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Industry survey to obtain a relative abundance index for spawning eastern gemfish - traditional and innovative methods

Ian Knuckey, Euan Harvey and Matt Koopman

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Executive Summary

Eastern gemfish (*Rexea solandri*) are midwater fish caught along the edge of the continental shelf off southern Australia and New Zealand. They comprised a very significant proportion of trawl landings off south-eastern Australia during the 1970s and 1980s with trawling targeting winter pre-spawning aggregations of mature fish. Eastern gemfish became the first species in the South East Fishery (SEF) to be subject to a Total Allowable Catch (TAC) quota in 1988, when a TAC of 3,000t was imposed. However, in the early 1990s the spawning stock was significantly reduced by a series of very poor cohorts (spawned between 1985 and 1989), and the TAC was progressively reduced to zero by 1993. The TAC remained at zero for 1994, 1995 and 1996 due to concerns about low stock size resulting from an extended period of low recruitment; however this made it difficult to assess the status of the stock because there had been no valid targeted catch rate data to use as an index of stock abundance.

Industry strongly suggested that some level of recovery of the eastern gemfish stock had occurred. This has subsequently been supported to some extent by the Integrated Scientific Monitoring Program (ISMP) which reported increased catches and discarding of juvenile gemfish during the early to mid 2000s. Industry called for some type of survey to help quantify this apparent recovery. During 2006, both the Slope Resource Assessment Group (SlopeRAG) and Shelf Resource Assessment Group (ShelfRAG) also supported the need for a survey to provide a relative index of abundance that could be used to compare with the targeted fishing of eastern gemfish over a decade earlier and the industry surveys of 1996 – 1998.

This report details the results of the Industry survey to obtain a relative abundance index for spawning eastern gemfish using traditional and innovative methods.

The objectives of this project are:

- Collect timely, accurate and contextual data on targeted catch rates and size composition of the catch during the 2007 eastern gemfish season.
- Supply Slope/ShelfRAG with 2007 catch and effort and size composition data by 1 September 2007.
- Assess the efficacy of stereo-mounted cameras on an open-ended codend to measure the length frequency and mass of eastern gemfish captured in an experimental trawl net.
- In an alteration to the project agreement, the first two objectives were repeated for the 2008 eastern gemfish season.

For the traditional survey component of this project, 23 trawl shots were conducted during 2007 using two industry vessels to collect timely, accurate and contextual data on targeted catch rates and size composition of the catch. In addition, a 2008 survey was conducted in response to the Eastern Gemfish Rebuilding Strategy which recommended to “undertake a 2008 spawning run survey (June–September) to resolve uncertainty in the recent 2007 survey catch rates”. The survey fleet was increased to four vessels during the 2008 survey which resulted in the completion of 63 targeted trawl shots.

Targeted catch and effort data were collected for eastern gemfish during the 2007 and 2008 winter surveys. Standardised catch rates of 1,063 kg/day and 809 kg/day were calculated for each year respectively. Length measurements recorded during 2007 show that samples were dominated by immature fish 23–27 cm fork length, male fish 52–55 cm fork length and

female fish 68–74 cm fork length. Length measurements recorded during 2008 were dominated by male and female fish 48–54 cm fork length, male fish 56–62 cm and female fish 72–80 cm fork length. In addition, otoliths from 666 and 1,456 eastern gemfish were collected during the 2007 and 2008 surveys respectively from which the Central Ageing Facility in Queenscliff obtained 665 and 631 age estimates.

Catch and effort, size composition and age data were provided to ShelfRAG for incorporation into annual stock assessments. These data filled important information gaps for management of eastern gemfish and contributed in the decision by NSW not to list the species as endangered. These data are also a vital given that the species is being considered for listing as endangered under the EPBC Act, 2007.

Several different stereo-video systems were trialled to determine the efficacy of using non-destructive, stereo-video systems in open-ended codends to measure the length-frequency of gemfish non-destructively and to estimate the mass of fish entering the trawl. The prototype proved unsuitable for installation in a trawl net, and subsequent modified designs were refined to adapt to the unique challenges of trawl fishing. The first modified design used Sony CX7 camcorders encased in aluminium housings with light provided by four 3 mW Royal Blue LEDs (450 nm). The lights and camera housings were mounted on a base bar inside a role cage. While trials were successfully undertaken, and adequate imagery obtained, the stereo-video system and the floatation it used encountered a lot of water resistance which created uneven drag in the trawl. The commercial fishers believed that this was altering the shape and efficiency of the net. The water resistance also forced the orientation of the stereo video system to change inside the net.

A third prototype was constructed and trialled. This prototype changed the orientation of the system in the net from vertical to horizontal and incorporated buoyancy into end caps on a torpedo shaped frame. The performance of this system was superior to former designs and did not appear to interrupt the performance of the trawl net. Further, it was able to be used to count and measure gemfish and other species as they moved through the trawl. Thus, if deployed on a trawl with an open codend, this low-cost, light-weight, stereo-video system could be used to collect relatively accurate and precise, non-destructive length measurements for a number of species.

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NOT INCLUDED

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AN ELECTRONIC COPY OF THIS APPENDIX CAN BE SUPPLIED ON REQUEST

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1 Introduction

Gemfish (*Rexea solandri*) are a midwater fish caught along the edge of the continental shelf off southern Australia and New Zealand. Genetically distinct stocks occur to the west of Tasmania and probably also in New Zealand (Colgan and Paxton, 1997). Mature eastern gemfish move north along the NSW shelf break during winter in large aggregations to spawn off central and northern New South Wales (Scandol *et al.* 2008).

Eastern gemfish comprised a significant proportion of trawl landings off south-eastern Australia during the 1970s and 1980s, when targeted fishing occurred on pre-spawning aggregations of mature fish during winter (Rowling 2001). In the late 1980s the impact of fishing on the gemfish stock became apparent, with declining mean length of fish in the spawning population and reduced catch rates in the winter fishery (Rowling 1987). Eastern gemfish became the first species in, what was then called the South East Fishery (SEF), to be subject to a Total Allowable Catch (TAC) quota in 1988, when a TAC of 3,000 t was imposed. During the early 1990s the spawning stock was significantly reduced by a series of very poor cohorts (spawned between 1985 and 1989) and the TAC was progressively reduced to zero in 1993 (Punt and Smith 1999).

A zero TAC made it difficult to assess the status of the stock because there was no valid targeted catch rate data to use as an index of stock abundance. This lack of data prompted the first industry survey of gemfish which was conducted during 1996 (Prince 1996). The aim of that survey was to estimate catch rates for targeted gemfish fishing that were directly comparable to estimated catch rates prior to the managed reduction of gemfish catches. Similar surveys were also conducted in 1997 and 1998 (Punt and Smith 1999).

A 1,000 t TAC was set for the 1997 winter season, however landings only amounted to about 300 t, and analysis of the fishery and biological data suggested that the spawning biomass remained well below the target level (Little *et al.* 2007). In subsequent years a 'non-target' TAC was applied for eastern gemfish and allocated to fishers in proportion to their eastern gemfish quota holdings. When first applied in 1998 this 'non-target' TAC was 300 t, but was subsequently reduced to 100t in 2002, and has remained at this level since.

The application of the 'non-target' TAC to eastern gemfish is thought to have reduced the incidence of discarding which occurred under the 'trip limit' management arrangements that applied during the mid 1990s. Statistically rigorous monitoring of discards by the Integrated Scientific Monitoring Program (ISMP) began during 1998, when moderate levels of discarding (8%–19%) were observed during 1998–2002. Evidence of a relatively strong cohort appeared during 2003 which led to increased discarding of juvenile gemfish that continued up until at least 2006 (Koopman *et al.* 2007).

Concern that the apparent increase in abundance of juvenile gemfish associated with the progression of this cohort through the population was not being adequately quantified was voiced by industry members. This was supported to some extent by the ISMP which reported increased catches and discarding of juvenile gemfish (Koopman *et al.* 2007). With no targeted fishing or industry survey in place, there was no relative index of abundance that could be used to evaluate the status of the stocks or whether any level of recovery had occurred under the bycatch TAC. Industry called for some type of survey to help quantify this apparent recovery. Resource Assessment Groups also supported the need for a survey to provide a relative index of abundance that could be used to compare with the targeted fishing of eastern gemfish over a decade earlier and the industry surveys of 1996 – 1998.

In addition to repeating the industry surveys, this project evaluates the possibility of using a stereo-video system as a means of conducting 'non-destructive' surveys. A video system installed inside trawl nets could be used to obtain "catch rates" of species if a suitable mounting could be developed that maintains orientation of the camera and ensures the field of view is consistent so that all fish that enter the trawl can be identified and counted. Stereo-video technology (Harvey and Shortis 1996) has been shown to be capable of making accurate and precise measurements of fish length both in aquaculture (eg Harvey *et al.* 2003, Phillips *et al.* 2008) and on free swimming wild fish (Harvey *et al.* 2002, Shortis *et al.* 2009). If a stereo video system could be adapted for use in trawl nets, by leaving the codend open, non-destructive surveys may be an option to replace trawl surveys to obtain estimates of catch rates and length-frequencies of target and non target species.

2 Objectives

1. Collect timely, accurate and contextual data on targeted catch rates and size composition of the catch during the 2007 eastern gemfish season.
2. Supply Slope/ShelfRAG with catch and effort and size composition data by 1st September 2007.
3. Assess the efficacy of stereo-mounted cameras on an open-ended codend to measure the length frequency and mass of eastern gemfish captured in an experimental trawl net.

In an alteration to the project agreement, the first two objectives were repeated for the 2008 eastern gemfish season.

3 Material and Methods

3.1 Survey - Traditional Methods

3.1.1 Planning and vessel selection

A workshop was held during March 2007 to refine the design details of the eastern gemfish winter survey. Further discussion with industry participants was undertaken to select two suitable vessels to undertake the survey work. It was agreed that a charter arrangement that allowed 50% retention of the research quota by the vessel provided incentive for the skipper and crew to commit to the survey and to handle and store the fish properly so that price from its sale would be optimised. This would be more appropriate than a straight charter fee with the vessel retaining none of the catch. It was agreed that the following criteria be used to determine which skipper/vessels take part in the survey:

1. The skipper must have fishing experience in typical gemfish areas (34 and 35 degree latitude boxes);
2. The skipper must have had a minimum of 3 years historic involvement in targeted gemfish fishery (June – August) during the 1990's;
3. The vessel must have a minimum of 3 years eastern catch history in the fishery.

