The Fisheries Biology of Bluethroat Wrasse (*Notolabrus tetricus*) in Victorian Waters.

David C Smith, Ian Montgomery, K. P. Sivakumaran,

Kyne Krusic-Golub, Ken Smith and Ross Hodge

Final Report

Project No. 97/128

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Victoria
The Place To Be

Fisheries Research and Development Corporation

The Fisheries Biology of Bluethroat Wrasse (*Notolabrus tetricus*) in Victorian Waters

David C Smith[1], Ian Montgomery[1], K. P. Sivakumaran[1], Kyne Krusic-Golub[1], Ken Smith[1] and Ross Hodge[2]

[1]Marine and Freshwater Resources Institute
PO Box 114 Queenscliff
Queenscliff, VIC 3225

[2]Seafood Industry Victoria
Level 2/177 Toorak Rd
South Yarra VIC 3141

January 2003

ISBN: 1 74106 544 5

NON-TECHNICAL SUMMARY

97/128	The Fisheries Biology of Bluethroat Wrasse (*Notolabrus tetricus*) in Victorian Waters.

Principal Investigator: Ross Hodge[1]
Co-Investigator: David C Smith[2]

Address:

[1]Seafood Industry Victoria,
Level 2/177 Toorak Rd
South Yarra Vic 3141
Tel: 03 9824 0744

[2]Marine and Freshwater Resources Institute
P.O. Box 114
Queenscliff Vic 3225
Tel: 03 5258 0111 Fax: 03 5258 0270

Objectives:

1. To describe the biology of and fishery for bluethroat wrasse in Victorian waters.
2. To provide the scientific data necessary for rational management of the resource.

Summary

During the early 1990s, a market was established for live bluethroat wrasse. The total catch rose rapidly from less than 10 tonnes to almost 60 tonnes in 1995/96. The number of fishers targeting wrasse also increased with 50 Victorian fishers taking wrasse by hand line during 1995/96 compared too less than 5 in 1989/90. Bluethroat wrasse is the major species but saddled wrasse (*Notolabrus fucicola*) are also taken.

In response to the rapid increase in the fishery and lack of biological and fishery information, this collaborative project between the former Victorian Fishing Industry Federation (now Seafood Industry Victoria) and the Marine and Freshwater Resources Institute (MAFRI) was developed.

Commercial catch and effort statistics were analysed. Bluethroat wrasse were sampled monthly between August 1997 and January 1999 from commercial catches off western, central and eastern Victoria. Biological information collected included total length, weight, sex and gonad weight. Saggital otoliths were taken for ageing and whole gonads were preserved for histological examination. Biological

information was also collected for saddled wrasse on an opportunistic basis. Wrasse were tagged and released, using t-bar tags, by project staff, wrasse fishers and recreational fishers.

Catches in the fishery rose rapidly to a peak of over 90 tonnes in 1998 but subsequently declined to about 50 tonnes. Much of this decline was due to a reduction in fishing effort. Wrasse were taken along the entire Victorian coast but catches were highest off central Victoria and off the west coast. Catches of saddled wrasse were higher in the west. Catch rates peaked in the mid 1990s. It appears that high catch rates have been maintained by the industry fishing new areas. The fishery is relatively “clean” with low catches of by-product species. Discards can be relatively high but discarded species are returned to the water live.

Spawning of bluethroat wrasse occurs during spring. The size-at-maturity for females occurs between 20 and 25 cm TL. Histological examination provided the basis for staging gonads. Bluethroat wrasse are protogynous hermaphrodites; females change to males. All males were secondary and transition gonads were characterised by proliferating testicular tissue in the presence of degenerating ovarian tissue. It was estimated that about 12% of females change sex per year after age 4.

Ages were estimated from sectioned otoliths and were validated by examining marginal increments, flourochrome marks in otoliths and the growth of tagged individuals. Fish ranged in age from 3 to 23 years. The youngest male was 5 years. Growth was initially fast but then slowed. There were indications that growth was faster in the east than the west. The growth of saddled wrasse was similar to bluethroat wrasse but the maximum age was 16 years. Commercial catches of female and male bluethroat wrasse were dominated by ages 5 and 9, and 8-17 years, respectively. Total mortality was estimated, by catch curve analysis, to 0.32. Natural mortality was estimated to be about 0.2.

Recapture rates of tagged and released fish were low for both species (2.4 and 1.3%). The results suggest that the small fish had a higher tagging mortality or tag loss. Most recaptured fish were taken in the same area as they were released, particularly saddled wrasse. However, for bluethroat wrasse there were a number of movements >10 kms that suggest that some fish, at least in Victorian waters, move further than was previously reported.

Unlike standard per recruit analyses, analyses for bluethroat wrasse have to take into account the implications of sex change. At recruitment all individuals are female. When the recruits reach a certain age some change sex, from female to male, each year so that the proportion of males in the cohort, originally zero, gradually increases with age.

A simple interactive per recruit model was developed that enabled the implications of changing fishing mortality and size at first capture on yield and the proportion of males to be evaluated. These analyses showed that when setting legal minimum lengths (LMLs) there is a trade-off between yield and the proportion of males. The current LML (28cm TL) appears appropriate for the estimated fishing mortality. A LML of 26cm would give a higher yield but a LML of 30 cm gives a higher proportion of males. The results are important in a sex-change species like bluethroat wrasse where it is the number of males in the population that are most affected by exploitation rather than egg production which is normally the case. In fact eggs-per-recruit calculations indicate that the female population achieves maximum reproductive potential at age 5, below the current LML.

Outcomes Achieved

This project has provided the first comprehensive study of the biology of and fishery for bluethroat wrasse in Victorian waters. The project has demonstrated that joint industry-science collaborations are a cost-effective means of assessing low value fisheries. Management implications of the study were discussed and agreed at a workshop held at the end of the project. Fisheries Victoria is using the results of this study in developing management arrangements for the fishery.

Keywords

Notolabrus tetricus, bluethroat wrasse, saddled wrasse, *Notolabrus fucicola*, fisheries biology

CONTENTS

NON-TECHNICAL SUMMARY

97/128	The Fisheries Biology of Bluethroat Wrasse (*Notolabrus tetricus*) in Victorian Waters.

Principal Investigator: Ross Hodge[1]
Co-Investigator: David C Smith[2]

Address:

[1]Seafood Industry Victoria,
Level 2/177 Toorak Rd
South Yarra Vic 3141
Tel: 03 9824 0744

[2]Marine and Freshwater Resources Institute
P.O. Box 114
Queenscliff Vic 3225
Tel: 03 5258 0111 Fax: 03 5258 0270

Objectives:

1. To describe the biology of and fishery for bluethroat wrasse in Victorian waters.
2. To provide the scientific data necessary for rational management of the resource.

Summary

During the early 1990s, a market was established for live bluethroat wrasse. The total catch rose rapidly from less than 10 tonnes to almost 60 tonnes in 1995/96. The number of fishers targeting wrasse also increased with 50 Victorian fishers taking wrasse by hand line during 1995/96 compared too less than 5 in 1989/90. Bluethroat wrasse is the major species but saddled wrasse (*Notolabrus fucicola*) are also taken.

In response to the rapid increase in the fishery and lack of biological and fishery information, this collaborative project between the former Victorian Fishing Industry Federation (now Seafood Industry Victoria) and the Marine and Freshwater Resources Institute (MAFRI) was developed.

Commercial catch and effort statistics were analysed. Bluethroat wrasse were sampled monthly between August 1997 and January 1999 from commercial catches off western, central and eastern Victoria. Biological information collected included total length, weight, sex and gonad weight. Saggital otoliths were taken for ageing and whole gonads were preserved for histological examination. Biological

information was also collected for saddled wrasse on an opportunistic basis. Wrasse were tagged and released, using t-bar tags, by project staff, wrasse fishers and recreational fishers.

Catches in the fishery rose rapidly to a peak of over 90 tonnes in 1998 but subsequently declined to about 50 tonnes. Much of this decline was due to a reduction in fishing effort. Wrasse were taken along the entire Victorian coast but catches were highest off central Victoria and off the west coast. Catches of saddled wrasse were higher in the west. Catch rates peaked in the mid 1990s. It appears that high catch rates have been maintained by the industry fishing new areas. The fishery is relatively “clean” with low catches of by-product species. Discards can be relatively high but discarded species are returned to the water live.

Spawning of bluethroat wrasse occurs during spring. The size-at-maturity for females occurs between 20 and 25 cm TL. Histological examination provided the basis for staging gonads. Bluethroat wrasse are protogynous hermaphrodites; females change to males. All males were secondary and transition gonads were characterised by proliferating testicular tissue in the presence of degenerating ovarian tissue. It was estimated that about 12% of females change sex per year after age 4.

Ages were estimated from sectioned otoliths and were validated by examining marginal increments, flourochrome marks in otoliths and the growth of tagged individuals. Fish ranged in age from 3 to 23 years. The youngest male was 5 years. Growth was initially fast but then slowed. There were indications that growth was faster in the east than the west. The growth of saddled wrasse was similar to bluethroat wrasse but the maximum age was 16 years. Commercial catches of female and male bluethroat wrasse were dominated by ages 5 and 9, and 8-17 years, respectively. Total mortality was estimated, by catch curve analysis, to 0.32. Natural mortality was estimated to be about 0.2.

Recapture rates of tagged and released fish were low for both species (2.4 and 1.3%). The results suggest that the small fish had a higher tagging mortality or tag loss. Most recaptured fish were taken in the same area as they were released, particularly saddled wrasse. However, for bluethroat wrasse there were a number of movements >10 kms that suggest that some fish, at least in Victorian waters, move further than was previously reported.

Unlike standard per recruit analyses, analyses for bluethroat wrasse have to take into account the implications of sex change. At recruitment all individuals are female. When the recruits reach a certain age some change sex, from female to male, each year so that the proportion of males in the cohort, originally zero, gradually increases with age.

A simple interactive per recruit model was developed that enabled the implications of changing fishing mortality and size at first capture on yield and the proportion of males to be evaluated. These analyses showed that when setting legal minimum lengths (LMLs) there is a trade-off between yield and the proportion of males. The current LML (28cm TL) appears appropriate for the estimated fishing mortality. A LML of 26cm would give a higher yield but a LML of 30 cm gives a higher proportion of males. The results are important in a sex-change species like bluethroat wrasse where it is the number of males in the population that are most affected by exploitation rather than egg production which is normally the case. In fact eggs-per-recruit calculations indicate that the female population achieves maximum reproductive potential at age 5, below the current LML.

Outcomes Achieved

This project has provided the first comprehensive study of the biology of and fishery for bluethroat wrasse in Victorian waters. The project has demonstrated that joint industry-science collaborations are a cost-effective means of assessing low value fisheries. Management implications of the study were discussed and agreed at a workshop held at the end of the project. Fisheries Victoria is using the results of this study in developing management arrangements for the fishery.

Keywords

Notolabrus tetricus, bluethroat wrasse, saddled wrasse, *Notolabrus fucicola*, fisheries biology

FINAL REPORT

97/128 The Fisheries Biology of Bluethroat Wrasse (*Notolabrus tetricus*) in Victorian Waters

Background

Bluethroat wrasse (*Notolabrus tetricus*) are distributed from Sydney (NSW) to the Spencer Gulf (South Australia) and are the most abundant wrasse in south eastern Australian waters (Gomon *et al.* 1994). The species occurs on both sheltered and exposed reefs from 0 to at least 40 m, although generally in the deeper waters on exposed reefs. In Tasmanian waters, bluethroat wrasse are reported to grow to 50 cm in length, and the diet is predominantly molluscs, echinoids and crustaceans, particularly decapod crustaceans (Edmunds 1990).

During the early 1990s a market was established for live bluethroat wrasse. The species has a high 'live fish' market value and was increasingly exploited by commercial fishers with endorsements to fish in ocean waters. Prices in the Sydney market for mostly gilled and gutted fish averaged between $6 and $7 during 1994 and 1995. Prices for live fish ranged between $9 and $12.

The total catch rose rapidly from less than 10 tonnes during the early 1990s to almost 60 tonnes in 1995/96. The number of fishers targeting wrasse also increased with 50 Victorian fishers taking wrasse by handline during 1995/96 compared with less than 5 in 1989/90. Bluethroat wrasse is the major species targeted but saddled wrasse (*Notolabrus fucicola*) are also taken. Unlike bluethroat wrasse this species does not show a major difference in colour pattern between males and females and does not undergo sex change (Gomon *et al.* 1994, Barrett 1995).

Bluethroat wrasse are taken primarily by handlines. The method ensures that fish are captured in optimum condition. Live fish are held in boat wells or specially constructed tanks on board vessels. At port, fish are held in holding cages prior to being supplied to wholesalers.

Wrasse, in general, tend to be highly territorial with most species demonstrating sexual dichromatism associated with sex reversal. Sequential hermaphroditism, a phenomenon characterized by an individual changing from one sex to another at some point in its life history, is widespread in teleost fishes (Atz 1964: Reinboth 1970). In some species, individuals change from male to female (protandry) and in others the situation is the reverse (protogyny). The occurrence of protogynous hermaphroditism is better known in the Labridae than in other families.

In many of these species, a single male maintains a harem of females; on the death of the male, the dominant female undergoes sex reversal and assumes the role of the male in the harem. This life history characteristic plus their relatively sedentary nature, makes the species highly susceptible to high fishing pressures, particularly if there is a minimum size at which sex reversal occurs (i.e. the large fish tend to be the males).

Need

Currently there is no information available on the biology and population dynamics of bluethroat wrasse in Victorian waters and, except for taxonomic and biology notes, very little has been published (Barrett, 1995, 1999; Shepherd and Hobbs, 1985).

