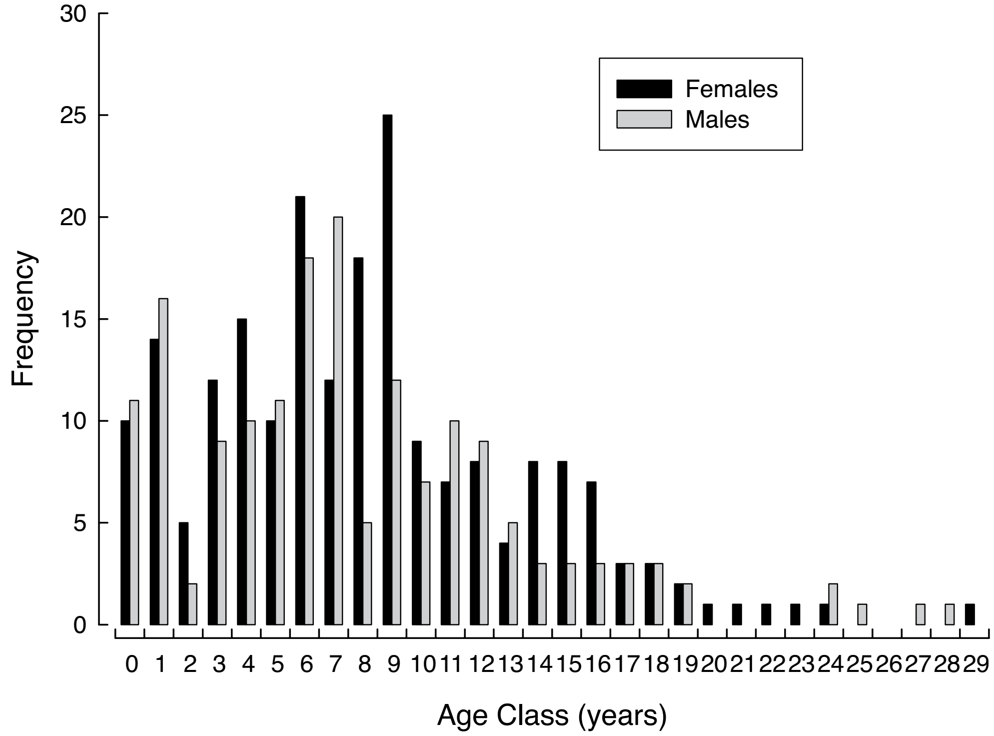

Figure 5.4. Age distribution for male and female Samson fish determined from sectioned otoliths. n_{males} = 167, $n_{females}$ = 207.

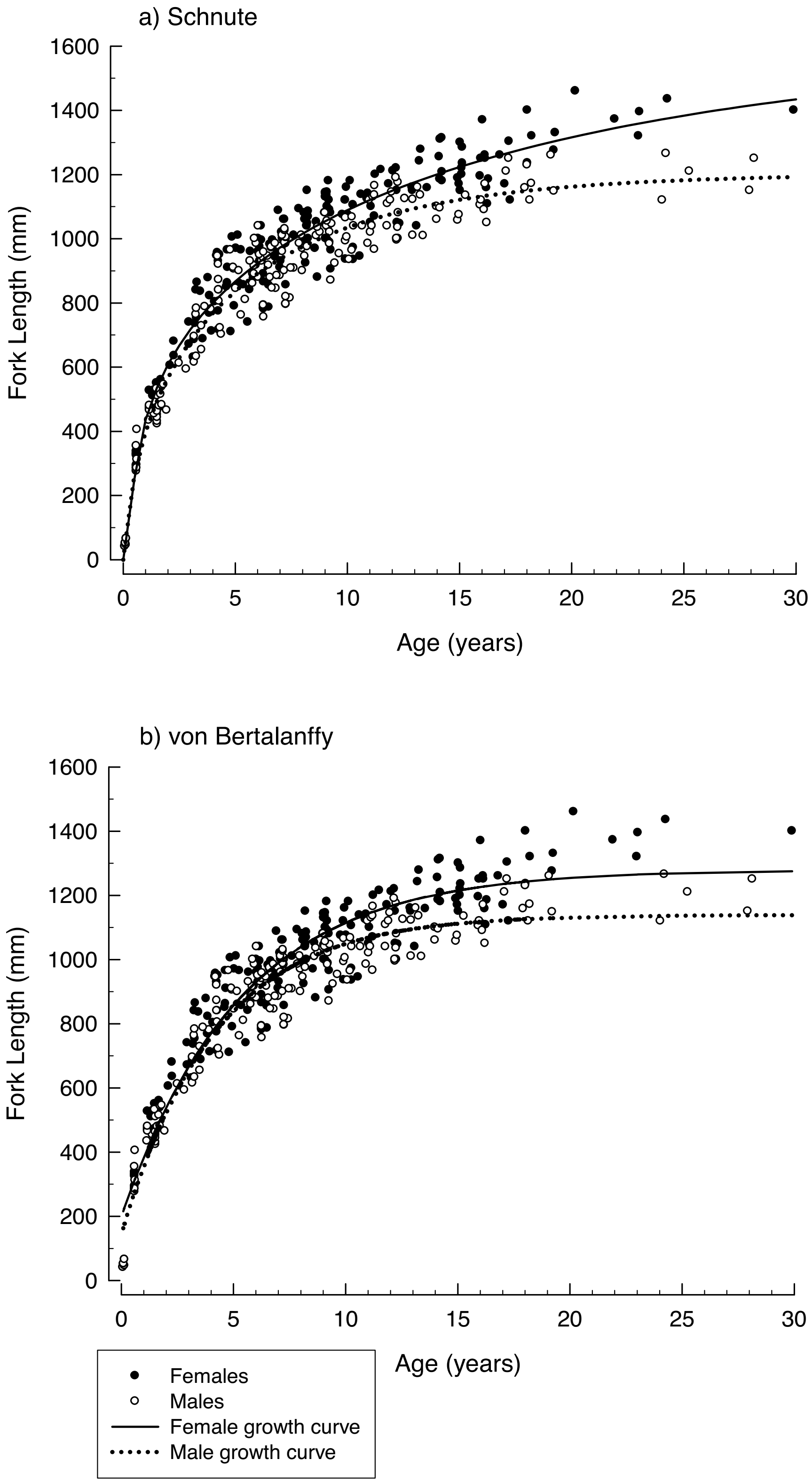

Figure 5.5. a) Schnute and b) von Bertalanffy growth curves fitted to the lengths at age for males (dotted line and open circles) and females (solid line and closed circles) of Samson fish. n_{males} = 167, $n_{females}$ = 207.

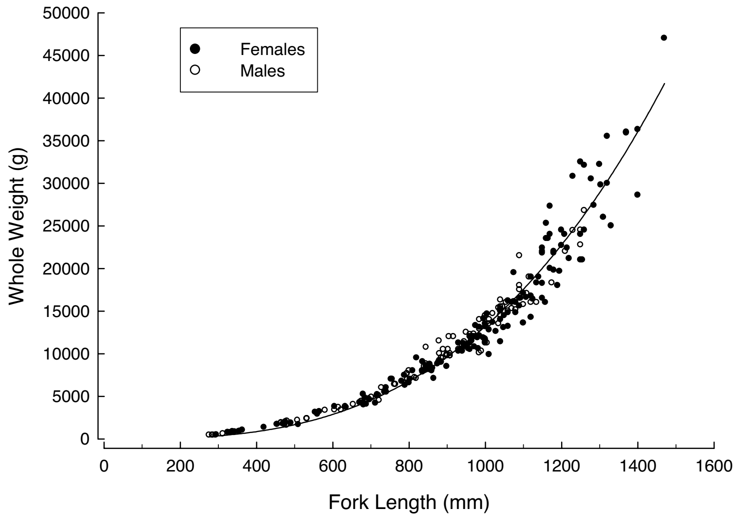

Figure 5.6. Relationship between fork length and whole weight for male and female Samson fish. n_{males} = 103, $n_{females}$ = 161.

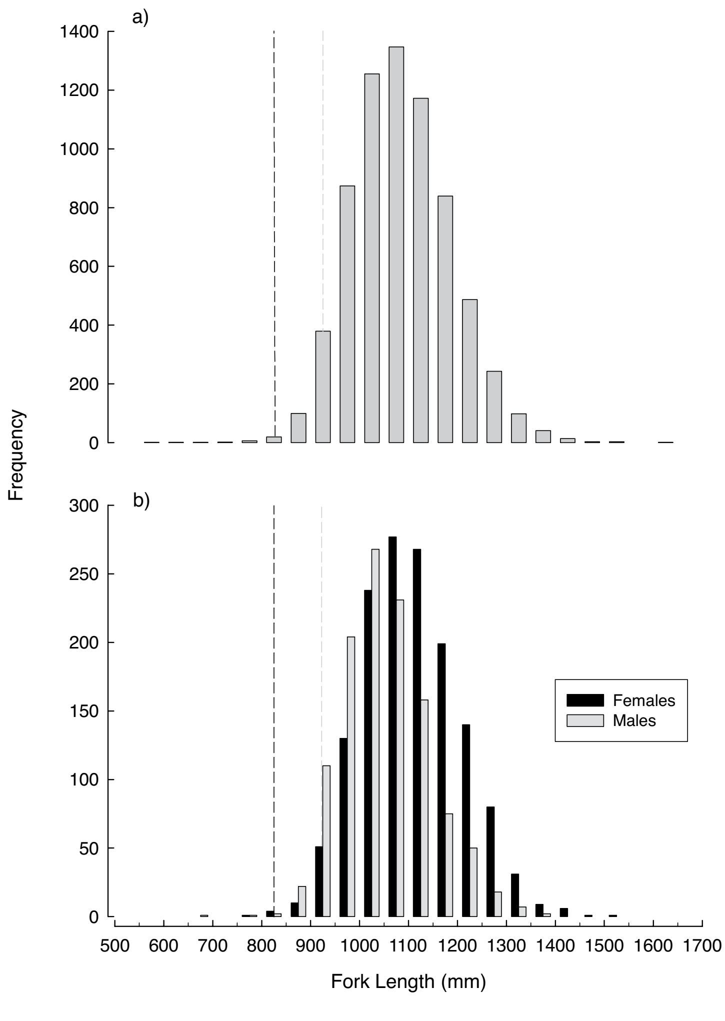

Figure 5.7. Length frequency distributions of a) all Samson fish tagged and released (*n* = 6885) and b) Samson fish for which sex was determined prior to tag and release (n_{males} = 1149, $n_{females}$ = 1446) at Rottnest island spawning aggregations. Black and grey dashed lines represent L_{50} and L_{95} at first maturity for females, respectively.

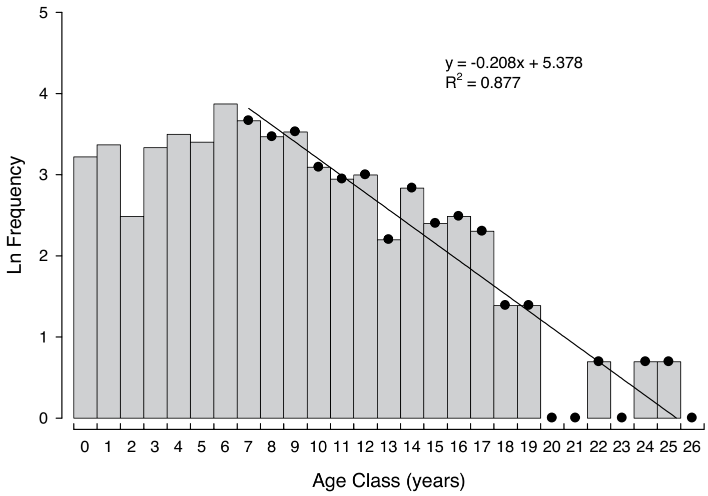

Figure 5.8. Log transformed age frequency distributions of Samson fish used to determine Z. Regression equation and coefficient of determination values are also shown.

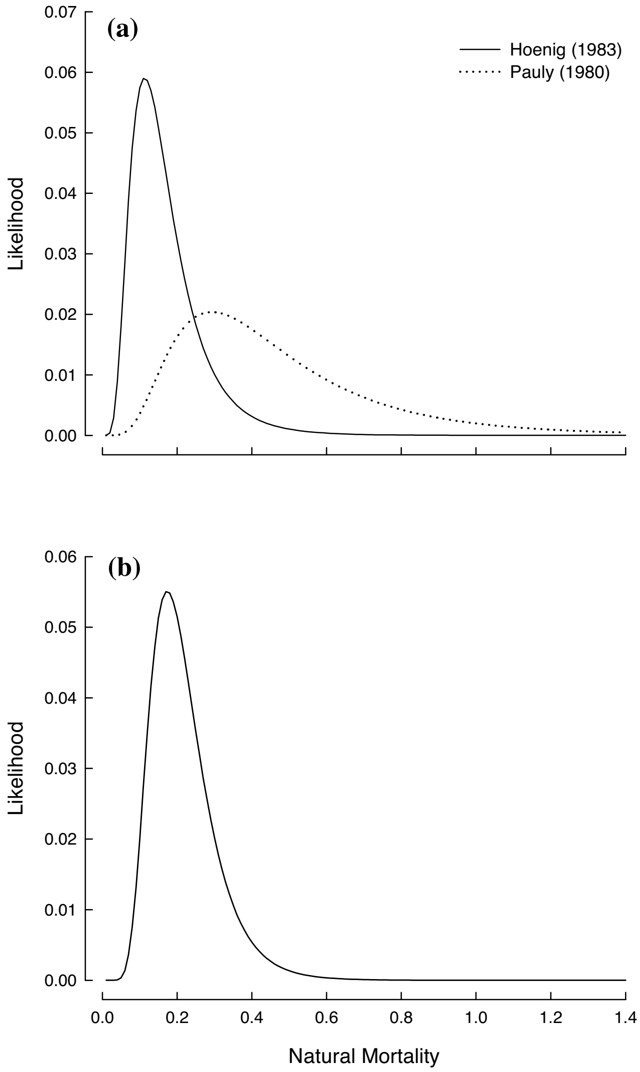

Figure 5.9. (a) Estimated likelihood distributions for natural mortality derived from the Pauly (1980) equation and Hoenig (1983) equation for fish. (b) Combined posterior probability distributions for *M* for Samson fish, derived from the separate likelihood distributions shown in (a).

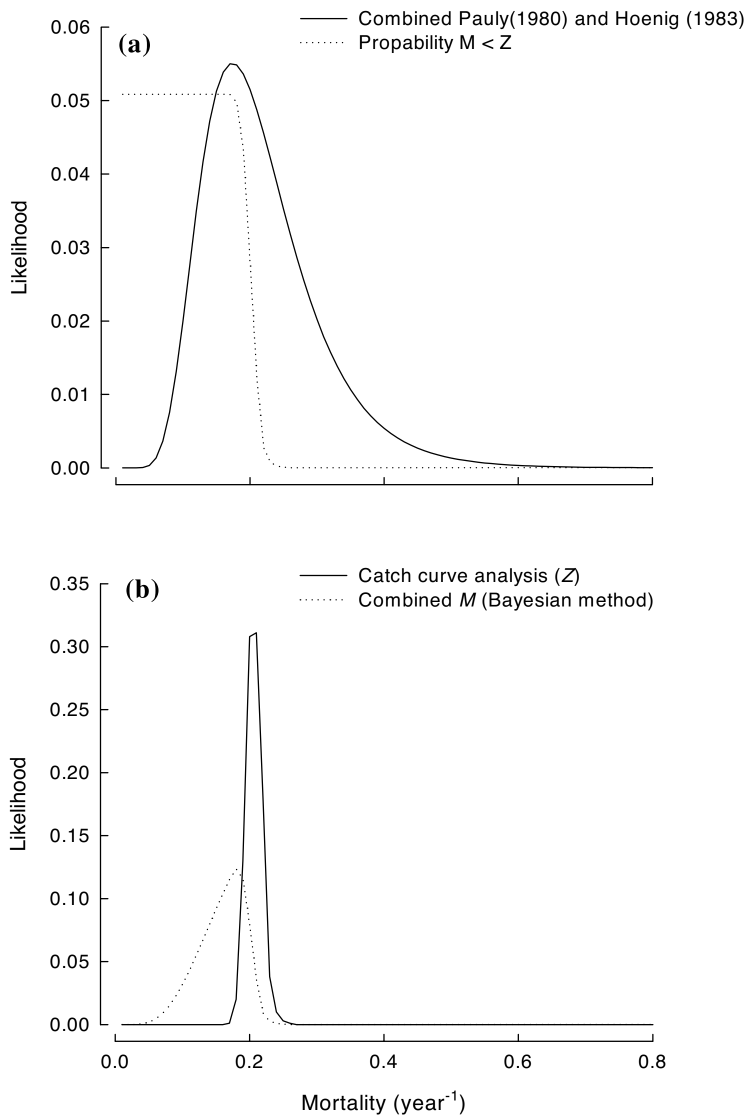

Figure 5.10. (a) Likelihood distributions for natural mortality for Samson fish from the combined likelihood distribution for *M*, i.e. combined distribution from Pauly's (1980) equation and Hoenig's (1983) method, and the likelihood function for *M*, assuming *M* is less than the catch curve estimate of *Z*. (b) Combined posterior probability distributions for *Z* and *M* for Samson fish, from the catch curve analysis for *Z* and the Bayesian method of Hall *et al.* (2004) for ***M*.**

5.1.2 Reproduction

A total of 552 gonads from males, females and juveniles were collected and staged macroscopically during this study. Of these, 205 were processed using histological techniques for more detailed examination. The gonads of female and male Samson fish are elongate, bi-lobed organs that are joined posteriorly with a short gonoduct leading to the urogenital pore. During peak spawning the gonads of mature individuals of each sex occupy a majority of the body cavity volume. The weight of ovaries in the samples ranged from 1.2 to 3337 g, whereas testes ranged from 0.8 to 2240 g.

Sex ratios

Sex determination through canulation of Samson fish captured at the spawning aggregation sites near Rottnest Island (2004 – 2007) revealed a sex ratio of females to males of 1.26:1 (n = 2596). The sex ratio of female to male Samson fish collected for biological analysis in this study was 1.36:1 (n = 552).

Spawning season and gonad development

The gonadal stages in the corresponding months for the different regions were pooled for analysis due to the low number of gonad samples obtained. The mean monthly gonadosomatic indices (GSI) for female Samson fish ($\geq L_{50}$ at first maturity, i.e. 831mm) remained low (~1) from April to September. During October the indices rose sightly as ovaries developed. GSI and ovarian development reached a peak of ~6% in November and stayed at this level until January, coinciding with a high proportion of ovaries being stage 5 (i.e. spawning) at this time (Figure 5.11). Even though many females were still spawning during February (Figure 5.12) the large drop in GSI shows that the supplies of vitellogenic oocytes within the ovaries were reduced. This drop in GSI continued until April.

The ovaries of all female Samson fish $\geq L_{50}$ at first maturity caught on the west and south coasts between April and August were stage 2 (Figure 5.12). Fish were first observed with developing (stage 3) or developed (stage 4) ovaries during early spring (September), and by November 75% of fish encountered had developed gonads. Fish possessing spawning (stage 5) gonads were also first caught in November and were encountered in the ensuing months until March. The percentage frequency of individuals with stage 5 ovaries was highest in January (32%) and February (31%). Fish with spent and recovering ovaries (stage 6) were found between January and March.

Oocyte diameter frequency distributions in the ovaries of three spawning female Samson fish (i.e. stage 4) indicate oocytes at several different stages of development (Figure 5.13). A prominent modal class at 50 – 99 µm represents oocytes at the chromatin nucleolar and perinucleolar stages. Oocytes > 500 µm correspond to vitellogenic oocytes (i.e. yolk granule stage), while the oocytes with intermediate diameters were generally cortical alveolar oocytes. In each case a largely continuous overall distribution of oocyte diameters is displayed i.e., the presence of oocytes of all stages confirming asynchronous oocyte development in this species.

Length and age at first maturity

During the spawning season the ovaries of all Samson fish with lengths < 700 mm FL were immature, i.e. stages I/II (Figure 5.14). Fish with ovaries at stages II-VI were first recorded in the 700-750 mm FL length class in which they contributed 33%. All individuals in the 950-1000 mm FL and subsequent length classes were mature. From the logistic regression analysis the L_{50} for female Samson fish at first maturity was 831 mm FL, which, on the basis of the Schnute growth equation, corresponds to an age of *ca* 4 years (Figure 5.14, Table 5.6).

Fecundity

A relationship between batch fecundity (BF) and FL (mm) was obtained from counts of hydrated oocytes within ovaries that were determined to be prespawning (stage 5a) through histology. Fecundity estimates were made for six females ranging in size from 1060 to 1200 mm FL and from 16 to 24.5 kg WW. These ranged from 51122 (± 5361) to 1472000 (± 21628) showing an increase in egg number with increasing FL and WW of fish. The BF to FL (mm) relationship was explained with a linear equation, while the BF to WW (kg) relationship was described with a power curve:

$$BF = 5021 \times FL - 4698076 \qquad (R^2 = 0.815, n = 6)$$

$$BF = 3474 \times WW^{1.901} \qquad (R^2 = 0.750, n = 6)$$

Table 5.6. Length at maturity (L_{50}/L_{95}) and 95% confidence limits derived for female Samson fish.

Parameter	L_{50} (FL mm)	L_{95} (FL mm)
Estimate	831	942
Upper 95%	867	992
Lower 95%	803	902

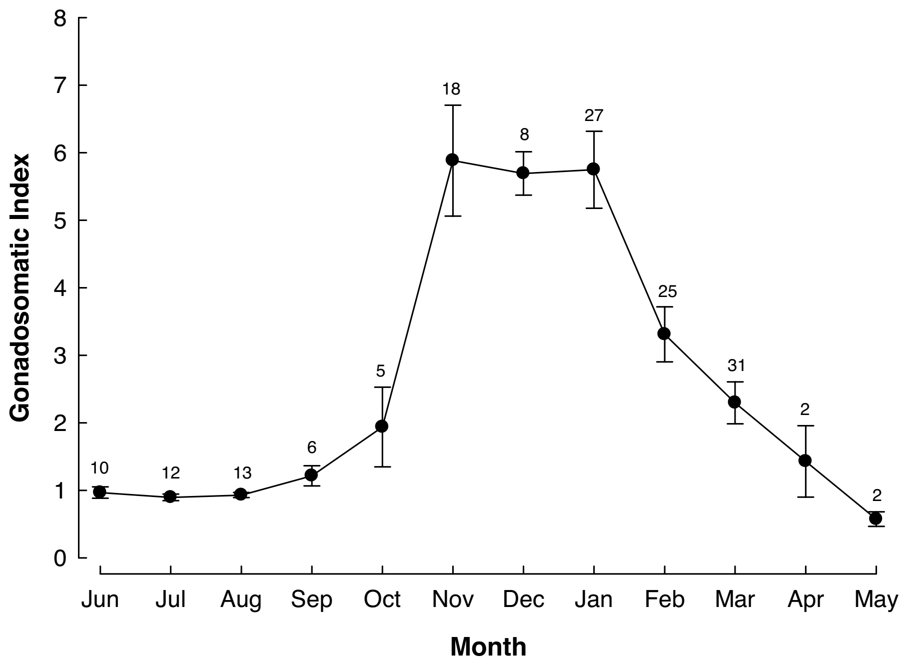

Figure 5.11. Mean monthly gonadosomatic indices ± 1 SE for female Samson fish ≥ L_{50} at first maturity. Sample sizes in each month are given.

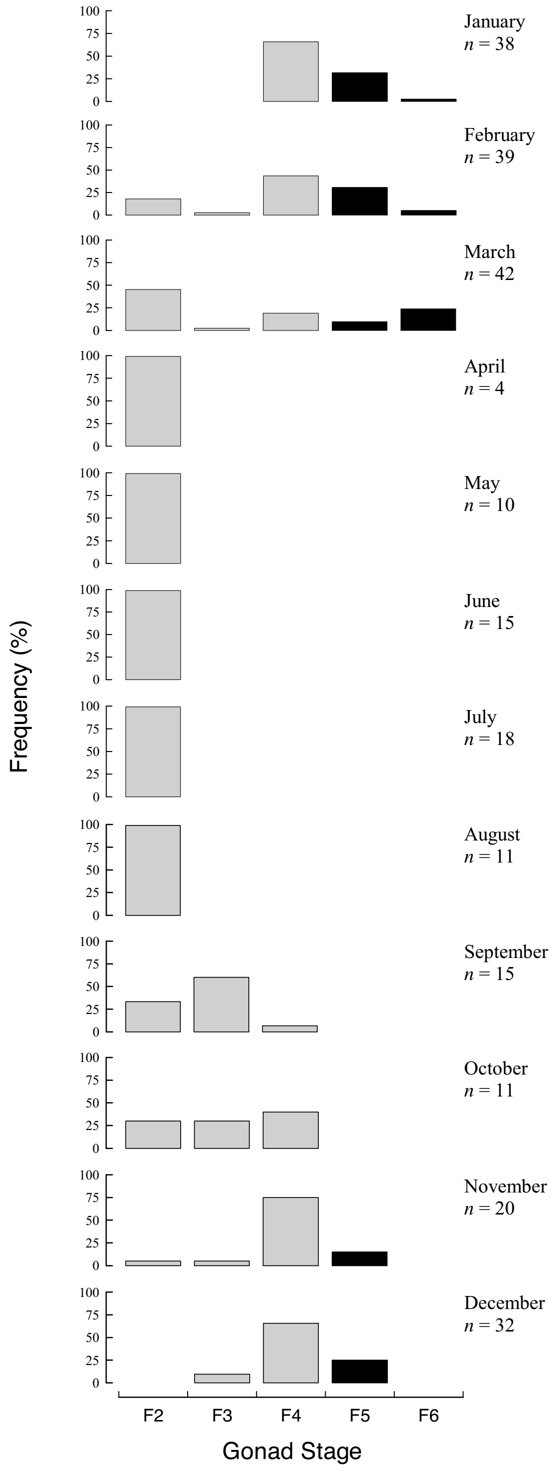

Figure 5.12. Monthly percentage frequency of occurrence of sequential gonadal stages in female Samson fish ≥ L_{50} at first maturity as determined from histological sections. n = sample size in each month.

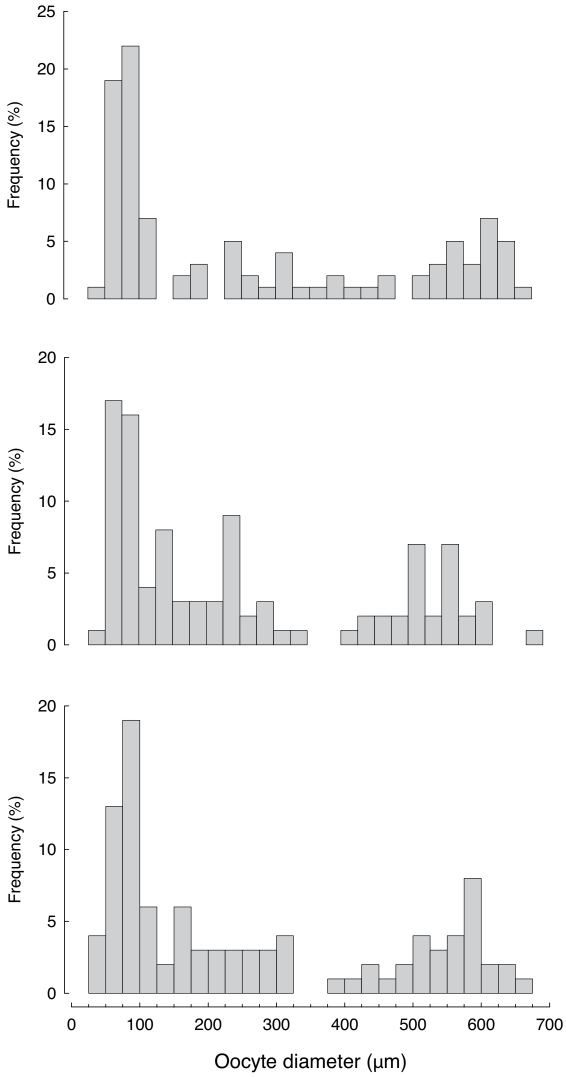

Figure 5.13. Oocyte frequency distributions for stage 4 ovaries of three female Samson fish.

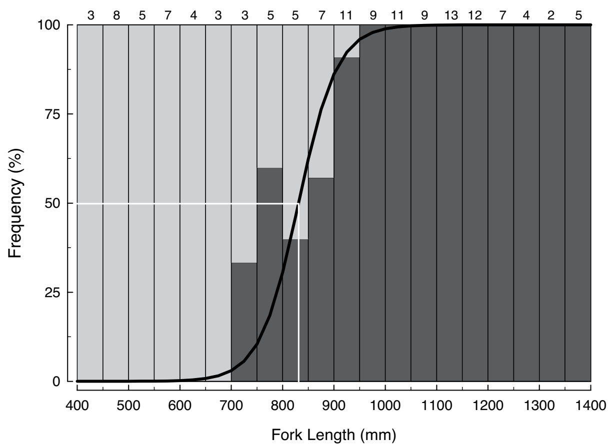

Figure 5.14. Frequency distribution of female Samson fish sampled during the spawning season with stage 3 to stage 5 gonads. The predicted percentage of mature fish at each length derived using logistic regression analysis is shown. The sample size within each 50 cm size class is shown along the top of the graph.

5.1.3 Diet

Dietary investigation of Samson fish from the WCB revealed that fish were not feeding while aggregated for spawning. This observation is supported by anecdotal evidence from fisherman who can only catch these fish on bait after they have been excited with lures. Outside the spawning aggregations the diet of Samson Fish (> 252 mm FL) comprised mainly cephalopods (26% Volume) and a variety of teleost fishes (74% V) (Table 5.7). Although Samson fish consumed a wide assortment of fishes, pilchard (*Sardinops sagax*) was the most important of these by both volume (18%) and occurrence (24%). The second most important teleost taxon in the diet of Samson fish was a group of demersal species from the genus *Centroberyx* (8.3%V, 6.9%F). Squid was the most common cephalopod consumed by Samson fish contributing 17% volume to the overall diet of this species (Table 5.7).

Table 5.7. Percentage volumetric contribution (%V) and percentage occurrence (%F) of the different prey items found in Samson fish (252 mm to 1370 mm FL) captured in the West Coast Bioregion. The number of stomachs that contained food = 87.

Prey	Percentage Volumetric Contribution (%V)	Percentage Occurrence (%F)
Cephalopods	25.7	29.9
Squid (Teuthoidea)	17.4	19.5
Cuttlefish (*Sepia* sp.)	6.6	10.3
Octopus (*Octopus* sp.)	1.7	1.2
Crustaceans	0.1	1.2
Prawn (Penaeidae)	0.1	1.2
Teleosts	74.2	83.9
Pilchard (*Sardinops sagax*)	17.8	24.1
Red/Swallowtail Snapper (*Centroberyx* sp.)	8.3	6.9
Yellowtail scad (*Trachurus novaezelandiae*)	7.1	6.9
Scaly Mackerel (*Sardinella lemuru*)	4.5	3.5
Goatfish (Mullidae)	3.9	5.8
Leatherjacket (Monacanthidae)	3.7	5.8
Grinner (Synodontidae)	3.6	3.5
Garfish (Hemiramphidae)	4.4	3.5
Skippy (*Psudocaranx dentex*)	1.9	1.2
Gurnard (Triglidae)	1.3	1.2
Wrasse (Labridae)	0.8	2.3
Whiting (*Sillago* sp.)	0.2	1.2
Unidentified	16.7	36.8

5.1.4 Discussion

Age and Growth

Difficulty in age determination has been noted in other studies of *Seriola* spp., and this is reflected in the variety of methods and structures used, such as scales, vertebrae, opercular bones, dorsal spines and otoliths (Baxter 1960, Gillanders *et al*., 1999a, Thompson *et al.* 1999, Kozul *et al.* 2000, Manooch and Potts 1997). However, although delineation of opaque zones was sometimes difficult to detect in Samson fish, monthly marginal increment analysis demonstrated seasonal development of the otolith margin and the formation of a single opaque zone annually in the otoliths of this species. The recapture of a Samson fish individual subsequent to an injection of calcein also validated the annual formation of annuli in the otoliths of this species. Thus, as with yellowtail kingfish *S. lalandi* from the waters of New South Wales (Stewart *et al.* 2004) and *S. dumerili* from the Atlantic (Manooch and Potts 1997, Thompson *et al*. 1999), it is appropriate to use the number of annuli in sectioned otoliths to age Samson fish.

The formation of the opaque zone in Samson fish occurs during late spring/summer (November – January) with development of a new translucent zone occurring during autumn. This is later than for other species in south-western Australia such as West Australian dhufish *Glaucosoma hebraicum* (Hesp *et al.* 2004), mulloway *Argyrosomas japonicus* (Farmer *et al.* 2005), silver trevally *Psudocaranx dentex* (Farmer *et al.* 2005) and Australian herring *Arripis georgianus* (Fairclough *et al.* 2000), in which the delineation of the annual opaque zone occurs in spring. The processes that govern the deposition of the opaque zones and annuli in otoliths have been the source of considerable discussion (Beckman and Wilson, 1995). Annulus formation has been related to various factors resulting from interactions between internal and/or external cycles such as somatic growth, annual migrations, temperature and spawning (Beckman and Wilson 1995; Tserpes and Tsimenides 1995; Franks *et al.* 1999; Cappo *et al.* 2000; Ewing *et al.* 2003). Trends exhibited in the timing of annulus formation in Samson fish show good correlation with the summer spawning period, which is generally associated with large-scale migration, rapid development of the gonads and a substantial decrease in feeding activity.

The formation of annuli in the otoliths of Samson fish is paralleled by other reef-associated pelagic species, including cobia, *Rachycentron canadum* of the monotypic family Rachycentridae, a sister taxon to Carangidae (Reed *et al*. 2002). Franks *et al.* (1999) reported that annulus deposition in the otoliths of *R. canadum* from the Gulf of Mexico occurred during summer and was more related to the northern migration of that species during spring than to its summer spawning activities. It is therefore likely the annulus deposition in Samson fish is related to both spring/summer migration and spawning. It is also possible that somatic growth slows considerably during this time as fish invest considerable energy towards migration and gonadal development. Formation of the translucent zone, therefore, does not occur until summer spawning activities cease and the somatic growth rate increases.

The growth of juvenile Samson fish is rapid with this species reaching minimum legal length for retention (MLL) of 600 mm TL within the second year of life. Fast growth continues during the first 5 years of life after which time it slows down as this species becomes sexually mature. Once maturity is reached female Samson fish grow at a faster rate and attain a larger size than males. This pattern of sexual dimorphism is common in many species of fish (see Parker 1992 and references therein) and has also been recorded in other species of carangids, such as Bluespotted Trevally *Caranx bucculentus* (Brewer *et al.* 1994), and Crevalle Jack *Caranx hippos* (Kishore and Solomon 2005), and also *R. canadum* (Brown-Peterson *et al.* 2001). However, in a study on the closely related *S. dumerili* from the Gulf of Mexico, Thompson *et* *al.* (1999) found no differences in the growth rates of females and males. Likewise, Stewart *et al.* (2004) found no differences in rates of growth of male and female in *S. lalandi* from the waters of New South Wales. Difference in growth rates and maximum size of female and male Samson fish may reflect different selection pressures acting on the body size of the two sexes. A larger size in female Samson fish is favoured because it increases fecundity, whereas male size is most likely driven by male-male competition for females and egg fertilization (Parker 1992). Intense competition between males for a larger female during group broadcast and paired spawning events has been reported in other carangid species, including *S. lalandi* and *S. dumerili* (Graham and Castellano 2005; Moran *et al.* 2007). Although Thompson *et al.* (1999) reported no differences in rates of growth between female and male *S. dumerili*, these authors did observe sex related differences, in that females grow larger than males, and attributed these findings to age related differential mortality in that males die younger. This is not the case for Samson fish as males and females were equally represented in all age classes.

