Assessment of the implications of target fishing on black jewfish (*Protonibea diacanthus*) aggregations in the Northern Territory

Michael Phelan

Fishery Report No. 91

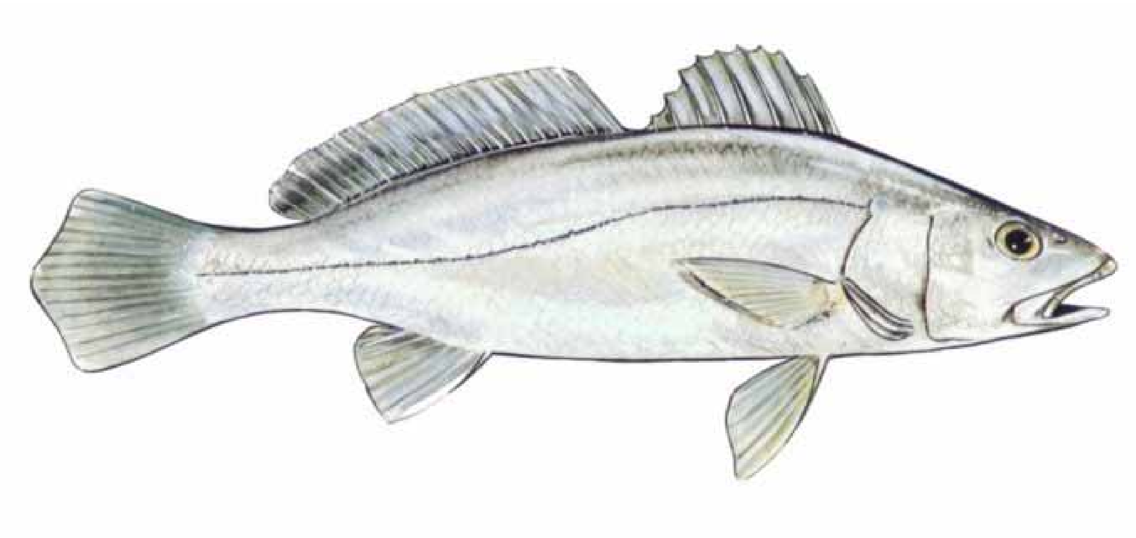

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TABLE OF CONTENTS

LIST OF TABLES V

LIST OF FIGURES VI

ACKNOWLEDGEMENTS X

1. NON-TECHNICAL SUMMARY 1

2. BACKGROUND 4

3. NEED 5

4. OBJECTIVES 7

5. DESCRIPTION OF THE BLACK JEWFISH (COASTAL LINE) FISHERY OF THE NORTHERN TERRITORY 8

5.1 Introduction 8
5.2 Objectives 8
5.3 Methods 9
5.4 Results 9
5.4.1 Commercial sector 9
5.4.2 Recreational sector 12
5.4.2 Fishing tour operator sector 12
5.4.4 Indigenous sector 14
5.5 Monitoring black jewfish landings 14
5.5.1 Sex ratio 14
5.5.2 Seasonal patterns in length 15
5.5.3 Length-weight relationships 16
5.5.4 Morphometrics 18
5.6 Discussion 20

6. REPRODUCTIVE BIOLOGY OF BLACK JEWFISH FROM NORTHERN TERRITORY COASTAL WATERS 22

6.1 Introduction 22
6.2 Objective 22
6.3 Methods 23
6.3.1 Sampling 23
6.3.2 Analysis 23
6.4 Results 27
6.4.1 Size at maturity 28
6.4.2 Time of spawning 28
6.5 Discussion 32

7. AGE AND GROWTH OF BLACK JEWFISH FROM NORTHERN TERRITORY COASTAL WATERS ... 34
7.1 Introduction ... 34
7.2 Objective ... 34
7.3 Methods ... 35
7.3.1 Sampling ... 35
7.3.2 Otolith mass ... 35
7.3.3 Otolith preparation ... 35
7.3.4 Reading protocol ... 36
7.3.5 Comparison of age estimates ... 37
7.3.6 Data analysis ... 38
7.4 Results ... 39
7.5 Discussion ... 43
8. KEY HABITAT CHARACTERISTICS OF BLACK JEWFISH AGGREGATION SITES IN NORTHERN TERRITORY COASTAL WATERS ... 46
8.1 Introduction ... 46
8.2 Objective ... 46
8.3 Methods ... 46
8.3.1 Site selection ... 46
8.3.2 ADCP surveys ... 47
8.3.3 BRUVS surveys ... 48
8.4 Results ... 48
8.4.1 Chambers Bay - bottom topography ... 48
8.4.2 Chambers Bay - current flows ... 55
8.4.3 Chambers Bay - Turbidity/productivity ... 55
8.4.4 Channel Point - bottom topography ... 57
8.4.5 Channel Point - current flows ... 60
8.4.6 Channel Point - turbidity/productivity ... 61
8.5 Discussion ... 61
9. IMPLICATIONS OF BAROTRAUMA AND HOOK TYPE ON CATCHING AND RELEASING BLACK JEWFISH ... 63
9.1 Introduction ... 63
9.2 Objectives ... 63
9.3 Methods ... 64
9.4 Results ... 70
9.4.1 Eyes ... 70
9.4.2 Swim bladder ... 71
9.4.3 Abdominal viscera and stomach ... 72
9.4.4 Liver ... 73
9.4.5 Circulatory system and the spleen ... 74
9.4.6 Other organs ... 74
9.4.7 Fishing method and hook type ... 74
9.4.8 Fish length ... 76
9.4.9 Likely effect of injuries ... 76
9.5 Discussion ... 77

9.5.1 Eyes 77
9.5.2 Swim bladder 79
9.5.3 Abdominal viscera and stomach 81
9.5.4 Liver 84
9.5.5 Circulatory system 87
9.5.6 Hook type 88
9.6 Conclusions 90
9.7 Advice for catching and releasing black jewfish 91
10. BENEFITS AND ADOPTION 92
11. FURTHER DEVELOPMENT 93
11.1 Justification for further research 94
11.2 Proposed objectives 94
12. PLANNED OUTCOMES 95
13. CONCLUSION 96
14. REFERENCES 98
15. APPENDIX 1: INTELLECTUAL PROPERTY 102
16. APPENDIX 2: STAFF 103

LIST OF TABLES

Table 2.1 Estimated weights of black jewfish landed per sector, NT only, 1995 5

Table 2.2 Estimated weights of black jewfish landed per sector, NT only, 2005 5

Table 5.1 Description of head and fin morphometric measurements 9

Table 6.1 Macroscopic ovary staging schedule for black jewfish 24

Table 6.2 Microscopic ovary staging schedule for black jewfish 24

Table 6.3 Images of microscopic ovary staging schedule for black jewfish 25

Table 7.1 Batch registration details of black jewfish otoliths 35

Table 7.2 Criteria used to convert increment count to age class in black jewfish 37

Table 7.3 Length of Indian black jewfish (cm TL) representative of number of growth bands in otoliths (n = 350) 44

Table 9.1 Description of observed eye condition in black jewfish and likely effect of barotrauma 65

Table 9.2 Description of observed swim bladder condition in black jewfish and likely effect of barotrauma 66

Table 9.3 Description of observed abdominal viscera in black jewfish and likely effect of barotrauma 67

Table 9.4 Description of observed liver condition in black jewfish and likely effect of barotrauma 68

Table 9.5 Description of observed spleen condition in black jewfish and likely effect of barotrauma 69

Table 9.6 Barotrauma effects in black jewfish landed from various depths 77

Table 16.1 Project staff 103

LIST OF FIGURES

Figure 2.1 Illustration of an adult black jewfish (*Protonibea diacanthus)*..... 4

Figure 5.1 Composition of landings reported in the NT Coastal Line Fishery, 1990-2006 (Hand-line catch only)..... 10

Figure 5.2 Tonnage of black jewfish retained as by-product in commercial fisheries other than the NT Coastal Line Fishery..... 11

Figure 5.3 Catch, effort and CPUE for the vertical line component of the NT Coastal Line Fishery, 1990-2006..... 11

Figure 5.4 Location of the key black jewfish fishing grounds/aggregation study sites..... 12

Figure 5.5 Number of black jewfish landed by FTOs from their five most important sites for this species..... 13

Figure 5.6 Kept and released black jewfish, fishing tour operator sector only, 1997 to 2006..... 13

Figure 5.7 Proportions of black jewfish kept and released in FTO sector, 1997 to 2006..... 14

Figure 5.8 Proportion of male and female black jewfish sampled between August 2004 and August 2006; n = 1570; proportions estimated for January and February 2005..... 15

Figure 5.9 Monthly mean length and standard deviation of female black jewfish sampled between August 2004 and August 2006; pooled by month across years; n = 737..... 15

Figure 5.10 Monthly mean length and standard deviation of male black jewfish sampled between August 2004 and August 2006; pooled by month across years; n = 833..... 16

Figure 5.11 Length-weight relationship of black jewfish sampled in 2004; sexes pooled; n = 415..... 16

Figure 5.12 Length-weight relationship of black jewfish sampled in 2005; sexes pooled; n = 667..... 17

Figure 5.13 Length-weight relationship of black jewfish sampled in 2006; sexes pooled; n = 405..... 17

Figure 5.14 Length-weight relationship of all black jewfish sampled between 2004 and 2006; sexes pooled; n = 1487..... 18

Figure 5.15 Relationship between the lip length and total length (TL) for black jewfish; n = 108..... 18

Figure 5.16 Relationship between the operculum length and total length (TL) for black jewfish; n = 108..... 19

Figure 5.17 Relationship between the dorsal fin length and total length (TL) for black jewfish; n = 108..... 19

Figure 5.18 Relationship between the pectoral fin length and total length (TL) for black jewfish; n = 108..... 20

Figure 5.19 Relationship between the anal fin length and total length (TL) for black jewfish; n = 108..... 20

Figure 6.1 The number of black jewfish sampled each month (pooled across years and sites) between August 2004 and August 2006 for the reproduction study..... 27

Figure 6.2 Number of black jewfish ovaries collected each month (pooled across years and sites) between August 2004 and August 2006 that were examined histologically; n = 505..... 27

Figure 6.3 Estimated size of maturity (L_{50}) of female black jewfish with 95 % confidence interval based on 1000 bootstrap samples. S+ function code used to estimate size at maturity courtesy of John McKinlay, WA Fisheries..... 28

Figure 6.4 Monthly frequency of F2 “developing” ovaries in black jewfish..... 29

Figure 6.5 Monthly frequency of F3 “developed” and F4 “pre-spawning” ovaries in black jewfish..... 29

Figure 6.6 Monthly frequency of F5 “spawning” ovaries in black jewfish..... 30

Figure 6.7 Monthly frequency of F6 “spent” ovaries in black jewfish 30
Figure 6.8 Monthly frequency of F7 “resting” ovaries in black jewfish 31
Figure 6.9 Mean (± standard deviation) monthly GSI for female black jewfish greater than 80 cm TL; n = 529 31
Figure 6.10 Mean (± standard deviation) monthly oocyte size of female black jewfish; n = 505 32
Figure 7.1 Transverse section of black jewfish sagittal otolith viewed with transmitted light 37
Figure 7.2 Total length-otolith mass plot for the black jewfish. Area and year of capture combined (n = 991) 39
Figure 7.3 Estimated age class (birthday adjusted)-otolith mass plot for black jewfish; area and year of capture combined (n = 991) 39
Figure 7.4 Length-frequency distribution of black jewfish. Area and year of capture combined (n = 991) 40
Figure 7.5 Age-frequency distribution of black jewfish; area and year of capture combined 40
Figure 7.6 Age-length relationship for black jewfish with fitted von Bertalanffy growth curve; area and year of capture combined 41
Figure 7.7 Distribution of differences between primary and secondary readings of black jewfish age (n = 252) 41
Figure 7.8 Distribution of bootstrapped average percent error readings between primary and secondary age estimates (n = 5000) 42
Figure 7.9 Age-frequency distribution of black jewfish examined by James Cook University (n = 481)...... 42
Figure 7.10 Age-length relationship for black jewfish examined by James Cook University (n = 481)........ 43
Figure 8.1 Mounting of ADCP on vessel 47
Figure 8.2 Three-dimensional relief map showing seabed topography of Chambers Bay transects 1 & 2; x-axis length 500 m 49
Figure 8.3 Three-dimensional relief map of seabed topography of Chambers Bay transects 1 & 2; x-axis scale 500 m 50
Figure 8.4 Three-dimensional relief map of seabed topography for Chambers Bay transect 3; x-axis scale 1 km 51
Figure 8.5 Three-dimensional relief map of seabed topography Chambers Bay transect 3; x-axis scale 1 km 52
Figure 8.6 Three-dimensional relief map of seabed topography Chambers Bay transect 4; x-axis scale 800 m 53
Figure 8.7 Three-dimensional relief map of seabed topography Chambers Bay transect 4; x-axis scale 800 m 54
Figure 8.8 Bathymetry and current vectors; Chambers Bay transects 1 & 2 55
Figure 8.9 Bathymetry and current vectors; Chambers Bay transect 3 56
Figure 8.10 Bathymetry and current vectors; Chambers Bay transect 4 56
Figure 8.11 Snap shot (typical) of profiles of velocity magnitude and direction of current flows at Chambers Bay 57
Figure 8.12 Turbidity contour plot along transect at Chambers Bay using acoustic backscatter; transect length 3.4 km 57
Figure 8.13 Two-dimensional map of bottom topography at the Channel Point site.................................. 58
Figure 8.14 Three-dimensional map of bottom topography at the Channel Point site 59

Figure 8.15 Snapshot of current flows at the Channel Point site; arrow sizes are proportional to strength of currents and current vectors range from 0.3-1.0 m/s 60
Figure 8.16 Velocity contour plots showing the detailed velocity distribution at the Channel Point site 60
Figure 8.17 Profile plot of current velocity magnitude and direction at the Channel Point site 61
Figure 8.18 Turbidity contour plot along transect at the Channel Point site using acoustic backscatter. Transect length 1.7 km 61
Figure 9.1 ABC Radio interviews Dylan Campbell, and volunteers Elizabeth Payne and Sarah Watkins, while they dissect a black jewfish held in a cradle. Note the orientation of the fish in the cradle and the incision to expose the abdominal organs. 64
Figure 9.2 Percentage of black jewfish from various depths observed with haemorrhaging in the eye....... 70
Figure 9.3 Percentage of black jewfish from various depths observed with exophthalmos 70
Figure 9.4 Percentage of black jewfish from various depths observed with hyperinflated swim bladders 71
Figure 9.5 Percentage of black jewfish from various depths observed with perforated swim bladders 71
Figure 9.6 Percentage of black jewfish from various depths observed with displacement of the stomach and intestines within the abdominal cavity 72
Figure 9.7 Percentage of black jewfish from various depths observed with everted stomachs protruding into the pharyngeal cavity or beyond 72
Figure 9.8 Percentage of black jewfish from various depths observed with liver tissue trauma 73
Figure 9.9 Percentage of black jewfish from various depths observed with damage to the hepatic veins that connect the liver to the heart 73
Figure 9.10 Percentage of black jewfish from various depths observed with splenomegaly 74
Figure 9.11 Location hooks set in black jewfish when fishing with 6/0 circle hooks (n = 100) 75
Figure 9.12 Location hooks set in black jewfish when fishing with 6/0 j-hooks (n = 58) 75
Figure 9.13 Eye of a black jewfish showing no visible signs of damage 78
Figure 9.14 Severe haemorrhage within the cornea along the periphery of the conjunctiva 79
Figure 9.15 Severe exophthalmos of an eye of a black jewfish exposing the extraocular muscles........ 79
Figure 9.16 Normal size of a swim bladder in black jewfish 80
Figure 9.17 Severe hyperinflation of a swim bladder presenting in a black jewfish 81
Figure 9.18 Swim bladder of a black jewfish presenting a single perforation (circled)........ 81
Figure 9.19 Normal position of stomach and intestine within the abdominal cavity in a black jewfish........ 82
Figure 9.20 Visceral mass dissected from a black jewfish landed from water 0-10 m deep showing intact mesentery and normal position of abdominal organs. 83
Figure 9.21 Displaced visceral mass and everted stomach in a black jewfish landed from 15-20 m. Compare with disposition of the organs in Figure 9.19. 83
Figure 9.22 Visceral mass dissected from above specimen showing displaced organs, everted and congested stomach and thrombosis of gonadal artery 84
Figure 9.23 Everted stomach of a black jewfish 84
Figure 9.24 Normal position of liver and hepatic veins (circled) observed in black jewfish........ 85
Figure 9.25 Dissected liver and hepatic veins (circled) of black jewfish landed from water 0-10 m deep 86
Figure 9.26 Anterior displacement of the liver in a black jewfish landed from 15-20 m 86

Figure 9.27 Dissected liver and hepatic veins (circled) of black jewfish landed from 15-20 m. Note the two liver lobes are no longer connected by a thick layer of liver tissue and the portal veins are stretched. 87

Figure 9.28 Normal sized spleen of a 108 cm TL black jewfish (Actual size) 88

Figure 9.29 Enlarged spleen of a 106 cm TL black jewfish landed from water 15-20 metres deep (Actual size) 88

Figure 9.30 X-ray image of a black jewfish with a 6/0 circle hook set at the anterior end of the lower jaw (i.e. “lip hooked”) 89

Figure 9.31 X-ray image of a black jewfish with a 6/0 j-hook set at the anterior end of the abdominal cavity (i.e. “gut hooked”) 90

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1. NON-TECHNICAL SUMMARY

FRDC 2004/004 Assessment of the implications of target fishing on black jewfish (*Protonibea diacanthus*) aggregations in the Northern Territory

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OBJECTIVES:

1. Identify key sites of black jewfish aggregations and monitor fishing activity at these sites.

2. Determine the degree of movement between two known aggregation sites (this objective now refers to FRDC project 2004-02: Spatial management of reef fisheries and ecosystems: Understanding the importance of movement).

3. Determine the temporal, spatial and biological nature of the aggregations (note linkage to FRDC project 2004-02).

4. Review and adjust management arrangements as appropriate.

Two smaller studies (one on barotrauma and the other on morphometrics), that used black jewfish collected as part of this project, were initiated in 2007 and had the following subsidiary objectives:

1. Quantify the extent of barotrauma-related injuries in black jewfish relative to capture depth, fish length and fishing method.

2. Develop advice for fishers on catching and releasing black jewfish.

3. Assess the viability of a fin-return size monitoring program for black jewfish.

SUMMARY:

Outcomes achieved to date

In September 2006, NT Fisheries hosted a public workshop in which the preliminary results of this project were presented and discussed. Around 30 delegates representing various stakeholder groups participated. Future research needs were reviewed during the workshop, which led to a broadening of the scope of this project to include a study of the effects of barotrauma on black jewfish. Apart from this project, other studies were expanded or implemented that value-added to the investigations funded by FRDC.

Future management directions were discussed at the workshop and attendees supported a proposal to reconvene the Coastal Line Fishery Management Advisory Committee so that it may review: 1) the information gained during this project and 2) the appropriateness of current management arrangements. In response, NT Fisheries has undertaken steps to convene a meeting of the Committee shortly after the publication of this report.

The black jewfish, *Protonibea diacanthus*, is one of northern Australia's iconic fish species. They reach sizes greater than 150 cm TL and 45 kg in weight. These features, in combination with the inshore aggregating behaviour of black jewfish, has lead to an increase in target fishing by all sectors (primarily using hook-and-line). Estimates of the combined landings of black jewfish in the NT have risen from ~450 tonnes in 1995 to ~670 tonnes in 2005.

Since 2005, NT Fisheries has implemented a series of research studies focused on black jewfish. The key findings of this project are:

Age and reproduction studies

Studies of the age/length frequency of some 1000 black jewfish, and the reproductive status of 500 black jewfish, caught between August 2004 and August 2006, revealed:

- Black jewfish in the coastal waters of the NT grow extremely fast, reaching around 60 cm TL in their first year and 90 cm in their second year.
- Black jewfish live for at least 12 years (specimens 140-142 cm TL).
- 50% of black jewfish are sexually mature at 89 cm TL (two years old).
- Spawning occurs over several months, and peaks in December.

Habitat mapping and acoustic tagging studies (note link to FRDC Project 2004/002)

Acoustic Doppler Current Profiler surveys were undertaken at the aggregation sites at Chambers Bay and Channel Point on 14-15 February 2006 and 25-28 July 2006, respectively. A total of 44 black jewfish at the Chambers Bay site had acoustic tags implanted during September and November 2005. Likewise, 40 black jewfish at the Channel Point site had acoustic tags implanted during December 2004, and April and October 2005. These studies showed:

- Black jewfish aggregation sites vary significantly in terms of bottom contour and current profiles as revealed in 2-D and 3-D maps of these sites.
- Black jewfish have an affinity for particular aggregation sites, with fish recorded in the same area up to 18 months later.
- Some fish appeared to be permanent residents at the aggregation site, while others moved away and returned up to nine months later.

Barotrauma study

Autopsies conducted on 108 black jewfish (obtained from commercial fishers and research fishing) revealed:

- Black jewfish are highly susceptible to barotrauma, showing a range of conditions. These included; haemorrhage and exophthalmos of eyes, hyperinflation or rupturing of the swim bladder (as a consequence of hyperinflation), displacement and damage to visceral organs and damage to the circulatory system.
- Black jewfish landed from less than 10 metres (m) water depth showed few signs of barotrauma and were likely to survive if released. Forty six percent and 100% of black jewfish landed from 10-15 m and 15-20 m respectively had injuries that rendered them unlikely to survive.
- The degree of barotrauma-related injuries was tested against variables such as capture depth, fishing method and fish length. Unlike water depth at capture, the size of the fish, and the method of fishing, did not appear to affect the type or extent of barotrauma.
- Depth-specific post-release mortality rates (which can be incorporated into future stock assessments for this species).

Management responses

NT Fisheries has advanced a proposal to reduce the personal possession limit for this species from five fish to three fish. This proposal is currently subject to Government consideration. Brochures promoting catch and release advice specific to black jewfish have been produced and distributed as a direct result of the findings of the barotrauma study.

KEYWORDS: Black jewfish, *Protonibea diacanthus*, Sciaenidae.

2. BACKGROUND

Members of the family Sciaenidae are widely distributed across tropical and subtropical waters (Trewavas 1977, Sasaki 1996). They commonly dominate epibenthic fish assemblages in near-shore waters of both regions (e.g. Blaber et al. 1990, Rhodes 1998, Vidthayanon and Premcharoen 2002), and often form the basis of commercial, recreational and indigenous fisheries (e.g. Mohan 1991, Apparao et al. 1992, De Bruin et al. 1994, Williams 1997, Mohanraj et al. 2003).

Black jewfish, *Protonibea diacanthus,* are the largest tropical Sciaenids inhabiting Australian waters (Figure 2.1). They can exceed 150 cm in length and 45 kg in weight (Grant 1999). Because of their large size, black jewfish are increasingly targeted by fishers from all sectors. In the NT, the combined landings of these fish have increased from ~443 tonnes in 1995 to ~667 tonnes in 2005 (Tables 2.1 and 2.2).

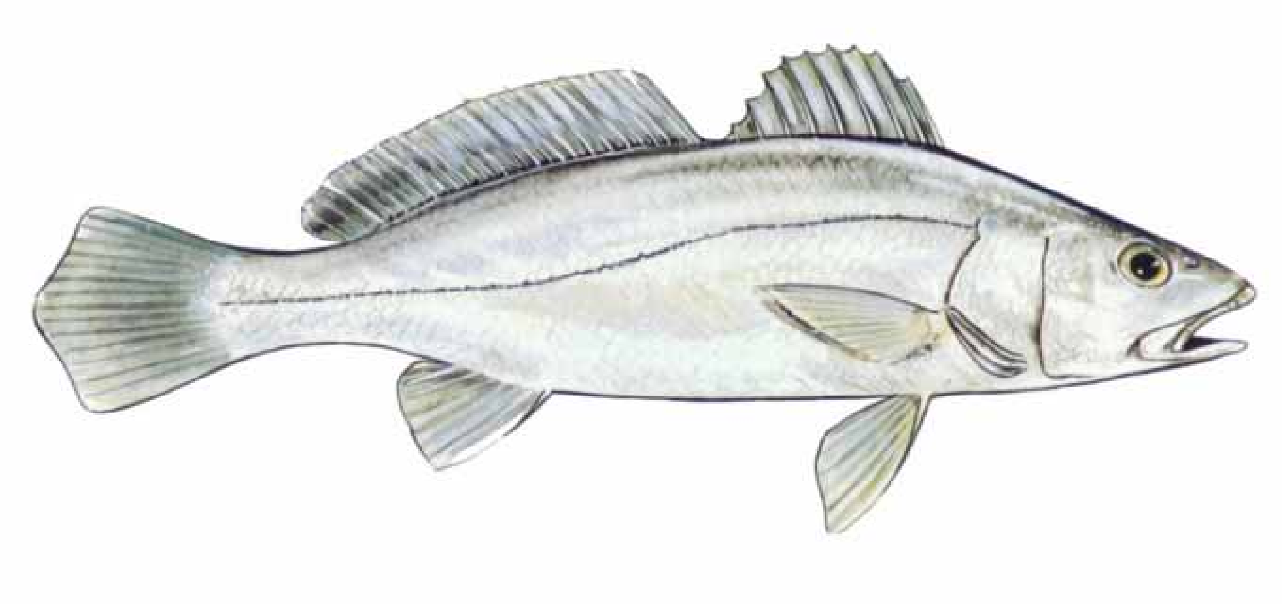

Figure 2.1 Illustration of an adult black jewfish (*Protonibea diacanthus)*

Black jewfish are found in estuarine and coastal waters over muddy bottoms and offshore to depths of 100 m. They feed mainly on crustaceans and small fishes, and have been described as 'opportunistic feeders' (Rao 1963). The time and location of spawning in Australian waters is unknown and may be associated with the large aggregations which have been reported at a number of northern Australia locations extending from Central Queensland (Bowtell 1995) to northern Western Australia (Newman 1995).

The effects of fishing an aggregation is influenced by several factors, including the number of sites used by the fish, catchment distance (i.e., how far individuals move to specific aggregation sites), aggregation fidelity (i.e., whether or not fish move between different aggregations), participation rate (i.e., proportion of the population participating in an aggregation event), residence time of individual fish at aggregation sites and potential differences between the sexes in any of the above factors (Johannes et al. 1998, Zellar 1998).

Table 2.1 Estimated weights of black jewfish landed per sector, NT only, 1995

Fishing sector	Most recent landings record	Reference
Commercial (all NT fisheries)	43 446 kg (3 621 fish at 12 kg[1])	Phelan and Elphick (2006)
Fishing tour operators	9 804 kg (817 fish at 12 kg[1])	Phelan and Elphick (2006)
Indigenous	6 816 kg (568 fish at 12 kg[1])	Henry and Lyle (2003)[2]
Recreational	383 244 kg (31 937 fish at 12 kg[1])	Coleman (1998)
Total	**443 310 kg** (36 943 fish at 12 kg[1])	

[1] Estimated average weight; [2] Refers to 2000-01 estimate of indigenous catch, no other data available.

Table 2.2 Estimated weights of black jewfish landed per sector, NT only, 2005

Fishing sector	Most recent landings record	Reference
Commercial (all NT fisheries)	251 022 kg (20 916 fish at 12 kg[1])	Phelan and Elphick (2006)
Fishing tour operators	63 516 kg (5 293 fish at 12 kg[1])	Phelan and Elphick (2006)
Indigenous	6 816 kg (568 fish at 12 kg[1])	Henry and Lyle (2003)[2]
Recreational	346 116 kg (28 843 fish at 12 kg[1])	Coleman (2004)[3]
Total	**667 470 kg** (55 620 fish at 12 kg[1])	

[1] Estimated average weight; [2] Refers to 2000/2001 estimate of indigenous catch, no other data available; [3] Refers to 2000-01 estimate of recreational catch, no other data available.

There are many examples around the world of aggregation fishing rapidly undermining the health of fish stocks. Chronic effects of aggregation fishing include the truncation of size and age structure (e.g. Beets and Friedlander 1992) and deterioration of the stock's reproductive capacity (e.g. Elklund et al. 2000). Acute effects include the total loss of aggregations (e.g. Sadovy 1994).

To ensure the ongoing sustainability of this important species, researchers from NT Fisheries have joined forces with the Australian Institute of Marine Science (AIMS), the Tasmanian Aquaculture and Fisheries Institute (TAFI) and the Fisheries Research and Development Corporation (FRDC), to improve the information base on the effects of fishing on black jewfish.

3. NEED

The black jewfish is one of northern Australia's iconic fish. Popular with recreational, indigenous and commercial fishers alike, they are the subject of increasing fishing pressure throughout their range. Target fishing for black jewfish in the NT has grown to the extent that there is growing concern within the fishing community that the resource may be at risk of over-fishing.

Black jewfish are a member of the family Sciaenidae, a group that includes several other species which grow over 140 cm TL. The large size of these fish and their tendency to aggregate appears to make them vulnerable to over-exploitation, with most of the large Sciaenids now described as threatened due to over-fishing. Well documented examples include the yellow-lipped Croaker (endemic to South East Asia) and Totoaba (endemic to the Gulf of Mexico); both of which are described as almost extinct (Apparao et al. 1992, True et al. 1997).

Black jewfish are not immune to over-fishing. There are numerous examples in the scientific literature which clearly illustrate the health of black jewfish stocks will decline in a rapid and pronounced manner if management arrangements allow over-fishing. Changes are evident as significant declines in both the number and average size of fish.

An extreme example of the negative impact of over-fishing on black jewfish catches comes from India. In the 1980s, the Gujarat coast supported a fishery of 3250 to 4550 tonnes of black jewfish per annum. However, in the early 1990s landings had fallen dramatically and "these fisheries had become non-existent" (James 1994).

Closer to home, over-fishing of black jewfish aggregations in northern Queensland provides a clear example of how rapidly the average size of the harvested fish can decline under intense fishing pressure. The FRDC Project 1998/135 (Phelan 2002) revealed that black jewfish landed from aggregations in Cape York were almost exclusively immature fish (< 80 cm TL). Anecdotal reports revealed that large mature fish ~150 cm TL were still being caught only five years earlier, but had now disappeared.

As a follow-up investigation in 2002-03 revealed, the two-year prohibition on the take of black jewfish which resulted from the FRDC Project 1998/135 provided only a slight recovery in the stock, despite the extreme nature of this action (Phelan et al. in press). This situation is not unique to Sciaenids. Published literature reveals that fish aggregations are particularly vulnerable to over-fishing, with over 50 examples of declines or losses. There are no examples in the literature of aggregations returning to their former condition despite several being granted long-term protection from over-fishing.

A stock assessment of several NT fisheries in 1996 indicated that a sequential localised depletion of coastal fish stocks was occurring, particularly around major population centres (Walters et al. 1997). Since this assessment, total annual landings of black jewfish from NT waters have increased by 50%. Black jewfish landings have grown from ~443 tonnes in 1995 to ~667 tonnes in 2005.

A large proportion of this increase is explained by growth in the commercial fishery. Black jewfish now form the backbone of the Coastal Line Fishery, consisting of 87% of the commercial catch. The commercial fishery is managed by a range of input/output controls and has a 2:1 licence reduction program in place. Recent licence trading indicates that some of the latent capacity in the fishery is likely to become active in the near future. Hence, further pressure on stocks is likely.

Despite recent advances in our knowledge of the biology and status of black jewfish in northern Australian waters, several critical aspects remain uncertain; in particular, the biological significance of the annual aggregations. The gaps in our understanding of the life cycle of this species preclude a more comprehensive assessment of the status of the stock, and creates uncertainty in the development of management arrangements for resource sustainability at an appropriate geographic scale.

4. OBJECTIVES

1. Identify key sites of black jewfish aggregations and monitor fishing activity at these sites – achieved.

2. Determine the degree of movement between two known aggregation sites (this objective now refers to FRDC project 2004-02; see corresponding independent report) – achieved.

3. Determine the temporal, spatial and biological nature of the aggregations (note linkage to FRDC project 2004-02) – achieved.

4. Review and adjust management arrangements as appropriate – achieved.

Subsidiary Objectives:

1. Quantify the extent of barotrauma related injuries in black jewfish relative to capture depth, fish length and fishing method – achieved.

2. Develop advice for fishers on catching and releasing black jewfish – achieved.

3. Assess the viability of a fin-return size monitoring program for black jewfish – achieved.

5. DESCRIPTION OF THE BLACK JEWFISH (COASTAL LINE) FISHERY OF THE NORTHERN TERRITORY

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5.1 INTRODUCTION

Black jewfish represent a key fishery resource in northern Australian waters and form large annual inshore aggregations at several sites from the northern coast of Western Australia to the central Queensland coast. The largest of these aggregations involves several thousand fish (Phelan 2002). The predictable nature of these aggregations, together with their inshore location, has made black jewfish popular with all fishing sectors.

The practice of aggregating is one of the most widespread behavioural mechanisms used by marine species to reduce natural predation (Die and Ellis 1999). Yet it is this behaviour that often promotes increased fishing effort and higher catches, as concentrations of fish are both easier to detect and more efficient to harvest (Turnbull and Samoilys 1997). Consequently, a large proportion of fishery harvests are obtained through targeting aggregations formed for migration, feeding or spawning.

NT Fisheries collects catch and effort data from commercial fishers and fishing tour operators via a monthly logbook system. Ad hoc catch and effort surveys provide additional information from recreational and indigenous fishers. Although catch and effort data is often utilised to monitor the status of harvested fish stocks, this approach is not well suited to monitoring black jewfish as they form aggregations that may disguise changes in catch rates.

Size-based monitoring appears more suited to this species, but is currently both cost and logistically prohibitive. Size monitoring requires either frequent observer trips (hindered by a lack of room on the small vessels in this fleet and high staff costs) or requires fishers to bring back whole fish for measuring (hindered by the large amount of space and ice required for whole fish and the need for two staff to be available at short notice during irregular hours).

This study investigated the relationship between fin length/total length of black jewfish with the aim of developing a practical, cost-effective size monitoring method. If a fin/total length relationship can be established, a size monitoring program can be implemented in which fishers remove and dry (or cold) -store fins until they can be measured by Fisheries staff. If successful, this approach will allow a large percentage of the total annual landings to be measured.

5.2 OBJECTIVES

Identify key sites of black jewfish aggregations and monitor fishing activity at these sites (Objective 1).

Assess the viability of a fin-return size monitoring program for black jewfish (Subsidiary objective 3).

5.3 METHODS

Black jewfish aggregation sites/fishing grounds were identified in a review of the NT logbook data provided by commercial fishers and fishing tour operators. The monthly logbook returns provide time, place and catch details. This information was supplemented by details provided by fishers from each sector. The exact location of the key aggregation sites/fishing grounds was identified as part of the project, but is not revealed in this report for privacy reasons.

Length frequency and sex ratio data (n = 1487) was collected through the sampling programs for the reproductive and age/growth studies (see Chapters 6 and 7). The fish were collected from Channel Point, Caution Point and Chambers Bay between August 2004 and August 2006. The interpretation of this data requires caution as a small percentage (<2%) of the specimens were not randomly selected for sampling. Specimens between 80-85 cm TL and >130cm TL were targeted in 2006 to fill gaps in the size range in the otolith collection.

The barotrauma study provided the opportunity to collect morphometric data to investigate size monitoring options. A range of head and fin measurements (see Table 5.1) were recorded for 108 black jewfish collected primarily from Charles Point, Chambers Bay and Channel Point. The head and fin data was correlated against the total length of the fish. While the data set is limited, it is sufficient to determine the feasibility of a pilot scale monitoring program.

Table 5.1 Description of head and fin morphometric measurements

Measurement	Description
Lip	The distance between the forward-most nostril and the posterior edge of the maxillary (lip).
Operculum	The distance between the anterior margin of the maxillary (lip) to the posterior margin of the operculum (measured from the inner side of the groove that is located above posterior tip/point).
Dorsal fin	The distance between the base and the distal end of the second ray (spine) from the anterior.
Pectoral fin	The distance between the base and the distal end of the anterior ray (spine) of the pectoral fin.
Anal fin	The distance between the base and the distal end of the anterior ray (spine) of the anal fin.

5.4 RESULTS

5.4.1 Commercial sector

The black jewfish (*Protonibea diacanthus*) is the primary target species in the NT Commercial Coastal Line Fishery (Figure 5.1) and is retained as by-product in several other NT commercial fisheries (Figure 5.2). This species constituted 87% of the fishery's landings in 2006, equating to 236 tonnes, which represents a decrease in catch from 311 tonnes in 2004. This decline may be due to a reduction in market demand or a fall in the abundance of black jewfish.

The NT Commercial Coastal Line Fishery began operating as a multi-species line fishery, targeting reef-associated species such as snappers, emperors, cod and various pelagic species. Between 1990 and 1998, a variety of reef fish dominated the catch. However, since 1999 there has been a substantial increase in the proportion of black jewfish harvested by this sector. The amount of black jewfish caught as by-product of the NT Barramundi Fishery has also increased during this period.

Commercial licensees in the Coastal Line Fishery are permitted to use a variety of fishing gear including vertical lines, drop lines, fish traps, cast nets, scoop nets and gaffs. A maximum of five fish traps per licence may be used in the area seaward of two nautical miles from the low water mark. Similarly, the use of drop lines is also permitted only seaward of the two nautical mile mark. The fishery is open year-round and there is no size limit for commercially-harvested black jewfish.

Line fishing remains the most common method for the Coastal Line Fishery. Commercial fishers are permitted to use up to five hooks per vertical line, but fishers most commonly choose to use two hooks per line. The use of different fishing gear was reported for the first time in 2002, with drop lines and traps adopted by a small number of commercial fishers. Commercial fishers may use up to 40 hooks per drop line, while the actual number of hooks utilised ranges between 4 and 20.

Fishing effort (for the vertical line component of this fishery) reached a peak of 28,970 hook days (total number of hooks) in 1992 then declined to an all time low in 1998. This was followed by a small peak of 7133 hook days in 2004 and a decline to 4474 hook days in 2006.

The catch per unit effort (CPUE) for the vertical line component of the fishery has steadily increased as the fishery has developed (Figure 5.3). There was a lull in the catch rate from 2001 to 2003 but this was followed by a sharp rise (above the 2000 figure) in 2004 and a continued increase thereafter. The catch rate in 2006 was 52.7 kg/hook-day. In 2006, there were 22 licences active in the Coastal Line Fishery. The number of active licences does vary each year, with 26 licences active in 2005 and 25 licences active in 2004.

The Coastal Line Fishery extends from the high water mark to 15 nautical miles from the low water mark. The fishery spans the entire NT coast (bar sacred sites and reserve areas), although most commercial fishing effort occurs within 150 km of Darwin. Chambers Bay, Channel Point, Charles Point and Caution Point are known black jewfish ”hotspots” and formed the primary study sites for this project (see Figure 5.4).