Given what is known about the life history of wrasses in general and this species in particular, the possibility of rapidly over-fishing wrasse in Victorian waters could not be discounted. A number of fishers who target bluethroat wrasse had also raised concerns that catch rates had declined and the size of fish had decreased.

In response to the rapid increase in the fishery and lack of biological information, the former Victorian Fishing Industry Federation (now Seafood Industry Victoria) convened a wrasse workshop that was held at the Marine and Freshwater Resources Institute (MAFRI) on the 6th November 1996. Commercial fishers, scientists and fishery managers attended the workshop. Representatives at the workshop discussed several future management options for the fishery and subsequently reported them to Victoria's Fisheries Co-management Council. The Council recommended that, until sound biological information is available, interim measures should be implemented including adoption of a minimum legal size and that a specialised fishery be declared based on catch history.

This collaborative project between the Victorian Fishing Industry Federation (VFIF), the Marine and Freshwater Resources Institute (MAFRI) and individual fishers was developed to provide this biological information.

Objectives

1. To describe the biology of and fishery for bluethroat wrasse in Victorian waters.
2. To provide the scientific data necessary for rational management of the resource.

Methods

The Commercial Fishery

Fishing practices were described following discussions with industry and from onboard observations.

Commercial catch statistics were examined by method, area and season. The Victorian coast was divided into three zones, designated west (South Australia-Victoria border to Apollo Bay), central (Apollo Bay to Cape Liptrap approx 146^{o}E) and east (Cape Liptrap to the Victoria-NSW border) (Figure 1). These zones do not have any management significance but were intended to provide the basis for examining whether there was spatial variability across the fishery and/or population structure along the Victorian coast. Data for the period 1990 to 2000 were used in these analyses.

Prior to 1998, wrasse fishers reported their catch and effort on General Fishing Returns. Catches were reported by area but the grids used were quite large (1 degree grids or larger). Revised logbooks implemented during 1998 required fishers to report their catches at a finer resolution (10 minute grids). In addition, unlike the previous returns, depth was also recorded.

To enable the spatial extent of annual catch to be examined over the full period, data from 1998-2000 were allocated to the larger grids used previously. In addition, catches at the finer resolution were examined for the period 1998-2000 in aggregate.

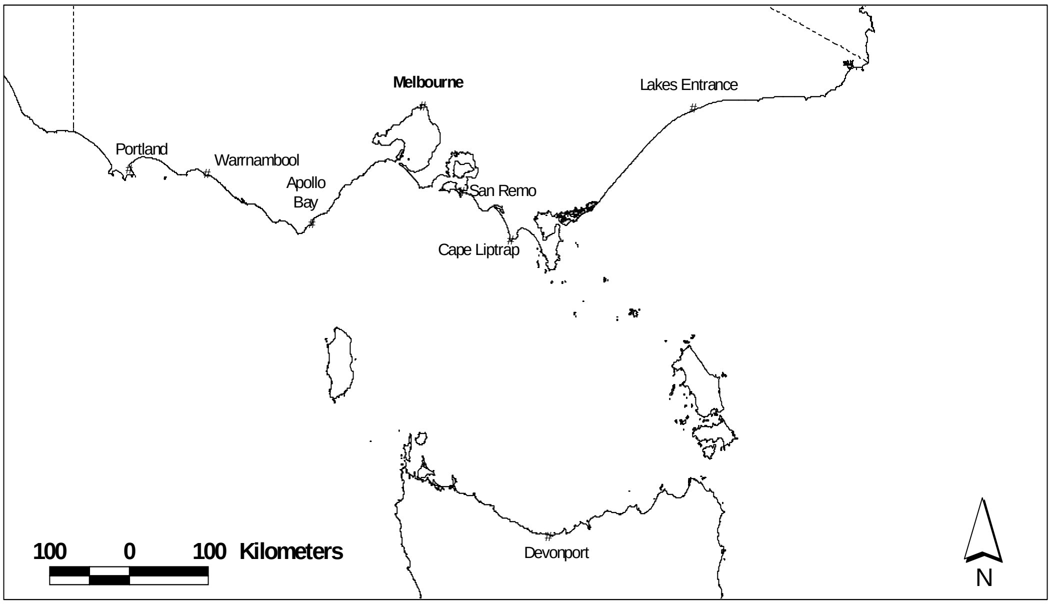


Figure 1 Map of Victoria showing key localities.

Spatial trends in the fishery were examined by examination of maps produced by GIS. The original data were summarised in spreadsheet format and consisted of two data types. One consisted of the catch for each year from 1995 to 2000 based on the fishing grids used by Bass Strait fisheries (including Bass Strait Scallop and General Fishing) up to the end of March 1998. The other dataset consisted of the catch over a three-year period from 1998 to 2000 based on the fishing grids used by the ocean fisheries (including scallop, general and trawl) since April 1998, as implemented under the *Fisheries Act 1998*.

Both datasets consisted of the catch and the number of vessels for each area code. In order to display and query these data in the ArcView GIS, the data was first manipulated in MS Excel. The data from the old area grids were arranged so that each year had two rows of data, one showing the catch and the other the vessels, with each column containing the data for one area. For confidentiality reasons, catches in areas where less than five vessels operated were flagged.

After the manipulation of the data had been completed, they were read into ArcView using its “SQL Connect” function to make an Open Data Base Connectivity (ODBC) connection to the data in MS Excel files.

The data collated under the new area grids were then joined to the spatial theme that defined the boundaries of these blocks and a "No Data" class was enabled in the theme's legend and labelled as "Confidential Data".

For the data from the old area blocks, each year of data needed to be saved to its own dBASE file. Each file was saved after querying each year of data in turn. The new files were then separately joined to the area grids, and the same steps as for the new area grid data were carried out to show a catch of 0 in area grids to distinguish them from confidential cells.

General linear modelling (GLM) was used to standardise catch per unit effort (CPUE) for a range of factors including vessel, area and season.

Field sampling

Biological and fishery data were collected by project staff and with the assistance of bluethroat wrasse fishers. During the first 6 months of the project, data were collected by project staff and sampling protocols developed and appropriate tagging methods determined (see below). Fishers were provided with measuring boards with 1 cm gradations. In conjunction with industry, project staff developed a scientific logbook in which catch, effort, and length and tagging data were recorded.

Commercial catches of wrasse were sampled from August 1997 to January 1999. Samples were monthly, from ports in the designated western, central and eastern zones. Sample sizes per zone per month ranged from 0 to 100 depending on availability but averaged 44 (Table 1). Overall, coverage was relatively good, with samples taken from 12, 14 and 15 of the 18 months sampled in the eastern, central and western zones, respectively.

Table 1. Summary of bluethroat wrasse samples collected from August 1997 to January 1999.

Month	Number of fish sampled in each zone		
	Eastern	**Central**	**Western**
August 1997	50	37	52
September	0	65	100
October	0	64	38
November	40	97	80
December	0	29	0
January 1998	0	77	7
February	86	0	54
March	59	33	0
April	53	20	66
May	40	8	42
June	37	0	72
July	24	27	50
August	50	14	53
September	39	0	30
October	0	8	18
November	31	28	20
December	0	0	24
January 1999	50	18	0
Total	**559**	**525**	**706**

In most cases, fish, stored on ice, were returned to the laboratory for processing. Biological information collected included total length (measured to the nearest millimetre in the laboratory; the nearest centimetre below in the field), weight (g), sex and gonad weight (left and right gonad to the nearest 0.1 g). Saggital otoliths were taken for ageing and stored dry in envelopes on which relevant information was recorded. In addition, a sub-sample of whole gonads were taken for later histological examination (see below). The gonads were preserved in 10% formalin in seawater until ready for processing.

Similar biological information was also collected for saddled wrasse on an opportunistic basis.

Reproductive biology

The gonadosomatic index $\left(GSI, \frac{\text{Gonad weight}}{\text{Total weight}} \times 100\right)$ was calculated for each fish.

The relationship between GSI and length, and monthly trends were examined for each sex.

The nomenclature for description of the stages of oogenesis and spermiogenesis followed Yamamoto et al. (1965), Nagahama (1983) and Hunter and Macewicz (1985). Classification of males and females into ontogenetic stages and developmental stages followed the adaptation by Ferreira (1993) from Moe (1969) and Hasting (1981). Sex determination can be done macroscopically only if the gonads are active. Individuals can be classified as ripe females or males and the information can be used to determine periodicity of spawning (Ferreira 1995). Consequently, fish were not staged macroscopically; they were staged microscopically from histological examination.

The fixed gonads were dehydrated in ethanol and then cleared in toluene before being embedded in paraplast by an automatic processor using the methods described by Knuckey and Sivakumaran (2001). Transverse sections were cut from several positions, where possible, along the length of the embedded gonad at 6 um thickness. Once cleared, the sections were stained with eosin and haematoxylin. The stained sections were then examined for evidence of sex inversion, and to determine whether the testes were of primary or secondary origin. The histological sections were also used to describe the different stages of oocyte development. A large sample size was needed in order to search for evidence of transitional gonads, and for primary and secondary males which, if present, may have been rare.

For the fecundity estimation the methods described by Bagenal (1978) and Cailliet et al (1986) were used. From a sub-sample of about 50 ovaries, 5 to 10 random samples of 0.05 to 0.1 g each were taken from the anterior, middle and posterior regions of the ovary. These sub-samples were pooled to form a single composite sample of approximately 0.5 g. The weight of this sample was determined to the nearest 0.001 g. The samples were preserved in Davidson’s solution.

The preserved samples were thoroughly mixed in a solution made to 115 ml with the addition of 70% alcohol to an accuracy of two decimal places. Five, 1 ml sub-samples were extracted and examined under a dissecting microscope at x10 magnification and the number of eggs in each sub-sample counted. Eggs greater than 100μm diameter were counted, although in some samples smaller eggs were present.

Age determination

Bluethroat wrasse saggital otoliths were processed and aged at the Central Ageing Facility (CAF) at MAFRI using standard procedures (Morison *et al* 1998). To ensure age estimates were unbiased otoliths were sub-coded and ages obtained with no reference to zone, season, sex or fish length.

The otoliths are small and anvil-shaped (Figure 2). The profile of the distal surface is convex with a pronounced crista superior (dorsal side); there is little, or no development of the crista inferior (ventral side). Either the left or the right sagittal otolith from each fish was weighed on an electrical balance to the nearest 0.001g.

Otoliths ranged in length from 3.6 to 5.8 mm and in width from 2.1 to 3.2 mm. They ranged in weight from 3 to 25 mg.

Age estimates from whole otoliths were made by viewing the otoliths immersed in water against a black background under reflected light (Figure 2). However, becuase the depth of the otolith relative to the width of the otolith in older fish is high (width/depth > 1.9), age was also estimated using sectioned otoliths. In most cases, the CAF has found that sectioned otoliths provide more reliable estimates of age.

To obtain thin sections, otoliths were embedded in rows of 5 in polyester resin. A minimum of four transverse sections (0.3 mm thick) were cut from each row of otoliths ensuring that the primordium of each otolith was included in at least one of the sections. Sections were cleaned and mounted with resin on glass microscope slides under coverslips.

Sectioned otoliths reveal a large opaque inner region followed by alternating translucent and opaque zones, which under transmitted light appear light and dark, respectively (Figure 3). The first two opaque zones appear quite wide, particularly close to the distal surface. The distance between successive opaque zones (presumed annual increments) and the width of the opaque zones generally decreased with estimated age. Increments after the first 4-5 increments were generally fine and regular.

Bluethroat wrasse otoliths were aged from the primordia out to the proximal edge on the ventral side. Increments were also visible on the dorsal side and in some individuals the clarity was superior to that on the ventral side. However, usually dorsal increments were inconsistent, particularly within older specimens, and consequently, a ventral transect close to the sulcal grove was used for age estimation.

The majority of sectioned otolith examined had numerous sub-annular increments between the annual increments. These were recognised as fine narrow opaque zones that were not continuous throughout the section and were unevenly spaced. Age was therefore estimated as the number of completed opaque zones.

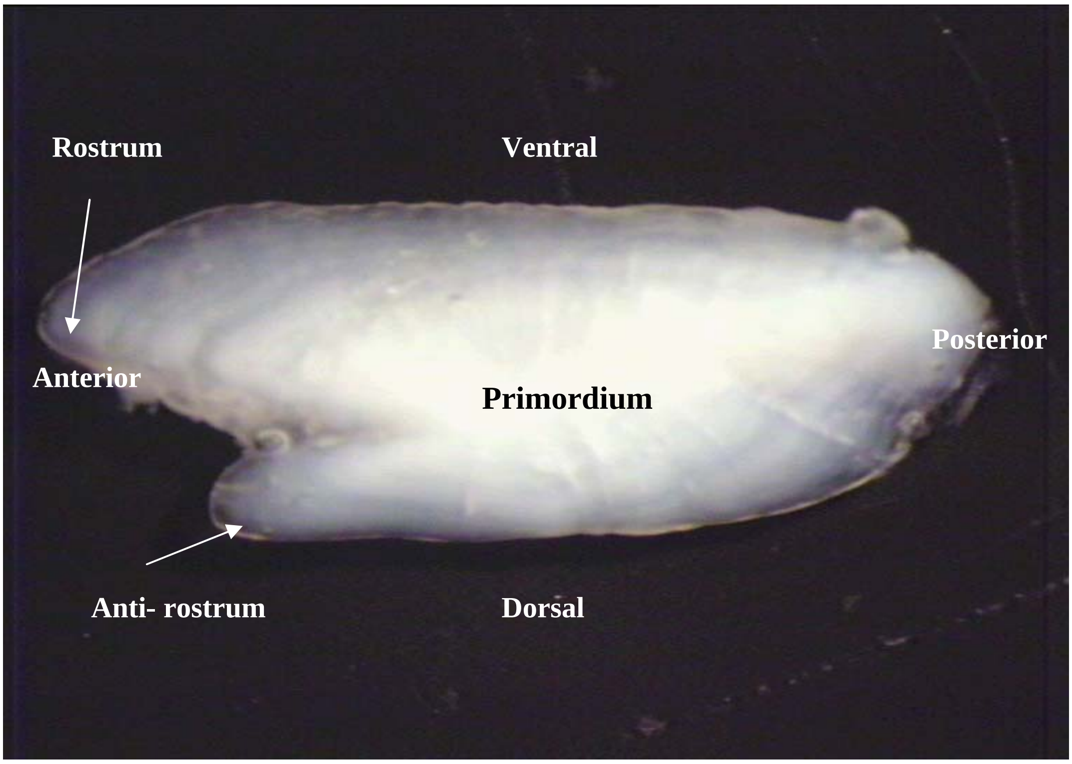


Figure 2. Whole bluethroat wrasse otolith showing particular features on the distal face.