The maximum age recorded for Samson fish in this study was 29 years. This is considerably higher than the maximum ages published for any other *Seriola* species. The oldest *S. dumerili* recorded was 17 years from the North Atlantic Ocean (Manooch and Potts 1997), whilst Thompson *et al.* (1999) recorded a maximum age of 15 years for that species in the Gulf of Mexico. In eastern Australian waters *S. lalandi* has been documented to attain an age of 21 years (Stewart *et al.* 2004). The higher longevity of Samson fish compared to other *Seriola* spp. may be attributed to this species living in cooler higher latitude waters (Heibo *et al.* 2002). Similarly, the oldest carangid thus far studied is *Psudocaranx dentex* from New Zealand waters that was reported to reach an age of 46 years (James 1984).

Juvenile Ecology

Juvenile Samson fish > 100 mm in length were only found in surface waters underneath jellyfish or associated with drifting detached seagrass and brown algae, such as *Posidoina*, *Sargassum* and *Eclonia* species, in both near shore and offshore waters ranging in depth from 5 to 150 m. Although individuals of this size were often encountered under a single piece of flotsam or clump of seaweed, they were more commonly encountered associated with large drifting mats of debris or windrows. Such floating structures increase the complexity of the pelagic environment and provide refuge from predators and supply a direct food source to many species of both pelagic and inshore, juvenile fish (Helfman *et al.* 1997), and are considered to be an integral component of many pelagic food webs (Rooker *et al.* 2006). Pelagic sargassum mats have been described as important habitat for other small juvenile *Seriola* species, such as greater amberjack *S. dumerili* in the Gulf of Mexico (Wells and Rooker 2004), Japanese amberjack *S. quinqueradiata* in the East China Sea (Sakakura and Tsukamoto 1997) and Pacific Ocean (Uehara *et al.* 2006), and almaco jack *S. rivoliana* and banded rudderfish *S. zonata* in the North Atlantic Ocean (Moser *et al.* 1998). It is likely that small juvenile Samson fish were more commonly encountered in offshore areas because of a proximity to the deepwater spawning aggregations sites. Similarly, Wells and Rooker (2004) in a study on the distribution of juvenile *S. dumerili* associated with drifting sargassum, found a greater abundance of juveniles (< 100 mm) in offshore zones than in inshore areas and attributed the observed spatial patterns to the offshore spawning habits of that species. Juvenile Samson fish (200 – 500 mm) mainly live in inshore areas that contain structures such as rocks, reef, pylons or jetties and where the water depth is < 20 m. Whilst individuals throughout the size range were encountered in inshore areas, the sampling regime and tagging suggest that this species moves into deeper water as it increases in size. For instance, a 250 mm juvenile Samson fish tagged at the mouth of the Swan River was recaptured as an sub-adult fish (790 mmTL) 17 km off the mainland coast.

Mortality

As the point estimate for natural mortality derived for Samson fish from Pauly's (1980) method was far higher and thus inconsistent with the point estimate derived for total mortality, *Z*, from catch curve analysis, it is likely that the method of Pauly (1980) provided an erroneous value for *M*. The fact that the Hoenig (1983) point estimate is slightly less than the value of Z would indicate that current fishing mortality is light. However, it should be recognised that the confidence intervals for this (and Pauly's method) were very wide.

The Bayesian approach of Hall *et al.* (2004) is thought to provide a more reliable estimate of *M*, as it combined the likelihood distributions associated with each of the point estimates of *M* and the point estimate for *Z,* i.e. was based on greater information through employing several probability distributions for *Z* and *M*. This approach always ensures *M* is less than *Z* (Fairclough *et al.* 2004; Hall *et al.* 2004; Farmer *et al.* 2005; Pember *et al.* 2005; Mant *et al.* 2006). Since the Bayesian approach incorporates the distribution values for *M* derived by the Pauly (1980) equation, an erroneously high estimate for this variable, bias will be incorporated into this ultimate estimate of *M*. However, when the estimate of *M* from the Pauly (1980) method was combined with that of the Hoenig (1983), the resultant value was very close to the original Hoenig (1983) estimate, i.e. the Pauly estimate has little influence on the overall estimate. Nevertheless, the estimate of fishing mortality, *F*, should be treated with some caution. The low point estimate of *F* suggests that Samson fish is not currently subjected to heavy fishing mortality. This agrees with the general perception by recreational anglers that Samson fish is primarily a catch and release sportfish rather than a table fish. Although about 80 – 100 tonnes of Samson fish are captured by commercial fishers annually, given the large individual size and apparently large stock size of this species, it is possible that these catches represent a minor proportion of the overall population.

Reproduction and Spawning

The mean monthly GSI's of female Samson fish, together with the changes in ovarian stages throughout the year and the prevalence of fish with spawning ovaries in November to March, demonstrate that this species spawns during late spring and throughout summer. Similarly other large *Seriola* species have been reported to spawn during late spring and summer, such as *S. dumerili* (Harris 2004) and *S. lalandi* from eastern Australia in which peak gonad activity was observed in December (Gillanders *et al.*1999b).

Furthermore, the presence of post-ovulatory follicles in female gonads that were not fully spent, and the fact that oocytes of all stages were present in the ovaries of spawning females, confirms that Samson fish is a serial spawner with indeterminate fecundity. Thus, the potential annual fecundity of Samson fish is not fixed prior to the commencement of spawning and females of this species release more than one batch of eggs during the spawning season (Hunter *et al.* 1985). Fecundity estimates provided by this study show that Samson fish is highly fecund, particularly given the fact that the highest batch fecundity estimate of almost 1.5 million eggs was obtained from a female that was well below the maximum size attained by this species. The mean relative fecundity calculated for Samson fish of 57.4 eggs/g ovary-free body weight is comparable to other pelagic species for which such data are available. This includes the carangid, *R. canadum*, for which Franks *et al.* (1999) estimated a mean relative fecundity of 53.3 egg/g ovary-free body weight. Similarly, Farley and Davis (1998), determined the relative fecundity of southern bluefin tuna, *Thunnus maccoyii*, to be 57 eggs/g, while Schaefer (1996) a found a relative fecundity of 68 eggs/g in yellowfin tuna, *Thunnus albacares*.

Although this study focussed on the large spawning aggregations in deepwater (80–120 m) west of Rottnest Island, data collected shows that spawning by this species is not restricted to any particular region or water depth. Many recreational fishers report large aggregations of spawning Samson fish in shallower waters, particularly in areas south of Cape Naturaliste and west of Mandurah. During the current study Samson fish with gonads at spawning stages were caught at various depths (5-200 m) and locations (1 to 60 km from shore) in western and southern coastal waters of W.A.

Management

The fork length at which female Samson fish typically attain maturity (L_{50}) (831 mm) is equivalent to a total length of 888 mm, thus exceeding the minimum legal length of retention (MLL) of 600 mm TL. Therefore, many Samson fish may get harvested prior to reproduction. Gillanders *et al.* (1999b) reported a very similar length at 50% maturity for females of 834 mm FL in the closely related *S. lalandi* from the waters New South Wales. However, although the minimum legal length of Samson fish is over 250 mm less than the length at maturity, recent reductions in the maximum daily recreational bag limit of this species from 4 to 2 per fisher may be all the management input controls needed at this stage. Samson fish is also a relatively hardy species that has a high post release survival rate (see Section 5.3) and is generally only targeted by sportfishers for the purpose of catch and release. In addition, anglers fishing for food release this species as it is considered to have low table qualities. Furthermore, evidence that Samson fish has a high reproductive output and an offshore spawning and migratory habit that excludes many fish from the fishery may also account for the fact that current fishing pressures does not appear to have a marked impact on the numbers of Samson fish.

5.2 Fisheries

Andrew Rowland, Paul Lewis, Michael Mackie and Howard Gill

5.2.1 Recreational Fishery

Due to their poor reputation as a food fish, Samson fish are rarely targeted by recreational anglers for their eating qualities. Nevertheless, this species is common in recreational catches on the west and south coasts of WA due to its abundance and broad distribution. Often this is as a by-catch when targeting other species such as dhufish and pink snapper, with many boat fishers regarding Samson fish as a nuisance fish. It is mainly targeted during fishing competitions because of its high point value, and by catch-and-release sportsfishers.

There are little data on catches of Samson fish by recreational fishers. Surveys conducted in the West Coast Bioregion (WCB) during 1996-97 (Sumner and Williamson 1999) indicated that 5687 (66%) Samson fish were kept by boat anglers whilst 2934 (34%) were released. The National Recreational and Indigenous Fishing Survey undertaken in 2000/01 (FRDC 2003) estimated an annual harvest of 10,890 fish in WA for catch described as kingfish/Samson fish, with an estimated weight of 98 642 kg. It is likely that the majority of these fish were Samson fish as opposed to the less common yellowtail kingfish (*Seriola lalandi*) or amberjack (*Seriola dumerili*) which where also included in this grouping.

Samson fish are recognised for their game fish attributes and targeted by sportsfishers within the WCB, particularly in waters of around 100 metres west of Rottnest Island where the species aggregates to spawn during summer (November to March). Prior to the 1990s this species was rarely targeted except on occasion by members of local game fishing clubs. During the mid 1990s two charter boats based in Fremantle began to specifically target Samson fish for the purpose of catch and release sportsfishing. Clients for these day trips targeting these fish were mainly international visitors from Asian countries such as Japan and Malaysia, where the deepwater jigging style of fishing for similar species is popular.

Over the following years these charter boat operators would also stop at the Samson fish aggregations for short periods with local clients to allow standard demersal charter groups the experience of catching these fish. In 1998 one operator stopped targeting Samson fish due to concerns over mortality of released fish. It was at this time the charter operators commenced discussion with DoFWA scientists that ultimately led to the current FRDC project into 'Management and monitoring of fish spawning aggregations'.

The remaining charter operator continued targeting Samson fish west of Rottnest Island, building an international reputation for specialist catch and release sportsfishing charters. Tagging of fish became an integral component of these charters as a means to aid research. During this period the aggregation sites were visited on irregular occasions by larger private boats, typically chasing this species during fishing competitions. By 2001 two other charter boats started making intermittent trips to the aggregations, as the popularity of catch and release fishing increased among international visitors and local fishers.

Recognition of this fishery steadily increased through local fishing media exposure and promotion by tackle stores and by 2003 private boats were regularly undertaking trips to specifically target Samson fish west of Rottnest Island for catch and release. A fishery that was once only within reach of knowledgeable skippers with electronics needed to find fish in deepwater is now a popular fishery with local fishers as information about the fishing methods and aggregation locations has become common knowledge. However, access to the Rottnest Island Samson fish aggregations is generally limited to boats greater than 6 m in length due to the large distance offshore and the strong sea breezes commonly encountered in this area during summer. Interest in this fishery has also increased due to the depleted state of traditionally targeted demersal species and the associated decline of quality fishing experiences.

Most anglers targeting these fish have adopted the methods promoted through the fishing media, based on rod and line fishing with deepwater jigs - the technique also used by most charter operators. This method uses a painted metal or lead jig rigged with a single barbless hook attached to a heavy braided line of 24 to 40 kilogram breaking strain. Jigs are usually attached to the braided line via heavy monofilament leader (70 to 90 kilogram breaking strain), which provides shock absorption when a fish strikes the jig and also allows the fish to be effectively controlled when near the boat for timely release. Jigs weighing between 200 and 500 grams rigged by this method are dropped vertically from the vessel to the bottom and are retrieved in a jerking motion to imitate prey. Schooling Samson fish are very receptive to this method of fishing and are readily caught. This species is also captured using a baited rig with hook and sinker.

5.2.2 Commercial Fishery

Commercial catches of Samson fish increased rapidly during the early 1980s reaching a peak of just over 126 tonnes in 1987. Most of this catch is taken in the Mid-west and Metro regions, and most is taken by hand and dropline (Figure 5.15). In 2005 the total commercial catch of Samson fish was 86.6 tonnes (mean 1995-2005 = 102.1 tonnes), with 28.2 and 31.8 tonnes of this captured from the Mid-west and Metro regions, respectively.

Most of the catch in the Metro area is likely to be taken from aggregations that occur in deep water west of Rottnest Island (noting that generally there is little overlap in commercial and recreational fishing activities for this species). Although peaks in catches may occur in spring-summer when Samson fish are aggregating for spawning, they are also caught throughout the year in most areas (Figure 5.16). Note that analysis of the data is limited by the large scale of the reporting blocks.

The value of landed Samson fish varies markedly depending on the quality of fish and demand. The price at market for whole fish ranges from $0.80/kg for gillnet bycatch with lice damage to $3.50/kg for premium smaller line caught fish. There is generally a low demand for Samson fish and it is not uncommon for catches to be passed in when offered at the Perth Fish Markets. The average market price for landed Samson fish is $1.50 to $2.00 /kg whole fish.

The target market for Samson fish landed commercially is mostly fish processors who fillet and sell onto supermarkets where it is retailed as low-priced fillets labelled as kingfish. Premium quality fish are also purchased by processors or seafood retailers to be sold as fillets or fish for sashimi.

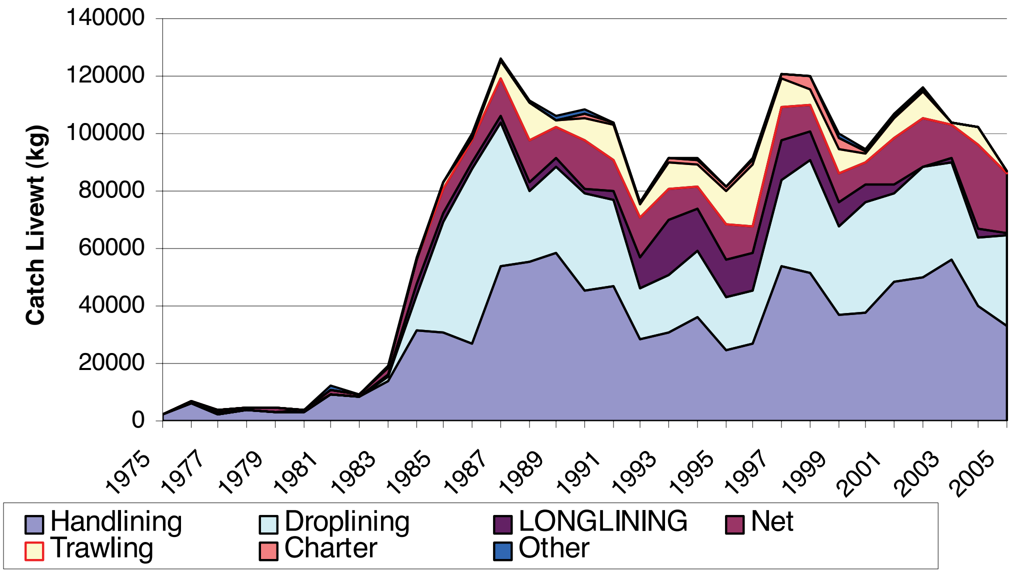

Figure 5.15. Annual commercial catch of Samson fish by each fishing method.

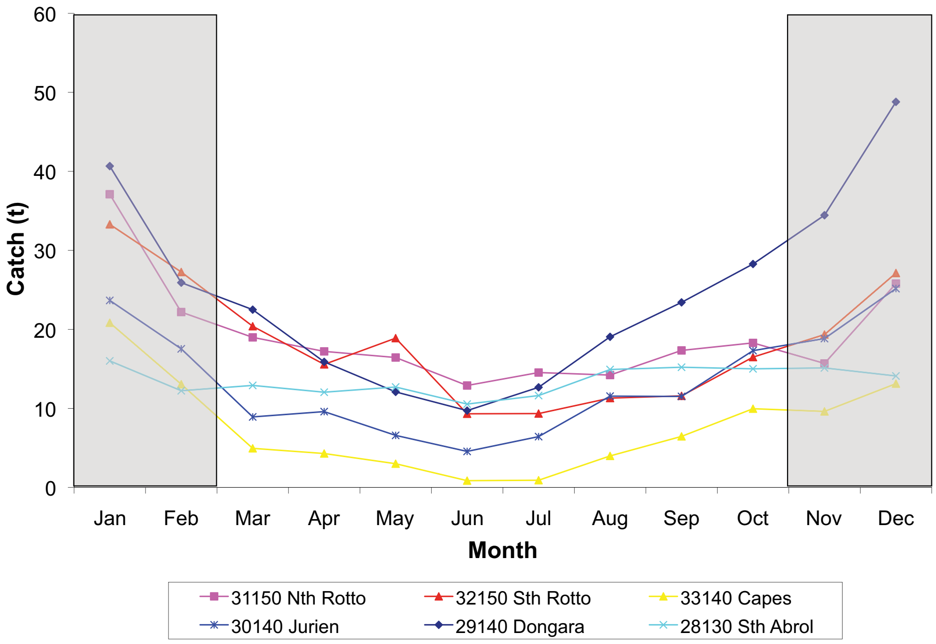

Figure 5.16. Total commercial catch of Samson fish (1979-2006) per month for the main CAES blocks, indicating spawning season (shaded area).

5.3 Samson Science and the impacts of catch-and-release sportsfishing

Andrew Rowland, Michael Mackie, Howard Gill and Paul Lewis

5.3.1 Samson Science

The initial aim of this FRDC project was to determine the impacts of catch-and-release sportsfishing on spawning aggregations of Samson fish that form west of Rottnest Island each summer. This followed discussions with concerned charter boat operators, and ultimately led to the current more broadly focussed study. Nevertheless, the study of Samson fish remained a key objective, firstly because the Rottnest aggregations were ideal for trialling various methods of monitoring aggregations, and secondly because of the strong support that was received from the recreational fishing community.

This high level of community support ultimately led to a high profile collaboration between research staff (DoFWA and Murdoch University) and recreational fishers, charter boat operators, tackle shops, volunteer fisheries liaison officers, fishing media, and Recfishwest. This collaboration became widely known as 'Samson Science', and was recognised for its involvement of a broad cross-section of recreational anglers in a large-scale, scientifically rigorous tagging study[5].

The main objective of Samson Science was to tag and release a large number of Samson fish from the Rottnest aggregations, using a number of strictly controlled capture, handling and release methods, and with accurate and detailed recording of data. These data, along with subsequent recapture information, were then to be used to describe the sportsfishery, to

[5] e.g. the FRDC R&D Newsletter Volume 13.

develop protocols aimed at minimising the impact of the sportsfishery, to describe migration patterns of Samson fish to and from the aggregations, and to estimate their numbers whilst at the aggregations. The latter was soon discounted because short-term recaptures showed that abundance estimates would be biased by fish movement patterns. The other aims have been met, bolstered by an extension of the tagging study and a new study of short-term survivorship. Nevertheless, the biggest success of Samson Science was in the strong link developed between scientists and fishers, and the positive attitude it engendered towards responsible fishing attitudes.

Full information about Samson Science is provided in the newsletters sent to participating anglers (Appendix 8). In brief, Samson Science was comprised of an intensive period in the lead up to the first summer of the project (2004-05) during which a series of seminars and workshops were held in Perth and other locations to raise awareness about the study and to recruit and train volunteer fishers, taggers and support staff. The actual tagging period was initially intended to run for three weeks during January 2005, but in practise this period was extended by two weeks to make up for days lost to poor weather. More than 270 anglers, 37 recreational boats and charter boats took part in the project, tagging and providing a catch and release dataset for 2427 Samson fish (3163 for the year; Table 5.8). When the long travel time, poor weather and exhausting task of capturing these powerful fish from twenty miles out to sea in water depths of 100 and more metres is taken into account, this is a very credible effort.

Feedback of results and information were provided to stakeholders via the 'Samson Science' newsletters and a forum on the Western Angler website, via workshops, via radio interviews, and via reference in other media (Appendix 9). T-shirts were provided to all participants, and prizes given for particular feats (e.g. most complete datasheets, largest fish tagged). These prizes were provided by industry. Data entry and coordination of tagging events was assisted by volunteer fisheries liaison officers. Fremantle Sea Rescue provided radio coverage, and the charter vessel 'North Star 2' assisted with at-sea coordination of vessels and tagging.

Given the success of Samson Science and the encouragement of recreational anglers and Recfishwest, additional funding was received from the FRDC to fund it for a second year (2005-06). 'Samson Science 2' had smaller metropolitan tagging goals and a new focus on tagging in the Geographe Bay and Albany areas. This focus on southern waters occurred because virtually all recaptures of fish tagged at the Rottnest aggregations were from there. Samson Science 2 also required an intensive period of seminars and workshops, with 18 boats in the southwest and 35 boats in the metropolitan area ultimately taking part. In this second year a further 3322 Samson fish were tagged (Table 5.8), providing additional information about Samson fish migratory behaviour and fishing activities. Although Samson Science was scaled back in subsequent years as other objectives took priority, it has become widely known as a good example of positive social liaison in fisheries research and management. Details of Samson fish tagging results are shown below.

Summary of Samson fish tagging

A total of 9769 Samson fish were tagged at spawning aggregation sites near Rottnest Island between November 2001 and January 2007 (7503 of these during the current study; Table 5.8). Of these, 203 (2.1%) have been recaptured to date (Table 5.9). All fish were tagged in the months from September to April in waters ranging in depth from 95 to 120 m. Fish tagged at the spawning aggregations ranged in length from 550 to 1600 mm FL and were recaptured after being at liberty for periods ranging from 0 to 1795 days (almost 5 years), with an average time at liberty of 385 days (± 25 days S.E.).

In addition to tagging at the Rottnest spawning aggregations, a further 518 Samson fish were tagged in coastal waters of southwest WA from Mandurah to Margaret River, between May 2005 and September 2006. Twenty-six (5.0%) of these have been recaptured to date (Tables 5.8 and 5.9). Most of these fish were tagged near Mandurah in waters ranging in depth from 13 to 28 m, and near Cape Naturaliste in waters ranging from 38 to 55 m in depth. These 'southwest' fish ranged in length from 380 to 1480 mm FL, with recaptures being at liberty from 4 to 743 days. One volunteer recreational fisher within this southwest region tagged 187 Samson fish within a small area (< 20 km^2) in the inshore waters west of Dawesville. The recapture rate of this group of fish was 8.6% and included three fish that were recaptured twice, all within the same area.

Summary of data obtained from tagging data sheets completed by angler

A variety of data were obtained during Samson Science. Recaptures of tagged fish have provided considerable information about movement patterns of this species, as detailed below in Section 5.4. In addition, information obtained from the angler data sheets and from discussion with fishers has been important for understanding the nature and impact of catch-and-release sportsfishing for Samson fish (as detailed below). These data sheets (Appendix 10) provided specific data on fishing methods and handling techniques for 5464 Samson fish tagged during the project. The percentage of these fish caught and released by fishers recording this information is summarised in Table 5.10. Of these fish 3356 (61.4 %), and 2108 (38.6 %) were caught and released by fishing charter boats, and small boat fishers, respectively. Most (94%) fish were caught using artificial metal jigs, whilst the remainder were captured using baited hooks. Most anglers also preferred to used fishing line with breaking strains over 30 kg. Gut hooking, which included the stomach, oesophagus and gills, was rare with most fish hooked in the jaw area of the mouth. A small number of fish (1.8%) were classed as foul hooked, mostly due to hooks lodged in the operculum and in the head, or in the body near the pectoral fin. The majority of fish (96%) were successfully released by use of the 'spearing' method, whereby the fish is thrust head first into the water as the body weight is supported by one hand behind the head with the other around the caudal peduncle. Whilst most fish swam down when released on the first attempt (97.7%), 2.3 % were only release successfully with two or more attempts after refloating to the surface. The remaining fish were released using a release weight, or revived first by flushing the gills with a deck hose or towing them alongside the boat.

The mean fork length of fish that floated after the initial release attempt was significantly higher than the overall mean fork length of fish tagged during each season (2005, $t = 6.69$, $P < 0.001$; 2005/06, $t = 10.05$, $P < 0.001$) (Table 5.11). The overall number of fish that floated was higher (5.7%) during the first season of tagging compared to the 2005/06 season (3.8%). The use of a release weight also increased considerably (from 36 to 105 occasions) during the second season of tagging. This may account for the significantly lower number of fish that floated during that season (Table 5.11), despite an increased in the number caught and released (3037 *cf* 2427), and may be attributed to changes in angler behaviour as a consequence of fishing protocols developed during this project.

Table 5.8. Release and recapture information for Samson fish tagged (1) at the spawning aggregation near Rottnest Island between November 2001 and January 2007 and (2) for fish tagged in the south-west region of WA between May 2005 and September 2006. Number recaptured and percentage recaptured refer to overall recaptures of fish tagged during corresponding periods.

Years / Seasons / Region	Number Tagged	Number Recaptured	Percentage Recaptured
2001-2004 (Prior to Samson Science)	2265	77	3.4
Samson Science 1 (2004/05)	3163	73	2.3
Samson Science 2 (2005/06)	3322	49	1.5
2006-2007 (Post Samson Science)	1019	4	0.4
Spawning aggregation total	9769	203	2.1
Samson Science South-west (2005/06)	518	26	5.0
Overall	10287	229	2.2

Table 5.9. Number of recaptured Samson fish by recapture location and release location between November 2001 and January 2007.

Release Location	Recapture Location						
	Outer Patch	North Barge	South Barge	Hillarys Patch	South of Rottnest	North of Rottnest	Total
Outer Patch	27	10	1	4	26	2	70
North Barge	22	37	2	4	55	4	124
South Barge	3	1	1		2	1	8
Hillarys Patch				1			1
South–west Region	2	4			20		26

Table 5.10. Summary of the details collected by fishers involved in tagging Samson fish at the sportfishing grounds west of Rottnest Island. The fishing gear, position of hook, lift and revive methods, and release condition as a percentages of the 5464 Samson fish caught and released during the 2004/5 and 2005/6 seasons. N.B. all fish that died may not have been recorded; gut refers to stomach, oesophagus and gills.

Method/technique		Percentage
Fishing method	Bait	5.8
	Jig	94.2
Line class (kg)	< 15	2.2
	15 – 30	32.9
	30 +	64.9
Hook position	Mouth	97.8
	Gut	0.4
	Other	1.8
Lift method	Net	1.4

	Leader	64.7
	Leader and tail	25.0
	Other	1.9
Revive method	Speared	95.7
	Towed	0.8
	Deck hose	0.8
	Release weight	2.7
Release condition	Healthy	94.7
	Floated/revived	4.7
	Died	0.6

Table 5.11. The total numbers and mean lengths of Samson fish that were tagged and released in the 2004/06 and 2005/06 seasons and the numbers and size of those that floated and/or were released with the use of a release weight. Numbers in parentheses are the percentage of overall fish tagged during the specified season.

Season	Overall		Floaters		Use of Release weight		
	Total tagged	Mean FL (cm)	Number (%)	Mean FL (cm)	On floaters	1st attempt	Overall
SS1 2005	2427	107.0	137 (5.7)	113.5	31	5	36 (1.5)
SS2 2005/06	3037	107.1	115 (3.8)	117.9	47	58	105 (3.5)

5.3.2 Impacts of catch-and-release

Barotrauma

Barotrauma refers to injuries to body tissues and organs that are caused by the sudden decrease in ambient pressure as a fish is pulled to the surface during capture. This rapid decompression can result in swim bladder overexpansion and potential damage to associated organs, exopthalmia (bulging eyes), internal and external haemorrhaging, everted stomach, intestinal protrusions, and loss of equilibrium (Brueswitz *et al* 1993; Parrish and Moffitt 1993; Wilson and Burns 1996; Rummer and Bennett 2005).

Initial autopsies of Samson fish following capture from depth showed that typically the swim bladder was fully inflated but rarely was it overexpanded or ruptured. In addition, signs of haemorrhaging by blood vessels were uncommon. It was also noted that Samson fish commonly released gases from the operculum region during capture, particularly when about five metres from the surface (Plate 5.1). External examinations subsequently confirmed the presence of a single ovate or circular hole generally 6-10 mm in diameter in an area of soft, vascular tissue underneath the dorsal part of each operculum (Plate 5.2). Generally a single hole was present on both the left and right sides of an individual, however some specimens only had an opening on one side. During the survival study described below, venting holes were found on 86, 100, and 97% of fish captured from 34, 80-113 and 195 m depth respectively. The percentage of fish with a hole under both opercula also increased with depth (Table 5.12).

Internal examination revealed an opening on the dorso-posterior surface of the swim bladder leading to a sinus that runs forward between the dorsal surface of the swim bladder and the spine (Plate 5.3.). Near the anterior of the swim bladder the sinus splits into two before joining with the exit holes under each operculum. It is likely that expanding gases fill the swim bladder to maximum carrying capacity during ascent, before further expansion forces gas out through this sinus. This does not appear to be detrimental to the health of the individual and evidence collected from personal observations and from fishers revealed that release of excess swim bladder gases is common in Samson fish captured in waters greater than 20 m in depth. Furthermore, this phenomenon has also been witnessed within this species under more natural conditions. Samson fish have been observed to vent excess swim bladder gases on ascent at high speed following rock lobster pots being winched to the surface (Craig Radford *pers comm.*). Recreational SCUBA divers have also observed this species venting gas on ascent. Underwater gas release was also often observed during the current project at the deepwater (110 m) spawning sites when non-hooked fish followed hooked fish to the surface, these fish had presumably ascended from considerable depth.

Short-term survival study

General Observations

Over the 10-day period in May 2006, 55 fish were used in the short-term post release survival trials. During March 2007 a further 21 fish were captured for use in the enclosure trials. The length of time each fish was held in the enclosure varied as it was dependent on weather, fish catchability and fish transport time. Trial times for individual fish therefore ranged from 2 to 31 hours. The details of the trials conducted in each year are summarised in Table 5.13. Of the fish captured for these trials, 40 were males ranging in length from 520 – 1275 mm FL with an average of 919 mm FL (±29 mm S.E.). Females (*n* = 36) ranged from 575 – 1120 mm FL with an average FL of 878 mm (±22 mm S.E.). All fish used in the trials were caught by jig, hooked in the jaw and had no major hooking injuries.

Most Samson fish spent the majority of their time in the bottom half of the sock where they formed a small school facing into the current. Alternatively, when there was little current, the fish would swim in a circle. Observations showed that when the fish first went into the enclosure they were highly stressed (barred appearance) and often had difficulty swimming and keeping themselves upright for the first few minutes. Once the initial stress had passed (usually 5-6 hours) most fish showed little sign of stress in the enclosure, even when it was circled by a large hammerhead Shark (*Sphyrna* sp.) for four hours (Figures 5.19 and 5.20).

Survival

The transport time between catching the fish and releasing them into the sock (i.e. surface interval time) was found to be a critical factor for the survival of fish captured at the deepwater Derwent site (195 m). The mortality of these fish greatly increased with surface interval times of over 20 minutes[6] (Figure 5.17) and, as such, any fish from this site that took longer than 20 minutes to transport was not included in post release survival analysis. Moreover, these high surface interval times, whereby these fish caught in very deepwater and transported in shallow containers, are not indicative of the sportfishery where such fish would be released relatively quickly and presumably return to the depth of capture.

Survivorship of fish caught at 34 m depth (*n* = 12) and held in the enclosure for between 21 and

[6] Note that fish were kept in a well flushed holding tank during the surface interval.

25 hours was 100%. Overall, 93% of Samson fish captured at depth ranging from 80 to 113 m (*n* = 28) survived their duration in the enclosure, which ranged from 2 – 22 hours for different individuals. Enclosure trial involving fish caught from a depth of 195 m (*n* = 24) lasted for between two and 30 hours in which 83% of fish survived (Figure 5.18).

Overall six of the 64 fish (9.3 %) died during the trials, representing an overall survival rate of 90.7%. Of the fish that died, two were males caught from 110 m depth, one of which floated in the enclosure and was unable to descend due to expanded swim bladder gases, the other died within 4 hours of release. All other mortality encountered involved three females and a male captured from a depth of 195 m. In each of these cases mortality occurred within the first five hours post release (Figure 5.19). The lengths of fish that survived (*n* = 58) ranged from 520 to 1182 mm FL and had a mean of 914 mm FL (± 21 mm .S.E.), whilst the length range of the fish that died ranged from 640 to 1275 mm FL with a mean of 897 mm FL (± 87 mm S.E.). There was no significant difference between the lengths of the fish that survived and died throughout these trials ($t = 0.248$, $P = 0.805$) or between the survival of males and females (Pearson $\chi^2 = 0.021$, $df = 1$, $P = 0.883$).

The mean health score of fish that survived capture at 195 m depth reached a score of 5 (i.e. all fish appear healthy) within 5 hours post release (Figure 5.19). Similarly, all fish that survived capture from 80 to 113 m depth appeared to show normal colour and behaviour within six hours of being released into the enclosure (Figure 5.20). There was no significant difference between survival of fish caught from depths of 80-110 m and 195 m (Pearson $\chi^2 = 1.148$, $df = 1$, $P = 0.284$).

Internal observations

Seven fish examined internally had ruptured swim bladders (i.e. displaying small holes and tears) (Table 5.12). No fish captured at 34 m depth showed any signs of swim bladder damage, whereas 3.6% and 17.6% of fish captured from 110m and 195m depth had ruptured swim bladders, respectively. The survival rate of fish that had ruptured swim bladders and were included in the post release survival trials (*n* = 5) was 80 %.

Overall, six fish (8.1% of fish examined internally) captured from depth ranging from 34 to 195m showed signs of internal haemorrhaging or clotting. Of these, fish 5 survived for between 4 and 24 hours before being euthanased for internal examination at the end of the respective trial by which time three fish were categorised as being healthy and two were categorised as stressed. The remaining fish died after 5 hours in the enclosure. Internal clotting was noted in 8.3% (1), 14.2% (4) and 2.9% (1) of fish captured from depths of 34 m, 110 m and 195 m, respectively.

Blood physiology

It has been well documented that capture and handling of fish during angling causes acute physiological responses (see Pankhurst and Sharples 1992; Pankhurst and Dedual 1994; Wang *et al.* 1994; Barton 2002; Arlinghaus *et al.* 2007). These studies cover a wide range of teleost species and have established characteristic physiological responses in fish subjected to catch and release by measuring the changes in various haematological parameters after physical exhaustion.

The primary stress response in fish involves the initial neuroendocrine reaction. This response includes the rapid release of catecholamines (such as adrenaline) from the chromaffin cells and corticosteroid hormones (principally cortisol) from the interregnal cells, each of which are located in the head kidneys, into the blood stream (Wendelaar Bonga 1997; Mommsen *et al.* 1999). An elevation of plasma cortisol is the most widely used indicator of stress in fish and is typically used to measure physiological disturbance, and thus stress (Wendelaar Bonga 1997). Secondary stress responses include changes in blood and tissue ion and metabolite levels related to the effects of the released hormones as well as to physiological adjustments caused by processes such as respiration, metabolism, cardiac output and cellular responses (Mommsen *et al.* 1999). Changes in plasma lactate and glucose are typically used to describe such responses in fish after a stressful event (Wendelaar Bonga 1997). Tertiary stress responses are detrimental long-term effects which refer to the fish's overall function such as growth, immune responses, reproduction and survival.