Based on tenders submitted and charter price quotes, the vessels *Shoalhaven* and *Giuseppa* were selected to conduct the survey out of Ulladulla and Wollongong respectively. Surveys were conducted during the spawning season, aiming to achieve 15 days sampling on each vessel. Unfavourable weather during the 2007 spawning season prevented this level of sampling, so for the 2008 survey, two additional vessels were employed, the *Francesca* out of Sydney and the *Illawarra Star* out of Wollongong.

3.1.2 Survey Procedure
Because results of these surveys are to be used for comparison to historic targeted fishing catch rates; no fixed sampling design was set. Instead, it was left up to the skippers to determine where and when they would fish. To assist in their decision making; weather forecasts, mean sea level pressure analysis charts and sea surface temperature charts were circulated daily. Sea surface temperature charts are provided in Appendix 1. Skippers were also in regular contact with other vessels to share information on eastern gemfish movements.

3.1.3 Scientific Observation
Scientific observers accompanied survey vessels throughout the gemfish spawning season. Details of each shot were recorded including:

1. Time and location at which each shot was commenced (brakes on) and finished (winching up commenced).
2. Sea conditions together with approximate wind speed and direction during the shot.
3. Catch composition of each shot. Estimates of eastern gemfish catch were adjusted according to weights measured on catch disposal records.
4. The lengths (caudal fork length) of a representative sample of approximately 200 gemfish were measured from each shot. Caudal fork length was measured to the next lowest centimetre and recorded by sex.
5. Otoliths from a representative sample of approximately 25 gemfish were extracted from shots containing at least 200 kg of eastern gemfish. Caudal fork length, sex and shot details were recorded with each pair of otoliths.

3.1.4 Data Analysis
The primary objective of this survey was to provide catch and effort data for the 2007 gemfish run; comparable with the existing 1986 – 1992 SEF1 catch and effort data and the abundance index used in the assessment. As such, the survey has a focus on data collection rather than data analysis. The data collected was entered into an Olfish database and supplied to Slope/ShelfRAG in Excel spreadsheets for further analysis.

3.2 Survey – Inovative Methods

Investigations were made to determine the efficacy of using stereo-video systems in open-ended codends to measure the length-frequency of captured gemfish and estimate the biomass of fish entering the trawl. The method trialled was modified from successful work conducted using Underwater Visual Census (UVC) techniques on baited traps (Harvey *et al.* 2007; Watson *et al.* 2009) and diver transect surveys (Harman *et al.* 2003; Harvey *et al.* 2004).

The prototype stereo-video system to be used was adapted from existing technology. Trials were conducted to examine the performance of the system in a trawl net, and to modify it accordingly. The prototype consisted of a NESS EDSR400M mobile security recorder mounted in an underwater housing and connected to two JAI CVS3200 cameras. Lighting was provided by blue Light Emitting Devices (LEDs) and the system was designed to operate at 600 m depth. This trial was the first of its kind in the world. As such, modifications to the system were made after each trial. The evolution of this system is described in the Results section.

A stereo-video camera system comprises two or more cameras in housings fixed to a base bar where the separation and angle of convergence (relative orientation) of the camera lenses to one another remain fixed and stable, providing points of perspective (Harvey and Shortis. 1996; Cappo *et al.* 2007). Given some basic information on the characteristics of the cameras being used (pixel spacing and ratio, focal length and recording format) and a set of calibration images, the relative orientation and the focal lengths of each camera are determined using calibration software. Using these calibration files it is possible to measure the location of points in three dimensions relative to the cameras and base bar (X,Y and Z coordinates),(see Figure 6). These three coordinates allow computation of the length, range, angle and bearing of targets anywhere in the field of view (Shortis and Harvey 1998).

4 Results

4.1 Survey - Traditional Methods

4.1.1 2007 survey

The 2007 survey was conducted during 2nd July and 27th July by the fishing vessels *Giuseppa* and *Shoalhaven*. Despite unfavourable weather conditions, 23 shots were successfully completed over nine different fishing days (see Table 1). Numerous days of gale and strong wind warnings for Illawarra and South coastal waters were reported during this time which limited sampling opportunities. To aid selection of sampling days and to locate fish, weather forecasts, mean sea level pressure analysis charts and sea surface temperature charts were circulated daily. Sea surface temperature charts are provided in Appendix 1.

Use of only two vessels had the added difficulty of reducing the 'searching power'; especially given they had to leave the main spawning run to return to port every day or two.

Eastern gemfish were caught in all 23 shots observed, in quantities ranging 10–2800 kg (Table 1). Shot duration ranged 180–275 minutes. A standardised catch rate of 1,063 kg/day was estimated from the 2007 survey and incorporated into the quantitative stock assessment model (Little *et al.* 2008). The model was able to fit to this data point reasonably well (Figure 4). Sensitivity analysis revealed that by omitting this data point, estimates of 2008 spawning biomass dropped from 14% to 11%.

The lengths of 4,307 eastern gemfish were measured during the 2007 survey. Four main modes of fish length were observed; immature fish 23–27 cm fork length, male and female fish 40–45 cm fork length, male fish 52–55 cm and female fish 68–74 cm fork length (Figure 1a). The largest fish measured was a 105 cm female. Model fits to these length-frequency data were deemed adequate (Little *et al.* 2008).

Otoliths from 666 eastern gemfish were collected as a good representative sample of the 2007 spawning run. Otoliths were passed on to the Central Ageing Facility (Fisheries Victoria, Queenscliff) who obtained age estimates for 665 fish. Length and age-frequency histograms of aged fish are shown in Figure 2a and Figure 3a. Immature fish in the 22–27 cm length class appeared to be under represented in the age samples, but the three other dominant length classes were well sampled. The dominant age classes in 2007 samples were 2–5 year-olds. Males dominated the 2–4 year-old age classes, while females dominated the others. These data were also incorporated into the 2007 stock assessment, and as for length-frequency data, model fits were deemed adequate (Little *et al.* 2008).

4.1.2 2008 survey

The 2008 survey was conducted during 29th June and 5th August by the fishing vessels *Francesca*, *Illawarra Star*, *Giuseppa* and *Shoalhaven*. The two additional vessels were employed during 2008 to ensure sufficient sampling occurred during this time of typically unfavourable weather. Increasing the number of vessels also increased the searching ability for the survey. The four vessels conducted a total of 63 successful shots during the spawning run. As in 2007, weather forecasts, mean sea level pressure analysis charts and sea surface temperature charts were circulated daily to aid selection of sampling days and to locate fish. Sea surface temperature charts are provided in Appendix 1.

Eastern gemfish were caught in all 63 shots observed in quantities ranging 4–3,928 kg). Shot duration ranged 120–310 minutes. A standardised catch rate of 809 kg/day was estimated from the 2008 survey and incorporated into the quantitative stock assessment (Rich Little, CSIRO, Hobart *pers. comm.*). Results from 2008 assessment were similar to those of 2007 (see Figure 5) and supported similar conclusions about stock status. The 2008 base-case assessment estimated that current (2008/09) spawning stock biomass is 16.7% of the unexploited spawning stock biomass (Little and Rowling 2008).

The lengths of 9,039 eastern gemfish were measured during the 2008 survey. Four main modes of fish length were observed; male and female fish 40–45 cm fork length, male and female fish 48–54 cm fork length, male fish 56–62 cm and female fish 72–80 cm fork length (see Figure 1b). The largest fish measured was a 116 cm female. These data have been provided for inclusion in the 2008 quantitative stock assessment.

Otoliths from 1,456 eastern gemfish were collected during the 2008 survey. These were passed on to the Central Ageing Facility (Fisheries Victoria, Queenscliff) who obtained age estimates for 631 fish. Length and age-frequency histograms of fish from which age estimates were obtained are shown in Figure 2b and in Figure 3b. Length-frequencies of these fish have representatives from each of the four main length modes observed in Figure 1b and are considered to be representative of the 2008 spawning run. The most common age classes were 3–6 year-olds. The younger age classes were dominated by male fish while older ages classes were dominated by females. These data have also been provided for inclusion in the 2008 quantitative stock assessment (Little and Rowling 2008).

4.2 Survey – Innovative Methods

4.2.1 Original design

In designing a cost effective stereo-video system which could be incorporated into a non-destructive trawl net a number of requirements needed to be taken into consideration. These included; operating depths, recording mode and time, power supply, lighting, operational accuracy, ease of deployment and the overall cost.

4.2.2 Operating depths

Eastern gemfish have historically been caught off the shelf break of southern New South Wales by demersal trawling in depths of 350–450 m (Scandol *et al.* 2008). To account for this, and allowing leeway for deeper tows, it was decided to design the system with an operational depth limit of 600 m.

4.2.3 Surface or bottom recording of video imagery

Transmitting underwater images to the surface via cable is commonly used for video sampling in deepwater, because it has the advantages of real time viewing of imagery, surface supply of power to cameras and lights, and surface control of cameras and other equipment using RS232 or RS422 communication technology. There are a number of disadvantages, the greatest of which is cost. For deployment during eastern gemfish trawls, at least 1,200 m of heavy duty armoured cable would be needed at a cost of ~$72,000. In addition, a second cable would need to be purchased in case of equipment malfunction. To store, deploy and retrieve the cables, a motorised reel would need to be welded to the vessels deck. Both, the cost, the complexity and logistical difficulties associated with mobilisation, deployment and retrieval of a system of this design meant it was unfeasible.

It was decided that any system should have a self contained subsea recording and power supply capacity. The system needed to be easy to deploy and operate, and be relatively inexpensive so that systems could be cost effectively replicated and deployed off industry vessels. An additional benefit of a simple system is that it could be installed and operated by industry partners with minimal training.

4.2.4 Recording time

Eastern gemfish tows are typically 3-4 hours in duration but can be up to seven hours. Recording digital or analogue videos to tape, enables maximum recording times of three hours using longplay mode. However, a reduction in image quality during longplay mode decreases the accuracy and precision of stereo-video measurements. While there are many hard drive cameras that can record up to 7 hours continuous recoding, these cameras are equipped with a “motion drop” sensor which stops the hard drive from recording if the camera is accidentally dropped. Simulations have shown that these cameras will most likely switch off when deployed from the back of a vessel in the manner a trawl net is deployed.

One way of overcoming this problem is to use a security camera recording system such as those which are installed in trucks, cars and planes. These systems are “ruggedized” and built to be operated when in motion.

4.2.5 Power supply

Operating power for cameras and recorders in an autonomous recording system is challenging. The best option is to ensure that cameras, recorders and ancillary equipment all operate off a 12 volt power supply.