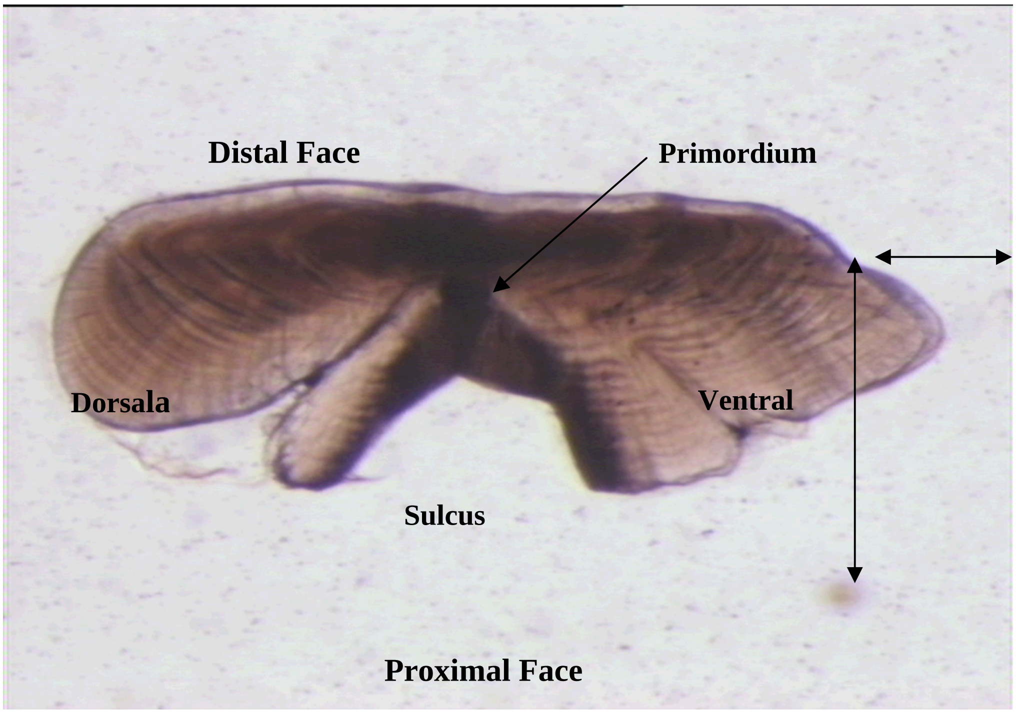


Figure 3. A sectioned bluethroat wrasse otolith showing the decrease in dorsal ventral deposition (horizontal line) after approximately 4 to 5 years relative to the continuous deposition on the primordial face (vertical line).

A range of standard CAF diagnostics, including the relationship between otolith weight and estimated age, were examined. In addition, ages estimated from whole and sectioned otoliths were compared.

Precision and validation

Precision is defined as the reproducibility of repeated measurements on a given structure, whether or not those measurements (age estimates) are accurate (Campana 2001). Repeated readings of the same otoliths provide a measure of intra- and inter-reader variability. They do not validate the assigned ages but provide an indication of size of the variability to be expected within a set of age estimates, due to variation in interpretation of an otolith. Beamish and Fournier (1987) developed an index of average percent error (IAPE), which has become a common method for quantifying this variation. The IAPE is calculated as

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

where N is the number of fish aged, R is the number of times fish are aged, X_{ij} is the ith determination for the jth fish, and X_j is the average estimated age of the jth 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 *et al*. 1992).

The importance of validating assigned ages cannot be overstated (Beamish and McFarlane 1983, Smith 1992). Campana (2001) reviews the best available methods for quantifying ageing accuracy. In the current study, two approaches were used.

- First, the Marginal Increment Ratio (MIR) was used. Here, the marginal increment is defined as the distance from the last completed opaque zone to the edge expressed as a percentage of the width of the previous completed increment (translucent and opaque zones).
- Second, captive bluethroat wrasse were injected with oxytetracycline (OTC) (see below) to provide a fluoro-chrome mark on their otoliths. These marks were examined at the CAF using UV light and the incremental structure beyond the OTC mark recorded. This provides a direct method of determining the number of zones/increments recorded during a known period.

In addition, some inferences were also gained from the growth of tagged and released fish.

Age composition, growth and mortalities

Age-length distributions, combined with length-frequency distributions, provided the basis for estimates of age composition. Growth was examined by plotting length against age and by fitting the von Bertalanffy growth curve using least squares.

Total mortality was determined using catch curve analysis. Because wrasse change sex it was not possible to calculate total mortality for the sexes separately. For example, for females the slope of the right-limb represents fishing and natural mortality but also a proportion changing to males. Consequently, catch curves were constructed for the sexes combined.

Natural mortality was estimated using the relationship $M = \ln(100)/t_{max}$

Tagging experiments

Aquaria trials

Aquaria trials were undertaken to develop tagging methods that could be used easily in the field, particularly by fishers, and for age validation work. Live wrasse taken by fish traps (under research permit) were held in aquaria (large outdoor tanks) at MAFRI's Queenscliff campus. Fish were held in three 5000 l tanks with flow-through seawater.

Two types of tags were used.

- Dart tags were yellow Hallprint nylon headed tags (50 mm long and 2 mm diameter), with an angled plastic bar.
- T-bar tags were yellow Hallprint nylon headed tags (50 mm long and 2 mm diameter), with a horizontal bar.

These were chosen for potential ease of application given that it was planned that considerable tagging would be undertaken by industry during normal fishing operations.

Approximately half of all tagged fish were injected with OTC to provide a flourochrome mark. Based on experience with a range of other species, a dosage of 0.3 gm per kilo body weight was used.

Otoliths were removed and stored in dark containers for later examination under UV light.

Tagging by commercial fishers

At-sea tagging methods were developed during the early part of the project. Results from tank trials indicated there was little difference in the efficacy of the two tag types. However, application of t-bar tags, using a tagging gun, was simpler and more efficient than application of dart tags, particularly on the generally small vessels used in the fishery. In addition, Barrett (1995) used t-bar tags for both wrasse species with a high recapture rate reported. For these reasons, t-bar tags were used for tag and release in the field.

Tagging kits were made up and distributed to industry. Each kit consisted of:

- A numbered series of t-bar tags

- A monarch tagging gun
- Waterproof data sheets
- A measuring board
- Tagging instructions.

Kits were distributed to all interested fishers so that wrasse below market size could be tagged and released during normal fishing operations. In most cases, fish of market size were purchased from individual fishers and tagged by project staff on commercial vessels.

Tagging methods were demonstrated directly to individual fishers in port and, collectively, at the Wrasse Workshop held on 2 July 1998.

Material advertising the tagging was circulated to fishers and buyers. No rewards were made available for returned tags but project staff and SIV were continually in contact with fishers and buyers during the life of the project.

Tagging by recreational fishers

Bluethroat wrasse were also tagged by recreational anglers during the project as part of the Victag program. Victag is a fish tagging program jointly operated by the Victorian Branch of the Australian National Sportfishing Association (ANSA Victoria) and the Victorian Department of Natural Resources & Environment (DNRE).

The program is funded from a variety of sources, including participating anglers, ANSA Victoria, commercial and recreational fishing industry sponsors, and DNRE.

A list of priority tagging species is reviewed annually by DNRE and ANSA Victoria and updated when necessary. Wrasse were included as a priority species during the project period.

Currently the Victag program has a membership of about 100 anglers who tag about 10,000 fish per year. Participating fishers use predominantly t-bar tags. Each tag has a freecall phone number to expedite reporting of recaptures.

Details of releases and recaptures are maintained on a database that is held by both Victag and MAFRI.

Field trials with different tag types

Recaptures were generally low for wrasse throughout the project (see below). Similar low recaptures of tagged saddled wrasse were also reported in Tasmania (Jeremy Lyle personal communication). However, fin-clipped fish had higher recaptures suggesting that tags were shed. In some cases it appeared that tags had been bitten off by wrasse or other species.

To ascertain whether this was the case in Victoria, fish were tagged and released with both dart and anchor tags and with a proportion fin-clipped. Wrasse were caught using fish traps in a small area at the entrance of Port Phillip Bay. Project staff subsequently fished at the site three times over a period of about a year and recorded any tagged or fin-clipped fish taken.

Sex-change per recruit modelling

Unlike standard per recruit analyses, analyses for bluethroat wrasse have to take into account the implications of sex change. At recruitment all individuals are female. When the recruits reach a certain age some of them change sex, from female to male, each year so that the proportion of males in the cohort, originally zero, gradually increases.

A simple interactive per recruit model was developed that enabled the implications of changing fishing mortality and size at first capture on yield and on the proportion of males to be evaluated.

Results and Discussion

The Fishery

Commercial Fishing Practices

The following is derived from onboard observations and direct contact with most operators engaged in the fishery.

Area, Bottom type and Depth range:

The fishery for bluethroat wrasse extends along the entire Victorian coastline from Portland to Mallacoota on reef areas with good seaweed cover. The depth varies from 5m to 45m but in general catches are preferred from shallower depths to help reduce the degree of swimbladder inflation (in the majority of cases the swimbladder needs to be deflated with a needle type apparatus). In the western part of the fishery, a market has been developed for saddled wrasse These are caught in the shallower reef areas along with some bluethroat wrasse (see below). At sometime, fishers have operated from nearly every port or launching ramp along the Victorian coastline.

Fishing Methods:

Traps: Some fishers have used traps, substituting them for a craypot; one fisher has a fish trap permit. The traps have varied in size and shape with one or more entrances necks and usually a hatch to allow the easy and quick removal of the fish. These are baited, with baits including octopus, fish frames and abalone viscera. Traps are left to soak from one to five hours depending on the tides or other fishing practices of the fisher. Most fishers considered this method less efficient than hooking and also an uneconomic use of craypots.

Hooking: The most popular method used is hooking either by handline or rod and reel; when the fish are located and biting, only one line per fisher is generally used. The bait varies but mainly octopus, squid or fish fillets is used. The hook size and type also varies, usually with the barb filed off for easy and quick fish removal. The line is generally rigged with two hooks on short snoods above a sinker (the sinker weight depends on the tide/current and bottom type).

Vessel type:

A variety of vessels have been and are used in this fishery. These include planing hull vessels (6 to 15 m) with recirculating seawater tanks, runabouts or dinghys (4 to 8 m) with recirculating seawater tanks and displacement hull vessels with wet wells or recirculating tanks. Fishing trips are mainly day trips with a few of the larger vessels doing multiple day trips. Most operators have one or two deckhands.

Holding tanks:

At sea:

All vessels need a system to keep the fish alive until either brought into shore-based tanks, off-loaded into offshore caufs or sold immediately on return to port. Some rock lobster vessels have existing wet wells with a continuous supply of fresh seawater at ambient sea temperatures. This system works well at sea but some problems have occurred when fish are held in these wells in port due to poor water quality and warmer water temperatures. All other vessels have onboard recirculating tanks.

Land based holding tanks:

The operators that do not hold their fish in wet wells or offshore caufs have purchased or built live fish holding facilities. These all have filters, skimmers, circulating pumps and oxygenation systems. Most also have refrigeration systems to hold the fish at a cool temperature. Some commercial units also have a water sterilisation system. All these systems are capable of holding 300 or more fish for long periods.

A few operators have also built or purchased specialised transport systems.