Blood plasma samples were taken from a total of 36 Samson fish in March 2006 and February 2007 during the enclosure trials. These fish ranged in fork length from 630 to 1182 mm with a mean of 908 (± 26.4) mm. Large increases in both mean plasma cortisol and plasma lactate levels were evident after capture. Each of these indices increased relatively quickly and peaked soon after the stressor which was followed by a gradual decrease over a longer period of time (Figures 5.21 and 5.22).

Mean plasma cortisol levels ranged from 40 ng ml^{-1} immediately after capture (time 0), and peaked at 259 ng ml^{-1} 4 hours post capture before declining to 60 ng ml^{-1} 31 hours after the stressful event (Figure 5.21). This study demonstrated that cortisol elevations in Samson fish, in response to an acute stressor, are within the 30 to 300 ng ml^{-1} range characteristic of other fishes subjected to stress events (Barton 2002).

Although plasma cortisol values can vary markedly depending on species, stock, developmental stage, nutritional state and environmental factors (Barton 2002), Samson fish reacted to catch and release with a typical teleost plasma cortisol response (Mommsen *et al.* 1999). For instance Samson fish demonstrated the general overall trend whereby the concentration of cortisol in the blood increased significantly within 4 hours following the stressor. The elevated cortisol levels in Samson fish then displayed a gradual decline and exhibited similar recovery to other fish species following acute stress, such as barramundi *Lates calcarifer* (de Lestang *et al.* 2004), pink snapper *Pagrus auratus* (Pankhurst and Sharples 1992), carp *Cyprinus carpio* (Pottinger 1998) and two species of coral trout *Plectropomus leopardus* and *P. maculatus* (Frisch and Anderson 2005).

Although plasma cortisol levels decreased markedly after 5 hours, these levels remained higher at 31 hours than those recorded at capture. A similar occurrence was described by (de Lestang *et al.* 2004) who investigated the effects of catch and release angling on barramundi and suggested that elevated cortisol levels after 24 hours post release were possibly due to additional stress associated with the retention of fish in holding nets during the recovery period. It is also highly likely that confining Samson fish in a relatively small enclosure during this study caused some level of confinement stress that perhaps obscured the actual recovery of cortisol to baseline levels. Furthermore, Milligan *et al.* (2000) suggest that post exercise inactivity, i.e. confinement in an enclosure, after exhaustive exercise actually causes elevations in plasma cortisol concentrations which prolongs recovery and leads to artificially long recovery times. These authors propose that the recovery profile of fish swimming during recovery after exhaustive exercise is more relevant to natural conditions. It is therefore highly likely that Samson fish released back into the water under normal fishing conditions would experience faster recovery than the fish used in the present study that had their natural swimming impeded by containment.

Elevated plasma lactate levels, which are a secondary stress response, occur as a consequence of respiration under anaerobic conditions in which glycogen supplies are depleted and lactate accumulates in the white muscle fibres (Milligan and Girard 1993). Levels of plasma lactate are, thus, not used as a measure of stress as such but are used to determine the time required for recovery from the respiratory effects of exhaustive exercise or a strenuous event (Pankhurst and Dedual 1994; Pottinger 1998). The mean plasma lactate level in Samson fish was 5.4 mmol L^{-1} upon capture by angling and peaked 2 hours after capture at 31 mmol L^{-1}. This level then declined below the concentration at capture after 17 hours to 1.9 mmol L^{-1} and remained below the level at capture for the duration of the trial (i.e. 30 hours) (Figure 5.22). As was the case with plasma cortisol, recovering levels of elevated plasma lactate in Samson fish were also consistent in duration with the general trend documented for other species for which complete recovery occurred within 24 hours post release, such as barramundi (de Lestang *et al.* 2004), carp (Pottinger 1998) and rainbow trout (*Oncorhynchus mykiss*) (Pankhurst and Dedual 1994).

Whilst no other studies on the stress response of fish after catch and release are directly comparable with the current study in terms of species and design, the results nonetheless follow a similar pattern and demonstrate that Samson fish respond in a similar manner to that typically reported for many fish species. The results clearly established that the capture and release of Samson fish with rod and line evoked a neuroendocrine stress response and the exhaustive exercise associated with this capture resulted in metabolic disturbances. Although baseline plasma cortisol and lactate levels of undisturbed Samson fish where not recorded in this study, each of these levels decreased to below, or near to, capture levels during recovery. Furthermore, since all mortality observed during the trials was attributable to barotrauma related injuries such as internal haemorrhaging, post release mortality in Samson fish does not appear to be caused by physiological dysfunction associated with the stress of capture. The results demonstrated that each of these primary and secondary stress responses in Samson fish subjected to catch and release angling are within physiological tolerance limits. It also should be noted that, as with the enclosure trials above, these results should be considered as extreme scenarios and are not truly indicative of the sportfishery where fish would be released relatively quickly, presumably return to the depth of capture and exhibit normal swimming behaviour during recovery.

Table 5.12. Number of Samson fish that had intact and ruptured swim bladders and had obvious signs of having vented caught from depths of 34, 81-113 and 195 metres. N.B. * includes one fish captured at 55 m; not all fish were examined post-mortem.

Depth (m)	Swim Bladder (%)		Vented (%)			
	Intact	Ruptured	None	LHS	RHS	Both
34*	100 (12)	0	14 (2)	50 (7)	28 (4)	7 (1)
80-113	96.4 (27)	3.6 (1)	0	21.4 (6)	25 (7)	53.6 (15)
195	82.4 (28)	17.6 (6)	3.1 (1)	21.9 (7)	6.25(2)	68.8 (22)

Table 5.13. Overall post-release survival of Samson fish caught from depths of between 30 & 195 and 55 & 113 metres and held in an enclosure for between two & 31 and two and 21 hours in 2006 and 2007, respectively. N.B. Post release survival (PRS) only refers to fish that had a surface interval time < 20 mins.

Year	Number of Fish			Hours in enclosure	Capture depths	% survival (PRS)
	Male	Female	Total			
2006	21	34	55	2 – 31	30 - 195	83 – 100
2007	17	4	21	2 – 21	55 - 113	100
Totals	40	36	76			

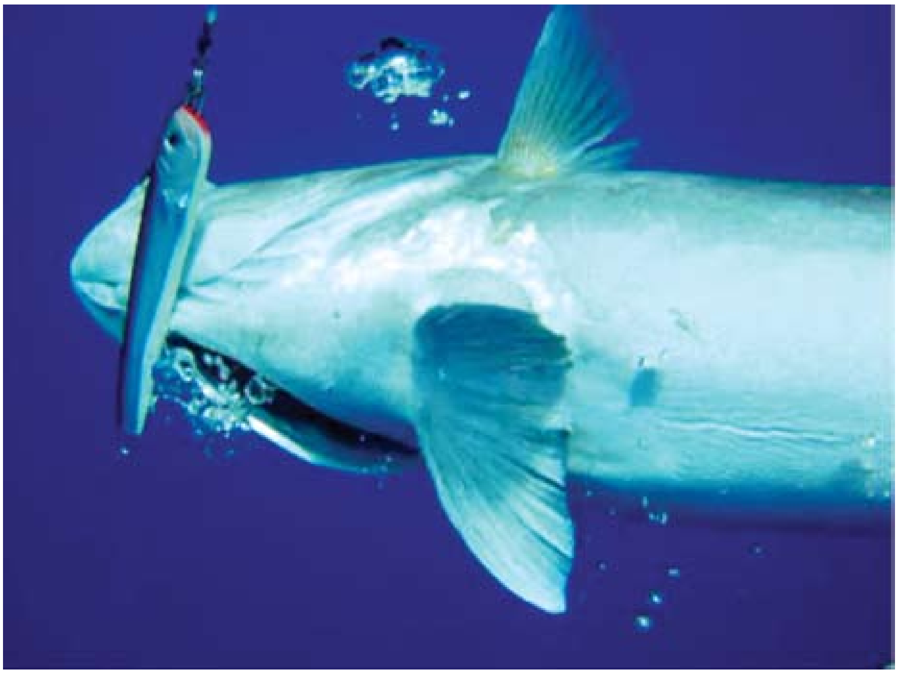

Plate 5.1. Release of gas from under the operculum of a captured Samson fish.

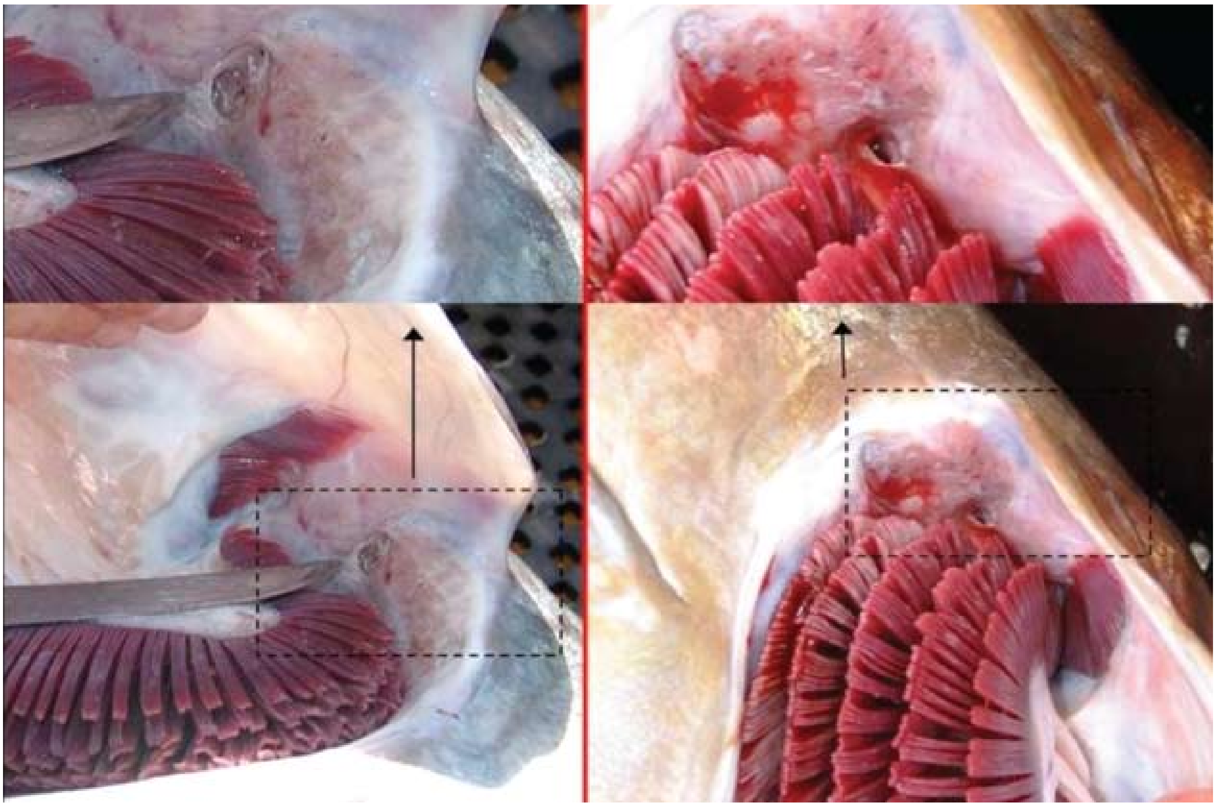

Plate 5.2. Hole found under the operculum where gas is released from the swim bladder of Samson fish during ascent.

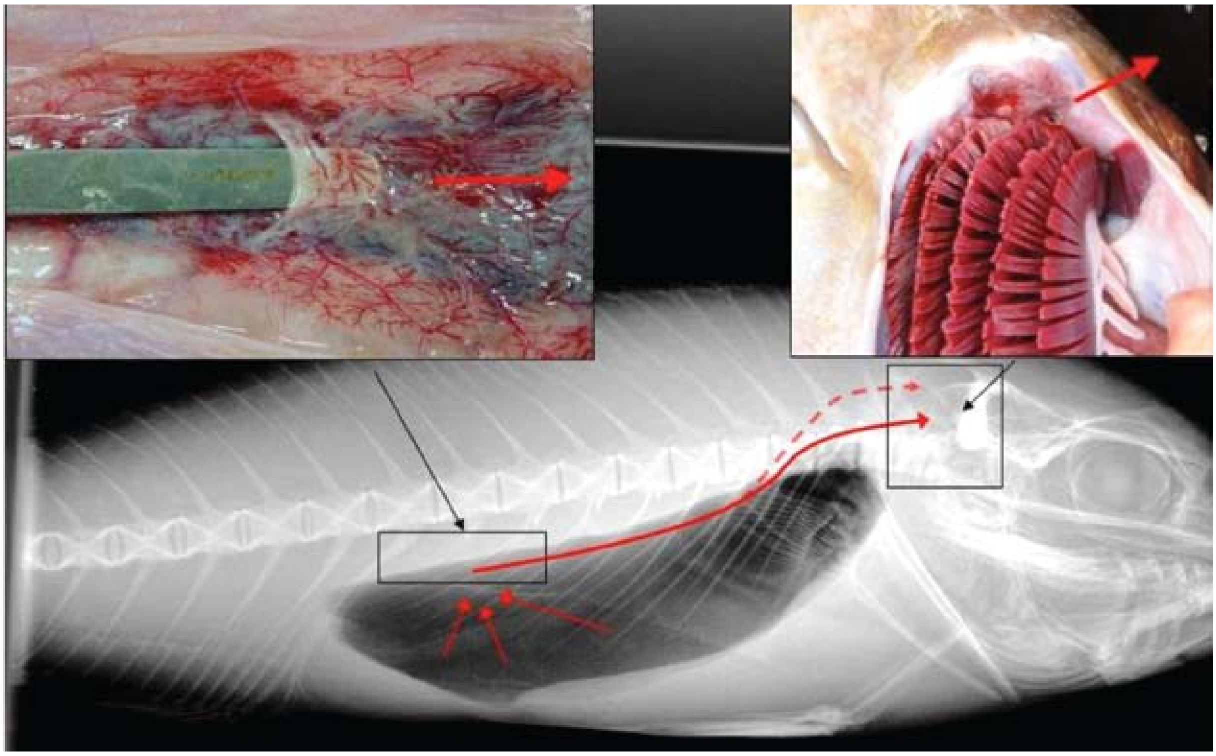

Plate 5.3. Top left photo; the opening in the top of the swim bladder that allows the release of expanding gases through vasculated areas underneath each operculum (tope right photo). The x-ray image shows the path taken by expanding gases through the opening and along a membrane-lined sinus towards the opercula. The dashed line denotes split of sinus as gas is directed to each operculum.

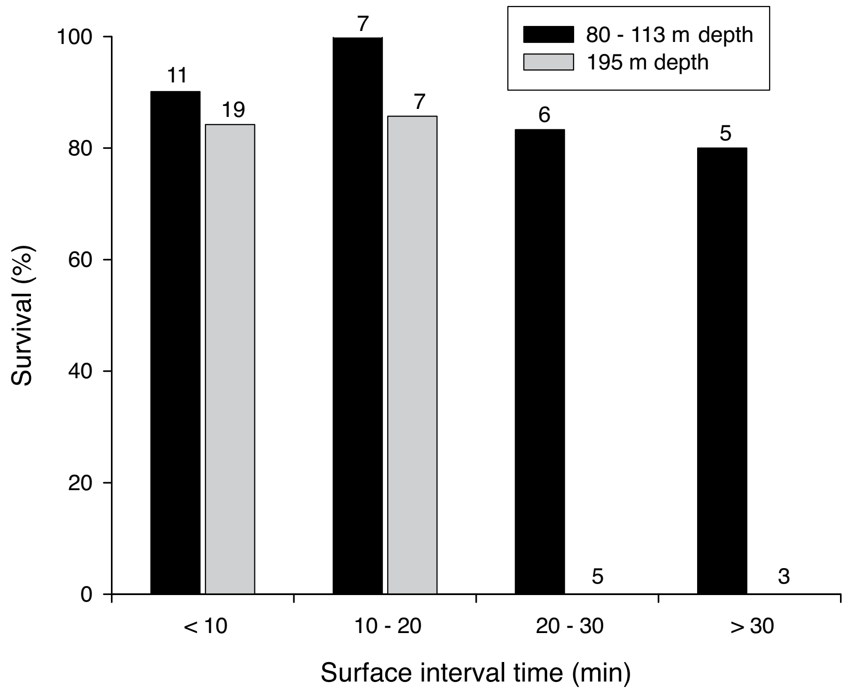

Figure 5.17. Survival of Samson fish caught from 80-113m and 195 m depth subjected to different surface interval times.

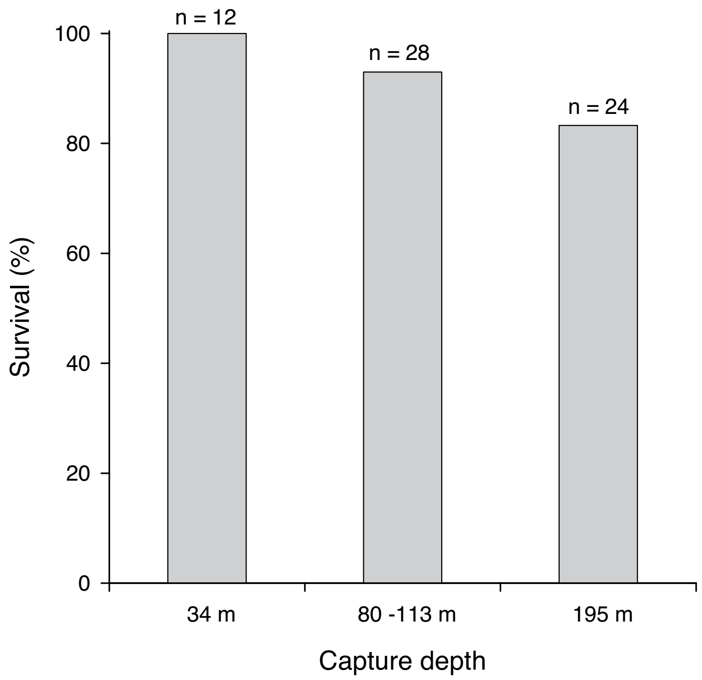

Figure 5.18. Post release survival of Samson fish from three depths of capture.

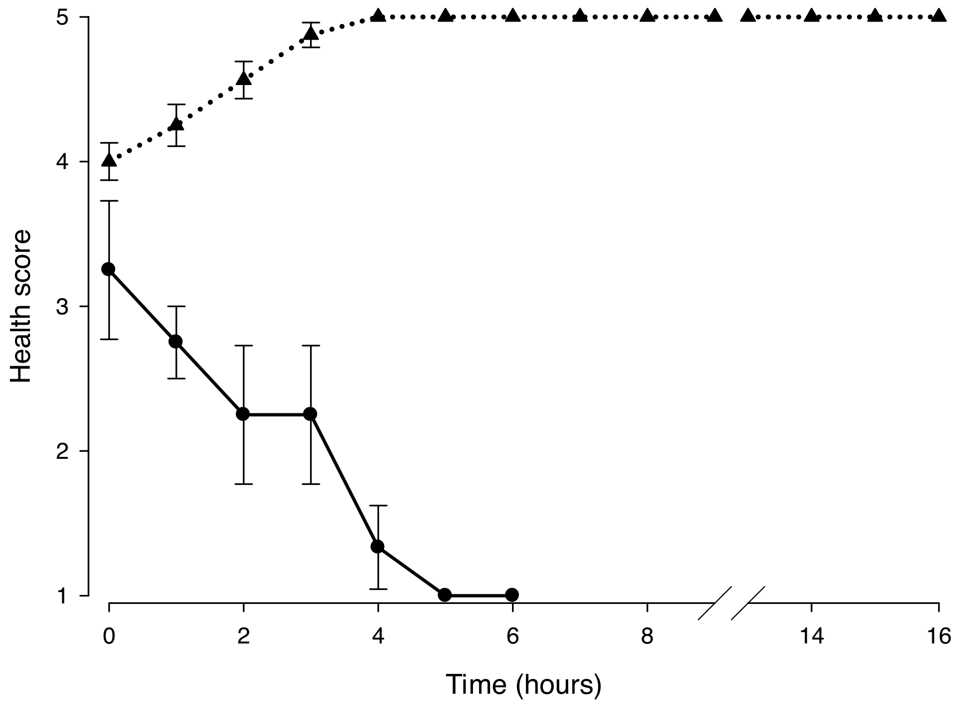

Figure 5.19. Mean health score of Samson fish that survived (dashed line) and died (solid line) after capture from 195 m depth. Note all mortality occurred with 5 hours. Mean health score ranged from 1 (dead) to 5 (healthy); refer to Section 2.11.2.

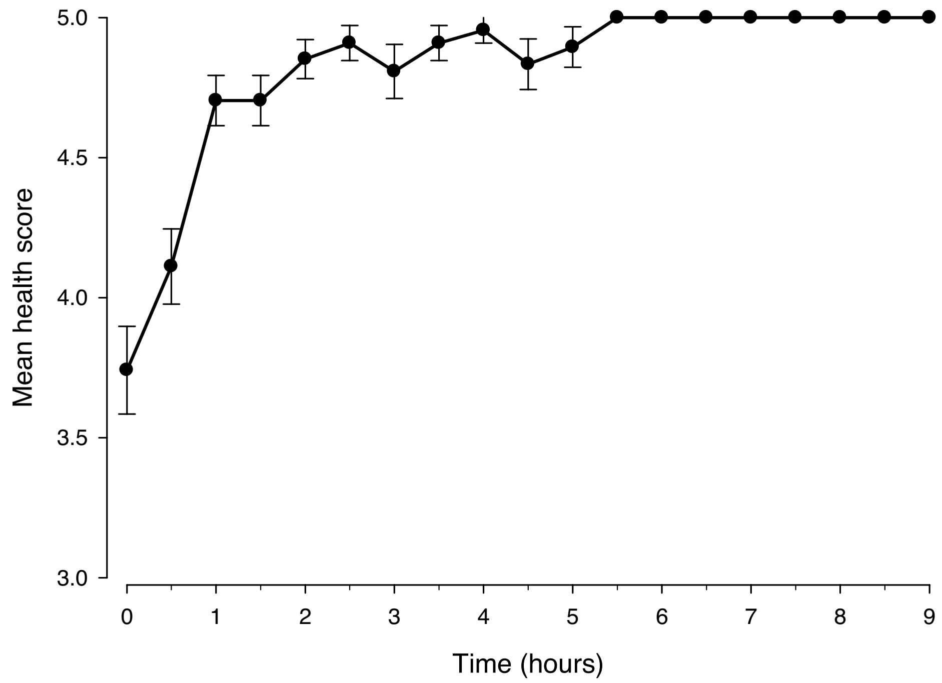

Figure 5.20. Mean health score of Samson fish that survived capture from 80 – 113 m depth. Note two fish died after capture from this depth range. Refer to Section 2.11.2 for details of health score given to fish.

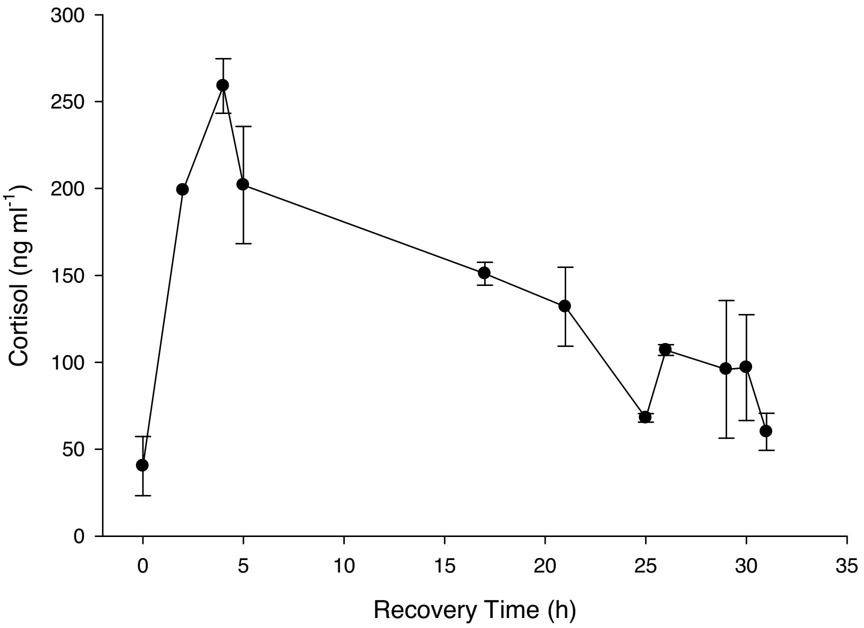

Figure 5.21. Mean (± 1S.E.) plasma cortisol levels in Samson fish for each recovery period.

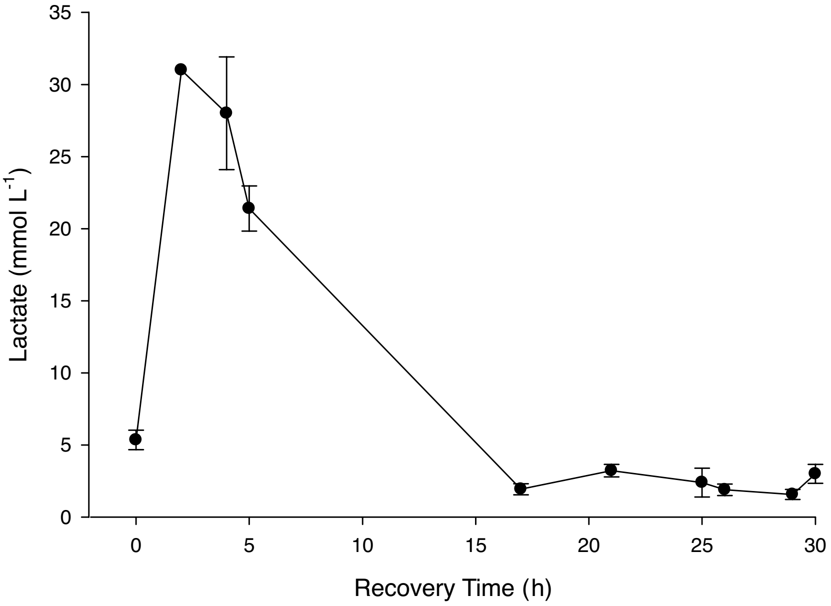

Figure 5.22. Mean (± 1 S.E.) plasma lactate levels in Samson fish for each recovery period.

5.3.3 Samson fishing protocols

Based on the data presented above and observations made by research staff and anglers the following broad statements can be made about the impacts of fishing on Samson fish[7]:

1) Almost all lure caught fish were hooked in the hinge of the jaw and very few were bleeding. Most fish that were deep hooked and the vast majority of fish that were bleeding were

[7] The brochure 'Catching and caring for Samson fish' provides a summation of protocols for anglers (Appendix 11).

caught on baited hooks. However, current studies from elsewhere in the world indicate that the use of circle style hooks (i.e. hooks in which the point points directly at the hook shank rather than being parallel to the shank) with no or only a minimum offset (i.e. the plane of the hook point is parallel or close to the plane of the shank rather than the plane being offset by as much as 15°) would result in less deeply hooked fish and less trauma (see Cooke and Suski, 2004 for a review of hook damage by different style hooks). Although circle hooks have been shown to have lower capture efficiency than other conventional hook types in some species this is invariably a result of the anglers striking at bites as they would when using normal J-shaped hooks, such a strike has the effect of pulling a circle hook out of the fishes mouth as they are designed to roll over and catch in the hinge of the jaw as the fish takes a bait, turns and swims away (Cooke and Suski 2004). However, even without a change in fishing practices this type of hook is still very effective in the capture of Samson fish, as even though several strikes may not result in hook ups at most sportfishing sites, hook ups will inevitably occur due to the abundance and voracious striking nature of this schooling species. Thus, jigs with single barbless hooks are the preferred method of capture, whilst bait fishermen should use barbless circle style hooks with minimum offset. If barbless hooks are unavailable anglers can use pliers to crush or break the barb on barbed hooks.

2) The sock trial and tagging data sheets show that the longer fish are out of the water the greater the mortality. It is also likely that sub-lethal trauma increases with time out of water. These findings are in agreement with several published studies that consider reducing the time out of water is a critical factor in maximising the survival of released fish (Cooke and Suski 2005, Arlinghaus 2007 and references therein). To minimise fish exposure time the following should be adhered to: a) unhook fish in the water if possible, b) use barbless hooks or crush the barb on barbed hooks to make unhooking easy and fast, c) if deep hooked, cut the line a few centimetres outside the mouth (this stops the line interfering with feeding), d) if fish are removed from the water for dehooking and tagging, have all necessary equipment to hand, work swiftly and ensure that fish are placed on a wet, cool surface, e) if fish are removed for photographs, ensure that the camera is ready and everyone knows where the photographer and subject will stand/sit before removal from the water.

3) In their natural environment Samson fish are supported by water. When possible Samson fish should be left in the water alongside the boat for de-hooking and release. Barbless hooks can simply be removed and the fish orientated into position of 'spear' release. If fish have to be brought onboard, do not gaff them, do not use grips to lift them by the lower jaw, and do not lift them just by the tail or gills. Preferably support each fish by both the head and tail, or if necessary use a knotless landing net.

4) The most effective way of returning Samson fish is to 'spear' them back into the water. This procedure entails supporting the weight of the fish with one hand just behind the head and under the gut, and the other around the caudal peduncle (the narrow wrist section anterior to the tail). The fish is then speared head first into the water, in the vast majority of cases the fish will swim strongly back to the school below (underwater video shows just how quickly fish recover when this method is used). In contrast fish that are dehooked and then gently released tend to swim downwards for a short distance before resurfacing and floating off. This method of spearing fish back into the water also seems to be effective for other species such as pink snapper (*Pagrus auratus*) and silver trevally (skippy; *Pseudocaranx dentex*). However, be careful not to slam the fish back into the water with excessive force.

5) If a fish returns to the surface and floats, lines should be immediately brought in, fishing ceased, and the fish followed and retrieved as quickly as possible. On retrieval the health of

the fish should be assessed, if the fish appears relatively healthy the spearing method should be reattempted. Alternatively, if the fish is deemed to be tired or has an inflated abdomen it should be released with the aid of a release weight. The weight is attached to a hand-line or rod and reel (preferably all ready set up and specifically used for this purpose). The hook is then placed in the jaw of the fish and the fish released, the weight quickly takes the fish to deeper water, compressing the swim bladder and gas in sinuses as it descends. Once the fish has reached approximately 40 metres a series of sharp tugs on the line frees the fish, it is worth noting that one can often feel the fish start to swim strongly and release itself well before this depth is attained. In the case of fish that the angler deems to be less healthy or completely exhausted (little or no movement and shallow and rapid movement of the gill covers) or if the release weight needs to be made ready, the fish should be swum by the side of the boat or brought onto a wet, cool boarding platform and have a deck hose placed in its mouth, this procedure ensures that the well oxygenated water is passed over the fishes gills. Fish revived using a deck hose should have their eyes covered with a wet hand or towel to reduce the effects of UV light on their retina. Once the fish shows signs of revival (deep slow movement of the gills and strong tail beats) it should then be attached to a release weight and released. Although the low number of recaptures currently precludes statistical validation of the effectiveness of the release weight, the fact that tagged fish that anglers considered in very poor condition and released using this method have been recaptured after more than a year at liberty suggests that the method can only benefit the welfare of the animal.

6) Various shark species, including shortfin mako (*Isurus oxyrinchus*) and whaler sharks (*Carcharinus* spp.) appear regularly at the aggregation sites and attack hooked and released Samson fish. Immediate mortality caused by acute injuries or predation when fish are hooked at the Hillarys spawning aggregation can often approach 100%, to the point where fishers are unable to land a single fish. If Samson fish are constantly being taken by sharks fishing should cease and anglers should move to other fishing grounds.

7) If anglers intend to take some fish for a meal then the best practise is to place the fish in an ice slurry and then bleed the fish by cutting the gill bars or area in front of the heart just behind where the gill plates join. For fish that are too big to be easily anesthetised in an ice slurry it should still be bled and then kept covered by a wet towel. An iki jimi can also be used, but if not properly used can injure the fish or fisher. It can also damage the otoliths that are used to age the fish, thereby limiting its use in research.

5.4 Movement

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5.4.1 Results

Most of the recaptured Samson fish originally tagged at the metropolitan spawning aggregations were recaptured either within the metropolitan area (56%) or between 10 and 2500 km south and east (41%) of these aggregations. Only 3% of these 'metropolitan' fish were recaptured to the north of the aggregations, having travelled distances of between 10 and 330 km (Figure 5.23). For fish in which sex was determined using cannula techniques prior to release ($n = 30$), recapture rates of females to males was 2:1.

Of the 82 Samson fish recaptured south of the spawning region, 79% (or 32% of all recaptures) had moved > 100 km and 42 % (or 16% of all recaptures) had moved > 500km. The mean distance travelled by fish that had moved south of the aggregations was 440 km (± 52 km SE). Two Samson fish tagged at the Rottnest aggregations were recaptured on the eastern side of the Great Australian Bight near Kangaroo Island in South Australia, a distance of over 2400 km (Figure 5.23), these fish were at liberty for 215 and 276 days.

The number of recaptures versus days at liberty for fish tagged at the spawning aggregations sites showed distinct periodicity with peaks in recaptures corresponding to the return of Samson fish to the summer spawning aggregations (Figure 5.24). The average days at liberty for Samson fish recaptured at the spawning aggregation sites during the two subsequent spawning seasons was 372 (± 6.1 SE, $n = 49$) and 721 days (± 6.1 SE, $n = 22$), or almost exactly one or two years later.

Thirty Samson fish were released and recaptured at the spawning aggregations sites within the same spawning season. The duration at liberty ranged from 0 to 36 days with an average of 12 days (± 1.8 days SE). This indicates that fish can stay at the aggregation sites for over a month. Although most of these fish (70 %) were recaptured at the same aggregation site, 30% (9 individuals) were recaptured at an aggregation other than the site of release (Figure 5.25).

Movements between spawning aggregations were also considerable between spawning seasons (Table 5.9). Of the 124 recaptured Samson fish released at the north barge, 22 (18%) were recaptured at the outer patch in subsequent spawning seasons. During the same period, 10 (14%) of the 70 recaptured fish tagged at the outer patch were recaptured at the north barge and eight fish from the spawning aggregations near Rottnest Island moved to the spawning aggregation off Hillarys (Table 5.9).

Tagging of Samson fish in the southwest region confirmed that individuals were also moving northwards to the aggregation sites west of Rottnest Island. Of the 26 recaptured fish released in the southwest region 6 (23 %) showed northward movement > 50 km (Figure 5.26). This included four Samson fish tagged near Cape Naturaliste that were recaptured at the aggregation sites after being at liberty for between 53 and 423 days. One individual originally released near Mandurah was recaptured after northern movement to the spawning aggregations and then recaptured for a second time after returning south to the original tag site. This Samson fish was clearly migrating between the summer spawning grounds west of Rottnest Island and an area to the south (possibly Mandurah).

Many recaptured Samson fish tagged at the spawning aggregation sites showed fast southward movements (Figure 5.27). For instance, one Samson fish (1250 mm FL) released at the Rottnest Island spawning aggregations was recaptured approximately 1000 km southeast near Esperance (34° 16.79' S, 122° 02.38'E) after being at liberty for 26 days, which is equivalent to at least 39 km day^{-1}. Another smaller individual (1080 mm FL) was recaptured east of Bremer Bay (34° 26.52'S, 120° 03.56'E) after 25 days at liberty and displayed a movement rate of at least 34 km day^{-1}. Overall eight fish (4 %) moved at a rate > 10 km day^{-1} after leaving the spawning aggregations. This indicates that fish quickly return to habitat in the south, and corroborates observations that the number of fish at the aggregations diminishes quickly at the end of the aggregating period. No correlation between distance moved and time at liberty was found for fish that were recaptured away from the spawning aggregations within a 365 day time period ($R^2 = 0.04$, $df = 40$, $P = 0.79$) (Figure 5.21).