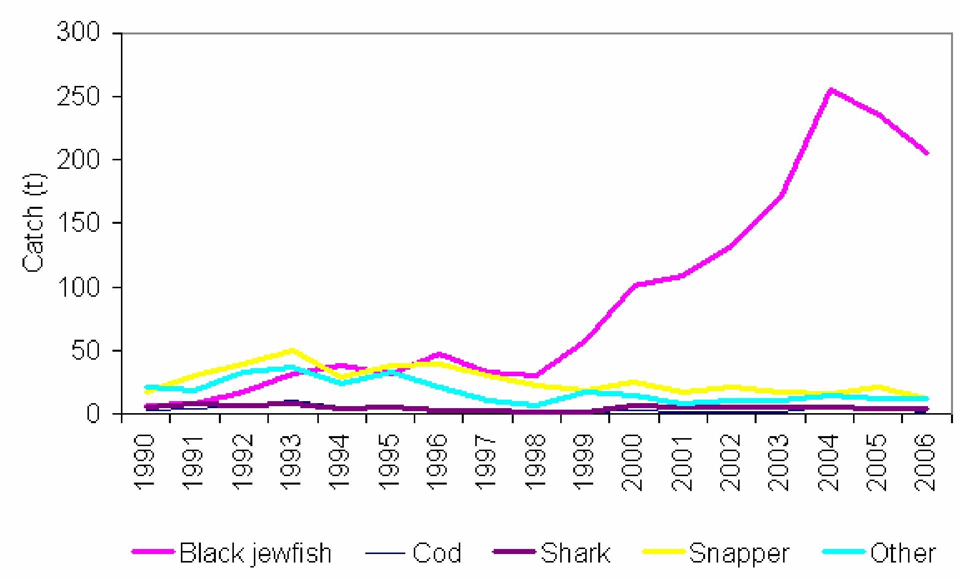

Figure 5.1 Composition of landings reported in the NT Coastal Line Fishery, 1990-2006 (Hand-line catch only)

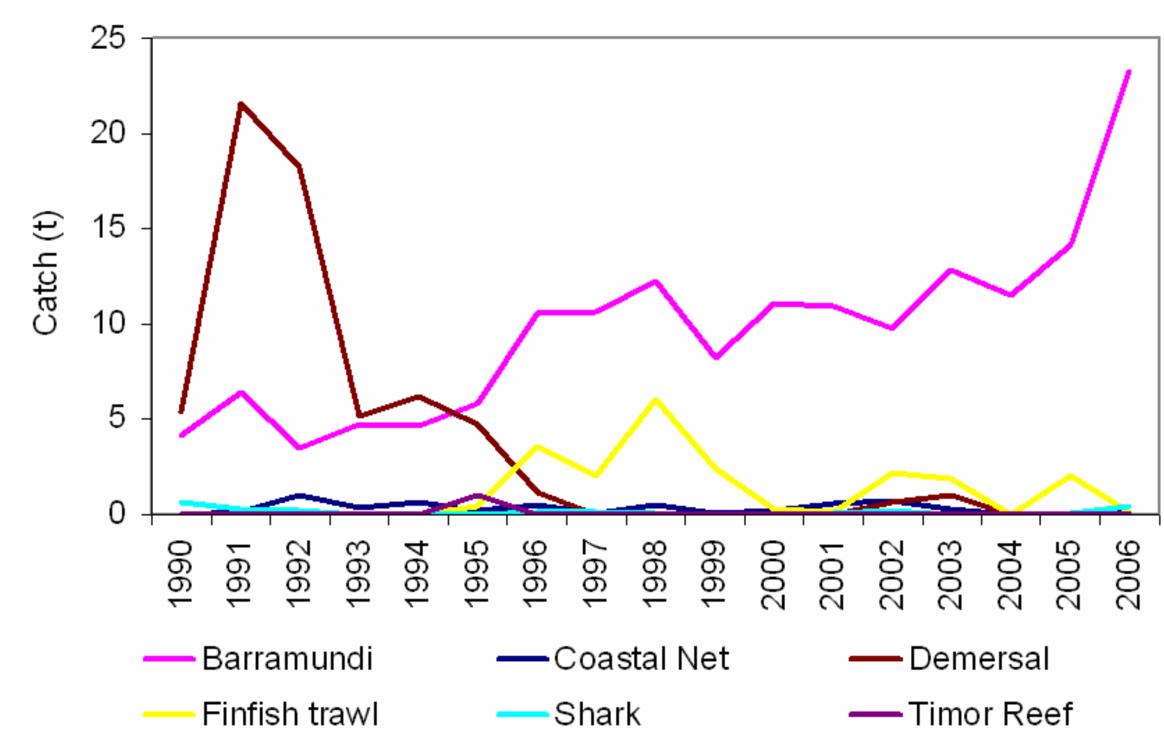

Figure 5.2 Tonnage of black jewfish retained as by-product in commercial fisheries other than the NT Coastal Line Fishery

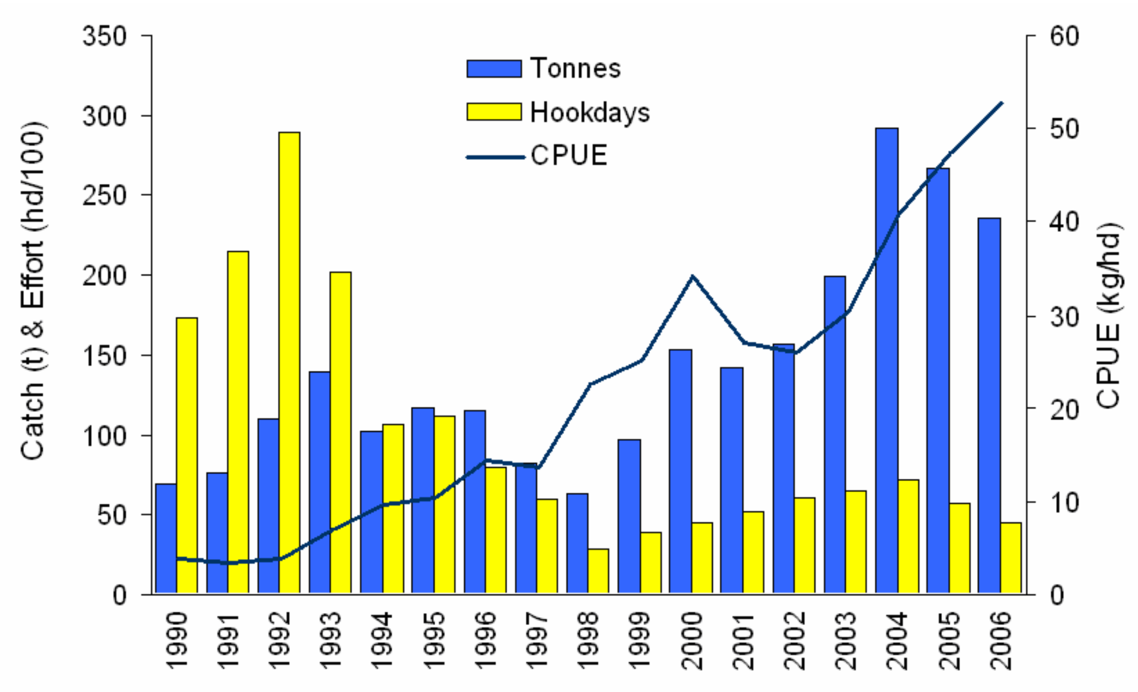

Figure 5.3 Catch, effort and CPUE for the vertical line component of the NT Coastal Line Fishery, 1990-2006

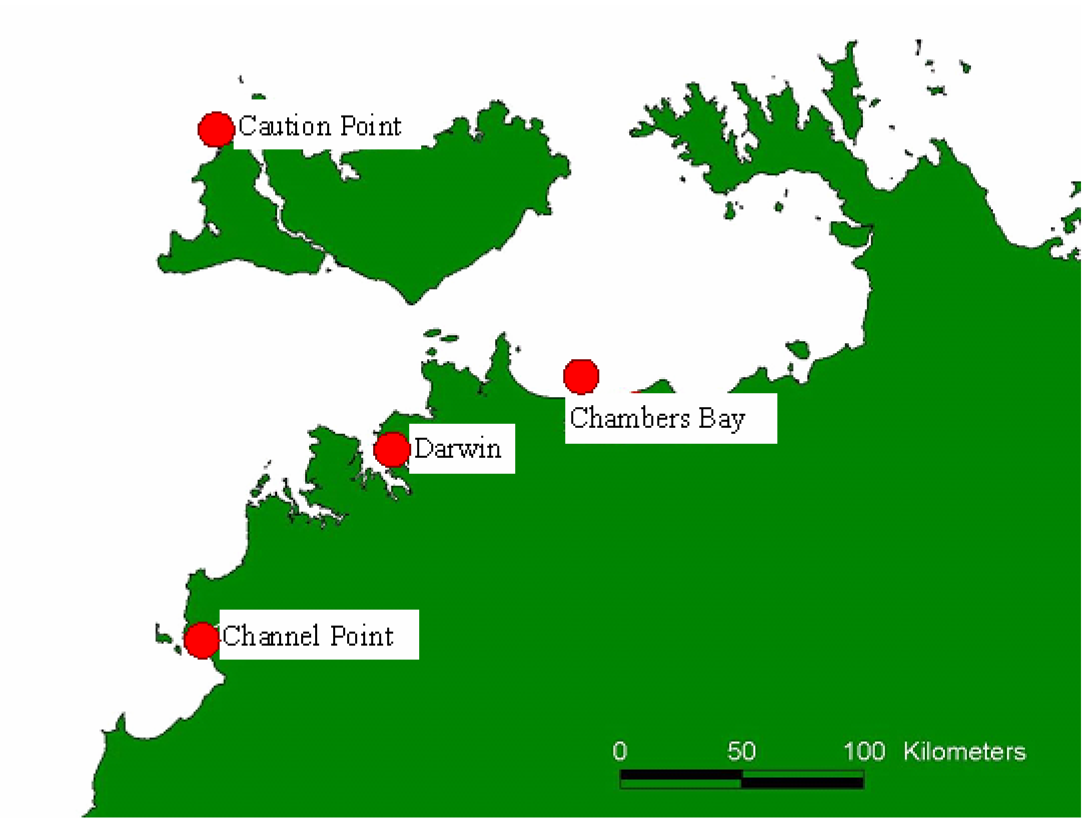

Figure 5.4 Location of the key black jewfish fishing grounds/aggregation study sites

5.4.2 Recreational sector

Recreational fishing for reef species including black jewfish occurs throughout the coastal waters of the NT. The most important areas are close to the larger population centres – the coastal strip between the Adelaide and Daly Rivers and the Nhulunbuy area. The Darwin area supports 31% of the total recreational fishing catch in the NT.

The National Recreational and Indigenous Fishing Survey conducted in 2000-01 (Henry and Lyle 2003) indicated that ~685,000 fish were landed by recreational fishers in the NT during the 12-month survey period. The survey also revealed that black jewfish account for 2% of this catch. This equates to about 28 800 black jewfish per annum, of which 11 000 (or 38%) are subsequently released. Using the former figure and an estimate of 12 kg per black jewfish, the recreational catch of this species in the NT (at the time of the survey) was approximately 346 tonnes, which exceeded that year's commercial catch by over 100 tonnes.

5.4.2 Fishing tour operator sector

Most fishing tour charters in the NT operate from Darwin, although a small number work out of Nhulunbuy, Borroloola and across Arnhem Land. Fishing tour operators (FTOs) reported landings of black jewfish from almost 250 sites between 1997 and 2006. At 12 of these sites, catches averaged over 100 black jewfish per annum. However, inter-annual variation in catch was high and no consistent pattern was evident. Landings at the five most productive sites are shown in Figure 5.5. The trend is increasing catch numbers over time. The location of these sites is not revealed for confidentiality reasons.

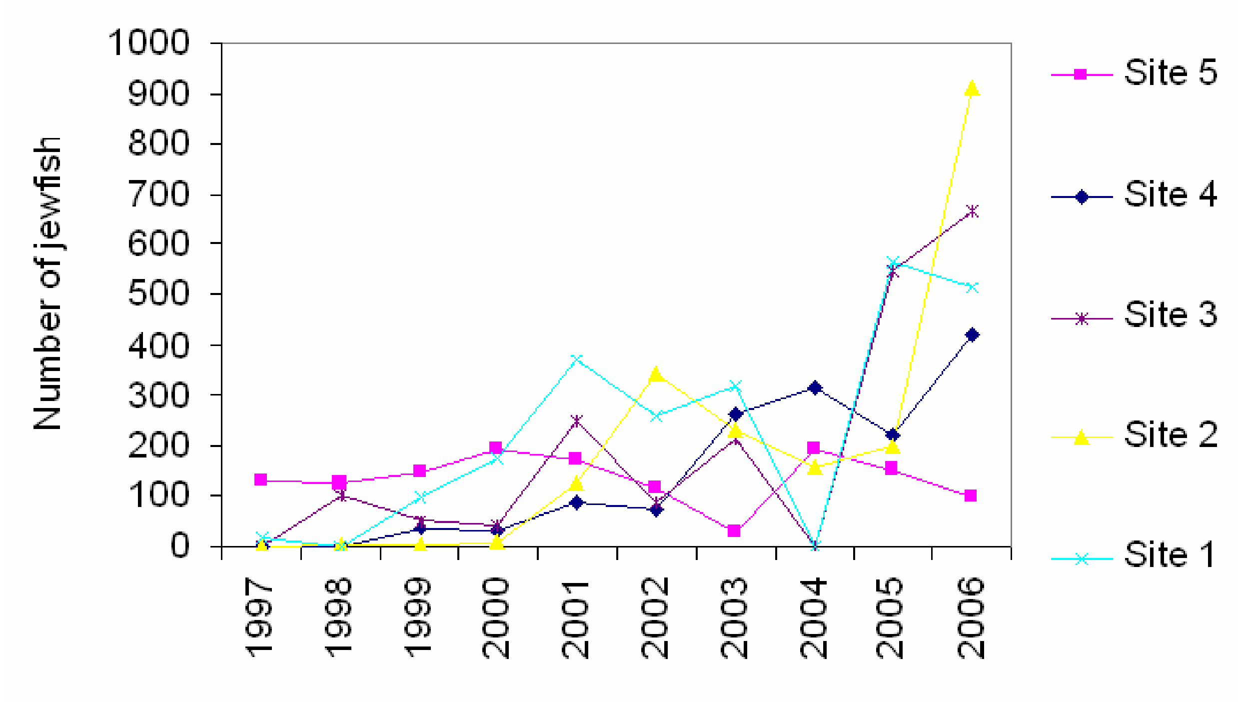

Figure 5.5 Number of black jewfish landed by FTOs from their five most important sites for this species

Fishing guides use the same gear as recreational fishers and mainly fish for reef fish by using lines with bait. FTO clients use bait for 95% of the hours spent fishing for reef species. The total number of black jewfish caught by FTO clients has increased over a ten year period from 1278 in 1997 to 7480 in 2006 (Figure 5.6). The proportion of these fish subsequently released has remained relatively consistent, averaging 30% during the same period (Figure 5.7).

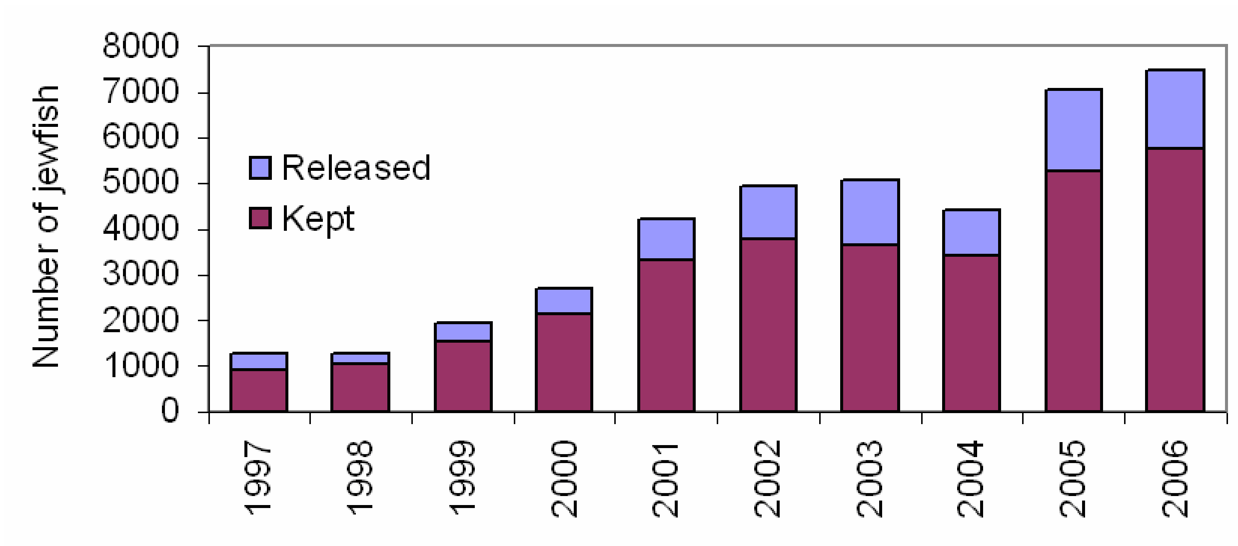

Figure 5.6 Kept and released black jewfish, fishing tour operator sector only, 1997 to 2006

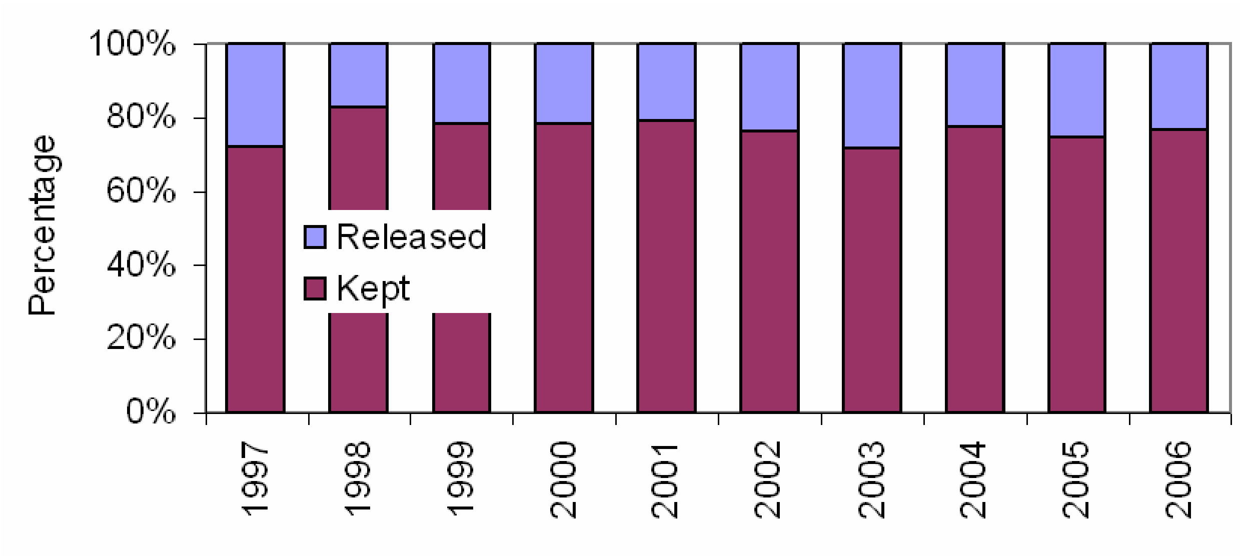

Figure 5.7 Proportions of black jewfish kept and released in FTO sector, 1997 to 2006

5.4.4 Indigenous sector

Most indigenous fishing effort in the NT is localised and centred close to communities or outstations. The National Recreational and Indigenous Fishing Survey in 2000-01 revealed that over 90% of all indigenous fishing in the NT was shore-based, with half of those events using baited lines (Henry and Lyle 2003). This work estimated that the annual black jewfish harvest by indigenous fishers in the NT was less than 1000 (mullet and snappers forming the bulk of the catch).

5.5 MONITORING BLACK JEWFISH LANDINGS

The increase in black jewfish landings explains the bulk of the growth in the Coastal Line Fishery with annual landings of this species rising from less than 50 tonnes in 1995 to almost 250 tonnes in 2005. As black jewfish now form the backbone of the commercial sector of the Coastal Line Fishery, an understanding of the fishery dynamics of the species and a means to monitor the size structure of the catch is vital to ensure the sustainability of this important resource. The information presented below is based on commercial catches (as a surrogate for the entire fishery) between August 2004 and August 2006. No data was collected in January or February 2005 due to staffing shortages.

5.5.1 Sex ratio

The monthly proportion of female black jewfish sampled from August 2004 and August 2006 (Figure 5.8) ranged from 25% (in May 2005) to 71% (in December 2005), with an overall mean of 43%.

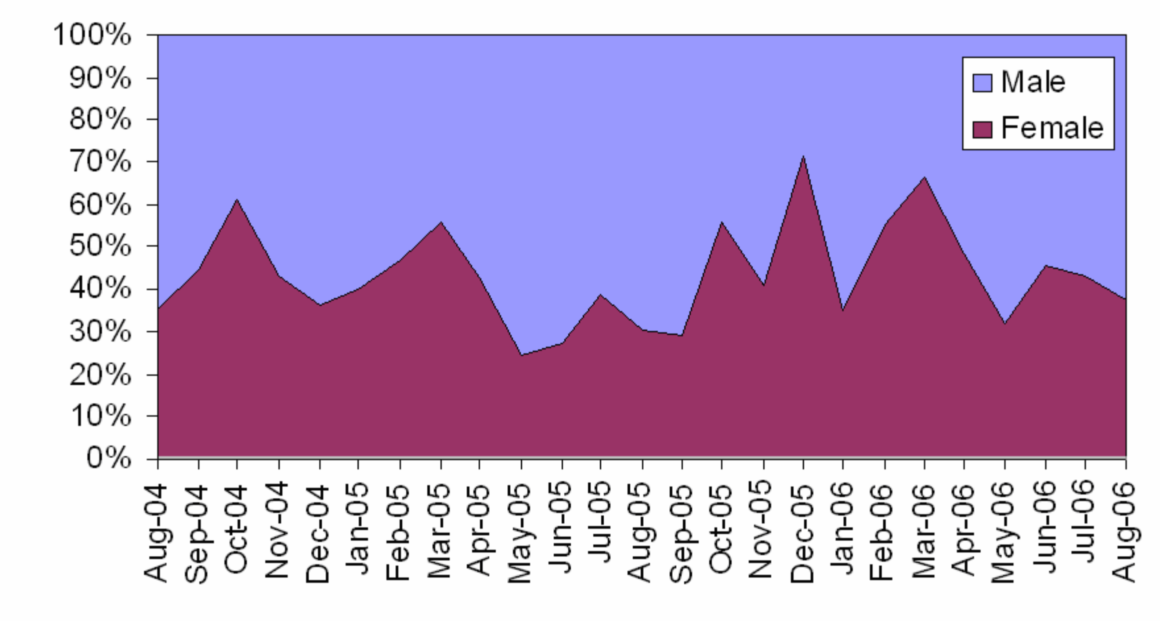

Figure 5.8 Proportion of male and female black jewfish sampled between August 2004 and August 2006; n = 1570; proportions estimated for January and February 2005

5.5.2 Seasonal patterns in length

The mean monthly length of female and male black jewfish (n = 1570) sampled between August 2004 and August 2006 (Figures 5.9 and 5.10) appear to follow similar patterns – that is, decreases in April and September/October and a peak in June/July – but the variability is such that the differences are not significant.

The decline in female size in April corresponds with a reduction in the catch rate of females at this time (Figure 5.8). However, the significance of this trend is hard to ascertain given the relatively short sampling period and the degree of variability in the length data.

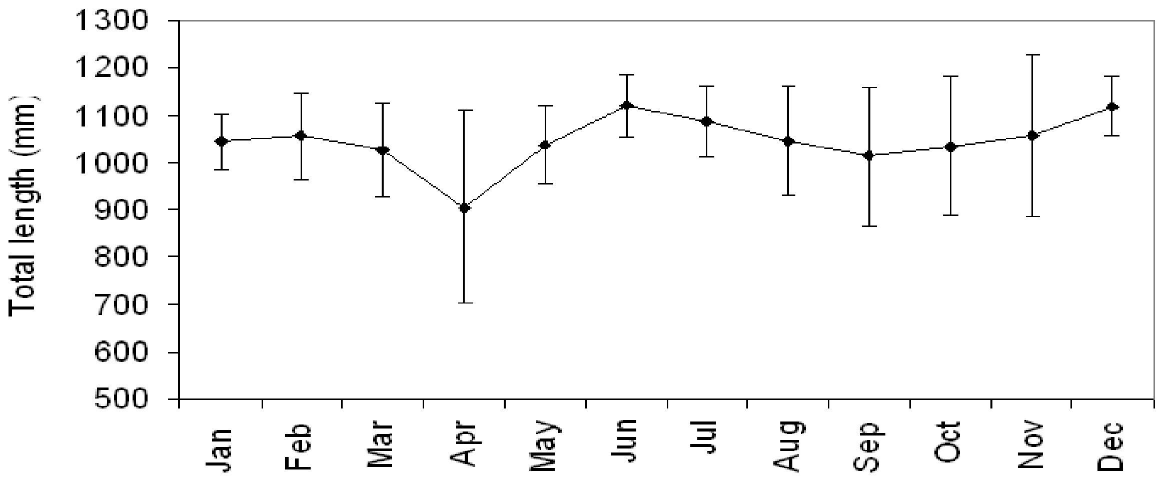

Figure 5.9 Monthly mean length and standard deviation of female black jewfish sampled between August 2004 and August 2006; pooled by month across years; n = 737

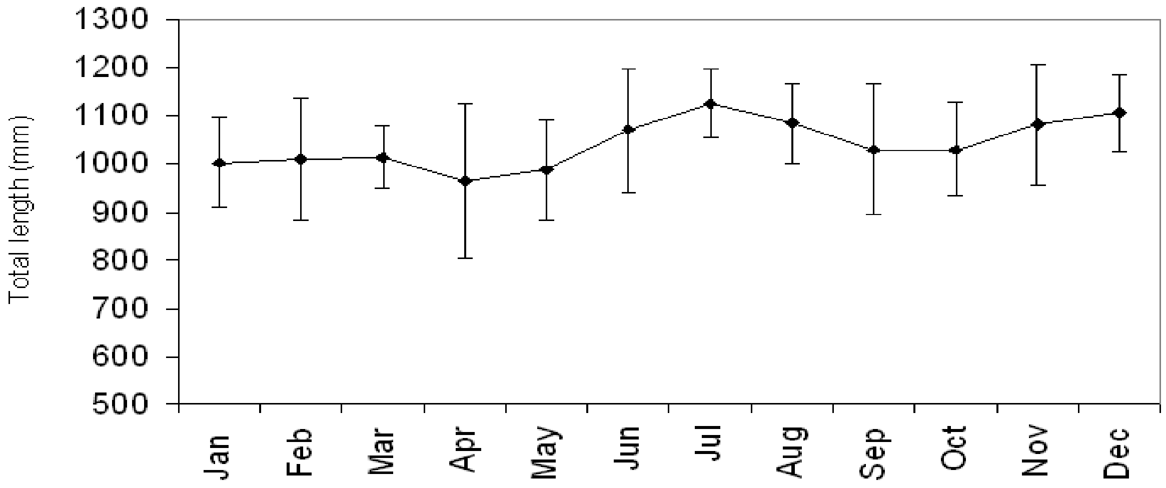

Figure 5.10 Monthly mean length and standard deviation of male black jewfish sampled between August 2004 and August 2006; pooled by month across years; n = 833

5.5.3 Length-weight relationships

The length-weight relationships for black jewfish sampled in each year from 2004 to 2006 (with sexes pooled) all had high correlation coefficients (i.e. r^2 > 0.95) but were slightly different from year to year (Figures 5.11 to 5.13). This is unlikely to represent a change in the size structure of the stock; rather it is probably due to differences in the size distribution, origin and number of jewfish sampled each year.

The length-weight relationship for all black jewfish sampled from 2004 to 2006 was $y = 0.00004x^{2.6543}$ (Figure 5.14) and had a correlation coefficient of 0.96. Whilst fish size ranged from 22 to 139 cm TL, 92% of the fish sampled were > 90 cm TL. Hence, a greater number of smaller fish is needed to improve the validity of the relationship.

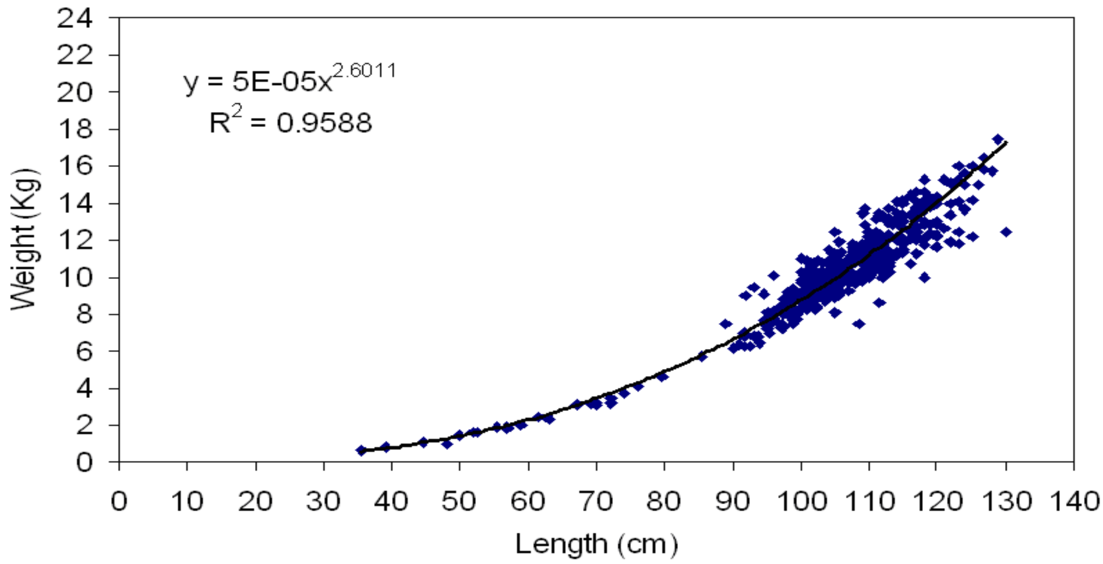

Figure 5.11 Length-weight relationship of black jewfish sampled in 2004; sexes pooled; n = 415

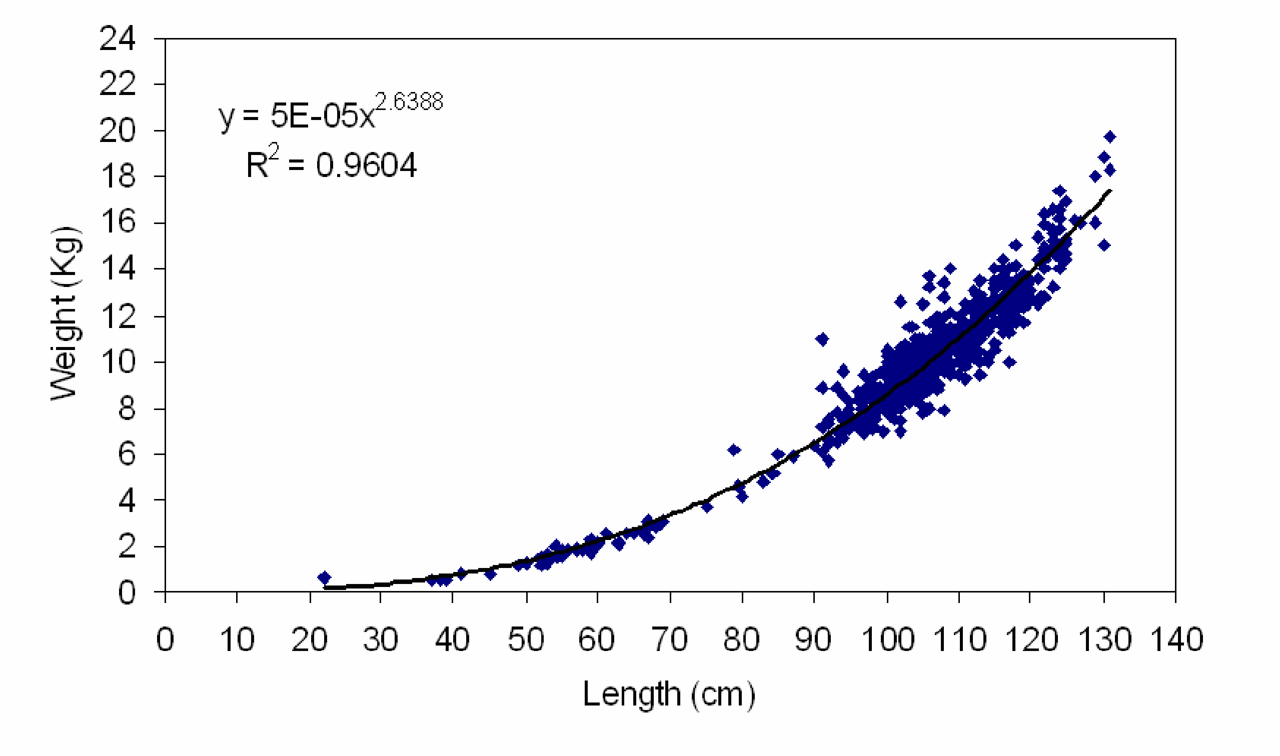

Figure 5.12 Length-weight relationship of black jewfish sampled in 2005; sexes pooled; n = 667

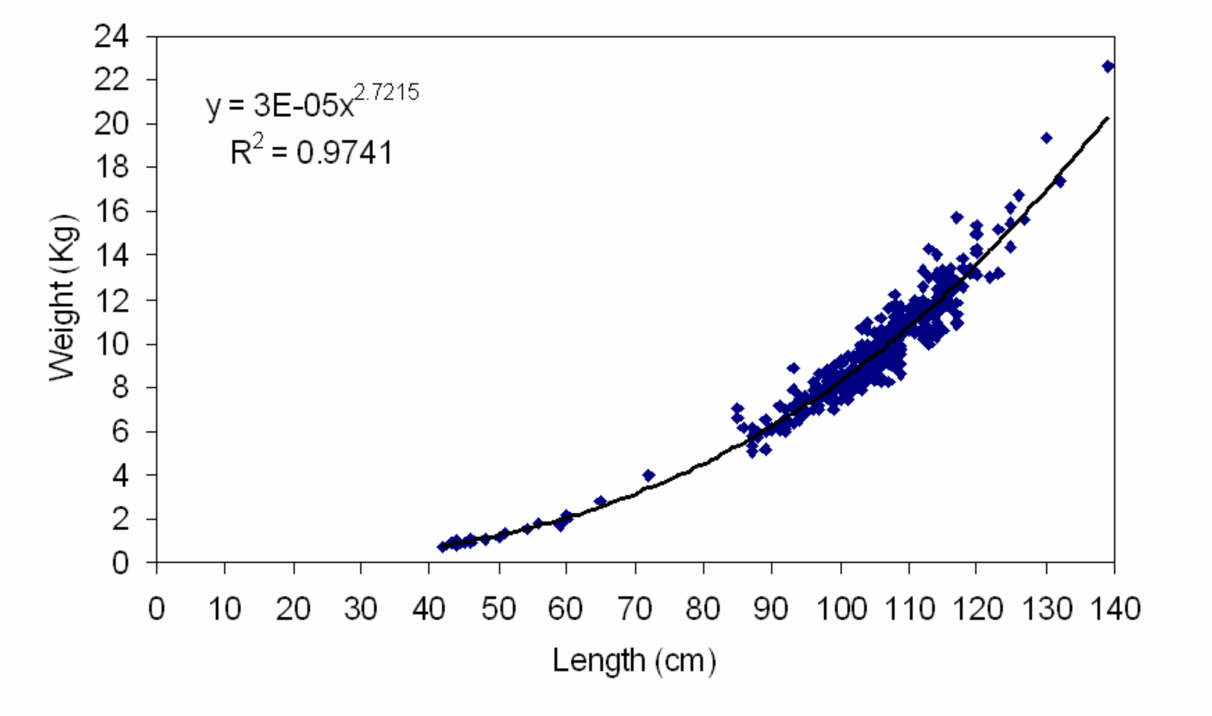

Figure 5.13 Length-weight relationship of black jewfish sampled in 2006; sexes pooled; n = 405

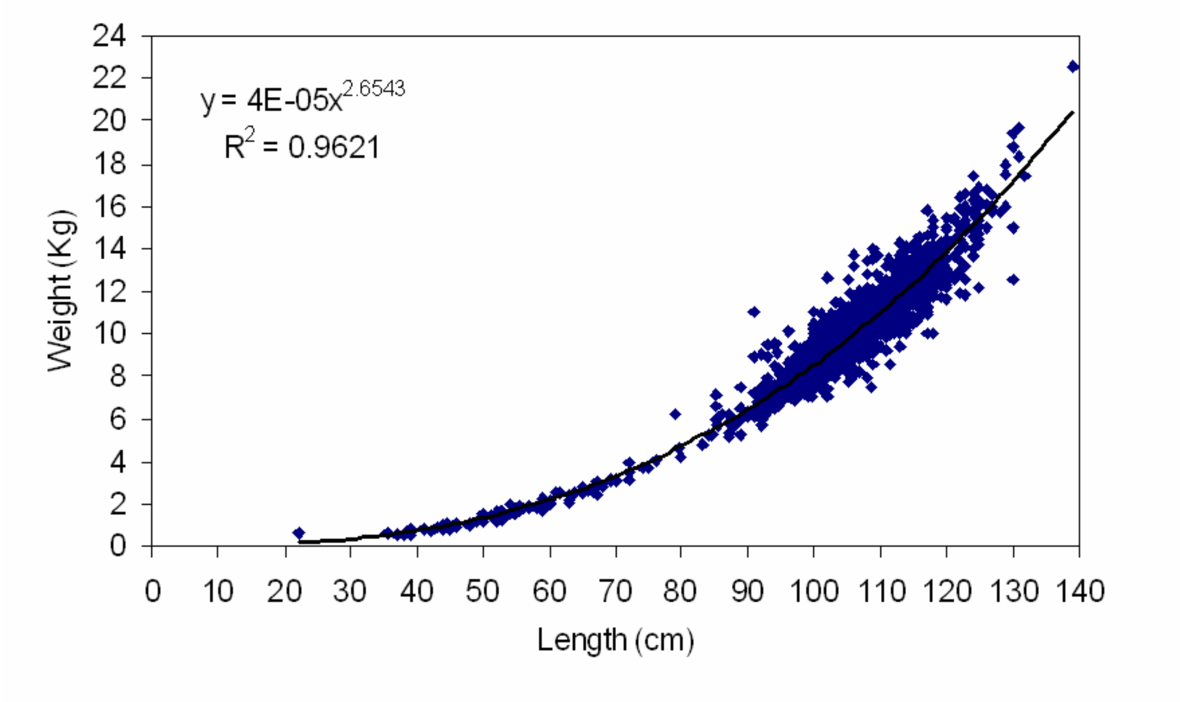

Figure 5.14 Length-weight relationship of all black jewfish sampled between 2004 and 2006; sexes pooled; n = 1487

5.5.4 Morphometrics

The morphometric study found highly correlated linear relationships between each of the different measurements (i.e. lip and operculum length, and dorsal, pectoral and anal fin length) and total fish length (Figures 5.15 to 5.19).

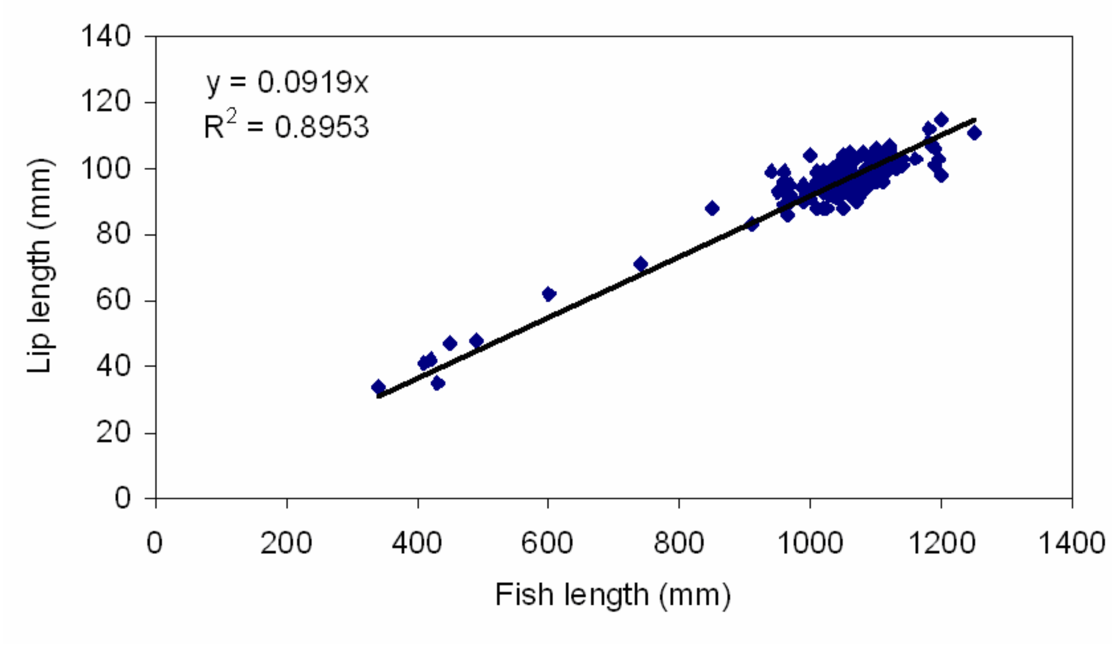

Figure 5.15 Relationship between the lip length and total length (TL) for black jewfish; n = 108

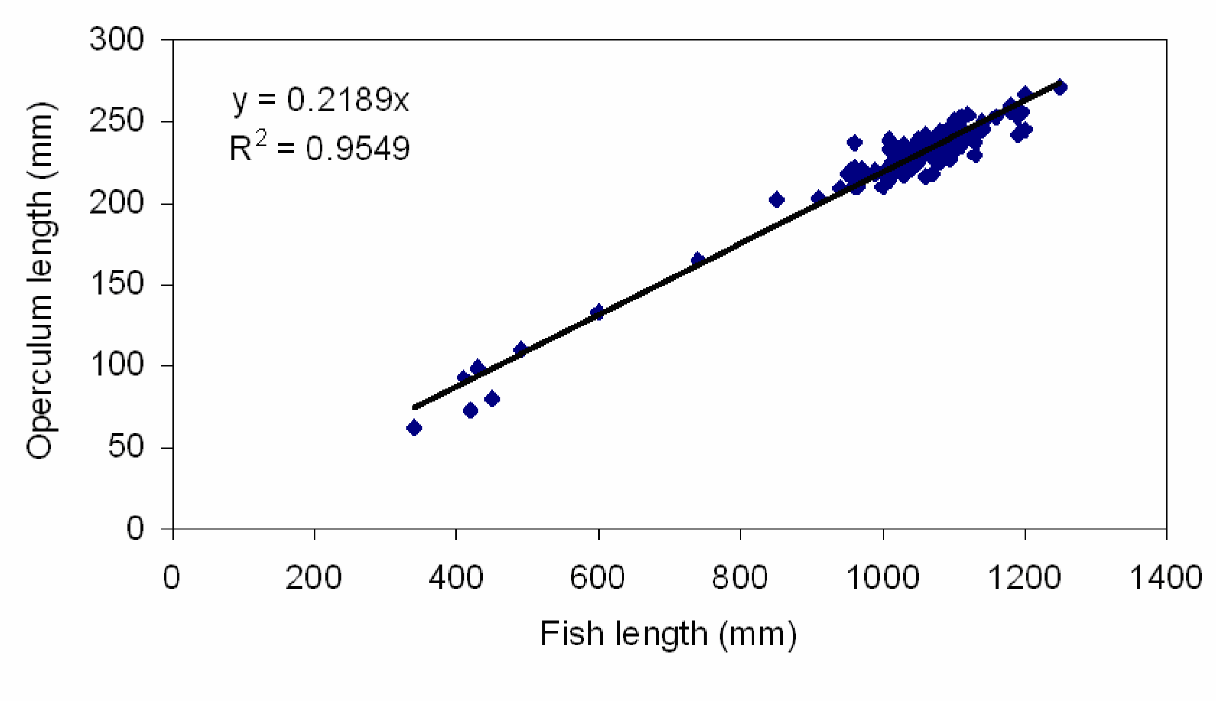

Figure 5.16 Relationship between the operculum length and total length (TL) for black jewfish; n = 108

Of the three fin measurements, pectoral fin length showed the strongest correlation with total length (r^2 = 0.91) and is considered the best candidate for a size monitoring study. Lip and operculum length (while highly correlated with total length) were not considered viable as they would involve either measurement by the fisher or retention of the entire fish head (as opposed to a single fin).