4.2.6 Lighting

Natural light will only penetrate to ocean depths of 70–120 m depending on the amount of productivity and sediment in the water. Normal depths trawled when targeting eastern gemfish fall within the range of 300–600 m, requiring the use of artificial lighting or low light cameras.

One of the major problems with providing artificial lighting from a self contained light source for 7 hour periods is the size of the battery pack required. Additional considerations include how the light penetrates the water and how this light affects the behaviour of fish. Red light in the 670 nm range is beyond the spectral sensitivity of many fish however, this wave length of light does not penetrate far through the water, regardless of the amount of power used. The diameter of the trawl net where the cameras will initially be mounted is about 3.5–4 m. Past trails have shown that red light will not transmit this far in a reliable manner. White light tends to penetrate the water much further, but causes reflective glare off the flanks of silver coloured fish. It has also been noted that white light does alter the behaviour of fish in contrast to other spectral ranges (Harvey unpublished data). Blue light of the 460 nm range has good penetration through the water and does not cause excessive reflective glare.

Low light cameras are an option, and will be investigated further.

4.2.7 Operational accuracy

In most research programs, length measurements of eastern gemfish are made to next lowest whole centimetre on fish measuring boards. Correspondingly, the goal for the accuracy of the stereo-video system was set at one centimetre.

4.2.8 Proto-type design

A NESS EDSR400M security recorder was modified and fitted to an underwater housing (Figure 7a). The modification involved moving the video connectors from the rear of the unit to the top (Figure 7b). The EDSR400M is a 12V security recorder with 4 video input channels and is robustly designed for mobile operations. Having 4 video input channels overcomes the need for multile units and provides spare inputs if mechanical failure was to occur. The unit can record at a range of resolutions including 720 x 576 PAL format. Imagery is recorded onto a HITACHI 250 GB hard drive. The hard drive is capable of storing up to 24 hours of footage while recording 720 x 576 PAL format at 25 frames per second. Exchanging hard drives takes about two minutes. Two canisters of rechargeable batteries were constructed to power the cameras and recorder for at least 7 hours continuous operation (Figure 8).

The EDSR400M is capable of remote power up and shut down and can be programmed to start recording after the trawl has left the deck and shut down before it is brought back on board. This minimised potential damage to the hard drive during these times.

Two JAI CVS 3200 security cameras were mounted inside underwater housings (Figure 9) These cameras output 720 x 576 interlaced PAL images. The cameras can be externally synchronised in a master slave configuration to ensure that the shutters are firing at exactly the same time. These cameras have low light capacity, however artificial lighting is still required at the depth of operation.

Illumination was supplied by four 3 mW LEDs (light emitting devices) that emit royal blue light with a wavelength of about 460 nm. Light of this wavelength penetrates better into water than other light sources. This system will illuminate to a distance of 4–5 m in clear water which is adequate for these trials. Power for these lights was supplied by a 12 V motor cycle battery, delivering up to 20 hours continuous operation.

All equipment was pressure tested to a depth of 600 m without failure.

4.2.9 Advantages

One of the main advantages of this system was that it was constructed of relatively cheap, off the shelf components, which can be readily replaced. This system has a long recording time and the overall financial risk was reduced by using existing equipment. The use of a hard drive recorder means that analogue AVI files can be downloaded directly to a computer without the need for file conversion. This greatly increases the speed of counting and measuring of fish in the imagery.

4.2.10 Limitations

The major limitation of this system is that it records analogue interlaced imagery. True progressive scan imagery would improve the overall measurement accuracy and precision. This technology, was not available in this configuration at the time the prototype was built. Progressive scan digital images would also facilitate automated recognition and fish measurement.

4.2.11 Estimated accuracy and precision

Stereo measurement from calibrated images is based on knowing the relative orientation of the cameras to one another (distance between the cameras, convergence angle, tilt and roll), the focal length of each camera, the size of the sensors and the pixel spacing on the sensors. With this information is it possible to design the optimal configuration and estimate the accuracy of potential measurements.

Estimates of stereo measurement accuaracy are shown in Table 3. Past experience has shown that measurements tend towards the best estimates. It was anticipated that on a straight object at distances of 4 m, length measurments would be within 5 mm of the true length. These estimates are based on a camera separation of 1 m and an inward convergence of 12 degrees.

Horizontal and verticle overlap at a distance of 2 m from the cameras, was estimated to be 3 m and 1.9 m respectively (Table 4). A net/extension will need to be constructed that forces the fish to the side of the codend away from the cameras.

4.2.12 Preliminary field trials.

Between 28th February and 3rd March 2008 the prototype stereo-video system was transported to Bermagui for deployment off the trawl fishing vessel *Shoalhaven*. At that time Harvey spent 2 days on the boat talking with the skipper and crew and observing their operations. The commercial fishermen considered that the prototype stereo-video system was too heavy and fragile to work in a commercial trawl setup. They were concerned that the cables between the camera housings and the recorder would be damaged.

A second system was developed in response using the new generation of Sony memory stick camcorders to reduce the overall weight and fragility. The Sony CX7 Handycam (now out of date) was the first off-the-shelf high definition camcorder that recorded to a Sony memory stick. These cameras came onto the market in Australia during April 2008 and are available with 4, 8 or 16 GB memory sticks. The 16 GB memory stick facilitated continuous recording of between 2.5 and 10 hrs, depending on the image resolution selected. These cameras are small and robust, mainly because there are no heads or tapes. The Sony CX7 used a CMOS sensor, making it more light sensitive than many other camcorders. The cameras were fitted with a Raynox 0.3 wide angle converter lens and mounted in purpose built underwater housings. The total cost of this unit including lighting was $11,000.

Cameras and lights were mounted on a base bar inside a role cage (Figure 10). Eight floats were added to make the system neutrally buoyant. The complete system weighed 33 kg out of water without the floatation.

4.2.13 Field trials of the modified prototype

The modified prototype was deployed during 4 shots over 28th May-29th May 2008 in the net of the trawl fishing vessel *Shoalhaven*.

4.2.14 Positioning of the cameras system in the net and deployment

After consultation with the *Shoalhaven's* skipper (Charlie Lavalle) the system was initially placed inside the net, about 5–8 m in front of the codend for two tows. On a further two deployments the system was mounted further forward towards the mouth of the net to increase the likelihood of capturing fish in the field of view for a longer time.

To mount the system, the net was piled onto the deck and split open on the side. The cameras and lights were started, and the frame sewn into the net (Figure 11 and Figure 12). Part of the codend was lifted over the stern allowing water drag to pull the whole codend into the water. The stereo-video system was balanced on the roller until drag pulled the net into the water. Deployment of the net containing the stereo-video system required extra effort from the skipper and crew, taking about 15 minutes just to sew in the stereo-video system.

4.2.15 Retrieval

Retrieval of the net with the stereo-video system also required extra work from the skipper and crew. The net was retrieved onto the net drum. When the stereo-video system came over the roller, the drum was stopped and a strop placed around the net and roller to remove pressure. The stereo-video system was cut out of the net prior to the rest of the net being hauled on board. This process took the skipper and crew ~10 minutes to complete.

4.2.16 Outcomes

Day 1 – 28th May, 2008

The stereo-video system was deployed using standard definition and long play settings; which enabled two transfers to be recorded without taking the camera system out of the net. One camera was accidently switched off while being put into the housing. The potential for this occurring again was eliminated by placing a fastener over the switch. Good quality imagery was obtained of the net and the scale bar. The synchronisation diode placed on the opposite side of the net was visible. Species identification was possible; however the majority of fish observed were swimming with the current and moved too quickly through the cameras field of view to make reliable measurements.

Day 2 – 29th of May, 2009

Based on observations from Day 1, the stereo-video system was moved forward to the mouth of the net to increase the likelihood of capturing fish in the field of view for a longer time. Two deployments were successfully completed with the cameras set on high definition and standard resolution options. This enabled 4.5 hours of continuous recording to capture imagery from entire tows.

Imagery recorded from this position was more amenable to successful stereo measurement. Fish could be seen trying to swim against the current and out the mouth of the net with fish either drifting back against the current or swimming down into the mouth of the net.

It was estimated that the net on the opposite side from the cameras was approximately 7 m away. While it was not possible to see the net at that distance, mirror dory caught in the mesh could be seen.

4.2.17 Evaluation of robustness and suitability of equipment

The stereo-video system was neutrally buoyant with eight shark bouys and did not appear to affect the shape or performance of the trawl net. Ideally however, buoyancy would be built into the system rather than attaching buoys to make the system less cumbersome and reduce drag.

The cameras were able to record for up to 10 hours on standard definition and 4.5 hours on high definition modes. The system withstood the rigours of deployment, trawling and recovery.

The stereo-video system was sewn into the inside of the net rather than being attached to the outside. It took 10–15 minutes to install or remove the system from the trawl net.

One light was flooded due to a catch being popped open by the net. This can be avoided with simple pins to lock the latches.

Lighting was adequate over distances of 2–4 m, but for greater distances, as required when the system was placed at the mouth of the net, more powerful lights are required. Replacement LEDs were ordered for the lights.

Imagery more suitable for measurement and counting was obtained when the camera was located near the mouth of the net. To obtain quantitative counts and length frequency measurements, “wing nets” would need to be placed inside the trawl to move fish away from the camera and funnel them through the field of view.

4.2.18 Third round of field trials

After further changes were made to the 2nd prototype, the stereo-video system was deployed with five shots during 21st–24th July 2008 inside the trawl net of the fishing vessel *Shoalhaven*. Deployments were made in depths ranging 100–500 m off the coast of Ulladulla, NSW. These trials showed that alterations were required to the design and construction of the system for it to be successfully used in a trawl net.

4.2.19 Modifications to the System

One of the outcomes of the previous field trip (28–29th May 2008) was that lighting needed to be increased to obtain imagery all the way across the net. The increase in lighting was required because the position of the cameras in the net was moved forward to increase the chance of obtaining quality imagery from which accurate counts and measurements could be obtained. The new position in the net, near the mouth, increased the distance between the cameras and the opposite side of the net, requiring increased lighting to penetrate further through the water.

The existing lighting systems were modified such that the four 2 mW LEDs in each light were replaced with a CREE XR-E Royal Blue Quad PCB with a Medium Optics lens and reflector to control the angle of reflection. Power to the LEDs was regulated by a Fatman driver. These units incorporate four 3 mW LEDs within a reflector. We chose to continue using LEDs that emit royal blue light with a wavelength of about 450 nm as it penetrates through the water column further than other colours and reduces flare in the imagery from reflection off the sides of silver fish.