Tagging suggests that Samson fish undertake similar migration patterns and may possibly even travel together. For instance, two individuals (1200 and 1000 mm TL) tagged at the north barge on the same day in January 2004 were recaptured 24 and 30 days later, respectively, in the same area near Albany. Similarly, three individuals released near Mandurah on the same day in April 2006 were each recaptured ten kilometres north of the tag site, on the same day and by the same fisher, 80 days later. These individuals varied substantially in length from 920 to 1210 mm TL.

Data for mean monthly sea level at Rottnest Island, used as an index of the strength of the southward flowing Leeuwin Current, shows that Samson fish are migrating north to the aggregation sites west of Rottnest Island when this current is at its weakest (Figures 5.28).

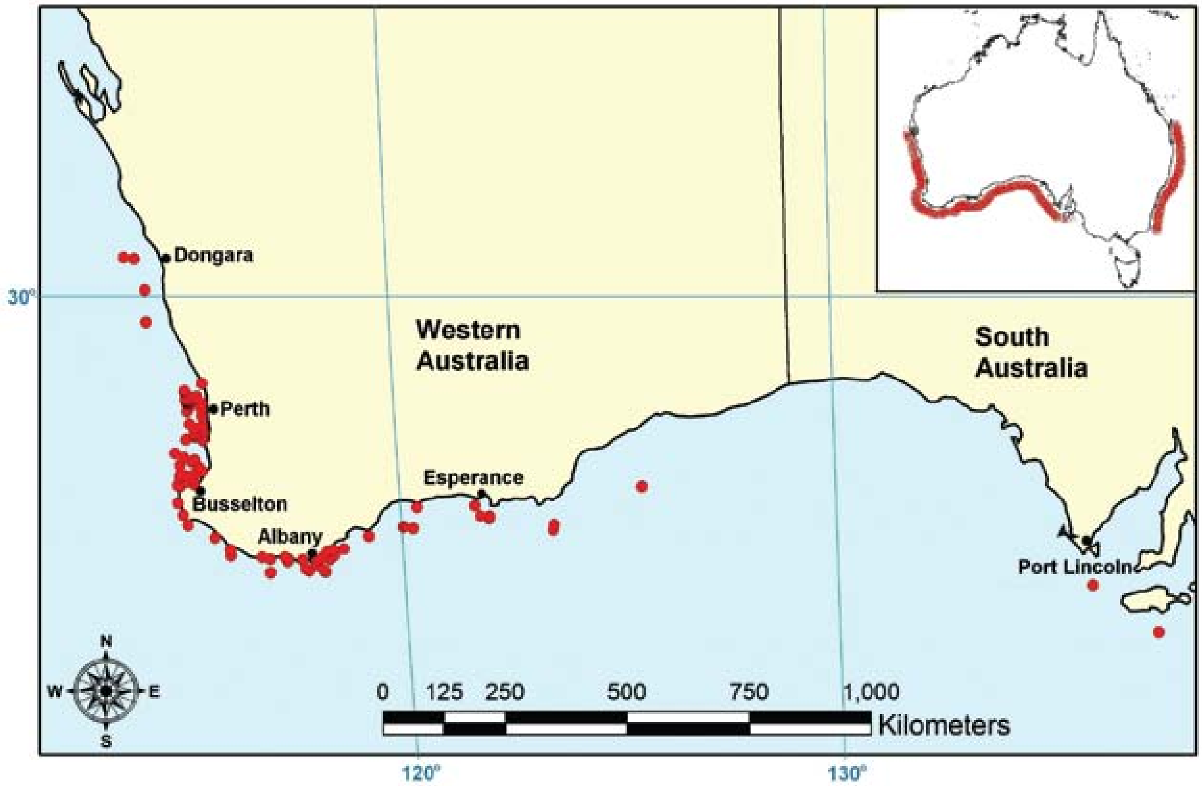


Figure 5.23. Map of south west Australia showing recapture locations of Samson fish tagged and released at the summer spawning aggregations west of Rottnest Island. The inset shows the distribution of this species in Australian waters, highlighting the large area over which individuals tagged at the Rottnest aggregations were recaptured.

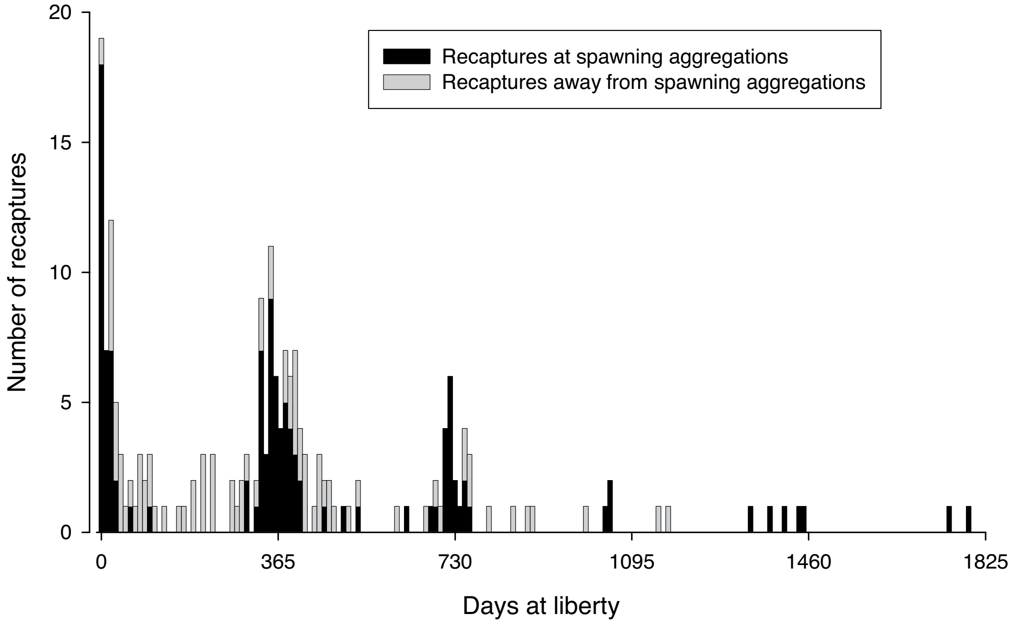


Figure 5.24. Number of recaptures plotted against time at liberty for Samson fish tagged at the spawning aggregation sites west of Rottnest Island. Days at liberty are in 10 day intervals. Recaptures at, and away from, the spawning aggregations are indicated.

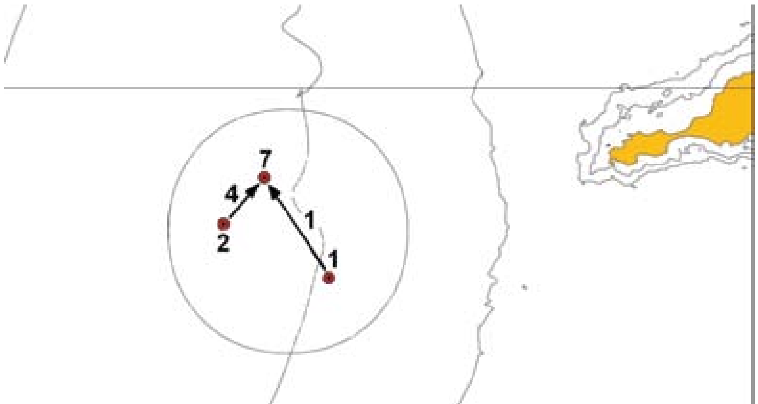


Figure 5.25. The location of Rottnest aggregations showing the number of Samson fish tagged and either recaptured at the same aggregation or at another aggregation (arrows indicate the direction of movement).

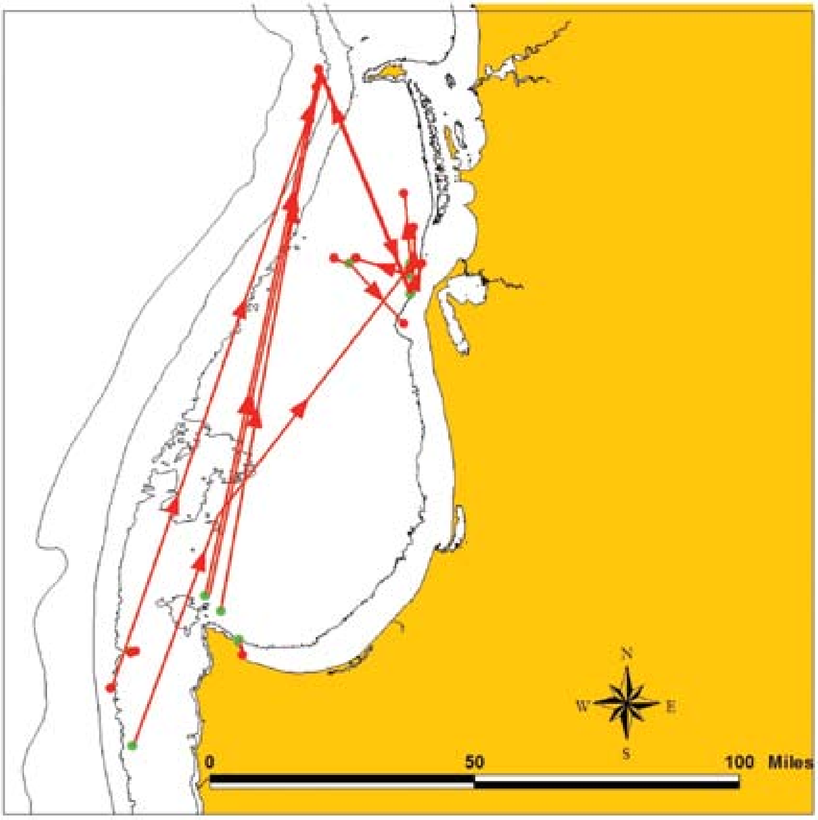


Figure 5.26. Movements of Samson fish tagged and released in the Southwest region of Western Australia.

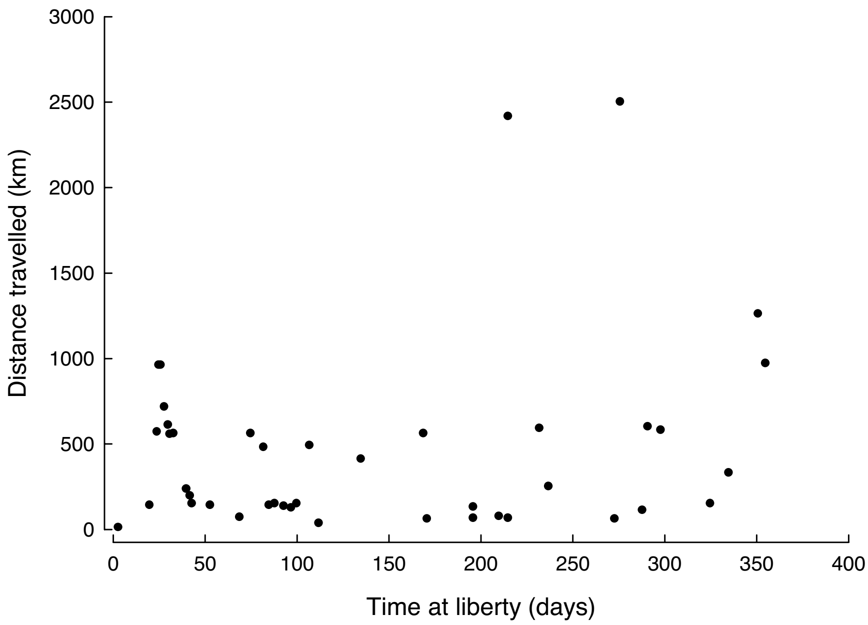


Figure 5.27. Distances moved and times at liberty of Samson fish tagged at the spawning aggregations west of Rottnest Island. Data only shown for fish at liberty for < 365 days that were recaptured away from the spawning aggregation tag site.

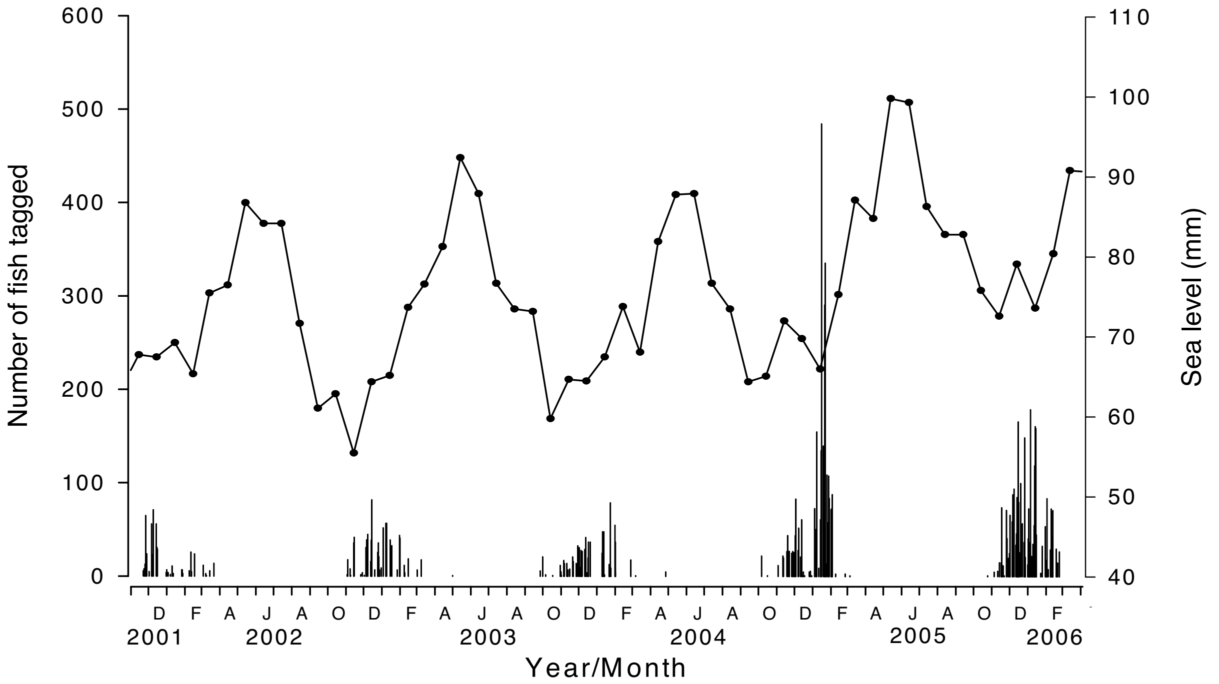


Figure 5.28. The numbers of Samson fish tagged at the spawning aggregations west of Rottnest Island between November 2001 and March 2006 and the mean monthly sea level at Fremantle (an index for the strength of the Leeuwin Current) throughout that period.

5.4.2 Discussion

During this study, Samson fish tagged at the aggregations sites west of Rottnest Island were subsequently recaptured throughout most of the species range in the south and west of Australia. This indicates that the 'western' population of Samson fish is well mixed. Nevertheless, the majority of fish that participate in the RI aggregations move there from southern waters. This is supported by observations from fishers that, whilst Samson fish numbers remain fairly constant during winter, a large increase in the numbers of Samson fish occurs between October and March. This presumably reflects mass movements of this species through these coastal regions at this time.

Distances moved by Samson fish migrating to the Rottnest aggregation sites may be relatively short, perhaps from Mandurah or closer, or they may be from as far away as Kangaroo Island in South Australia. Long distance movement between spawning and feeding grounds has also been reported in other *Seriola* species (Baxter 1960; Thompson *et al.* 1999). In a tagging study of *S. lalandi*, Gillanders *et al.* (2001), found large-scale movements (> 500 km) of individuals along the east coast of Australia, with three fish travelling over 2000 km from New South Wales to New Zealand waters.

It is clear, therefore, that the Rottnest aggregation sites are important for spawning by southern populations. However, reproductive data indicates that individuals with reproductively ripe gonads are found in locations further south (see biological section), indicating that spawning occurs elsewhere as well. The spawning and associated migration pattern of fish to the north of the metropolitan area is unclear. Nevertheless, biological data shows that fish in these northern areas are also reproductively active.

When at the aggregating sites individuals may stay there for over a month. However, observations made at the end of the aggregating period indicate that most fish leave the Rottnest Island area quickly, and move rapidly back to southern habitat. The fact that no fish tagged in the southwest were recaptured south of the original tagging location suggests that individuals return to the same location after spawning and reside there in the general vicinity over the winter months. The high recapture rate displayed in the southwest region, including the particularly high recapture rate (8.6%) by one particular fisher who fished within a small area, also indicated that this species is likely to inhabit the same reef area for most of the time between spawning events and return to that area after spawning. Comparable rates of recapture were also found for *S. lalandi* from waters off N.S.W. (8%) and South Australian (8.2%) which did not target spawning aggregations and where the majority of fish were recaptured within 50 and 5 km of the release point, respectively (Gillanders *et al.* 2001; Hutson *et al.* 2007). Samson fish also show strong spawning ground fidelity as the many of fish released at the spawning aggregations were recaptured at the exact same spawning site. Interestingly, the temporal pattern displayed in these recaptures also revealed that most Samson fish return to the spawning aggregations at the same time in subsequent years, for example the average days at liberty of these returning fish was 372 and 721 days.

It is likely that Samson fish migrate to and from the aggregation sites in schools, as indicated by the often sudden arrival and departure of fish at fishing grounds, and the fact that individuals within these schools are usually similar in body size. Travelling in schools is likely to provide individuals with energetic savings and increased endurance during migration, because wakes and vortices generated by fish around them reduce hydrodynamic resistance (Weihs 1973). For instance, in a study on another carangid species, Zuyev and Belyayev (1970) found that the tail beat frequency of trailing fish with in a school of horse mackerel (*Trachurus mediterraneus*) was 71-85% the frequency of the leading fish. Similarly, Herskin and Steffensen (1998) found the tail beat frequency of a sea bass (*Dicentrarchus labrax*) individual swimming at the rear of a school was up to14% lower than when at the front which corresponded to a 9-23% reduction in oxygen consumption rate. Likewise, through modelling methods, Weihs (1975) showed fish could gain up to a 65% energy saving when travelling in schools.

In addition to energy saving demonstrated by swimming in schools, energy savings are also likely during migrations of Samson fish as fish return to their feeding ground on the southerly moving Leeuwin Current. The Leeuwin Current is an annual southward flowing warm water mass that has been shown to play an integral role in the life history of many marine fish on the west coast of Australia, including pilchards (*Sardinops sagax neopilchardus*), whitebait (*Hyperlophus vittatus*), Australian salmon (*Arripis trutaceus*), and Australian herring (*Arripis georgianus*) (Caputi *et al.* 1996). This dominating ocean current flows most strongly during the southern autumn and winter months (April to September). The speed of this current is generally around one knot (0.5 ms^{-1}), although speeds of two knots (1 ms^{-1}) are common and a maximum speed of over three knots (1.7 ms^{-1}) has been recorded (Cresswell 1980). The current generally flows along the continental shelf eastwards across the Great Australian Bight after rounding Cape Leeuwin (Maxwell and Cresswell 1981).

During late spring and summer (November and March) strong northward wind stresses in the south west of WA slow the Leeuwin current, pushing it offshore (30 to 90 km), and drive the northerly flowing Capes Current (Pearce and Pattiaratchi 1999). The Capes Current is strongest between Cape Leeuwin and Cape Naturaliste where it flows along the inner continental shelf. Measurements near Perth suggest that this current transports cooler water past Rottnest Island during the summer months. The Capes Current may therefore provide assistance to Samson fish moving westward around Cape Leeuwin and up the west coast on their return to the spawning grounds during late spring and summer. Similarly, the Leeuwin Current may greatly aid adult Samson fish returning to feeding grounds in southern waters. The increase in the speed of the Leeuwin Current and its expansion into inshore waters as the Capes Current dissipates at the end of the spawning season may also facilitate the dispersal and subsequent recruitment of larvae and juvenile Samson fish into inshore habitats in the south western and southern coast of Australia.

Although the overall recapture rate of Samson fish between 2001 and 2007 (2.2%) was similar to that recorded for Samson fish tagged in South Australian waters (2.3%) (Hutson *et al.* 2007), the rates of recapture of fish tagged at the spawning aggregations varied considerably. This is most likely because fish tagged in the earlier years have been at liberty for longer and therefore have had a greater chance of encounter. The overall recapture rate of Samson fish is low compared to other marine fish for which conventional tagging studies have been undertaken within Australia, such as pink snapper (*Pagrus auratus*, 7.9%) and yellowtail kingfish (*S. lalandi*, 8.2%) (Hutson *et al.* 2007; Moran *et al.* 2003). The low recapture rate of Samson fish in the current study is most likely due the large scale migratory movements of this species and the fact that many tagged individuals are likely to move into southern waters where there is limited or no fishing effort. Further, this species is not normally targeted by recreational fishers for eating purposes, and relatively few fishers in the southwest target this species for sport compared to the metropolitan area.

5.5 Otolith microchemistry

Steven Fisher, Michael Mackie, Cameron Scadding, John Watling, Allen Thomas and Paul Lewis

5.5.1 Preliminary assessment of the effect of sample preparation on the analysis of the elemental composition of otoliths from Samson fish using LA – ICPMS techniques

This preliminary study showed that the (normalised) abundance of ^{88}Sr changes across the otolith section surface, increasing from the distal edge (nearest the primordium) outwards (Figure 5.29), and that the rate of change differs between the otoliths of different fish. Analyses also show that within a single section of an otolith, there are slight differences in ^{88}Sr abundance, depending on which portion of the surface was analysed i.e. which track the laser followed (Figure 5.30).

The data from all of the elements of low abundance have not been analysed in detail here. Instead ^{55}Mn, the abundance of which is about three orders of magnitude less than ^{88}Sr, has been used as a surrogate for these. In general, the abundance of ^{55}Mn is higher closer to the primordium than at the outer margins, but the variability between sections from the same otolith is much more pronounced than for ^{88}Sr (Figure 5.31).

Provided the otoliths are prepared carefully, we can obtain a surface representative of the otolith material around the primordium amenable to LA-ICPMS analysis. The cut section to be analysed must be within approx 500 - 600 µm of the otolith primordium. Consistency in selecting the portion of the surface to be ablated is also important. This study showed that the ventral ageing transect yields consistent results for ^{88}Sr and ^{55}Mn between surfaces of the same otolith, and this would therefore be the preferred transect for comparison of the elemental composition between otoliths using LA-ICPMS.

A series of ablated discrete spots yields less comparable yet less ambiguous data from LA-ICPMS analysis than does a continuous line since the latter results in a continuous moving average signal or "smearing" of the data. The highest resolution analysis of the surface would be achieved by ablating a series of discrete spots with their edges just failing to intersect. Another advantage of this technique is that the initial seconds of the laser ablation of each spot can be considered as decontamination of the surface, and the data disregarded until a stable signal is acquired.

The raster laser pattern was also investigated here, although detailed analysis of the data is not presented. Notwithstanding the incomplete data analysis, because the laser was directed across the otolith section in the dorsal/ventral direction, the signal was "smeared" in this direction rather than along the ageing transect, a distinct advantage over the linear tracks. The raster pattern also enabled mapping most of the otolith surface, from which any heterogeneity should be more apparent than from linear tracks with either continuous or spot analysis. Using the raster pattern in a series of discrete spots would be the method of choice to map the surface were it not for the prohibitive time required for data acquisition and analysis.

5.5.2 Preliminary assessment Part II - 25 μm spot analysis.

In addition to the previously determined elements (i.e. ^{24}Mg, ^{39}K, ^{44}Ca, ^{55}Mn, ^{88}Sr, ^{138}Ba and ^{208}Pb), chromium-52 (^{52}Cr), chromium-53(^{53}Cr), copper-63(^{63}Cu), zinc-66(^{66}Zn) and cadmium-111(^{111}Cd) were also determined (e.g. Figure 5.32). Here, each data point represents the average abundance of each element normalised against that of ^{44}Ca with the first five seconds of the 30 seconds of ablation considered to be affected by artefacts of the sample preparation and therefore ignored.

Comparison of 25 μm spot analysis with previous continuous line analyses: ^{88}Strontium and ^{55}Manganese

The trend in abundances of ^{88}Sr and ^{55}Mn from the spot analysis across the otolith surface is comparable with those from the continuous-line analysis along tracks T1, T2, T4, T5, T7, T8, T10 and T11. For example in Figure 5.32 for ^{88}Sr, where the abundance increases from the core of the otolith to the outer edge, and also for ^{55}Mn., where the abundance decreases from the core outwards.

The normalised abundance at each point, however, is generally lower in the spot analysis. The reason for the attenuation of ^{88}Sr response relative to ^{44}Ca is unclear, however it is most likely to be due to a change in the performance of the mass spectrometer from July 2006, when the continuous line analysis was performed, to April 2007, when the spot analysis was performed.

Analysis of otoliths from other specimens of Samson fish

One otoliths from each of ten specimens of Samson fish was prepared as a thin section in an identical manner to that used for R1060201(2). Each section was analysed using the 25 μm spot analysis along a single track aligned along the dorsal ageing transect on the anterior surface. The distribution of normalised abundances along the ablated track for each of the differed between the otoliths, in particular those identified as potentially useful elemental tags (i.e.^{39}K, ^{52}Cr, ^{53}Cr, ^{55}Mn and ^{88}Sr), however the significance of these differences is difficult to assess in the absence of any biological information (ontogeny).

Further work required

1. Examine the sections under a microscope to determine the position of the growth rings relative to the ablated spots.
2. Superimpose the position of these rings on the *x-axis* of the graphs of individual specimens shown in Figures 39 to 50.
3. Assign a date (i.e. year) to each of the growth rings and superimpose on the *x-axis* of the graphs shown in Figures 39 to 50.
4. Perform a statistical analysis on especially ^{39}K, ^{52}Cr, ^{53}Cr, ^{55}Mn and ^{88}Sr abundances, to determine the significance of differences in each between years.
5. Perform a multivariate analysis amongst these elements between years.

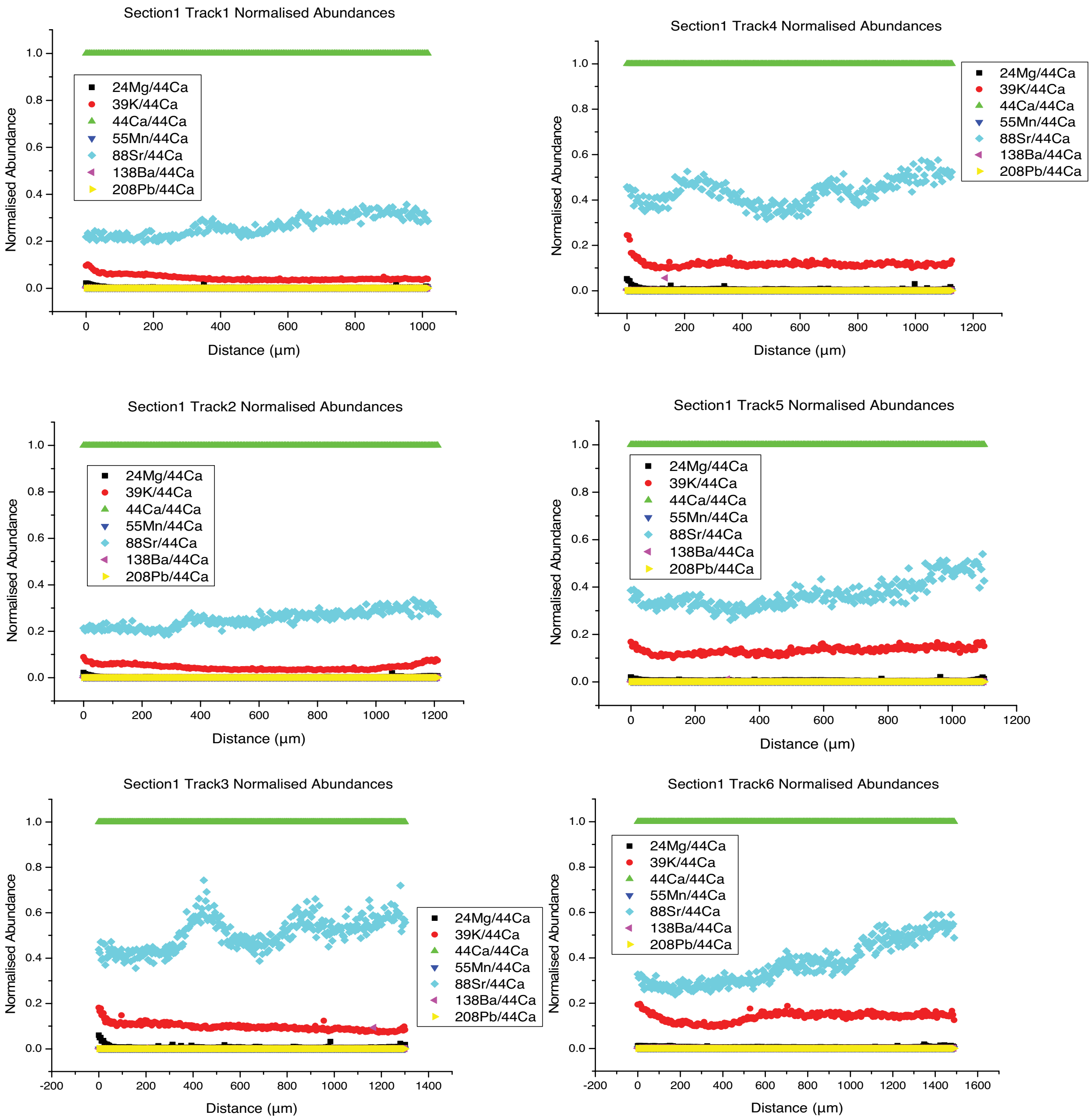


Figure 5.29. Abundances of elements determined using LA-ICPMS along Tracks 1-6 across the anterior surface of Section 1, removed from the Samson fish otolith R1060201. Abundances are normalised to ^{44}Ca. For each, the distance was measured long the ablated laser track starting on the distal side of the otolith.

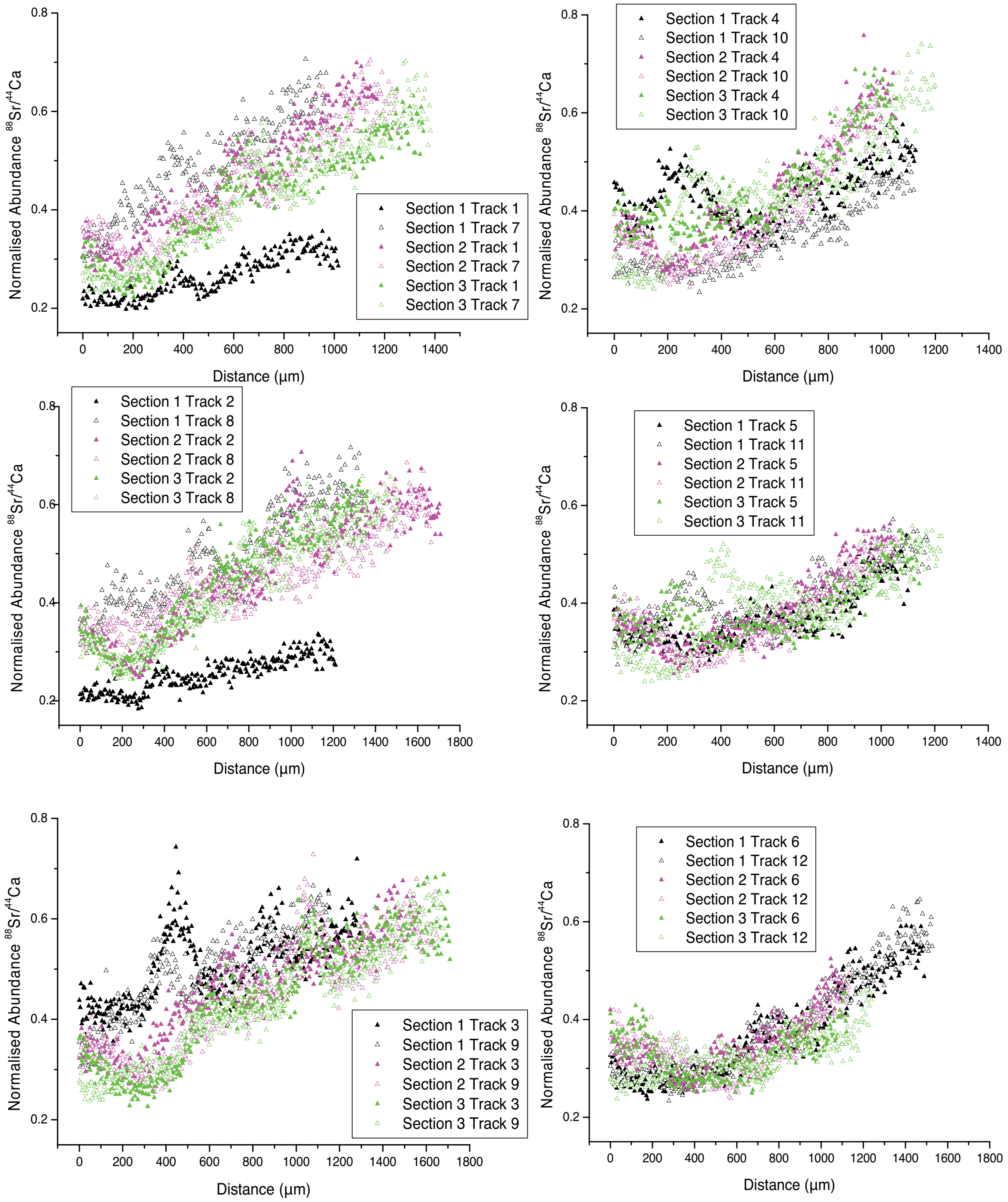


Figure 5.30. Abundances of strontium-88 determined using LA-ICPMS along comparable tracks across the anterior and posterior surfaces of Sections 1, 2 and 3, removed from the Samson fish otolith R1060201. Abundances are normalised to ^{44}Ca. For each, the distance was measured along the ablated laser track starting on the distal side of the otolith.