Catch and effort statistics - overview

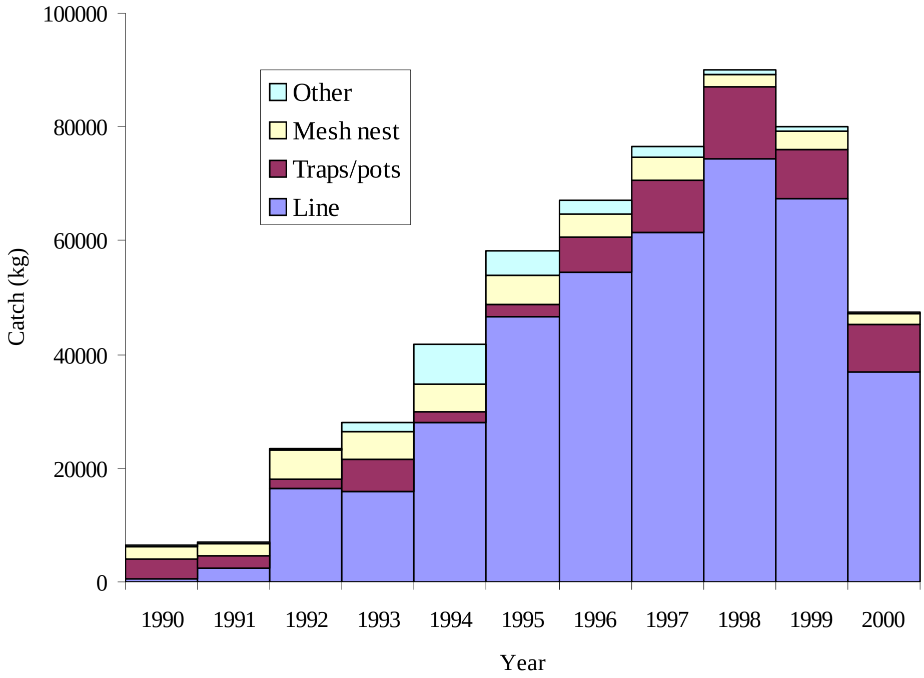


Figure 4. Annual catch of wrasse by method, 1990-2000. Source: Catch and Effort Unit

The fishery for wrasse developed rapidly during the early 1990s peaking in 1998 at almost 90 tonnes (Figure 4). Catches have subsequently declined. Handlines catches contributed the greatest amount, over 80% in 1998, followed to a much lesser extent by traps and pots, and meshnets (Figure 4).

Bluethroat wrasse is the dominant species (see below), but a large proportion of the catch in logbooks is recorded as unspecified wrasse (Figure 5). The other major species, saddled wrasse, was only recently identified separately on logbooks.

Following the trend in catches, the number of vessels that reported catching wrasse by handline increased rapidly from less than 20 during the early 1990s to a peak of 72 in 1997 but subsequently declined to less than 60 (Figure 6).

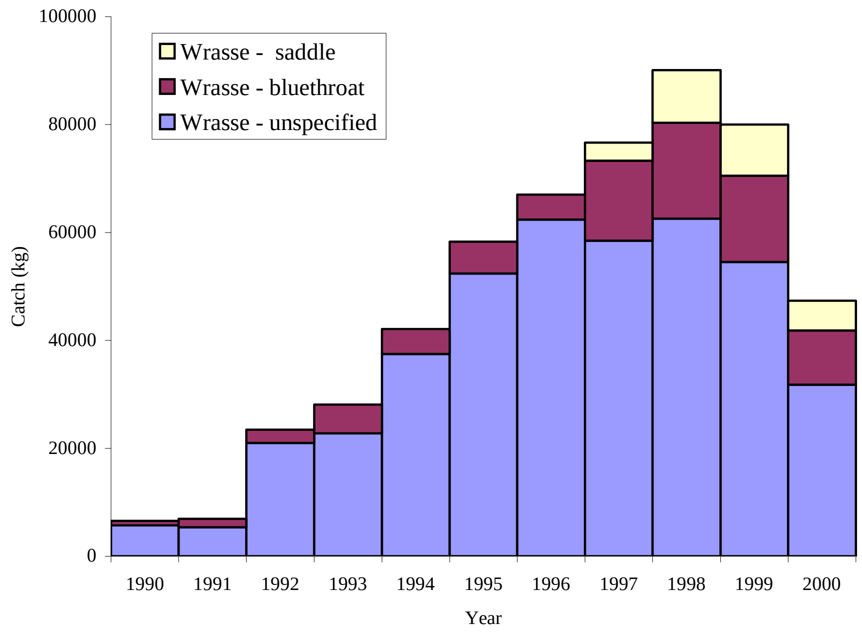


Figure 5 Annual catch of wrasse by species, 1990-2000. Source: Catch and Effort Unit

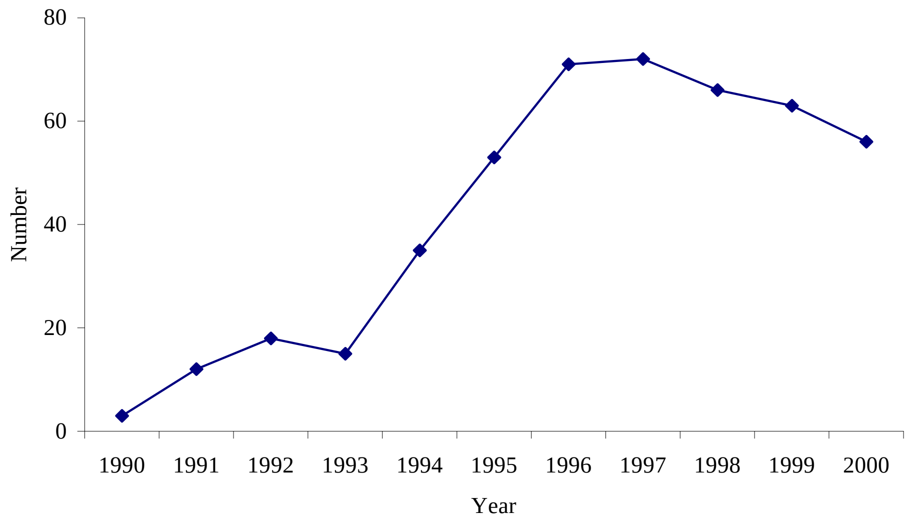


Figure 6 Number of vessels reporting wrasse catch by handline, 1990-2000. Source: Catch and Effort Unit

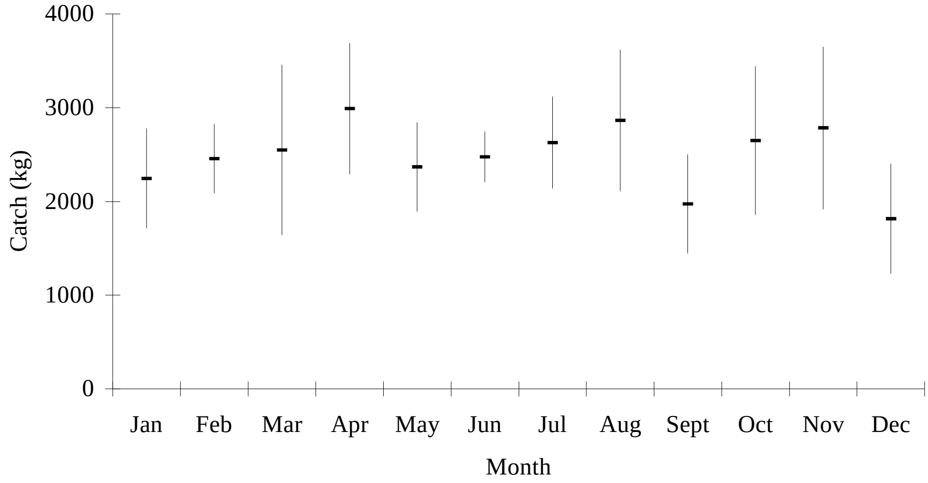


Figure 7 Mean monthly catch (kg) of wrasse taken by handline (+/- 1 se), 1995-1999. Source: Catch and Effort database

There are no clear seasonal trends in the fishery. Mean monthly handline catches for the period 1995-1999 ranged from about 1800 kg to 3000 kg (Figure 7).

The bulk of the handline catch is taken from depths of less than 50 m (Figure 8). The preferred depths for bluethroat wrasse are 20-40 m. In contrast, saddled wrasse are taken at slightly shallower depths with most reported in depths of 10-30 m.

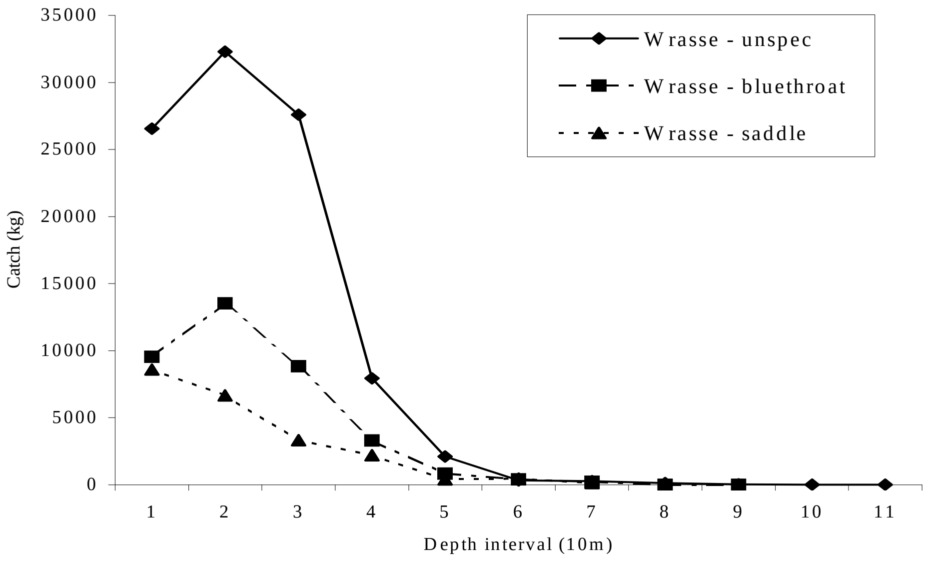
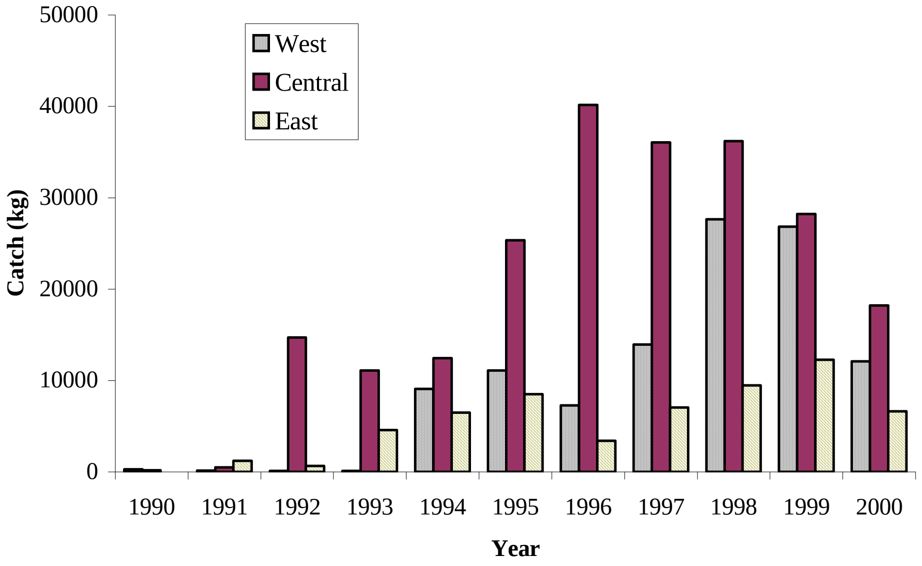


Figure 8 Handline catch by 10-m depth interval (1=0-10m) for wrasse by species, 1998-2000. Source: Catch and Effort Unit

The catch and the number of vessels reporting catch was greatest off central Victoria but the proportion taken off the west increased during the late 1990s (Figure 9).

a)



b)

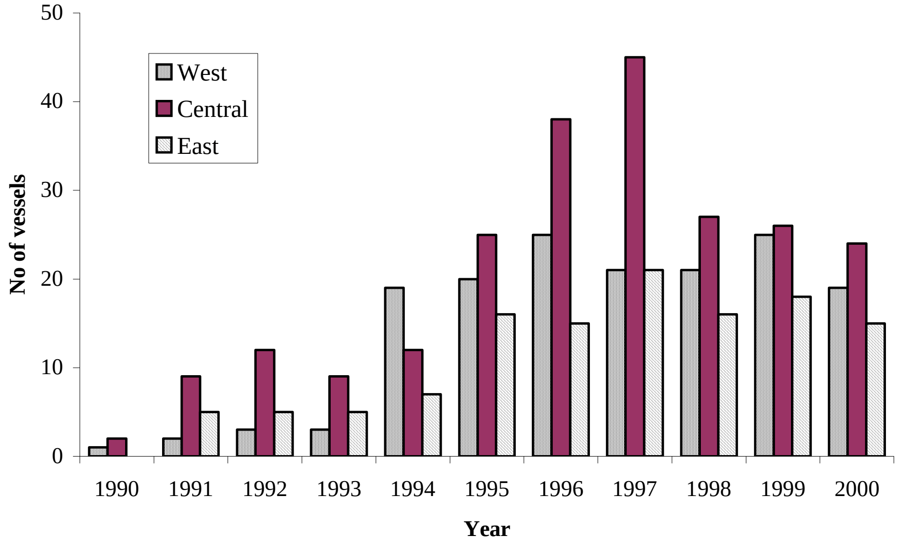


Figure 9 a) Wrasse handline catch (kg) by area, and b) number of vessels by area, 1990-2000 (see text for details). Source: Catch and Effort Unit

Byproduct species are reported by wrasse fishers on their fishing returns. In most cases it was clear when fishers were fishing for wrasse. However, because some operators fished for other species it was sometimes unclear what was byproduct and what was the target species during a particular fishing trip. In addition, bycatch species are not reported. Consequently, byproduct and bycatch species were obtained from industry information recorded on scientific data sheets when it was clear that wrasse was the target species. These data are summarised in Tables 2 and 3. Overall, byproduct in the fishery is low. Bluethroat wrasse made up 84% of the catch by number and saddled wrasse 12% by number. Saddled wrasse made up a higher proportion of the total reported catch by number in the west compared to the east, 15% and 8%, respectively. More than 20 other species were recorded but few of these were caught relative to the number bluethroat and saddled wrasse (Table 2). The most numerous reported were leatherjackets, perch, sweep and maori wrasse.