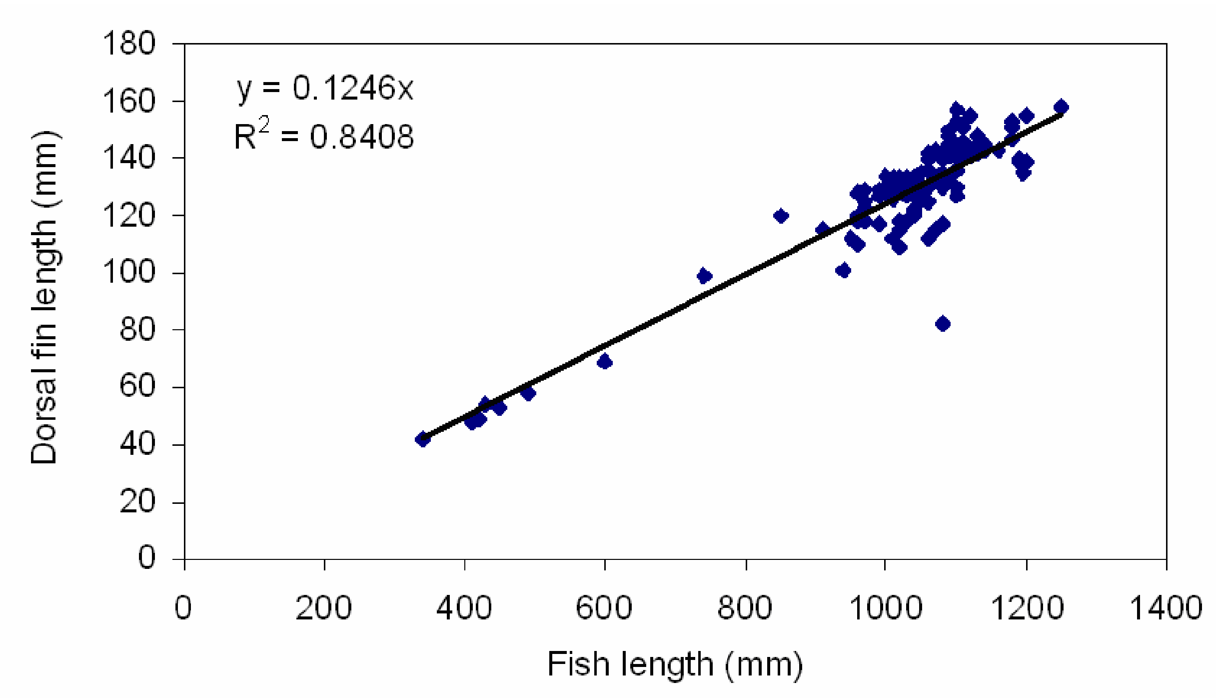

Figure 5.17 Relationship between the dorsal fin length and total length (TL) for black jewfish; n = 108

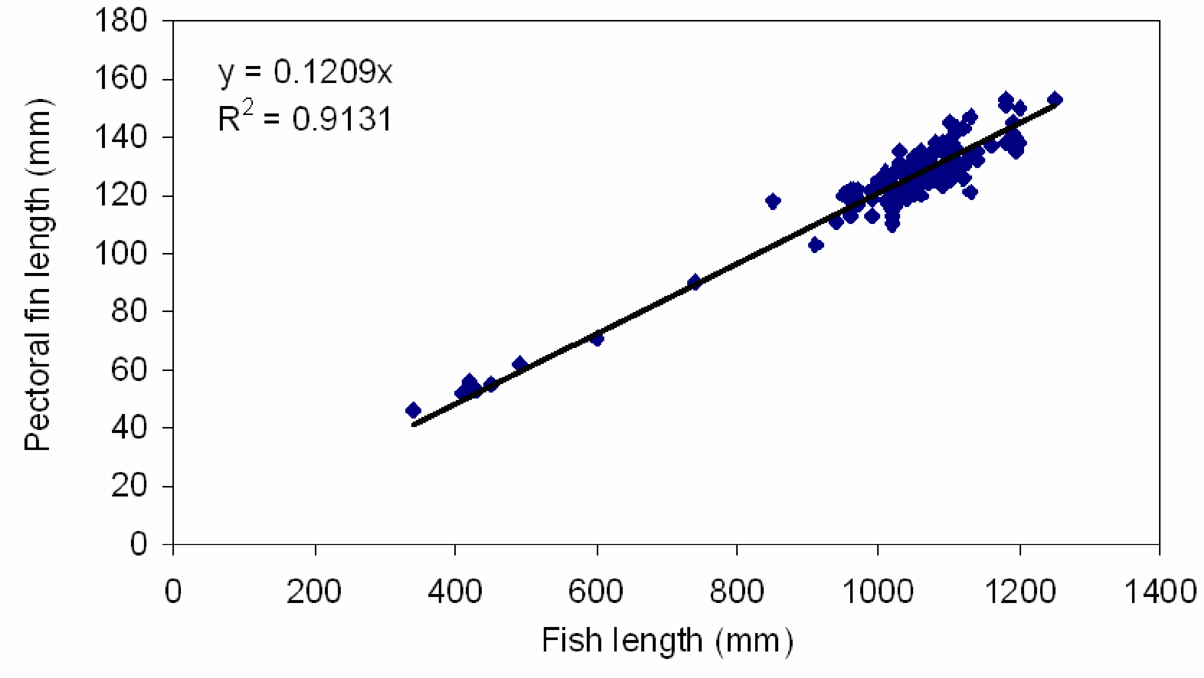

Figure 5.18 Relationship between the pectoral fin length and total length (TL) for black jewfish; n = 108

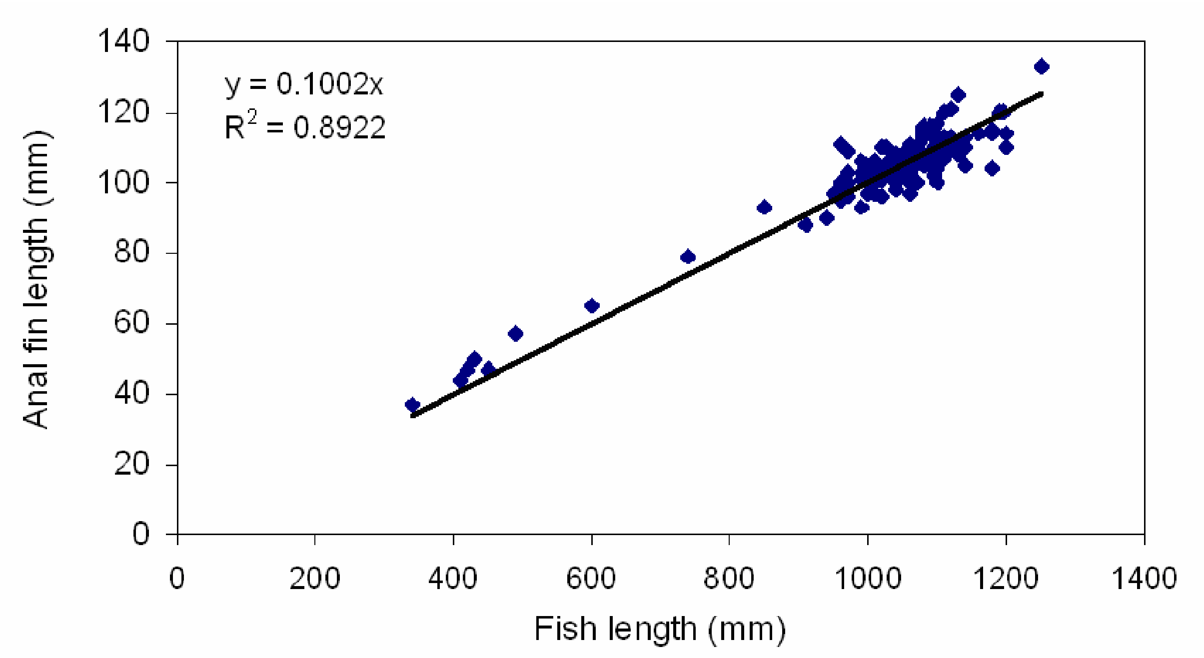

Figure 5.19 Relationship between the anal fin length and total length (TL) for black jewfish; n = 108

5.6 DISCUSSION

The combined harvest of black jewfish in the NT rose from 443 tonnes in 1995 to at least 667 tonnes in 2005 - an increase of 150%. During this time, the harvest by commercial fishers and fishing tour operators has increased by 580% and 650%, respectively. The indigenous catch is estimated at less than 1000 black jewfish per annum (i.e. approximately 1% of the total harvest; Henry and Lyle 2003).

The estimated recreational harvest of black jewfish decreased by almost 10% between 1996 and 2000, although this may be due to different survey methods adopted by Coleman (1998) and Coleman (2004). Despite the apparent decrease in recreational harvest during this period, the estimated catch by this sector in 2000 exceeded the commercial harvest by over 100 tonnes. Comparisons of the jewfish catch by each sector since that time are complicated by a lack of recreational and indigenous catch data.

The NT Motor Vehicle Registry provides an indicator of the potential increase in recreational fishing in recent years, with the number of boat trailers >5 m registered between 2000 and 2005 increasing by 219% (noting that not all vessels carried by these trailers will be used for fishing).

There was a strong correlation (r^2 = 0.96) between the length and weight of black jewfish (sexes pooled) harvested from NT waters between 2004 and 2006. Whilst the validity of the relationship could be improved (through more data on smaller [i.e. < 90 cm TL] fish), the existing data provides a starting point for the development of yield-per-recruit models for this species (at least in NT waters).

The high degree of correlation (r^2 = 0.91) between pectoral fin length and total length in black jewfish means that this structure is a suitable candidate for a size monitoring program for this species. It is envisaged that (after consultation and training) commercial fishers will remove the pectoral fin from each jewfish and freeze it until such time as the fin can be measured by NT Fisheries staff. Clearly, such a system would involve some extra work by commercial fishers, but the advantages (i.e. a greatly improved understanding of the size frequency of the stock) would far outweigh the disadvantages (i.e. a decrease in processing speed). Indeed, several commercial coastal line fishers have already indicated that they would be willing to participate in such a program if it were to be implemented. NT Fisheries will also examine the feasibility of rolling out the program to include FTOs and recreational fishing competitions.

6. REPRODUCTIVE BIOLOGY OF BLACK JEWFISH FROM NORTHERN TERRITORY COASTAL WATERS

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6.1 INTRODUCTION

Reproductive strategies of teleosts present great diversity that varies according to such factors as sexuality (which may range from strict gonochorism to simultaneous hermaphroditism) to specific features of gametogenesis (such as the duration of vitellogenesis) (Jalabert 2005). Despite this diversity of approaches, the underlying processes of oocyte development among gonochoric teleosts are uniform enough to allow comparisons of reproductive studies.

A significant characteristic of the life cycles of many Sciaenids is the seasonal aggregation of adult fish for spawning (e.g. Griffiths 1996, Norbis and Verocai 2005). Aggregations of Australia's largest tropical sciaenid, the black jewfish, have been reported at a number of locations in northern Australia extending from Central Queensland (Bowtell 1995) to northern Western Australia (Newman 1995). Despite the growing importance of black jewfish to many fishing sectors, little is known about the life-history of the species in Australian waters.

Fish aggregations are particularly vulnerable to targeted fishing (Turnbull and Samoilys 1997) and often warrant special regulatory measures to govern their use. Intensive fishing of spawning aggregations may have negative effects on the proportion of reproductively active fish with consequences for future fishery yields (Johannes et al. 1998). For example, the largest member of the family Sciaenidae, *Totoaba macdonaldi*, is now considered critically endangered (IUCN 2004) as a consequence of commercial and recreational fishing activity which targeted aggregations of this species (True et al. 1997).

A sound knowledge of the reproductive strategies employed by fish is vital to the development of management practices that ensure the protection of breeding stocks (Fowler et al. 1999). Understanding the reproductive traits of targeted species is required to determine appropriate legal size restrictions, to provide protection of vulnerable breeding aggregations and to aid in the understanding of the replenishment processes that are integral to the maintenance of local populations (McPherson 1997).

Establishing the spatial and temporal peaks of reproductive activity in northern Australia's black jewfish stocks is therefore a priority to ensure the sustainable use of this culturally and economically important species. In this paper we examine aspects of the reproductive biology of black jewfish off the NT. Specifically, we determine sex ratio, fecundity, and spawning patterns in relation to season and area.

6.2 OBJECTIVE

Establish the reproductive strategy of black jewfish inhabiting the coastal waters of the NT (Objective 3).

6.3 METHODS

6.3.1 Sampling

Between August 2004 and August 2006, up 70 fish per month were sampled from commercial catches on an ad hoc basis (i.e. when weather and logistical factors allowed). They were caught using handlines at Channel Point, Caution Point and Chambers Bay from depths ranging from 5 to 20 m. No fish were collected in January or February 2005 due to staff shortages.

The fish were sampled either at sea shortly after capture (when fisheries staff were on board the vessel) or at the DPIFM laboratories within three days of being caught (when staff were not on board). All fish were fresh, whole, and had been stored until sampling in a brine-well containing an ice/water slurry. The fish were later processed by the commercial fisher.

Whole ovaries from each female fish were placed in an air-tight plastic bag and stored on ice. Back at the laboratory, the weight of the individual lobes were recorded to the nearest gram and a 2-3 cm section of one lobe was preserved in 10% phosphate buffered formalin, and then processed (as per Phelan 2002) for histological examination. Once preserved, the tissues were embedded in paraffin wax, microtomed in 5 μm (micron) sections and stained using haematoxylin and eosin.

The diameter of 100 oocytes (sectioned through the nucleus) was determined for each female (using an eyepiece graticule) and the mean oocyte diameter was calculated.

6.3.2 Analysis

The length-weight relationship for black jewfish was calculated using the equation:

$$Y = ax^b$$

where y = fish weight (kg), x = total length (cm), and a and b are constants.

Ovaries were assessed for reproductive activity using two different methods – macro/microscopic examination and the gonadosomatic index (GSI). Macroscopic and microscopic examinations were used to determine the stage of the gonad development. A reproductive stage was assigned to each gonad according to the schedule based primarily on the most advanced oocyte seen (Table 6.1 and 6.2). The GSI was calculated as follows:

$$GSI = (\text{gonad weight (g)} \times 100) \div \text{whole weight (g)}$$

Size at first maturity and size at 50% maturity (L_{50}) were also calculated. They were defined as the sizes (TL) at which the smallest fish sampled and 50% of all fish sampled were mature (i.e. stage F3+), respectively.

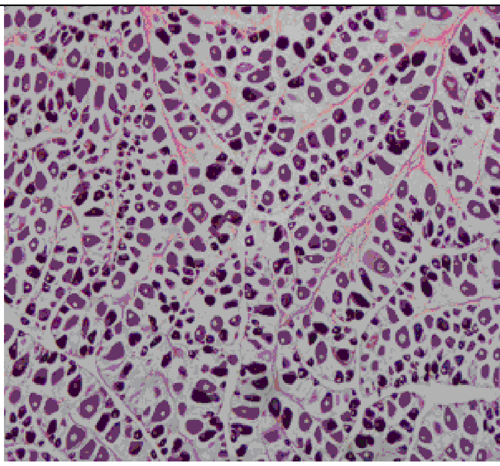
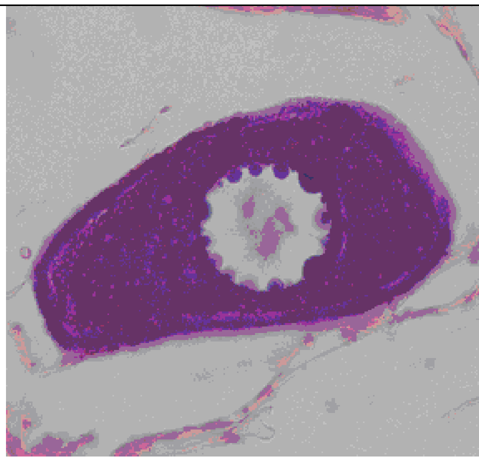
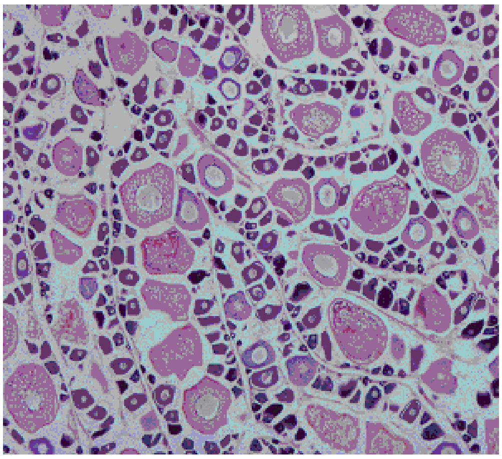
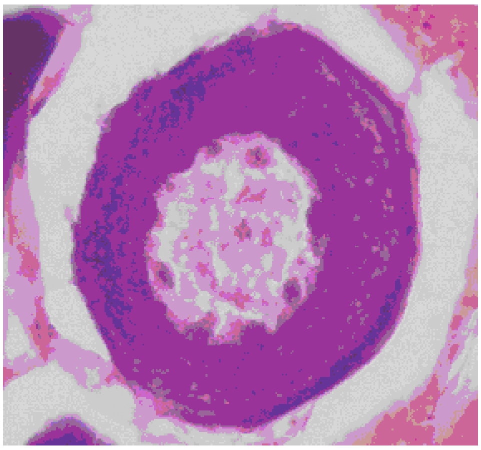
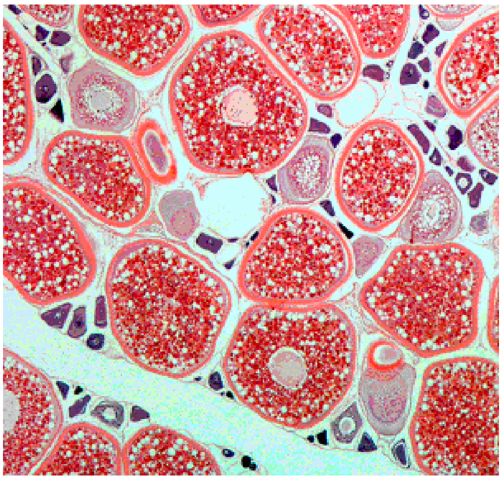
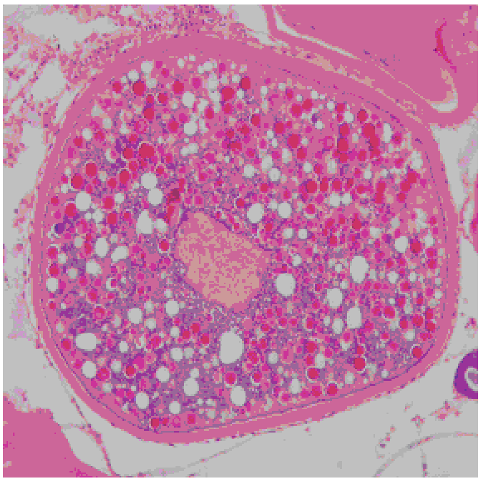
Table 6.1 Macroscopic ovary staging schedule for black jewfish

Stage		Key criteria
F1	Immature	• Ovary small, translucent pale pink. • Oocytes not visible.
F2	Developing	• Ovary increased in size. • Ovary translucent pale pink. • Few oocytes just visible.
F3/F4	Developed	• Ovary further increased in size. • Ovary semi-translucent, speckled or granular in appearance. • Gonad wall thin. • Individual eggs visible both externally and when cut.
F5	Spawning	• Ovary varying from enlarged to flaccid. • Ovary semi-translucent, speckled or granular in appearance with prominent blood vessels. • Gonad wall thin. • Hydrated oocytes visible, sometimes in lumen.
F6	Spent	• Ovary flat and flaccid, but with time from spawning become firmer and rounder. • Ovary semi-translucent, speckled or granular in appearance, with prominent blood vessels. • Gonad wall thin, but contracts and thickens with time from spawning. • Lumen prominent, brown bodies and blood clots may be present. • Few oocytes visible.
F7	Resting	• Difficult to distinguish macroscopically. • Ovary flat and flaccid, but becomes firmer and rounder with time from spawning. • Gonad wall becomes thicker as it contracts with time from spawning. • Ovarian tissue developing, but few oocytes visible.

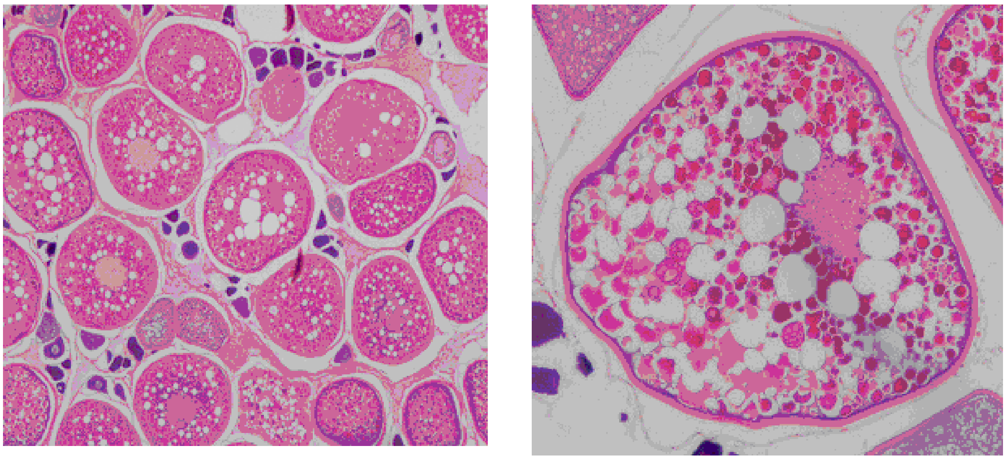
Table 6.2 Microscopic ovary staging schedule for black jewfish

Stage		Most advanced oocyte	Other key creteria
F1	Immature	Chromatin nucleolar or perinucleolar	Thin gonad wall; Brown bodies not present; Compact, well packed lamellae; May have atretic cortical alveoli oocytes.
F2	Developing	Cortical alveoli (yolk vesicle)	May have atretic oocytes; May also have post-ovulatory follicles and brown bodies.
F3	Developed	Yolk globule	May have atretic oocytes; May also possess brown bodies.
F4	Pre-spawning	Migratory nucleus	Ovary appears disorganised; Brown bodies may be present; May have post-ovulatory follicles if fish has spawned already.
F5	Spawning	Hydrated	Ovary appears disorganised; Post-ovulatory follicles, brown bodies and atretic oocytes may be present.
F6	Spent	Atretic vitellogenic	Lamellae disrupted and disorganised; Vacuolated in late spent stage; Brown bodies generally present.
F7	Resting	Chromatin nucleolar or perinucleolar	Thick gonad wall; Brown bodies common but not always present; Lamellae not compact, often vacuolated.

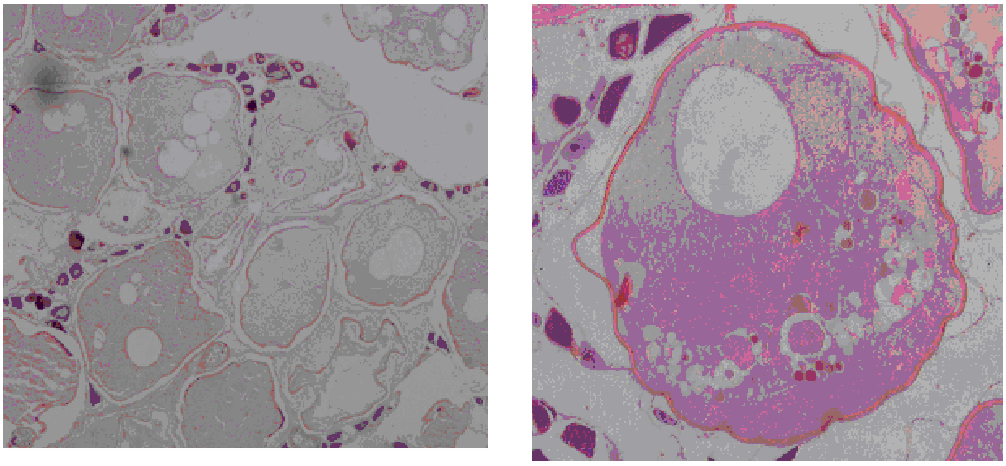
Table 6.3 Images of microscopic ovary staging schedule for black jewfish

Stage	Microscopic view	Microscopic close-up
F1 Immature		
F2 Developing		
F3 Developed		

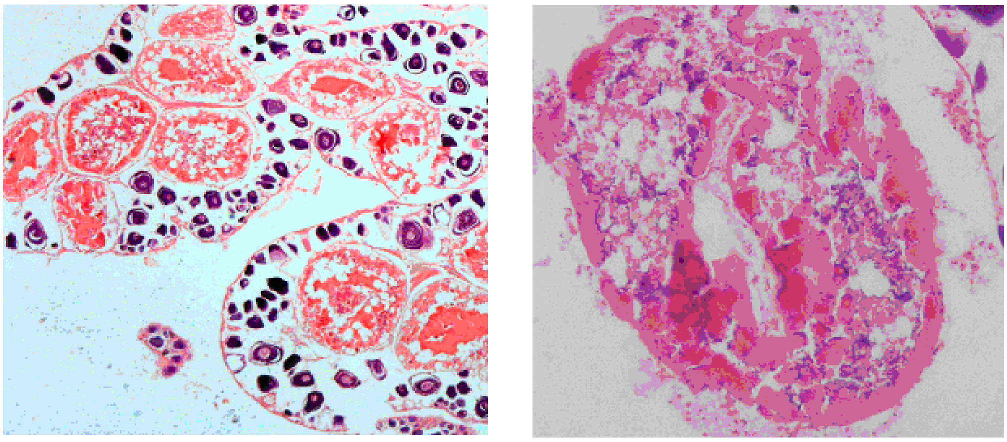
F4 Pre-spawning



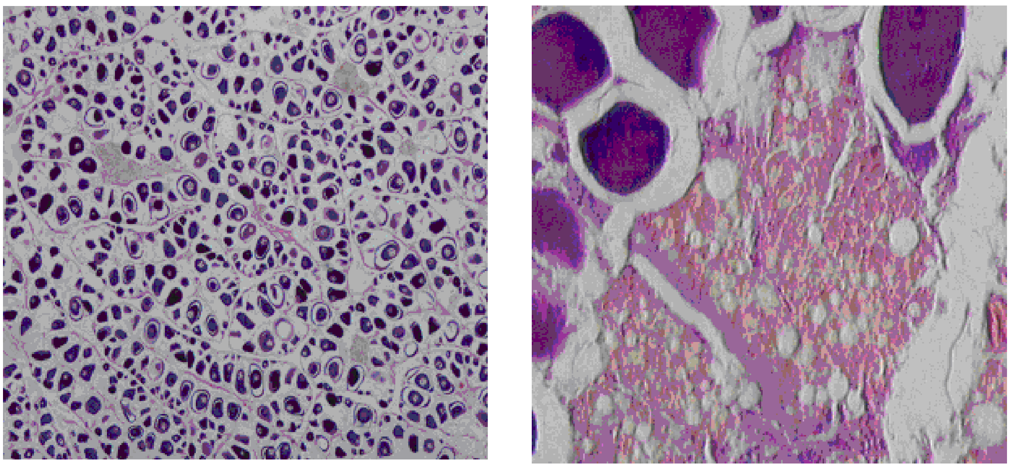
F5 Spawning



F6 Spent



R7 Resting



6.4 RESULTS

A total of 1500 black jewfish were measured, weighed and sampled between August 2004 and August 2006 (Figure 6.1). Specimens ranged in size from 22 cm to 139 cm TL (see Figure 5.14), and weighed from 0.5 kg to 22.6 kg. A sub-set of 505 females was selected for histological examination (Figure 6.2).

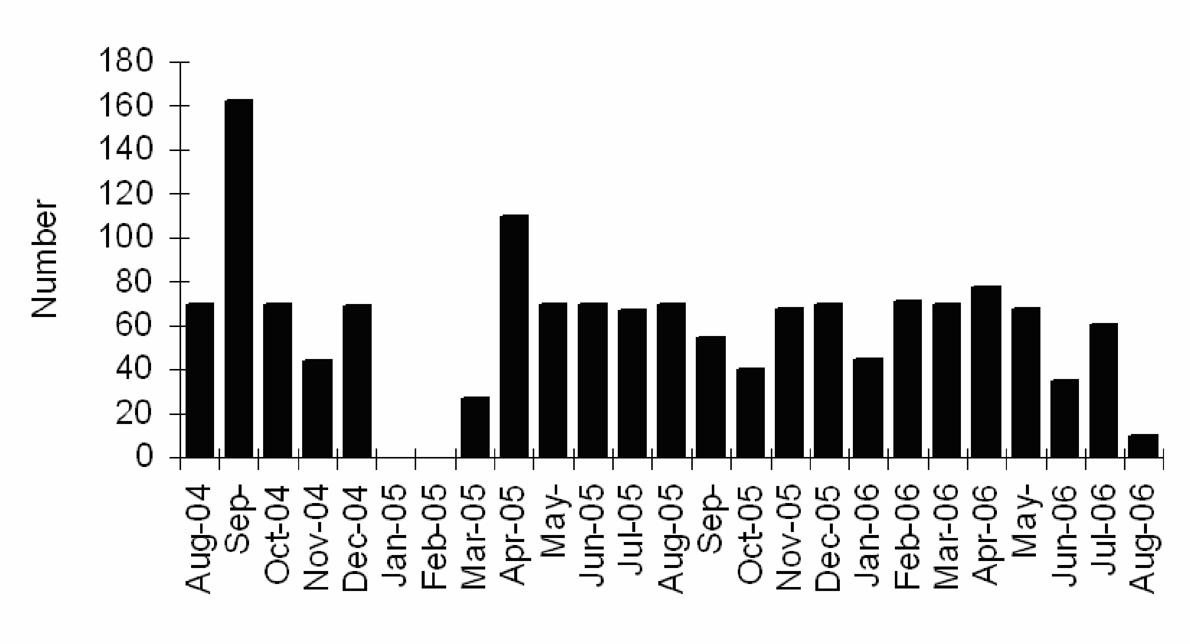


Figure 6.1 The number of black jewfish sampled each month (pooled across years and sites) between August 2004 and August 2006 for the reproduction study

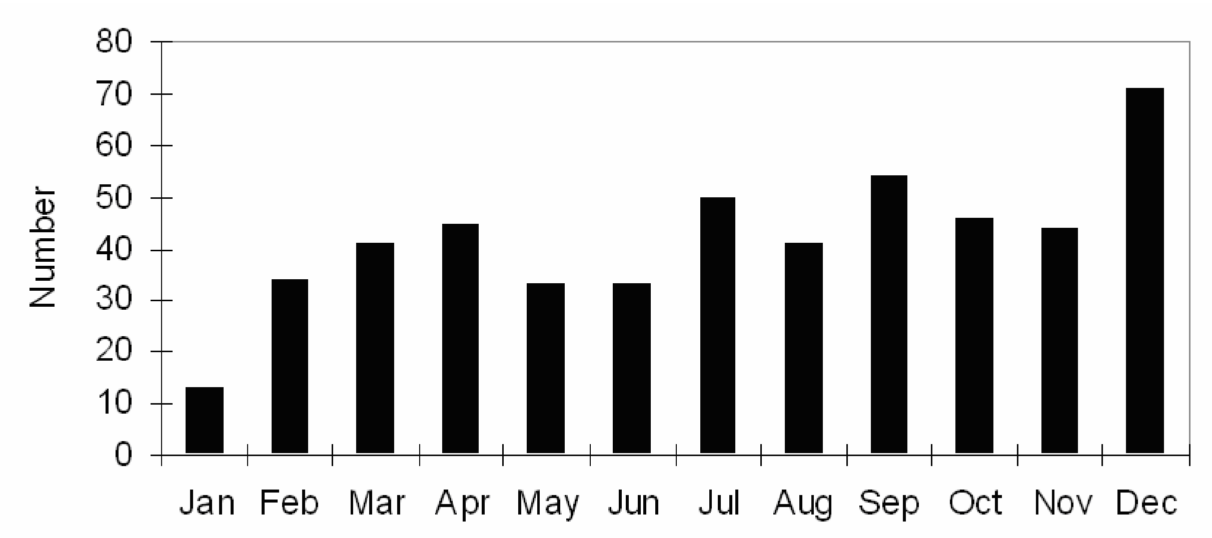


Figure 6.2 Number of black jewfish ovaries collected each month (pooled across years and sites) between August 2004 and August 2006 that were examined histologically; n = 505

6.4.1 Size at maturity

Size at sexual maturity (L_{50}) of female black jewfish was estimated at 89.21±1.74 cm TL (see Figure 6.3). This equates to an estimated age at maturity of 2^+ years (the using age-length curve - Figure 7.6). The smallest sexually mature female fish encountered in the collection was 85 cm TL, while the largest immature fish was 100 cm TL.

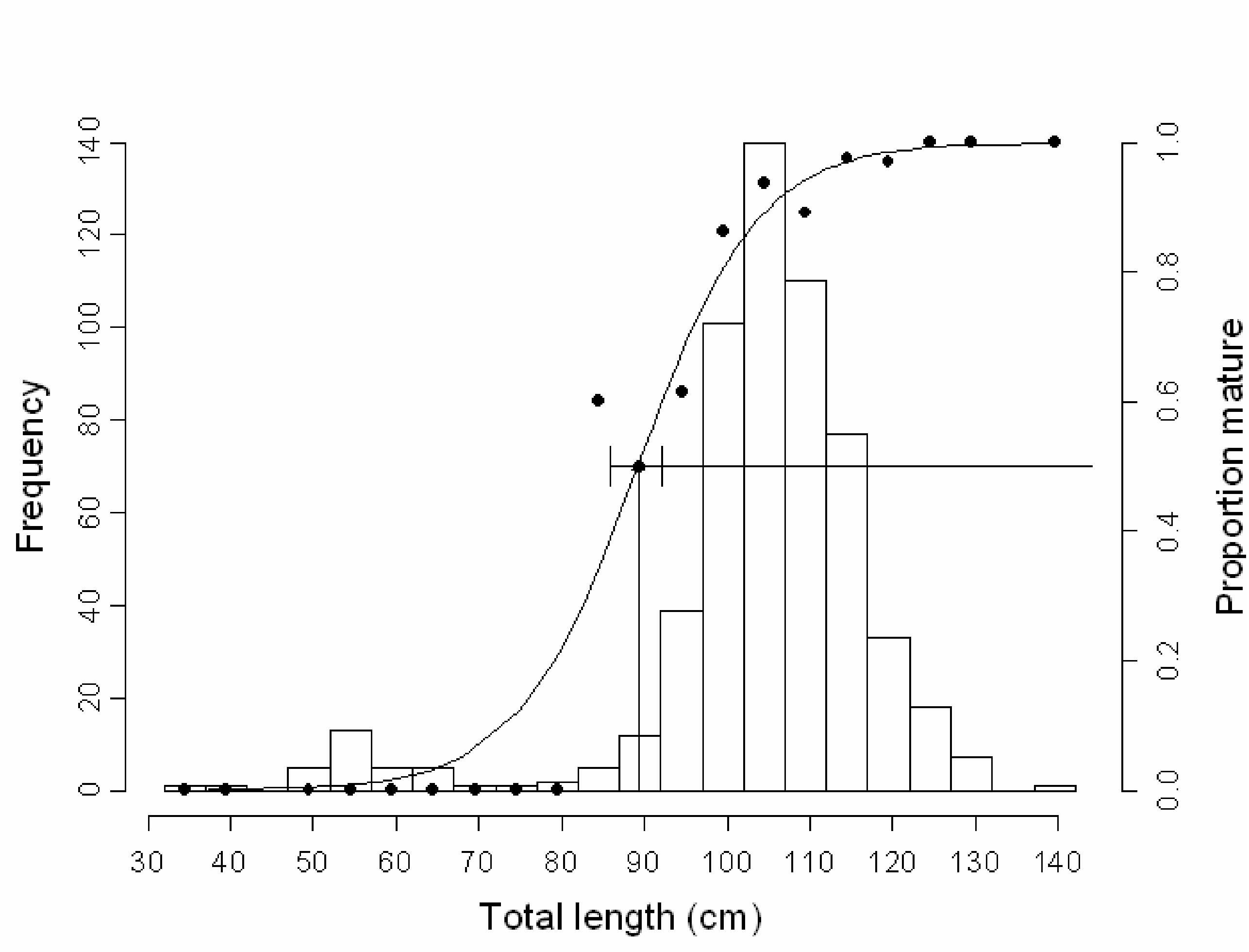


Figure 6.3 Estimated size of maturity (L_{50}) of female black jewfish with 95 % confidence interval based on 1000 bootstrap samples. S+ function code used to estimate size at maturity courtesy of John McKinlay, WA Fisheries

6.4.2 Time of spawning

Modes in the ovarian development of black jewfish are traceable. The number of F2 'developing' ovaries observed in the monthly collections peaked in July (Figure 6.4), with the transition to F3 'developed', F4 'pre-spawning' and F5 'spawning' occurring though August to December (Figures 6.5 and 6.6). The frequency of F6 'spent' ovaries observed was greatest in February (Figure 6.7), while F7 'resting' ovaries were most frequently observed between March and July (Figure 6.8).

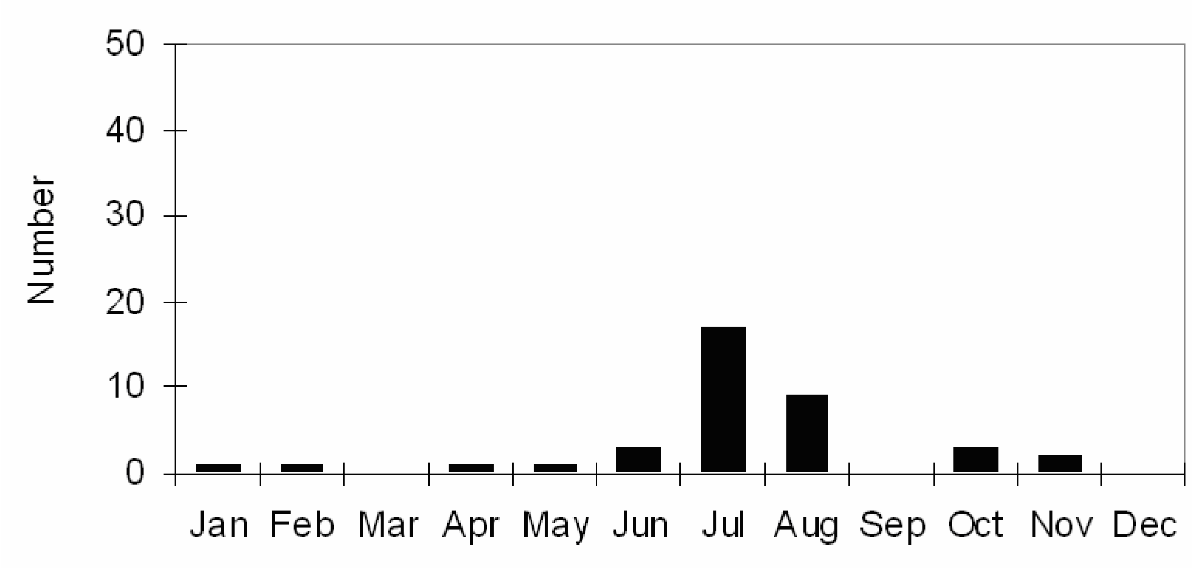


Figure 6.4 Monthly frequency of F2 “developing” ovaries in black jewfish

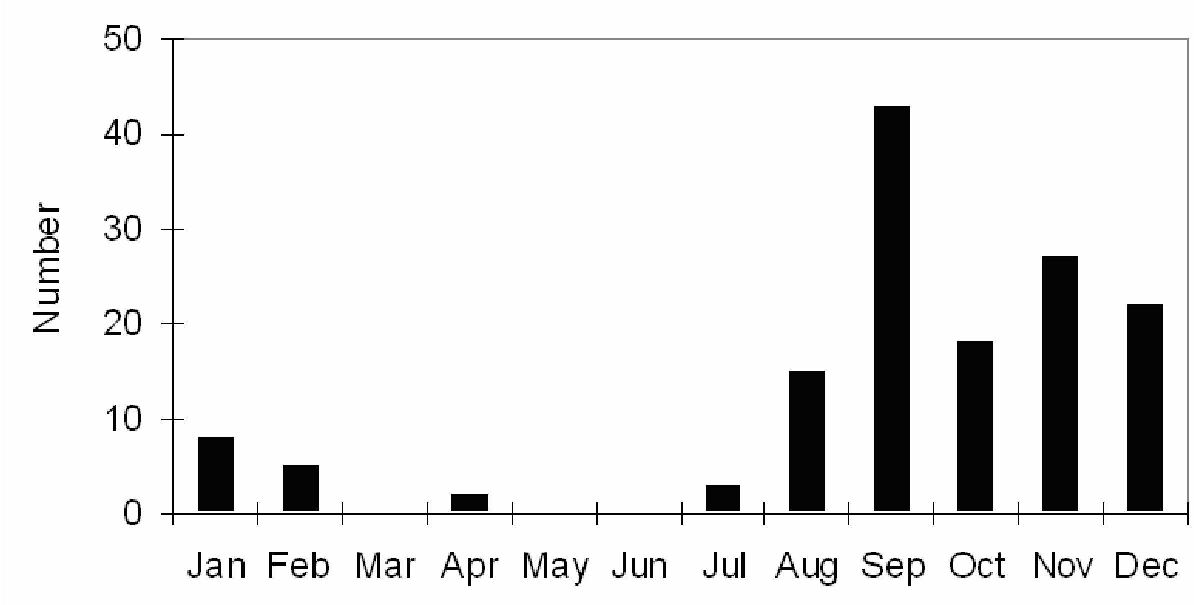


Figure 6.5 Monthly frequency of F3 “developed” and F4 “pre-spawning” ovaries in black jewfish

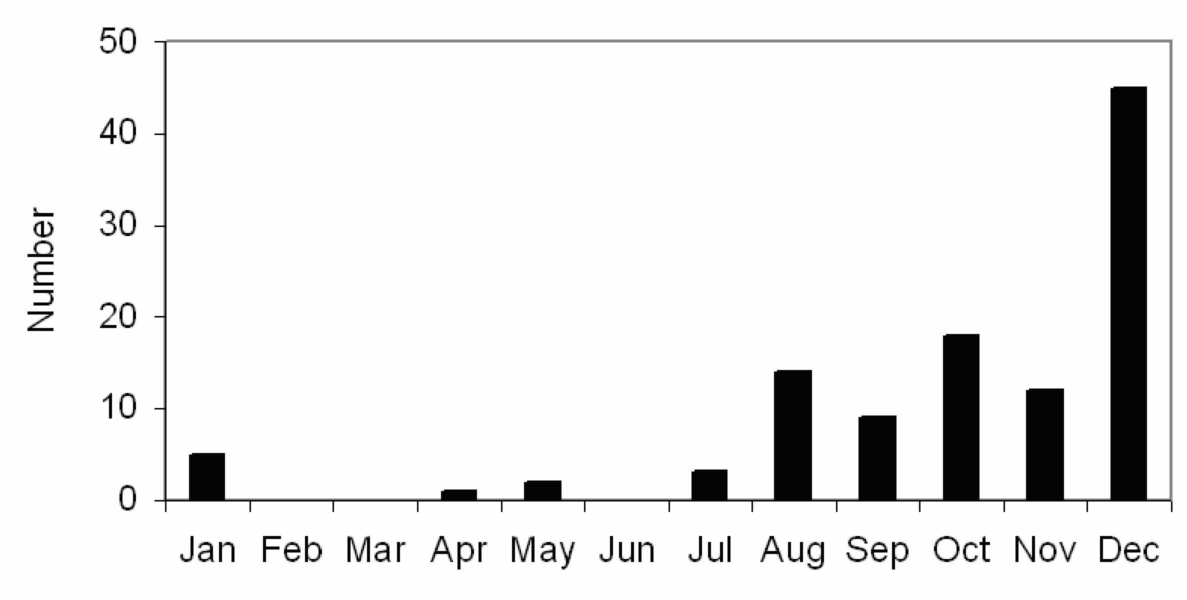


Figure 6.6 Monthly frequency of F5 “spawning” ovaries in black jewfish

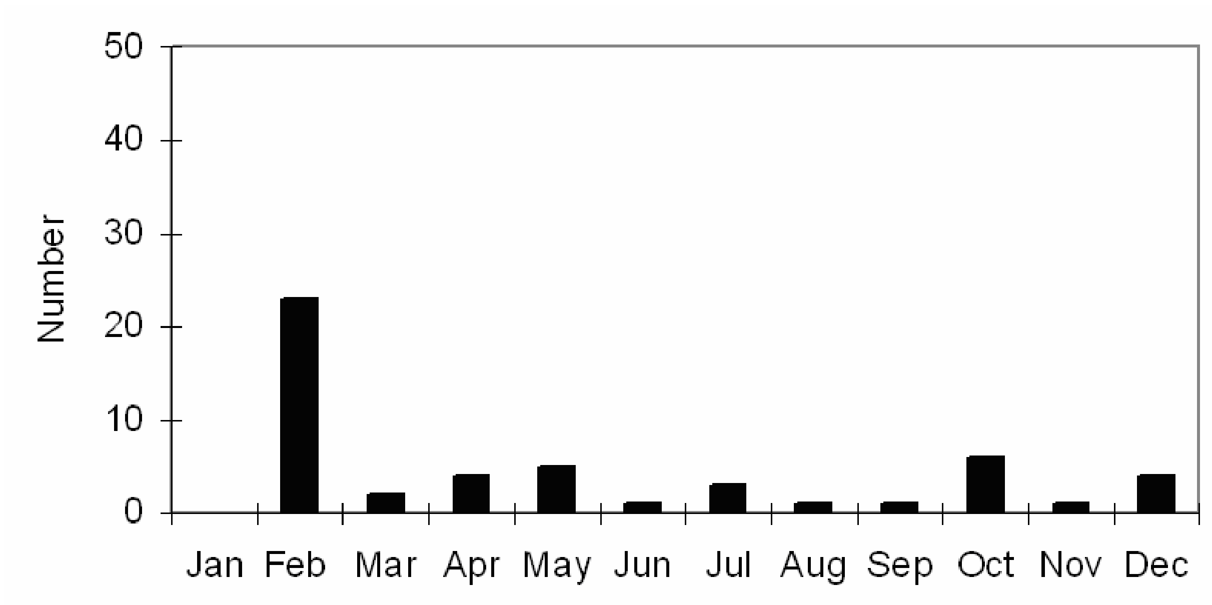


Figure 6.7 Monthly frequency of F6 “spent” ovaries in black jewfish

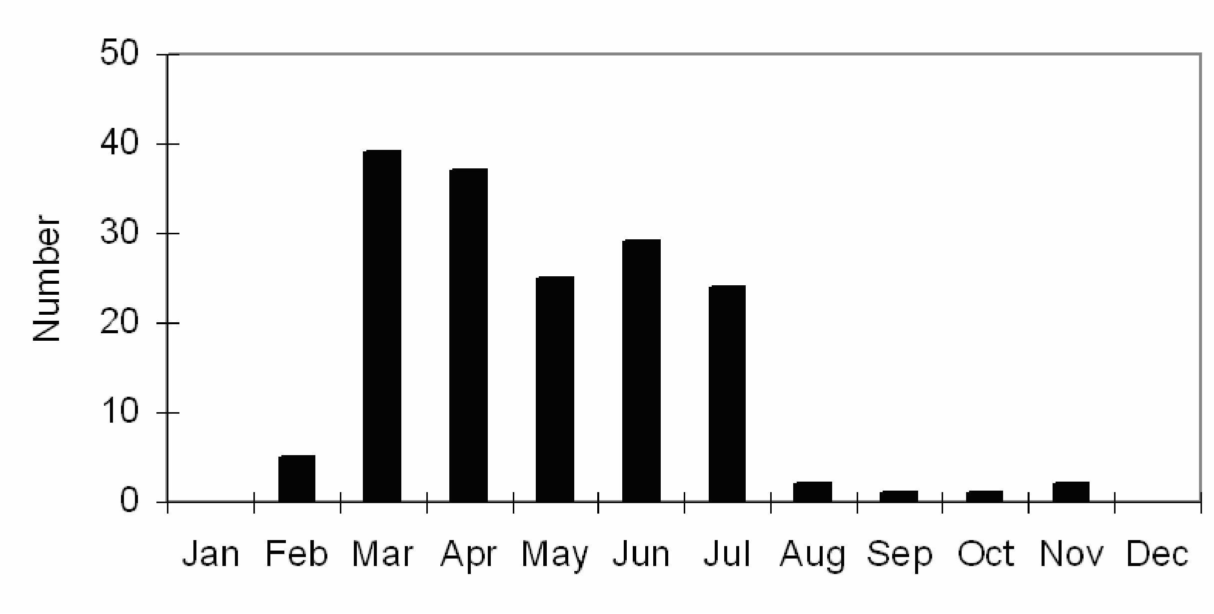


Figure 6.8 Monthly frequency of F7 “resting” ovaries in black jewfish

The results of histological analysis were consistent with the GSI data, although the later suggested that spawning may extend though to January (Figure 6.9). The GSI shows a general increase in ovarian development from July with a peak in December and January where females had a mean GSI value greater than 2. Mean oocyte size increased from July, peaked (at around 450 µm) in September and declined post January (Figure 6.10).