Position and orientation of the camera in the net was again experimented with in consultation with the skipper (Charlie Lavalle).

Day 1 – 21st July

Two deployments were completed with the camera oriented vertically on the side of the net approximately 8m back from the mouth. On the first deployment not enough floats (6 floats) were used and the camera did not remain upright on the side of the net. On the second deployment another float was attached to the camera frame which created neutral buoyancy. The far side of the net could just be seen and fish were recorded swimming and drifting into the net.

Because the camera frame is not hydrodynamic in profile, the drag associated with vertical orientation twisted the cameras towards the back of the net. Fish were recorded moving past the cameras quickly, but still slow enough to facilitate stereo-measurement.

Day 2 – 22nd July

The skipper suggested placing the stereo-video system just behind the head-line, and attaching bridles from the head-line to the frame to stop it from turning back into the net. During the first shot the field of view of the cameras was too far forward and recorded the substrate just in front of the ground-line. On the second deployment the camera system was correctly oriented and recorded the ground-line and fish going into the net (Figure 13). This is not a good location for the stereo-video system for obtaining imagery to measure the fork length of fish, because a dorsal view is obtained and the fork is hidden. A further problem is that the mouth of the net is wider than it is higher, and full video coverage cannot be achieved unless multiple stereo-video systems with overlapping fields of view are rigged. Identification of fish is also more difficult from the dorsal view.

Day 3 – 24th July

One further deployment was completed with the stereo-video system placed on the side of the net, above the ground-line, looking across the mouth of the net. Once the net reached the sea floor and began fishing, the top of the camera system tilted over such that the cameras recorded the bottom of the net. Despite the unfavourable orientation, acceptable images were recorded (Figure 14).

4.2.20 Problems

The main problem with the stereo-video system was its stability and orientation in the net because the trawl net did not have the rigidity to cope with the large amount of drag created by the stereo-video system. Adding to this problem is that neutral buoyancy is obtained using a series of shark buoys tied to the top of the frame (Figure 1). This causes uneven distribution of drag on the system causing it to tilt on its vertical axis. The skipper believed that drag affected the performance of the net and had an adverse impact on the catch.

4.2.21 Solutions
To overcome the issue of drag, the system should be:

- oriented so that it is fixed horizontally in the net rather than vertically, reducing the surface area, and hence the drag,
- torpedo shaped with end caps that eased the flow of water around the system,
- made neutrally buoyant without using shark floats.

Prototype 2 was refined by creating a new frame to encompass the existing camera and light housings.

An aluminium frame was constructed to hold the cameras and lights. Two end caps were constructed to minimise the water drag. These end caps were filled with syntactic foam which acted as the buoyancy. Syntactic foam is a specialist product which is used in the sub-sea industry for creating neutral buoyancy, particularly in Remote Operated Vehicles.

The torpedo array (prototype 3) weighed 84 kg (including cameras, lights, frame and syntactic foam) which was ~ 35 kgs more than anticipated. It was neutrally buoyant in the water and cost ~$10,000 to construct. Forty four litres of syntactic foam was required to overcome the weight of the frame, housings, batteries and cameras. Each litre of foam has a weight of 1 kg. The total weight made deployment and retrieval more difficult, but it was manageable.

The solution posed one challenge. The vertical positioning of the cameras was designed so that maximum image coverage would be obtained. Because the CCD sensor in the video camera used is rectangular, with the longest side being in the x-axis, the cameras would need to be physically rotated 90 degrees to ensure that the maximum possible height of the net is recorded. While this is physically possible it does cause some additional challenges with calibration.

4.2.22 Forth round of field trials
During 3rd–4th February 2009, 2 deployments of a torpedo shaped stereo-video system were made inside the net of the trawl fishing vessel *Shoalhaven*. The two deployments were made in depths of 70 m and 270–300 m.

4.2.23 Position of the camera system in the trawl net
Both deployments were completed with the camera system oriented horizontally on the side of the net approximately 8 m back from the mouth of the net. The camera system did not appear to distort the net and was slightly positive in the water. The camera system floated just under the surface when inside the net, but quickly sank with the weight of the net.

4.2.24 Calibration and Measurement procedure
The stereo-video system used in the 3rd prototype was calibrated following the procedures described in Harvey and Shortis (1996) and Shortis and Harvey (1998) using Cal software (www.seagis.com.au). To count and measure fish we used a combination of Event Measure and Photomeasure software (for a full description of the software see www.seagis.com.au).

4.2.25 Deployment 1
The trial on the 3rd of February 2009 was carried out in a depth of 70 m. At that depth there was adequate natural light. The net was bottom fishing and after a short period of time a cloud of sediment obscured the lower part of the net (see attached Trawl 3_2_09 net.avi). A synchronisation diode provided a scale bar for estimation of error. Twenty measurements were made of an object 153.2 mm in length. A mean error of 1.53 mm was recorded (1 standard deviation = 5.32 mm) with a maximum error of 9.4 mm.

4.2.26 Deployment 2

On the second deployment, the skipper deliberately set the cameras in deeper water and during the night (4 am) to trial the effectiveness of the lighting system and the sensitivity of the cameras. Cameras were set to night shot mode. We deployed only 1 light with the system and used a different net to the previous trawl. Even with one light we were able to see the seam on the other side of the net (see Net1.avi), and it was possible to make measurements of fish as far as 5 m away. Measurements were made of a subset of the fish seen (for example see Figure 6) to provide some length-frequency data. Species seen and measured included squid (mean length = 336.2 mm; n= 42), barracouta (mean length = 788.9 mm; n = 42), greeneye dogfish (mean length = 422.6 m; n = 122), ocean jacket (mean length = 316.0 mm; n= 222) and gemfish (mean length = 364.2 mm n = 117). Length-frequency histograms have been developed for the later three species (Figure 7).

Movie files of each of the species entering the net and at different time intervals have been included in a CD attached to this report. These images have been compressed from full high definition to standard mpeg definition to facilitate computer viewing.

4.2.27 Unresolved issues

To obtain quantitative counts of all the fish and to measure the lengths of all, or a large representative sample of fish, the catch will need to be funnelled into an area which encompasses the overlap in the cameras field of view. At present, fish that are too close to the stereo-video system are in "blind spots". As the distance from the cameras increases, the overlap in the camera images and hence stereo-video coverage also increases (see Figure 6 and Table 5).

Because of the design of the stereo-video system, smaller fish such as ocean jacket, squid and small gemfish could not be measured at distances less than 1.2 metres from the camera, as either the head or tail of the fish could not be seen in the imagery from both cameras simultaneously. Similarly, at close ranges there are fish which go below and above the field of view of the cameras. If this system is to be successfully implemented "wing nets" would need to be placed inside the trawl to move fish away from the camera systems "blind spots".

One of the major challenges with implementing this research is trying to maintain the orientation of the camera systems when they are fixed to a non rigid structure (the net). Movement of the cameras can be seen in the mpegs attached to the report. This movement is extremely difficult to control, and a resolution to this issue will require the input of a professional net maker.

At 84 kg, the system is heavy to manoeuvre into the housing and around the deck of the boat. We believe that the weight of the system can possibly be halved by using new and innovative materials. Decreasing the weight of the underwater housings would allow a corresponding decrease in the amount of syntactic foam used, further reducing the overall weight of the system.

While visibility on the whole was very good, the deployment on the 3rd February 2009 clearly demonstrates that if the trawl doors, rollers and net cause a lot of sediment to enter the back of the net, fish cannot be seen.

5 Discussion

5.1 Survey - Traditional Methods

Despite bad weather severely hampering sampling opportunities of the two survey vessels during the 2007 spawning run, 23 shots were successfully completed. Originally not in the project design, a 2008 eastern gemfish winter trawl survey was conducted in response to the Eastern Gemfish Rebuilding Strategy which recommended to "undertake a 2008 spawning run survey (June–September) to resolve uncertainty in the recent 2007 survey catch rates." To increase sampling opportunities in anticipation of bad weather, an additional two vessels were employed during the 2008 survey. The four vessels successfully completed 63 shots, and it also increased the searching power of the survey 'fleet'.

Targeted catch and effort data were collected for eastern gemfish during the 2007 and 2008 winter surveys. Standardised catch rates of 1,063 kg/day (Little *et al.* 2008) and 809 kg/day were calculated for each year respectively (Rich Little, CSIRO, Hobart *pers. comm.*). Length measurements recorded during 2007 show that samples were dominated by immature fish 23–27 cm fork length, male fish 52–55 cm fork length and female fish 68–74 cm fork length. Length measurements recorded during 2008 were dominated by male and female fish 48–54 cm fork length, male fish 56–62 cm and female fish 72–80 cm fork length. In addition, otoliths from 666 and 1,456 eastern gemfish were collected during the 2007 and 2008 surveys, from which the CAF obtained 665 and 631 age estimates.

Catch and effort and size composition data were incorporated into the 2007 and 2008 stock assessment models and the results presented at the ShelfRAG meetings and the 2007 SESSF Joint MAC TAC setting meeting. Age estimates obtained by CAF from otoliths collected during the surveys was also provided for inclusion into the stock assessment models (Kyne Krusic-Golub, DPI Victoria, pers. comm.). The 2007 survey information was a critical aspect of the assessment, revealing that the stock is rebuilding from a low level under the current management arrangements (Figure 4) and has ultimately resulted in the decision by NSW not to list the species as endangered. This is a vital piece of information given that the species is being considered for listing as endangered under the EPBC Act, 2007. Results from the 2008 eastern gemfish stock assessment are similar and support the results from the 2007 stock assessment (Little and Rowling 2008).

6 Non-capture survey techniques

Stereo-video systems installed in the trawl net were trailed to assess the efficacy for use as a non-destructive method of obtaining estimates of relative biomass and to provide size composition data. Stereo-video systems have been used successfully for underwater visual census including obtaining length measurement of fish during baited trap (Harvey *et al.* 2007, Watson *et al.* 2009), diver transect surveys (Harman *et al.* 2003; Harvey *et al.* 2004), aquaculture (Harvey *et al.* 2003, Phillips *et al.* 2009) but to our knowledge have not been used for trawl applications.

A prototype was developed using existing systems, taking into consideration the unique requirement for installation onto a trawl net including operating depth, recording mode and duration, lighting, operational accuracy, ease of deployment and overall cost. Initial field testing and discussions with the skipper revealed that the prototype was too heavy and fragile to work inside a commercial trawl net.

The stereo-video system was refined (prototype 2) over a further two field trips resulting in a manageable, robust system that could withstand the rigors of commercial trawl applications.