Discarding was relatively high, 25% by number in the east and 36% in the west (Table 3). This was primarily bluethroat (24% and 35% in the east and west, respectively) and saddled wrasse (16% and 39% in the east and west, respectively). However, because it is a live fish fishery, all most all of these fish were returned live to the water. Discarded fish were generally small (see below), under the minimum legal length for bluethroat or not of marketable size for saddled wrasse. Other species discarded included leatherjackets, perch (unspecified species) and maori wrasse.

Table 2 Handline catch (number) by species and area reported by industry

	Number of fish reported by zone			
Common name	Eastern	Central	Western	Total
Cod, [Unspecified]	5			5
Cod, Rock			4	4
Flathead, [Unspecified]	1			1
Gurnard, [Unspecified]	1			1
Leatherjacket, [Unspecified]	10		33	43
Mackerel, [Unspecified]	1			1
Morwong, [Unspecified]	1		3	4
Morwong, Jackass	2			2
Mullet, Red	5			5
Wrasse, (Unspecified)	46		33	79
Wrasse, Bluethroat	2518	353	3406	6277
Perch, [Unspecified]			39	39
Sergeant-baker	2			2
Shark, draughtboard	2			2
Snapper	1			1
Snook	7			7
Sweep	1		28	29
Whiting, King George	1			1
Wrasse, Maori	42			42
Wrasse, Saddled	240	1	622	863
Wrasse, Senator			4	4
Total	2886	354	4172	7412

Table 3 Handline retained and discarded catch (number) by area reported by industry

Common name	Eastern		Western	
	Retained	Discarded	Retained	Discarded
Cod, Rock				2
Cod, [Unspecified]	5			
Gurnard, [Unspecified]		1		
Flathead, [Unspecified]	1			
Leatherjacket, [Unspecified]	8		4	29
Luderick	0			
Mackerel, [Unspecified]	1			
Morwong, [Unspecified]	0		1	
Morwong, Jackass	2			
Mullet, Red	5			
Wrasse, (Unspecified)	31	15	9	24
Wrasse, Bluethroat	1933	585	2308	1098
Perch, [Unspecified]			1	38
Sergeant-baker		2		
Shark, draughtboard		2		
Snapper	1			
Snook	7			
Sweep	1		26	2
Whiting, King George	1			
Wrasse, Maori		42		
Wrasse, Saddled	199	39	387	215
Wrasse, Senator			1	3
Total	2195	686	2737	1411

Catch and effort statistics - detailed analyses

GIS plots for the period from 1995 to 2000 show that the bulk of catches until 1998 were taken off central Victoria between Lorne and Cape Liptrap (Figure 10). The next highest catch was to the west of this area. However, during most years the spread of catch east and west of this central area was fairly uniform. Note that the magnitude of catch is not shown in grids in which 5 or less vessels operated during a particular year. However, where catches were taken is indicated.

From 1998 onwards, increased annual catches were taken from the most western logbook grid off Portland. The relative importance of the catch between Lorne and Cape Liptrap also declined during this period (Figure 10).

Examination of catch at a finer spatial scale (Figure 11) shows that wrasse were taken along the entire Victorian coast during 1998 to 2000 but there are a number of areas with higher catches. The highest reported catch came from an area off Portland in the west of the State. Also off western Victoria, relatively high catches were reported along the Warrnambool coast and off Cape Conron. For central Victoria, the highest catches were reported east of Port Phillip Bay, off Western Port and Cape Paterson. Catches were also relatively high around Wilson’s Promontory.

Unstandardised catch rates (kg/day) for handline fishers are shown in Figure 12. Fishermens returns were examined for each year and wrasse handline data extracted. The catch rate is the total annual wrasse catch divided by the total number of days fished. Several fishers reported only small quantities in some years. Consequently, to assess the impact these fishers may have on trends in the data, an adjusted catch rate was also computed. The adjusted catch rates were calculated using data only from operators who landed more than 250 kg in a given year. This had very little effect on the analysis (Figure 12). Trends were identical with the adjusted catch rates, but as expected, were slightly higher. Catch rates rose rapidly from 1990 to peak at 50 - 60 kg/day during 1992 - 1994. Catch rates dropped in 1995 but have remained relatively stable since at just over 30 kg/day.

Catch rates were also examined by area (Figure 13). Catch rates were variable across Victoria and not all areas showed the same trend as the consolidated analysis (Figure 14). Off Portland (grid no 4) catch rates peaked in 1994, declined in 1995 and were relatively stable until 2000. In grid 5 (the Warrnambool coast) catch rates were low until 1994 but have remained stable since. Off Port Phillip Bay (grid no 7) catch rates were variable in the early 1990s but were relatively stable between 1994 and 2000. Off Western Port (grid no 8) catch rates mirrored those off Portland peaking in 1994. However, they slowly declined between 1995 and 2000. Adequate catch rate data were available for only one area off Eastern Victoria (grid no 9 – east of Wilson's Promontory). Here catch rates were extremely variable during the early 1990s but were relatively stable between 1996 and 2000.

For the GLM analyses, data were constrained to those vessels reporting catches for 2 or more years and with annual catches > 250 kg. Standardised CPUE was determined using two models (Figure 15):

Model 1, CPUE = year month vessel area

Model 2, CPUE = year month vessel area year*area

The interaction term was included because of the possibility, indicated by the unstandardised data, that areas included in the analyses did not contribute equally in all years.

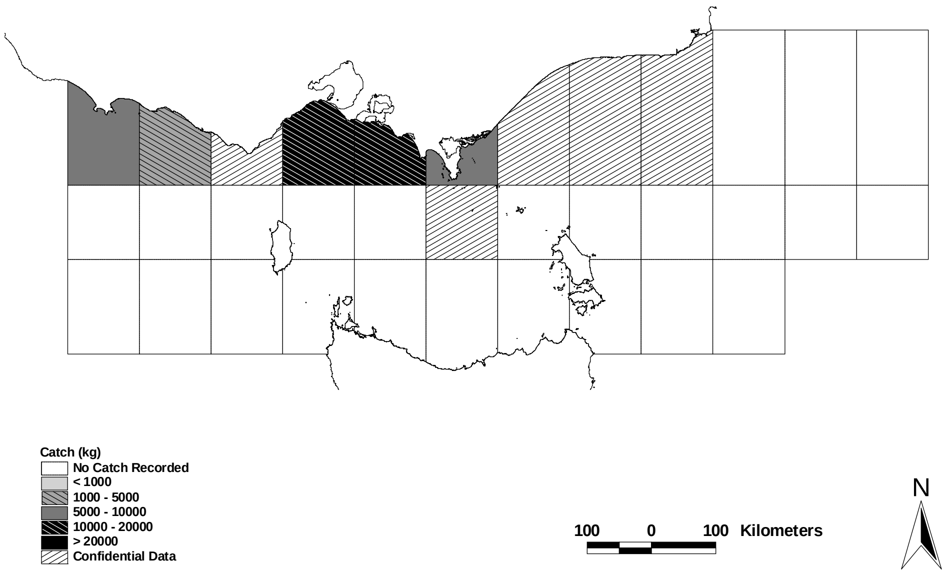
Model 1 (Figure 15a) accounted for 44% of the variation in the data set. Standardised CPUE peaked in 1994 followed by a slow but continuous decline between 1995 and 2000.

For Model 2, only data from grids 4, 5, 6, 7, 8, 9 and 12 were used. Data were available for other areas but the year area coverage was not good and the analyses were sensitive to the data used. Thus although the final model accounted for 45% of the variation in the data, the results from Model 2 (Figure 15b) should be treated cautiously.

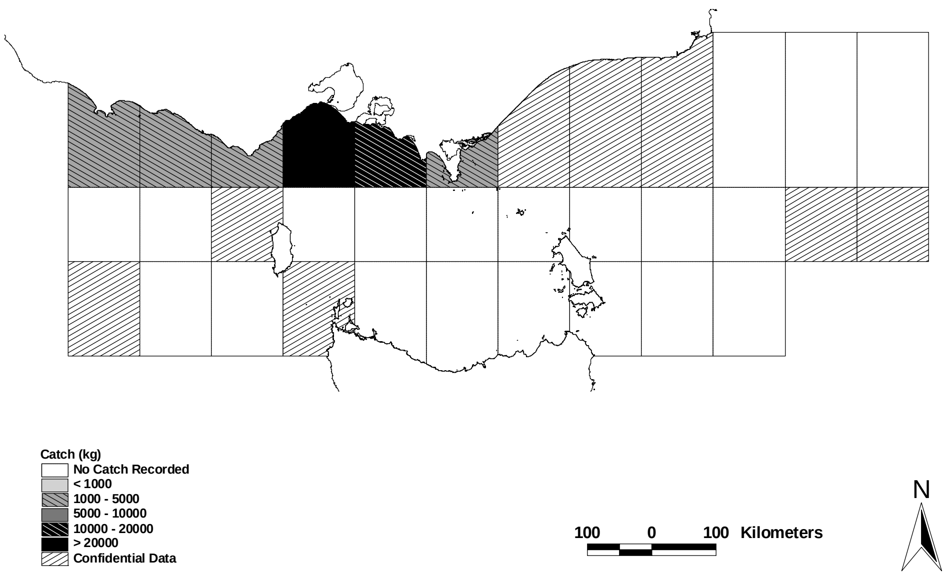
There were clear differences in the standardised CPUE trends between the two models. Model 2 gave results similar to the unstandardised catch rates (Figure 12) although the drop between 1994 and 1995 was more pronounced. There are clear year*area interactions in these data. This indicates that overall CPUE is maintained by higher catch rates in different areas and suggests that areas may be fished down sequentially. To some extent this agrees with industry observations (see below) that in new areas catches are initially high and then decline to a lower but consistent catch.

Figure 10 Annual handline catch (kg) of wrasse (bluethroat and saddled combined) by fishing grid, 1995 to 2000. Source: Catch and Effort Unit.