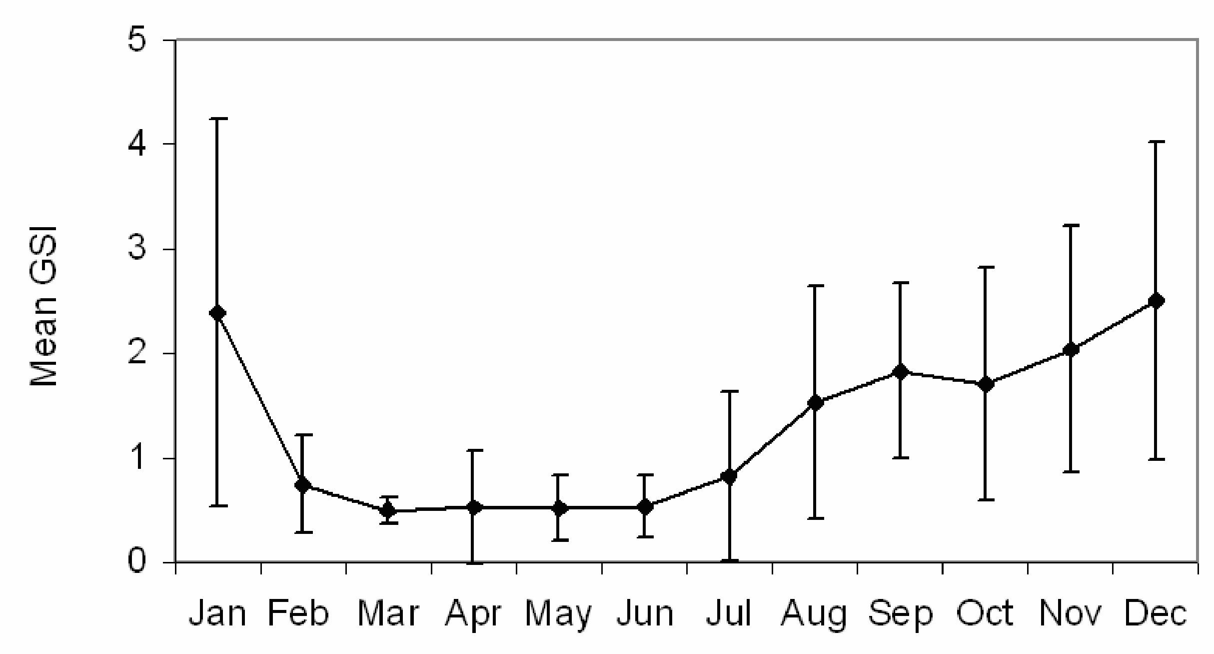


Figure 6.9 Mean (± standard deviation) monthly GSI for female black jewfish greater than 80 cm TL; n = 529

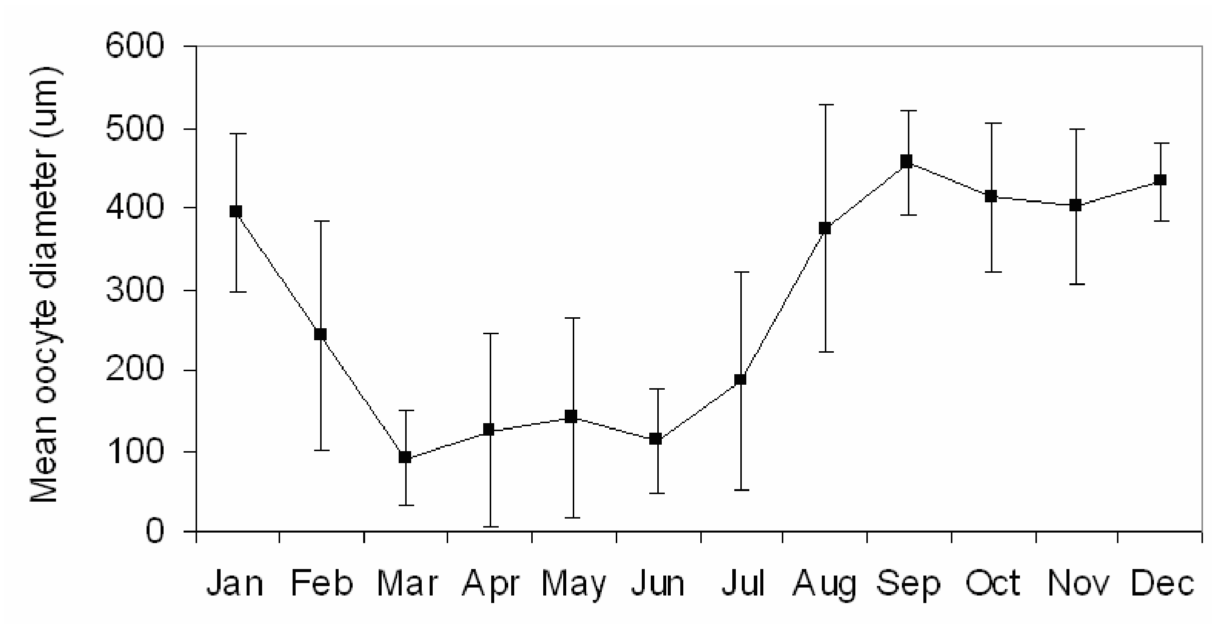


Figure 6.10 Mean (± standard deviation) monthly oocyte size of female black jewfish; n = 505

6.5 DISCUSSION

This study established a size at 50% maturity (L_{50}) of 89.21±1.74 cm TL for female black jewfish from NT waters. This represents a significant departure from the L_{50} estimate of 97.8 cm TL for female black jewfish (n = 157) from northern Queensland (McPherson 1997). Highlighting the scale of the difference, McPherson (1997) observed a minimum size of maturity (92 cm TL) which is greater than the L_{50} estimate for conspecifics in the NT.

Phelan (2002) reported a minimum size of maturity of 79 cm TL for female black jewfish (n = 64) sampled from the northern Cape York Peninsula, Queensland. Whilst that author was unable to develop an estimate of the L_{50} (due to the limited number of mature gonads observed), the minimum size at maturity of fish from this Peninsula site was similar to that reported by Rao (1963) for conspecifics from north-western coast of India. Rao (1963) reported that 10% of black jewfish were mature at 75-79 cm TL, 50% were mature at 80-84 cm TL and 100% were mature at 90-94 cm TL.

Peak reproductive activity of black jewfish in the coastal waters of the NT occurs during a single, extended season that extends from August to January. Spawning activity appears to peak in December, with F6 'spent' ovaries dominating in February and F7 'resting' ovaries most common between March and July. The single, protracted season of reproductive activity is consistent with the findings of Rao (1963). He concluded black jewfish in the waters of north-west India spawn between June and August.

Whilst the peak in reproductive activity of black jewfish in the coastal waters of both the NT (August to January) and north-west India (June to August) do not coincide on the Gregorian calendar year, they do coincide in terms of the weather cycle. Spawning in both areas occurs during the summer monsoons which brings elevated water temperatures, significant rainfall and river runoff, and high turbidity in coastal waters.

Both McPherson (1997) and Phelan (2002) were unable to determine the period of peak reproductive activity of black jewfish in the waters off Queensland. An insufficient number of mature fish were available in Phelan's (2002) study to establish the period of spawning through histology or from the gonadosomatic index data, yet the traditional owners of the area, who eat the eggs of many fish, recall ripe eggs were readily available during previous aggregations. From this information, Phelan (2002) thought it likely that in northern Cape York, gonadal development may coincide with the annual fish aggregation period of April to September.

The period of April to September that Phelan (2002) suggests for the spawning of Cape York black jewfish follows the end of the monsoon period in the area. By contrast, NT jewfish appear to be most reproductively active through the monsoon season. Differences in the peak reproductive period of sciaenid fishes from widely separated locations are well known, even within the one species. For example, Dhawan (1971) reported 'stage IV' female black jewfish off Goa four months earlier in the year than reported by Rao (1963) for fish sourced from the more northerly waters off Mumbai. The differences highlighted above demonstrate the importance of repeating biological studies on spatially separated aggregations.

7. AGE AND GROWTH OF BLACK JEWFISH FROM NORTHERN TERRITORY COASTAL WATERS

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7.1 INTRODUCTION

Knowledge of the age structure, growth and developmental rates of fish populations is fundamental to evaluating the effects of fishing (Sergio 2007). Fortunately, fish retain a record of growth in several anatomical structures; otoliths, scales and bone. Among these structures, otoliths provide a record that is often the clearest and of the highest temporal resolution (Chambers and Miller 1995).

Otoliths are acellular structures, that grow through accretion (i.e. the addition of external layers - similar to molluscan shells), rather than ossification, i.e. the calcification of structures – bone growth (Secor et al. 1995). Because of their unique growth process, otoliths are not subject to resorption and remodelling as are other hard parts (Secor et al. 1995). Black jewfish have relatively large sagittae, which is typical of most Sciaenids and other non-ostariophysean fishes for which communication is important (Popper and Jones 1985).

The growth of the otolith continues throughout a fish's lifetime, with the fish continuously depositing alternating translucent and opaque bands that allow age determination once the periodicity of their formation has been determined (Morales-Nin and Moranta 1997). The quantification of these bands remains a complex task and the accuracy of the subsequent age estimate dependent on the researcher's skills (Campana 2001).

Three pairs of otoliths occur in teleosts and they each differ in size, shape and ultrastructure. These pairs of otoliths are most commonly termed the lapillus, astersci and sagittae. Age studies traditionally utilise the largest otolith, which are the sagitta in non-ostariophysean fishes, as they contain the widest increments, thereby providing the clearest resolution of microstructural features (Secor et al. 1991).

Although three ageing studies have already examined black jewfish (Rao 1961 and 1966, Bibby and McPherson 1997), it is important to examine fish sourced from the NT. Variations in the age/size frequency of fish stocks are often observed in fish species from marine and freshwater environments due to variations related to water temperature (Neuheimer and Taggart 2007) and river discharge (Jonsson et al. 1999).

7.2 OBJECTIVE

Provide age estimates which contribute to the description of the biological nature of the black jewfish aggregations (Objective 3).

7.3 METHODS

7.3.1 Sampling

A total of 1500 black jewfish from the NT Coastal Line Fishery were sampled on an ad hoc basis (i.e. when weather and logistical factors allowed) between August 2004 and August 2006. The fish were caught at several sites near Darwin, from depths between 5 and 20 m. Biological information such as the total length (TL), otolith mass and sex of each fish was recorded as was the date and area of capture. Sagittal otoliths were removed from the neurocranium auditory capsule of each fish and stored dry in numbered envelopes.

Otolith pairs from a sub-sample of 1005 black jewfish were sent to the Central Ageing Facility (CAF), based at Primary Industries Research Victoria (PIRVic) Queenscliff Centre. Details of batches of otolith pairs sent to the CAF are shown in Table 7.1.

Specimens in this sub-sample were caught at one of five locations: Chambers Bay, Charles Point, Channel Point, Caution Point, Bathurst Island and Lorna Shoal.

Table 7.1 Batch registration details of black jewfish otoliths

CAF batch number	Date of registration	Number of fish
901-001	July 2006	60
901-002	August 2006	938
902-003	November 2006	7
Total		**1005**

7.3.2 Otolith mass

Left and right otolith mass was recorded to the nearest milligram. Otolith mass is a useful diagnostic tool for assessing potential errors in age estimates. Otoliths grow linearly in length and width with increasing fish size, and grow linearly in thickness and mass with increasing fish age. In long-lived species, plots of otolith mass against estimated age show an increasing slope at older ages if the ages have been underestimated. Also, large variation in the relationship may indicate a lack of precision in the samples.

7.3.3 Otolith preparation

Otolith preparation was undertaken by Corey Green of PIRVic. To determine the position of the first ‘presumed annual’ increment, a sub-sample of ten otoliths from small fish was selected for daily age estimation. One otolith from each pair was embedded and transversely sectioned. The section was attached to a heated glass slide using clear thermoplastic glue (Crystalbond™), and using 1200 grit emery paper the otolith was ground down to the primordium (see Figure 7.1) to obtain a transverse section <0.07 mm thick. Between grindings the otolith was checked using a compound microscope until finer, presumably daily growth rings, were visible throughout the section. Otoliths were viewed at up to 100x magnification to examine the presumed daily growth structure.

One otolith from each pair belonging to fish in the major collection was then embedded, transversely sectioned and mounted (Morison et al. 1998). To embed the otoliths, a thin layer of clear polyester casting resin was poured onto the base of a silicon mould and left to partially cure. Otoliths were arranged in two rows of three on the resin. Resin blocks were labelled and coated with another layer of resin and then oven-cured at 55°C for 24 hours.

Otolith sections were cut using a Gemmasta™ lapidary saw fitted with a diamond impregnated blade. From each row of otoliths, four sections were taken (approximately 350 μm in thickness). This was to ensure that the primordium of each otolith was included. Sections were cleaned using alcohol and stored in vials. For identification, each vial contained a sample identification label consisting of batch and fish number.

Sections were mounted on a small amount of resin on a glass slide (50 x 75 mm) with the resin and the identification label placed at the top of the slide. Once the resin had semi-cured, further resin was applied to the preparations and coverslips applied. The slides were then oven-cured at 30˚C for 3 hours.

7.3.4 Reading protocol

Otolith readings were undertaken by Corey Green. An attempt was made to count "daily" increments to the first annual increment (identified as a translucent zone bordered by an opaque zone). If the daily increment count was approximately similar to the time difference between spawning date and the annual increment formation date, then the first annual increment was successfully located.

Annual age estimation assumes:

- increments counted are formed on an annual basis; and
- one translucent zone and subsequent opaque zone represents one annual growth increment.

For annual age estimation, otoliths were viewed under a dissecting microscope to allow the reader to become familiar with the morphological structure unique to the species. Sections were examined using transmitted light under a Leitz Wild M3C binocular microscope at 6.3x magnification. Higher magnification was sometimes required for the examination of the fine growth increments near the otolith edge from larger, presumably older fish. Increments were counted along each transect from the primordium to the ventral edge of the otolith adjacent to the sulcus (Figure 7.1).

To avoid potential bias, all counts were made without knowledge of fish size or otolith mass. A customised image analysis system (Morison et al. 1998) was used to mark and count increments along the ageing transect and to measure the distance from the primordium to each of the increments.

Increment counts were converted to an age class to enable the sample to be assigned to an appropriate cohort. Assigning an age class relies on increment count, the amount of translucent material on the otolith margin, classified as 'wide' or 'narrow' and a nominated birthday (July 1). Given that the spawning season extends from August to January (see Chapter 6) and increment formation was thought to occur between late winter and spring (as with other teleosts from the Southern Hemisphere), the criteria established to convert increment count to age class are shown in Table 7.2.

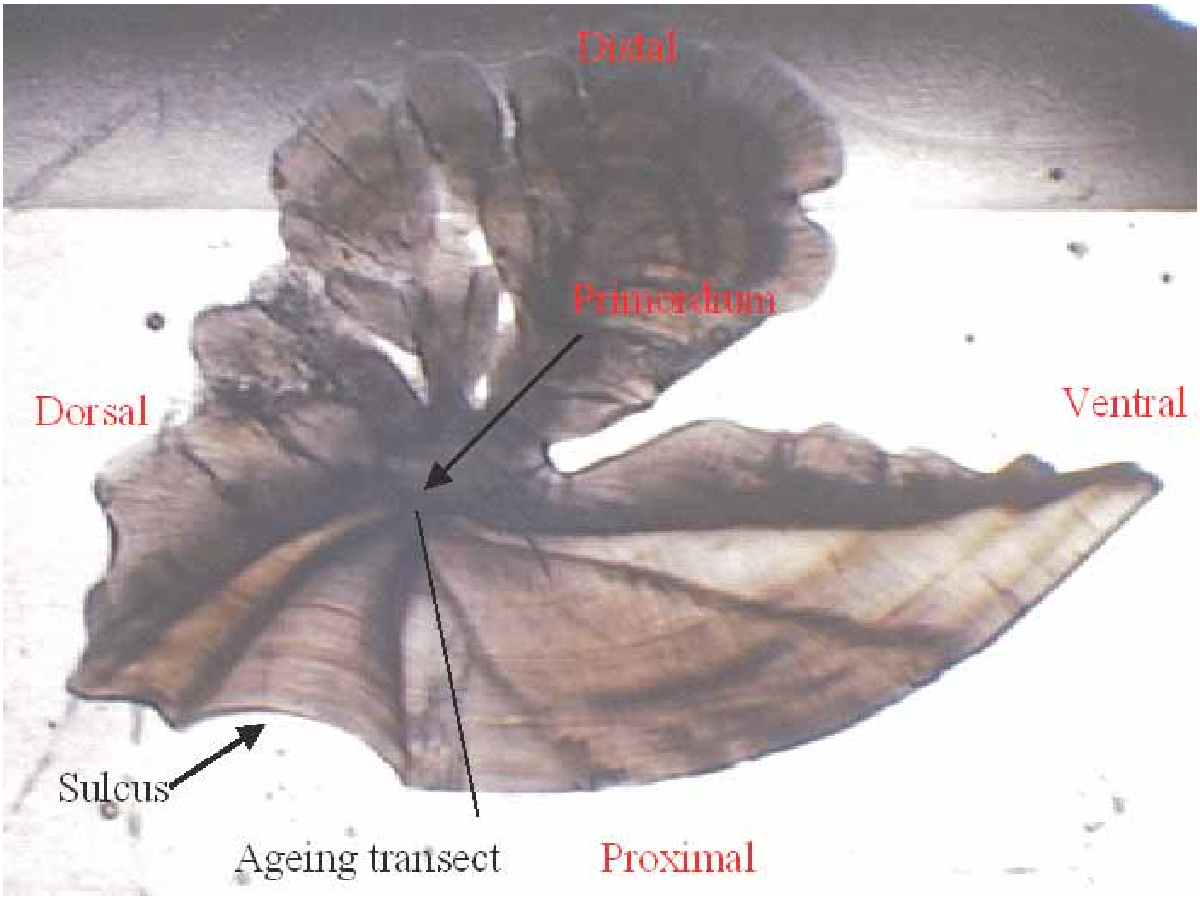

Figure 7.1 Transverse section of black jewfish sagittal otolith viewed with transmitted light

Table 7.2 Criteria used to convert increment count to age class in black jewfish

Date of capture	Wide translucent edge	Narrow translucent edge
Jan. 1 to Jun. 30	Age class = Increment count	Age class = Increment count -1
Jul. 1 to Dec. 30	Age class = Increment count +1	Age class = Increment count

7.3.5 Comparison of age estimates

Twenty five percent of all otolith sections were read a second time by the primary reader. The index of average percent error (IAPE) was calculated, and the distributions of the differences between repeated readings were also inspected as another indicator of ageing errors, and of any bias between readings.

Repeated readings of the same otoliths provide a measure of intra-reader variability. They do not validate the assigned ages but provide an indication of the size of the error to be expected with a set of age estimates, due to variation in otolith interpretation. IAPE is a common method for quantifying this variation (Beamish and Fournier 1981) and is calculated by the equation:

$$APE = \frac{100}{N} \sum_{j=1}^{N} \left[\frac{1}{R} \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j} \right]$$

where N = number of fish aged

R = number of times fish are aged

X_{ij} = i_{th} determination for the j_{th} fish

X_j = the average estimated age of the j_{th} fish.

The index has the property that differences in age estimates for younger fish will contribute more to the final value than will the same absolute error for older fish (Anderson 1992).

To establish confidence intervals to these estimates of precision, a bootstrap technique was employed on the individual error estimates following methods described by Efron and Tibshirani (1993). Five thousand samples of error estimates (each the same size as the original) were randomly taken with replacement from the repeat readings, and a new IAPE was calculated for each. The mean of these replicate IAPEs is the mean bootstrap IAPE and the standard deviation is the standard error of the mean. The bootstrap procedure exaggerates any bias present in the original estimate, so it is necessary to correct for this by adding the difference between the original statistic and the bootstrap mean, to the original estimate. The bias-corrected bootstrapped IAPE is thus calculated as:

Bias-corrected IAPE = Original IAPE + (original IAPE- mean bootstrap IAPE)

The 95% confidence interval was calculated as:

95 % C.I. = Bias-corrected IAPE ± (1.96* standard deviation of bootstrap IAPE)

Regression analysis is used to test differences between readings to determine whether significant biases are present.

7.3.6 Data analysis

The relationship between biological attributes was used to determine whether any inconsistencies or outliers were present within the data. Age estimates were combined with fish length and otolith mass data. Length- and age-frequency distributions were produced for each independent area.

Von Bertalanffy growth curves were fitted to length-at-age data using the non-linear least squares method. The growth equations were determined using the equation:

$$L(t) = L_\infty (1 - e^{-k(t-t_0)})$$

where L_∞ = the mean asymptotic TL (mm)

k = the growth constant

t_o = the theoretical age at length zero.

7.4 RESULTS

Total length-otolith mass plot for black jewfish collected during 2004–06 is given in Figure 7.2. Fewer than ten data points were removed from the dataset as they did not correlate with the majority of data due to incorrect fish length or otolith weight. These outlying data were not used in subsequent analysis.

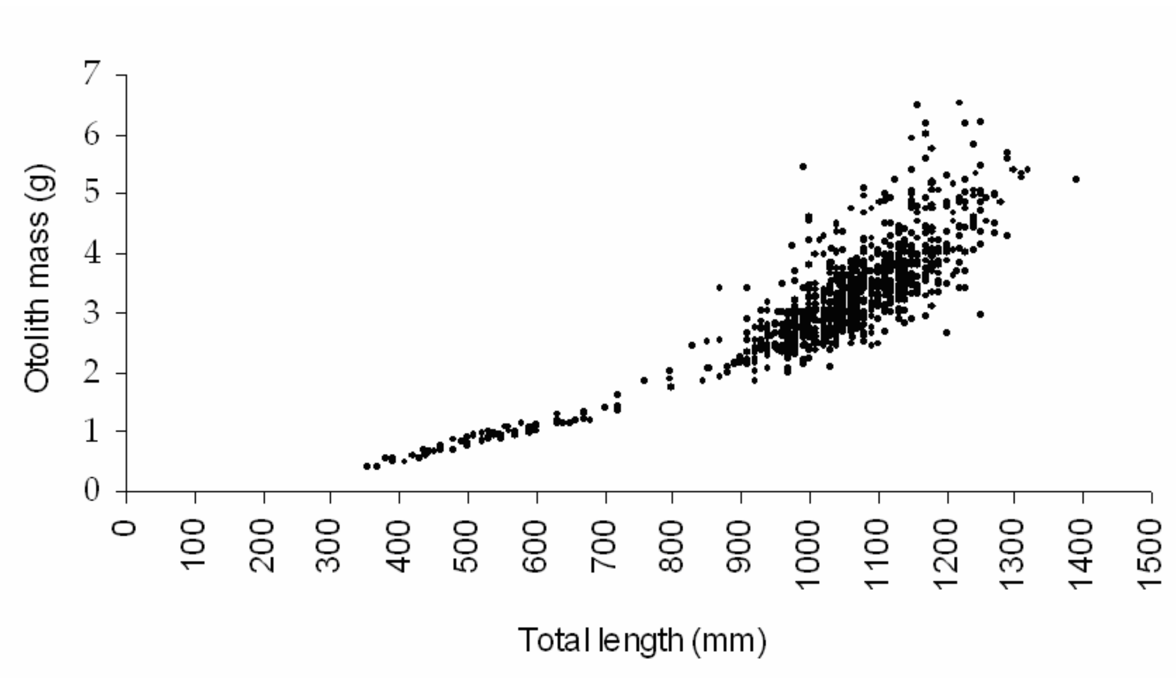

Figure 7.2 Total length-otolith mass plot for the black jewfish. Area and year of capture combined (n = 991)

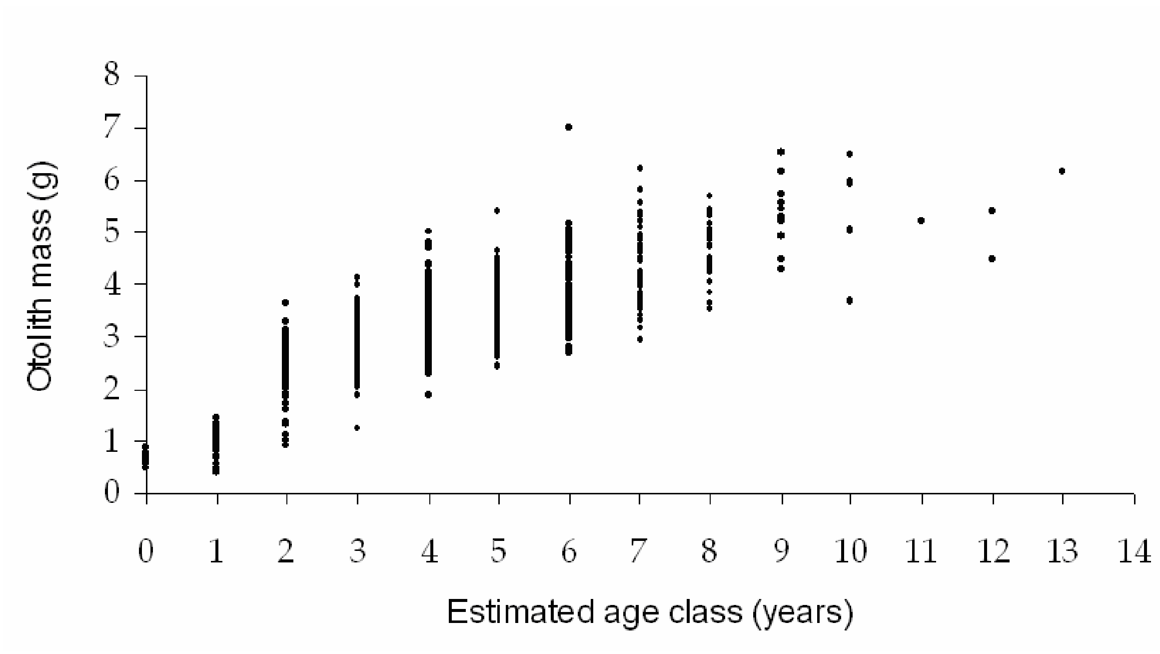

Figure 7.3 Estimated age class (birthday adjusted)-otolith mass plot for black jewfish; area and year of capture combined (n = 991)

Although a sub-sample of otoliths was prepared for daily ageing, the incremental structure was difficult to decipher as structure was quite irregular. As a result, daily estimates were not determined. The estimated age (birthday adjusted)-otolith mass relationship for jewfish collected during 2004–06 is presented in Figure 7.3. It appears jewfish have a two-stage otolith growth function as after approximately four years of growth there is a gradual decline in the rate of otolith mass increase.

In the collection for age determination, fish length ranged 355–1410 mm TL with a modal length of 1050 mm TL (Figure 7.4). Age estimates ranged 0–13 years with a modal age of four years (Figure 7.5). Von Bertalanffy growth parameters were estimated ($L\infty$ = 1115, k = 0.945 and t_0 = 0.258) for fitting a growth curve to length-at-age data (Figure 7.6).

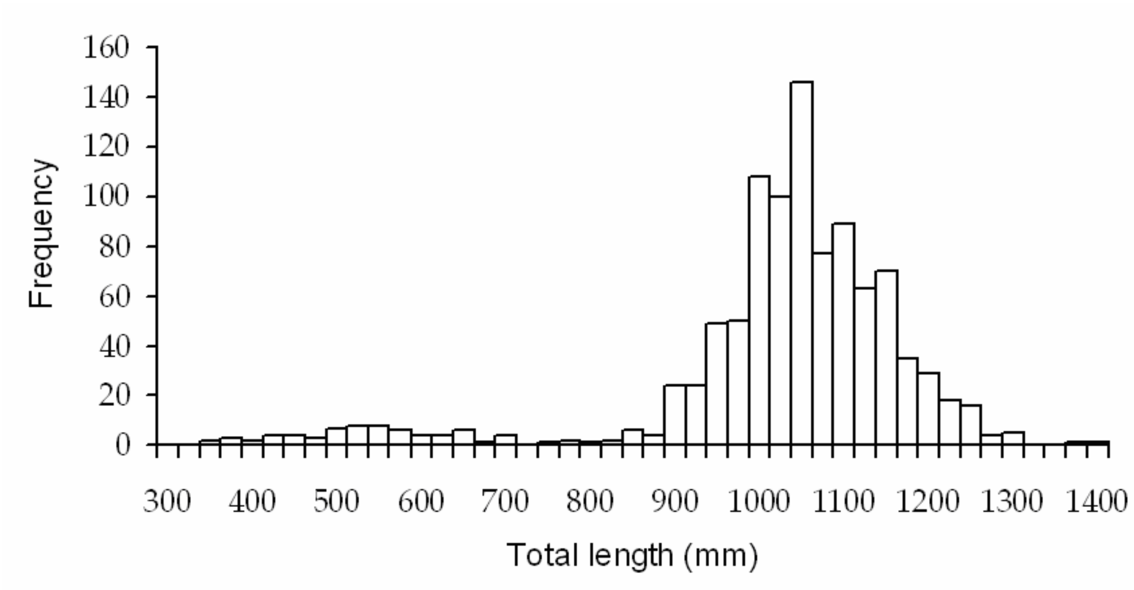

Figure 7.4 Length-frequency distribution of black jewfish. Area and year of capture combined (n = 991)

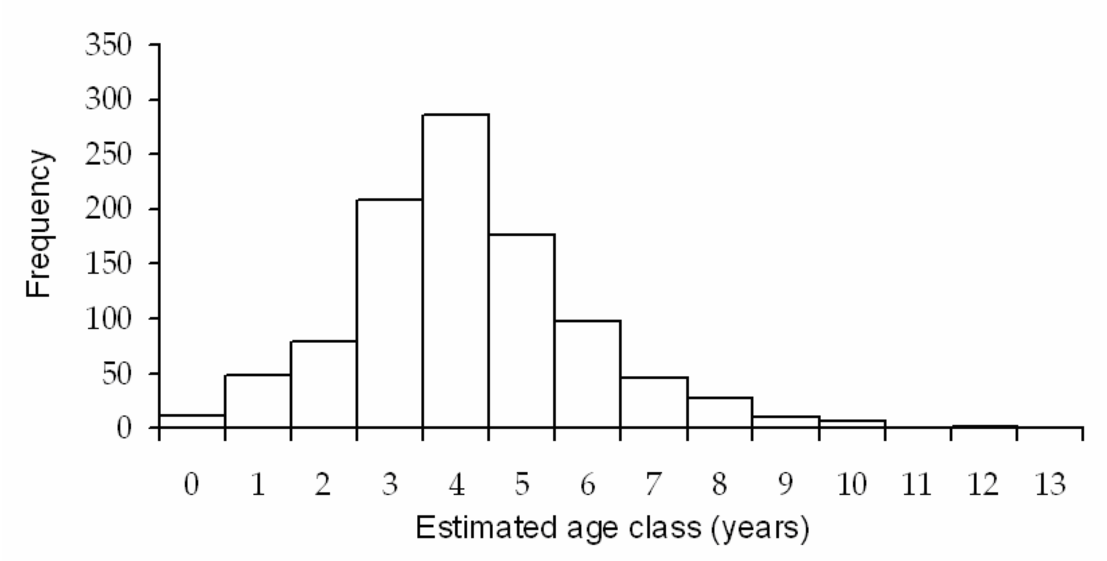

Figure 7.5 Age-frequency distribution of black jewfish; area and year of capture combined

Figure 7.6 Age-length relationship for black jewfish with fitted von Bertalanffy growth curve; area and year of capture combined

As ‘presumed’ annual incremental structure was relatively clear, secondary readings were consequently similar to the first. Age estimates were consistent between the primary and secondary readings; 69% of all secondary readings agreed with the primary age estimate, and 99% of the secondary readings were within ± 1 year of the primary readings (Figure 7.7).

The index of average error between primary and secondary readings was 3.45%. The bias corrected IAPE was 3.45% with 95% C.I. ± 1.3%. The distribution of the bootstrapped IAPE is shown in Figure 7.8. A regression analysis between first and second age estimates indicates a slope and intercept of 0.997 (95% C.I. +0.963 to +1.031) and 0.026 (95% C.I. -0.133 to +0.186), respectively. The distribution of differences, IAPE and regression analysis all confirmed that no biases were present.

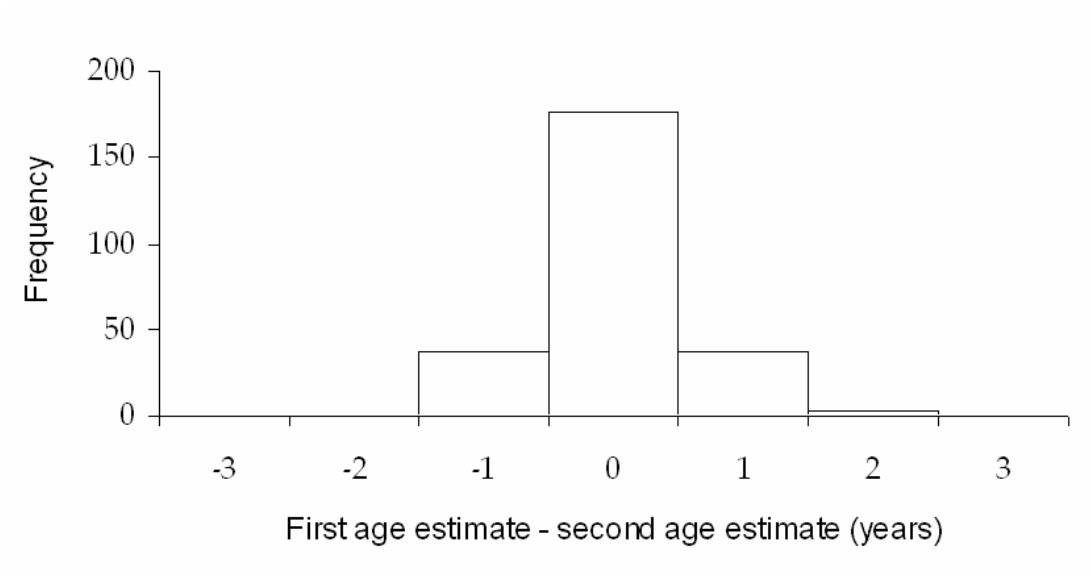

Figure 7.7 Distribution of differences between primary and secondary readings of black jewfish age (n = 252)

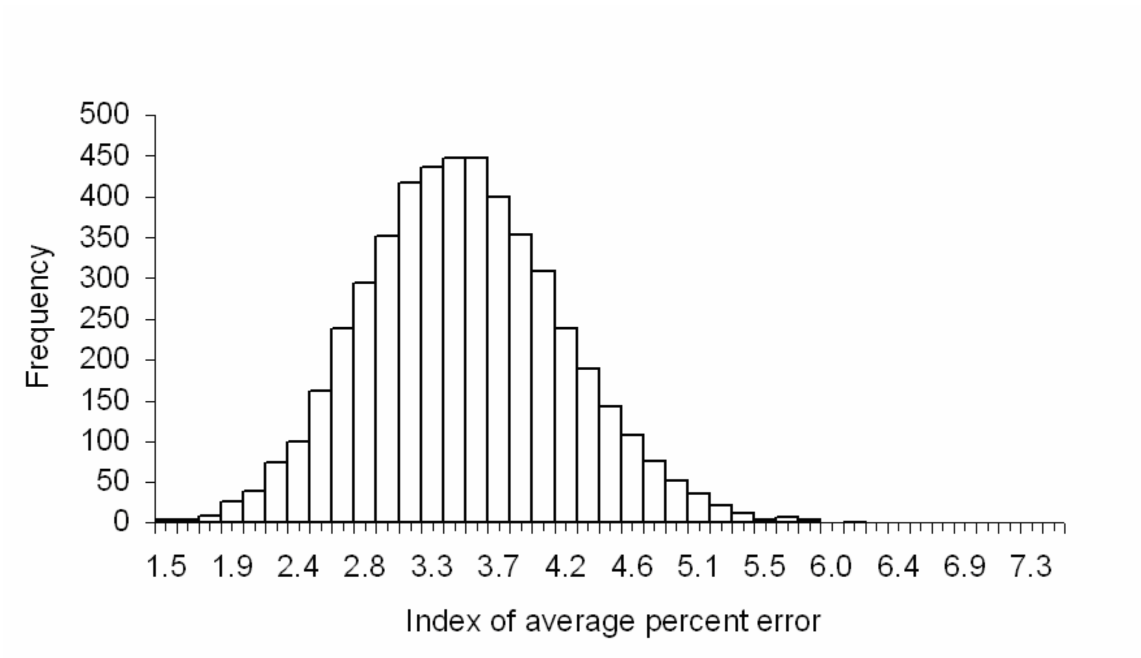

Figure 7.8 Distribution of bootstrapped average percent error readings between primary and secondary age estimates (n = 5000)

Otoliths of black jewfish examined by James Cook University (Ashley Williams, unpublished) provided comparable estimates. Age estimates ranged 0–7 years with a modal age of three years (Figure 7.9). Von Bertalanffy growth parameters were calculated to be as follows: L_∞ = 1160, k = 0.765 and t_0 = 0.189 (Figure 7.10). As per the primary data set reported on above, there was considerable variation in the length of black jewfish at any given age.