Location of the stereo-video system in the trawl net was another consideration that was tested during these field trips. It was found that mounting it on the side panel in the mouth of the trawl net provided the optimal position of stereo measurements because the eastern gemfish would remain in the field of view for a longer time. The drawback from this position was that the net was wider at this point, and stronger lights were required to enable capture of imagery across the entire width.

This system provided some good imagery from which length measurements could be made. Increased lighting in the final system refinement enabled the opposite side of the net to be seen when positioned in the side panel in the mouth of the trawl net. This system was relatively easy to deploy, taking about 15 minutes to sew into the net, but enabled redeployment within 5 minutes of coming on deck. It withstood the rigours of commercial trawling and was successfully deployed to a depth of 500 m.

While it withstood the rigours of commercial trawling, this system cannot perform the desired task of non-destructive sampling of catch rate and length measurements. The main problem is that trawl nets are a flexible platform to attach a camera system to, especially a system that generates as much drag as the current system does. Apart from the ‘bulky’ shape, the system used 7 or 8 shark buoys to maintain buoyancy. The uneven distribution of drag causes the system to tilt on its vertical axis orientating the field of view in an unfavourable direction.

A new frame was designed and constructed to overcome the excess and uneven drag. The concept is torpedo shaped in design, with in-built buoyancy to remove the need for shark buoys (). It was designed to be fixed horizontally in the net rather than vertically, further reducing its surface area.

Trials of the torpedo shaped stereo-video system demonstrated that it is possible to make accurate (1.53 mm mean error) and relatively precise (SD = 5.32 mm) measurements of fish length in a trawl net at depth. The lighting system was adequate to measure fish at distances of up to 5 m. While some fish could not be measured because either their body was bent through all the images recorded while passing through the field of view, or they were too close to the system and not recorded on both cameras simultaneously, a large proportion of the fish recorded could have been measured. The identification of some smaller fish was difficult, but could be improved by noting the species composition of the entire catch on deck. Minor modifications to the existing frame, using progressive scan high definition Handycams with compatible wide angle lenses and updated LEDS for lighting will only improve the imagery, the resulting measurements and the ease of deploying and retrieving the system.

7 Conclusions

A survey to collect timely, accurate and contextual data on targeted catch rates and size composition of the catch during the 2007 eastern gemfish winter spawning season was undertaken; which despite bad weather, sampled 23 trawl shots using two Industry vessels. In addition, a 2008 survey was conducted in response to the Eastern Gemfish Rebuilding Strategy which recommended to “undertake a 2008 spawning run survey (June–September) to resolve uncertainty in the recent 2007 survey catch rates.” Increasing the survey fleet to four vessels during the 2008 survey resulted in the completion of 63 targeted trawl shots. Otoliths were also caught during these surveys which were provided to CAF to obtain age estimates. Catch and effort, size composition and age data were provided to ShelfRAG for incorporation into annual stock assessments. These data filled important information gaps for management of eastern gemfish, and contributed to the decision by NSW not to list the species as endangered. These data are also a vital given that the species is being considered for listing as endangered under the EPBC Act, 2007.

Investigations were made to determine the efficacy of using non-destructive, stereo-video systems in open-ended codends to measure the length-frequency of captured gemfish and estimate the mass of fish entering the trawl. The prototype was modified from existing equipment designed for non-trawl applications. The prototype proved unsuitable to instillation in a trawl net, and subsequent modified designs were field tested and adapt to the rugged characteristics of trawl fishing. While trials were successfully undertaken, and adequate imagery obtained, the stereo-video system suffered from a high degree of drag that was unevenly distributed. Combined with being mounted on a flexible trawl net, the system too regularly tilted and the field of view changed to an unsuitable direction. A new concept was designed and built to overcome these issues. This torpedo shaped system was shown to collect relatively accurate and precise length measurements for a number of species. This research demonstrates the feasibility of developing and deploying a suite of low cost, light weight stereo-video systems to be placed in nets for non-destructive sampling of trawl fish.

8 Acknowledgments

We would like to thank Rocco Musemici, Charlie Lavalle, Tony Lavalle, Tony Bagnato and Rocco Musemici, skippers of the *Giuseppa, Shoalhaven, Francesca* and *Illawarra* for their assistance and input, along with the efforts of the crew of the vessels in the collection of biological data. We appreciate the work of Jeff Nemec, Peter Deas, Michael Davies and Russell Hudson who were the scientific observers in charge of the collection of biological data. Thanks also to Kevin Rowling and Jeremy Prince for valuable input into the design of this project and on-going support and guidance. We also received cooperation from other owners and skippers of the east coast trawl fleet and unloading staff and factory staff of the Ulladulla Fishermen's Co-op, the Wollongong Fishermen's Co-op and the Shellharbour Square Fishmarket.

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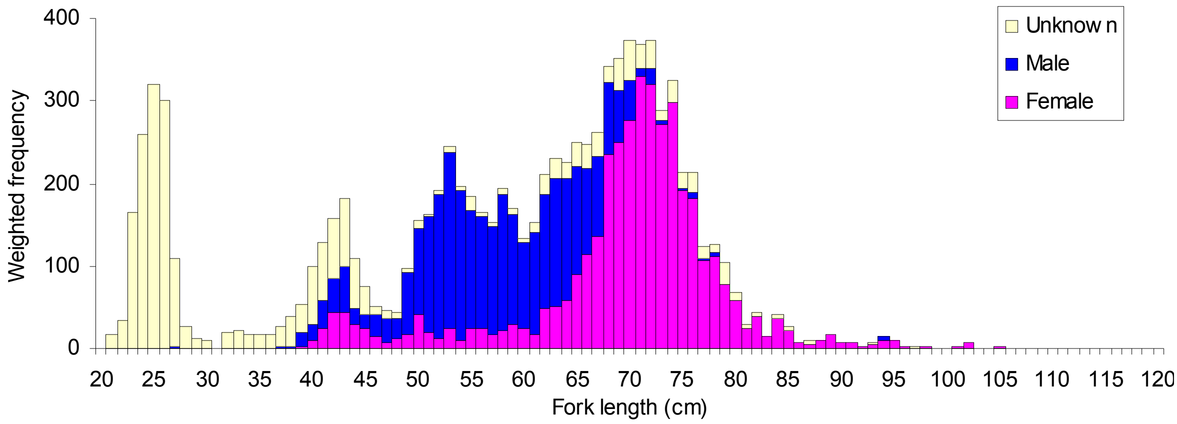
a



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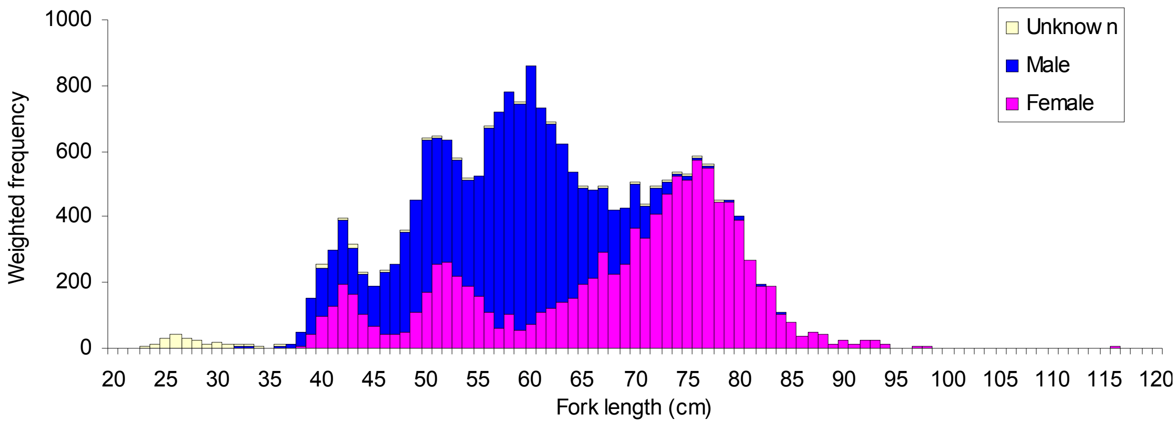
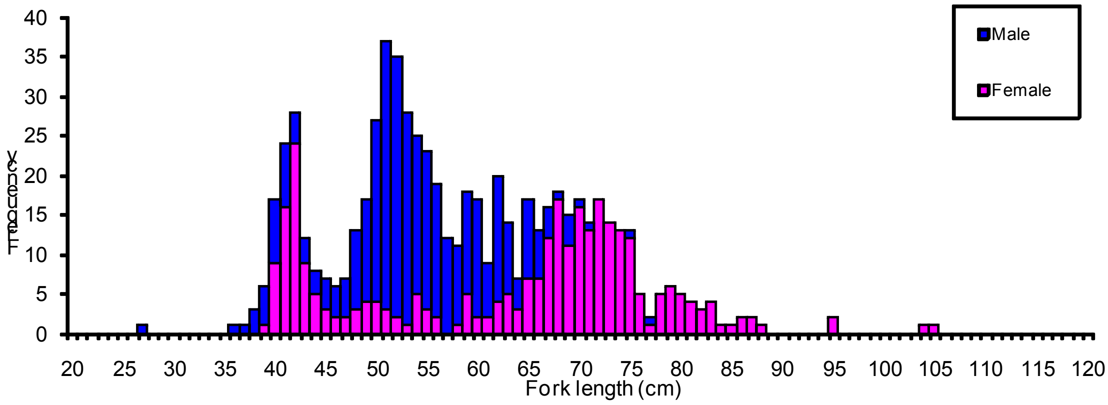


Figure 1. Weighted length-frequency histograms of eastern gemfish measured during the 2007 (n = 4,307) and 2008 (n = 9,039) surveys.

a



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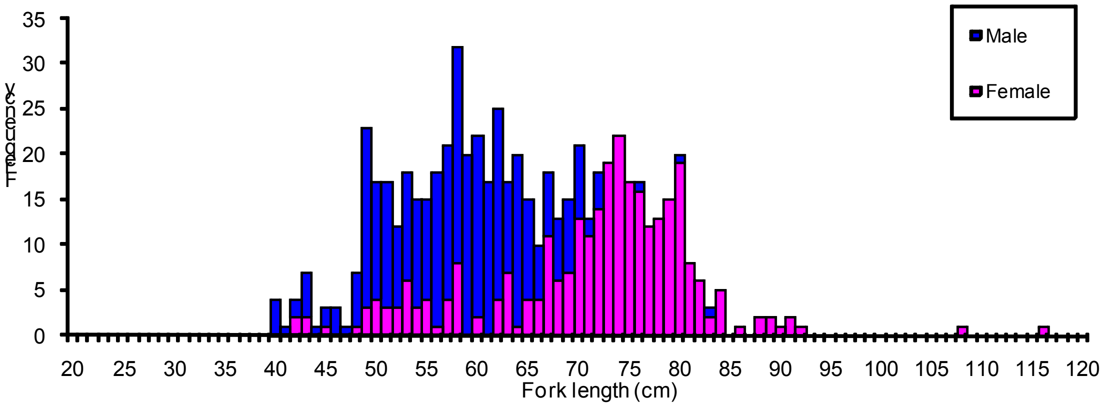


Figure 2. Length-frequency histogram of fish that were aged by the Central Ageing Facility from the 2007 (n=665) and 2008 (n=631) surveys.