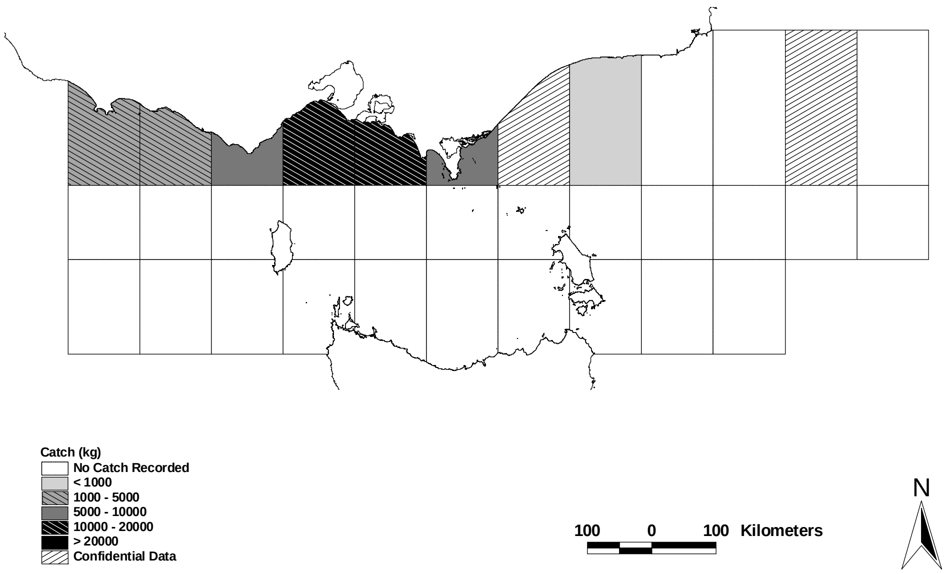
Catch of all Wrasse during 1995



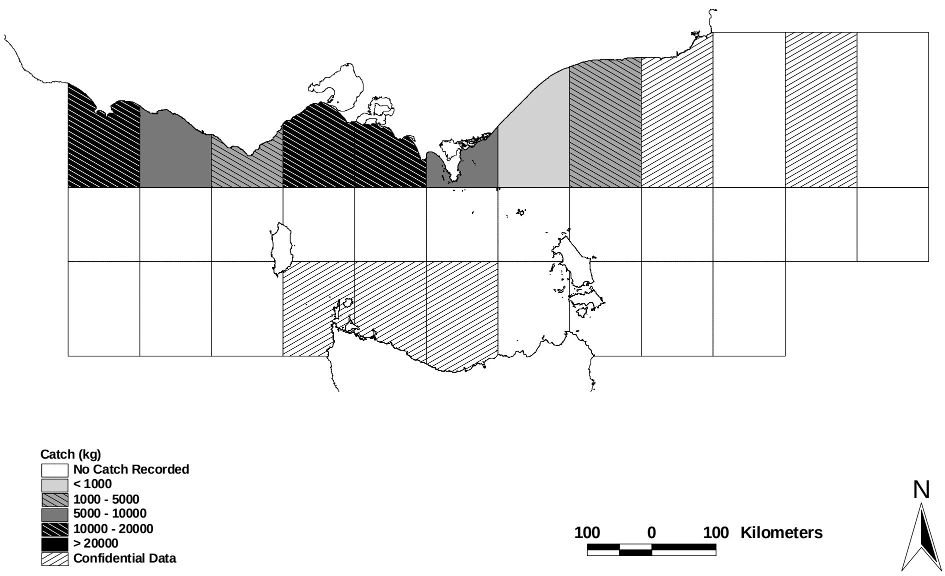
Catch of all Wrasse during 1996



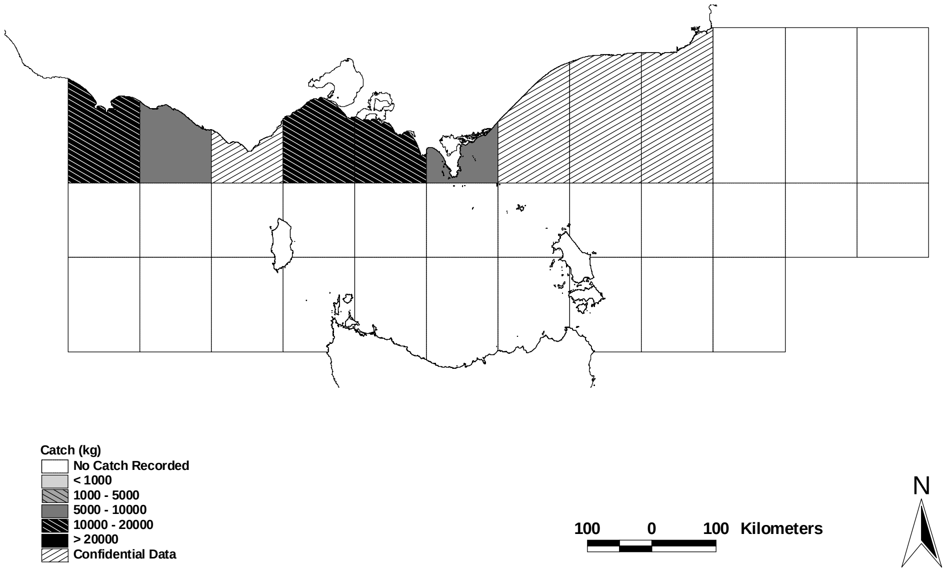
Catch of all Wrasse during 1997



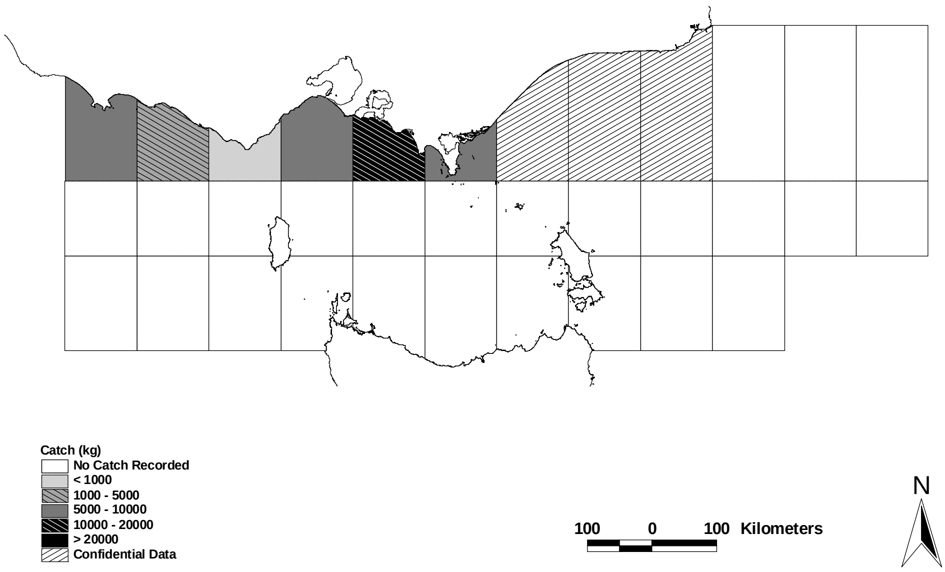
Catch of all Wrasse during 1998



Catch of all Wrasse during 1999



Catch of all Wrasse during 2000



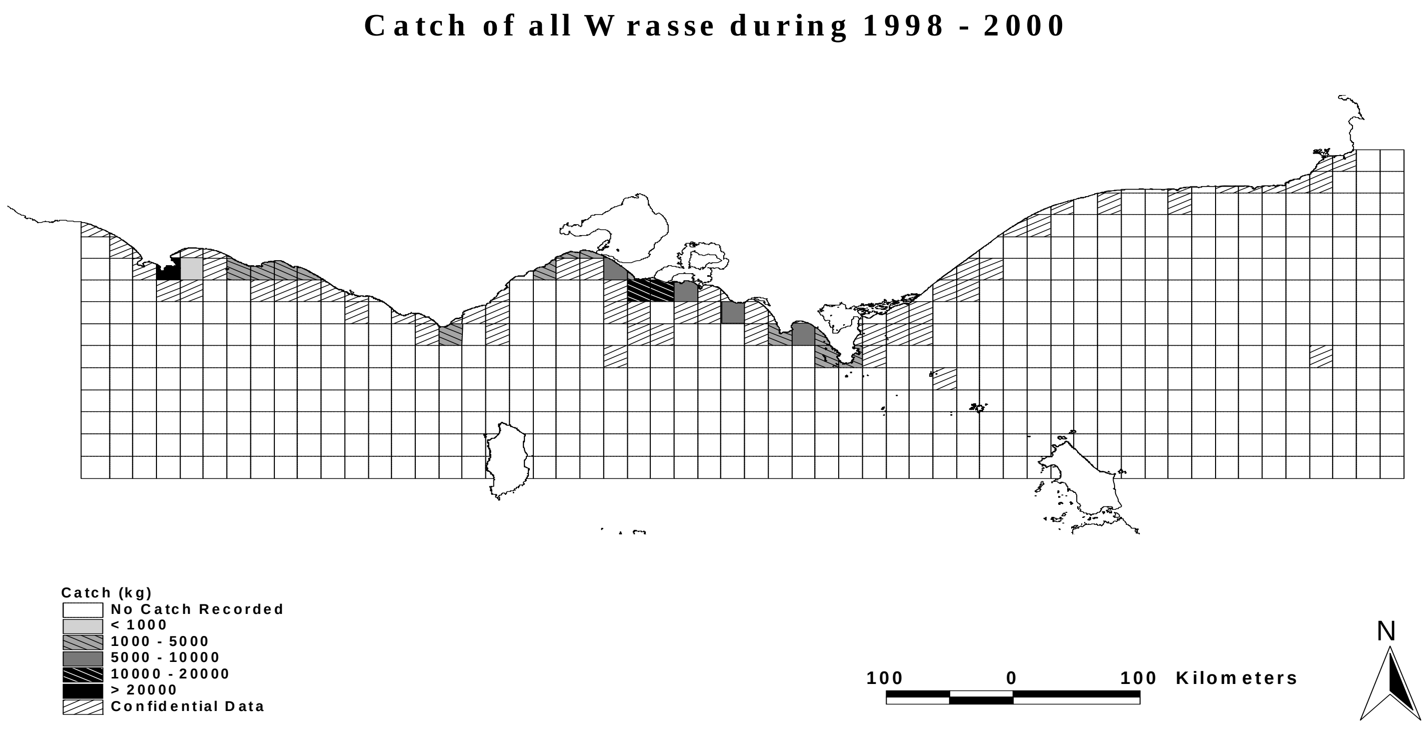


Figure 11 Catch (kg) of wrasse (bluethroat and saddled combined) by fishing grid, 1998-2000 in aggregate. Source: Catch and Effort Unit

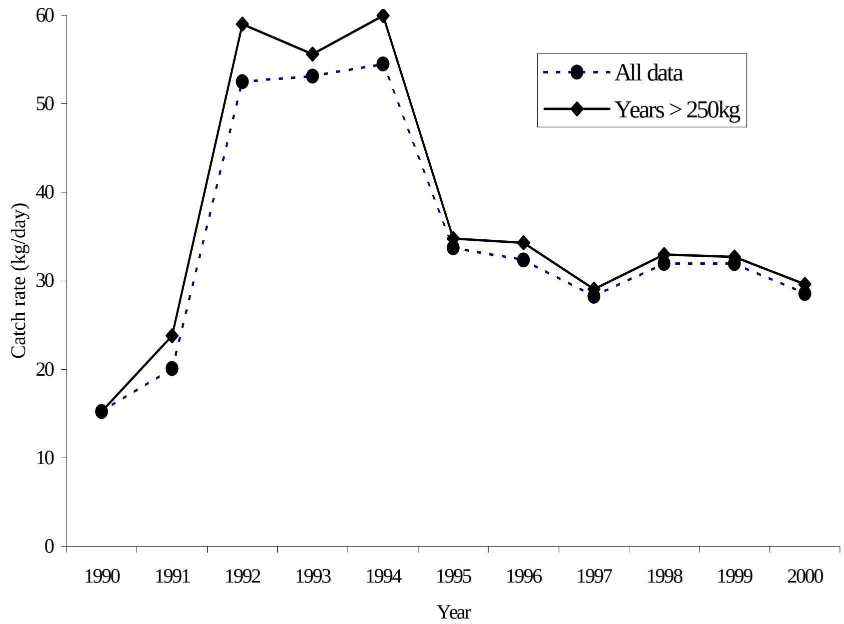


Figure 12. Annual unstandardised catch rates for wrasse 1990-2000. The solid line includes all data; the dotted line excludes vessels reporting an annual catch <250 kg.

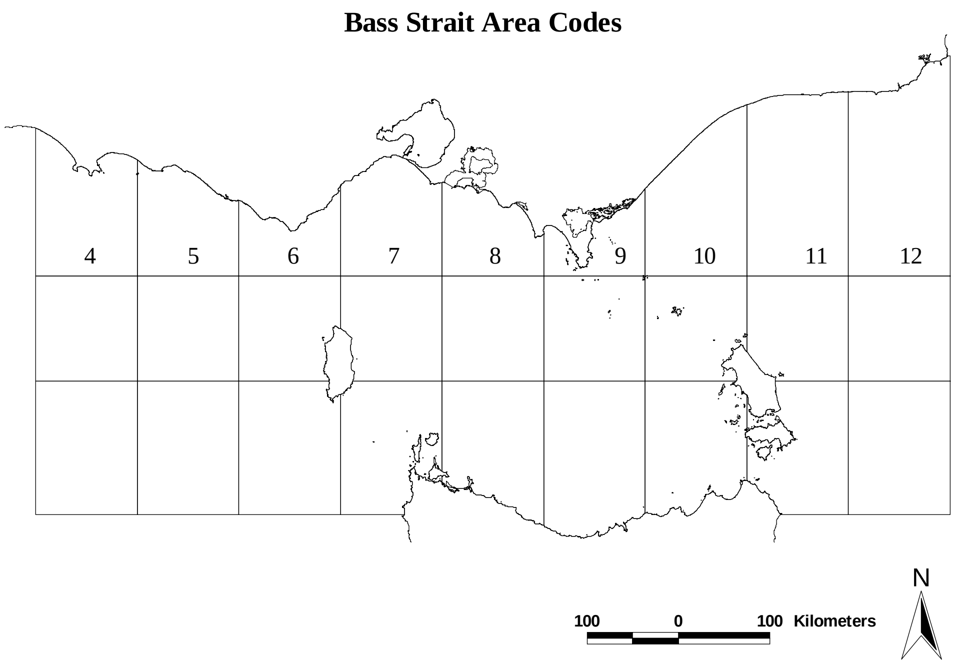


Figure 13. Catch and area grid numbers referred to in Figure 14.