Figure 7.9 Age-frequency distribution of black jewfish examined by James Cook University (n = 481)

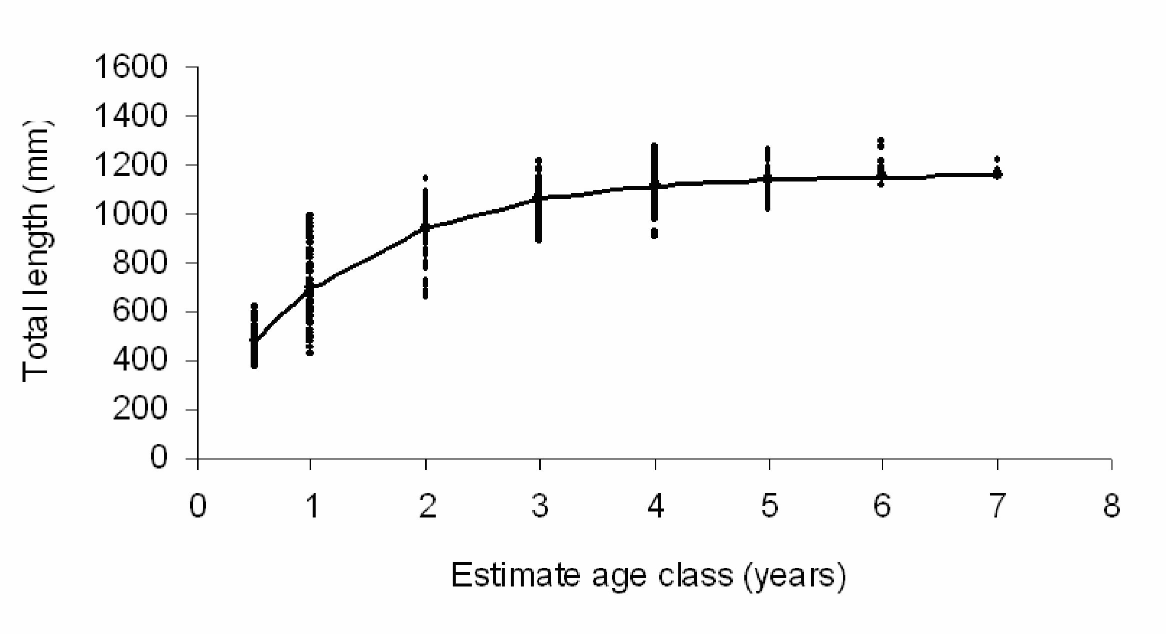

Figure 7.10 Age-length relationship for black jewfish examined by James Cook University (n = 481)

7.5 Discussion

The oldest black jewfish aged in this study was 13 years old (123 cm TL). The length-frequency relationship shows a modal TL of 105 cm TL, which corresponds to a modal age class of four years. This information combined with the von Bertalanffy growth parameters indicate a relative fast growing species. As described for many species of fish, there was considerable variation in the length at age of black jewfish.

The relationship between estimated age class and otolith mass, and estimated age class and total length respectively show a wide spread of data around the dependent variable, age. Although this appears as though there is a high level of growth variability, this may not be the case as samples were collected during different months, different years and from different areas.

During this study, an attempt was made to count the number of daily increments formed from the primordium to the first increment to determine the position of the first annual increment, within a transversely sectioned otolith. If the increment count was less than 365 “days” the first annual increment was successfully located. Although an increment count could be made to the first ‘presumed’ annual increment, the reader was not confident as to whether the increments were consistent for daily age estimation.

The position of the first annual increment was determined by locating the first presumed annual increment and visually comparing this to the position of subsequent increments. Although this method can be subjective, an experienced reader is often correct based on the experience of ageing other known age species. Such information, combined with length frequency data, date of capture and timing of increment formation, highlighted the most likely position of the first increment.

For annual age estimation, transverse sections of black jewfish sagittal otoliths display relatively clear contrasting opaque and translucent zones and show a consistent pattern in the appearance of increments. The amount of translucent structure formed on the edge was also relatively easy to decipher. This meant that converting an increment count to an age class was relatively straightforward. As ‘presumed’ annual incremental structure was relatively clear, secondary readings were similar to the first.

Evidence supporting the annual nature of otolith band formation in black jewfish is provided by Bibby and McPherson (1997) in the observation of the consistent increase of the mean focus-to-last-annulus distance up to ten years. Rao (1966) and (1961) also accept that band formation is of an annual nature through spatial sampling over twelve months of the year. Rao (1961) suggests that high feeding rate may be responsible for the formation of the opaque zone.

Bibby and McPherson (1997) determined the period in which the opaque annuli form to be during the months of October and December (late dry season to early wet season) as evidenced by the differentiation of Edge Growth Ratios for the various months. Rao (1966) and (1961) concluded that the translucent rings formed during the period October to January (late wet season to early dry season) based on the months when the largest percentage of otoliths displayed a translucent edge.

Bibby and McPherson (1997) employed Schnute's Growth Model which mathematically cast historical growth models as sub-models to which the most appropriate model and best method for estimating model parameters is selected by analysis of variance (Schnute 1981). Using back-calculated length-at-age data, the Schute Case Five growth model provided the most parsimonious fit. Parameters of the von Bertalanffy growth function were:

$L_{\infty} = 136.6$ $\quad t_o = 0.18$ $\quad K = 0.32$ $\quad n = 197$

Rao (1966) produced a similar growth curve using the original format of the von Bertalanffy equation. Parameters adopted by Rao (1966) were determined from a Ford-Walford Plot. Estimates of the parameters of the von Bertalanffy equation were:

$L_{\infty} = 122.14$ $\quad t_o = -0.31$ $\quad K = 0.315$ $\quad n = 428$

Rao (1966) states he was unable to conduct back-calculations as the presence of bulbous excrescence in the nuclear region did not allow measurement of the intermediate and total lengths within otolith samples examined. Rao (1961) did not apply any mathematical equations to the length at age data, yet it is evident that the presented length frequency distribution per growth ring data is in close agreement with that displayed by Rao (1966) (Table 7.3)

Table 7.3 Length of Indian black jewfish (cm TL) representative of number of growth bands in otoliths (n = 350)

Age Class	**I**	**II**	**III**	**IV**	**V**
Rao 1961	30-60	65-75	75-85	85-95	95-100
Rao 1966	44.05	68.24	83.24	92.06	97-6

There is good agreement in the growth curves produced by Rao (1966) and Bibby and McPherson (1997), and the length modes per growth ring presented by Rao (1961) and (1966). However, the growth curve for black jewfish given in Rao (1966) shows a smaller asymptotic size than that in Bibby and McPherson (1997). This is most probably due to the larger (and older) fish sampled by the latter authors. Our estimates of length at age suggest black jewfish from NT coastal waters have a faster growth rate than conspecifics from northern Queensland (Phelan 2002).

Growth differences between areas are often observed in fishes and have been observed in other Sciaenids. For example, Griffiths (1996) found mulloway (*Argyrosomus inodorus*) in the south-western Cape Province of South Africa initially grew faster than those in adjacent regions, but the growth rate slowed earlier and a smaller maximum size was attained. Sheppard and Grimes (1983) found that initial growth rate of weakfish (*Cynoscion regalis*) from three regions in the Atlantic Bight were inversely correlated with maximum size.

Different growth rates may reflect different environmental or ecological conditions. It is well established that growth in fishes is influenced predominantly by temperature of the water (Beverton and Holt 1959) and food availability (Boehlert and Yoklavich 1983). Griffiths (1996) and Sheppard and Grimes (1983) suggest that the size of the prey may explain regional differences in predator growth rates (Wootton 1990).

Alternatively, growth differences may reflect genetic or population differences. While black jewfish sampled from the waters of the NT and Queensland do form the same genetic stock (Phelan 2002), the preliminary results of solution-based otolith microchemistry suggest population structure may be evident at a scale less than 100 km (unpublished data). This may explain some of the wide range in sizes (TLs) for a given age class in the pooled data (Figure 7.6).

8. KEY HABITAT CHARACTERISTICS OF BLACK JEWFISH AGGREGATION SITES IN NORTHERN TERRITORY COASTAL WATERS

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8.1 INTRODUCTION

Black jewfish form a substantial component of the NT commercial and recreational inshore fisheries catch. The targeting of black jewfish is of concern as they form aggregations in shallow coastal waters. Aggregation sites located close to major population centres, such as Darwin, are well known and are readily accessible by all stakeholder groups.

The habitat mapping study was originally composed of two components. The first mapped the turbidity, small scale oceanography, current flow and profiled bottom topography within aggregation sites using an Acoustic Doppler Current Profiler (ADCP). The second described the behaviour of jewfish in aggregation sites using Baited Remote Underwater Video Systems (BRUVS). Together this research aimed to provide an understanding of the factors determining the location of aggregation sites, aggregation behaviour and activities of fish within aggregations.

8.2 OBJECTIVE

The primary objective of the ADCP surveys was to map bathymetric features at known locations of jewfish aggregations, collect water velocity data along selected transects at these locations to map the synoptic distribution of currents and to provide information on the small scale oceanography of the area (e.g. turbidity - Objective 3).

8.3 METHODS

8.3.1 Site selection

Two sites, the first at the Channel Point and the second at Caution Point (Bathurst Island) were originally selected for this study (Figure 5.4). Immediately after the establishment of the acoustic array and ADCP mapping of the Caution Point site, the area was hit by a category 5 cyclone. The vulnerability of this area to cyclones and loss of array equipment resulted in the site being abandoned and a more accessible site established at Chambers Bay (Figure 5.4).

8.3.2 ADCP surveys

ADCPs utilise high-frequency acoustic pulses to measure vertical profiles of water speed and direction. This technology measures the Doppler-shift between a transmitted acoustic pulse and its echoes backscattered from waterborne particles (e.g., plankton and sediment) and determines along (acoustic) beam velocity components. If the water is moving, then the return frequency is shifted and using the Doppler principle the speed of the water can be determined. The Doppler equation for the ADCP is:

$$F_d = 2F_s(V/C)\cos B.$$

Where F_d = received frequency (Doppler shifted)
F_s = transmitted frequency
V = combined water and boat velocity
C = speed of sound in water
B = beam angle of the instrument.

Acoustic beams generated in multiple directions allow determination of three dimensional currents with an onboard compass to reduce the measured velocities to north/south, east/west, and vertical velocity components. Vertical velocity profiles are produced by range-gating the echoes so that velocities are determined at preset intervals along the acoustic path (called bins). ADCPs also precisely measure water depth due to the strong echoes from the seabed. Vessel-mounted ADCPs may be set up to track the vessel's path over the seabed to correct the ADCP data relative to vessel motion and produce measurement of absolute currents. To provide synoptic information on bathymetry and water velocity, ADCP data is collected along transects while the vessel is underway along a grid of straight tracks through the survey area.

An RD Instruments (RDI) Workhorse Sentinel ADCP with bottom-tracking was used to measure water velocity profiles and a handheld global positioning system (GPS) receiver was used for navigation and positioning.

Figure 8.1 Mounting of ADCP on vessel

The ADCP was mounted over the side of the vessel and set to collect velocity profile information every 2.5 seconds (Figure 8.1). The ADCP contained an integral navigation system using a solid state flux gate compass and acoustic pulses to measure speed and direction over the bottom. Using this technique, accurate location data was incorporated into the recorded data set of water velocity and bottom depth. Prior to the commencement of measurement transects, an *in situ* ADCP compass calibration was performed.

Single ping accuracies for an ADCP are a few cm per second and the velocity measurement was further refined by averaging several pings. For the measurements made by our study, the ADCP was set to ping every 0.2 seconds and those pings then averaged over a 2.5 second cycle. The ADCP sampled the return echoes in microsecond intervals and was therefore able to assign depth classed to the derived velocities.

GPS data was recorded in the ADCP data files (see above) and output was transmitted to a moving map program to ensure survey transects were navigated accurately. A pressure sensor was also placed on the seabed to record tide levels during the surveys. These recorded levels were later compared with predicted tides for the sites. The recorded tide levels and predicted tides compared very well. Depths recorded with the ADCP were reduced to tidal datum using the predicted tides and bathymetric maps were made of the survey sites.

ADCP mapping was completed at Chambers Bay between 14-02-2006 and 15-02-2006 and at the Channel Point between 25-07-2006 and 28-07-2006.

8.3.3 BRUVS surveys

The abandonment of the Caution Point site had major implications for BRUVS work as a moderate level of water visibility (3-4 m) is required in order for cameras to record details of fish behaviour. Caution Point had been selected as a site for BRUVS sampling as there was a reasonable certainty that sufficient visibility was attained on at least some parts of the monthly tidal cycle (the latter part of neap tides).

A pilot study in Darwin Harbour demonstrated that BRUVS were able to sample fish communities under such conditions. However, this was not the case at the Channel Point site or at Chambers Bay where the close proximity of river outflows (Daly and Mary Rivers, respectively) meant that light levels and clarity were not sufficient to sample using BRUVS under all but very exceptional circumstances.

It was not possible to establish other sites offshore in greater water clarity as these could not be sampled with sufficient frequency to reduce the risk of cyclones on gear loss. Sites closer to Darwin were also unsuitable since the majority of aggregations in these areas had been fished out. For these reasons, BRUVS sampling could not be completed for this study.

8.4 RESULTS

8.4.1 Chambers Bay - bottom topography

Depth and positional data provided by the ADCP was input into SURFER software and a grid developed over the four transects at Chambers Bay. These four transects corresponded to the deployment sites of the VR2 receivers. The topography of all transects was characterised by flat fine mud sediments interspersed with small rocky outcrops in waters depths of <10 m. Three-dimensional images of each transect are shown in Figures 8.2 to 8.7.

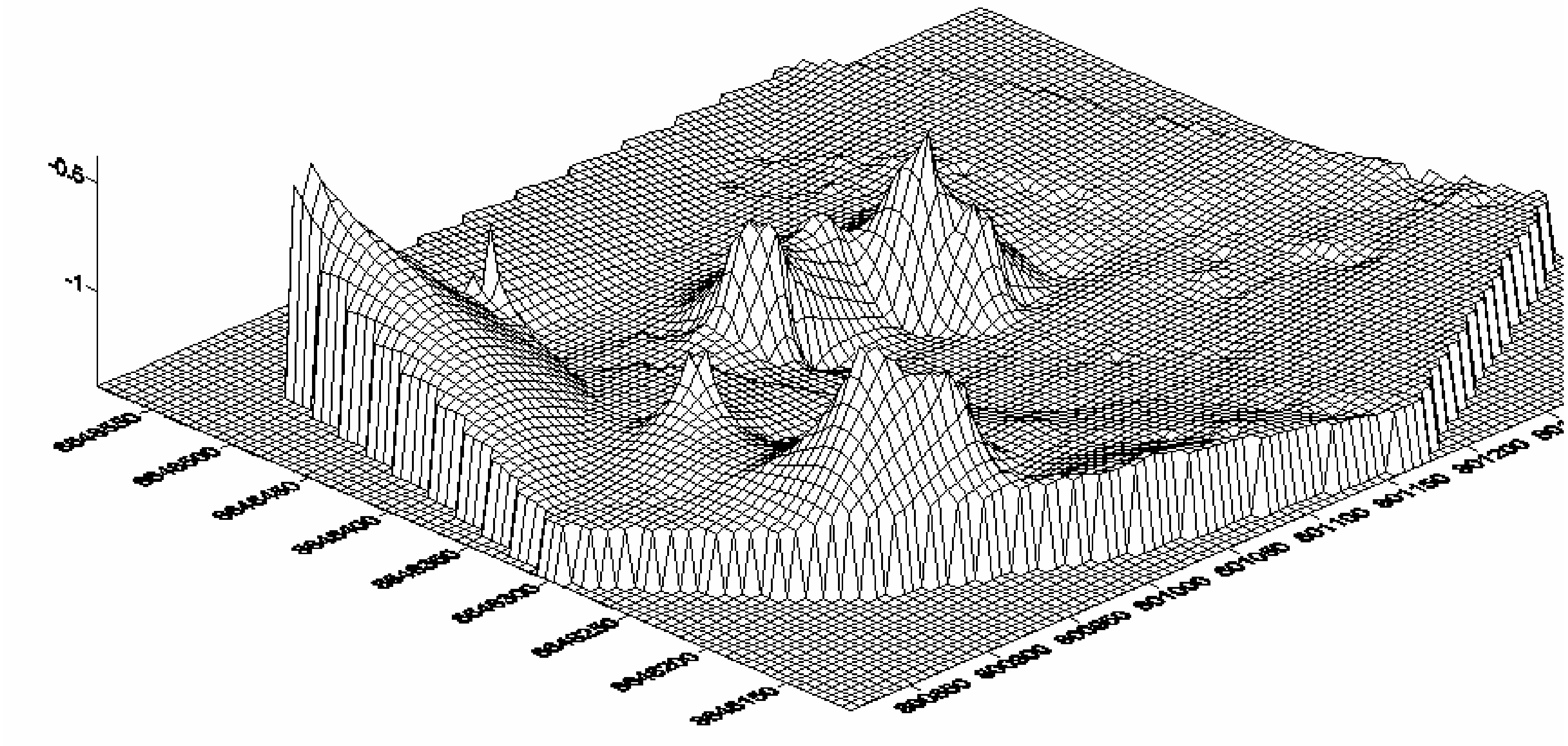

Figure 8.2 Three-dimensional relief map showing seabed topography of Chambers Bay transects 1 & 2; x-axis length 500 m

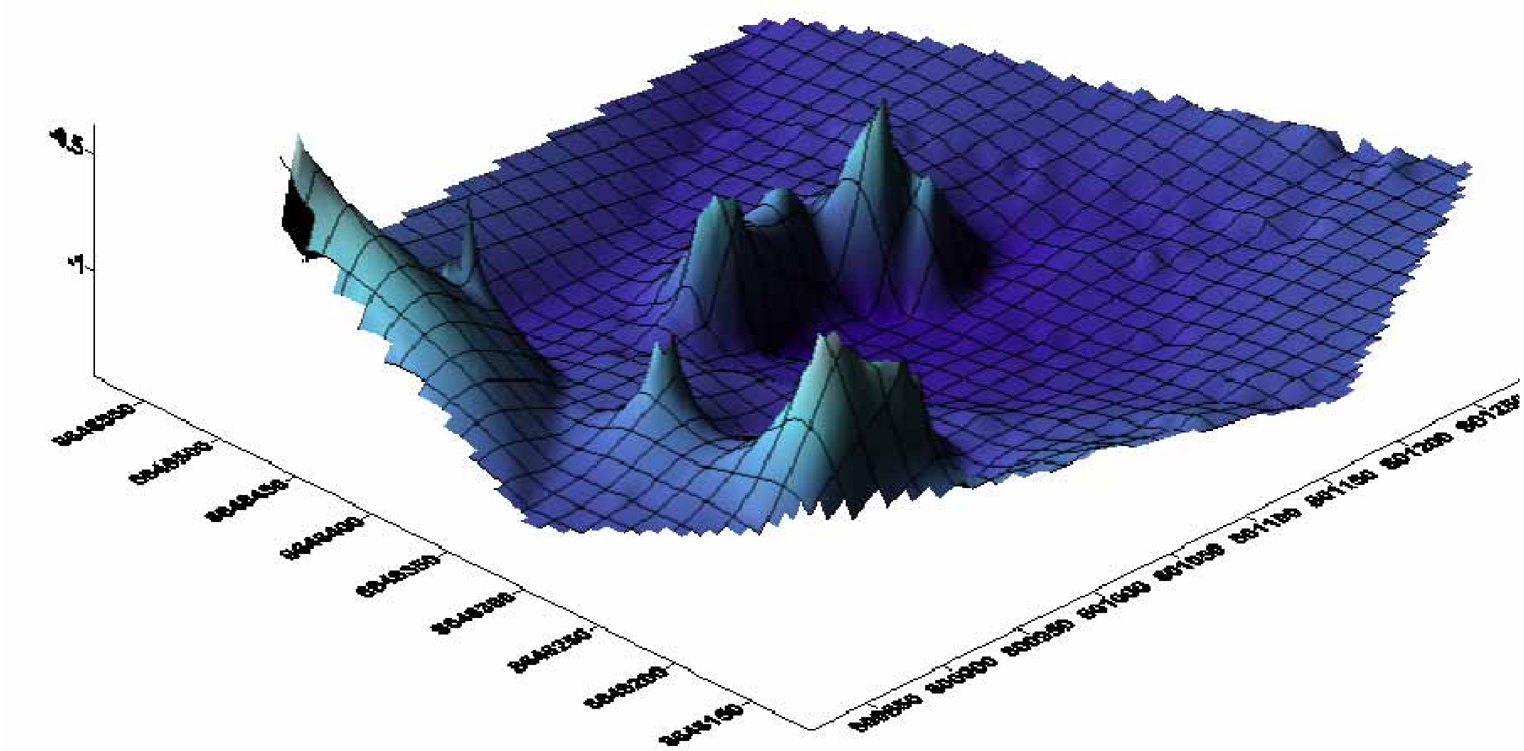

Figure 8.3 Three-dimensional relief map of seabed topography of Chambers Bay transects 1 & 2; x-axis scale 500 m

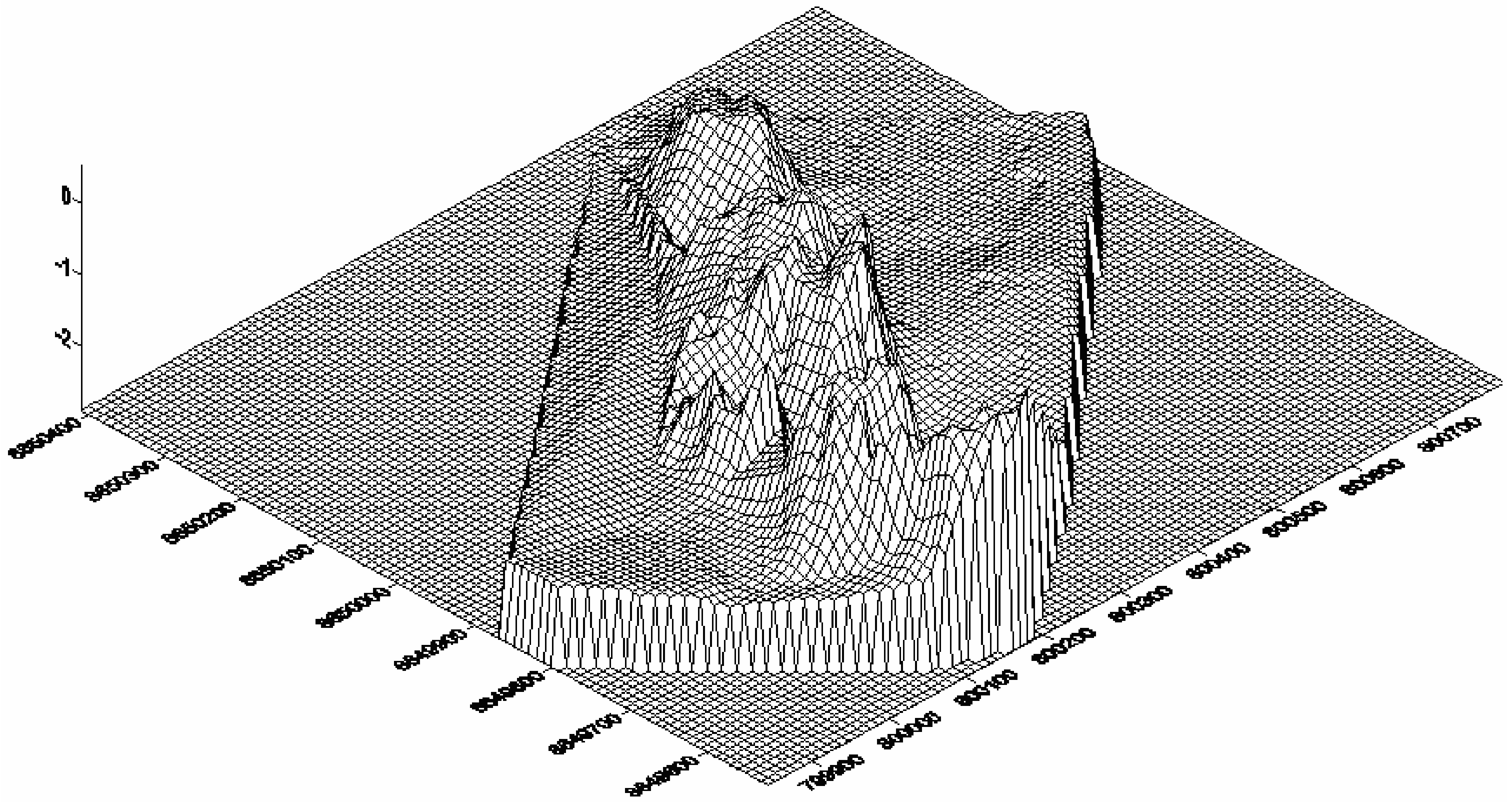

Figure 8.4 Three-dimensional relief map of seabed topography for Chambers Bay transect 3; x-axis scale 1 km

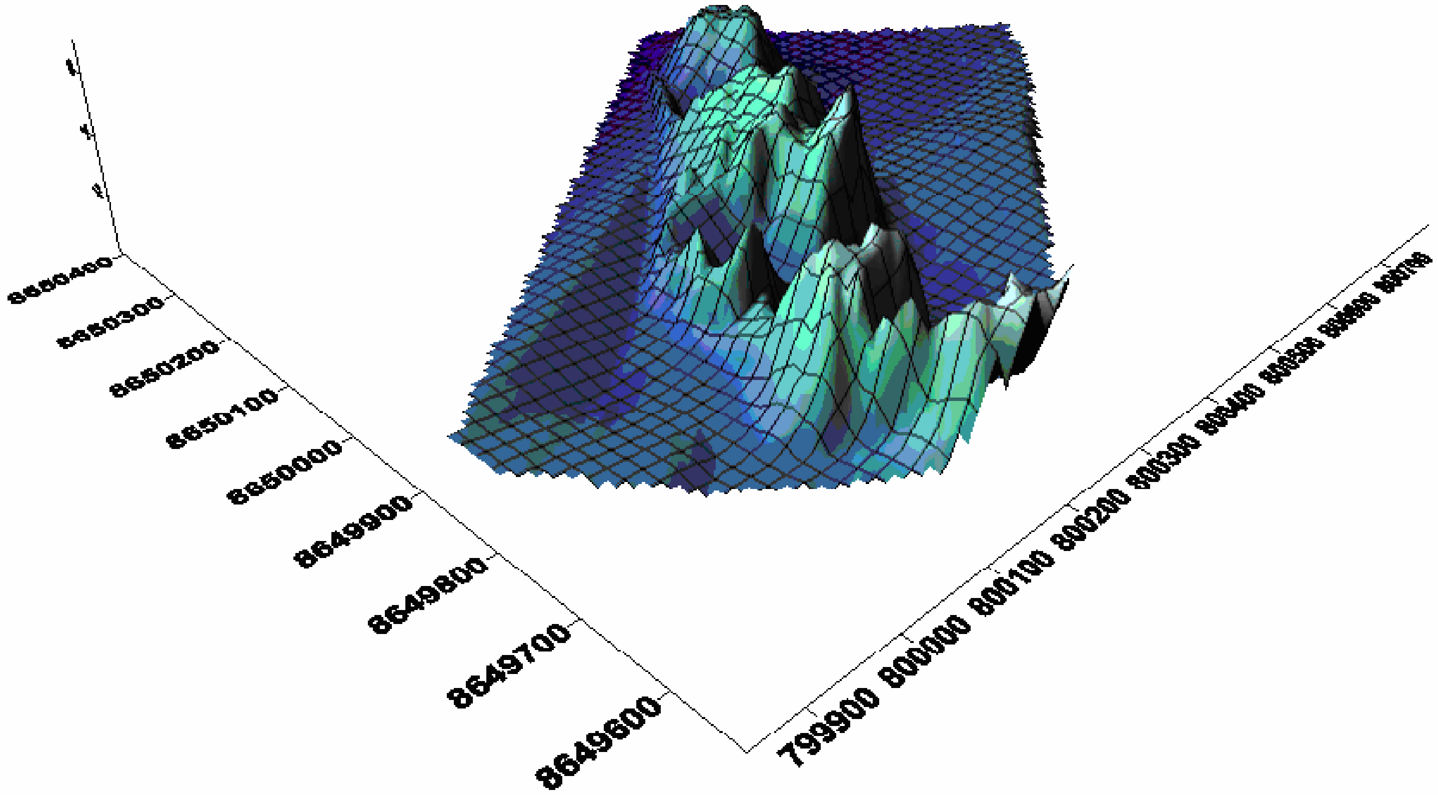

Figure 8.5 Three-dimensional relief map of seabed topography Chambers Bay transect 3; x-axis scale 1 km

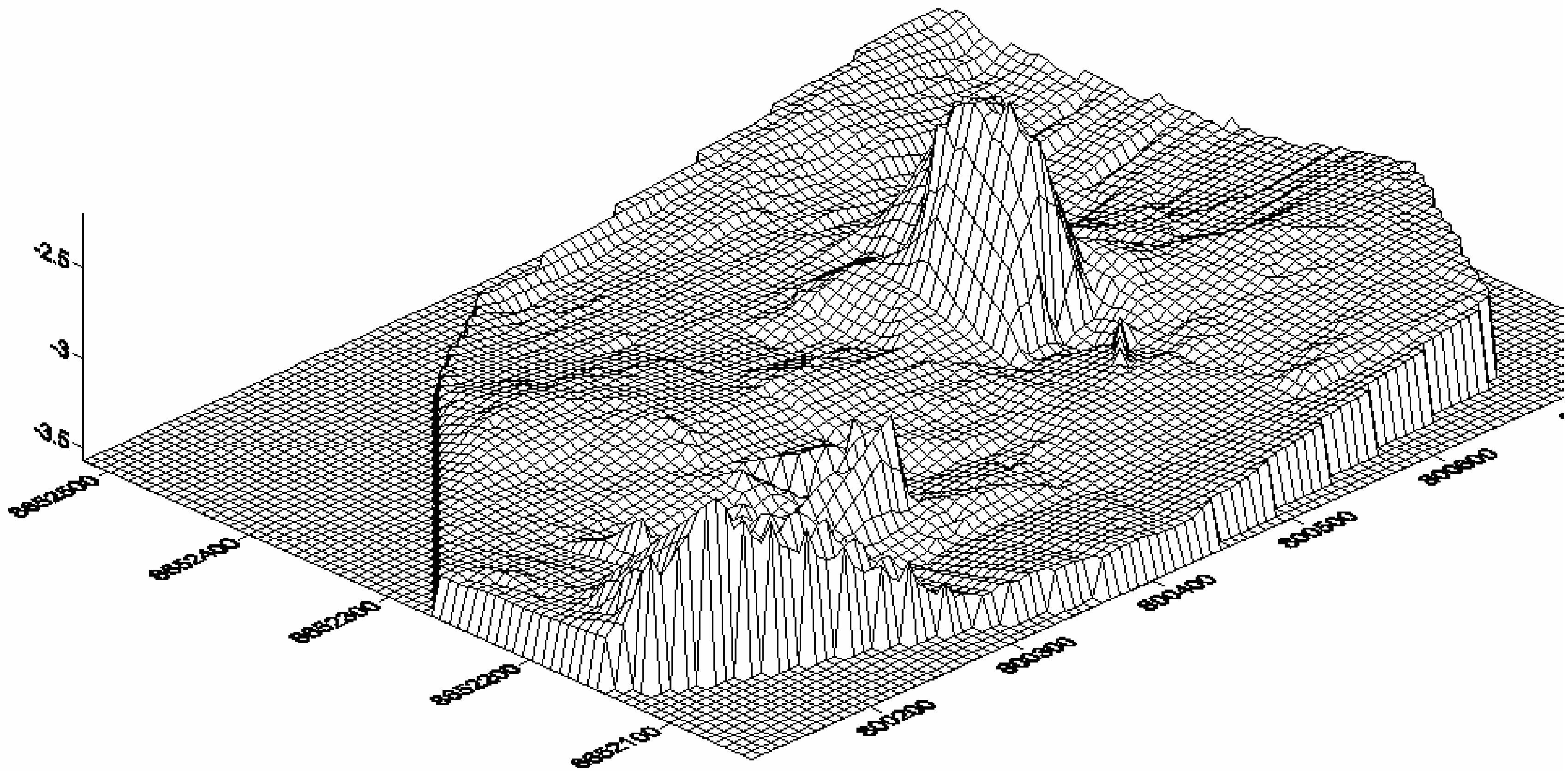

Figure 8.6 Three-dimensional relief map of seabed topography Chambers Bay transect 4; x-axis scale 800 m

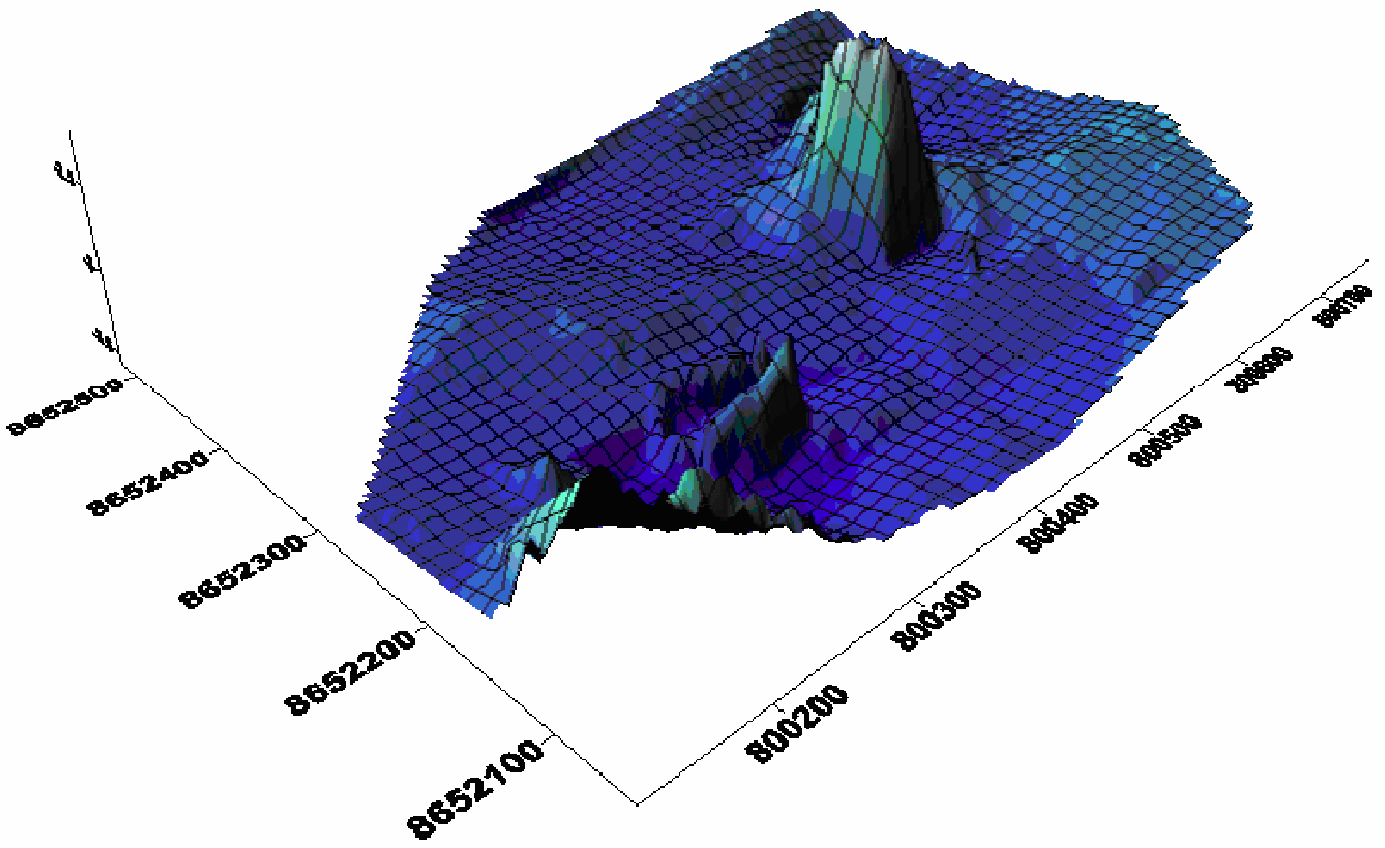

Figure 8.7 Three-dimensional relief map of seabed topography Chambers Bay transect 4; x-axis scale 800 m

8.4.2 Chambers Bay - current flows

Current flows along each transect at Chambers Bay were unidirectional. There was no evidence of eddies or other physical mechanisms that might retain eggs or larvae in the area of the aggregation site, or promote increased fertilization of pelagic eggs.

A snapshot of peak current velocities and directions for ebb tides for each transect are shown in Figures 8.8 to 8.10. Arrow sizes are proportional to strength of currents and current vectors range from 0.2–0.5 m/s. There was little change in current velocity or direction with depth (Figure 8.11).

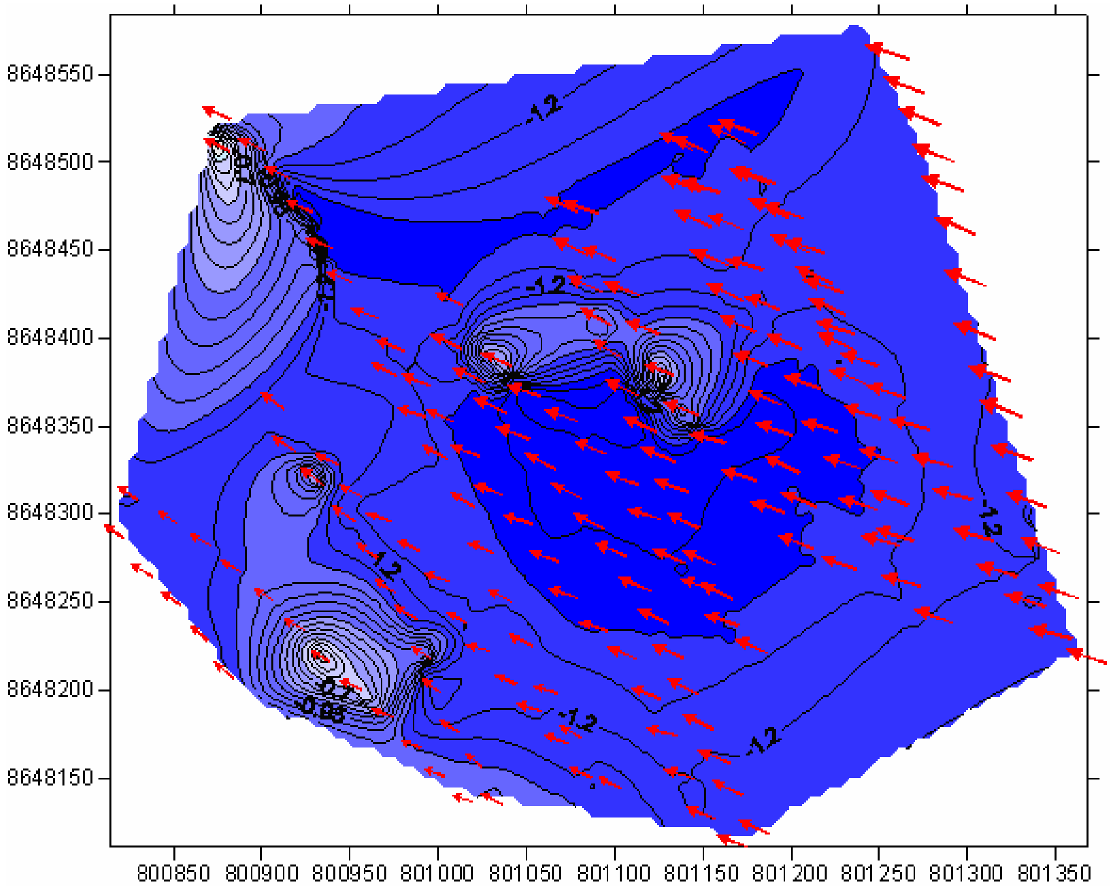

Figure 8.8 Bathymetry and current vectors; Chambers Bay transects 1 & 2

8.4.3 Chambers Bay - Turbidity/productivity

In terms of sediment and plankton, the water column at Chambers Bay was very well mixed. It was a turbid environment with little stratification. The water column was difficult to characterise close to the bottom where soft sediment created noise in the sonar signal. Figure 8.12 shows a turbidity profile typical of transects at Chambers Bay.