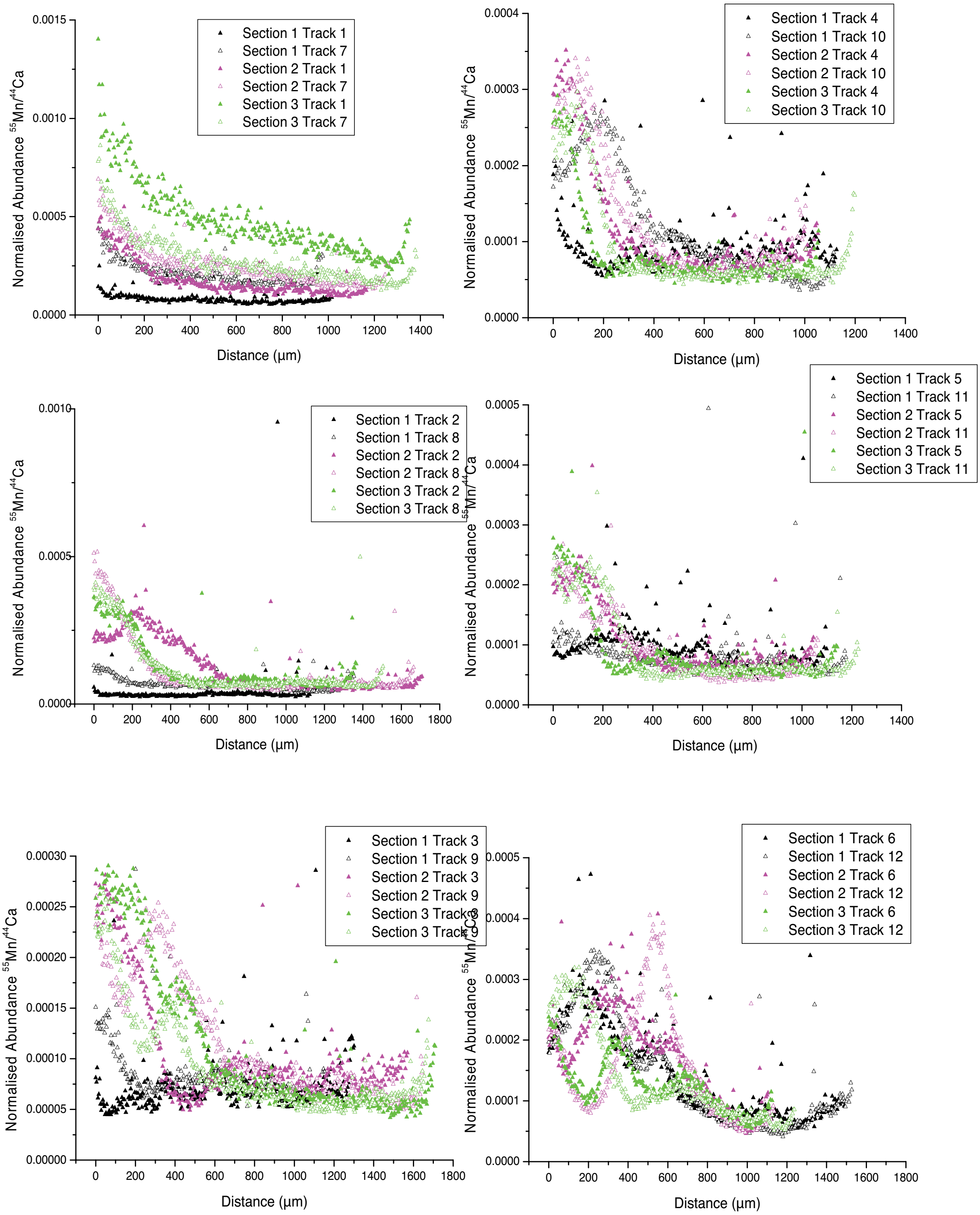
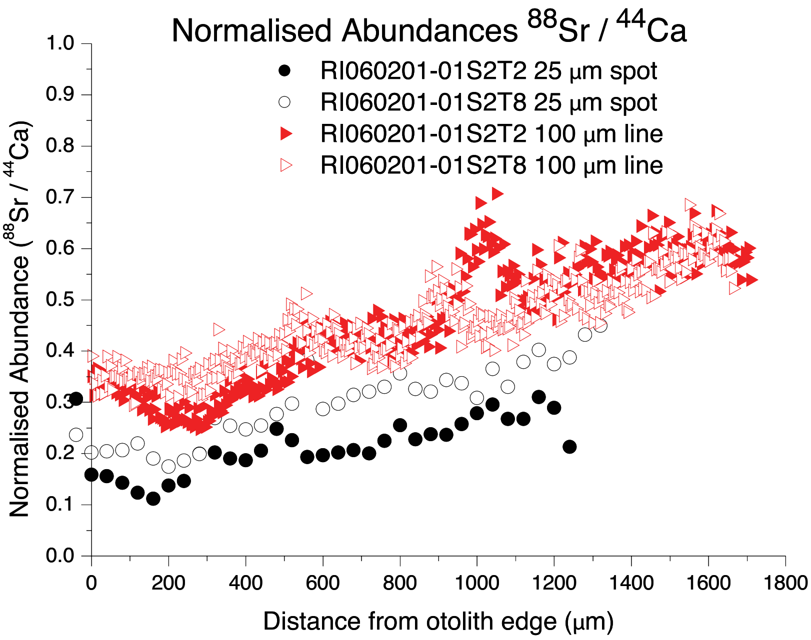


Figure 5.31. Abundances of manganese-55 determined using LA-ICPMS along comparable tracks across the anterior and posterior surfaces of Sections 1, 2 and 3, removed from the Samson fish otolith R1060201. Abundances are normalised to ^{44}Ca. For each, the distance was measured along the ablated laser track starting on the distal side of the otolith.



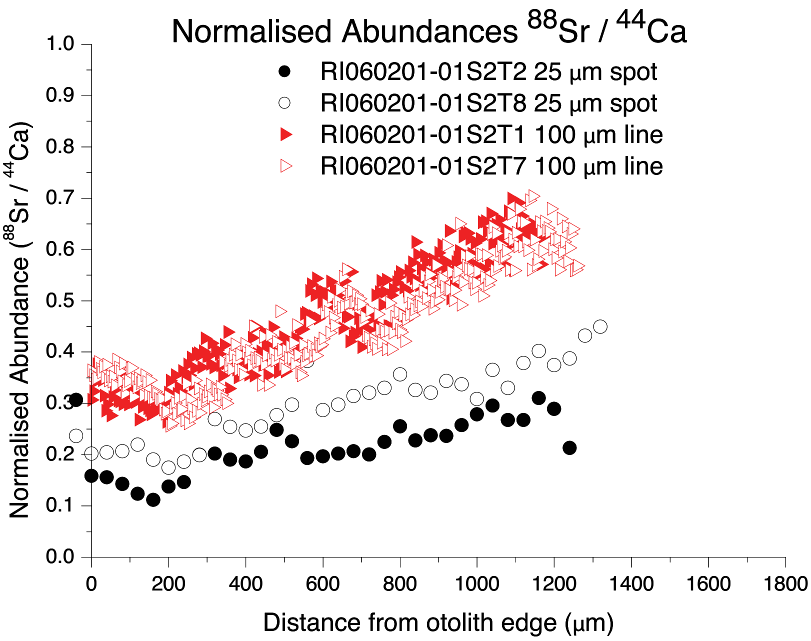


Figure 5.32. Abundances of strontium-88 determined using LA-ICPMS along comparable tracks across the anterior and posterior surfaces of Section 2, removed from the Samson fish otolith R1060201. Abundances are normalised to ^{44}Ca. For each, the distance was measured along the ablated laser tracks T1, T2, T7 and T8, starting on the distal side of the otolith. Circles denote the average values from the analysis of 25 µm spots, triangles denote the results of continuous line analysis.

6.0 Management of Aggregating Species within the West Coast Bioregion

Michael Mackie

The importance of spawning aggregations in fisheries management has become widely recognised, particularly in tropical regions where the imbalance between low stock productivity and high fishing effort has created major sustainability issues. This is exemplified by the fate of the once common Nassau grouper (*Epinephelus striatus*), which now is officially endangered in the Caribbean and tropical western Atlantic as a consequence of aggregation fishing (Sadovy and Domeier 2005). Similarly, even highly productive temperate water species that aggregate to spawn are far from immune to overfishing with, for example, stocks of the once 'indestructable' Atlantic cod (*Gadus morhua*), now severely depleted through overfishing. As such, management of this species now also includes options to protect spawning aggregations (e.g. in the Irish Sea; www.opsi.gov.uk).

There has also been increased awareness of the need to manage aggregation fishing in Australian waters (e.g. www.dpi.qld.gov.au; Tilzey *et al.* 2006). An early example of this is found in the Shark Bay commercial pink snapper fishery, where temporal closures were introduced in 1986 in an attempt to avoid overfishing (Anon 1999). Unfortunately this and other management measures at the time, including a split season to reduce targeting of spawning fish, were only partially successful due to increases in fishing efficiency. Nevertheless, protection of pink snapper when aggregated for spawning has been identified as one of the most effective ways of sustaining stocks of this species, with a temporal closure enforced since 2000 to protect an aggregation forming each summer within Cockburn Sound (Anon 2004).

These changes in the management of Cockburn Sound snapper have preceded broader changes occurring in the management of demersal scalefish throughout the West Coast Bioregion (WCB). This is being driven by the adoption of an ecosystem based approach to the conservation of marine resources by the DoFWA, and recent research highlighting the poor state of dhufish and pink snapper stocks in this bioregion (Anon 2007, Wise *et al.* 2007). Central to these changes is a significant reduction of fishing effort in order to reduce the rate of fishing mortality on dhufish and snapper to a more sustainable level. As both of these species aggregate to spawn, it is important that the strategies to control fishing effort should consider this reproductive trait. Further to this, it is important that all components of the management process, from stock assessment to stock monitoring, take into consideration aggregating behaviour and how it may affect the outcomes from these components.

This chapter focuses on key components of the management process - stock assessments, strategies for controlling fishing, and monitoring programs - and discusses how they may incorporate knowledge about aggregating behaviour. Because effective monitoring of stock status is an essential part of management, a recommended program for monitoring the abundance of key species within the WCB is also provided.

6.1 Stock Assessments of Aggregating Species

Stock assessments are used to establish the status of the resource and the levels at which it may be sustainably exploited (King 1995). Clearly, therefore, the outcomes of stock assessments should be enhanced by consideration of the role that the aggregating phenomenon has on a species' ecology and its interaction with fishers. In terms of stock assessments, the following points should be considered when analysing data and determining the potential effects of fishing on an aggregating species:

- What proportion of the annual catch is taken during the spawning period (and hence possibly from spawning aggregations).
- What temporal and/or spatial effect does aggregating behaviour have on catch data (e.g. 'spikes'), and how can this be incorporated into models. For instance, a weighting factor to allow for greater catchability of dhufish from the Cape Naturaliste region in December and January may be considered.
- What is the 'catchment' area of spawning aggregations (ie how far do individuals migrate to the aggregation site), and does this describe the spatial extent of a particular stock – and therefore the spatial scale of management.
- Is a unit of fish taken from a spawning aggregation equal to a unit taken at another time? For example, removal of a tonne of spawning snapper from Cockburn Sound may be expected to have a greater impact than removal of a tonne of non-spawning snapper captured elsewhere.
- How are estimates of biological and ecological parameters affected by biased sampling from spawning aggregations? It can be the case that individuals captured from aggregations are relatively large compared to elsewhere.
- How should sampling regimes be altered to accommodate aggregation spawning? For instance, use of the daily egg production method to estimate spawning biomass requires sampling of females just prior to spawning, and sampling of eggs from the time of release to time of larval hatching. It also assumes that the sampling area has defined borders. As such, for aggregating species it will be important to know where the aggregations form and when spawning takes place within them.
- How does aggregation spawning influence the patterns we see in the data? For example, do individuals of otherwise spatially discrete populations mix during the spawning season, thereby resulting in genetic homogeneity but otolith chemical heterogeneity? This is considered to be the case with king mackerel (*Scomberomorus cavalla*) populations (Broughton *et al.* 2002), and possibly also for Spanish mackerel (*S. commerson*) along the WA coast (Mackie *et al.* 2003).

The points listed above can potentially be used as direct inputs into models, to improve the quality of data needed for these inputs, and to determine the best way to manage fishing in response to stock assessments. These are discussed below.

6.1.1 Input of aggregation data into fisheries models

Fisheries models aim to simulate a particular process or phenomenon, and their ability to do so is dependent on the relevance and understanding of each model input parameter (Haddon 2001). Because reproductive characteristics are a typical component of fisheries models, and to ensure that the model outputs are properly put into context, it is important that the aggregating phenomenon is duly considered within the modelling process, and when interpreting the results. Given the common occurrence of aggregating species, this may not have been the case in many previous studies, largely because of a lack of knowledge or appreciation of this spawning strategy. However, examples to the contrary include the use of catch rate data for eastern gemfish taken during their annual spawning migration, and the use of acoustic survey data as a sensitivity test during a stock assessment of blue grenadier (Tilzey *et al.* 2006).

The two examples just listed come from relatively high value finfish fisheries. However, it is often the case that finfish stocks are managed on relatively small budgets and less sophisticated stock assessments that rely on simple models such as biomass dynamics (BDM) and yield and egg per recruit models (YPRM and EPRM). Along with more sophisticated age-structured models (ASMs), these models have previously been used in stock assessments of fish species in WA waters. A brief review of these models and how they may incorporate the aggregating phenomenon is provided below:

Biomass dynamics (surplus production) model.

This model provides a simple means of assessing the overall productivity of the exploited stock (Hilborn and Walters 1992, Haddon 2001). In its most basic form this model provides a measure of stock size without reference to age- or size-structure, growth, recruitment or other parameters. This model only requires a time series of catch and effort data. The following should be considered with such data:

- Catch per unit effort (CPUE) is not directly proportional to abundance in highly aggregating species.
- Catch rates may vary seasonally due to seasonal migrations.
- The effective fishing effort increases at a greater rate than nominal effort if there are increases in fishing efficiency.
- The catch and effort data need to have ‘contrast’ (ie sufficient temporal change) in order to properly model the dynamics of the population.

Clearly, the first two points are inherent problems when dealing with aggregating species, and unless catch and effort data can be standardised both spatially and temporally to accommodate these the model outputs are likely to be unreliable. This requires quite detailed information about the reproductive strategies of a particular species, as well as a means of adjusting the data to allow for changes in catchability and abundances.

As per the last two points, the catch and effort data also need to be appropriate for the analysis. This is a major issue with the DoFWA commercial database, although recent introduction of daily logbooks in some scalefish fisheries is expected to greatly improve the usefulness of catch and effort data in future stock assessments of key species.

Yield and egg per recruit models

These models estimate, for the whole cohort over time, overall gains in biomass due to growth (minus losses due to total mortality) at varying rates of fishing mortality (F) and ages at first capture. In order to overcome unrealistic assumptions of the classical Beverton and Holt (1957) YPR model, Quinn and Deriso (1999) developed a generic approach that could be adapted and extended to most fisheries and which utilises the exploitation fraction, cumulative survival, and the mean weight of fish.

As such, YPRMs are used to determine the F that optimises yield, based on the premise that this is generally not achieved by fishing as hard as possible so that a large number of small/young fish are captured, but rather by controlling effort to catch fewer, larger fish. Unfortunately, these fish typically contribute more to spawning output than do smaller individuals, and their loss may also have greater impact on the social stability of the population. In other words, it is a decision about the value of larger fish to the population and environment, and it is essential that this is properly considered when using YPRMs on aggregating species.

In contrast to YPR analyses, EPRMs attempt to avoid size-related impacts of fishing and subsequent recruitment overfishing, through a balance of yield and reproductive output. Such analysis requires estimation of the expected lifetime egg production based on information about the average fecundity of mature females in each age group and their cumulative survival since recruitment. The data required for YPR and EPR analyses include parameters for growth, fecundity at age, size and age at sexual maturity, and rates of fishing and natural mortality. Egg per recruit models are therefore more ecologically relevant and reliable for use with aggregating species than are YPRMs.

As such, information about the aggregating behaviour and spawning strategy of a particular species, including fecundity, size at maturity and spawning season, is essential for reliable per recruit analyses. As with BDMs this information may also be used to test model assumptions and to standardise the data. For instance, to standardise the estimates of exploitation fraction and mean weight in order to compensate for seasonal changes due to targeted fishing of aggregations. However, a key uncertainty with EPRMs is the estimation of fecundity, since this parameter exhibits considerable individual variation as a consequence of both environmental and social factors, particularly in species with complex social systems such as dhufish (Chapter 3).

Age-structured models

These include information about each cohort in the population and, if the necessary data are available, may reflect natural population processes and the impacts of harvesting much better than simple whole-population models (Haddon 2001). They also enable a much broader scope of data exploration and analyses, including spatial/temporal changes in exploitation rate, spawning biomass, recruitment and vulnerable biomass (Hilborn *et al.* 2003).

Data that are incorporated into ASMs include:

- Catch and effort
- Catch at age
- Numbers at age
- Catch at length
- Growth parameters
- Mortality
- Gear selectivity
- Average weight
- Fecundity, age/length at maturity

Data can be segregated to refine analyses (e.g. spatially, temporally, by sex, by fishing method). Knowledge of spawning and aggregating behaviour is of clear benefit to these refinements, for instance in allowing for seasonal changes in catchability, vulnerability, numbers at age, and catch at length. It can also be used to simulate the effect of management measures such as seasonal/temporal fishing closures. As noted above, information on spawning behaviour is also important for interpreting model outputs, and in highlighting areas of uncertainty such as in estimation of fecundity. However, as also noted previously, any models that utilise catch and effort information are inherently vulnerable to biases as a consequence of aggregating behaviour.

With an increased focus by the DoFWA on management of the broader ecosystem, models utilised in stock assessments of WA species are likely to incorporate a broader range of data than has previously been the case. Alternatively, in cases where the data for an integrated model are not available, a 'weight of evidence' approach involving holistic consideration of all relevant data may be used (Wise *et al.* 2007). With either approach, the discussion above provides insight into the importance of information about spawning behaviour and associated movement patterns when undertaking stock assessments. As discussed below, such information also has an important role in determining management actions resulting from these stock assessments, and in determining how to monitor their effectiveness.

6.2 Management of Aggregating Species

The focus of fisheries management in WA has broadened in recent years to include the cumulative effects of fishing activities and the wider environmental, social and economic issues[8]. This concept of ecosystem-based fisheries management (EBFM) requires a new approach to data gathering and management methods, and central to this is the determination of ways to reduce overall fishing mortality on key species. A variety of methods can be used to achieve this. These typically allow fishers to carry out fishing activities whilst limiting the size or number of fish that can be taken. As a consequence, 'illegal' fish (ie those that are too small or beyond a bag limit) must be released back into the water. Two issues arise with this. Firstly, survival of released fish can vary considerably, depending on the physiology of the species, the depth of capture, and the care taken during capture and release. With some species, such as Samson fish, most fish are likely to survive release if proper catch and release protocols are adhered to (see Chapter 5). However, with various other species, including dhufish, the survivorship of released individuals is often poor, particularly as fishers target stocks in deeper waters and the incidence of barotrauma-related injuries increases (e.g. St John and Syers 2005, Wyanski *et al.* 2000, fisher interviews).

The second issue relates to the broader impact of fishing activities beyond the removal of individual fish. These impacts include habitat damage from fishing gear, imbalances in predator-prey relationships, and disruption to the social organisation of surviving members of the target species. The effects of these impacts will depend on the species and type of fishing activity, however, it is likely that disruption to social organisation will be particularly relevant to aggregating species with complex social systems. For example, fisher observations indicate that the capture of a large male from an aggregation of dhufish can cause the remaining fish to stop biting. In contrast, the capture of smaller fish does not have the same effect, suggesting that loss of dominant individuals creates disturbance to the social hierarchy. Similarly, the removal of a male from social units of the hermaphroditic chinaman cod (*Epinephelus rivulatus*) will disrupt spawning whilst remaining males and sex-changing females compete for the vacated territory (Mackie 2003).

It is further possible that movement to the aggregation area may be a learnt behaviour, with sexually immature fish following reproductive adults to the aggregation[9]. Evidence for this is provided by the fact that aggregations of the Nassau grouper made extinct through fishing no longer form despite removal of fishing pressure (Carleton *et al.* 2000).

The examples listed above illustrate potential secondary impacts of fishing activities that are rarely given consideration but which may nevertheless have considerable impact on spawning output (Russell, 2001, Vincent and Sadovy 1998). They are expected to have a greater impact on dhufish than pink snapper, which are physiologically more able to cope with capture and release (St John and Syers 2005), and have a social system that is unlikely to be as affected by loss of individuals (Chapter 5).

[8] DoFWA Staff Brief 9 – Ecosystem-based fisheries management (EBFM). May 2007.

[9] Sadovy, Y. Society for the Conservation of Reef Fish Aggregations Newsletter # 8, 2005.

More widely considered and of more concern to management is the truncation of population age/size structure and the reduction in genetic diversity that occur through overfishing (Pauly *et al.* 2002, Berkeley *et al.* 2004). These are a particular concern with aggregating species, particularly if larger, older fish become more vulnerable to fishing when spawning as, for example, is the case with the large-sized pink snapper that move into Cockburn Sound each summer. It is because of these issues that the management of aggregating species, particularly in tropical waters, is more frequently incorporating measures to let more fish spawn, and to be able to do so without disturbance to their aggregating and spawning behaviour.

These measures typically involve either temporary (seasonal) or longer-term closure of an area to fishing activities. Seasonal closures can be specifically aimed at protecting adults whilst aggregated for spawning or more generally as a means of reducing fishing effort during the spawning period, such as in the case of Nassau grouper[10] and pink ling (Tilzey *et al.* 2006). Seasonal closures of specific areas to protect particular aggregations are a common management strategy in tropical waters, because they enable more strategic deployment of scarce enforcement resources and enable fishers to continue fishing in other areas or in the same area at other times, and may provide greater overall protection than do other measures (Claydon 2004, Domeier and Colin 1997). As such, they have been used in the Caribbean since 1990 (Russell 2001).

Seasonal protection of specific aggregations may be impractical, however, with species that have numerous and widespread spawning aggregations. This is the case with grouper species in Palau, where a total ban on landing grouper species is enforced during the spawning period (Johannes *et al.* 1999). Protection of specific aggregations is also impractical if there is inadequate understanding of spawning behaviour or if the level of variation in spawning activity makes it difficult to properly determine when the closures should occur. Furthermore, short-term closures may be of limited use if fish are heavily targeted when moving to and from the aggregation area (Claro and Lindeman 2003), as shown by the demise of stocks of the eastern gemfish in southeastern Australia as a consequence of targeted fishing along migration routes (Tilzey *et al.* 2006). Similarly, these closures may not be of use if stocks are also subjected to heavy fishing at other times of the year, with overfishing during this time adversely impacting the spawning output of aggregations, as demonstrated with coral trout in Palau (Johannes *et al.* 1994). Within the Perth metropolitan area, it similarly appears likely that migrating pink snapper and mulloway are also targeted when moving to and from the local aggregation sites, as mentioned by fishers during interviews.

Seasonal closures to fishing activity are generally implemented with a specific focus in mind, such as protection of a spawning aggregation. However, the objectives of longer-term closures tend to be more broadly focussed, for instance in protection of biodiversity[11], even though they may fortuitously provide protection for aggregations, as is the case with baldchin groper and coral trout (*Plectropomus leopardus*) at the Abrolhos Island (Nardi *et al.* 2006, *pers. comm.*). Nevertheless, long-term closures may potentially be effective in conserving stocks of aggregating species, particularly through maintenance of demographic and social parameters and a more stable ecosystem.

Long-term ecological benefits that may be gained from spatial and temporal protection also need to be weighed up against short-term social and economic implications to stakeholders

[10] Society for the Conservation of Reef Fish Aggregations Newsletter # 8, 2005

[11] http://www.environment.gov.au/coasts/mpa/nrsmpa/index.html

(Russell 2001). With aggregating species there are a number of factors to consider when making decisions about fishing closures. These include the size, number and location of the aggregation(s), and the area over which individuals migrate to participate in the aggregation (ie the catchment area of the aggregation). Ultimately, enforcement limitations must add a certain pragmatism to the decision making process, particularly in WA where the coastline is vast. For instance, these limits mean that it is probably not possible to protect every aggregation, making it necessary to focus on the important ones (Russell 2001). Further, in some situations it may be best to locate closures in remote areas that are less frequently patrolled by inspectors but which are outside the range of most recreational anglers. Monitoring of commercial and charter operators via the DoFWA vessel monitoring system, may then be used to check on activities of these sectors as well. However, in other situations it may be better to enforce fishing closures in areas of heavier fishing activity that are more readily patrolled by DoFWA and concerned fishers. This may enable stocks to rebuild and supply recruits to neighbouring fished areas.

Other points to consider in the planning of fishing closures include the potential for nearby areas to be subjected to greater fishing pressure from displaced fishers, although this may be countered in the long term by enhanced reproductive output of fish within the closed areas, and by movement of adults from closed to open areas. It may also be countered through implementation of other measures, such as boat limits designed to reduce significant catches of large charter and recreational vessels. Nevertheless, it is certainly the case that the issue of fishing closures is complex and controversial, requiring a focus on clear objectives and adequate discussion with stakeholders if they are to be creditable and effective in achieving these objectives. As with all management initiatives, it is also important that the implementation of fishing closures is combined with a long-term monitoring program aimed at determining the consequences of these management actions. This is discussed below.

6.3 Monitoring Populations of Aggregating Species

Recent focus on the status of finfish resources in the WCB has identified the importance of monitoring stocks of key species, particularly dhufish and pink snapper. Much of the debate on this issue has centred on the use of fishery-dependent methods that utilise information on the age structure of exploited stocks and the catches and catch rates of fishers. These fishery-dependent means of monitoring fish stocks provide unique and important information, for instance in identifying changes in the age-composition of stocks and the influence of large recruitment events, and in understanding the dynamics of the fishery.

Alternatively, the current project has focussed on monitoring methods that are not directly associated with fishing activity. As described in Chapter 4, these methods also have their particular biases and constraints, and in some cases may not be appropriate at all. At the same time, their usefulness as alternative, unique sources of data can be significant, and in situations where fishing activities are limited or not present, these fishery-independent data sources may provide the only available option for determining the effectiveness of management measures. This is the case in areas where fishing closures prohibit the sampling of commercial and recreational catches. It is also likely to be true in areas open to fishing, as increased restrictions on catches reduce the ability of research staff to collect sufficient samples for stock assessments.

A key objective of this project has been to determine more effective means of monitoring stocks of aggregating species within the WCB. In doing this it is important to consider whether it is better to monitor the stock when fish are aggregated for spawning or at some other time. Specific monitoring of particular aggregations may enable resources to be more effectively focussed. It may also focus research onto the more relevant breeding proportion of the population, particularly the larger, more fecund individuals that may be rarely seen outside of the aggregations yet may be most important for maintenance of stock size. This is the case with pink snapper that aggregate in Cockburn Sound. Further, if a particular aggregation or aggregating area is being specifically managed to avoid overfishing it may be appropriate to directly study the consequences of any management action on that aggregation or area. This is the case in the trawl fishery that targets blue grenadier when aggregated for spawning west of Tasmania (Kloser *et al.* 2005).

However, aggregations can be difficult to locate on a regular basis, particularly if they are not site specific as appears to be the case with dhufish aggregations (see Chapter 3). The number of fish within an aggregation can also vary markedly over a short period of time, thus making it necessary to undertake sufficient replication of surveys to ensure estimates are reliable (Sadovy *et al.* 2005). The decision over when and how to monitor the stocks of an aggregating species will therefore depend on the particular species and circumstances, as detailed below.

6.3.1 A Program for Monitoring Aggregating Species within the West Coast Bioregion

The aim here is to develop a long-term program for monitoring key aggregating species within the WCB, using techniques and information gained during the current study. The expected outcomes are:

- An absolute estimate or relative index of fish abundance of key species at a number of fished and unfished locations within the WCB.
- Depending on method, a variety of additional information including species diversity, fish behaviour, sex ratios, and habitat type.
- A mix of video, acoustic and biological information for use in raising awareness and promoting stewardship amongst stakeholders.

This program comprises several sampling strategies aimed at particular areas and species (Table 6.1). It is important to note that monitoring programs rely on longevity for effectiveness because, with all things being equal, it is the trends through time that are often of most interest. This is particularly the case if the data provide a relative rather than absolute measure of biomass (as is typically the case).

It is also important to note that, whilst the current project provides a considerable amount of information on the techniques and species to be used in this monitoring program, further research should ideally be undertaken to maximise its effectiveness. This will be crucial in determining the timing and frequency of sampling, particularly in light of the rapid changes in fish abundance that can occur within an aggregation over a short space of time (e.g. Sadovy *et al.* 2005, this study). Furthermore, much of our current understanding about fish aggregations, in particular when and where they aggregate, is quite rudimentary, and hence the program will evolve somewhat as more information is obtained.

The sampling strategies provided in Table 6.1 are explained more fully here:

Surveys of remote hotspots - Fremantle to Cape Naturaliste (south survey), and Fremantle to Jurien (north survey).

Methods

Stereo- and mono-BRUVs will be the main tool used in these surveys. The addition of multi- and single-beam sounders would benefit the surveys, particularly of the Bight redfish aggregation, but would be dependent on collaboration with Curtin University. Otherwise basic acoustic information will be obtained using the vessel sounder and MaxSea software. Some fish may also be captured for biological sampling (e.g. of reproductive stage) and to validate stereo-video measurements, but only if this does not impact other sampling objectives. Other monitoring methods, including deployment of passive acoustic receivers aimed at monitoring fish choruses, and acoustic tags aimed at monitoring fish movement patterns relative to the monitoring site, would also be investigated further in collaboration with universities.

Surveys will focus on a few primary and a number of secondary sites. At each primary site, selected for good fish abundance and expected low fishing activity, multiple surveys will be conducted over three consecutive days in order to assess short-term temporal variability in fish numbers and other data. Surveys at secondary sites will be less rigorous but may nevertheless provide valid data if variability at primary sites is shown to be minimal. Monitoring of these sites will also enable a broader overview of stocks and the general marine environment, including areas not previously examined. The number of primary sites during each southern and northern survey is expected to be three.

Seasonal timing

The timing of these surveys is based on dhufish ecology, weather and *RV Naturaliste* availability, however once established these times (whether relative to moon phase or date) should be kept similar each year.

The southern survey should ideally be conducted at the start of February each year, the time when the R.V. Naturaliste commences operation each year, when dhufish should still be spawning in this area, and when Bight redfish may have commenced aggregating in shallower waters. This is also the time of year when good numbers of dhufish were observed at one of the primary study sites. Although strong sea breezes are likely, the weather at this time is expected to be reasonable for conducting the surveys. Each survey (return to Fremantle) should take 14 -15 days to complete. Figure 6.1 shows the proposed route for this survey, which includes three primary sites and a number of secondary sites that encompass a variety of habitats and fish communities.

The northern survey should ideally be conducted in April each year. The weather should generally be good this time of year, and whilst dhufish may not be spawning, they have been observed aggregating at one of the primary monitoring sites during this month and they should be found in higher densities in inshore waters at this time. This survey should also take about 15 days to complete, with two alternative routes provided. One of these would cover a larger area of coastline as far north as Dongara but include only two primary sites, whereas the other would cover less area but do so more thoroughly (Figure 6.2). These surveys would also cover a wide variety of habitats and fish communities.

Costs

Costs of these surveys include use of the R.V. Naturaliste. Extra video equipment may need to be purchased. Preparation of video equipment and post-field analyses of video tapes will be very time consuming and require considerable computer and technical resources. Collaboration with universities may be beneficial in reducing costs in this area to the DoFWA whilst providing research opportunities for students.

Surveys of metropolitan hotspots

The locations of proposed monitoring locations within the metropolitan area are shown in Figure 6.3. Surveys of these locations would be based on stereo- and mono-BRUVs, complemented by biological sampling where appropriate. These surveys would be completed with the R.V. Snipe (or equivalent), and be conducted on a monthly or bimonthly basis. Each site would be surveyed once each sampling period. Weather and other commitments will have a strong influence on sampling periodicity and the number of areas monitored. These surveys would complement the surveys of marine parks in the metropolitan area (see below), but be more focussed on dhufish and other exploited species. Data gathered would include species diversity, fish abundance and lengths for key species, fish behaviour, and habitat description.

Surveys of pink snapper aggregations within Cockburn Sound

The daily egg production method (DEPM) of estimating spawning biomass has been successfully used to monitor pink snapper stocks in the past (e.g. Wakefield 2006), and is likely to remain the main method for monitoring the Cockburn Sound aggregation (R. Lenanton *pers. comm.*). These surveys may be complemented with acoustic/conventional tagging and otolith microchemical analyses aimed at determining adult and ontogenetic movement patterns.

Surveys of marine parks within the metropolitan area (Swan Catchment Council project)

These surveys were commenced in 2007 with funding provided by the Swan Catchment Council and the DoFWA. They involve surveys of fish and benthic communities within marine parks at Rottnest Island, Warnbro Sound and Hillarys (Figure 6.4), with stereo- and mono-BRUVs used for the fish component. Because of their size and location, these marine parks are not expected to be ideal for monitoring key exploited species. However, surveys in deeper water nearby these marine parks should make this study more relevant to exploited species.

Surveys of mulloway aggregations in the Swan River

This monitoring program is a continuation of the passive acoustic study conducted during the current project in collaboration with Curtin University (Chapter 4). If it were possible to continue this collaboration, ongoing annual surveys and further research into mulloway sounds and ecology is envisaged. This research would be conducted as student projects co-supervised by Curtin and the DoFWA. It is expected to be a relatively low cost project and logistically easy to undertake, and the information would be beneficial to the management of mulloway and the Swan River area in general.

Surveys of Samson fish aggregations west of Rottnest Island

Considerable effort was spent during the current project on surveys of Samson fish aggregations that form over wrecks during spring and summer each year (e.g. Chapters 4 and 5). Although Samson fish stocks are not considered to be over-exploited at present, this species is a major component of WCB ecosystems. Ongoing monitoring of the aggregations would require acoustic surveys conducted every one or two years in collaboration with Curtin University. Video would also be used to confirm the identity of species within the aggregations and to obtain length information if necessary. It may be possible to combine a survey of the Samson fish aggregations as an addition to surveys of remote hotspots. Additional data may be available from recreational fisher logbooks. These were initiated during the current project, although this scheme is reliant on the continuing support of recreational and charter fishers. As the locations at which the Samson fish aggregate are also used by a number of other species including pink snapper, skippy, mulloway and grey nurse sharks, mono- and stereo-BRUVs would ideally be used to obtain additional information on fish communities associated with these wrecks.

Surveys of Abrolhos Island Reef Observation Areas

This monitoring program would be an extension of that previously established by Kim Nardi (DoFWA) in 1993 using diver-based surveys, and more recently by Di Watson (University of WA) using stereo-BRUVs (Watson and Harvey 2007). The value of this long-term dataset is considerable and the monitoring study should ideally be continued using compatible techniques. This ongoing monitoring program would focus on sites used previously by Watson. It could also be broadened to include an area where dhufish are known to aggregate. In addition to video-based surveys, acoustic tags could be used to assess movement patterns of dhufish within this aggregation. The seasonal timing of these surveys would be compatible with the earlier studies, and most likely be conducted on an annual basis with use of a DoFWA patrol vessel if available.

Table 6.1. Proposed monitoring program for key finfish species within the West Coast Bioregion. Note that a preliminary study to improve understanding of the temporal dynamics of aggregating behaviour is required to properly determine the temporal timing of surveys. The proposed lunar periodicity of sampling is based on preliminary observations of fishers. DEPM; Daily Egg Production Method.

Priority	Survey Focus	Target Species	Survey Means	Tools	Survey Period
1	Surveys of remote hotspots - Fremantle to Cape Naturaliste See Figure 6.1. and Table 6.2.	Dhufish Pink snapper Other species	R.V. Naturaliste	Baited stereo/mono video Potentially, biological sampling Potentially, single and multi-beam acoustics	Ideally biannual:
1	Surveys of remote hotspots - Fremantle to Dongara See Figure 6.2. and Table 6.3.	As above	R.V. Naturaliste	As above	Ideally biannual
1	Surveys of metropolitan hotspots	As above	R.V. Snipe and recr/comm vessels	As above	Monthly or bimonthly
1	Seasonal surveys of aggregations within Cockburn Sound	Pink snapper	R.V. Snipe or similar	DEPM. Potentially, acoustic and conventional tags. Potentially, multibeam sonar	Annual
1	Metropolitan Marine Parks (Swan Catchment Council project)	Variety	R.V. Snipe or similar	Baited stereo/mono video	Biannual
1*	Seasonal surveys of aggregations within the Swan River	Mulloway	Collaboration with Curtin University	Passive acoustics	Annual
2	Seasonal surveys of wrecks west of Rottnest Island	Samson fish Other species	R.V. Snipe and recreational vessels / R.V Naturaliste	Sing/multi-beam acoustics Stereo/mono video Fisher logbooks	Annual or every second year
2**	Surveys of remote hotspots - Abrolhos Islands	Dhufish Baldchin groper Other species	As above or P.V.	Stereo/mono video Acoustic tags	Annual or biannual

* Priority if done in collaboration with Curtin University. Given the focus on environmental health of the Swan River this should be given consideration.