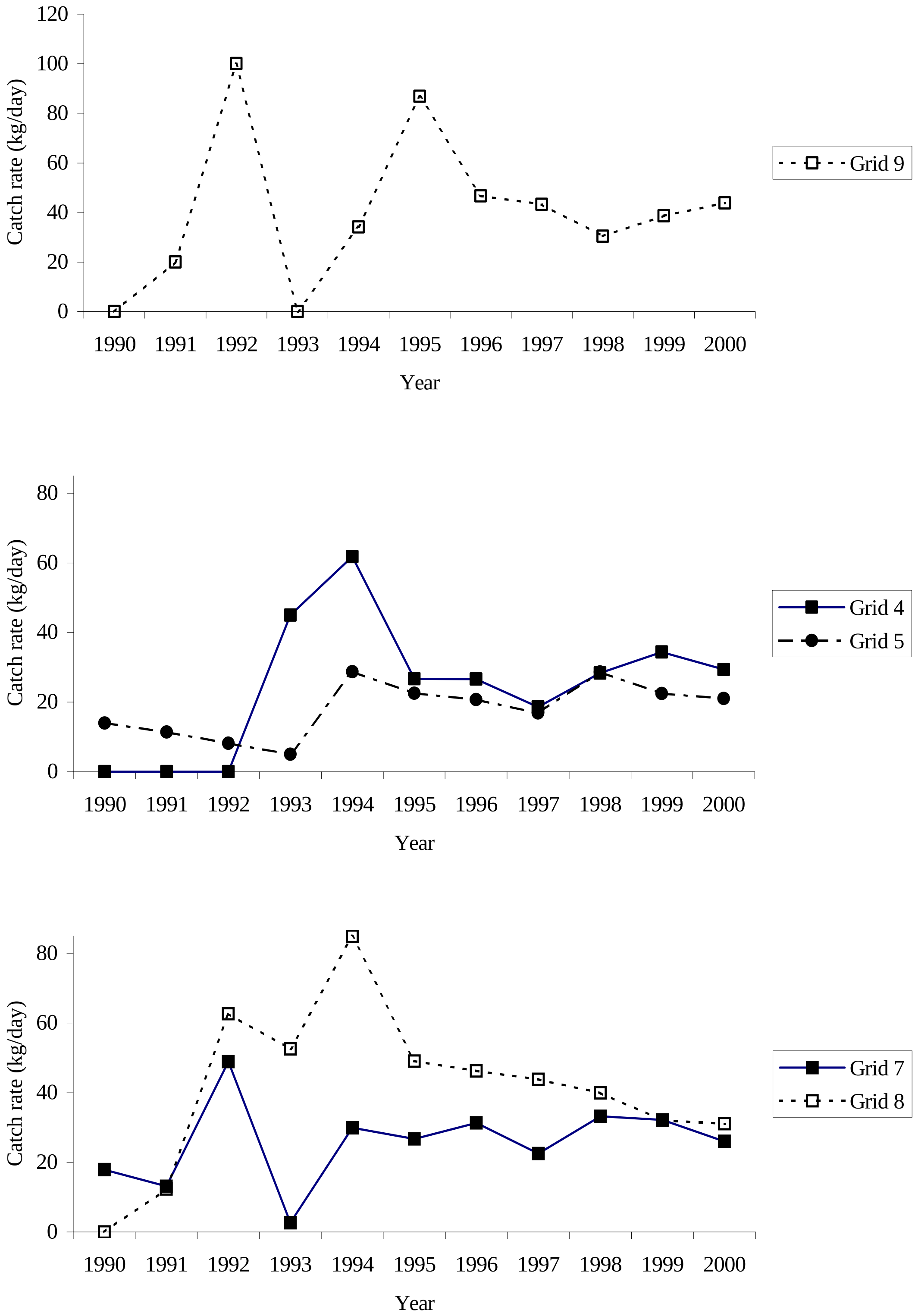
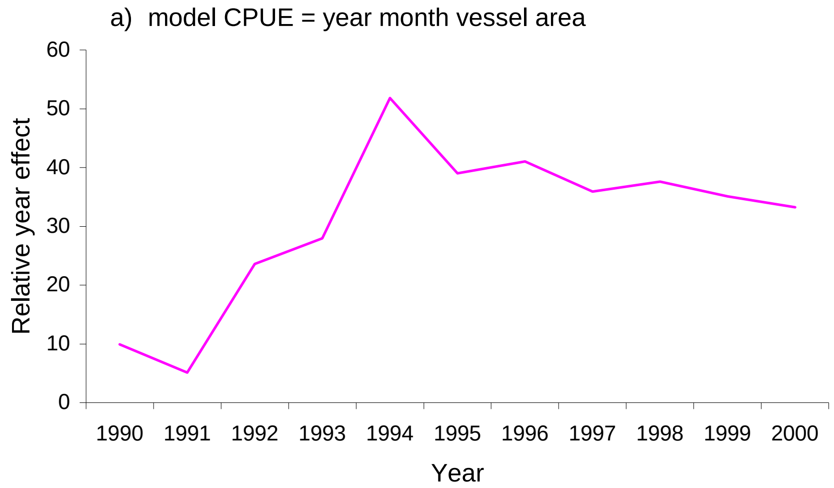


Figure 14 Unstandardised catch rate (kg/day) by catch and effort grid, 1990 - 2000.



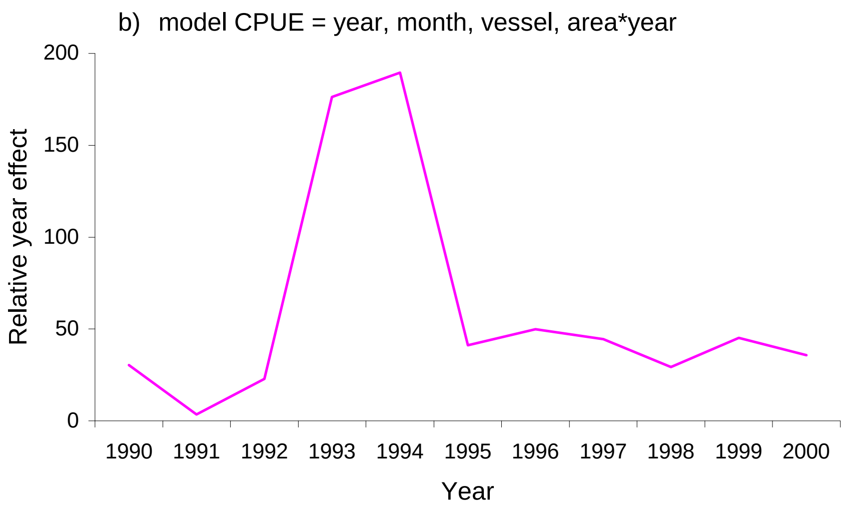


Figure 15 Results of GLM analyses for two different models. Data are for vessels with an annual catch > 250 kg and 2 or more years in the fishery.

Industry perspective

This section is synthesised from the comments of 19 wrasse fishers who attended the wrasse workshop held at MAFRI, Queenscliff, on 11 May 2001.

General

- Generally, most fishers were relatively optimistic about their fishery. They also were extremely interested and supportive of the research that had been done and many had contributed significantly to the project.

- Reasons for the decline in catches in recent years, particularly during 2000 were discussed. Most fishers agreed that the large drop in 2000 reflected a decline in fishing effort, with relatively few operators targeting wrasse. It was suggested that catches may have peaked.

- Industry aims to get a good product to market. Getting air out of fish swim bladders is important for survival. Depth and water temperature are also important; fish taken from more than 30 m are hard to keep alive and there are some losses. Large males are often aggressive and sometimes “dentistry” is performed to avoid damage due to fish attacking each other. Holding fish in the dark is also reported to reduce aggressive behaviour. Water temp and water quality are crucial and enclosed reticulated refrigerated holding systems have been developed. It was suggested that a code of conduct for handling fish be developed.

- Industry reported that catch rates are high when areas are first fished then consistent but lower catches are maintained. Weather is important and different grounds are fished in different conditions. This was argued to be good for sustainability because areas are not fished all the time.

- Generally, “dirty” water and a large swell are not good for catching either species. It was reported that good days for working were less during 2000 than in previous years.

- There is a need to look at distribution of species from different ports: Warrnambool, bluethroat wrasse; Portland, saddled wrasse. The types of ground differ, they are shallower and more sheltered off Portland.

- Relationship between depth and the size of fish is unclear. Some suggested a size-depth relationship existed but others thought not, arguing it depended more on whether an area had been fished or not

- Industry reported seeing few tagged wrasse: the low number of tags reported was not due to people not returning tags.

- Continuation of industry length-frequency measuring/tagging was requested.

Issues:

- Industry was concerned by the amount of latent effort in the fishery.

- Some supported some zoning in the fishery whereas others opposed it.

- Recreational fishing is a problem in some areas where recreational fishers were reported to kill fish before returning them to the water. However, the commercial sector is working closely with anglers at Portland. It was suggested that anglers need to be educated and that a bag limit is needed.

- Seal interactions were reported to be a problem for some.

- Industry requested a size limit on saddled wrasse.

- In general terms, the fishery is regarded as relatively “clean”. Discards are high but fish are generally alive when returned to the water.

Reproductive biology

Gono-somatic indices and sex ratios

Gono-somatic indices (GSIs) were calculated for 1004 fish sampled during the project. Fish ranged in length from 14 to 46 cm TL. Of these, 661 were macroscopically identified as females (14 to 39 cm TL) and 337 as secondary males (23 to 46 cm TL).

Individual GSI values were mostly less than 5 for females and 2 for males (Figure 16). From these data, it is difficult to determine a size at first maturity. However, for females it appears that a proportion of fish less than 25 cm TL are mature.

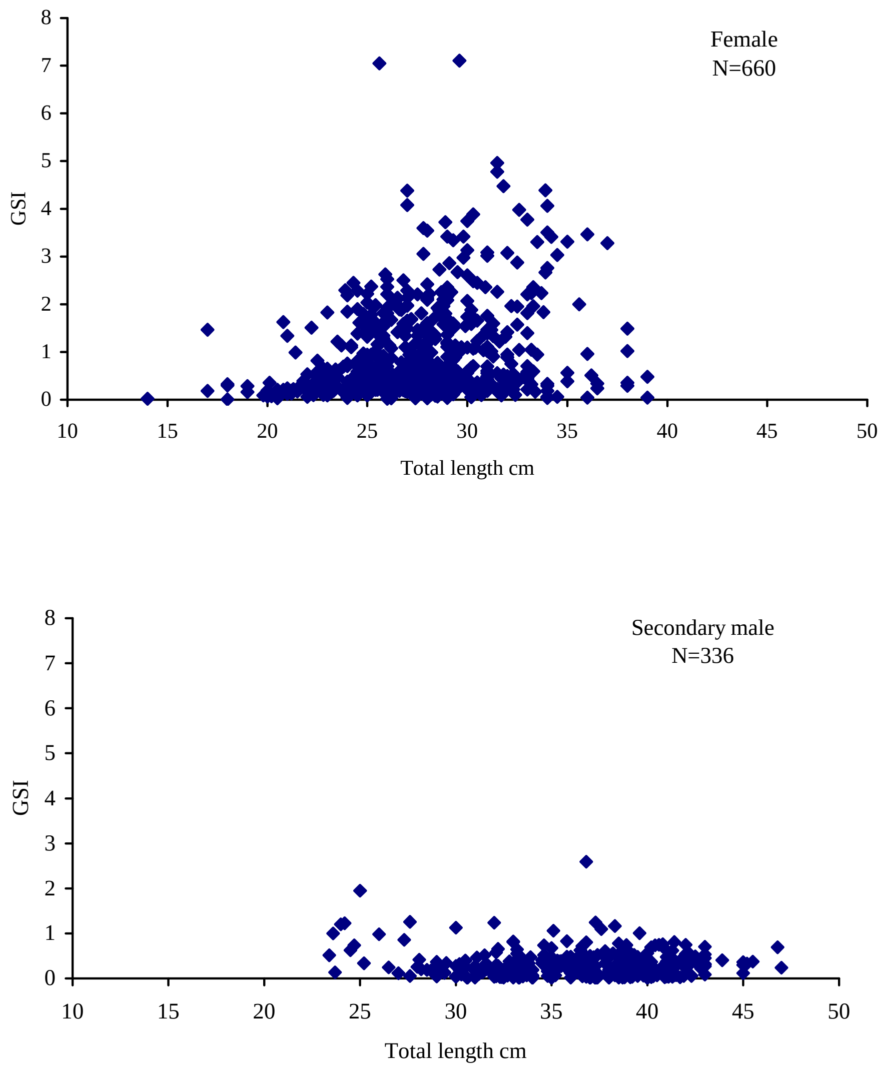


Figure 16 GSI vs length for female and secondary male bluethroat wrasse.

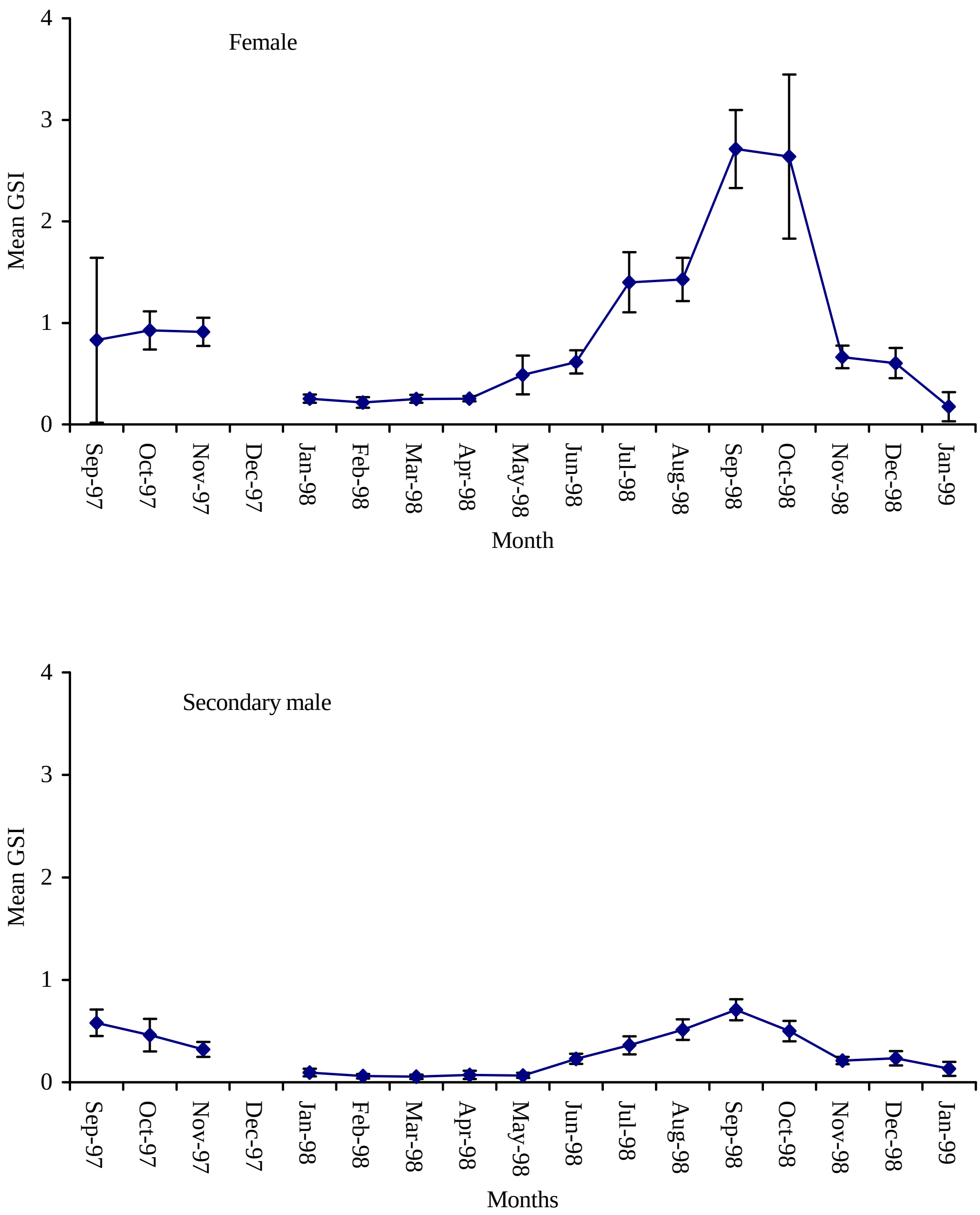


Figure 17 Monthly mean GSIs for females and secondary males (+/- 1 se)

Monthly mean GSIs for females and secondary males, shown in Figure 17, indicates that maturation of females and secondary male gonads begins in May/June and continues through September and October. There is a rapid decline in mean GSIs between October and November 1998 for both secondary males and females.