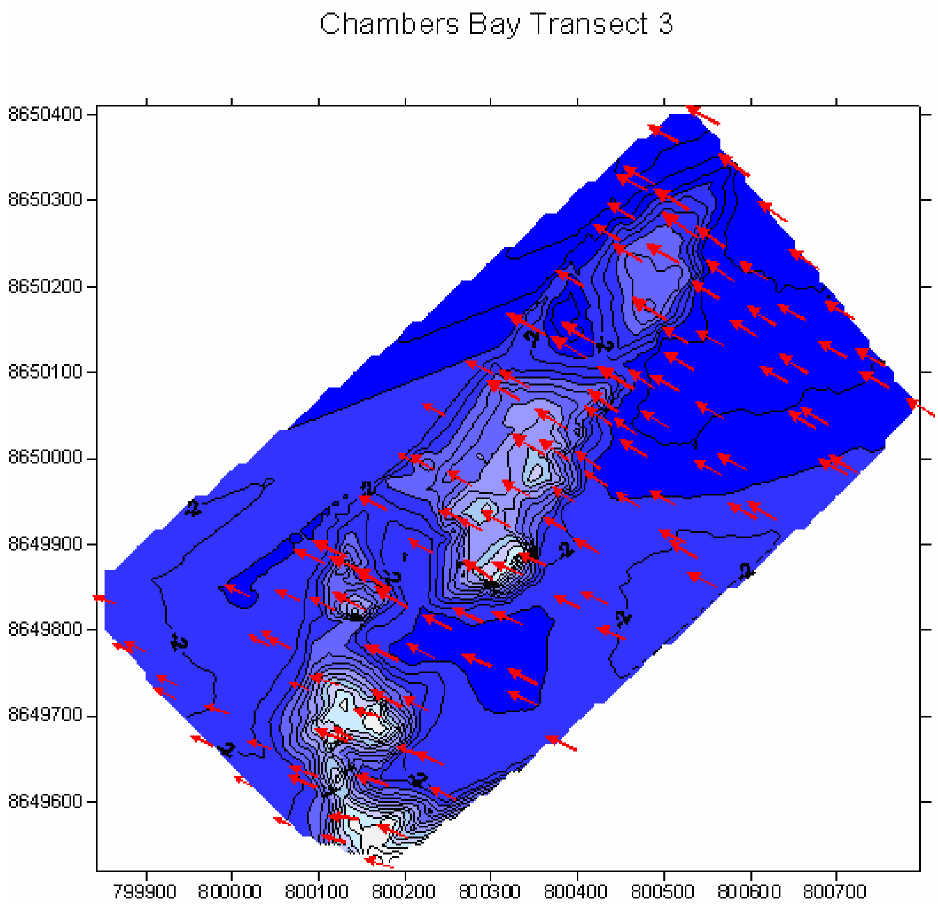

Figure 8.9 Bathymetry and current vectors; Chambers Bay transect 3

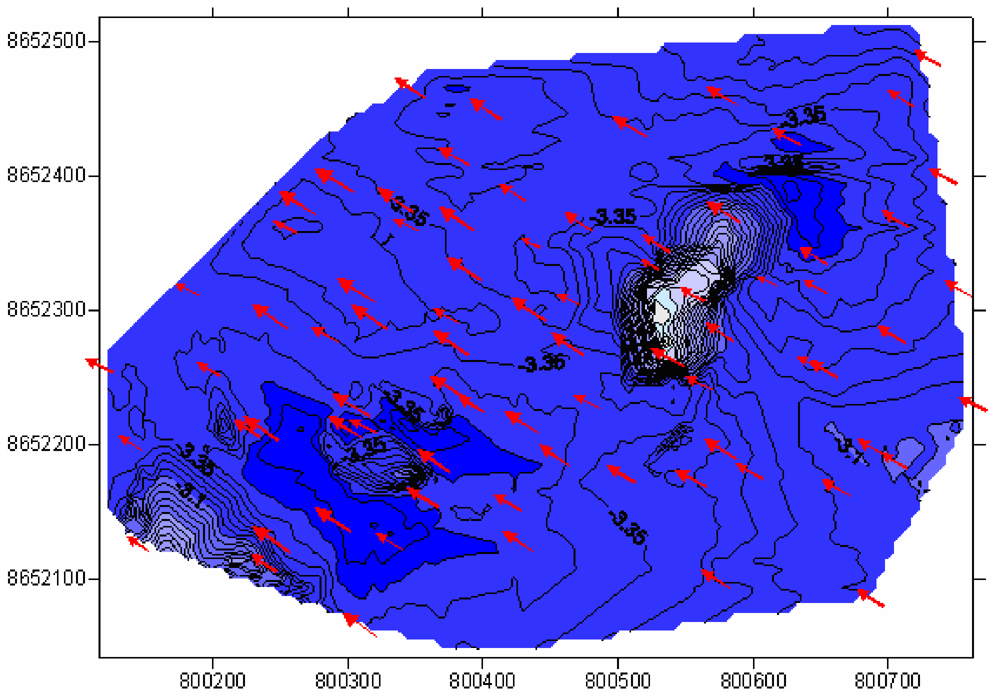

Figure 8.10 Bathymetry and current vectors; Chambers Bay transect 4

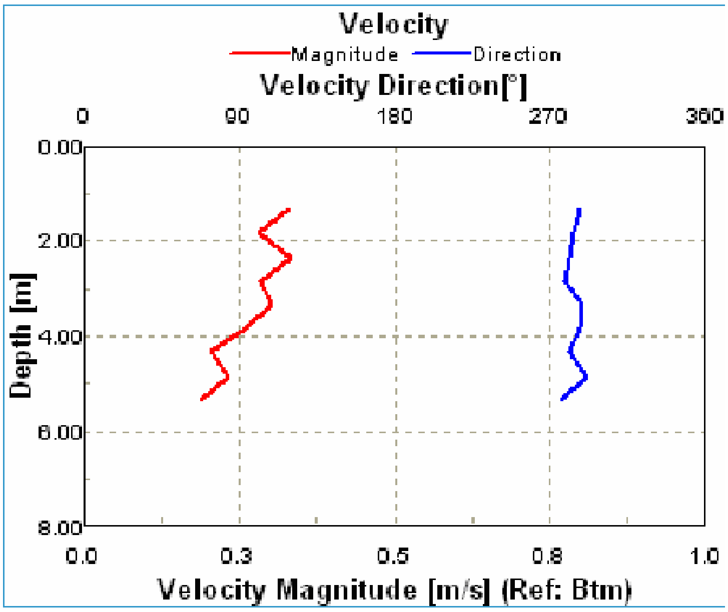

Figure 8.11 Snap shot (typical) of profiles of velocity magnitude and direction of current flows at Chambers Bay

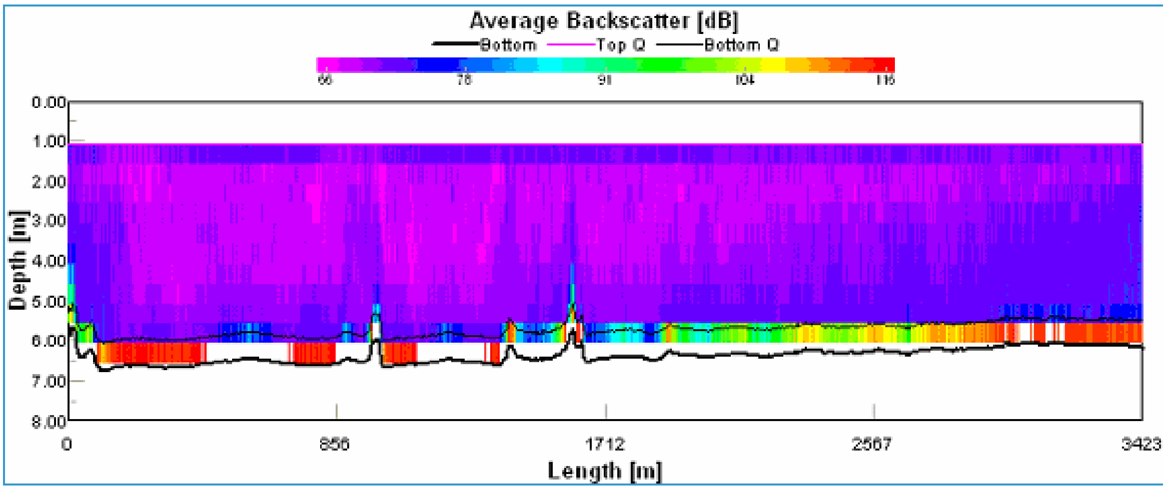

Figure 8.12 Turbidity contour plot along transect at Chambers Bay using acoustic backscatter; transect length 3.4 km

8.4.4 Channel Point - bottom topography

Bottom topography at Channel Point was extremely variable. It ranged from a shallow (5 m) flat shelf to a steep-sided, deep (30 m) channel. Bottom sediments consisted of mud and medium siliceous sands. Two and three-dimensional plots of topography are shown in Figures 8.13 and 8.14.

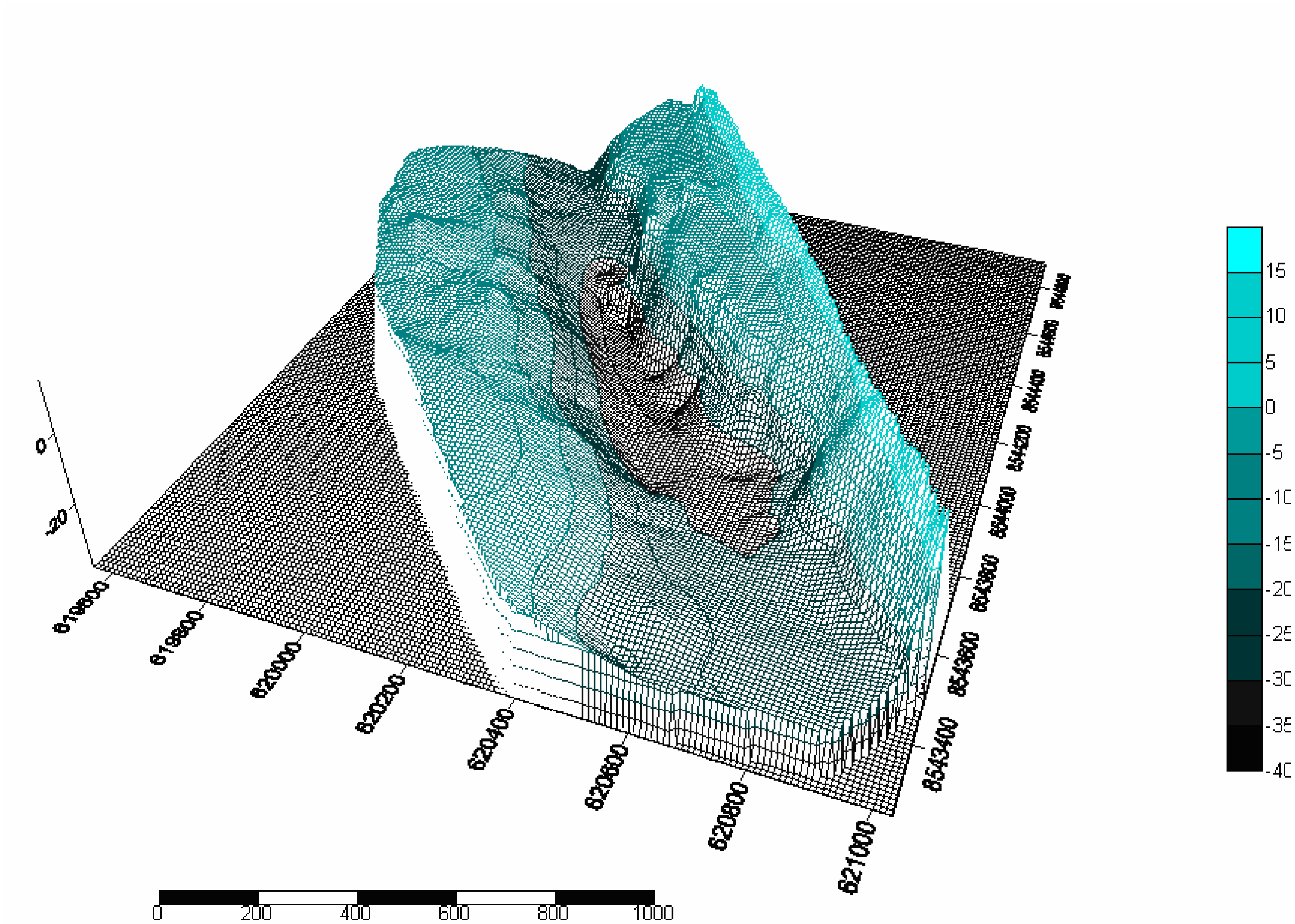

Figure 8.13 Two-dimensional map of bottom topography at the Channel Point site

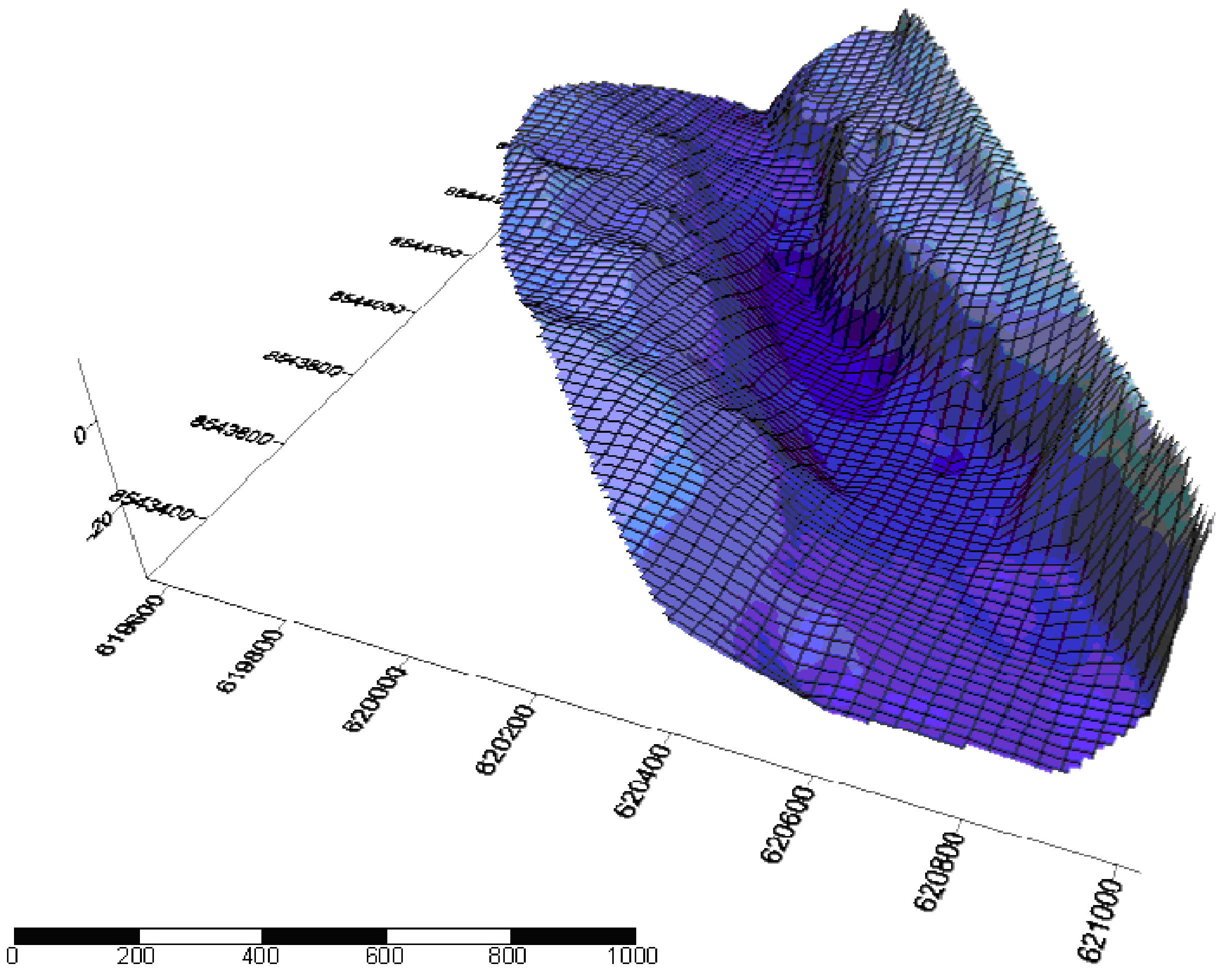

Figure 8.14 Three-dimensional map of bottom topography at the Channel Point site

8.4.5 Channel Point - current flows

Current flows at Channel Point were unidirectional and there was no evidence of eddies or turbulent flows (Figure 8.15). There was little change in current velocity or direction with depth (Figures 8.16 and 8.17).

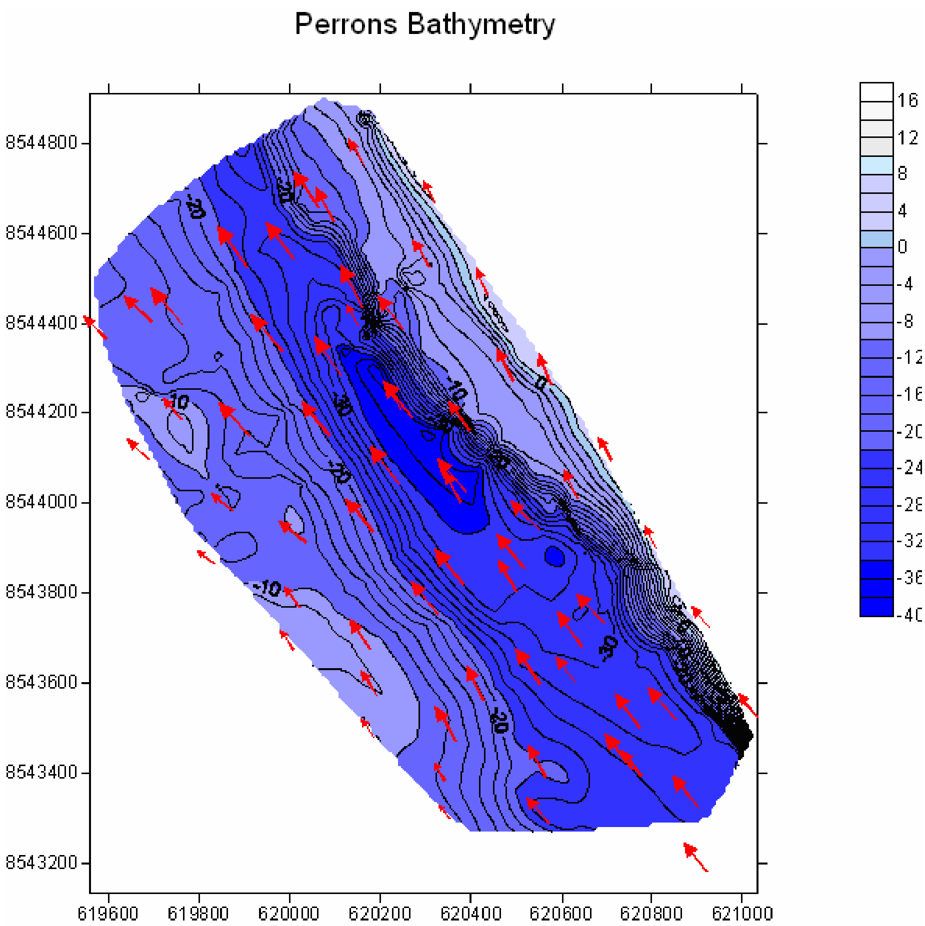

Figure 8.15 Snapshot of current flows at the Channel Point site; arrow sizes are proportional to strength of currents and current vectors range from 0.3-1.0 m/s

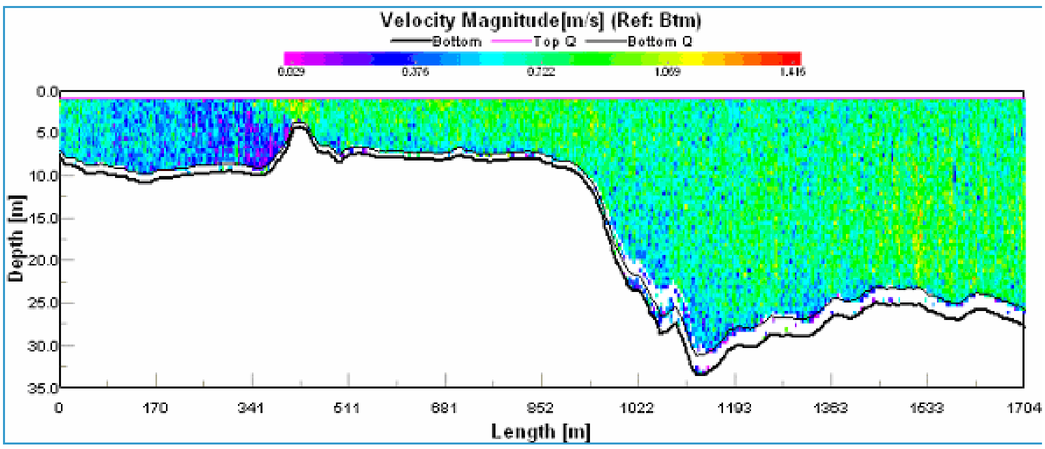

Figure 8.16 Velocity contour plots showing the detailed velocity distribution at the Channel Point site

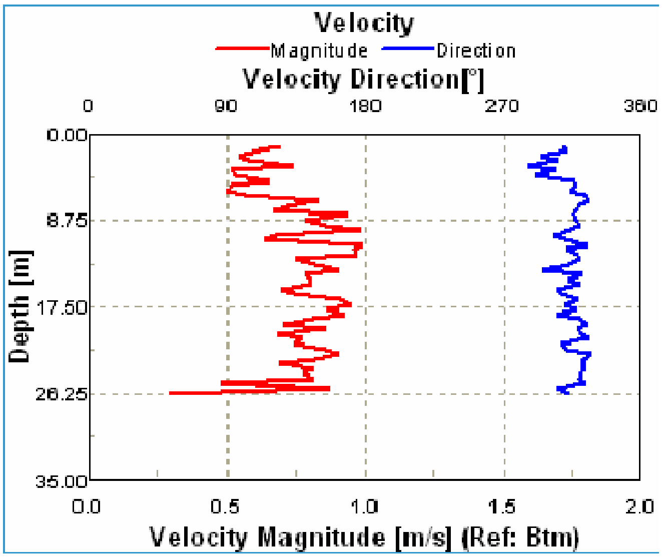

Figure 8.17 Profile plot of current velocity magnitude and direction at the Channel Point site

8.4.6 Channel Point - turbidity/productivity

The water column at Channel Point was very well mixed. It was a turbid environment with little stratification, although there was a slightly more turbid layer at the surface. Figure 8.18 shows a turbidity profile typical of transects at Channel Point.

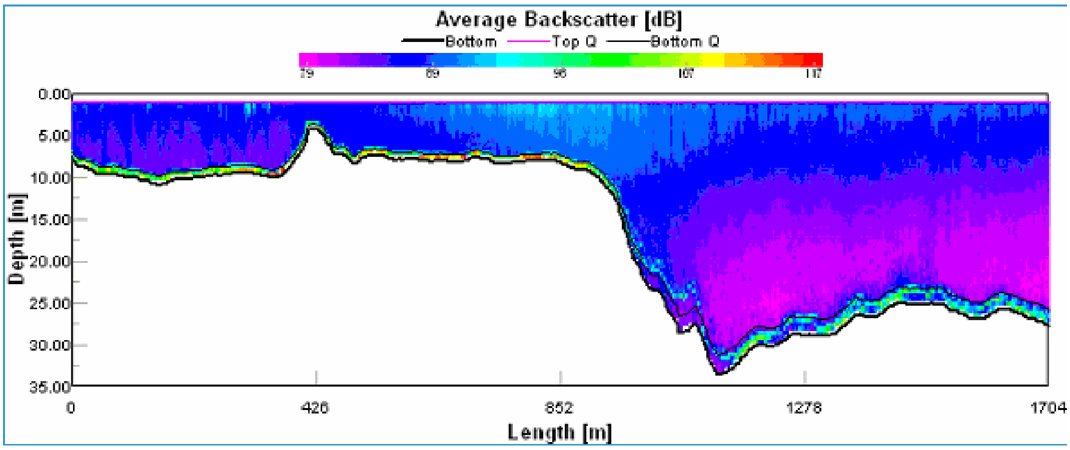

Figure 8.18 Turbidity contour plot along transect at the Channel Point site using acoustic backscatter. Transect length 1.7 km

8.5 Discussion

There were no consistent patterns in bottom topography at either aggregation site. The aggregation site at Chambers Bay was characterised by a flat mud bottom with small rocky outcrops in shallow (<10 m) water, while the site at the Channel Point consisted of a deep (30 m) trench that sloped steeply from a flat shallow (5 m) shelf. Similar works elsewhere have shown that most tropical reef fish aggregation sites (which are typically used for spawning) show consistent patterns of bottom topography and small scale physical oceanography (see review by Domeier and Colin 1997). Spawning aggregation sites in areas of coral reefs often occur in reef passes or on reef spurs where the eggs are swept away from predators close to the reef (Domeier and Colin 1997). The lack of consistency in bottom topography between the sites examined here suggests that NT black jewfish may not necessarily form aggregations for spawning purposes.

Some authors have suggested that tropical reef fish aggregate to spawn at places and at times where the larvae may be retained near reefs to reduce the loss of larvae through advection (Domeier and Colin 1997). Our work found no evidence of this phenomenon; current flows were unidirectional throughout the water column and waters were well mixed and very turbid at both sites. There was no evidence of small scale eddies or boundary layers that might retain eggs or larvae in the local area.

A better understanding of potential reasons for aggregation behaviour in black jewfish may come from integrating the different components (biological sampling, habitat mapping and tracking) of this study. The sites of listening stations and the tracks of jewfish can now be superimposed on the three-dimensional maps produced here. Furthermore, current flows will be animated so that fish movement patterns can be visualised over the tidal cycle. This information combined with data on the size, age and reproductive status of black jewfish, will aid in describing the nature and purpose of aggregation behaviour in this species.

9. IMPLICATIONS OF BAROTRAUMA AND HOOK TYPE ON CATCHING AND RELEASING BLACK JEWFISH

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For information flyers relating to the findings/advice generated by this study, visit:
http://www.nt.gov.au/dpifm/Fisheries/

9.1 Introduction

Black jewfish are distributed across northern Australian waters from approximately Yeppoon in Queensland to Port Hedland in Western Australia. These large epibenthic fish utilise a variety of habitats ranging from holes or channels within estuarine systems, to offshore bommies or reefs. In such environments, they traverse a wide range of depths from less than 5 metres (m) to over 100 m.

Popular with recreational, indigenous and commercial fishers alike, the black jewfish is the focus of increasing levels of fishing effort. Reflecting the widespread adoption of the catch and release message promoted by fisheries management agencies and recreational fishing organisations, a growing number of black jewfish are released. It is estimated that 10-12 000 black jewfish are now released each year in NT waters alone (unpublished logbook data and Coleman 2004).

In recognition of the importance of this practice, delegates at the 2006 Jewfish Workshop in Darwin (held to discuss the preliminary results of FRDC Projects 2004/002 and 004) ranked understanding of the effects of barotrauma on black jewfish as the most urgent research need. Barotrauma is physical damage caused by a significant reduction in barometric pressure. In the case of fish, the change in barometric pressure is caused by the rapid and/or extreme ascent to the surface when landed and is manifest by expansion of gas in internal organs, notably, the swim bladder.

Previous studies have examined the implications of barotrauma on a variety of species and the results of each have shown all species are affected in different ways (McLeay et al. 2002). Hence, examining the effects of barotrauma on black jewfish is an essential prerequisite to developing specific advice on catching and releasing this species. This type of information is also necessary for fishery managers to establish appropriate management arrangements and for stock assessors to incorporate post-release survival estimates in their calculations.

9.2 Objectives

Quantify the extent of barotrauma-related injuries in black jewfish relative to capture depth, fish length and fishing method (Subsidiary objective 1).

Develop advice for fishers on catching and releasing black jewfish (Subsidiary objective 2).

9.3 METHODS

Black jewfish were sourced from commercial fishers or dedicated research sampling trips using handlines with 200 lb+ monofilament lines or rods with 50 lb braid lines. The fish were landed from three depth brackets: 0-10 m (n = 15); 10-15 m (n = 35); 15-20 m (n = 58). The results indicate fish from water >20 m were not required to profile the effects of barotrauma on jewfish. Specimens ranged from 34 to 125 cm TL.

The first ten fish collected were dissected purely for familiarisation purposes. One side of the abdominal wall was removed to expose the abdominal cavity, and the operculum removed to expose the pharyngeal and pericardial cavities. Visceral organs were then dissected free from the attached mesentery for subsequent examination.

Although the above dissection method was occasionally used to enable photography of the internal organs, most fish were examined by opening the abdominal cavity along the midline between the anus and the anterior point of the branchiostegals. Fish examined in this manner were held in position by a custom-made plastic cradle (Figure 9.1). All fish were examined between one and 24 hours after capture.

Based on observations made during the initial autopsies, each organ affected by barotrauma was categorised by its ‘condition’ (Tables 9.1 to 9.5). The ‘likely effect’ of each condition was categorised as fatal (will cause imminent mortality), critical (life-threatening), detrimental (will have some impact on the fish's health), or minimal (will have little impact on the fish’s health). Determination of the ‘likely effect’ was based on evidence available in the literature (e.g. McLeay et al. 2002), and the nature and severity of tissue/organ damage.

Figure 9.1 ABC Radio interviews Dylan Campbell, and volunteers Elizabeth Payne and Sarah Watkins, while they dissect a black jewfish held in a cradle. Note the orientation of the fish in the cradle and the incision to expose the abdominal organs.

Table 9.1 Description of observed eye condition in black jewfish and likely effect of barotrauma

Organ / injury	Condition	Description	Likely effect	Justification
Eyes / haemorrhage	Normal	Iris silver, clear with no evidence of blood vessels.	Nil	The eye is richly supplied with blood vessels. Intra-ocular haemorrhage is caused by rupture of blood vessels. The cause is uncertain, but likely relates to gaseous emboli rupturing smaller capillaries or physical trauma associated with increased intra-ocular pressure. Minor haemorrhage may resolve but severe haemorrhage may result in diminished visual acuity associated with retinal damage, retinopathy and blood pigments in the aqueous and vitreous humour.
	Mild haemorrhage	Iris has slight haemorrhage notable under close examination.	Minimal	
	Moderate haemorrhage	Iris has significant, concentrated haemorrhage in which ruptured blood vessels are obvious.	Minimal	
	Severe haemorrhage	Iris has acute, extensive haemorrhage continuous around periphery of iris/conjunctiva.	Detrimental	
Eyes / exophthalmos	Normal	Globe protrudes only slightly from the orbit at the edge of the conjunctiva, with the cornea showing only a slight convex peaking at the pupil.	Nil	Protrusion of the eye may result from increased intra-ocular pressure or from increased pressure in the peri-ocular region. In barotrauma, it is likely that both intra-ocular and peri-ocular pressure increases due to gas accumulation in the blood vessels. Mild exophthalmia may resolve, however, severe exophthalmos may be accompanied by vascular and nerve damage, resulting in blindness, as well as predisposing to subsequent trauma of the eye.
	Mild exophthalmos	Globe protrudes less than 5 mm from orbit.	Detrimental	
	Moderate exophthalmos	Globe protrudes between 5-10 mm from orbit.	Detrimental	
	Severe exophthalmos	Globe protrudes more than 10 mm from orbit.	Detrimental	

Table 9.2 Description of observed swim bladder condition in black jewfish and likely effect of barotrauma

Swim bladder / hyperinflation	Normal	Swim bladder inflated yet flexible under applied pressure. Room remains on the ventral side for organs in the abdominal cavity.	Nil	Hyper-inflation of the swim bladder results in compression of visceral organs, compression of blood vessels, particularly veins and capillaries and loss of venous return to the heart. Loss of venous return can lead rapidly to hypoxia, circulatory collapse and shock. In severe or prolonged cases, shock would likely be irreversible with death following. Prolonged circulatory failure will lead to tissue ischaemia, breakdown of tissues and release of toxic tissue breakdown products, again leading to shock and death. In addition, hyperinflation prevents fish swimming back to depth where the pressure might be reduced. Anomalous swimming behaviour, especially swimming on the surface, may result in predation or sun damage. Hyperinflation may also severely compromise auditory and lateral line function.
	Mild hyperinflation	Swim bladder slightly hyperinflated yet still flexible under applied pressure. Less room remain for organs in the posterior half of abdominal cavity.	Minimal	
	Moderate hyperinflation	Swim bladder significantly hyperinflated and resists applied pressure. Swim bladder fills posterior half of abdominal cavity squeezing fixed organs against the abdominal wall.	Minimal	
	Severe hyperinflation	Swim bladder acutely and severely hyperinflated and is hard/taunt. Swim bladder has obvious bulge at centre and fills posterior half of abdominal cavity squeezing fixed organs against the abdominal wall.	Detrimental	
Swim bladder / perforation	Normal	Swim bladder robust with generally consistent texture and thickness.	Nil	Perforation of the swim bladder results from hyperinflation and increased pressure to a point where the integrity of the wall of the swim bladder is lost. The resultant escape of gas into the abdominal cavity will occur suddenly. It is likely that this sudden release of gas may induce eversion and prolapse of the stomach. The release of gas into the abdominal cavity will also affect buoyancy; however, the influence of pressure on the abdominal organs due to compression by the hyper-inflated swim bladder would be expected to be reduced. Perforation and collapse of the swim bladder may seriously compromise auditory function. Given the importance of sound production in spawning of Sciaenids generally, swim bladder damage might interfere with reproductive function of individual fish
	Mild perforation	Swim bladder has a hole or lateral tear less than 5 mm in diameter or length.	Detrimental	
	Moderate perforation	Swim bladder has a hole or lateral tear between 5-10 mm in diameter or length.	Detrimental	
	Severe perforation	Swim bladder has a hole or lateral tear greater than 10 mm in diameter or length.	Detrimental	

Table 9.3 Description of observed abdominal viscera in black jewfish and likely effect of barotrauma

Abdominal viscera / displacement and compression	Normal	Visceral mass situated below swim bladder occupying anterior half of the abdominal cavity. Large intestine extends to anus at posterior of cavity	Nil	Hyper-inflation of the swim bladder will result in crushing injury to abdominal viscera and tearing of the mesentery associated with anterior displacement of the viscera. This occurs because of the visceral organs are compressed against the solid bony wall of the anterior body cavity. Direct and indirect consequences will occur as discussed under stomach, liver and spleen
	Mild displacement & compression	Visceral mass slightly displaced to the anterior of the abdominal cavity.	Minimal	
	Moderate displacement & compression	Visceral mass significantly displaced towards the anterior of the abdominal cavity. Stomach and small intestines only partly visible from ventral aspect.	Detrimental	
	Severe displacement & compression	Visceral mass acutely displaced towards the anterior of the abdominal cavity. Stomach and intestines barely visible from ventral aspect. Large intestine stretched between displaced small intestine and anus.	Critical	
Stomach / eversion and prolapse	Normal	Stomach situated below swim bladder occupying anterior half of abdominal cavity.	Nil	Eversion and prolapse of the stomach is a serious and irreversible consequence of barotrauma resulting from hyperinflation, together with perforation of the swim bladder forcing the stomach to evert through the oesophageal opening and prolapse to a varying extent into or out of the buccal cavity. In moderate to severe cases, the tissue trauma, tearing of mesenteric attachments, trauma to vasculature and nerves and architectural disruption of the abdominal viscera will ensure that no resolution is possible and the fish will ultimately die.
	Mild eversion and prolapse	Stomach partly everted and distal end situated within the pharyngeal cavity.	Detrimental	
	Moderate eversion & prolapse	Stomach fully everted and situated within the buccal cavity.	Critical	
	Severe eversion & prolapse	Stomach fully everted and protruding out of mouth.	Critical	

Table 9.4 Description of observed liver condition in black jewfish and likely effect of barotrauma

Liver / tissue trauma	Normal	A bridge of liver tissue and associated mesentery connects the two liver lobes situated on either side of the swim bladder.	Nil	Crushing trauma to the liver and subsequent separation and isolation of lobes of the liver may resolve in mild cases. In moderate or severe cases, tissue trauma would be expected to contribute to shock, especially if the blood supply was compromised. In the longer term, hepatic and pancreatic dysfunction is likely.
	Mild tissue trauma	Bridge of liver tissue and associated mesentery slightly torn or compressed.	Detrimental	
	Moderate tissue trauma	Bridge of liver tissue and associated mesentery significantly torn or compressed with nominal connection between liver lobes remaining.	Critical	
	Severe tissue trauma	Bridge of liver tissue and associated mesentery completely separated leaving two liver lobes isolated.	Fatal	
Liver / hepatic vein damage	Normal	Hepatic veins extend from near the midline of the liver tissue connecting the two lobes. They pass through transverse septum and connect to the heart.	Nil	The hepatic veins return blood from the liver to the heart. Rupture of these veins as a result of tissue trauma has dire consequences for the fish either due to acute haemorrhage or chronic metabolic dysfunction. Fish with severing of the hepatic veins will likely die.
	Mild hepatic vein damage	Hepatic veins slightly stretched but intact.	Detrimental	
	Moderate hepatic vein damage	Hepatic veins significantly stretched yet remain intact	Critical	
	Severe hepatic vein damage	Hepatic veins severed.	Fatal	

Table 9.5 Description of observed spleen condition in black jewfish and likely effect of barotrauma

Spleen / splenomegaly	Normal	Spleen elongated, triangular in shape. Spleen typically 1 cm wide by 6-7 cm long in black jewfish 100 -120 cm TL.	Nil	Splenomegaly (enlargement of the spleen) is a sign of circulatory collapse due to failure of venous return to the heart. It is a sign of shock. As above, prolonged or severe shock will become irreversible and the fish will die if the cause persists.
	Mild splenomegaly	Spleen slightly enlarged yet maintains normal shape. Spleen typically 1 cm wide by 7-8 cm long in black jewfish 100 -120 cm TL.	Detrimental	
	Moderate splenomegaly	Spleen significantly enlarged and slightly distorted in shape. Spleen typically 2 cm wide by 7-9 cm long in black jewfish 100-120 cm TL.	Critical	
	Severe splenomegaly	Spleen acutely enlarged and distorted in shape. Spleen typically 2-3 cm wide by 9-10 cm long in black jewfish 100-120 cm TL.	Critical	

9.4 RESULTS

9.4.1 Eyes

Various degrees of haemorrhaging within the globe (eyeball) were observed in 9% of fish landed from 10-15 m, and 12% of fish landed from 15-20 m (Figure 9.2). Haemorrhaging was contained within the cornea and was most prominent along the periphery of the conjunctiva. Exophthalmos was also observed in 9% of black jewfish landed from 15-20 m (Figure 9.3). Exophthalmos was not observed in fish landed from less than 15 m. No gas bubbles were observed within the globe of any fish.

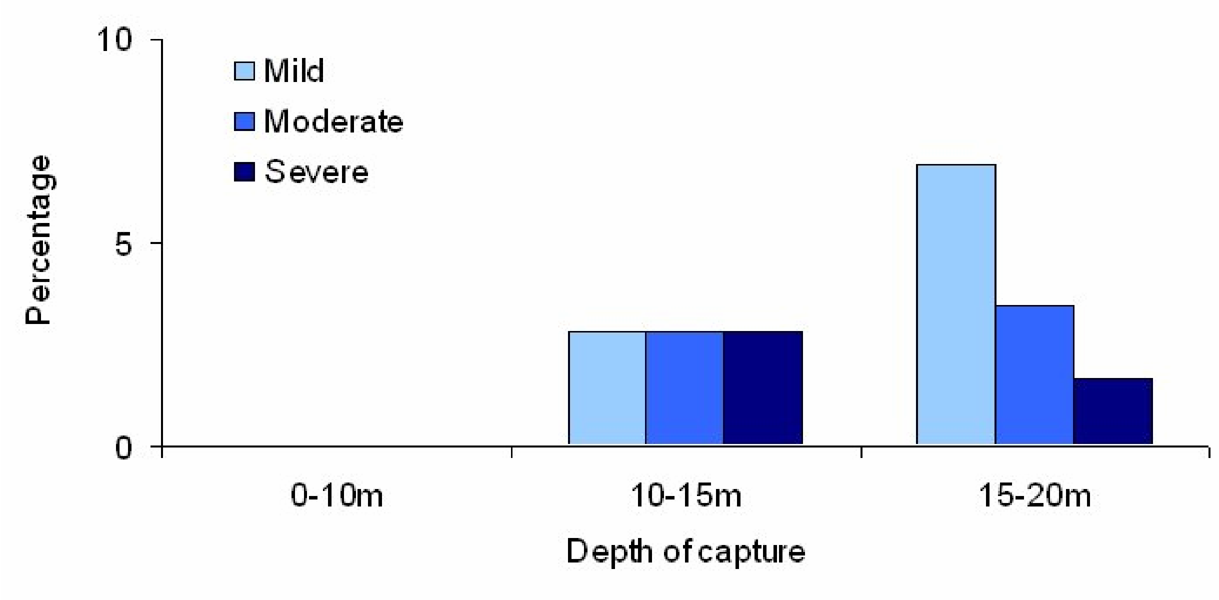

Figure 9.2 Percentage of black jewfish from various depths observed with haemorrhaging in the eye

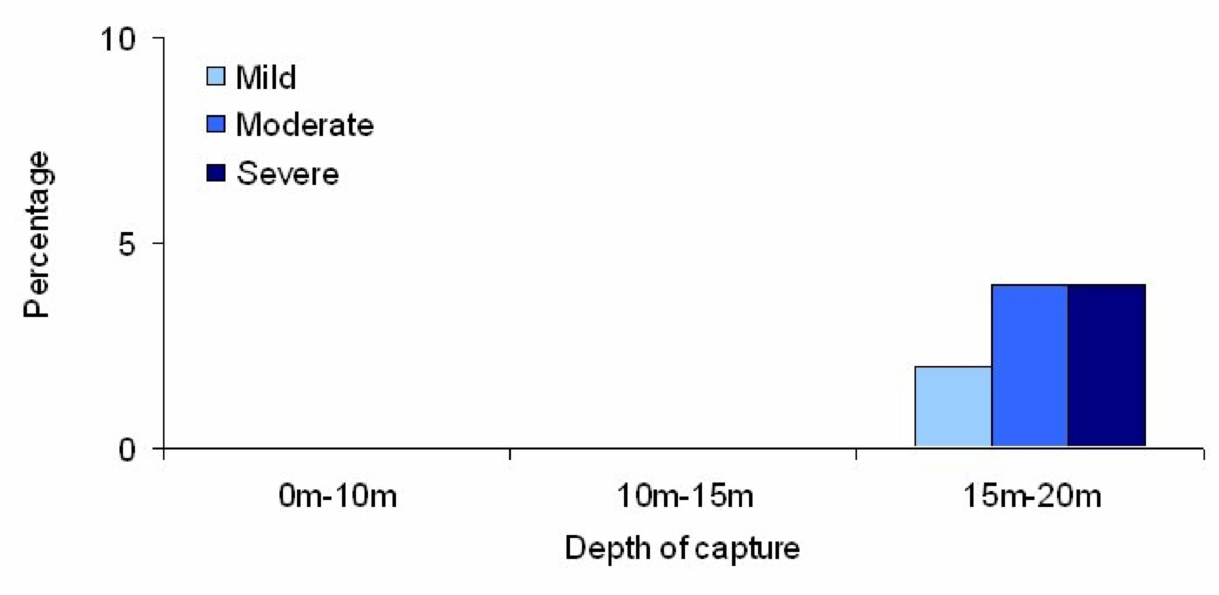

Figure 9.3 Percentage of black jewfish from various depths observed with exophthalmos

9.4.2 Swim bladder

Hyperinflation of the swim bladder was observed in 47% of black jewfish landed from 0-10 m, 92% of the fish landed from water 10-15 m deep, and only 16% of the fish landed from 15-20 m (Figure 9.4). The lower rate of hyperinflation in deeper water reflected the increased incidence of perforations in the swim bladder. Perforations were observed in only 3% of fish landed from water 10-15 m deep, but increased to 90% of fish landed from 15-20 m (Figure 9.5). There were no obvious weak points in the swim bladder wall as location of the perforations varied between individuals.