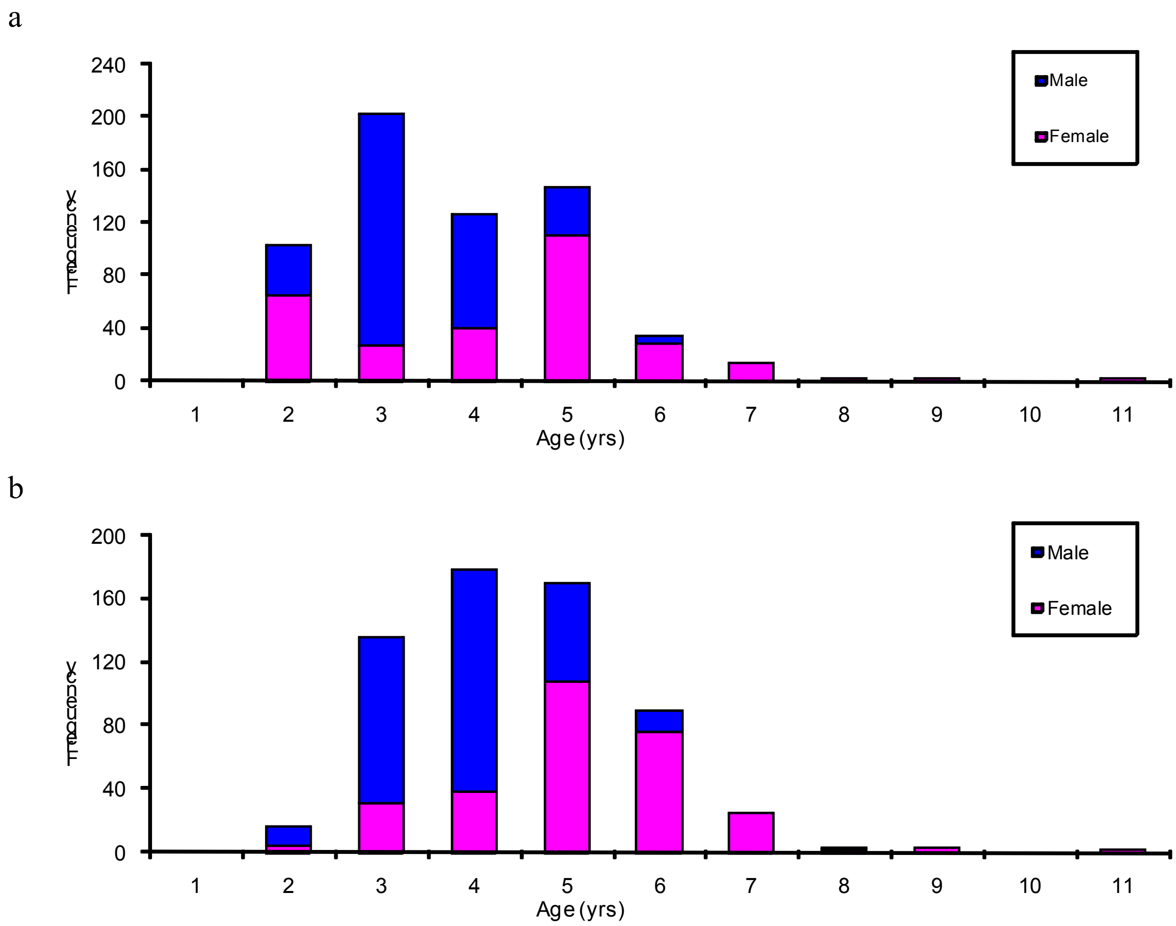


Figure 3. Age-frequency histogram of eastern gemfish that were aged by the Central Ageing Facility from the 2007 (n=665) and 2008(n=631) surveys.

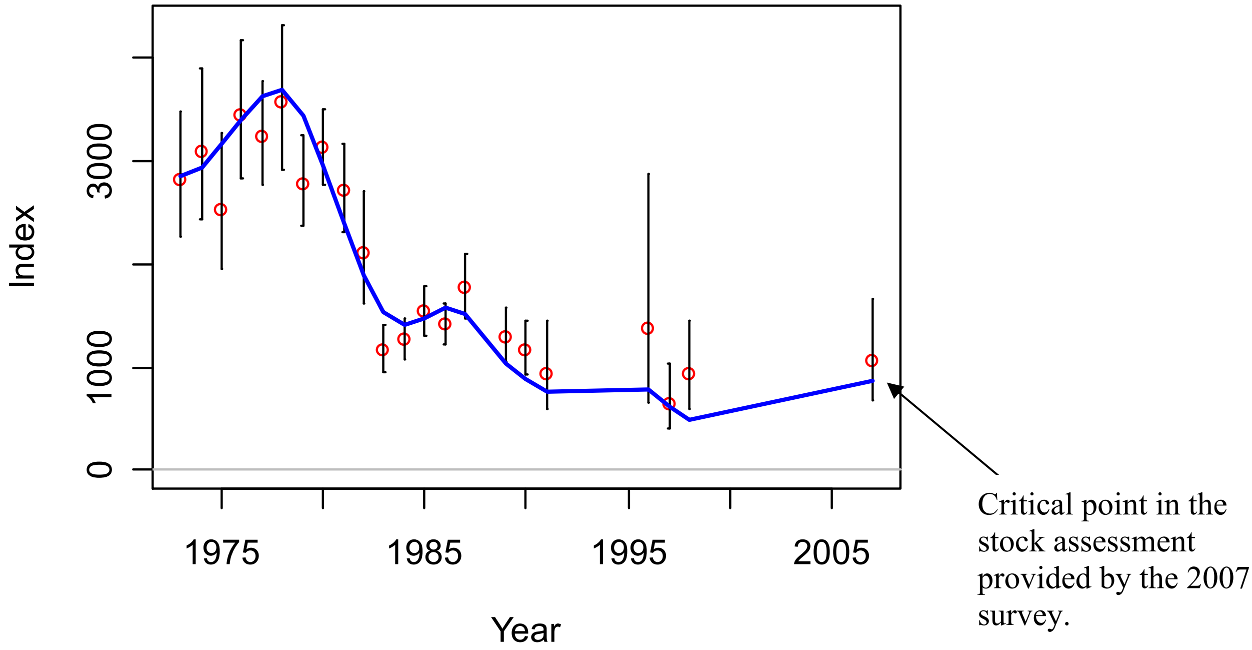


Figure 4. 2007 stock assessment model fit to catch rate indices of the winter target trawl fleet. The survey conducted as part of this project provided the critical last point in this time series.

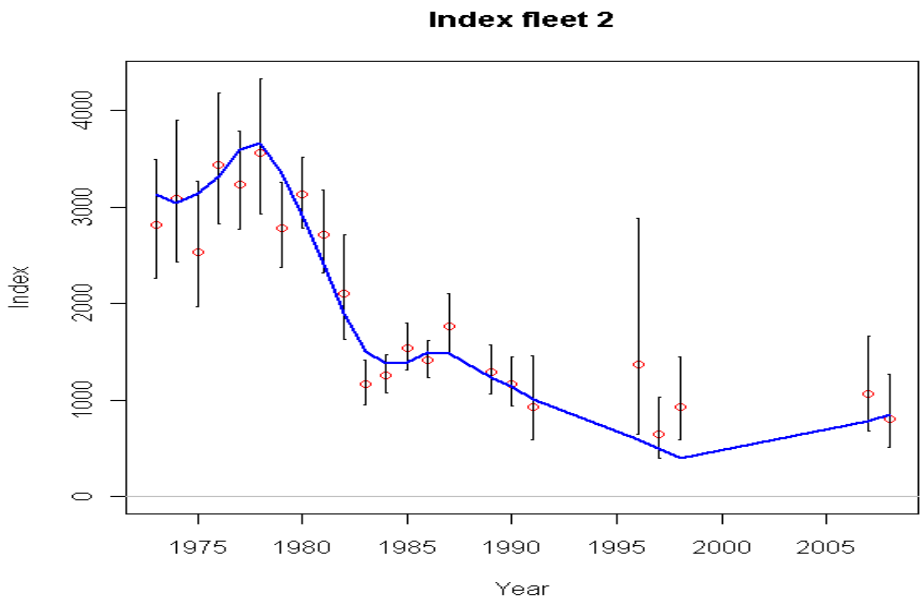


Figure 5. 2008 stock assessment model fit to catch rate indices of the winter target trawl fleet. The survey conducted as part of this project provided the critical last point in this time series.