** Increased focus on the Abrolhos Island area may make this a higher priority.

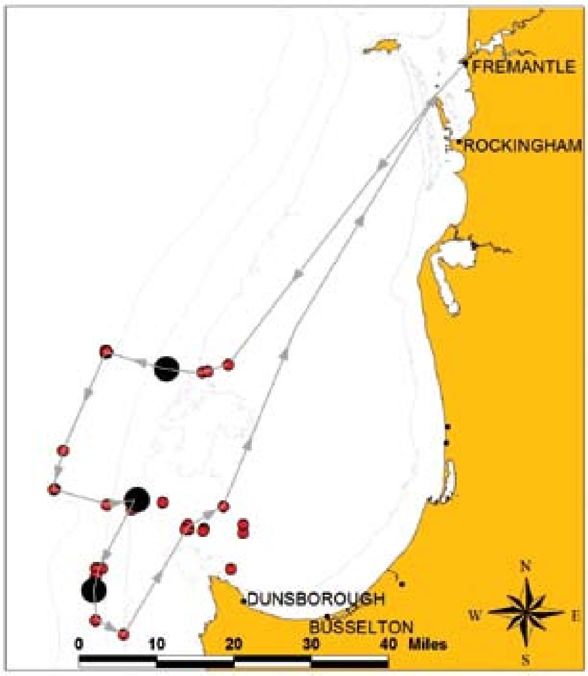


Figure 6.1. Survey route for southern WCB demersal finfish monitoring program. Primary sites at which repeat surveys will be made to assess temporal variability in data are shown by large black circles. Secondary sites where single surveys may be conducted are shown by small red circles. See text for survey details.

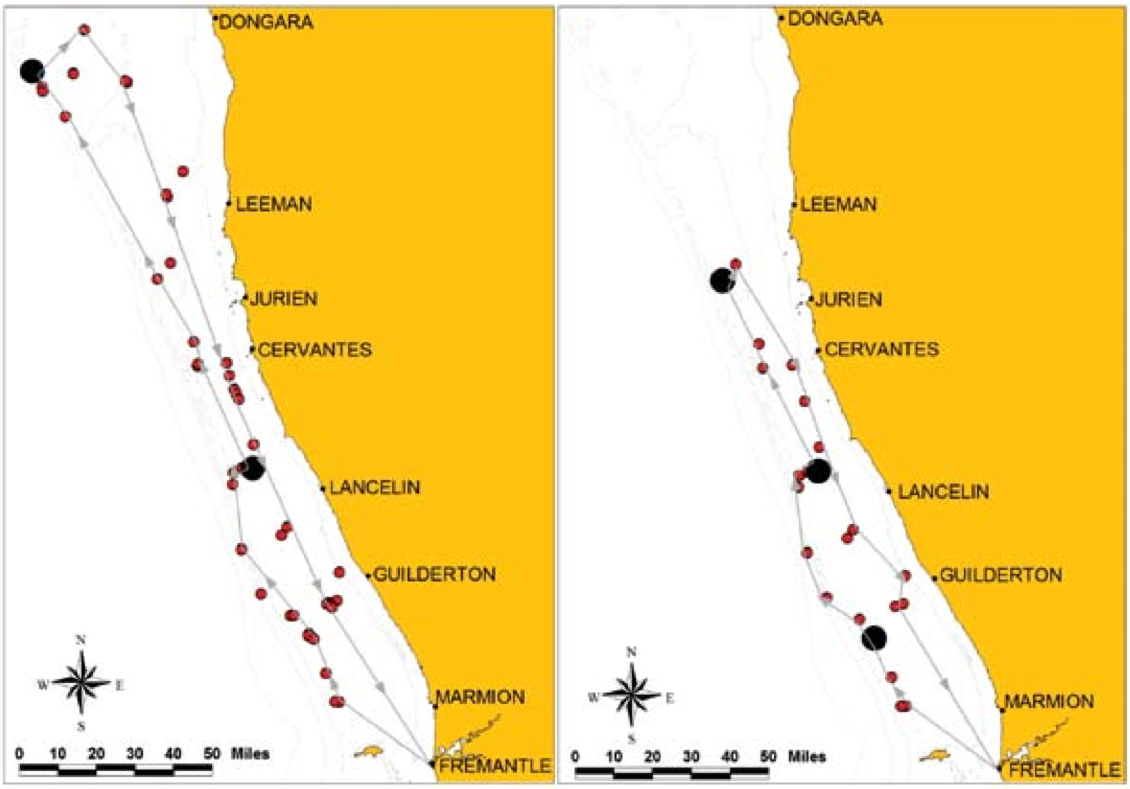


Figure 6.2. Survey route for northern WCB demersal finfish monitoring program. Primary sites at which repeat surveys will be made to assess temporal variability in data are shown by large black circles. Secondary sites where single surveys may be conducted are shown by small red circles. See text for survey details. Two options are provided – That on the left covers more coastline but less thoroughly than that on the right.

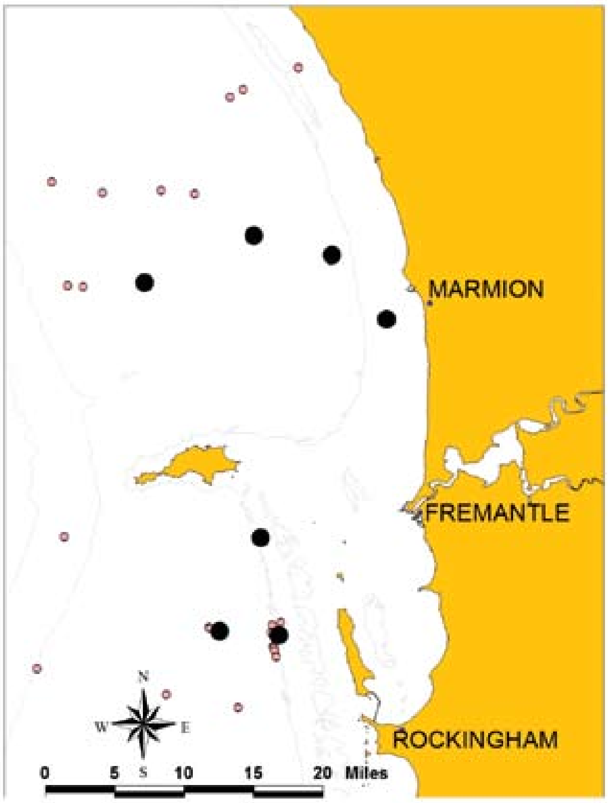


Figure 6.3. Monitoring sites for video surveys within the metropolitan area.

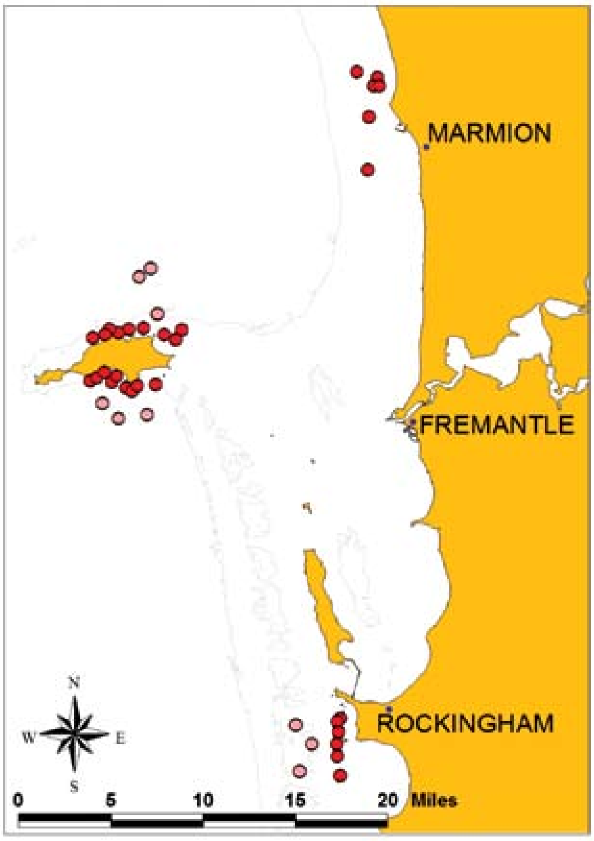


Figure 6.4. Monitoring sites for video surveys of marine parks within the metropolitan area.

7.0 Project summary

Paul Lewis and Michael Mackie

7.1 Benefits

The information provided in this report provides a better understanding of the ecology of key aggregating species within the West Coast Bioregion. This information has been important for recent changes in the management of fisheries for these species, thereby benefiting managers charged with making complex decisions, and the commercial and recreational fishers who aspire for a sustainable fishery.

The Samson Science project is an example of the benefits to be achieved from establishing a strong partnership between researchers and fishers. The project not only utilised the help of both charter operators and recreational fishers but also provided a significant amount of feedback through seminars, presentations and newsletters to those involved. This involvement and education has provided a sense of stewardship among recreational fishers of the metropolitan Samson fish sportsfishery and many were involved with the development of a protocol, which has been widely dispersed and serves to educate recreational fishers to their responsibilities in this sportsfishery.

The project has also provided recommendations for the future monitoring of each key species. During the current project various methods were trialled and it has given an indication as to the possible monitoring strategies required for each species identified as forming spawning aggregations or having the potential to form aggregations. The DoF will directly benefit from this through designing appropriate future monitoring techniques.

The responses of two beneficiaries to the project are provided in Appendix 12.

7.2 Further Development

The current study has given an overview into the biology of Bight redfish in WA, and shown that the commercial fishers in the Capes Region are targeting spawning aggregations of this species, which can be factored into stock assessments. The need for further investigation into the biology of Bight redfish has been recognised and led to a collaborative proposal for funding to address this.

The apparent suitability of species such as dhufish and bight redfish for monitoring with passive acoustics also requires further investigation as this may provide valuable information on these species. With some further development into suitable techniques and use of advances in technology it may be possible to utilise these passive acoustic techniques for monitoring and even stock assessments.

Although the use of acoustic tags on dhufish was not completely successful in the current study further advances in technology (smaller tags) and modifications in techniques (use of Vetbond glue) may allow this to be carried out successfully on them and other species, which would give further insight into their ecology and suitability for sanctuary zones.

The recent deployment of acoustic receiver arrays at various locations along the WA coast could be utilised to gather further information on the migration of Samson fish through an acoustic tagging study. The curtain arrays set up along the south coast and off the metropolitan coast would give invaluable information as to the timing, proportions, duration and patterns of migrations that the conventional tagging study has indicated occurs in this species.

The ongoing monitoring of Samson fish by recreational fishers is dependant upon the feedback they get and requires continued development of information.

The underwater and other video footage collected during the project has been incorporated into the Naturaliste Marine Discovery Centre and into a DVD, which has been widely distributed to recreational fishers and sponsors, but could be further developed into an educational DVD on the methods used for monitoring fish spawning aggregations.

7.3 Planned Outcomes

1. *Information about spawning aggregations and their exploitation will be used to examine ways to incorporate this phenomenon into stock assessments (e.g. through temporal/spatial adjustments to catch and catch rates) and the proposed integrated fisheries management plan that will be developed by the DoFWA to facilitate sustainable management of demersal finfish within the West Coast Bio-region (A. Cribb, pers. comm.). Specific information to be gathered will include the physical dimension, estimated biomass, timing, location, potential regional importance, accessibility and vulnerability (to fishing) of individual aggregations. Alternative management options that take into consideration species characteristics (e.g. vulnerability to release mortality), social impacts (e.g. loss of income), and value of the fishery (e.g. costs associated with enforcement and monitoring) will be subsequently presented to managers for consideration.*

The project has given a detailed description of factors resulting from the aggregation phenomenon that can be incorporated into stock assessments. With the increased focus by the DoFWA on management of the broader ecosystem any future stock assessments are likely to incorporate spawning aggregation information from the current project. Additionally, in cases where the data for an integrated model are not available, a ‘weight of evidence’ approach involving holistic consideration of all relevant data may be used (Wise *et al.* 2007). With either approach, the project provides important information about spawning behaviour and associated movement patterns when undertaking stock assessments. This information also has an important role in determining management actions resulting from these stock assessments, and in determining how to monitor their effectiveness.

The current suit of new management arrangements for the WCB introduced in October 2008 includes the need for further investigation into the appropriateness of introducing large scale fish reserves or closed areas to provide protection for large numbers of fish or over an area, which is particularly important to spawning. The current project is mentioned in FMP 231 as being one of a number that will provide additional information and help determine the appropriateness of introducing large-scale fish reserves in the West Coast Bioregion as an additional strategy to reduce fishing effort and protect the spawning stock. This information in this study on the species reproductive ecology, the timing and locations of spawning aggregations, particularly of dhufish is required in this assessment of spatial closures.

2. *Implementation of methods for monitoring fish spawning aggregations as part of ongoing stock assessments for key West Coast finfish species. The preferred method(s)and the frequency of implementation will be determined for each species/aggregation following assessment of cost, effectiveness and need. A key objective will be to establish a relatively simple (e.g. echo sounder based) monitoring program in which fishers provide data used to*

assess trends in aggregation size and size of aggregating fish through time.

The report has detailed the monitoring methods which are thought to suit each of the key species in the WCB, the implementation of these methods has yet to be undertaken but may be incorporated into the future monitoring. The use of BRUVs as a part of the WAMSI node 4 project to assess the status of the vulnerable 5 west coast species in the metropolitan area is a component of this. The suggested monitoring of the Cockburn Sound pink snapper stocks through DEPM surveys is set to continue and the recreational angler feedback on the size of samsonfish aggregations, although still in its infancy with only a handful of reports from last season is giving feedback on the status of the schools.

3. *An internationally renowned samson fish sportsfishery that is based on a good understanding of species biology, ecology, impacts of the fishery and care of catch, and which is considered a shining example of cooperative research and management between fishers and fisheries regulators. Information from the current project can be used by charter and tourist operators to promote the fishery to domestic and international markets. Proper management of this high profile, easily accessible fishery will potentially provide significant public relation benefits to the Department.*

The current project and particularly the PhD study on Samson fish has uncovered previously unknown aspects to their biology and physiology. This information has been conveyed to the general public and with the help of charter and recreational fisher involved, a protocol for the sportsfishery has been developed which has been distributed to tackle shops and charter boats to promote the sustainability of the Samson fish catch and release sportsfishery. The protocol utilized biological information gained during the project and was the product of workshops with charter boat operators and recreational fishers to provide valuable information on the correct techniques to enhance the survival of Samson fish for those new to the fishery.

4. *Greater awareness by fishers and the wider community of the ecological and fisheries importance of fish spawning aggregations and the need to ensure their protection (via outputs described in section B5).*

The Samson Science project, the various media releases, TV articles and newsletters have all helped to educate and inform the wider community on the ecological and fisheries importance of fish spawning aggregations. The underwater video and media articles arising from this project have been utilized in the Naturaliste Marine Discovery Centre and in the DoFWA media packages to help educate the community on the importance of fish spawning aggregations.

5. *Adoption by other fisheries agencies of protocols for researching and managing fish spawning aggregations*.

To date we are unaware of other Fisheries agencies adopting any of the protocols outlined here for the researching or managing of fish species that form spawning aggregations.

7.4 Conclusion

The project has met its four main objectives. It has utilised information from various sources including anecdotal evidence, biological information, direct observations, commercial catch and effort data and trialled many varied monitoring methods to identify 22 species of fisheries importance within the WCB that are known to or suspected of forming spawning aggregations. For the main species further information is provided on the location, size, timing and nature of spawning aggregations, past and present. The project has focussed on WA dhufish and Samson fish for which much new and important information on their ecology and reproductive biology has been discerned. The Samson Science community involvement study of the spawning aggregations of Samson fish in the metropolitan area has been widely regarded as a successful example of the partnership of recreational fishers and researchers. The information on spawning aggregations can be utilised in future stock assessments of these species to account for the influence that aggregation spawning can have upon the results from these models, which will be utilised in their future management. Finally as the project has undertaken a thorough assessment of various potential monitoring techniques for spawning aggregations it has provided recommendations on those suitable for each key species within the WCB.

The study has collected evidence from various sources that validate the formation of spawning aggregations by WA Dhufish. It has established the importance of the Capes region with evidence of dhufish forming large spawning aggregations in the past but also indicated that spawning and other aggregations can occur, often to lesser degree, elsewhere within the WCB. The commercial catch and effort data revealed commercial fishers are getting higher catch rates through the targeting of spawning aggregations in these same areas. The study has given a further insight into the ecology of the species and shown how the spawning behaviour is complex with 1 large male often having a harem of 3 to 8 females at a particular site during the spawning period. The finding of atresia in the gonads of smaller mature females on a number of occasions indicates there is some competition between females for the attention of the males, further illustrating the complexity of their spawning.

As Samson fish were the initial focus of the study, formed known spawning aggregations which were easily accessible off the Metropolitan coast and had 2 devoted PhD students studying them a great deal has been discerned into their ecology and methods for effective study of large pelagic spawning aggregations they form. The Samson science component of the project involved over 300 recreational fisher aboard more than 50 boats over 2 years and achieved the goals of tagging over 2000 and 3000 Samson fish in each year of the study in sometimes trying conditions five miles west of Rottnest Island. The project was focussed on quality of data by training each recreational fisher the correct techniques for tagging fish and giving presentations on the background information. The project received a great deal of community support with a number of industry supporters donating prizes for the participants. Overall the project has developed a sense of ownership amongst dedicated group of recreational fishers and charter boat operators who assisted with the production of the fishing protocols for the fishery, which have been widely accepted.

The study into the biology and physiology of Samson fish has revealed some very important results for this and related species. The species is sexually dimorphic with females attaining a larger size of up to 47 kg, relatively long lived with ages of up to 28 and 29 years for males and females respectively, and had a low estimate of *F* (fishing mortality) indicating the species is not subject to heavy fishing pressure. The reproductive biology confirmed the species is spawning at the aggregations west of Rottnest Island, has a length at maturity for females of 831mm (FL), and are highly fecund with batch fecundities of up to 1,427,000 for large females. The tag and recapture results indicate that fish predominantly come from the south coast and from as far away as Kangaroo Island in SA, a distance of over 2000 kilometres, to the spawning aggregations west of Rottnest Island, which has large implications to the importance of these aggregations for the species. The mechanism that allows this family of fish to "self vent" when dealing with barotrauma situations has been identified and further study of this by short term survival studies has validated the assumption that most (90%) of the fish survive the capture and release, even from depths of up to 195 m. This indicates that if the fish are treated correctly, following the protocols, the catch and release sportsfishery can operate on these aggregations of such importance, although recently an apparent increase in numbers of large sharks at the aggregation sites have made the capture and release of Samson fish difficult and increased the mortality rate of fish at some of the aggregation sites but this may also lead to a decrease in fishing pressure.

Although the above key species were the main focus of the study the fisher interviews and CAES data have revealed evidence for the formation of aggregations, many of them for spawning in 18 other species within the WCB such as Bight redfish. The confirmation of the formation of spawning aggregations in these species has implications for their effective future management, as discussed. The study has collected some preliminary, previously uncollected, biological information for Bight redfish within the WCB including the evidence that they form annual spawning aggregations in the Capes region, which have been recently (in the past 10 years) targeted by commercial fishers. The study has not only collected this reproductive information but has also collected over 600 otoliths from the commercial fishery in the Capes area which can be utilised in future studies of this species.

A thorough assessment of possible available techniques including acoustics and video for the future monitoring of these species was conducted during the study. This showed that each had its potential advantages and disadvantages. The use of a combination of these is often required for any study. One of the main disadvantages of multibeam acoustics is the cost but to get an overall estimate of a school size it was far superior to the single beam or video. For each of the key species the optimum technique for any future monitoring is suggested and advantages over other techniques suggested. In addition a range of future monitoring is suggested for the key species in the WCB.

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9.0 Appendices

Appendix 1. Intellectual Property.

No saleable items were developed during this project.

Appendix 2. Staff

Staff that were employed on the project using FRDC funds were:
DoFWA- Michael Mackie and Paul Lewis.

Students involved in aspects of the project were:
Curtin University- PhD student Miles Parsons, supervisor Rob McCauley.
Murdoch University- PhD student Andrew Rowland, supervisor Howard Gill.
Edith Cowan University- PhD student Mr Jason How, supervisor Glenn Hyndes.

Staff who assisted on the project using non-FRDC funds were:
DoFWA- Dan Gaughan, Ian Keay, Craig Skepper, Adam Eastman,
R.V Naturaliste crew (Mark Baxter, Theo Berden, Tim Shepherd, Kim Hillier)

Curtin University- Mal Perry – Electronics Technician, Frank Thomas – Research Engineer, Iain Parnum – Research Associate, Alec Duncan – Senior Research Fellow, Justy Siwabessy – CMST, Ann Smith – Administration.

Murdoch University- Gordon Thomson, Alex Hesp, Pete Coulson, Mike Taylor.

Appendix 3. Interview Form

Top section of interview form used to obtain information from fishers about spawning aggregation. The bottom of the form was left blank to write additional notes. This data was then entered into an excel database for further analyses.

Interview Form. *Fish spawning aggregation research.*

Name: ______________________ Experience: ______________________

Address: ______________________

Species ______________________

Evidence (roe, behaviour etc) ______________________

Location ______________________

Depth (m) ______________________

TOY ______________________

TOD ______________________

Aggr Size ______________________

Fish size ______________________

caught ______________________

Aggr still present? ______________________

Habitat ______________________

Typical # ______________________

Target? ______________________

Other spp there? ______________________

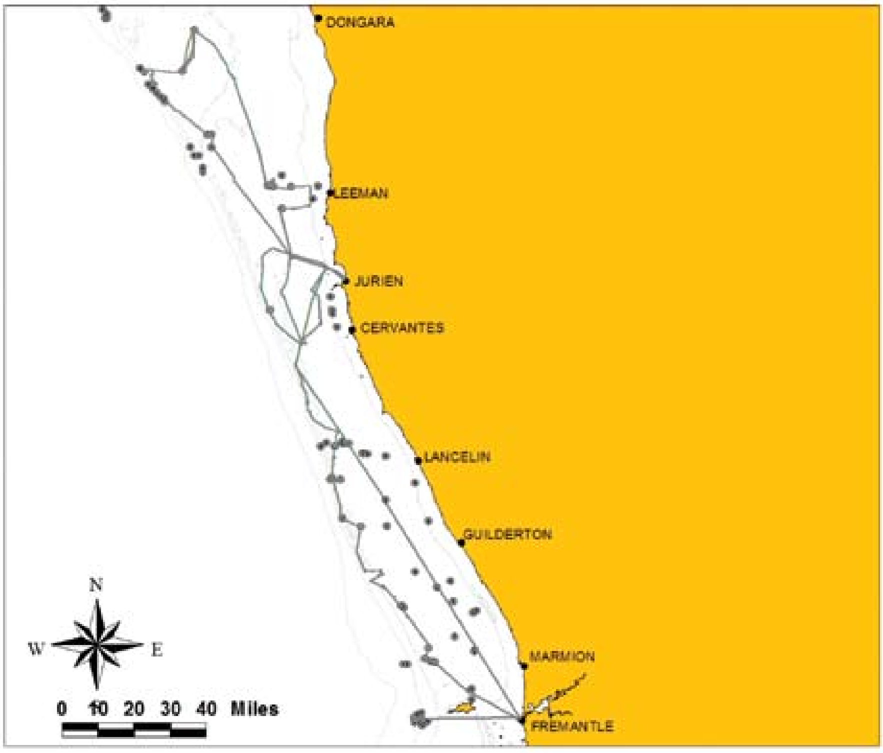
Behaviour/colour ______________________

Other:

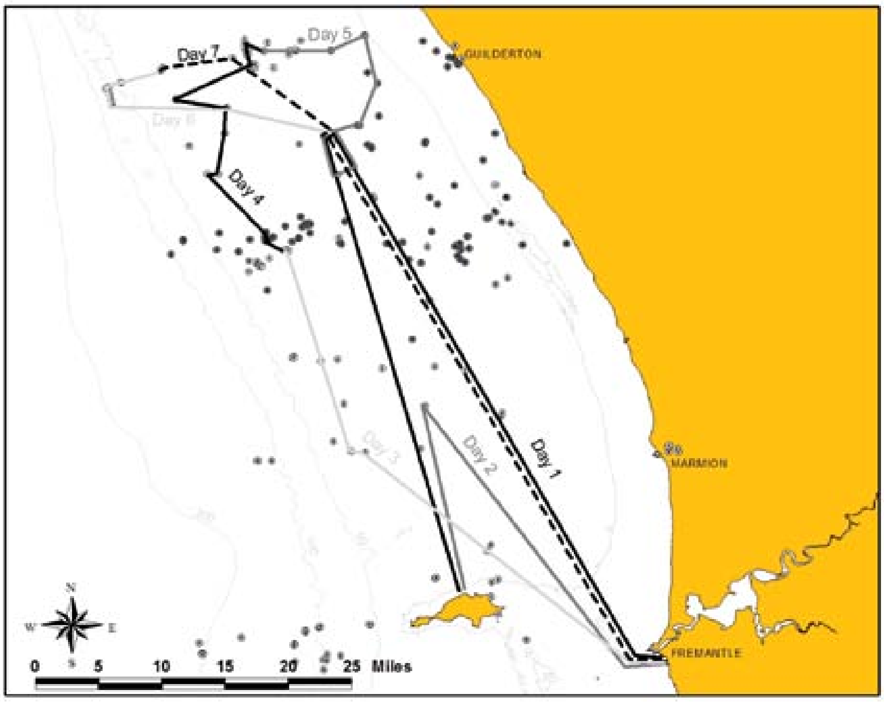
Appendix 4. Field sampling trips onboard the *RV Naturaliste*

Tasks undertaken included video and acoustic surveys of habitat and fish life with specific focus on aggregations, trialling of video and acoustic techniques, and biological sampling.