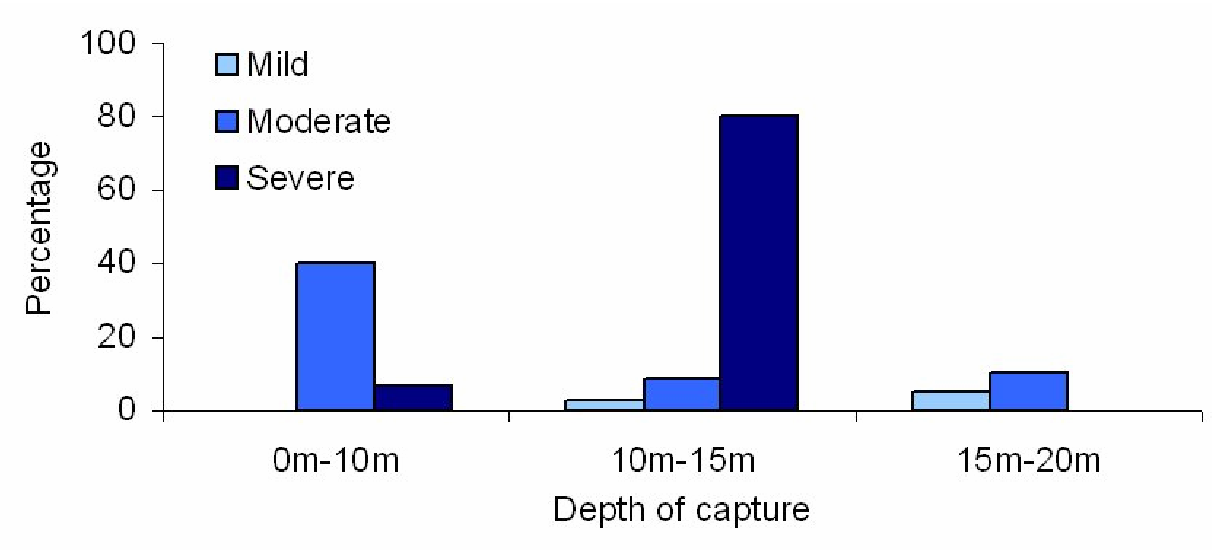

Figure 9.4 Percentage of black jewfish from various depths observed with hyperinflated swim bladders

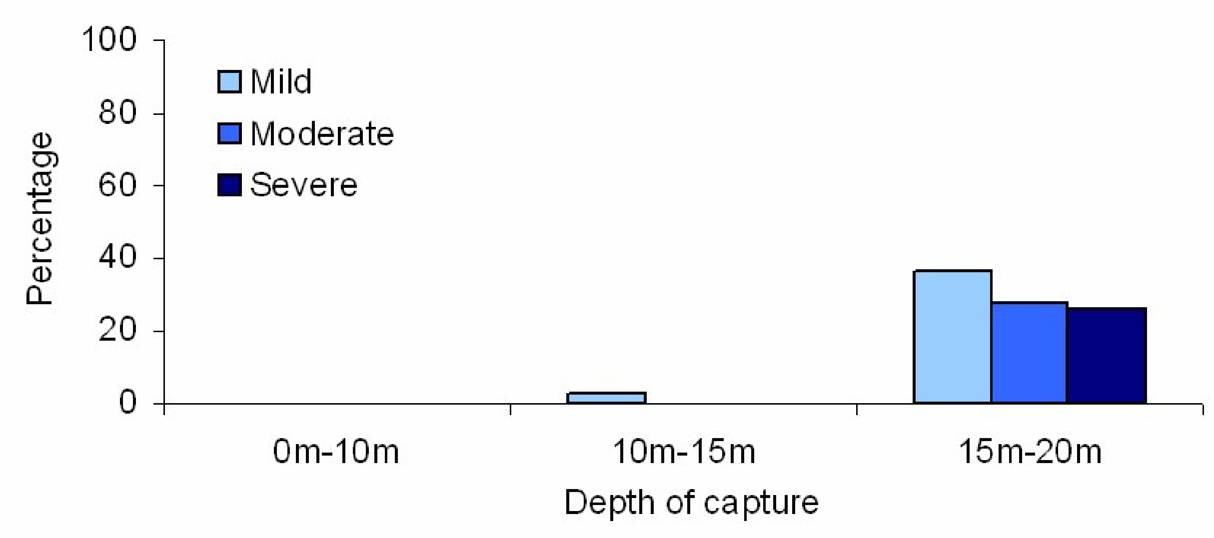

Figure 9.5 Percentage of black jewfish from various depths observed with perforated swim bladders

9.4.3 Abdominal viscera and stomach

Anterior displacement of the stomach and intestines within the abdominal cavity was related to the depth of capture. Displacement of the stomach and intestines occurred at all depths and was evident in 20% of fish from 0-10 m, 86% from 10-15 m, and 92% from 15-20 m (Figure 9.6). The stomach (and some of the alimentary canal nearest to the pyloric opening) was observed outside of the abdominal cavity in 17% of fish from 10-15 m and 100% of fish from 15-20 m (Figure 9.7). The stomach entered the pharyngeal cavity by everting through the oesophagus.

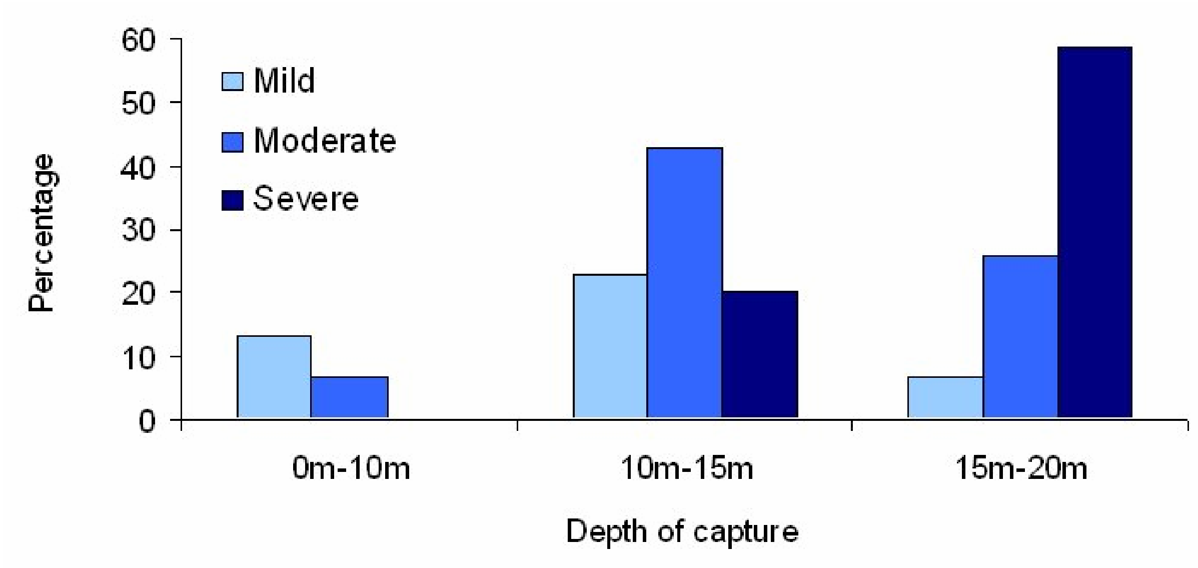

Figure 9.6 Percentage of black jewfish from various depths observed with displacement of the stomach and intestines within the abdominal cavity

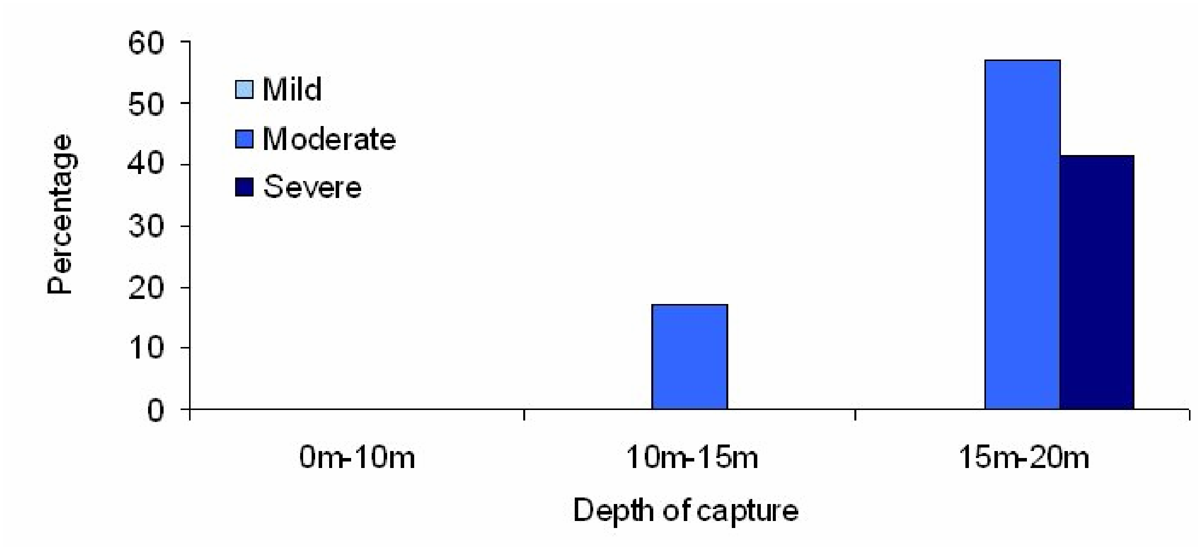

Figure 9.7 Percentage of black jewfish from various depths observed with everted stomachs protruding into the pharyngeal cavity or beyond

9.4.4 Liver

Liver tissue trauma was observed in 31% of black jewfish landed from 10-15 m, but only 3% of fish landed from 15-20 m (Figure 9.8). Severe liver damage, which is considered to be potentially fatal, was observed in 23% of the fish landed from 10-15 m. Damage to the veins which connect the liver to the heart was only observed in fish landed from 10-15 m (Figure 9.9). The damage affected 14% of fish landed from this depth. Severe vein damage, which is also considered to be potentially fatal, was observed in 11% of the fish from this depth.

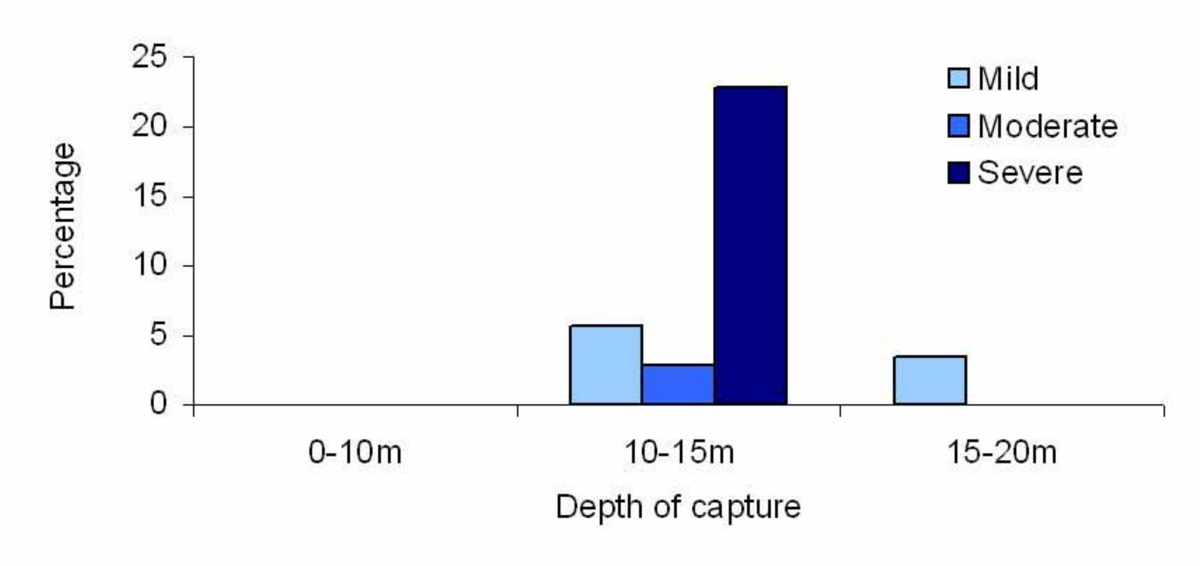

Figure 9.8 Percentage of black jewfish from various depths observed with liver tissue trauma

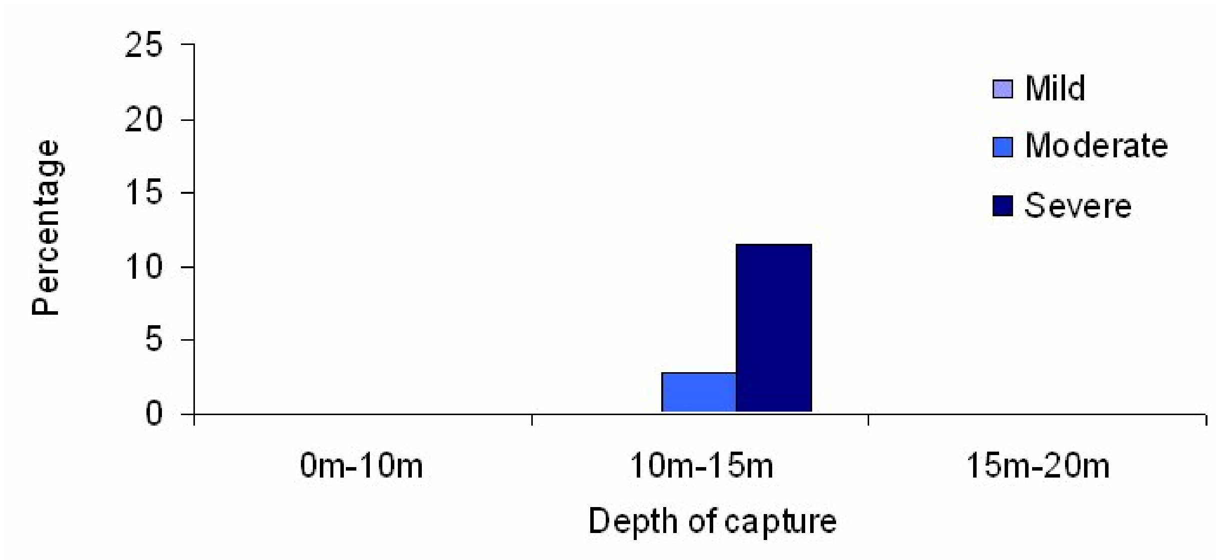

Figure 9.9 Percentage of black jewfish from various depths observed with damage to the hepatic veins that connect the liver to the heart

9.4.5 Circulatory system and the spleen

Congestion and thrombosis were observed in many fish, though the percentages are not presented as some instances may represent post-mortem changes. In addition to varying degrees of haemorrhage within the globe (Section 9.4.1) and stretched or ruptured hepatic veins (Section 9.4.4), barotrauma of the circulatory system was evident through the enlargement of the spleen in fish landed from 10-20 m (Figure 9.10). Splenomegaly was observed in 20% of fish landed from water 10-15 m, and 34% of fish landed from 15-20 m.

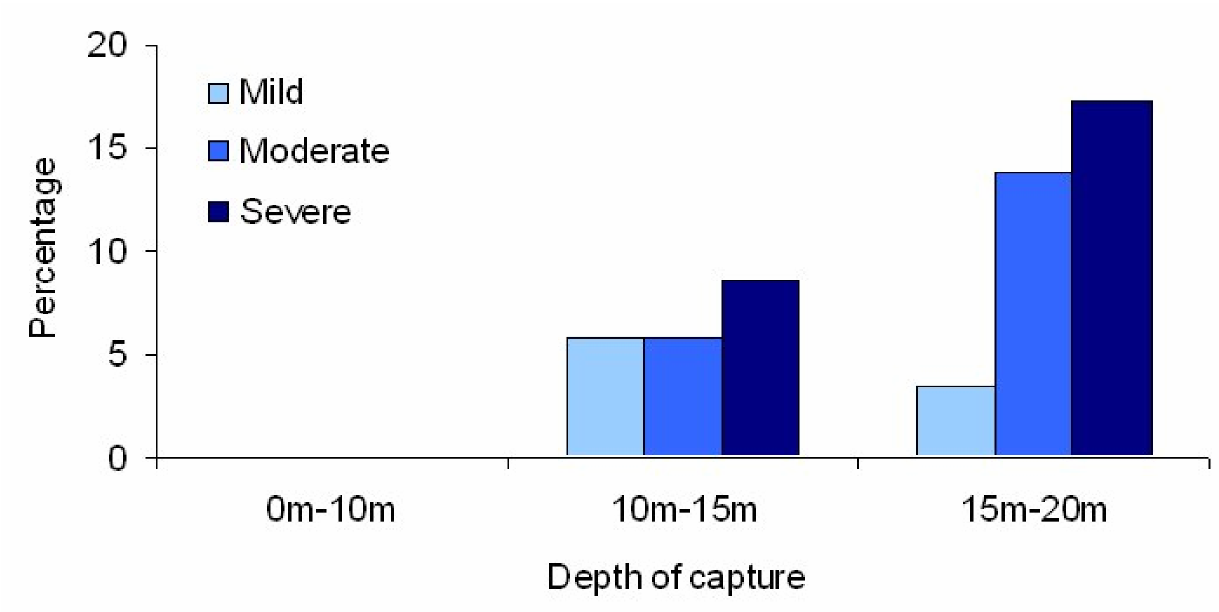

Figure 9.10 Percentage of black jewfish from various depths observed with splenomegaly

9.4.6 Other organs

The gall bladder of black jewfish is attached to the liver. Although the liver was often displaced (Section 9.4.3), the gall bladder was intact in all fish examined. Some fish showed staining of the adjacent liver tissue that suggested bile had leaked, however, the age and cause of the leak could not be determined.

The urinary bladder and gonads develop dorso-laterally at the posterior half of the abdominal cavity. Both organs are compressed by hyperinflated swim bladders; however, no damage was visible to the unaided eye. Histological sections of black jewfish ovaries (Chapter 6) revealed that some oocytes were damaged, though the cause could not be established.

The kidney of black jewfish is positioned on the ventral surface of the vertebral column and is protected by nodes on the vertebra; hence no damage was observed. The heart is situated in the pericardial cavity and is separated from the abdominal cavity by a rigid transverse septum. The pericardium sac was intact in all fish.

9.4.7 Fishing method and hook type

Black jewfish landed from 15-20 m were harvested by two fishing methods (handlines with 200 lb+ lines, n = 34: rods with 50 lb lines, n = 7). There was no apparent relationship between fishing method and the severity of barotrauma. This result was despite the different time taken to land a jewfish using 200 lb line (<2 minutes) versus 50 lb line (>4 minutes).

The type of hook used had a significant effect on the location of set hook at capture. Circle hooks set in the lip of black jewfish 93% of the time, with the remainder setting in the throat (Figure 9.11). When using j-hooks, only 28% were hooked in the lip, with a further 28% hooked in the throat (Figure 9.12). J-hooks set in the stomach of 41% of the black jewfish examined.

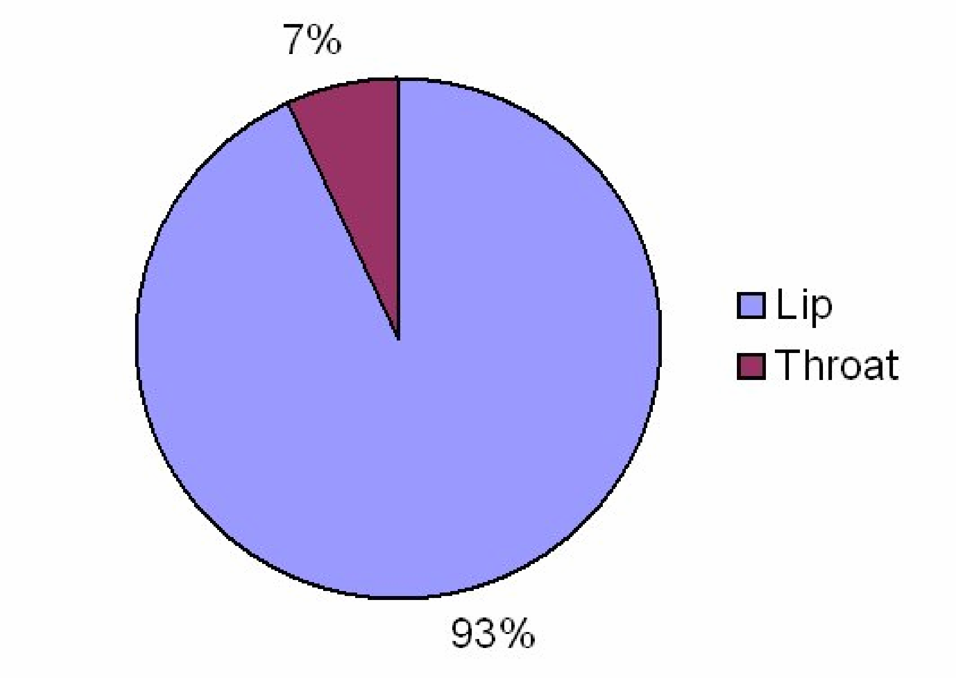

Figure 9.11 Location hooks set in black jewfish when fishing with 6/0 circle hooks (n = 100)

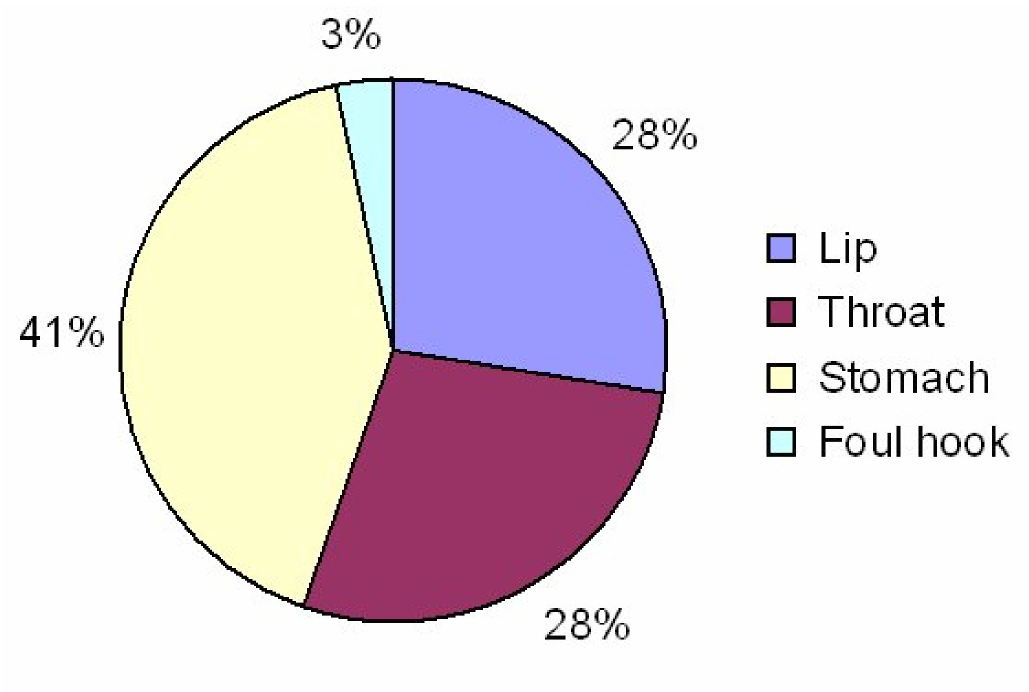

Figure 9.12 Location hooks set in black jewfish when fishing with 6/0 j-hooks (n = 58)

9.4.8 Fish length

Black jewfish landed from 15-20 m represented a wide range of sizes (<50 cm TL, n = 6; 51-100 cm TL, n = 6; >101 cm TL, n = 46). There was no apparent relationship between the size of the fish and the severity of barotrauma. Among the fish examined from this depth bracket:

- 100% of the fish had everted stomachs.
- >90% of fish from each group had displaced abdominal viscera.
- >80% of fish from each group had a perforated swim bladder.

9.4.9 Likely effect of injuries

The type and frequency of barotrauma-induced injuries was proportional to the capture depth. Black jewfish landed from water less than 10 m showed comparatively few effects of barotrauma. Swim bladder hyperinflation was observed in 47% of these fish and associated displacement of the abdominal viscera was observed in 20% of the fish. No other evidence of barotrauma was observed.

Black jewfish landed from 10-15 m were more prone to barotrauma. Swim bladder hyperinflation affected almost all fish (92%) and a small percentage had ruptured swim bladders (3%). Visceral organ displacement was also widespread (86%), and stomach eversion was evident (17%). Eyes showed haemorrhage in some fish (9%), though exophthalmos was not observed. The liver of 33% of these fish was damaged, the veins connecting the liver to the heart were damaged in 14% of the fish, and the spleen was enlarged in 21% of the fish.

When black jewfish were raised from 15-20 m, the prevalence of barotrauma-induced organ and tissue damage continued to increase. Swim bladder hyperinflation fell (16%) because most (90%) bladders had ruptured. Of particular detriment, displacement of the visceral mass and eversion of the stomach was evident in 100% of the fish. Haemorrhage and exophthalmos affected 12% and 10% of fish, respectively. While the liver and associated veins were exempt from damage (believed to be related to the large percentage of ruptured swim bladders), spleen enlargement occurred in 34% of the fish.

The likelihood of the fish not surviving these injuries increased with depth (Table 9.2). Among the black jewfish landed from 0-10 m, no injuries categorised fatal or critical were observed, though 14% of the fish had injuries deemed detrimental. Among the fish landed from 10-15 m, fatal and critical injuries affected 22% and 26%, respectively. A further 29% were affected by detrimental injuries. All black jewfish landed from 15-20 m were affected by injuries considered critical (Table 9.2).

Table 9.6 Barotrauma effects in black jewfish landed from various depths

Condition	0-10 m	10-15 m	15-20 m
Fatal effect			
Severe liver tissue trauma		22%	
Severe hepatic vein damage		11%	
Fish with single fatal injury		*11%*	
Fish with multiple fatal injuries		*11%*	
Total with fatal injury/injuries		**22%**	
Critical effect			
Severe abdominal viscera displacement		20%	60%
Moderate to severe stomach eversion		17%	100%
Moderate liver tissue trauma		3%	
Moderate hepatic vein damage		3%	
Moderate to severe splenomegaly		14%	31%
Fish with single critical injury[1]		*12%*	*33%*
Fish with multiple critical injuries[1]		*14%*	*67%*
Total with critical injury/injuries[1]		**26%**	**100%**
Detrimental effect			
Severe haemorrhaging within eye		3%	2%
Mild to severe exophthalmos			7%
Severe hyperinflation of the swim bladder	7%	80%	
Mild to severe swim bladder perforation		3%	90%
Moderate abdominal viscera displacement	7%	43%	26%
Mild stomach eversion and prolapse			
Mild liver tissue trauma		6%	3%
Mild hepatic vein damage			
Mild splenomegaly		6%	3%
Fish with single detrimental injury[2]	*14%*	*17%*	
Fish with multiple detrimental injuries[2]		*12%*	
Total with detrimental injury/injuries[2]	**14%**	**29%**	
Grand total	**14%**	**77%**	**100%**

[1] Excluding fish with fatal injuries. [2] Excluding fish with fatal or critical injuries.

9.5 Discussion

9.5.1 Eyes

The eyes of fish have a role in feeding, predator avoidance, social/schooling behaviour and possibly migration. In most black jewfish, the eyes showed no evidence of barotrauma-associated injury. The eyes of these fish showed a clear iris and the globe protruded only slightly from the orbit at the edge of the conjunctiva, with the cornea showing only a slight, even convex peaking at the pupil (Figure 9.13).

Almost 10% of the fish examined showed varying degrees of haemorrhage from the iris within the anterior chamber (Figure 9.14). Haemorrhage from the iris is likely to be the result of the rupture of capillary walls caused by decreased intravascular partial pressure, the release of gas from solution and the expansion of gas bubbles, possibly assisted by increased intravascular pressure. All fish with haemorrhage were landed from 10-20 m. No sign of intra-ocular haemorrhage was visible in fish from water shallower than 10 m.

Among the black jewfish landed from 15-20 m, 5% had exophthalmos (Figure 9.15). This condition may result from the enlargement of gas bubble nuclei within the eye and/or in retrobulbar tissues (Stephens et al. 2001). The factors initiating the formation of gas bubble nuclei are poorly understood despite their importance in supersaturated tissues in decompression sickness in humans (Stephens et al. 2001).

In humans, exophthalmos has been demonstrated to affect the muscles of the globe and the optic nerves (Ricker Polsdorfer 2006). In regards to fish, it is reasonable to suppose that the protrusion of the eye may damage the internal posterior muscles or the external rectus, oblique and extraocular muscles. Presumably, the optic nerve at the base of the eye may also be damaged in severe cases of exophthalmos.

The damage to the globe caused by haemorrhage or exophthalmos is likely to reduce or destroy vision at least temporarily and perhaps permanently in severe cases. Several fishers have informed the authors that they have seen many black jewfish with eyes that appear to be dysfunctional. Vision loss will affect all functions that the eye is associated with, though the impact on the fish will depend on the degree to which the function relies on the eyes versus other sensory organs.

It is evident that black jewfish remain able to feed without vision as they often take baited lines in water with zero visibility due to high turbidity. However, it would appear that the fish's ability to perform some other functions may be jeopardised, such as participating in spawning rushes (during which a female will rush towards the surface and a male will pursues her, each with the aim of spawning their gametes in close proximity).

Figure 9.13 Eye of a black jewfish showing no visible signs of damage

Figure 9.14 Severe haemorrhage within the cornea along the periphery of the conjunctiva

Figure 9.15 Severe exophthalmos of an eye of a black jewfish exposing the extraocular muscles

9.5.2 Swim bladder

Black jewfish have large, thick physoclistic (closed) swim bladders that almost fill the posterior half of the abdominal cavity (Figure 9.16). By adjusting the volume of gas in their swim bladder, fish can achieve neutral buoyancy and remain suspended at any depth with no muscular effort. The gas (mostly oxygen with variable amounts of nitrogen, carbon dioxide, carbon monoxide and argon) is sourced from the blood and secreted by the gas gland. The gas is removed by the resorption chamber and expelled via the gills.

When a forced, rapid or extreme ascent occurs during fishing, fish are unable to remove the gas as quickly as it expands under the decreasing pressure, resulting in hyperinflation (Figure 9.17). Hyperinflated swim bladders were observed in 47% of black jewfish landed from 0-10 m and increased to 92% in the 10-15 m bracket. Hyperinflation was evident in only 16% of fish landed from greater than 15 m as most of the swim bladders had ruptured (Figure 9.18).

Fish with hyperinflated swim bladders are often unable to descend unaided for a significant period of time. Parker et al. (2006) found that black rock fish (Sebastes melanops) require an average of 22 hours to become neutrally buoyant after a pressure increase equivalent to just 10 m. Fishers may ‘vent’ the fish with a hypodermic needle; however, this method is not suitable for large black jewfish due to the volume of gas within the bladder. Barbless weighted hooks are more suitable as they allow the prompt return to depth.

Perforated swim bladders may heal. For example, 77% of black rock cod with ruptured swim bladders were able to hold gas after 21 days (Parker et al. 2006). While the perforations heal, the fish can still swim through the water column as they are never much heavier than water (unit of mass of fish is 1.06-1.09 compared to marine water at 1.03 (Pelster 1993)). However, loss of swim bladder function would require the fish to expend more energy than normal at a time when the fish is unlikely to feed (Section 9.5.3).

The loss of swim bladder function may also impact on the fish’s ability to produce sound, which in turn may impact on spawning. Black jewfish have large sonic muscles within their lateral body walls and often produce a croaking sound when caught. If, like other Sciaenids, this sound is linked to courtship behaviours (Connaughton and Taylor 1995, Ueng et al. 2007), then damage to the swim bladder may reduce the fish’s ability to breed.

The swim bladder may also have a role in hearing. The presence of a compressible mass (gas in the swim bladder) in the vicinity of the otolithic organs of the inner ear is believed to amplify propagated pressure waves (sound). Sciaenids are believed to draw on this relationship to enhance the range and extent of their hearing (Ramcharitar et al 2001, Ramcharitar and Popper 2004). While this relationship has not been confirmed with black jewfish, it remains probable that the loss of swim bladder function may impact on a fish’s hearing. A similar relationship may also exist with the lateral line system (Webb 1998).

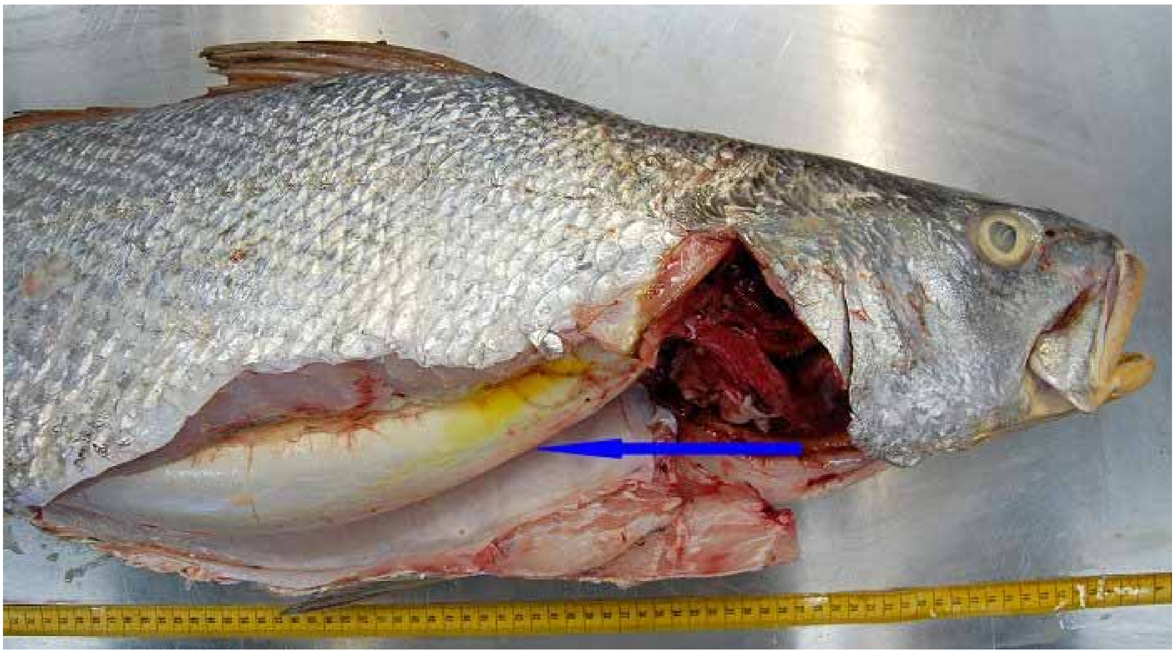

Figure 9.16 Normal size of a swim bladder in black jewfish

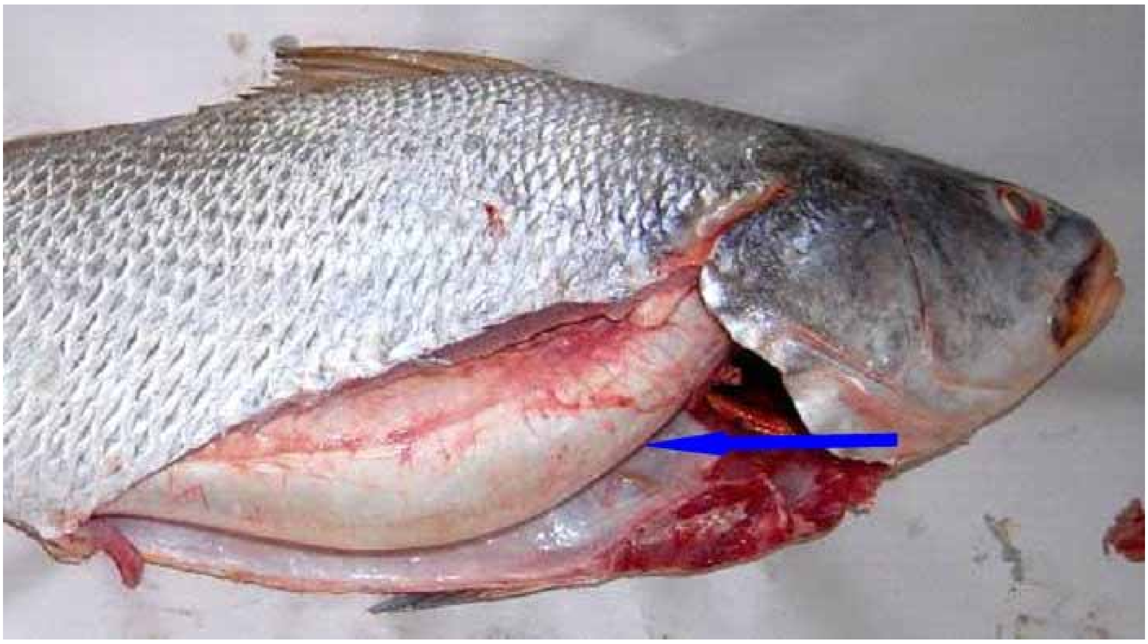

Figure 9.17 Severe hyperinflation of a swim bladder presenting in a black jewfish

Figure 9.18 Swim bladder of a black jewfish presenting a single perforation (circled)

9.5.3 Abdominal viscera and stomach

The black jewfish is an opportunistic predator (Rao 1963) and has a relatively short and simple digestive system typical of carnivores (Figures 9.19 and 9.20). Prey items pass through the short, distensible oesophagus and enter the stomach where digestion commences. The muscular stomach secretes protective mucus, pepsin, and hydrochloric acid, which maintains a stomach pH less than 4. The stomach contents enter the alimentary canal via the pylorus and move along the coiled small intestine before entering the large intestine.

When hyperinflation of the swim bladder occurred (Section 9.4.2), considerable force was applied to visceral organs located in the posterior half of abdominal cavity. Hyperinflated swim bladders were markedly distended and inflexible; exerting such pressure that architectural damage to the gonads and gametes cannot be excluded. Damaged oocytes were observed during the reproductive study of this project (Chapter 6) and the possibility of this damage occurring through barotrauma on capture warrants further examination.

Anterior displacement of the viscera within the abdominal cavity by the hyperinflated swim bladder was observed in most fish landed from depths greater than 10 m (86% at 10-15 m, 100% at 15-20 m). This displacement caused extensive damage to the mesenteric attachments supporting the abdominal organs, with potential to traumatise or obstruct the nerves and circulatory system (Section 9.5.5).

Eversion of the stomach was frequently observed (17% at 10-15 m, 98% at 15-20 m) and is considered to occur when gas from the perforated swim bladder entered the abdominal cavity (Figures 9.21, 9.22 and 9.23). It is contended that as a result, severe physiological dysfunction of the stomach will result from loss of protective mucus, altered pH and vascular obstruction. Protrusion of the stomach also further displaced the visceral mass. In severe examples, viscera were drawn into the pharyngeal cavity; being displaced to the extent that the large intestine was stretched (Figure 9.21).

It appears many fishers have punctured the organ protruding from the mouth in the belief they were piercing the swim bladder. While this practice will release the gas, perforating the stomach presents two potentially fatal risks. Firstly, the pyloric chambers and the small intestine are always present within everted stomachs, and they may be pierced or severed. Secondly, even if the fish is then able to draw its stomach back through the oesophagus, which is improbable, the perforation may allow water, acid, enzymes and bacteria to enter the abdominal cavity likely resulting in fatal peritonitis.

It is well established that the stomach and urinary organs are central to maintaining blood osmolality in adult teleosts (Varsamos et al. 2005, Forgan and Forster 2007). Any disruption to the function of these organs may render the fish unable to maintain homeostasis of the body's water content. It is possible dehydration may result from the displacement of the abdominal viscera, eversion of the stomach or its perforation. This has not been demonstrated in any fish species studied to date, but in theory could lead to the death of the fish.

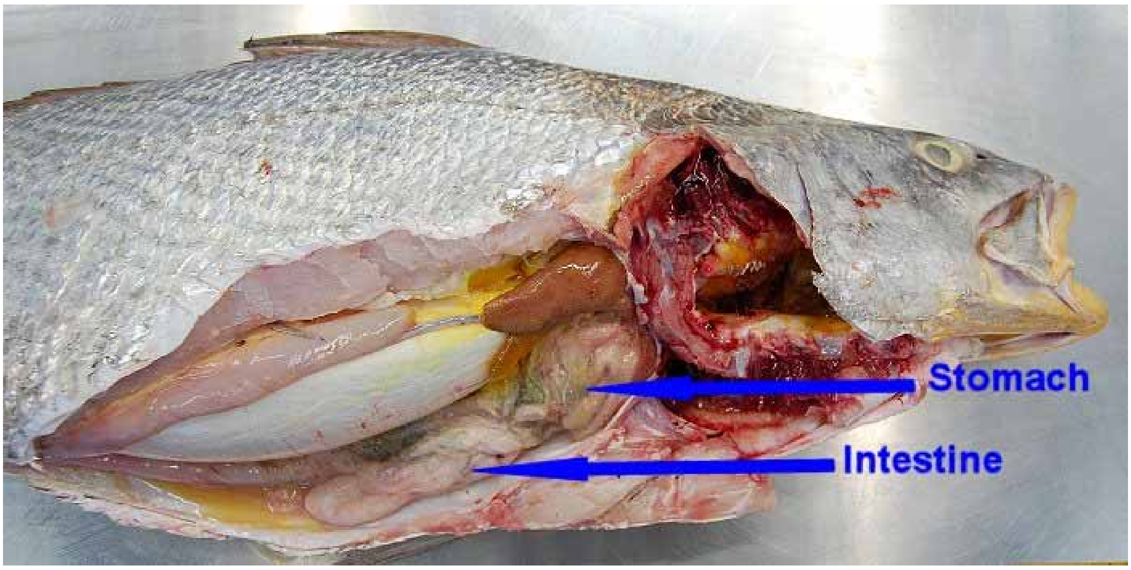

Figure 9.19 Normal position of stomach and intestine within the abdominal cavity in a black jewfish

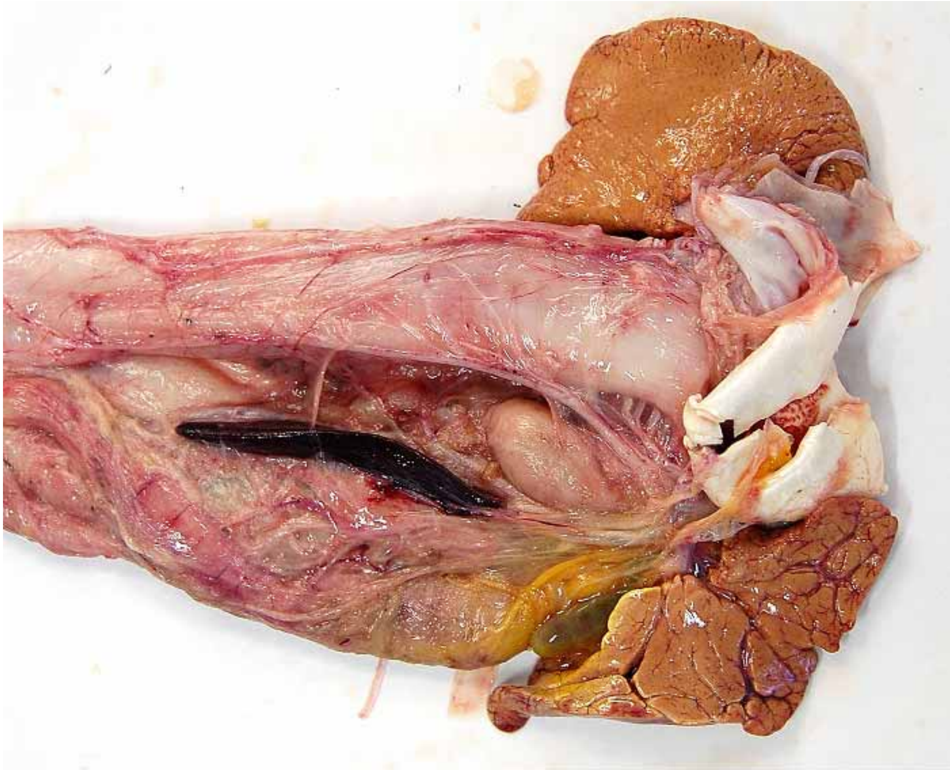

Figure 9.20 Visceral mass dissected from a black jewfish landed from water 0-10 m deep showing intact mesentery and normal position of abdominal organs.