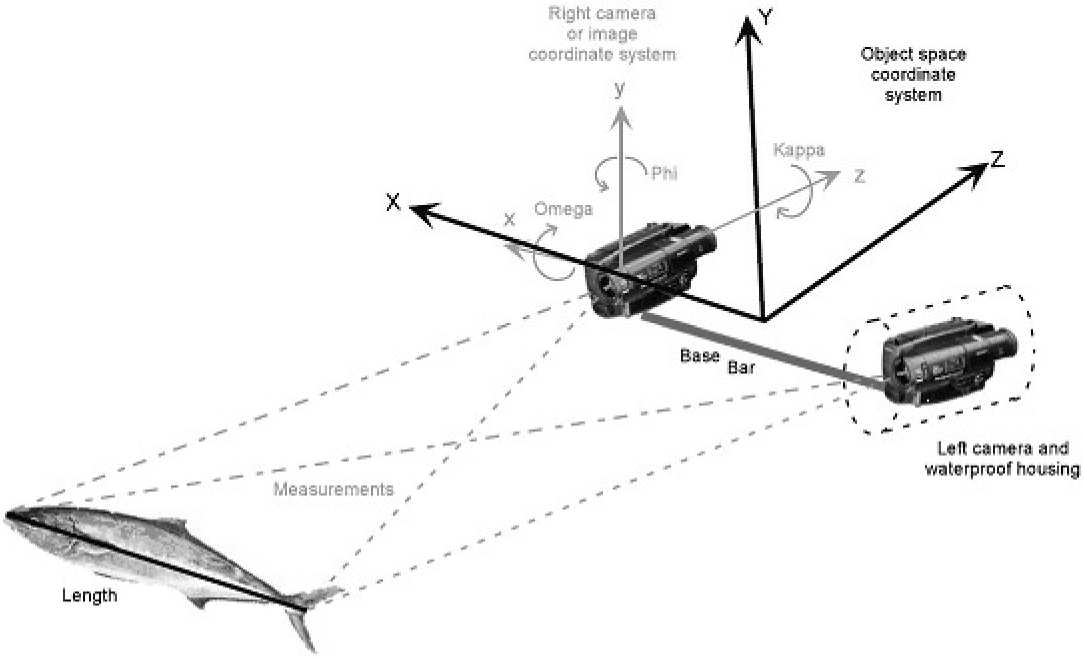


Figure 6. Schematic view of a stereo-video system and measurement of a length from 3D coordinates.

a b

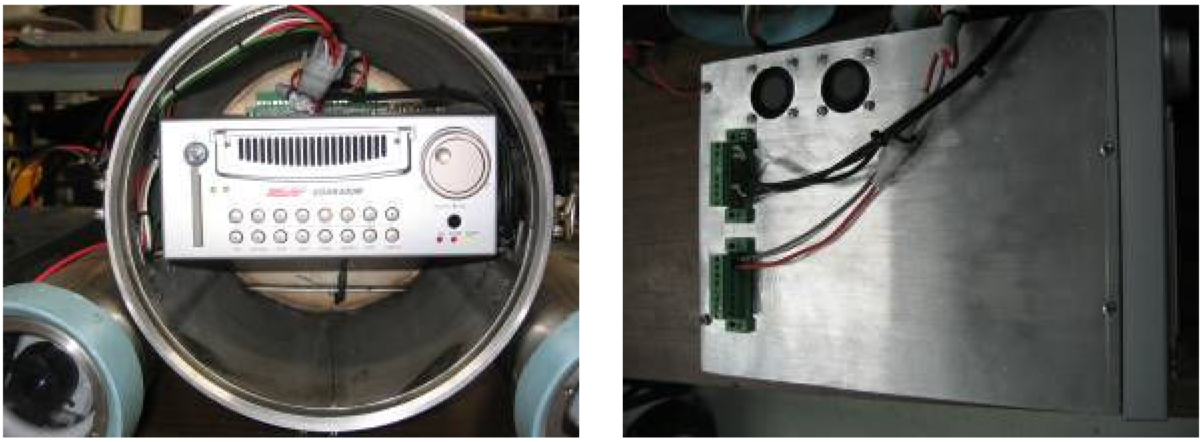


Figure 7. a) The NESS EDSR400M hard drive recorder mounted in the underwater housing; b) showing the breakout of video cables from the top of the unit rather than the rear.

Figure 8. One of the two battery packs for supplying 12 volt power to the cameras and hard drive recorder.

Figure 9. The two JAI CVS 3200 cameras mounted inside underwater housings. The battery pack that supplies power to the recorder and cameras is mounted below the recorder.

Figure 10. The stereo-video system showing camera housings, light housing and floats.

Figure 11. The stereo-video system being sewn into the net.

Figure 12. The stereo-video system ready for deployment.

Figure 13. Image from the stereo-video system mounted vertically just behind the head-line and facing downwards. The ground-line can be seen.

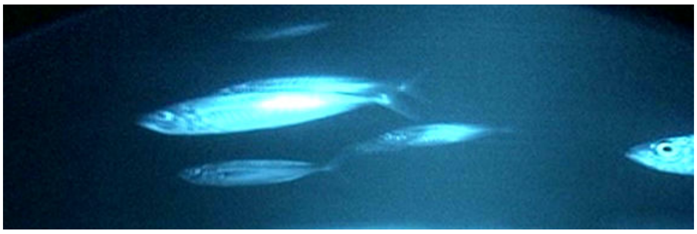
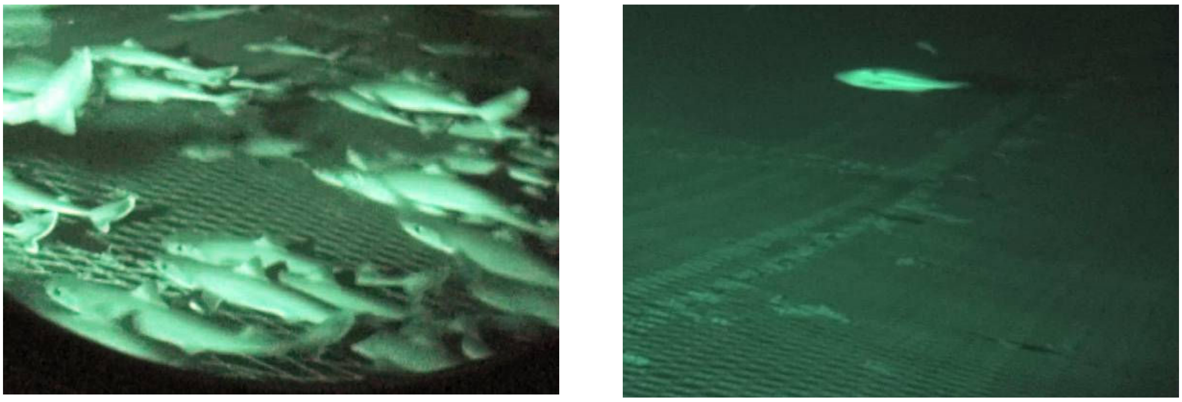


Figure 14. Image from the stereo-video system mounted on the side of the net facing across the net. Images from this orientation show fish entering the net that are measureable.

Figure 15. The torpedo shaped stereo-video system used during the fourth round of field trials. The centre two housings hold the light units and the outer two housings hold the video cameras.

a b



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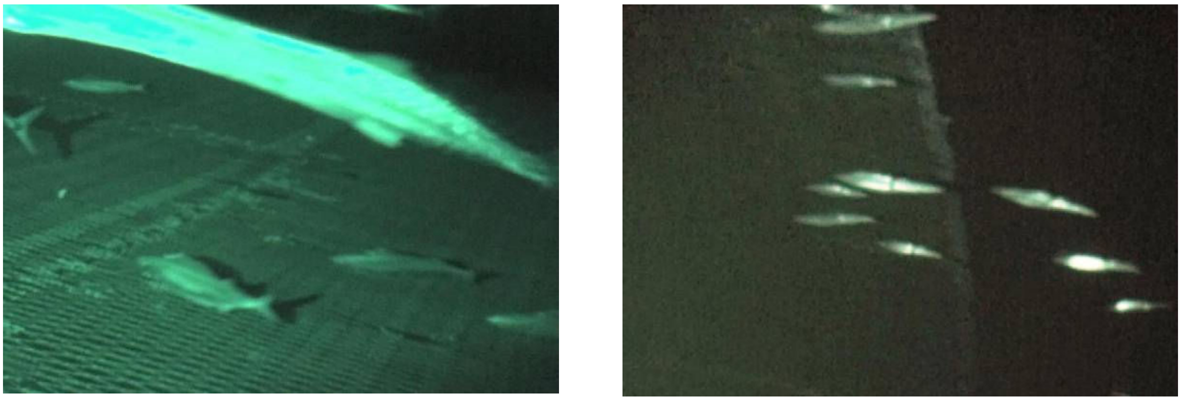

Figure 16. Examples of measurable fish in imagery taken from the stereo-video system of a) greeneye dogfish; b) ocean jacket; c) and eastern gemfish; and d) squid.

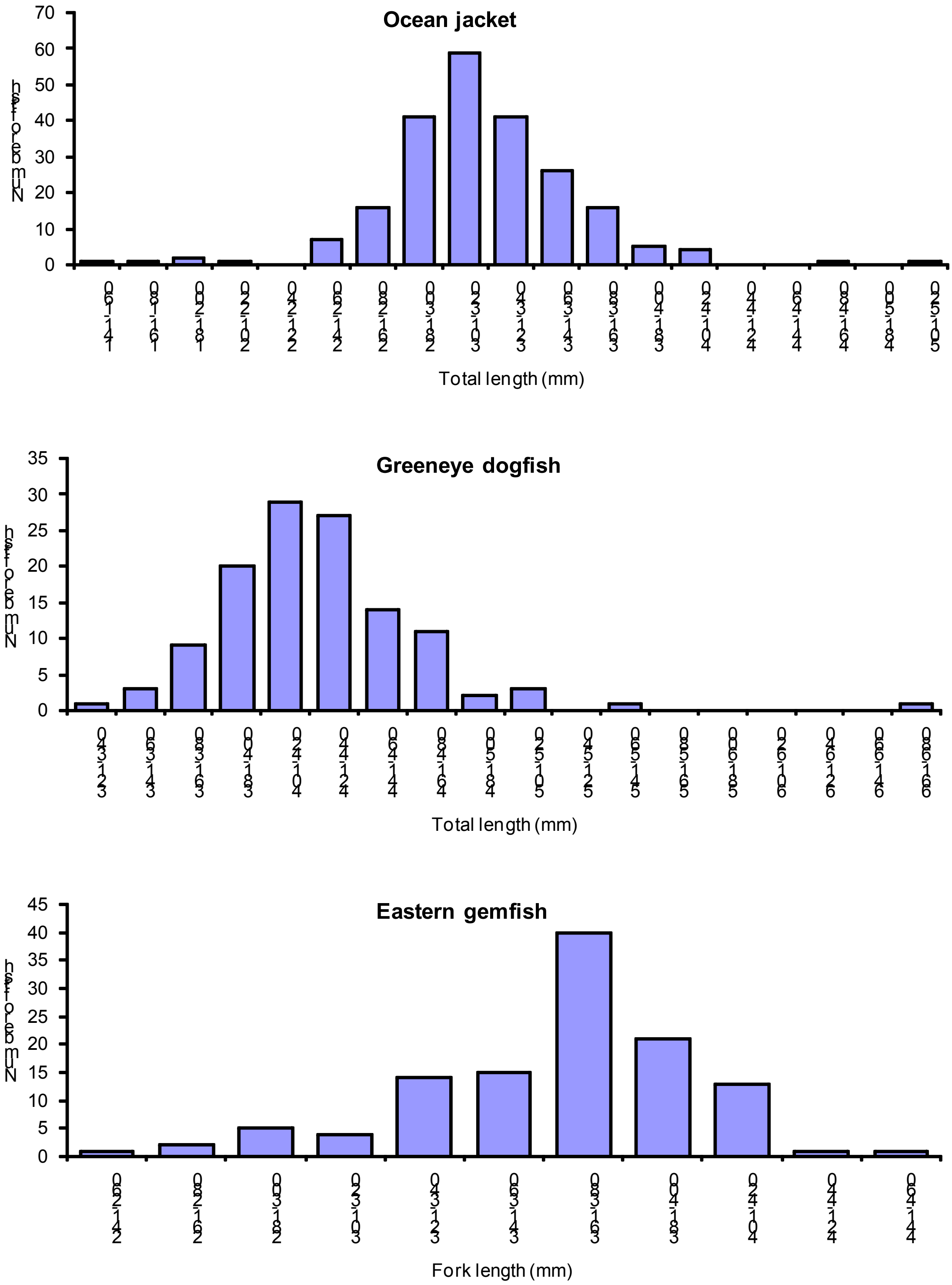

Figure 17. Length-frequency histograms from stereo-video measurements for ocean jacket, greeneye dogfish and eastern gemfish.