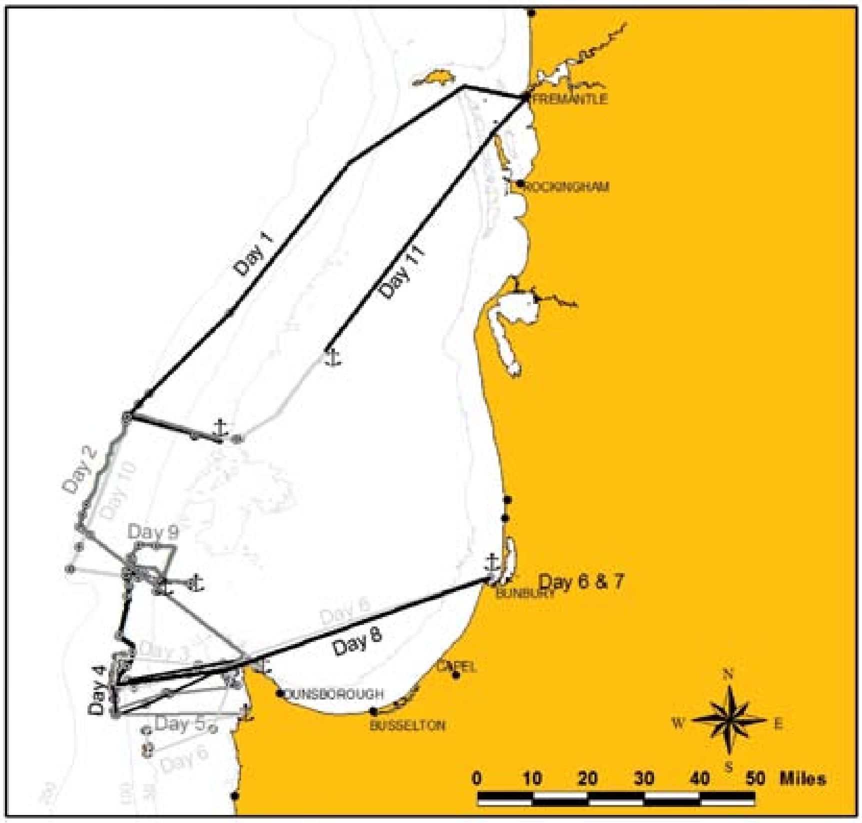
A) April 2005, Fremantle to Dongara



B). March 2006, Fremantle to Guilderton

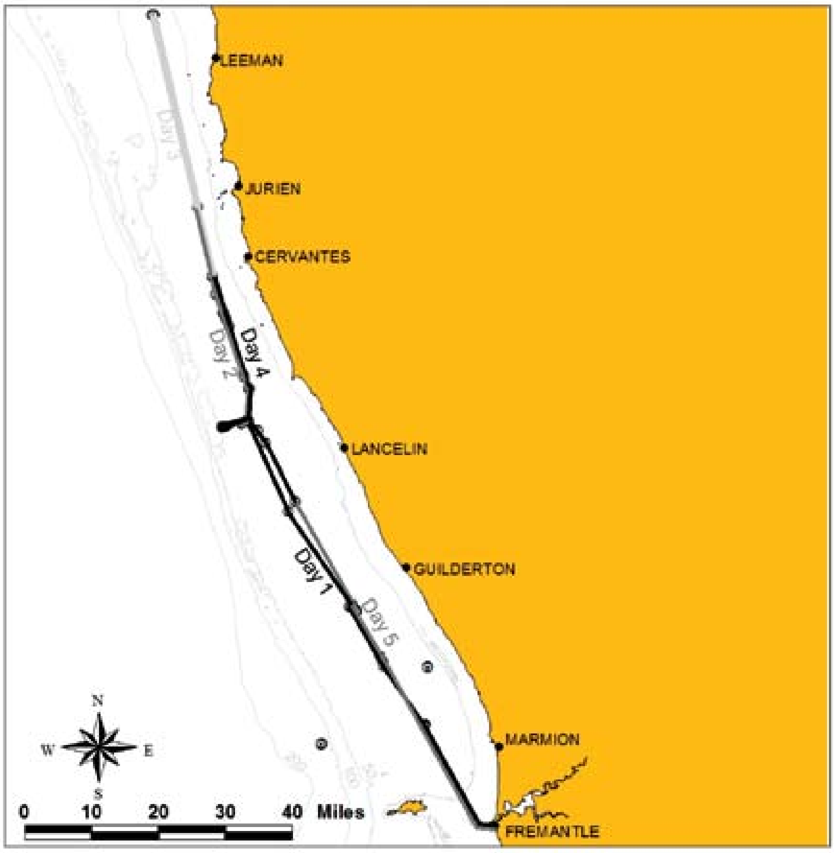


C) December 2006, Fremantle to Cape Naturaliste

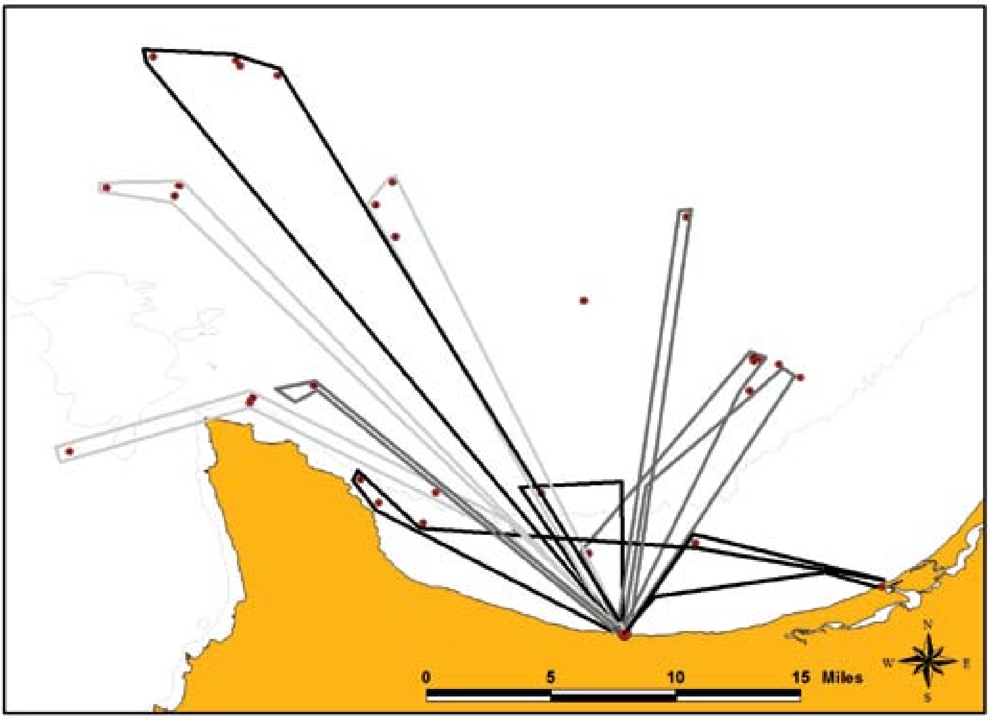


D) February 2007, Fremantle to Cape Naturaliste

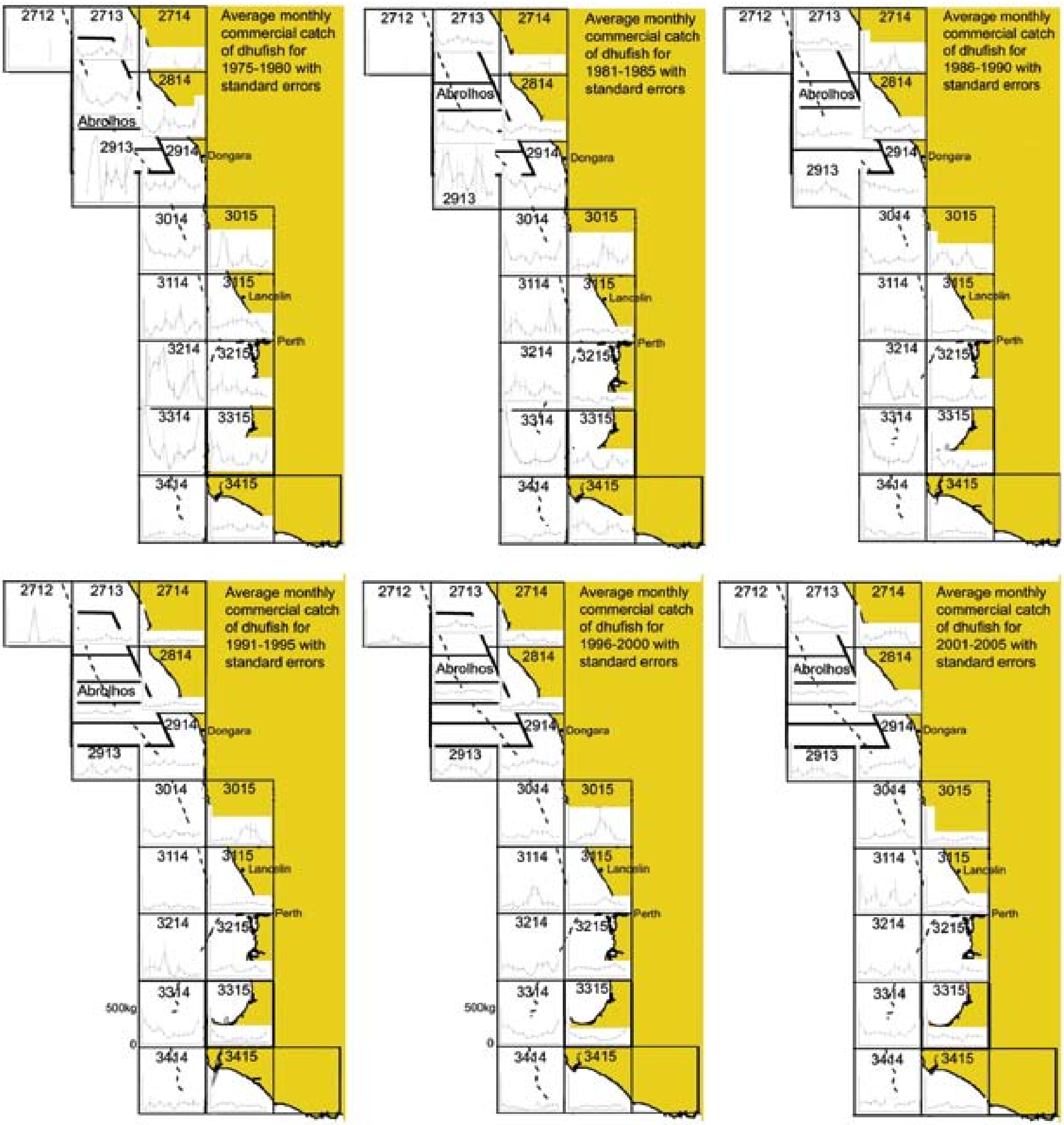
E) February 2007, Fremantle to Dongara



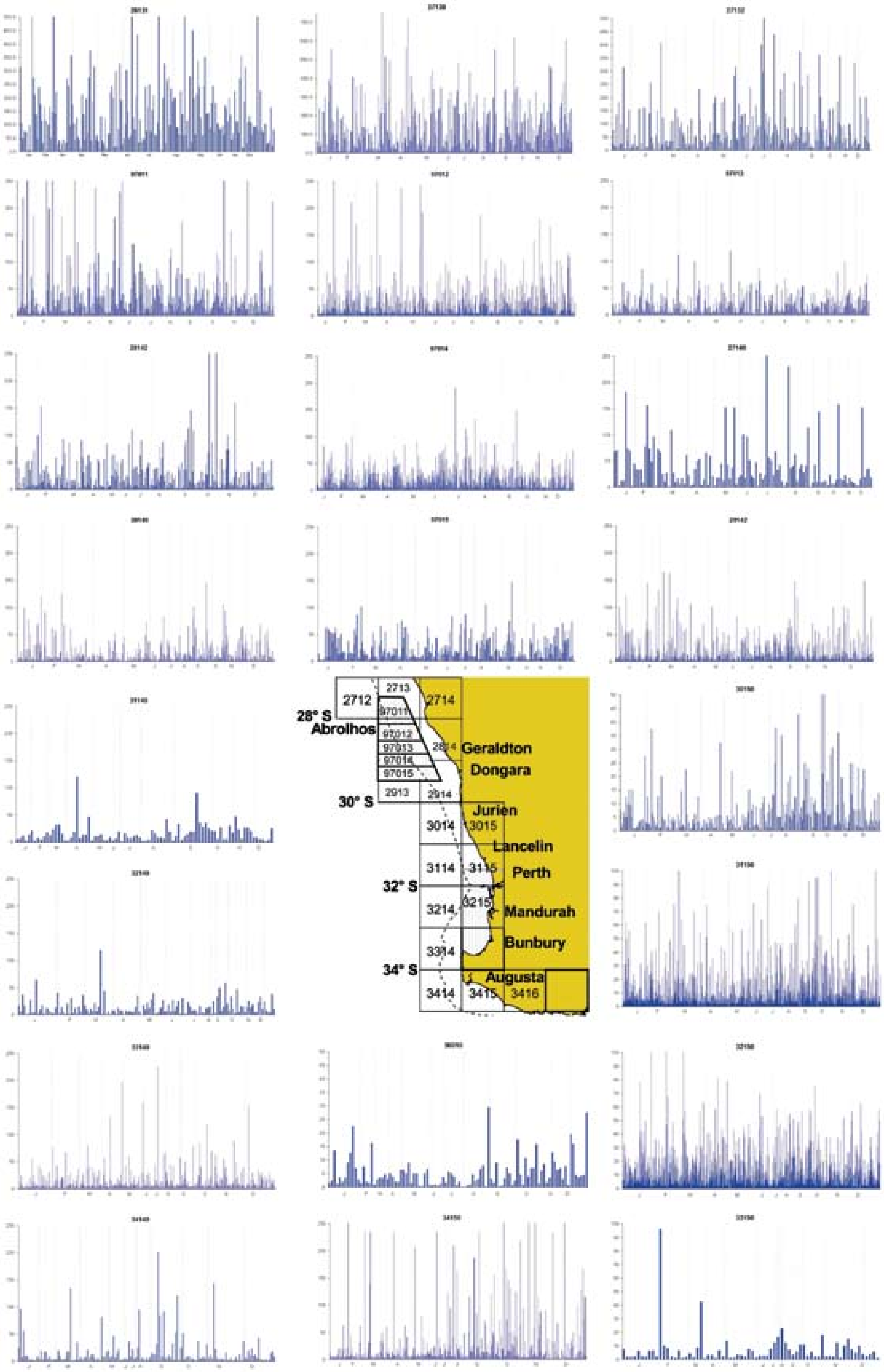
F). Geographe Bay sampling trip onboard the *RV Snipe*, November 2005



Appendix 5. Commercial catches of dhufish within the West Coast Bioregion between 1975 and 2005. Data are pooled into five-year blocks



Appendix 6. Commercial CPUE of pink snapper within reporting blocks of the West Coast Bioregion. Data by month from 1975 to 2006 is shown



Appendix 7. Summary of acoustic surveys conducted during the project

A. Catalogue of Transects over Rottnest Island Samson fish Aggregations

Date	No. of Surveys	Sites Surveyed (many multiple)
23/11/2004	18	0, 1, 2, 3, 5
20/01/2005	24	0, 1, 2, 3
23/01/2005	13	1, 2, 4
29/01/2005	16	1, 2
2/02/2005	26	0, 1, 2, 3, 4, 5, 6
3/02/2005	19	4, 5, 6
26/02/2005	19	1, 3, 4, 5, 6, 7
27/02/2005	4	2
21/12/2006	11	1, 2, 3
15/01/2006	9	1, 2, 3
13/02/2006	20	1, 2, 3, 4
15/02/2006	6	1, 2
21/03/2006	7	1, Geographe Bay
22/03/2006	2	Geographe Bay
24/03/2006	6	Geographe Bay
25/03/2006	2	Geographe Bay
13/09/2006	10	1, 2, 3
15/11/2006	9	1, 2, 3
Total	221	

B. Catalogue of Multi-beam Data

Date	No. of Surveys	Sites Surveyed (many multiple)
18/10/2005	30	1, 2, 3, 4, 7
19/10/2005	4	Cockburn Sound
20/10/2005	31	1, 2, 3
31/01/2007	1	Patch test
1/02/2007	11	1, 2, 3
2/02/2007	6	3
3/02/2007	18	Geographe Bay, Bunbury sponge garden
5/02/2007	9	Redfish Patch 1
6/02/2007	7	Redfish Patch 2
7/02/2007	56	2, 3, Derwent, south barges
Total	173	

C. Catalogue of Passive Acoustic Data

Tape	Folder	Date	Vessel	Deployment	Start	End	Site Covered
NT05_1		17/04/2005	Naturaliste	BRUV/Logger	17:12	21:12	Jurien Bay
NT05_2		19/04/2005	Naturaliste	Craypot/Logger	19:00	23:00	Jurien Bay
NT05_3		20/04/2005	Naturaliste	Craypot/Logger	7:48	9:58	Jurien Bay
NT05_4		21/04/2005	Naturaliste	BRUV/Logger	8:00	12:00	Jurien Bay
NT05_5		21/04/2005	Naturaliste	Craypot/Logger	19:00	23:00	Jurien Bay
NT05_6		22/04/2005	Naturaliste	Craypot/Logger	12:53	14:23	Jurien Bay
SR06_a	t2685	17/01/2005	Curtin	Drift/Hand held	19:30	22:45	Mosman Bay
SR06_b	t2725	19/01/2006	Curtin	Drift/Hand held	18:37	22:00:00	Mosman Bay
SR06_c	t2696	15/02/2006	Snipe	BRUV/Snipe	18:24	19:54	Mosman Bay
SR06_d		14/03/2006	Curtin	Drift/Hand held	19:48	21:04	Mosman Bay
SR06_d		15/03/2006	Curtin	Drift/Hand held	18:20	20:24	Mosman Bay
SR06_e		25/01/2006	Curtin	Drift/Hand held	17:58	19:35	Mosman Bay
SR07_a		5/09/2006	Curtin	Drift/Hand held	19:15	19:54	Mosman Bay
SR07_a		5/10/2006	Pier	Pier/Hand held	20:10	20:45	Barrack St
SR07_a		8/10/2006	Curtin	Drift/Hand held	18:25	18:59	Mosman Bay
TB07_a		17/10/2006	TAFE	Tank/Hand held	15:00	19:00	TAFE Tank
TR6a		26/03/2006	Naturaliste	Craypot/Logger	13:31	14:10	Two Rocks
TR6b		26/03/2006	Naturaliste	Craypot/Logger	14:45	16:45	Two Rocks
TR6c		28/03/2006	Naturaliste	Craypot/Logger			WPT 103
SR07b	t2999	13/02/2007	Bates	Moored/Hand held	20:05	22:55	Mosman Bay
SR07d	t3002	13/02/2007	Curtin	Moored/Hand held	20:12	22:20	Mosman Bay
Tristan	t3003	13/02/2007	Curtin	Riverbed/Logger	19:30	22:50	Mosman Bay
Sir Gareth	t3004	13/02/2007	Curtin	Riverbed/Logger	19:50	22:30	Mosman Bay
SR7a		15/02/2007	Curtin	Moored/Hand held	19:50	21:30	Mosman Bay
SR07c		15/02/2007	Bates	Moored/Hand held	19:40	21:50	Mosman Bay
Tristan		15/02/2007	Curtin	Riverbed/Logger	19:25	21:45	Mosman Bay
Sir Gareth		15/02/2007	Curtin	Riverbed/Logger	19:30	21:35	Mosman Bay
Guinivere	t2662	-	Curtin	Riverbed/ Logger	10/01/05	7/02/05	Mosman Bay
Guinivere	t2689	-	Curtin	Riverbed/ Logger	13/12/05	18/03/06	Mosman Bay
Guinivere	t2730	-	Curtin	Riverbed/ Logger	15/10/06	18/05/07	Mosman Bay

Appendix 8. Samson Science Newsletters

Sambo Science

the research behind *fish for the future*

Department of Fisheries • Curtin University • Murdoch University • UWA • You!

Hi there. Welcome to the inaugural 'Sambo Science' newsletter in which we describe what we're doing, why we're doing it and how you can be a part of this collaborative effort. We'll send out these newsletters regularly to keep you up to date with the research.

What we're doing…

Most people are probably aware of the big samson fish ('sambo') tagging study that is taking place through January and February next year. This is an ambitious project in which we want to tag at least 3000 sambos during a three week 'tagging blitz' in January 2005. This will be followed up about a week later with a one week 'recapture blitz' when we'll capture and release (without tagging) as many sambos as possible. From the ratio of tagged to untagged fish captured during the recapture blitz we can then estimate how many fish are in the school (you may also hear these schools referred to as aggregations). We also hope to determine the best way to handle and release the fish by comparing recapture rates of fish captured and released using different methods.

Whilst all this capture and tagging is underway we will also be filming the schools using underwater cameras either towed through or lowered down into the schools. Besides giving us an insight into the behaviours of these powerful fish whilst they are aggregated for spawning, the video will provide us with another estimate of fish numbers and hopefully a better idea of the fate of sambos that have been captured and released.

In addition to all this we'll also be using hydro-acoustic equipment to record fish noises and get yet another estimate of school size. So by the end we should have a pretty good idea of how many fish are in these schools, how they can best be monitored in the future, and how we can maximise survival of released fish. We'll also have some pretty hot gossip about sambo sex-life!

Why we're doing it…

So why all this fuss about sambos? Well for starters there is growing international and local interest in the sambo sports-fishery which targets their large spawning schools that form each year – particularly those to the west of Rottnest Island where our research will be focused. Whilst most of these fish are released after capture, there is concern amongst fishers over the survival of these fish due to the depth (often > 80 m) and trauma of capture. Commercial fishers also take a fair number of sambos for the local market, so it is important we gather this biological and ecological information to ensure their populations remain healthy.

Sponsored (thus far) by: Apache Charters, Bluewater Tackle, Department of Fisheries, Halco Tackle, Mako Tackle, Recfishwest, Saltwater Lab Jigs by Grifton Australia, Shikari Charters, WA Maritime Training Centre-Fremantle, Western Angler, Yantina Charters.

It's not just the sambos we're studying though – plenty of other species form spawning aggregations and the methods we develop during the sambo tagging study will be applied to these fish as well. We are particularly interested in snapper, which definitely aggregate to spawn, and dhufish, which may also aggregate but in a less obvious manner. This could be because male dhuies form breeding territories that are more spread out over the bottom, whereas sambos and snapper males are not territorial and mingle freely with other males and females.

The fact that these species have been around a long time clearly shows that schooling together in order to spawn is a successful evolutionary strategy, enabling fish to find spawning partners, synchronise reproductive development and release their eggs at a time and place that maximises their dispersal. However, these species never factored clever fishers and GPS into their strategies, and there is growing evidence around the world that targeted fishing of these aggregations can seriously reduce fish populations.

How you can be involved…

The sambo tagging study is therefore a crucial component of the broader project into management and monitoring of fish spawning aggregations, and its success requires a well co-ordinated and intensive team effort between scientists and anglers. If you are interested in being involved in this interesting research project please fill out the attached form and send it back to the address given below. Once we've collated all the names and worked out who can do what, we'll get back in touch (preferably via email) with more detailed info. It's a great opportunity to help look after our fish, however be aware that the fish are big and the waters can be rough out beyond Rottnest, so you will need to be reasonably fit and seaworthy to take part in the action as a fisher or tagger. Otherwise there may be spots available in some other capacity such as recording and/or entering data, coordination of daily boating and tagging activities and the like. In order for our research to stand up to tough scientific scrutiny all participating fishers and taggers must also be willing to attend a workshop and keep to a few simple fishing 'rules'. If this sounds like you then have a read of the schedule for the study (also attached) and let us know how you can help out and when!

Thanks for your time in reading this blurb. Feel free to send it on to others. Did we mention that all participants will receive some goodies from our sponsors and there will be awards given for certain achievements during the study? Look forward to hearing from you.

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Ph 92468 418 / 0427 472 121

Paul Lewis
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Sambo Science

the research behind *fish for the future*

Department of Fisheries • Curtin University • Murdoch University • UWA • You!
Supported by Recfishwest, the Australian National Sportfishing Association and Fremantle Volunteer Sea Rescue

Hi there,

welcome to the second 'Sambo Science' newsletter. We have had a great response to the first newsletter and the various media articles that have kindly featured our study, and we are getting together a big list of people who are interested in helping out with our research. These range from hard core blue water salties with a passion for catching fish to biology students with a passion for prodding at their innards. Regardless of their passion, most people express the same thoughts – that our fish resources need looking after and this is a great opportunity to contribute towards that goal. It really is encouraging to hear this, and it is a good message to remember – that it's up to each one of us to care for our valuable fish resources.

In the August newsletter we explained the importance of our study into the management and monitoring of fish spawning aggregations. Sambos are a focus of this study because of their growing reputation as a sportsfish and because their big aggregations west of Rotto are ideal for trialling the various methods we are using in our research. 'Sambo Science' is all about the community based tagging component of this research, and in these newsletters we will start focussing on the nitty gritties of this study (what is expected of you, day to day procedures during the event, tagger training, insurance and so on). We will also keep stressing the importance of good science so that the end results of our labours measure up to scrutiny. Therefore, in order to provide a better understanding of our sometimes weird boffin logic we will detail in these newsletters the science behind the sambo tagging project – so be ready for a crash course in marine science!

We would also like to make note of the organisations at the bottom of these pages that have provided assistance and donated rewards for the tagging study. These rewards will be given to volunteers during the study for specific achievements or just for lending a hand, and should provide plenty of incentive for getting out there. The support of these organisations is therefore much appreciated.

The 'science' of Sambo Science

There are several aims of Sambo Science, including:

- Estimates of the number of sambos within the west Rottnest aggregations using four different methods (tag-recapture, underwater video, sounder and hydro-acoustics). These estimates will be compared and the relative merits of each method evaluated so that we can

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determine the best way of monitoring aggregations in the future. The video work will be undertaken by UWA Masters student Caine Delacy and the hydro-acoustics by a PhD student at Curtin University.

- Survivorship of sambos tagged and released using different capture and handling methods. This will be determined from the recapture rates of fish tagged and released using each method, and will be used to establish protocols for the sambo sportsfishery. We also hope to assess the short-term impact of capture on released sambos using the video gear.
- Short and long-term movement patterns of sambos between the Rottnest aggregations and their normal place of resident outside of the spawning period. This will enable us to determine the regional importance of the sambo schools off Rottnest and the impact that fishing could have on sambo populations. Tagging by the Australian National Sportfishing Association (ANSA) has already shown that the Rotto aggregations attract sambos from as far away as Esperance (a distance of about 1200 km), and that they don't mess around getting there. For instance, a sambo tagged at the Rotto aggregation on the 13th January this year motored home to Albany, a distance of about 700 km, where it was caught just 24 days later. Another sambo caught and tagged at the same time and place off Rotto did the same journey and was caught just six days after it's mate!
- Characteristics of the Rottnest aggregations, such as size distribution of sambos, their duration, presence of other fish species and type of habitat they are forming over.
- Biology and ecology of sambos, undertaken by Andrew Rowland as part of his PhD through Murdoch University. Andrew is also the ANSA tagging facilitator with Recfishwest, and much of the Sambo Science tagging work will be part of his thesis.

The tagging study taking place in January will focus on the first three of these aims, and the success we have in achieving them is dependent on the number of fish we get tagged. It also depends on how closely we stick to the game plan, which will require that everyone involved with the study:

- Only catch sambos from specified aggregations within a small area west of Rottnest (see the map below). This will maximise the number of tagged fish we recapture during the recapture phase of the study, and therefore enable better estimates of fish numbers. Once the aggregations have formed later this year we will confirm which of these we will use during the study. We'll probably use three aggregations in total although another one or two may be added if boat numbers are too high on each aggregation and/or the fish start getting shy from all the action.
- Only capture and release sambos using a specified fishing/handling method. This is so we can identify which method results in the best recapture rate. We will keep these methods as typical as possible so please email back the attached form describing your typical fishing method so we can work out which ones to use (we will probably limit them to three general methods so that we get enough recaptures to distinguish which is best).
- Only use tags that have been specially made for the sambo study. Three different colours will be used, each indicating a specific catch and release method so that we may (hopefully) identify fish underwater using the video camera. Some fishers will also be asked to put two tags in each fish so that we can determine the rate of tag loss. Because we have a limited number of tags it is also important that fishers return any unused tags!
- Make sure that the tags are placed in the right place on the fish and that the data (tag numbers, fish lengths, date, location) are recorded accurately. Otherwise the results of the study could be misleading and we might come up with the wrong conclusions. That's why

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it is important that all taggers and data recorders attend at least one tagging workshop. If you have a boat but are not sure about tagging we will provide a tagger for you. Some of the bigger boats will require two taggers and/or a data recorder (although after a couple of hefty sambos there will be tired fishers who will be happy to record the data for awhile).

- Look after each fish properly so that they're not dying unnecessarily due to rough handling. This would also confuse the issue when we analyse the recapture data, so make sure the measuring board, rags and hands are kept wet and cool, that you don't stick fingers where they shouldn't go (gills, eyes), that you keep the eye covered with the rag (this also helps calm the fish), that you don't bang the poor critter around on deck, and that you get it back in the water as soon as possible. Of course, this is how we should treat every fish that we plan on releasing back into the water.

So that's a quick rundown of some of the detail behind the study. It's always a bit different bouncing around at sea with a big sambo that keeps sliding off the measuring board and a funny feeling in the stomach, but for the sake of good science we must keep things as structured as possible.

What do we expect of everyone?

Apart from stipulating that all fishers keep as strictly as possible to the methods described above, we will leave it up to individuals to participate whenever and however they can. It is particularly important that the boat skippers choose for themselves which days to head out and the time when they do so. Whilst some people will be spending considerable time fishing sambos during the study, work and other commitments will limit the availability of many people to a couple of days here and there. Whatever you're situation, we will appreciate your help and hope you can direct your efforts to ensuring that enough fish are tagged and subsequently recaptured during the event. All participants will need to sign an insurance form to ensure they are covered whilst at sea.

Because of the limited availability of many people we intend having a large number of people involved. This will make the organisational logistics more difficult, and we thus hope to have a 'command centre' back on shore (probably in Fremantle but perhaps also at Hillaries), that will be manned by VFLO and other volunteers. Tagging kits and data sheets can be picked up/dropped off at these locations. Skippers of boats that are short of crew or need a tagger can also phone into the command centre and request such help (preferably the day before). Arrangements can then be made for the appropriate person to meet them at the boat ramp at a set time. There are many keen fishers who do not own boats so there should not be any shortage of willing crew. For obvious reasons we will give preference to those who have fishing experience and have their own fishing gear that is suitable for tackling sambos.

Less experienced people who are keen for a taste of sambo fishing and want to help out can also jump onto one of the charter boats that will be helping out during the study. These boats are generally bigger and more comfortable, and the experience of the skipper and crew should ensure that you have an action packed day on the ocean. Some at least will also have the necessary fishing gear.

Please note that we are endeavouring to help out with costs where possible and various organisations are providing quality rewards and incentives to add to the experience, but generally

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there will be some cost involved to each fisher. These should be reasonable – chipping in for fuel on a private boat or paying a discount price on a charter boat (we'll provide a list of charter boats that have indicated their interest next newsletter). Anglers will also need their own fishing gear although there will be gear given out as rewards as well. Of course, the very impressive, limited edition 'Sambo Science' t-shirt that everyone will receive in addition to the good karma for helping our fish and the insight into the world of fisheries research will be a reward in itself!?

Those who are tagging and recording the data have the added responsibility of looking after the tagging kits and data sheets. The completed data sheets are very valuable to us, and need to be returned to either the command centre, the WA marine laboratories in Watermans or to some other designated drop off point. Because we will be entering the data each day to provide a running commentary on the Western Angler website during the study, it is important that the data sheets are returned daily (any photos that can be displayed on the website will also be welcome).

Some people are also keen to be involved with the research but would prefer not to be on a boat catching or tagging the sambos. There are several areas where such people can help out, including data entry, spending time in the command centre taking phone and radio calls, and distributing tags and gear to the fishers. These folk will certainly be a crucial component of the project and they won't be forgotten when the prizes are given out. They are also very welcome at any of the tagging and jigging demonstrations.

Information sessions and tagging and jigging demonstrations

With about three months to go before the big event we're going to start putting on some demos and info sessions so that things will happen as smoothly as possible on the water.

Firstly, we're kicking off with an information and tagging demonstration night organised by Recfishwest and ANSA on Tuesday the 26th of October at the Cockburn Power Boat Association, Woodman Point. During this night you'll get to hear Andrew Rowland talk about the latest fish tagging results and Mike Mackie about Sambo Science, with a tagging demo by Garry Lilley and Neil Daws. Unfortunately some people won't receive this newsletter before the 19th October when bookings for the event close, but don't worry as there will be other opportunities.

Each Saturday through November from 4 to 6 pm we'll also be conducting tagging workshops in the carpark near the end of Capo D'Orlando drive on the south side of Fishing Boat Harbour in Fremantle. Al Bevan and the crew from 'North Star II' will also be talking sambo fishing tactics and maybe cooking up a feed of smoked sambo so come along and join in. These workshops will go to schedule regardless of weather but give us a call beforehand so we have an idea of numbers (phone details are provided at the end of the newsletter, or call Al Bevan on 041 213 1958).

Jigging and tagging workshops will also be conducted immediately prior to the big event at Bluewater Tackle shops on the following dates:
- Tuesday 4th January (Morley Store)
- Wednesday 5th January (Scarborough Store)
- Thursday 6th January (Melville Store)

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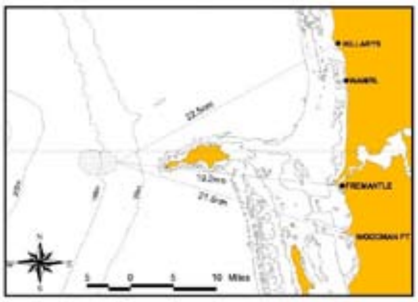
Times for these events will be provided later, and if you're after fishing gear check out some of the discounts on offer during these workshops. Again, give us or the fellows at Bluewater a call if you're interested so we have an idea of numbers.

Finally, there will be the big information day on Saturday January 8th next year (the day before the big tagging event gets underway). We'll explain this day in detail later, but there will be lots happening on this day besides further tagging demonstrations so make sure you keep it free. Of course, if anyone has any concerns over tagging or anything else to do with the study feel free to give us a call anytime.

Location Details

A map showing the general area of the aggregations is provided below to give you an idea of where the tagging will be taking place. This also gives the approximate distances from the major launching areas. The aggregations are in an area that ranges from 4 – 8 nm west of Rottnest Island and 80 - 120 m of water. More exact GPS coordinates will be provided to each boat closer to the event when the schools have properly formed and the locations are settled.



Research to date

At present much of our energy is directed towards getting everything prepared for the sambo tagging event. The sambo schools haven't formed properly yet so we haven't been spending alot time on the water west of Rotto, although we have been keeping an eye on what the other species are doing out there. Of interest is the fact that big skippy are using the same area at the moment to

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spawn. In order to determine why this area is such an important spawning ground for these species we will be deploying water temperature and current data loggers in November. These loggers will stay in place throughout the year and will be attached to a hydrophone so we can also listen in on fish doing their thing. We have also started testing the underwater video gear on snapper in Cockburn Sound. There are a lot of logistical considerations with using this equipment so the snapper are an ideal and very relevant species to work with until we go deep after the sambos.

Finally, we are also cranking up the collection of biological samples for sambos. Andrew Rowland is looking after this side of things, and has been busily tagging small juvenile sambos in the Fremantle area. He's always after more samples (eg sambo frames) so give him a call if you can help out.

Thanks again for everyone's support of Sambo Science. We hope that you get as much out of the project as we do. A minute spent filling out the attached form will help us to plan our strategy so please give it a go. We hope to see you at one of the information sessions and will be in touch with further details soon. Remember to treat each fish with care!

Michael Mackie
mmackie@fish.wa.gov.au
Ph 92468 418 / 0427 472 121

Paul Lewis
plewis@fish.wa.gov.au
Ph 92468 419 / 0427 774 551

Andrew Rowland
andrew@recfishwest.org.au
Ph 9387 7864 / 0418 326 747

Assisted by: Apache Charters, Bluewater Tackle, Dreamboats and WA Boat Charter, Eagle Australia, Halco Tackle, Mandurah Tackle Mart, Mako Tackle, Palatchie's Welding and Earthmoving Repairs, Saltwater Lab Jigs by Grifton Australia, Shikari Charters, WA Maritime Training Centre-Fremantle, Western Angler.

Samson Science

the research behind *fish for the future*

Department of Fisheries • Curtin University • Murdoch University • UWA • You!
Fisheries Research and Development Corporation
Supported by Recfishwest, the Australian National Sportfishing Association
and Fremantle Volunteer Sea Rescue

Hi there

In previous newsletters we discussed the importance of fish spawning aggregations and described the research methods we will be using during the big tagging blitz in January and February next year. Now, with the end of the year fast approaching and a clearer understanding of the nature of things (eg number of anglers, video and hydro-acoustic methods), the purpose of this third newsletter is to delve into the finer details of Samson Science. This is where we focus on the serious side of tagging these big, powerful fish the other side of Rotto during a windswept summer. More detail will also be given about the awards that can be obtained for assisting in the tagging project (as provided by the project supporters listed at the bottom of these pages).

Firstly though, a brief recap of the research plan early next year:

- 4-6th January (Tues – Thurs) jigging and tagging workshops (at Bluewater Tackle Morley, Scarborough and Melville stores – call 9245 1313 for more details).
- 8th January (Saturday). Information day at Murdoch University (10 am – 2 pm; see attached details).
- 9-30th January. Period during which a target of 3000 samson fish will be tagged and released by anglers and researchers fishing three aggregations west of Rottnest Island. During this time video and hydro-acoustic surveys of the aggregations will also be conducted.
- 31st Jan-4th February. Five day break to let fish recover and mingle.
- 5th-13th February. Capture and release of samson fish from the three aggregations. Fish won't be tagged this time, but they will be measured and all tag numbers will be recorded (as well as fish condition and capture location). Video and hydro-acoustic surveys will also be undertaken.
- 26th February. BBQ and presentation of rewards. Murdoch University 10 am – 2 pm (same location as the Information Day on 8th Jan). Preliminary presentation of results also provided. More details to come.

General fishing rules

The vagaries of weather and exploratory nature of our research mean that we have to maintain some flexibility to our planning during the study. For instance we may find that the fish become spooked by all the action and go off the bite so that we have to add another aggregation to the study (although ideally we want to only fish three aggregations in order to keep the recapture rate of tagged fish as high as possible). However, we also need to stick to a few rules so that the scientific integrity of the project is maintained, responsible fishing practises are adhered to and the safety of participants emphasised. These rules include:

Only take part in any of the research associated activities if you feel up to the task. We're happy just to know you've learnt something from these Newsletters or the various workshops that have been/will be held, and we'll appreciate your assistance whether you help out for two days or twenty. Remember too, that it will often be hectic, bouncy and tiring out on the water, so if you'd prefer to stay ashore there may be other ways of helping out (eg in the control room).

- Make sure that you have a properly trained tagger onboard who has attended one of our workshops and has all the proper gear. Although samson fish are pretty easy to tag it is essential that the tags are placed in the correct position so they don't fall out and so they can be seen underwater using the video.
- Make sure the data sheets are filled out properly, kept safe and returned to us as soon as possible. Otherwise the data is compromised, the results misleading and the fish injured for no purpose. By returning them to us immediately we can get results out as soon as possible (the plan is to give a running commentary of the project on the Western Angler website).
- Only tag samson fish within the three designated aggregations (GPS positions for these will be given in early January when we confirm their exact locations). By limiting our tagging area we should maximise the recapture rate of tagged fish so that we can get the best indication of the number of fish in each aggregation and the best protocols for maximising survivorship of released fish. A fourth aggregation may be added to the list if necessary.
- Focus on quality not quantity. We'd rather see each fish cared for properly than break any tagging records, and whilst most samson fish appear to handle the stress of capture okay they go downhill rapidly if handled and released incorrectly. A few simple rules should be followed here:
  - Keep work area wet.
  - Be organised and decisive when unhooking, measuring and tagging.
  - Cover eyes as much as possible.
  - Don't touch gills.
  - Don't lift the full weight of large fish by the tail or head – use both to avoid possible damage to gills or spine.
  - Don't let the fish simply float away – spear the fish back in (see picture) and if this doesn't work try reviving it by towing alongside or stick the deckhose just inside it's mouth (not too far in) to get water over the gills (low pressure only to avoid damage). Once the gill movement becomes regular and the fins and gills flare out when the fish is touched it is often ready to go by simply spearing back in again. If the fish dies pick it back up and keep it on board – we can use it for biological

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sampling and if properly iced samson fish are good eating (although the odd one will go mushy when cooked due to presence of a parasite). A release weight can also be used to get the fish down to the bottom, although you'll have to use more weight than normal for these big fish.
  - Be quick with the photos.
  - Leave fish in the water until the tagger is ready to go.
  - Work as a two person team where possible – one tagging and measuring, the other recording information onto the datasheet.
  - Use barbless hooks! Sambos are heavy-jawed and it's a real struggle getting the barbed variety out.
- Practise good boating etiquette and be mindful of other fishers. If you see someone in a spot of bother see if they need a hand.

Note also that your safety and the fish's welfare are most important, and if these are compromised we may need to call a halt to the tagging project or ask individuals not to participate.

Day to day running of project

Day to day fishing activity during January and February will be dependent on weather and the availability of boats. Weekends are likely to be much busier than weekdays, and as we only have a limited number of tagging kits there may be the odd day when some boats won't be able to participate in the event.

Skippers will have control over who goes fishing on their boat and when they are available for fishing/tagging samson fish. Naturally, skippers will also be responsible for the safety of their boat and are encouraged to log in with Fremantle Volunteer Sea Rescue every time they head to sea (details given below). We can provide taggers and fishers for each boat if required – just call the Control Room or one of us a day or two before heading out (details given below).

When logging out at the end of the day each skipper is also asked to let the radio operator at Fremantle Volunteer Sea Rescue know how many samson fish were tagged by them. This will help us keep a tally during the event.

Fishers and taggers should also call the Control Room to say when they are available. This will be manned each afternoon from 1 – 4 pm by VFLO and other volunteers who will coordinate this information and organise for the various parties to meet at a convenient location before heading out for the day.

Taggers won't be expected to pitch in for boating costs but they will have responsibility for the care of the fish, the tagging gear and return of properly completed data sheets. They must also be familiar with the methods we need to use when tagging and recording samson fish during this project. Their tagging kit will consist of:

- 1.5 m aluminium measuring board.
- 3 tag inserters.

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- tags.
- clip board with data sheets.
- plastic folder with spare data sheets, reply paid envelopes, pencils, rubber bands.

Taggers can hang onto the tagging kits if they're going out regularly, but otherwise will have to return them to the Research Labs in Marmion or the Control Room in Fremantle. Call us to make another arrangement if necessary. Spare tags will be available from the Labs or Control Room and also out on the water from Al Bevan on 'North Star II' or from the research vessel 'Snipe'. Note that tag supplies are limited so it is crucial that unused tags are returned. Data sheets can also be deposited at these locations or mailed to us via reply paid envelopes. Because we want to give regular updates during the tagging event it is important to get these data sheets back to us as soon as possible. We'll be giving away incentives to urge you to do this!

The data sheet is fairly straight-forward and will provide us with the information we need to achieve the objectives of the project. Some bits of the data sheet can be filled out before each fish is landed (eg tag number of the next fish to be caught), and other bits will remain the same for most fish (eg line class). Only some info will need to be filled out for each fish when caught (eg hook location).

Remember too that we'll be double tagging the first 1000 or so fish so that we can get an estimate of tag loss rate. Any fish that have the smaller ANSA tags are to be retagged with a samson science tag so to ensure the tag is visible underwater (don't forget to record the number of the ANSA tag). Fish that already have a samson science tag in place don't need to be tagged again but all the other details about length and fishing method need to be recorded.

Fishers will have the responsibility of keeping safe and catching sambos! They might also like to act as data recorders for the tagger whilst tired muscles are recovering. We'll certainly be trying to get all able-bodied people out for a fish but day to day availability of boats is unpredictable. Fishers may be asked by the skipper to chip in something for fuel costs. Samson fishing requires sturdy gear and fishers without such will have to rely on the boat having some (this will reduce their chances of a trip). The availability of charter boats will depend on weather and people numbers. Some will have fishing gear for use and this is a good way for less experienced or less able persons to get involved.