Figure 9.21 Displaced visceral mass and everted stomach in a black jewfish landed from 15-20 m. Compare with disposition of the organs in Figure 9.19.

Figure 9.22 Visceral mass dissected from above specimen showing displaced organs, everted and congested stomach and thrombosis of gonadal artery

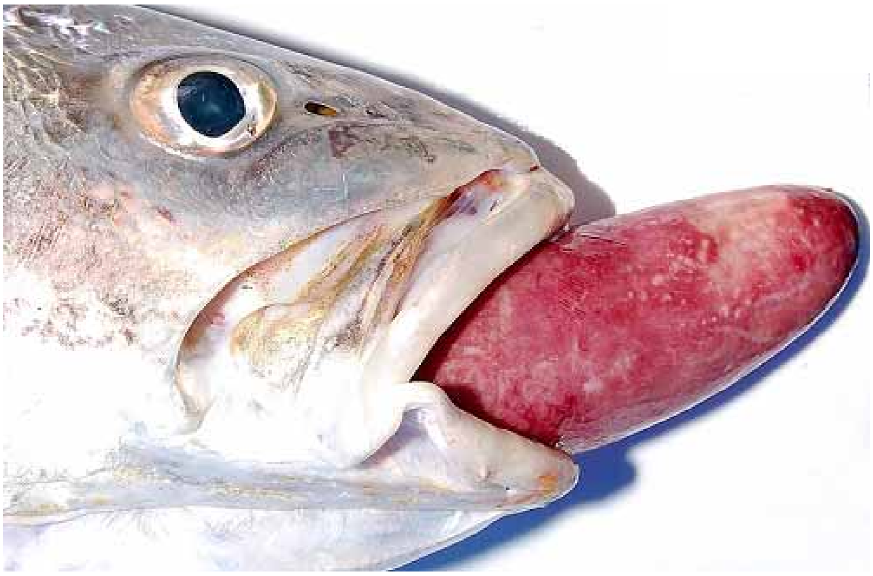

Figure 9.23 Everted stomach of a black jewfish

9.5.4 Liver

The liver performs an immense number of life-sustaining tasks that impact on all body systems. Key fundamental roles of the liver include:

- Vascular (e.g. formation of lymph and the hepatic phagocytic system).
- Metabolic (e.g. control of synthesis and utilisation of carbohydrates, lipids and proteins).
- Secretory and excretory (e.g. synthesis of bile).

The liver of black jewfish has two lobes (normally positioned on either side of the swim bladder) joined by a bridge of liver tissue covered by a fragile, clear mesentery (Figures 9.24 and 9.25). Two centrally located hepatic veins extend from the liver, pass through the transverse septum (which separates the abdominal cavity from the pericardial cavity) and connect to the heart.

Liver tissue trauma was observed in 31% of black jewfish landed from 10-15 m and 3% of fish landed from water 15-20 m (Figure 9.26 and 9.27). Among fish with severe liver damage (23%), the bridge of tissue was damaged to the extent that the two lobes were completely isolated. It appears this occurs when the swim bladder hyperinflates but does not rupture and the displaced abdominal viscera are held against the rigid transverse septum and muscular oesophagus.

The exact cause of damage to the liver bridge is uncertain, but may have formed in the following way:

- The fragile liver bridge mesentery tears when anterior displacement of the abdominal viscera forces the two laterally located lobes apart.
- The liver (and displaced viscera) push into the oesophagus and are subsequently damaged by the grinding action of the pharyngeal plates.
- Hard items in the stomach (such as crabs) compress or abrade the bridge of liver tissue.

Mild to moderate liver damage is likely to cause at least temporary interruption to vascular, metabolic, secretory and excretory functions. Whether permanent loss of function occurs, or the breakdown of the isolated liver tissue occurs, remains unclear. The liver is renowned as a highly regenerative organ, and so it may be possible that the liver may rebuild. Fish with severe liver damage are considered unlikely to survive. The isolated portions of tissue are likely to undergo degeneration and necrosis, inciting inflammation and release of toxic tissue products.

The hepatic veins between the liver and the heart were also damaged in 14% of the black jewfish from 10-15 m. Mild to moderate damage to these veins would seriously diminish the likelihood of the fish surviving if released. Fish with severe damage to these veins (11%) were considered unlikely to survive. Rupture of the hepatic veins may quickly result in haemorrhage, low blood pressure, circulatory collapse and shock. Any surviving fish would suffer severe hepatic dysfunction. Circulatory failure is discussed further in Section 9.5.5.

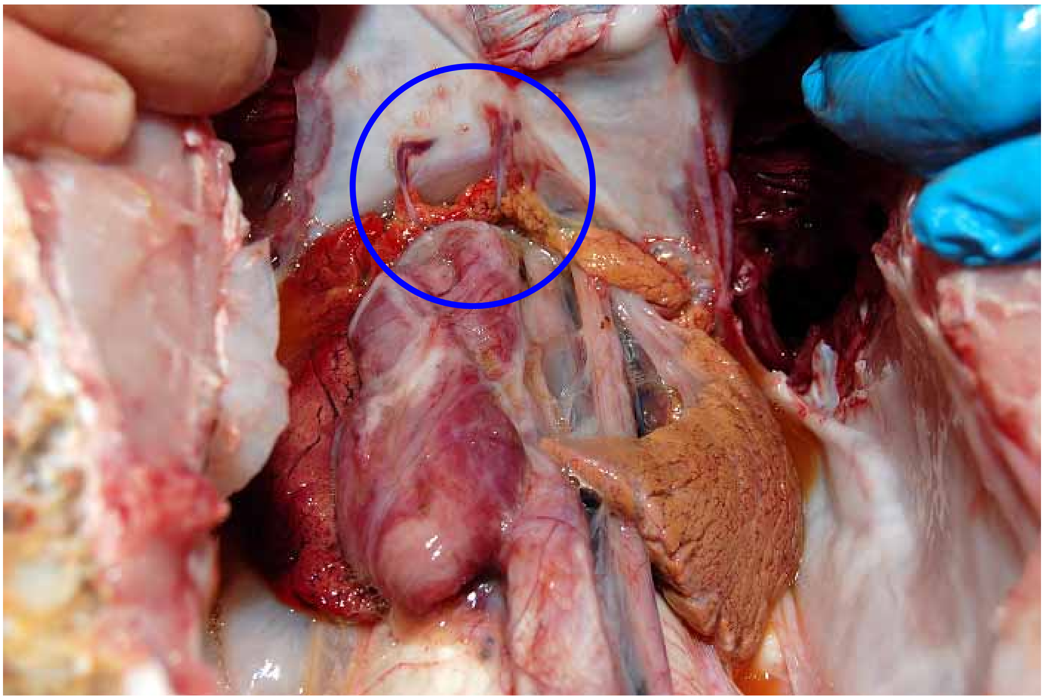

Figure 9.24 Normal position of liver and hepatic veins (circled) observed in black jewfish

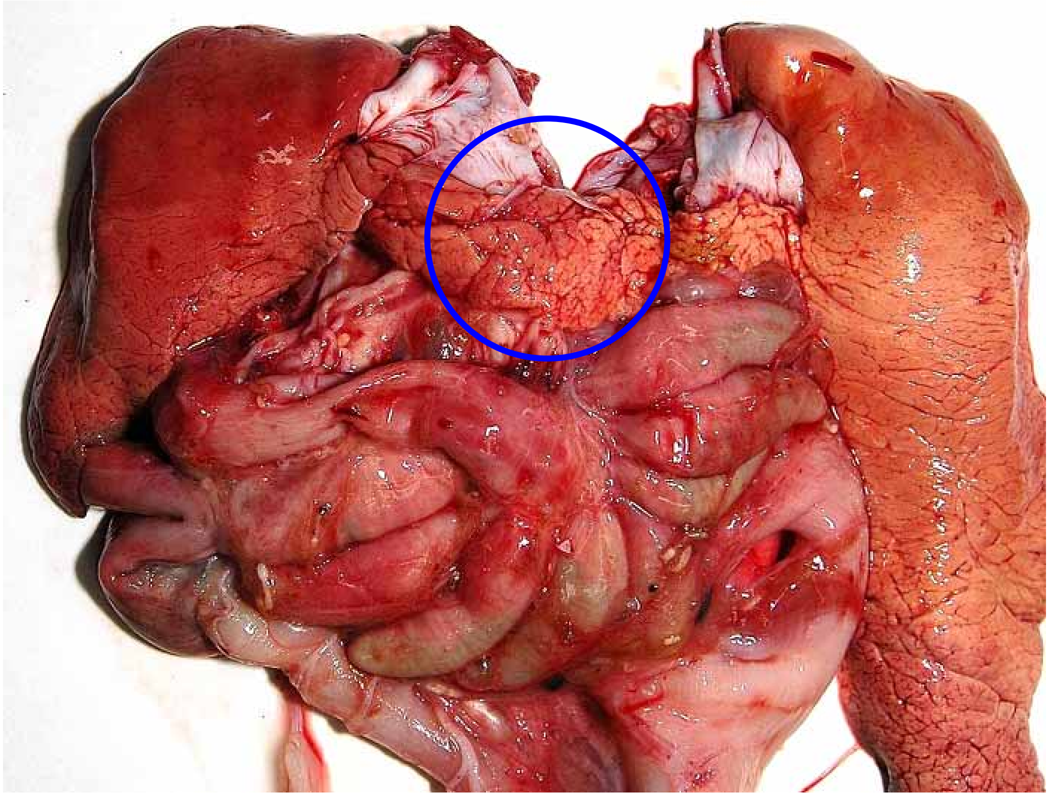

Figure 9.25 Dissected liver and hepatic veins (circled) of black jewfish landed from water 0-10 m deep

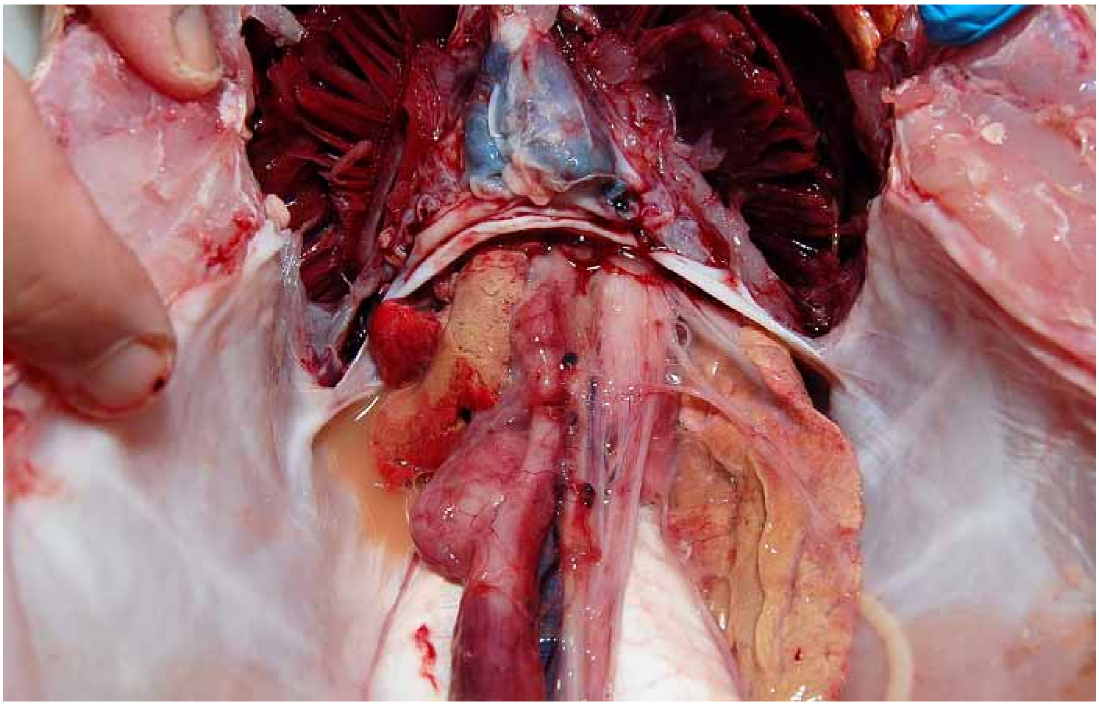

Figure 9.26 Anterior displacement of the liver in a black jewfish landed from 15-20 m

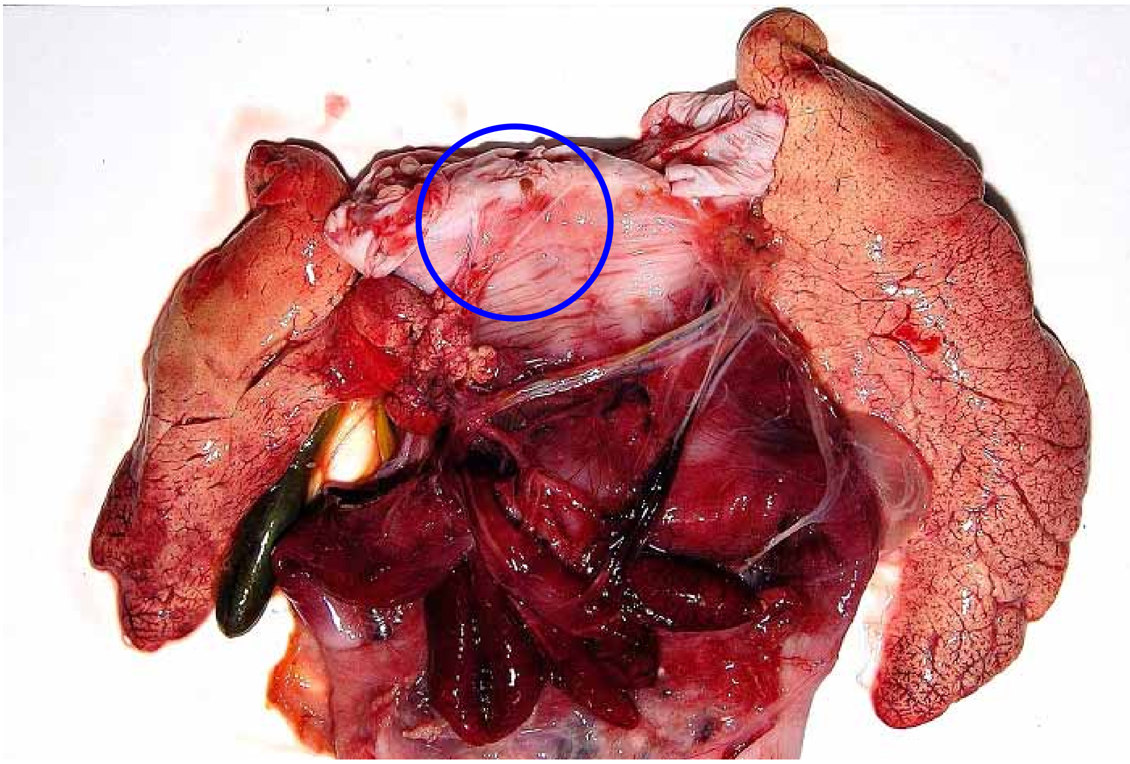

Figure 9.27 Dissected liver and hepatic veins (circled) of black jewfish landed from 15-20 m. Note the two liver lobes are no longer connected by a thick layer of liver tissue and the portal veins are stretched.

9.5.5 Circulatory system

The circulatory system of fish is relatively simple. Deoxygenated blood circulates from the heart to the gills, where it is oxygenated among the gill lamellae. It then continues through the dorsal aorta to the arteries supplying the various organs and tissues with oxygen and nutrients. The blood returns to the heart via the venous system. Among the black jewfish examined, interruption to the circulatory system was observed in several forms.

Haemorrhage (loss of blood from the vessels) was observed in the eyes of black jewfish (Section 9.4.1), and was likely a result of expanding gas emboli rupturing blood vessels. Thrombosis (blockage of a blood vessel by clotting) was also observed, most visibly within the gonadal artery (Figure 9.22). The blockage may also have been caused by a gas bubble, but appeared more likely to be a product of reduced blood flow resulting from the anterior displacement and compaction of the visceral organs (Section 9.4.3).

Congestion (the abnormal accumulation of blood in blood vessels) was most commonly observed in everted stomachs (Figure 9.22), the pyloric chambers and small intestine. Congestion of the stomach is considered the result of loss of venous return due to excessive stretching while inflated with gas from the swim bladder/abdominal cavity. The congestion of the pyloric chambers and intestine is considered to be the result of compression caused by displacement into the pharyngeal cavity, again with loss of venous return.

Damage to the veins connecting the liver and heart was considered critical when they were significantly stretched and fatal when they were severed (Section 9.3). Both may lead the fish into irreversible shock. Another type of damage involving the liver, splitting of the tissue connecting the two lobes, was also considered fatal when severe (Section 9.3). The associated damage to the circulation system was expected to lead to the breakdown of isolated liver tissue and result in the release of toxic tissue products.

Splenomegaly was observed in 25% of black jewfish examined and was interpreted as evidence of circulatory failure resulting from the obstruction of venous return (Figures 9.28 and 9.29). If this condition persists, the subsequent fall in blood pressure will lead the fish into shock. This implies if fish are to be released, they should be returned to depth as soon as possible to remedy the causes of the circulatory interference (such as gas bubbles and displaced viscera).

Parker et al. (2006) recommend that fish destined for release should also be brought to the surface relatively quickly. The longer a fish resists a forced accent, the more lactate and carbon dioxide will build-up in tissues, which will result in lower solubility of gases (McDonald and Milligan 1997). Parker et al. (2006) assert that this physiological effect means barotrauma may continue to worsen as long as the fish is at low ambient pressure, as blood pH will remain depressed or continue to decrease. This is supported by observations during this study, which include eversion of the stomach minutes after fish had been brought onboard the vessel.

Figure 9.28 Normal sized spleen of a 108 cm TL black jewfish (Actual size)

Figure 9.29 Enlarged spleen of a 106 cm TL black jewfish landed from water 15-20 metres deep (Actual size)

9.5.6 Hook type

The type of hook used had a considerable influence on the location where the fish would be hooked. Circle hooks proved most suitable for catching and releasing jewfish; 93% of the time they set in the lip (Figure 9.30). The remainder of circle hooks observed set in the throat. In contrast, j-hooks only set in the lips of 28% of the fish examined, with a further 28% being hooked in the throat.

Of concern, 41% of the fish landed with j-hooks had been hooked within the abdominal cavity (Figure 9.31). An autopsy conducted on one fish with a j-hook set in the abdominal cavity revealed how dangerous this situation may be to the fish. The hook had pierced through the liver tissue connecting the two lobes, only narrowing missing the hepatic veins which supply blood from the liver to the heart.

Furthermore, the hook had punctured the transverse septum and the tip of the barb had entered the pericardial cavity on the other side. The tip of the hook was in contact with the pericardium sac that surrounds the heart. If the hook had ruptured the sac, the pericardial fluid would have leaked. This fluid acts as a lubricant to allow normal heart movement within the chest. Hence, loss of this fluid may compromise the functioning of the heart.

Most comprehensive catch and release guides recommend fishers simply cut the leader when fish are hooked in the abdominal cavity. Common theory suggests the fish’s immune response may free the barb from the tissue; however, there is the risk that the hook may reset within abdominal cavity as the fish attempts to regurgitate it through the oesophagus.

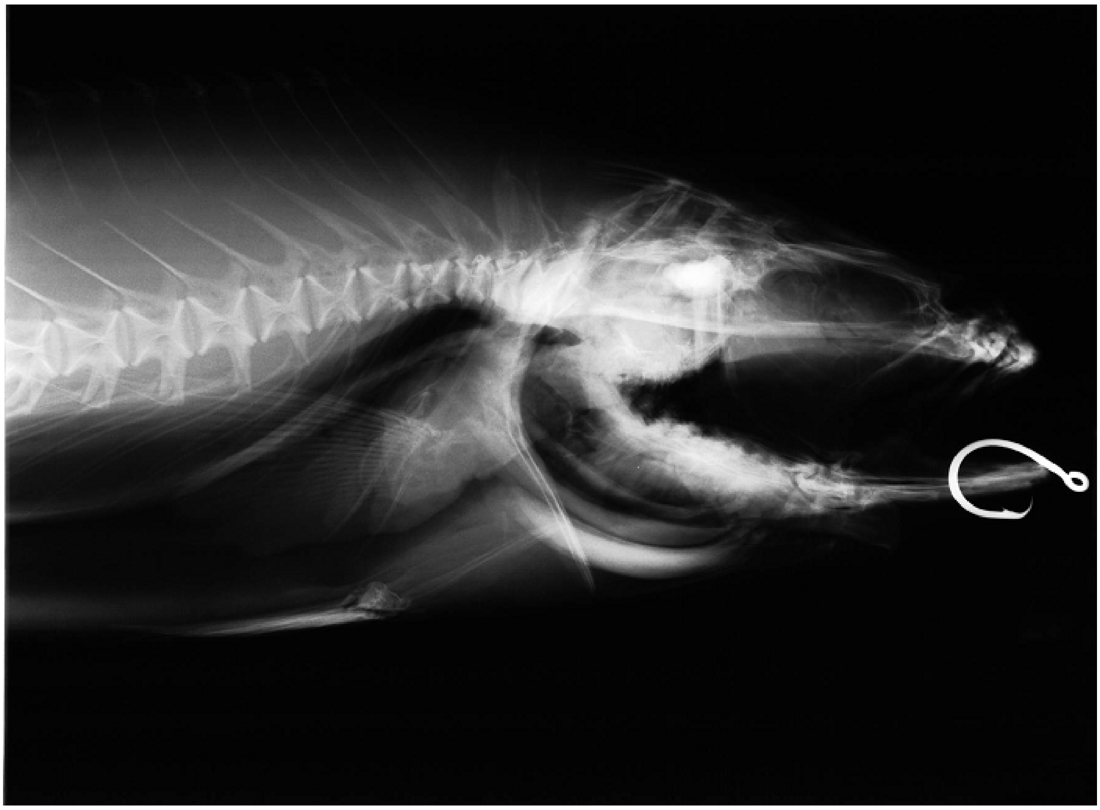

Figure 9.30 X-ray image of a black jewfish with a 6/0 circle hook set at the anterior end of the lower jaw (i.e. “lip hooked”)

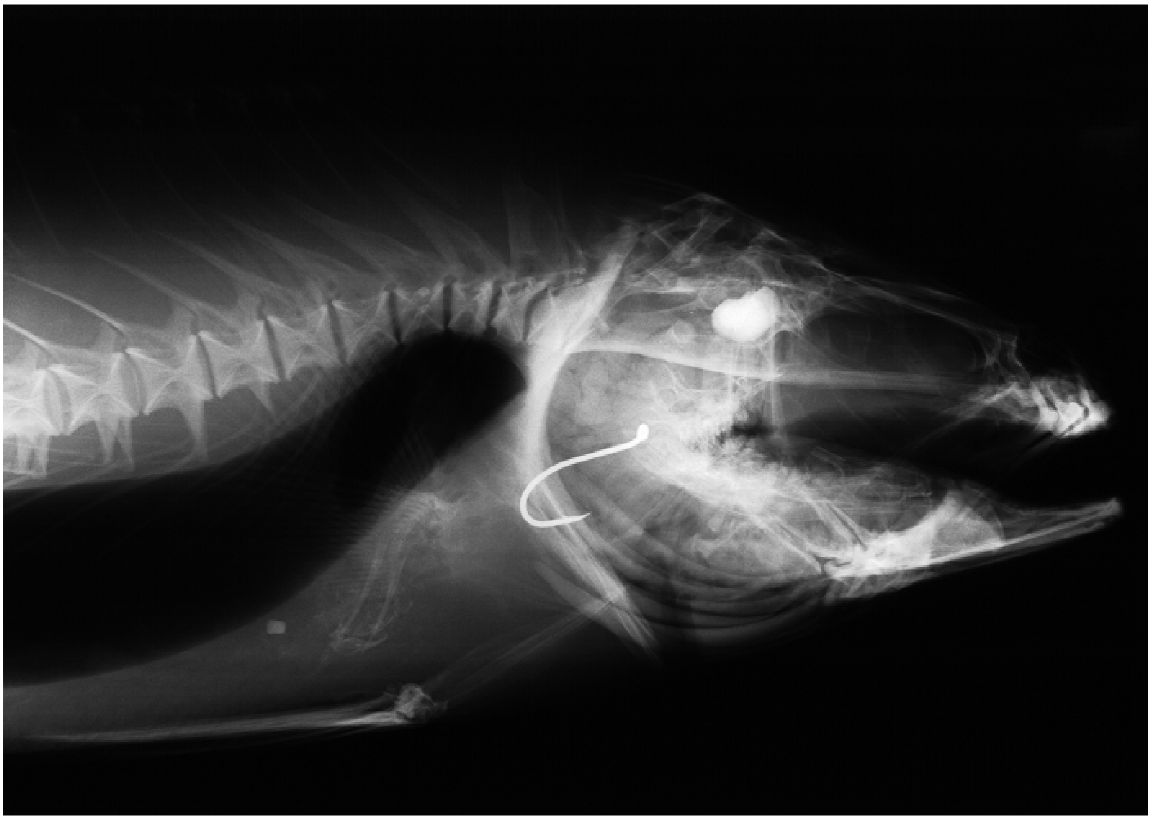

Figure 9.31 X-ray image of a black jewfish with a 6/0 j-hook set at the anterior end of the abdominal cavity (i.e. “gut hooked”)

9.6 CONCLUSIONS

Black jewfish are highly susceptible to barotrauma, showing a range of effects including; haemorrhage and/or exophthalmos of the eyes, hyperinflation or rupture of the swim bladder, displacement and damage to visceral organs (most notably the stomach and liver) and damage to the circulatory system. The size of the fish, and the method of fishing, had no affect on the type and extent of injuries. Rather, the injuries were related to water depth.

Black jewfish landed from less than 10 m water depth showed few signs of barotrauma. Of the fish examined from this depth range, no injuries categorised as fatal or critical were observed, and only 14% of the fish were affected by injuries categorised as detrimental. Detrimental injuries were described as significant but not life-threatening. It was deemed possible that all black jewfish landed from water 0-10 m deep could survive if handled and released appropriately (see Section 9.7).

Among the black jewfish landed from 10–15 m depth, 22% had injuries categorised as fatal and a further 26% of the fish had injuries categorised as critical. Fatal injuries were described as mortal damage, and critical injuries were described as life-threatening. It was therefore concluded that 48% of fish landed from water 10–15 m deep may not survive if released. Such estimates of depth-specific post-release mortality rates can now be incorporated into future stock assessments of black jewfish.

All black jewfish landed from 15–20 m had critical injuries that rendered them unlikely to survive if released. At this depth, the swim bladder typically ruptured allowing gas to escape into the abdominal cavity. This ultimately led to the stomach everting through the oesophagus. Puncturing the stomach to release the gas will not assist in the recovery of the fish even if the stomach is able to reposition itself within the abdominal cavity (Section 9.5.3).

Fishers wishing to catch and release black jewfish should fish in water less than 10 m deep. In deeper water, fishers should take action to avoid catching more jewfish once they have reached the legal possession limit (or their own limit). Fishers should change to a smaller hook size to target smaller fish such as snappers, or move to a new location. This advice is particularly relevant to those fishing in jurisdictions which have a minimum (and in some cases a maximum) size limit for black jewfish (e.g. Queensland).

While it will never be possible to eliminate all incidental mortality, sound catch and release practices are integral to achieving the optimal use of our fish stocks. Standard best practices should be applied to every fish; but because barotrauma affects even closely related species in different ways (see FRDC project 2003/019, National strategy for the survival of released line-caught fish: tropical reef species), specific advice is sometimes required for particular species or groups of fishes.

Research and management programs should continue to work towards improving the survival rate of released fish. Further research should be initiated to examine other species believed to be highly susceptible to barotrauma, particularly those species in which the stomach everts (e.g., tusk fish, snappers). Government and non-government organisations should continue to revise and promote advice for catch and release fishers.

9.7 Advice for catching and releasing black jewfish

It is recommended that fishers who wish to catch and release black jewfish should:

1. Use large circle hooks

Circle hooks set in the lip or mouth of all of black jewfish examined. Circle hooks are easy to remove due to the location they set and their unique design which allows the hook to be freed with a single, circular motion. These hooks help minimise handling time allowing the fish to be promptly released.

J-hooks set in the lip or throat of only 56% of the black jewfish examined, leading to the hook setting in the abdominal cavity of 41% of the fish. Hooks in the abdominal cavity may pierce vital organs or veins and cannot be removed by the fisher. This requires the fisher to cut the leader.

2. Fish as shallow as possible

Black jewfish examined during this study showed few signs of barotrauma when landed from less than 10 m. However, the effects of barotrauma increased with depth. Fatal or critical effects of barotrauma were evident in 48% of black jewfish landed from 10–15 m, and 100% of black jewfish landed from deeper than 15 m.

3. Do not return a jewfish with an everted stomach unless necessary

As a rule of thumb, we recommend that black jewfish with everted stomachs not be released unless necessary. The collective effects of barotrauma render these fish highly unlikely to survive. Fishers should target other species once they have reached the legal limit (or their own limit) of black jewfish. Perforating the everted stomach will not help the fish and is not recommended.

4. Promptly return healthy fish with a weighted hook

Time is critical in reversing the effects of barotrauma. 'Venting' black jewfish with a hypodermic needle is considered too slow given the large volume of gas in the swim bladder. Weighted hooks are recommended as they help to quickly return fish with inflated bladders.

5. Follow standard best practices for releasing fish

All fishers should be familiar with standard best practices for catching and releasing fish. These general rules should be applied at all times for all fish including black jewfish. A range of pamphlets are available from DPIFM (see inside cover for contact details) and InfoFish (www.info-fish.net/releasefish/).

10. BENEFITS AND ADOPTION

Information gained during this project (and the related FRDC Project 2004/002: Spatial management of reef fisheries and ecosystems: Understanding the importance of movement) has greatly enhanced our understanding of the biology and movement of black jewfish in the NT. Such knowledge will benefit commercial, recreational and indigenous fishers alike. The new information will be integrated into future stock assessments of black jewfish, thereby enhancing the capacity of fisheries managers to provide for the sustainable and optimal use of the resource.

The studies investigating the reproductive strategy and age/size frequency of black jewfish have provided baseline information required for informed assessment of the status of local stocks. Studies involving acoustic tagging, habitat mapping and otolith microchemistry (conducted outside of the scope of this project but based on otoliths collected in the age study) have developed information necessary to ensure that monitoring and management operate at an appropriate scale.

NT Fisheries has proposed a reduction in the personal possession limit for black jewfish from five to three fish. This matter is currently under Government consideration.

NT Fisheries also hosted a 'Jewfish Workshop' in September 2006 to present the preliminary findings of this project and discuss future research needs. The meeting was attended by around 30 delegates representing all relevant stakeholder groups. Attendees supported three initiatives and developed three new initiatives (see Section 11). Of these six potential works, two were implemented during the course of this project:

- *The effect of barotrauma on black jewfish*: This study was funded by the NT Government and FRDC (through funds saved in other areas of this project). The work generated specific advice for catching and releasing black jewfish. It also provided the first estimates of depth-specific post-release mortality rates for black jewfish, which can be incorporated into future stock assessments for this species. The Amateur Fishermen's Association of the NT and InfoFish are disseminating information generated by this study.

- *Black jewfish morphometrics.* NT Fisheries implemented this study with the aim of developing a cost-effective long-term monitoring program for black jewfish. The study has identified a positive correlation between the length of the fish and the length of some fins (See Chapter 5). It is anticipated a trial monitoring program that implements these findings will be initiated in 2008.

To ensure widespread understanding of the project's objectives, methods and findings, NT Fisheries and the Australian Institute of Marine Science developed a series of media releases and articles resulting in widespread coverage throughout all stages of this project. This project (and the related FRDC Project 2004/002) featured on at least 66 occasions through the following outlets:

- Newspapers (16)
- Magazines (10)
- Websites (10)
- Television (8)
- Radio (6)
- Newsletters (5)
- Poster (5)
- On-line forums (4)
- Pod casts (3).

Seven seminars relating to the results of this project (and the related FRDC Project 2004/002) were given by the principal investigator. A series of pamphlets and posters have also been produced by NT Fisheries to assist in the dissemination of the project's findings.

11. FURTHER DEVELOPMENT

The various initiatives supported and developed by attendees at the 'Jewfish Workshop' held in September 2006 were as follows:

Supported initiatives

- Expansion of the otolith microchemistry study to include more sites and more samples per site (otolith microchemistry providing an indicator of stock mixing or isolation).
- A study of black jewfish morphometrics to determine the cost-effectiveness of implementing a size or age monitoring program (to document potential changes in size or age structure of the stock).
- Monitor the potential of sonar-based biomass estimation software (to quantify stock biomass).

New initiatives

- A study of the effect of barotrauma on black jewfish to quantify the survival rate of released fish (to improve estimates of post-release mortality).
- Examination and promotion of 'best handling methods' for black jewfish (to further enhance the sustainability of the resource).
- Encourage the implementation of recreational fishing catch and effort surveys in the NT (to aid in stock assessments of coastal fishes).

In response to these endorsements and recommendations, NT Fisheries implemented two new studies in 2007 to describe: (a) the effects of barotrauma on black jewfish with the aim of developing specific advice for catch and release, and (b) the morphometrics of black jewfish to assist in the development of a cost-effective size monitoring program. The results of these studies are presented here. NT Fisheries also expanded the otolith microchemistry study and continues to monitor the potential of sonar-based software. The need for additional recreational fishing data is also recognised and a broad-scale survey of recreational fishing in the NT will take place over two financial years; 2008/09 and 2009/10.

In addition, the Coastal Research Unit is seeking additional funding to implement a new project to describe the key biological attributes and the effects of fishing on other coastal fish species in the NT. A proposal has been developed in consultation with key stakeholder groups and is presented in broad terms in Sections 11.1 and 11.2.

Stemming directly from needs identified at the jewfish workshop, NT Fisheries conducted an additional study to implement a cost-effective, long-term monitoring program. The study was conducted outside of the scope of the present project. The study has identified a positive correlation between the length of the fish and the length of some fins. NT Fisheries is working towards implementing a trial monitoring program involving commercial fishers and FTOs in 2008.

11.1 JUSTIFICATION FOR FURTHER RESEARCH

Coastal fish species have great social, economic and ecological value in NT waters. Harvested by indigenous, recreational, charter and commercial fishers alike, a diverse range of coastal species are famous for their highly-rated angling and table qualities.

Assessment of the status of the NT's coastal fish was last undertaken in 1996, but was only able to provide broad sustainable limit estimates (100–1000 tonnes per annum) due to the shortage of baseline information on the biology and population structure of coastal fish.

If the upper limit proves accurate, then consideration will need to be given to appropriate management responses. Conversely, if the results of the 1996 assessment underestimated the population size, opportunities for further growth may be lost.

Hence, a more comprehensive assessment of coastal fish stocks in the NT is required. However, there is a shortage of information for most species (with the exception of black jewfish). Therefore, key indicator species must be identified and baseline information on these species collected.

Relying on interstate studies of fish found in the NT presents inherit risks. For example, this study revealed that NT black jewfish grow much faster than those in Queensland and spawn at different times of the year (despite the fact that they appear to be one genetic stock (Phelan 2002) and were sampled from similar environments and similar latitudes).

The need for a range of indicator species is heightened by recent and predicted growth in coastal fish landings. For example, commercial line landings alone increased 100% between 2000 and 2005 and potential exists for latent effort to become active over time.

Likewise, other sectors have also grown. The number of active charter licences increased 70% between 2000 and 2005, and figures provided by the Motor Vehicle Registry indicate the number of boat trailers >5 m increased by 219% between 2000 and 2005.

11.2 PROPOSED OBJECTIVES

1. Identify four coastal fish suited as indicator species in future monitoring and assessment programs.
2. Develop biological and population information for each of the indicator species.
3. Develop a cost-effective approach to size-based monitoring for each of the indicator species.
4. Identify the post-release survival rate of these coastal fish and develop advice for catch and release fishers.

12. PLANNED OUTCOMES

This project on black jewfish has delivered outputs that will enhance the ability of resource users and managers alike to make informed decisions that contribute to the sustainable use of the resource. This final report and the associated audio-visual presentations should raise awareness of the biology, ecology and effects of fishing on black jewfish.

In September 2006, NT Fisheries hosted a public workshop in which the preliminary results of this project were presented and discussed. Fishers and representatives from each sector attended the workshop, with close to 30 delegates participating. Researchers and managers from interstate fisheries were also invited but were unable to attend.

Attendees at this workshop supported a proposal to reconvene the Coastal Line Fishery Management Advisory Committee so that it may review the current management arrangements in light of the new information. In response, NT Fisheries has undertaken the necessary steps to convene a meeting of the committee in the near future.

In acknowledgement of the need for proactive management of black jewfish, NT Fisheries has proposed a reduction of the personal possession limit for this species from five to three fish. This matter is currently subject to Government Review.

Whilst based on NT data, the results of this project will apply to all jurisdictions that harvest black jewfish. In particular, the results of the barotrauma study are of great relevance. Aggregations of other finfish species are also targeted and the methods developed here may assist research programs for other species.

To enable the widespread distribution of the information derived from this project (and FRDC Project 2004/002), NT Fisheries has developed a pod-cast of a seminar that summarises the key research findings. To view this pod-cast, visit:

http://www.nt.gov.au/dpifm/Fisheries/index.cfm?newscat1=&newscat2=&header=Final%20Results.

The dissemination of information will continue in the form of journal articles, posters and brochures.

13. CONCLUSION

This project has successfully achieved each of the original objectives (see below), and has delivered the planned outcomes.

Objective 1: Identify key sites of black jewfish aggregations and monitor fishing activity at these sites

- By developing a sound relationship with fishers from all sectors, and by conducting an extensive review of commercial and fishing tour logbook data, NT Fisheries has identified key black jewfish aggregation sites.
- The location of the aggregation sites is not published within this report, though the coordinates for most are widely known and often presented in guides such as the North Australian Fish Finder.

Objective 2: Determine the degree of movement between two known aggregation sites (This objective now refers to FRDC 2004/02).

- Significant information has been gained on the degree of movement at and between two key aggregation sites in the vicinity of Darwin, Chambers Bay and Channel Point. NT Fisheries and the Tasmanian Aquaculture and Fisheries Institute tagged and released 84 black jewfish at these sites and monitored their movement for up to 18 months. Refer to the final report for FRDC Project 2004-02.
- The acoustic tagging study utilised the two and three dimensional maps produced by the habitat mapping study to determine if potential differences in fish behaviour between sites could be attributed to differences in bottom topography (see Objective 3 for further details on the habitat mapping study).
- Stemming from the close working relationship developed between organisations involved in the present project, NT Fisheries, the Australian Institute of Marine Science and the Tasmanian Aquaculture and Fisheries Institute have joined forces with Charles Darwin University to implement a new study to investigate the spatial structure of black jewfish by applying solution-based microchemistry. This study has utilised the sagittal otolith collected in the ageing study of the present project.

Objective 3: Determine the temporal, spatial and biological nature of the aggregations (Note linkage to FRDC 2004/02).

- The reproductive study revealed the size at first maturity and spawning periodicity of female black jewfish in NT waters. It found that female black jewfish in the NT spawn at different times to conspecifics in northern Queensland, despite similarities in both latitude and environmental conditions at the aggregation sites.
- The age study described the age structure and length frequency of black jewfish from the NT. It found that the growth rate of black jewfish in NT waters was greater than that of conspecifics in northern Queensland, despite similarities in both latitude and environmental conditions at the aggregation sites
- Acoustic tagging provided an extensive set of data regarding the temporal and spatial scale of the aggregations. The data has been presented in various forms revealing movement patterns in relation to a suite of variables, such as tidal height and tidal range. The data revealed no movement between aggregations, suggesting they may be distinct.
- Habitat mapping was completed at the two key aggregation study sites; Chambers Bay and Channel Point. Two and three dimensional maps of various forms are now available. The maps were utilised

in the acoustic tagging study and may be of use in other/future projects on species which also make use of these locations.

Objective 4: Review and adjust management arrangements as appropriate.

- In September 2006, NT Fisheries hosted a public workshop in which the preliminary results of this project were presented and discussed. Close to 30 delegates representing each stakeholder group participated. Future management directions were discussed.
- Attendees at this workshop supported a proposal to reconvene the Coastal Line Fishery Management Advisory Committee so that it may review the current management arrangements in light of new information. In response, NT Fisheries has undertaken the necessary steps to convene a meeting of the committee in the near future.
- In acknowledgement of the need for proactive management of black jewfish, NT Fisheries has proposed to reduce the personal possession limit for this species from five to three fish. This matter is subject to Government consideration.

Subsidiary objective 1: Quantify the extent of barotrauma related injuries in black jewfish relative to capture depth, fish length and fishing method.

- The extent of barotrauma related injuries in black jewfish was related to capture depth. All fish retrieved from less than 10 m should survive if handled and released appropriately. Forty eight percent of fish caught at 10–15 m may not survive if released. All fish landed from deeper than 15 m are unlikely to survive if released.
- Neither fish length nor fishing method had any affect on barotrauma related injuries in black jewfish.

Subsidiary objective 2: Develop advice for fishers on catching and releasing black jewfish.

- The study produced specific advice (outlined in a series of oral presentations and a brochure) for catching and releasing black jewfish. The Amateur Fishermen's Association of the NT and InfoFish are disseminating information generated by this study.

Subsidiary objective 3: Assess the viability of a fin-return size monitoring program for black jewfish.

- The study has identified a positive correlation between fish length and the length of several fins, this most promising being the pectoral fin. Hence, a fin-return size monitoring program is viable and is expected to be implemented on a trial basis in 2008.

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15. APPENDIX 1: INTELLECTUAL PROPERTY

There are no intellectual property and/or valuable information issues arising from this research.

16. APPENDIX 2: STAFF

Table 16.1 Project staff

Position	Name	Organisation
Principal Investigator	Michael Phelan	DPIFM
Former Principal Investigator	Tracy Hay	DPIFM
Co-Investigators	Jayson Semmens	TAFI
	Mark Meekan	AIMS
Project Staff	Adrian Donati	DPIFM
	Alex Beatty	DPIFM
	Cary McLean	AIMS
	Charles Bryce	DPIFM
	Chris Errity	DPIFM
	Chris Tarca	DPIFM
	Corey Green	PIRVic
	Danny Argent	DPIFM
	David Williams	NRETA
	Dylan Campbell	DPIFM
	Kate Seidel	DPIFM
	Mark Grubert	DPIFM
	Mark Hearnden	DPIFM
	Nathan Croft	DPIFM
	Paul Williams	DPIFM
	Poncie Kurnoth	DPIFM
	Quentin Allsop	DPIFM
	Rachel Meldrum	DPIFM
	Wayne Baldwin	DPIFM
Budgets Officer	Anna Palmer	DPIFM
Executive Officer	Bruce Young-Smith	DPIFM