Table 1. Shot details and catch of eastern gemfish during 2007 winter survey.

Vessel	Date	Shot time	Shot duration (mins)	Start latitude	Start longitude	Gemfish weight (kg)
Giuseppa	8/07/07	*				780
Giuseppa	16/07/07	07:00	180	34°45.00'S	151°11.00'E	968
Giuseppa	16/07/07	12:00	195	34°37.00'S	151°15.00'E	2677
Giuseppa	22/07/07	06:50	180	34°29.00'S	151°18.00'E	32.2
Giuseppa	22/07/07	10:30	180	34°27.00'S	151°16.00'E	35.2
Giuseppa	23/07/07	07:00	180	34°38.00'S	151°15.00'E	158
Giuseppa	23/07/07	11:10	170	34°45.00'S	151°12.00'E	38
Giuseppa	26/07/07	06:55	194	33°35.6'S	151°57.70'E	1500
Giuseppa	26/07/07	12:26	200	33°36.0'S	151°57.60'E	2800
Giuseppa	27/07/07	06:10	200	33°35.2'S	151°58.60'E	1000
Shoalhaven	2/07/07	*				1108
Shoalhaven	3/07/07	06:00	270	35°25.00'S	150°47.00'E	943
Shoalhaven	3/07/07	11:00	240	35°37.00'S	150°41.00'E	193
Shoalhaven	7/07/07	06:30	240	35°14.00'S	150°58.00'E	449
Shoalhaven	7/07/07	11:30	240	35°25.00'S	150°51.00'E	1952
Shoalhaven	8/07/07	06:40	275	35°25.00'S	150°50.00'E	1437
Shoalhaven	16/07/07	06:52	224	34°50.7'S	151°10.00'E	1000
Shoalhaven	16/07/07	11:59	236	34°53.9'S	151°09.00'E	200
Shoalhaven	22/07/07	06:44	156	34°28.6'S	151°18.80'E	10
Shoalhaven	22/07/07	10:30	179	34°27.4'S	151°19.00'E	30
Shoalhaven	23/07/07	06:43	213	34°50.4'S	151°10.20'E	100
Shoalhaven	23/07/07	12:01	187	35°14.5'S	150°58.10'E	320

* No observer – fish measured at wharf.

Table 2. Shot details and catch of eastern gemfish during 2008 winter survey.

Vessel	Date	Shot time	Shot duration (mins)	Start latitude	Start longitude	Gemfish weight (kg)
Francesca	01/07/2008	6:30	210	35°30.00'S	150°45.00'E	134
Francesca	03/07/2008	6:50	205	35°35.00'S	150°41.10'E	258
Francesca	03/07/2008	11:29	209	35°44.00'S	150°35.10'E	60
Francesca	04/07/2008	6:45	230	35°14.00'S	150°58.00'E	342
Francesca	04/07/2008	12:30	120	35°16.10'S	150°54.10'E	30
Francesca	08/07/2008	6:58	157	34°59.72'S	151°06.69'E	133
Francesca	08/07/2008	13:16	129	34°45.71'S	151°11.70'E	375
Francesca	16/07/2008	7:26	171	34°38.28'S	151°14.73'E	303
Francesca	16/07/2008	12:45	192	34°37.26'S	151°15.51'E	4
Francesca	17/07/2008	7:08	197	33°43.56'S	151°51.38'E	45
Francesca	17/07/2008	11:45	154	33°37.00'S	151°56.00'E	51
Francesca	27/07/2008	6:30	191	33°42.00'S	151°50.10'E	15
Francesca	27/07/2008	10:55	135	33°36.08'S	151°56.31'E	15
Illawarra Star	07/07/2008	07:00	225	34°45.00'S	151°11.00'E	3928
Illawarra Star	08/07/2008	7:17	186	34°43.48'S	151°12.12'E	1298
Illawarra Star	08/07/2008	11:56	180	34°35.07'S	151°15.62'E	433
Illawarra Star	14/07/2008	7:05	185	34°47.05'S	151°11.19'E	789
Illawarra Star	14/07/2008	11:35	180	34°36.99'S	151°13.82'E	30
Illawarra Star	15/07/2008	6:50	200	34°37.62'S	151°14.16'E	1258
Illawarra Star	15/07/2008	11:20	205	34°46.14'S	151°11.38'E	3773
Illawarra Star	16/07/2008	7:21	180	34°44.37'S	151°12.35'E	1081
Illawarra Star	16/07/2008	12:27	180	34°43.62'S	151°12.88'E	1081
Illawarra Star	17/07/2008	6:48	180	34°00.00'S	151°00.00'E	2255
Illawarra Star	17/07/2008	11:09	176	34°43.75'S	151°12.14'E	2127
Illawarra Star	27/07/2008	6:51	191	34°45.15'S	151°11.43'E	340
Illawarra Star	27/07/2008	11:45	180	34°41.97'S	151°13.45'E	156
Illawarra Star	31/07/2008	6:54	190	34°46.43'S	151°11.29'E	373
Illawarra Star	31/07/2008	11:31	184	34°40.56'S	151°12.50'E	224
Illawarra Star	04/08/2008	6:55	193	34°46.45'S	151°11.26'E	835
Illawarra Star	04/08/2008	12:10	200	34°39.10'S	151°11.10'E	607
Illawarra Star	05/08/2008	7:06	180	34°45.99'S	151°11.62'E	275
Giuseppa	08/07/2008	07:00	225	34°21.00'S	151°22.10'E	420
Giuseppa	08/07/2008	7:15	185	34°42.00'S	151°11.10'E	1194
Giuseppa	08/07/2008	12:00	170	34°35.00'S	151°15.00'E	707
Giuseppa	08/07/2008	12:30	225	34°31.100'S	151°17.10'E	901
Giuseppa	14/07/2008	7:00	180	34°22.10'S	151°20.00'E	171
Giuseppa	14/07/2008	11:30	180	34°34.00'S	151°16.00'E	1108
Giuseppa	15/07/2008	7:00	180	34°21.00'S	151°22.10'E	205
Giuseppa	15/07/2008	12:00	180	34°32.10'S	151°16.00'E	3007
Giuseppa	16/07/2008	7:20	180	34°45.00'S	151°11.10'E	1255
Giuseppa	16/07/2008	12:30	180	34°42.00'S	151°13.00'E	682
Giuseppa	17/07/2008	6:45	180	34°36.00'S	151°13.10'E	1574
Giuseppa	17/07/2008	11:15	180	34°44.00'S	151°11.10'E	1792
Giuseppa	27/07/2008	6:50	190	34°44.00'S	151°11.00'E	358
Giuseppa	27/07/2008	11:50	180	34°40.10'S	151°13.00'E	270
Giuseppa	31/07/2008	7:00	180	34°45.10'S	151°11.00'E	444
Giuseppa	31/07/2008	11:35	180	34°38.10'S	151°11.10'E	556
Giuseppa	04/08/2008	7:00	195	34°45.00'S	151°11.00'E	786
Giuseppa	04/08/2008	12:15	195	34°40.100'S	151°11.10'E	337
Giuseppa	05/08/2008	7:00	185	34°45.100'S	151°11.00'E	267
Shoalhaven	29/06/2008	6:37	207	35°43.95'S	150°37.41'E	200
Shoalhaven	29/06/2008	10:56	159	35°57.53'S	150°30.40'E	111
Shoalhaven	03/07/2008	6:36	235	35°30.16'S	150°46.43'E	880
Shoalhaven	03/07/2008	10:05	310	35°40.57'S	150°39.19'E	55
Shoalhaven	04/07/2008	6:37	240	35°30.06'S	150°46.49'E	48
Shoalhaven	08/07/2008	6:30	210	34°50.00'S	151°09.10'E	1116
Shoalhaven	08/07/2008	10:00	240	35°00.00'S	151°05.10'E	1563
Shoalhaven	14/07/2008	6:42	218	34°37.70'S	151°14.65'E	387
Shoalhaven	14/07/2008	11:40	174	34°49.38'S	151°10.14'E	664
Shoalhaven	15/07/2008	6:42	204	34°15.70'S	151°26.80'E	167
Shoalhaven	15/07/2008	11:55	162	34°27.13'S	151°19.69'E	416
Shoalhaven	16/07/2008	7:17	189	34°46.52'S	151°11.42'E	659

Table 3. Estimates of the accuracy of stereo-video measurements

Range or Depth (m)		0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00
Length Precisions (mm)	Best	1.19	1.19	1.79	2.39	2.99	3.58	4.18	4.78
	Worst	0.30	1.19	2.69	4.78	7.47	10.75	14.64	19.12

Table 4. The estimated stereo over lap for the prototype stereo-video system with a 1 m camera separation and 12 degrees of camera convergence.

Computed Stereo Coverage (m)	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00
Horizontal (m)	0.00	0.99	1.99	2.98	3.98	4.98	5.97	6.97
Vertical (m)	0.46	0.93	1.39	1.86	2.32	2.79	3.25	3.72

Table 5. The estimated stereo over lap for torpedo stereo-video system with a 0.5 m camera separation.

Computed Stereo Coverage (m)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
Horizontal (m)	0.2	1.1	1.9	2.7	3.6	4.4	5.2	6.1	6.9	7.8	8.6
Vertical (m)	0.7	1.5	2.2	2.9	3.7	4.4	5.1	5.9	6.6	7.4	8.1