Some fishers are also planning on staying overnight at Rottnest Island. We'll probably be doing this a bit ourselves since this is a good way of cutting down fuel costs and maximising fishing time. Contact the RIA administration office in Fremantle ph: (08) 9432 9320 for more details or visit their website.

People interested in up-to-date news and photos during the tagging and recapture events in January and February can log into the Western Angler website (www.westernangler.com.au) where a special forum will be established.

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Great expectations!

Samson science is very much a volunteer driven project, and funding has not been provided to us to pay for people's time or costs. Nor can we provide much in the way of fishing gear which, in the case of deep sea jigging for samson fish can be fairly costly.

Nevertheless, the numerous supporters involved with the project are providing a range of goodies to reward many volunteers for their efforts. These rewards range from fishing gear to restaurant meals. As indicated by the attached list, the rewards will be given to a broad range of persons with a focus on proper tagging and release of fish. Note also that each participant will automatically receive a great t-shirt and be in the running for a couple of rewards for turning up to the workshop on January 8th (a BBQ will also be happening).

Insurance

The Department of Fisheries is conscious of the duty of care that it has towards volunteers and of the need to ensure that volunteers are aware of their responsibilities where safety is concerned. A range of personal and liability insurance cover will be provided whilst involved with the tagging project to guard against unforeseeable events (beyond the risks inherent with fishing at sea from a boat). To be covered, each volunteer must complete the **Volunteer/Work Experience Details Form** enclosed with this Newsletter. The form may be faxed/posted to us or filled out at the workshop on 8th January.

Important Addresses and Contacts

- **Control Room**
  Mews Road, Fremantle Boat Harbour
  Ph: 0407 385 334
  1-4 pm weekdays/weekends
- **Fremantle Volunteer Sea Rescue**
  Monitoring 24 hrs a day
  VHF Channel 73
  27 MHz Channel 90
- **Mike Mackie**
  Ph 042 747 2121
  mmackie@fish.wa.gov.au
- **Paul Lewis**
  Ph 042 777 4551
  plewis@fish.wa.gov.au
- **Andrew Rowland**
  041 832 6747
  andrew@recfishwest.org.au
- **Wally Parkin (northern suburbs)**
  041 791 8588
- **WA Marine Research Laboratories (Dept of Fisheries)**
  West Coast Drive
  Watermans (opposite Elvire Street)
  Ph 9246 8444

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That's all for now – have a great Christmas and New Years. See you January 8th at Murdoch! Don't hesitate to call if you have a query.

Photo: Gary Lilley on North Star II about to spear a samson fish back into the water. This is a quick method of getting the fish back through the surface layers so it can continue the descent under its own steam. Some fish may need more help to recover – eg by towing, hose in mouth and/or release weight. Note that damage can be done to the vertebral column of large fish by lifting them as shown – keep the head of big fish in the water when spearing back in to take weight off the tail.

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Samson Science Information Day

Where: Loneragan Building, Murdoch University (see Map)
When: 10 am – 2 pm, Saturday 8th January 2005
What's included:

10:00 – 10:30 Registration, collection of shirts etc.
10:30 – 11:00 Detailed run through of the tag and recapture project by Mike Mackie from Fisheries Research, Dept of Fisheries.
11:00 – 11:15 Discussion of safety issues by Mike Currie from Dept. of Fisheries.
11:15 – 11:25 Discussion of radio procedures by Frank Pasini from Fremantle Volunteer Sea Rescue.
11:25 – 2:00

- Tagging and jigging demonstrations (Recfishwest and Bluewater Tackle).
- Information desk: Registration, insurance forms, brochures, tagging kits for designated taggers.
- Displays by the samson science supporters (fishing gear etc).
- BBQ
- Prizes! For taking part in the samson science project you'll receive a show bag filled with goodies (t-shirt, tackle) and one of our limited edition 'samson science' t-shirts. But wait, there's more – we'll also be drawing a few special prizes (jigs and other fishing gear, romantic dinners for two, trips on charter boats).
- General discussion about marine and safety issues, research issues.
- Great video of samson fish at 100 m west of Rotto.

Map: Murdoch University and the location of the information day in the Loneragan Building (circled). Park your car in one of the car parks and look for the signs.

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Draft Reward List (for recreational anglers only – no person to win more than 2 individual awards)

Murdoch Information Day (January 8th)

T-shirts & showbag – all participants
Random Draws (5 x 3 jigs)
Random Draws (2 x fishing outfits)
Random Draws (TBA)

Skipper (Private)

Boat With Highest Average Number Tagged
Boat With Highest Single Day's Number Tagged
Boat With Highest Short Term Recaptures (February 2005)

Taggers

Most Tagged In A Day (individual)
Most Tagged In A Day (boat)
Champion Tagger (Male)
Champion Tagger (Female)
Champion Tagger (boat)
Most Subsequently Recaptured – March 2005 (individual)
Most Subsequently Recaptured – March 2005 (boat)
Most Subsequently Recaptured – March 2006 (individual)
Most Subsequently Recaptured – March 2006 (boat)
Lowest Tag Lost Rate (individual)
Lowest Tag Lost Rate (boat)
Quickest data sheet return – week one
Quickest data sheet return – week two
Quickest data sheet return – week three

Data Recorders

Champion Recorder (Male)
Champion Recorder (Female)
Neatest Entries
Most Complete Data Sheet
Least Mistakes

Fishers

Week One - Most Caught In A Day (individual)
Week One - Most Caught In A Day (boat)Week Two - Most Caught In A Day (individual)
Week Two - Most Caught In A Day (boat)
Week Three - Most Caught In A Day (individual)
Week Three - Most Caught In A Day (boat)
Recapture Period - Most Caught In A Day (individual)
Recapture Period - Most Caught In A Day (boat)
Most Fish Surviving – March 2005 (individual)
Most Fish Surviving – March 2005 (boat)
Most Fish Surviving – March 2006 (individual)
Most Fish Surviving – March 2006 (boat)

Controllers

King Controller
Best Phone Voice
Control Freak
Most Data Entered

General

Random Draw (week 1)
Random Draw (week 2)
Random Draw (week 3)
Random Draw (recapture week)
Most Memorable Event (week 1)
Most Memorable Event (week 2)
Most Memorable Event (week 3)
Most Memorable Event (recapture period)
Most Memorable Event (best of the best)
Most Valuable Player
Photo – 1st
Photo – 2nd
Photo – 3rd
Photo – Most Compromising
Photo – King Samson 2005
Photo – Queen Samson 2005

Note: this list is to be finalised.

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Hi there

A quick briefing to keep everyone up to date. We have about 1200 fish tagged after about 2 weeks – quite a feat given the lousy weather but still a way to go (indeed, some people thought we wouldn't get that many done even with good weather!). Last week was a blow-out, and just when we were starting to think of a ritual sacrifice to the weather gods last Monday broke with a relatively light easterly that eased off to a lovely day on the water. And what a day – about 500 Samson fish tagged and away. Just goes to show that we can get the 3000 done if we are given the opportunity. We are also thinking of extending the tagging part of the project by a week if necessary to allow for lost time. We would prefer not to do this though due to the increased likelihood of tagged fish moving away from the aggregations (this would affect our estimates of fish numbers in the aggregations).

Thanks to all who have put in an effort thus far – particular thanks to the VFLOs in the control room and to those braving the elements on the water. Of particularly note is the way everyone worked so well together and payed good attention to the welfare of each fish. Thanks for that! The data sheets are also being filled out well – this cannot be emphasised enough because this information is crucial to the study (also make note of any general observations you might make – eg presence of free-swimming sambos).

Please note that a couple of fish were taken by sharks so don't tempt fate by jumping in (let us know if any fish are taken). Also make sure you properly support the weight of each fish by cradling the rear end in one hand (minimal pressure on gut area) and the other supporting the head (no hands in the gills!). Bigger fish are more prone to lifting injuries due to their weight and don't seem to revive so well, so get them back in the water asap. Also, if you catch a previously tagged fish fill out the data sheet as usual (fork length etc), record the tag numbers and let the fish go again with tags intact (one enthusiastic angler pulled the tags out and sent them back to us). If the fish has been tagged with an old ANSA tag re-tagged it using a Samson Science tag after noting down the number of the old tag.

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Finally, a word on rewards – with another week to go and quite a bit of gear being lost we're giving away a few jigs (4) to fishers/boats who have been out quite a bit or tagged a good number of fish. These are:

Kevin Noack (4Play)
Mark Richter (Spash 2)
Jim Ireland (Profiler)
Tim Malseed (Little Bulldog)
Greg King (Reel Obsession)
Brad Pearce (Thalissos)

These can be picked up anyway possible such as when picking up tags. Also not that the rod and reel combos won by Brad and Cliff on the day of the workshop will be ready to pick up late Friday afternoon so we need to get them to you asap. We're still waiting on the sponsor for the fuel vouchers to Mark and Terry so don't despair (!).

That's about all for now – weather permitting we will be out on the water tomorrow with the Snipe (research vessel) doing some tagging, and again on Sunday doing hydroacoustic and video surveys. Apologies to all those frustrated taggers/fishers who haven't been able to get out yet due to the weather – keep in touch with Laurie and the VFLOs in the Control Room and we'll keep trying!

Cheers for now

Mike

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Fish Aggregation Research

Including!

Samson Science 2

the research behind *fish for the future*

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Hi there

This newsletter is going out to participants of the Samson Science project completed earlier this year. We've been busy through winter doing 'stuff' but now that spring is almost here and fish spawning activity is increasing we are planning another busy tagging and sampling season – hopefully you're interested in being involved and learning more about our research.

In a few months Samson fish will be re-appearing in large numbers west of Rotto and elsewhere in the metro area after their long swim from home waters. Thanks to the great job everyone did last time the Fisheries Research and Development Corporation (a Commonwealth funding body) have agreed to fund another version of the Samson Science project so that we can fill a few more of the knowledge gaps on this species. We're calling this new tagging study 'Samson Science 2', and it will come under the Fish Aggregation Research banner since we're also focussing on other species such as snapper and dhufish.

Samson Science 2 (SS2) will be led by Andrew Rowland from Murdoch University. As many people know, Drew also works with Recfishwest as tagging co-ordinator and is undertaking a PhD on Samson fish. Paul Lewis and myself will be working with Drew and also helping Miles Parsons from Curtin University continue with his PhD research involving acoustic surveys of Samson fish, snapper, mulloway and dhufish. In addition, we'll be collaborating with Jason How from Edith Cowan University with a study of movement patterns in dhufish using special acoustic tags, and we'll be spending more time with fishers gathering samples and data using video and fishing methods.

So we've got a pretty busy season planned, and we'd like you to be involved – by taking the time to learn about our research or by helping us tag fish and collect samples and data. To kickstart the new season we are having a workshop here at our new research facilities on the north side of Hillarys Boat Harbour. It's happening on Sunday September 11th (there's no footy on that day) and will include several research topics that should be of interest. See the details on the following page – we need to have an idea of numbers so email or call Paul or myself if interested in coming. Hope to see you there!

Mike Mackie (mmackie@fish.wa.gov.au) 9203 0209
Paul Lewis (plewis@fish.wa.gov.au) 9203 0203

1 August 2005

Fish Aggregation Workshop

Where: WA Fisheries and Marine Research Laboratories – see the map below.
When: Sunday 11th September 2005. From 1:30 to 4:00 pm.

Programme:

1:30 – 1:50	Introduction by Mike Mackie (Department of Fisheries) – What's been happening in our research and what will be happening during the workshop.
1:50 – 2:20	Samson Science 2 by Andrew Rowland (Murdoch University). A run through of results to date and details of the next episode of this well known project.
2:20 – 2:40	Acoustic surveys of fish aggregations by Miles Parsons (Curtin University). See and hear fish like never before - 3-D images of Samson fish aggregations and the grunting of mulloway. Not quite R-rated.
2:40 – 3:00	Light refreshments – tea/coffee/biscuits – or if you want real food the café downstairs will be open.
3:00 – 3:10	Regional variation in dhufish biology by Jill St John (DoF). Nothing stays the same.
3:10 – 3:30	Dhufish movement patterns by Jason How (Edith Cowan University) or Mike Mackie. Do they or don't they – and if they do, how do they do it?
3:30 – 4:00	Recreational fisher log books and a crash course in fish reproductive biology by Mike Mackie (DoF). Take a more pro-active approach to your fishing experience.
4:00 – 4: 05	Wind-up. The Breakwater Tavern is not far away…

2 August 2005

Fish Aggregation Research

Including!

Samson Science 2

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Hi there

Here we go with another update of our research, following on from the workshop held a few Sundays ago here at the new fisheries research laboratories. Thanks to all the people who attended that day (approximately 75 in all) – you should all be experts on fish gonads now!

In this newsletter I'd like to elaborate on some of the talks given during the workshop, including the Samson Science 2 and dhufish acoustic tagging projects that are being run over the next summer.

Samson Science 2

Samson fish have been an integral component of our research into fish aggregations – firstly because the big schools they form west of Rotto are convenient for trialling our acoustic and video methods, secondly because they are large, abundant, and therefore play a key role in the ecology of local waters (ie whatever happens to them can affect the balance of the system they are a part of). And finally, because they are targeted by commercial fishers supplying local markets and by recreational anglers who generally partake in catch and release. The latter is the one we've been focussing our efforts on over the past couple of years although the commercial fishery will also come under our scrutiny in order to provide a thorough understanding of the situation. Andrew Rowland, who most people will know from previous events and his ANSA tagging facilitator role with Recfishwest is leading the research on Samson fish as part of his PhD studies through Murdoch University.

Initially our research on Samson fish involved a single intensive season of tagging with the assistance of recreational anglers (as occurred Jan-Feb this year). We were hoping from this to estimate how many fish were in the Rotto aggregations and compare this estimate with those determined from video and acoustic methods (eg see the Figure below). However, as it turned out the fish were leaving the aggregations too quickly for us to carry out this plan, but the new insights we gained into migration patterns, biology and the fishery, along with the keen interest shown by the community to be involved in our study and strong support of Recfishwest led to plans to continue on with the show.

So we're back with 'Samson Science 2' – similar to last year but with a more focussed tagging effort that includes community assisted tagging events in the metro, Geographe Bay and Albany areas. Once again we're hoping to tag around 3000 fish this summer. Tagging of the first 500 or so of these is already

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underway in the Geographe Bay area after a workshop held in Busselton on the 14th to discuss tagging, data recording, fish handling and safety so that the same high standards set the previous year are maintained. The workshop was well attended, particularly by anglers from the Naturaliste Game and Sport Fishing Club and the Dunsborough Angling and Aquatic Club, and there are currently twenty boats taking part in the tagging. Because of the bad weather over the last few weekends we've extended the tagging period for this area to the end of November.

We hope that recaptures of the fish tagged during this event will give us a better insight into the proportion of fish moving north to Rotto for spawning. Biological sampling of fish taken at this time will also help us determine whether the fish are feeding on their way and whether they are ready for spawning when they arrive.

In November our focus will shift to the metro area, with a target of 2000 Samson fish to be tagged between November 19 and December 18th. Our surveys last week indicated that there are a lot of skippy on the wrecks but not as yet many Samson fish, so November is fairly early in their aggregating season. This will provide a good contrast to last season when we tagged them late in the season, and perhaps show up differences in the amount of time spent in the aggregations. We also want to get more information about the incidence of barotrauma related injuries, the effects of catch and release on spawning activity, and the best methods to maximise survivorship. Interestingly, methods we are using here to revive and release fish have been adopted by South Australian fishers to increase survivorship of sambos over there as well.

During the metro tagging event we'll be targeting Samson fish in northern areas as well as the west Rotto area because there seems to be little mixing of fish between the two. Basically, you can tag sambos wherever you find them, as long as you let us know the details! We'll also be restricting the number of boats to about 30, with taggers and fishers that have gear but no boat placed on a list and called when a spot is available. Alternatively, there will be opportunity to get onto the water aboard the charter boats that are joining the research effort. Of course, to ensure that quality data and good catch care are maintained we are stipulating that all participating boats have at least one trained tagger on board.

Finally, in March - April 2006 we'll be tagging a further 500 Samson fish in the Albany region with the help of local fishers. The timing of this event should coincide with many of the Rottnest fish returning to the south coast and so we'll also be looking out for previously tagged fish.

Much of the information we gather about movement patterns, the best way to maximising survival of released fish and general understanding of behaviours etc will be derived from the data sheets and the recaptures of tagged fish. This is why keeping clear and accurate data sheets and the reporting of any recaptures is so important. As such are offering some small prizes to the people sending in the neatest and most accurate data sheets, and will provide either a 'limited edition' Samson Science t-shirt or ANSA cap plus certificate for every recapture, as well as prizes for the largest, smallest and most reported recaptures. These prizes will be given out early next year during information sessions to discuss the results of the research to date.

The metro tagging event is almost upon us so we look forward to catching up soon with familiar faces from the previous event. Paul and I will be in Geographe Bay area for the start of the metro event (doing dhuie work – see below). However we'll be back in December for the latter half of the show so look out for the Snipe on the water!

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Dhufish Research

Dhuies are an important part of our research because it is likely that they aggregate for spawning and because they are under considerable pressure. They are also a very complicated animal in terms of their biology and ecology, so despite the previous good efforts of Alex Hesp at Murdoch Uni into their biology, the comprehensive tag/recapture database thus far compiled by ANSA and rec fishers that provides info about movement, and the ongoing work by Jill St John at DoF into release survivorship and biology, we are still some way off having the understanding we need to properly care for this species.

Hence, as part of our research into spawning aggregations, we are focussed on the following projects over the next couple of years:

- Ongoing collection of biological samples, particularly over the spawning period, to get specific information about their spawning behaviours. For instance, we want to determine whether spawning among different groups of dhuies occurs at a similar time, whether all fish in a particular aggregation take part in spawning (eg it may be just the larger fish), and whether there are environmental cues to spawning (eg moon phase, water temperature). This component of the project is being run by Paul Lewis and myself, and you may come across us cutting up fish somewhere. We're always on the scrounge of course so let us know if you have any frames or fish that we can remove the necessary bits from!

- Acoustic tagging of dhufish to clear up some of the uncertainty about movement patterns. This is a vexing issue that has important implications re the impacts that fishing may have on the species. Current theories vary from little or no movement to cross-shelf migrations to large long-shelf migrations. It's likely that there is a bit of truth in all of these – eg they are fairly sedentary for much of the year but undergo seasonal movements. It is also possible that different parts of the population are doing different things – eg males are moving around more or older fish are more sedentary than younger fish that are still trying to find the best place to live.

  This project is being undertaken in collaboration with Jason How as part of his PhD with Edith Cowan University. The acoustic tags are inserted into the fish's gut cavity and emit a signal that is picked up by receivers (see pictures below). The initial aim is to determine whether we can successfully use this technique on dhuies without killing them. Hence the first part of the study is to catch, operate on, release into a big cage, and monitor the health of several fish to see how they survive. This will be done in the metro area and down in Geographe Bay so if you know where a dhuie is lurking (maximum depth 30 m) and am interested in seeing what we do, give us a call and we'll take you out on our boat to give it a go.

- Video observations of aggregating dhuies to understand behaviours associated with spawning. This will be a hard thing to do, but the aim is to position a camera facing an area where the fish are schooled, and take time-lapse video throughout the day. If it comes off we hope to gain a better understanding of the social dynamics amongst dhuie groups – eg the role that the large males play, the territorial biffs they have with other males, and how they interact with females.

- Ongoing interviews with fishers. These are providing invaluable and unique insights into dhuies and other species that would be impossible otherwise to collect. I'm always keen to talk to fishers about their observations and theories so give us a call if interested.

- Single beam acoustic mapping of aggregations, similar to that already done for the Samson fish aggregations. Of course the dhuie schools are less obvious but this method provides very useful information about their aggregations.

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Together, these projects should provide a more comprehensive understanding of dhufish biology and ecology that will be of interest to fishers and be a real aid in sustaining stocks into the future.

We'll be particularly busy over summer and appreciate any assistance that we can get in achieving our goals. Stay tuned for more details and for information about the next round of seminars to show you what we've been finding out.

Cheers for now.

Mike Mackie	Paul Lewis	Andrew Rowland
mmackie@fish.wa.gov.au	plewis@fish.wa.gov.au	andrew@recfishwest.org.au
(0427472121)	(0427774551)	(0418326747)

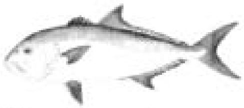
Pictures of the acoustic tag that emits the pulse (left), the seabed mounted receiver that picks up the pulse (middle), and insertion of the tag into a fish (right).

4 October 2005

Appendix 9. Details of workshops and seminars conducted during Samson Science

Date	Media	Publication/Program etc	Details
15th Aug 04.	Print	Samson Science Newsletter Aug04	Background information for Samson science volunteers
30th Aug 04.	Print	Fisheries Media Release 36/2004	Seeking volunteers for fish spawning study
3rd Sept 04	Radio	RTR-FM ‘Undercurrents’	
11rd Sept 04	Radio	6PR Karl Langdons fishing show	
8th Nov 04.	Print	Samson Science Newsletter Oct04	Background information for Samson science volunteers
14rd Nov 04	Print	Sunday Times	Recreational fishers wanted to help with tagging project
23rd Dec 04	Print	Samson Science Newsletter	Background information for Samson science volunteers
7th Jan 2005.	Radio	6PR Karl Langdons fishing show	
6th Jan 2005.	Print	Fisheries Media Release 1/2005	Tag team head out in name of Samson science
21st Jan 05.	Print	Samson Science Update	Progress report for first 2 weeks of tagging
22nd Mar 05.	Print	Fisheries Media Release 18/2005	Tagged samsonfish wanted
June 2005	Print	FRDC R&D News Volume 13 Edition 2	Samsonfish spring a surprise
5th Sep 05.	Print	Fisheries Media Release 43/2005	Volunteers wanted for southwest tagging project
5th Sept 05	Print	Fisheries Media Release 44/2005	Samson fish project gears up for summer at Hillarys
September 2005.	Print	Samson Science Newsletter Oct04	Background information for Samson science volunteers
Nov 05	Television	ABC Stateline	Fish acoustics
April 2006	Print	Research Angler Program (RAP) Newsletter 5	Samson science update and dhufish tagging
August 2006	Print	RAP Newsletter 6	Samson science and acoustic tags
Dec 2006	Print	RAP Newsletter 7	Samson science update and use of video
April 2007	Print	RAP Newsletter 8	Study of fish spawning aggregations
2007	Radio	ABC – Eoin Cameron Brekky Show	Dept of Fisheries National Marine Discover Centre (NMDC) official opening
2007	Video	Video presentation	NMDC
	Video	Video contribution to other projects	- Stateline program re: West Coast Management - NMDC video footage - ET fishing program - National Release Fish Survival video
2005	Radio	The Travelling Fisherman	Interview

Appendix 10. Datasheet used by recreational anglers when tagging and releasing Samson fish



Samson Science
Tagging Datasheet

Please return sheets or direct queries to Mike Mackie or Paul Lewis
c/o WAMRL PO Box 20 North Beach WA 6920
Ph 9246 8444 Mob 0427 472 121 or 0427 774 551

Fish for the future

Date ____/____/________ Vessel ________________ Skipper ________________ Crew ________________

Tag Colour ______________ Main Tagger ______________________ Fish Lift Height ________ m

	Latitude and Longitude	Angler / Tagger (if not main)	Tag 1 Number	Tag 2 Number if required	Fork Length (in cm)	Fishing Method	Line Class	Hook Postn	Lift Method	Revive Method	Release Condition	Comments eg bleeding, details of old tag. Note Other lift method, hook position, or details of release method etc
1						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
2						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
3						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
4						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
5						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
6						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
7						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
8						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
9						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
10						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
11						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
12						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
13						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
14						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	
15						Jig Bait	less 15kg 15-30kg 30+kg	Mouth Gut Other	Net Leader Tail Other	Speared Towed Deck hose Release wt	Healthy Floated/Revived Died	

Appendix 11. Booklet describing Samson fishing protocols developed and disseminated to fishers during the current project

Catching and caring for…

Samson Fish (*Seriola hippos*)

Introduction

Samson fish (*Seriola hippos*) are abundant along the lower west coast of Western Australia. They are known for their strong fighting abilities. Growing numbers of recreational anglers participate in a catch-and-release fishery for this species, particularly off the Perth coastline where Samson fish aggregate in large numbers to spawn during summer.

In response to community concern about the sustainability of Samson fish stocks in the fishery, the Department of Fisheries commenced a three-year research study in 2004 to learn about the species and the impacts of the catch-and-release study on stocks. The study is known as 'Samson Science' and is notable for the way in which the community has made an active contribution to data collection.

From this program and associated research a number of protocols aimed at maximising the survival of fish released by anglers have been developed. These protocols are practical and easy to adopt. They can also be used on other species. Please give them a serious go and look after this precious marine resource!

This publication was produced by the Department of Fisheries.
Fisheries Occasional Publication No. 43

PROTOCOL 1:
Use the right gear!

- Barbless hooks for easy removal.
- Jigs reduce the risk of injuries due to gut hooking – if bait fishing, use circle hooks to increase the chances of hooking the fish in the mouth.

- Heavy line class to minimise fight time (e.g. 80 pound/37 kg).
- Long and heavy terminal leader to control and lift fish when landing.
- Do not use gaffs. Preferably no landing net either to avoid wiping protective slime off. Samson fish are best caught off a boat with a low gunwale or marlin board so that they can be lifted and released properly. Take care at every stage of handling the fish.

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Samson Science

is a collaboration between scientists and anglers that has provided important information about the fish and associated sports fishery. All participating anglers underwent training to ensure that the fish were tagged and handled correctly and the data properly recorded. The collaboration will continue into the future with anglers recording their fishing activities in logbooks (a simplified logsheet has been attached for you to use if you would like to assist). This information is used to monitor the fishery and provide feedback to anglers via the Recreational Angler Program newsletter. Your help is appreciated.

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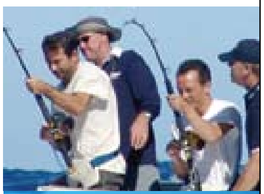
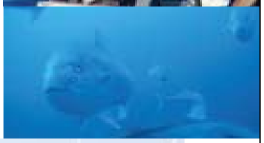
PROTOCOL 2:
Catching the fish...

- Keep fight times as short as possible to minimise stress and exhaustion of the fish.
- Slow the retrieval rate when the fish is in sight to give it time to vent the expanded swim bladder and decrease barotrauma injuries.
- Make sure you are prepared so that the fish is released as quickly as possible.





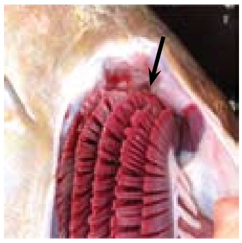
PROTOCOL 3:
Landing the fish...

- Ideally keep the fish in the water - barbless hooks should be easily removed with a dehooker or long-nosed pliers. Hooks lodged near the eyes or gills will require extra care in removal. Cut the hook off if necessary.
- If it is necessary to land the fish, make sure the weight is supported at the head and tail, as shown on the right (use two people if necessary).

- Make sure everything the fish touches is cool and wet – and don't land it onto a rough deck.
- Avoid direct sunshine, particularly in the eyes.
- Most Samson fish will be fairly docile when landed, although keep a clean, wet rag handy to place over the head of an active fish to calm it (but note that an abrasive rag can damage its eyes).

- Support the fish as shown below. Avoid pressure to the stomach area where sensitive organs are, and try not to wipe off the protective slime.
- Never put hands inside the gill area and never lift the fish up by just the head or tail – this can damage the backbone and gill structures of these large fish.

Barotrauma



This is a type of injury caused by the expansion of internal gases as fish are brought to the surface. This is a major issue with catch-and-release fishing. Fortunately, most Samson fish avoid serious injury by releasing expanding gases through a hole that develops beneath their gill plate (see arrow). This 'self-venting' mechanism may be an adaptation to a lifestyle involving rapid changes in depth.

More than 9,000 Samson fish have been tagged and the recaptures are providing exceptional information about movement patterns. For instance, most fish tagged off Rottnest Island head south after spawning – with some travelling over 2,500 km to Kangaroo Island in South Australia. Fish also return to Rottnest where they aggregate to spawn. These aggregations occur from about November through to February, although individual fish do not appear to remain for the whole period.

PROTOCOL 4:
Minimise deck time!

After capture, Samson fish are exhausted and urgently need to uptake oxygen through their gills. It is therefore essential to get the fish back in the water as soon as possible or they will quickly succumb. If you want to take a photo, have the camera ready and consider an in-water shot. But be quick – research shows that every minute is vital.

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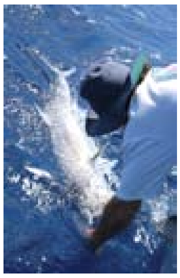
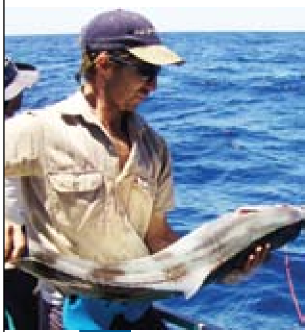
Release weights



Every tackle box should include a release weight, since data shows these increase the survival rate of released fish (note that Samson fish will require a heavier weight). The weight is hooked into the jaw and free-spooled to the bottom with fish attached. The fish comes free when the line is retrieved – back on the bottom where its internal gases have recompressed and where it can recover from the stress of capture.



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PROTOCOL 5:
Releasing the fish...

- The best way to release a Samson fish is to spear it back into the water. This is done by holding the fish by the tail with the other hand supporting the head area. The fish is then released head first with a firm push of the tail – but don't try to 'slam dunk' it.
- If the fish re-surfaces, have another go. If it is too exhausted, try reviving it with water through the gills (either by towing it or with a low pressure, high volume deckhose in the mouth).
- A release weight may be needed for larger fish and is preferred over venting to minimise injury and surface time.
- If the fish won't revive, don't let it float away – if bled properly and kept chilled, it will taste fine (although some suffer from 'mushy flesh').

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Samson fish,

and related amberjack and yellowtail kingfish - all members of the genus *Seriola* - are classed as Category One species (at high risk from overfishing). The minimum legal length for these fish is 600 mm (from nose to tip of tail), and the bag limit for all three species (combined) is 2.

Samson fish are suitable for tagging studies because they survive catch and release well if care is taken. Tagged fish provide information about movement patterns and growth rates – but only if recaptures are properly reported. Therefore, if you do catch a tagged fish, please call the West Tag hotline (1800 682 002) with the following information: tag number, date, depth and location of capture, fork length (nose to fork in tail) and total length (max length). Don't forget to include your name and address so a certificate can be sent out. Remember, incomplete or inaccurate data detracts from the quality of the research data and hence the resulting management advice.

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Samson Fishing Data Sheet

Please return to: Dept. of Fisheries, PO Box 20, North Beach, WA 6920
(Fax 9203 0199 / Ph 9203 0111).

Name: Email: Ph:

For each fishing spot record data in table below:

Lat/Long or Location	Start / Finish time	# Samson fish	Max # of other boats	# fish lost to sharks	DATE and Other (tag recaptures, general notes, other fish species etc.)

Samson Fishing Data Sheet

Please return to: Dept. of Fisheries, PO Box 20, North Beach, WA 6920
(Fax 9203 0199 / Ph 9203 0111).

Name: Email: Ph:

For each fishing spot record data in table below:

Lat/Long or Location	Start / Finish time	# Samson fish	Max # of other boats	# fish lost to sharks	DATE and Other (tag recaptures, general notes, other fish species etc.)

Samson Fish Length

Fish to be released should not be weighed. Use the table below as a guide:

Samson Fish Length Weight Table	
Fork Length (mm)	Weight (kg)
900	9.3
950	10.9
1,000	12.6
1,050	14.6
1,100	16.7
1,150	18.9
1,200	21.4
1,250	24.1
1,300	27.1
1,350	30.2
1,400	33.5
1,450	37.1
1,500	40.9

The really technically-minded can use this formula:

$$\text{Weight (kg)} = 0.0000000252 \times (\text{Forklength (mm)})^{2.9}$$

Final words

If you are interested in playing a part in looking after our fish resources, why not keep a research angler log book? It's a good personal record of your fishing experience and you'll also receive research updates! Contact 9203 0111 for further information.


Photo: Al Bevan

This brochure has been compiled by Michael Mackie, Andrew Rowland and Paul Lewis and is based on information gained from the Samson Science project and advice from recreational anglers. For more information about the Samson Science project call the Department of Fisheries on 9203 0111 or Murdoch University on 9360 2282 / 0418 326 747.

Acknowledgements: Alan Bevan, ANSA, and members of the Samson Science monitoring team who assisted with the development of this document.

Department of Fisheries

Australian Government Fisheries Research and Development Corporation

Murdoch University Perth, Western Australia

Recfishwest

Fish for the future

RES472 OCT07

Appendix 12. Response from Beneficiaries

Top
3/7/08

WA Recreational and Sportfishing Council (Inc) | Trading as RECFISHWEST | ABN: 77 922 817 608
Representing Western Australia's Recreational Anglers and Fishers

FISHERIES RESEARCH
FILE. REF: RS695/04-04
3 JUL 2008
DOCUMENT No: WMR4317
ACTION/OFFICER M. Mackie

Mr Michael Mackie
Finfish Research Scientist
Department of Fisheries
West Australian Fisheries & Marine Research Laboratories
39 Northside Drive
HILLARYS WA 6025

Dear Mike

Project 2004/051 Management and monitoring of fish spawning aggregations within the West Coast Bio-region of Western Australia

Recfishwest would like to acknowledge the success of the FRDC project *2004/051 Management and monitoring of fish spawning aggregations within the West Coast Bio-region of Western Australia.*

We believe this project has been of the highest standard for collaboration between researchers and recreational fishers. The high level of support from the recreational fishing sector to contribute to this project was due in no small part to the excellent relationship developed between researchers and fishers at the commencement of the project.

This project has helped build stewardship within the recreational for the Samson fish aggregations and has seen it develop into a world class sports fishery.

The project has also provided unique information about the spawning ecology of key West Coast demersal species and raised a number of important questions on how this fishery should be managed in the future.

Recfishwest looks forward to similar strong partnerships between researchers and recreational fishers in future projects.

Yours sincerely

Kane Moyle
Acting Executive Director

1 July 2008

Fish today for tomorrow

Correspondence to: P O Box 34 North Beach WA 6920
Ph: (08) 9246 3366 | Fax: (08) 9246 5955
Web: www.recfishwest.org.au | Email: recfish@recfishwest.org.au
Watermans Bay Research Centre | West Coast Drive | Watermans WA 6020

SunSmart

FISHERIES
WESTERN AUSTRALIA

Ref: 9/07

Dr Patrick Hone
Programs Manager
Fisheries Research and Development Corporation
PO Box 222
DEAKIN WEST ACT 2600

Dear Sir,

The Department of Fisheries, Integrated Fisheries Management Section, believes the FRDC project titled *"Management and monitoring of fish spawning aggregations within the West Coast Bio-region of Western Australia"* has been a resounding success.

The project has been one of the best examples of a collaborative approach between researchers and recreational fishers.

This project has provided significant information about the spawning ecology of key west coast demersal species and has allowed for a comprehensive review of techniques used to study and monitor aggregating species. Importantly, it has also improved our understanding of the mortality issues associated with fishing aggregations – particularly those aggregations that occur in deep water.

With the current focus on management options for demersal scalefish species within the West Coast Bioregion, this project is timely and has already been influential in discussion to date. In particular the project outcomes have been critical in the debate over temporal/spatial closures and in the assessment of options for monitoring populations of key species.

Yours sincerely

N. Harrison

Nathan Harrison

Principal Policy Officer South West Bioregion