Overall, two females were sampled for every male (Table 4). The sex ratio of males to females in individual samples varied considerably from 1 male to:0.6 females, to 1 male to 6 females. Care should be taken in interpreting these results because biological samples tended to be biased toward smaller fish and hence females. However, the overall sex ratio of fish measured onboard commercial vessels (see section on size-frequency distributions) was 1 male to 1.8 females, similar to the overall sex ratio for the biological samples.

Table 4 Summary of sex ratio by month and area; secondary male:female.

Month	Area			All Regions
	Central	East	West	
Sep-97			1:3	1:3
Oct-97	1:6		1:5.7	1:6
Nov-97	1:1.5	1:0.9	1:1.9	1:1
Jan-98	1:1.4			1:1
Feb-98	1:1.5	1:1.2	1:3.7	1:2
Mar-98	1:0.7	1:1.3	1:3	1:1
Apr-98	1:6	1:1.7	1:4.6	1:3
May-98		1:5.4	1:1	1:3
Jun-98		1:1.1	1:1.8	1:1
Jul-98	1:2.7	1:1.3		1:2
Aug-98	1:4.9	1:0.9	1:0.9	1:2
Sep-98		1:0.6	1:3.3	1:1
Oct-98		1:1		1:2
Nov-98	1:0.5	1:0.0	1:5.2	1:3
Dec-98			1:1.2	1:1
Jan-99		1:1		1:1
Overall	1:2	1:1.4	1:2.9	1:2

Histological description

Histological descriptions of bluethroat wrasse oocytes, spermatozoa and gonads are presented in Tables 5 to 7 and Figures 18 and 19.

In immature females, the ovaries show no sign of previous spawning. The ovary is thin in diameter and encased by a relatively thick wall. Microscopically, the lamellae are packed with previtellogenic oocytes in early and late perinucleolis stages. Gonia and chromatin nucleus stage oocytes are abundant.

Resting mature females have ovaries that are larger in diameter and are encased by a thinner and more distended gonadal wall. The lamellae are filled with previtellogenic oocytes. Gonia and chromatin nucleus stage oocytes are much less abundant than in immature females. As the gonads develop, oocytes are in early stages of vitellogenesis. Ripe gonads have oocytes in late stages of vitellogenesis. Oocytes are present at several stages but are dominated by the advanced yolk stage. In running ripe gonads oocytes at all stages are present, from unyolked to hydrated but the later stages dominate. In spent females, lamellae were disrupted and disorganized, with extensive vascularization. Follicular cells and remanants of post-ovulatory follicles were present throughout the gonad. Vitellogenic oocytes were in atresia.

Few individuals were sampled with gonads undergoing sex change. Transitional individuals were defined as having gonads that showed proliferating testicular tissue in the presence of degenerating ovarian tissue. In these gonads, unyolked oocytes dominated but partially yolked oocytes were sometimes present. There was a proliferation of small crypts of spermatogonia and spermatocytes. This description is consistent with Warner and Swearer (1991) who described sex change in bluehead wrasse, *Thalassoma bifasciatum*. Histological examination of individuals that had recently undergone colour change showed functional testes but with evidence of transition from the ovarian condition. Sex change occurred quickly and mature sperm can be produced as little as eight days after the initiation of sex change. This has been reported in other sex changing species.

In resting males, the testes were dominated by stromal tissue and early stages of spermatogenesis. As they develop, later stages of spermatogenesis and spermiogenesis were evident with spermatozoa starting to fill the dorsal sinus. Running ripe gonads were dominated by spermiogenesis. Dorsal sinuses were filled with spermatozoa. Spent gonads were characterised by development of crypts of spermatogonia and primary spermatocytes throughout the testis. Stromal tissue was well developed between crypts and old crypts were empty except for residual spermatozoa.

Table 5. Description of the development of oocytes, α-atretic oocytes and postovulatory follicles of bluethroat wrasse (modified from Hunter and Macewicz 1985).

Developmental Stage	Microscopic characteristics
Unyolked	Oogonia small (<103 µm; 170 oogonia measured from 34 ovaries), cytoplasm basophilic. Nucleus large, central, several nucleoli occur at nucleus periphery.
Partially yolked	Similar to above, but larger (64-315 µm; n = 160, 32 ovaries). Lipid granules throuhout cytoplasm. Follicular layer comprises two cell layers. Zona radiata present but still thin.
Advanced yolked	Oocytes large (264-488 µm; n = 90, 18 ovaries). Lipid granules and esinophilic yolk protein granules throughout the cytoplasm. Nucleus still central. Zona radiata thick and highly eosinophilic.
Migratory nucleus	Similar to stage 3, except nucleus has migrated to the peripheral cytoplasm (355-494 µm; n = 50, 10 ovaries). This represents the initiation of the hydration process.
Hydrated	Oocytes much larger (502-670 µm; n = 110, 22 ovaries) With uptake of fluid, nucleus absent. Yolk plates occupy entire volume of cytoplasm, then fuse to form a homogeneous mass. Zona radiata and follicular layers become greatly stretched.
α−atretic oocyte	Zona radiata dissolves, oocyte shape loses integrity Yolk globules begin to disintegrate and are less regular in shape.
Postovulatory follicle (new)	Remaining follicle soon after ovulation. It is large, highly Convoluted with an obvious lumen, and may contain fine granular material. The layered nature of both cell types (thecal and granulosa) remains intact.
Postovulatory follicle (old)	Convoluted nature much less apparent, lumen much reduced, even closed, and the thecal and granulosa cells no longer retain their orderly arrangement.

Table 6. Description of the development of spermatozoa

Development	Microscopic characteristics
Spermatogonia	They are usually spherical and present either singly or in small groups (nests) at all times. Cysts of spermatogonia formed which rapidly fill the lumen of the testis. (Largest cell visible in the testis, light staining with visible nucleus).
Primary spermatocytes	In the early stages, primary spermatocytes are morphologically similar to spermatogonia though somewhat smaller. They soon loose their nucleolus and are most commonly seen in prophase of the first meiotic division, the various stages of which cannot be readily distinguised. (Light staining, granular appearance).
Secondary spermatocytes	They are produced by the meiotic division of primary spermatocytes. They are small cells, do not have a distinct nucleus and are still located inside the lobules. (Dark staining with dense nucleus).
Spermatids	Continuing meiotic divisions of the secondary spermatocytes produce spermatids. Ther are smaller than the secondary spermatocytes, irregular in shape and are increasingly numerous in the testis. (Small cell with dense staining nucleus and clear cytoplasm).
Spermatozoa	They are the smallest of all germ cell types in the testis. Spermatozoa are released into the cavity of the lobule by rupture of the nest wall. (Small dense staining heads, tails often visible. Found in luminal ducts in the testis).

Table 7. Microscopic characteristics of the gonads of the bluethroat wrasse used in identification of developmental stages of females, transitionals, and males.

Stages	Microscopic characteristics
Female	
Immature	Ovaries showed no evidence of prior spawning. The ovary is small in diameter and encased by a relatively thick gonadal wall. The lamellae are well packed and filled with previtellogenic oocytes in early and late perinucleolus stages (unyolked oocytes). Gonia and chromatin nucleus stage oocytes are abundant.
Resting	The ovary is larger in diameter than those of immature females and encased by a thinner, more distended gonadal wall. The lamella are filled with previtellogenic oocytes in early and late perinucleolus stages oocytes (unyolked oocytes). Gonia and chromatin nucleus stages oocytes are present but not as abundant as observed in immature females. The presence of yellow-brown bodies is common.
Developing	Oocytes in early stages of vitellogenesis; unyolked and partially yolked oocytes present.
Ripe	Oocytes in late stages of vitellogenesis; oocytes at several phases: unyolked, partially yolked, but dominated by advanced.
Running ripe	Oocytes present at all stages from unyolked to hydrated but generally dominated by advanced yolk; nuclear migrated and hydrated.
Spent	Lamellae distrupted and disorganized, with extensive vascularization. Vitellogenic oocytes in atresia. Follicular cells, remanants of post-ovulatory follicles, present throughout the gonad. Proliferation of gonia and chromatin nucleus stage (unyolked stage) oocytes. Remnants of other oocytes sometimes present.
Transitional	Transitional individuals were defined as having gonads that showed proliferating testicular tissue in the presence of degenerating ovarian tissue. (Unyolked oocytes dominate; partially yolked oocytes sometimes present; proliferation of small crypts of spermatogonia and spermatocytes; crypts of spermatozoa sometimes present).
Male	
Resting	Testis dominated by stromal tissue and early stages of spermatogenesis (spermatogonia and primary spermatocytes present).
Developing	Later stages of spermatogenesis (secondary spermatocytes and spermatids present) and spermiogenesis; spermatozoa starting to fill the dorsal sinus.
Running ripe	Testis dominated by spermiogenesis. Most crypts containing spermatids and spermatozoa. Crypts of spermatozoa ruptured and joined within the testicular lobules, forming large intralobular or “central” sperm sinuses. Dorsal sinuses filled with spermaozoa.
Spent	Active development of crypts of spermatogonia and primary spermatocytes throughout the testis. Stromal tissue well developed between crypts. Old crypts empty with residual spermatozoa .

Fecundity

The relationship between fecundity and fish weight is shown in Figure 20. Although a sub-sample of about 50 ovaries was collected, the final number in the sample was 27. This was because, based on the histological analysis, ovaries that had postovulatory follicles and major atresia were not used for the fecundity analysis.

This relationship was used in subsequent per recruit analyses.

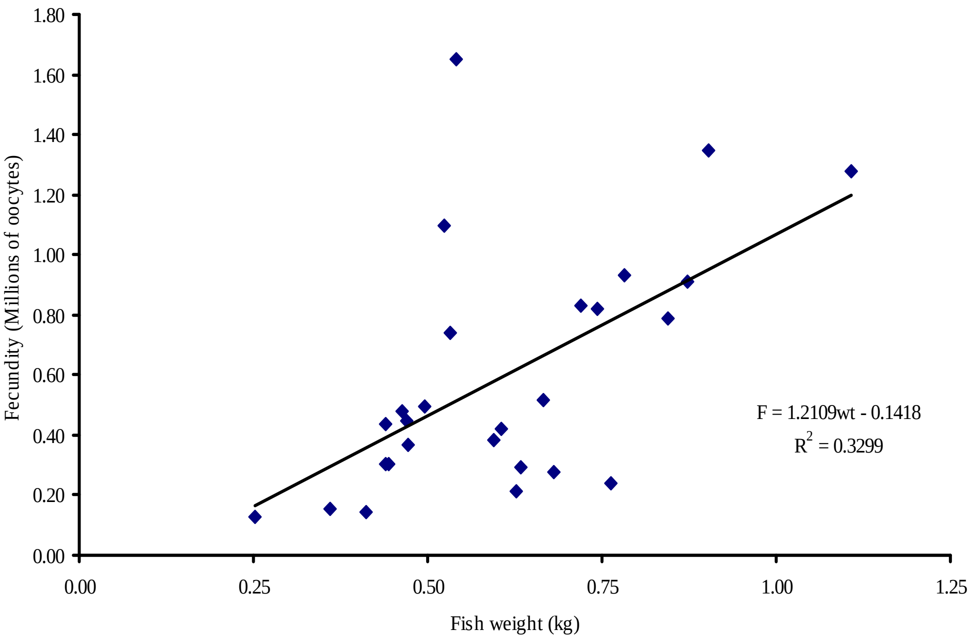


Figure 20 Relationship between fecundity and fish weight.

Size frequency distributions

Almost 6500 bluethroat wrasse were measured by industry and project staff between October 1997 and February 1999. Fish ranged in length between 15 and 50 cm TL (Figure 21) but most were in the range from 20 to 40 cm TL. Males were generally larger than females (Figure 21). Males were mostly between 30 and 45 cm TL compared with females at 20 to 35 cm TL. It is likely that small fish (< 23 cm) recorded as males were incorrectly identified because macroscopic and histological examination of gonads (see previous section) indicated that fish of this size were all female.

There were differences in the size distributions of fish sampled from each area (Figure 22). However, central zone fish were sampled from commercial landings early during the project and the sample size was relatively small. In addition, distributions for east and west included discarded fish. An LML of 28 cm was introduced in 1998 during the project so interpretation of differences in size distributions between areas should be treated cautiously.

Usually small bluethroat wrasse were not retained but returned live to the water (Figure 23). These were predominantly females. By number this ranged between 20-32%. Some fish below 28 cm were retained but these were from samples taken prior to the interim size limit. As above, the very small males were probably wrongly identified.

More than 600 saddled wrasse were measured opportunistically during the project. They ranged in length from 17 to 51 cm TL but most were between 20 and 35 cm TL. Saddled wrasse are not sexually dichromatic so it was not possible to sex fish non-destructively. As for bluethroat wrasse, fishers do not retain small fish although the size limit applies to bluethroat wrasse only (Figure 24).

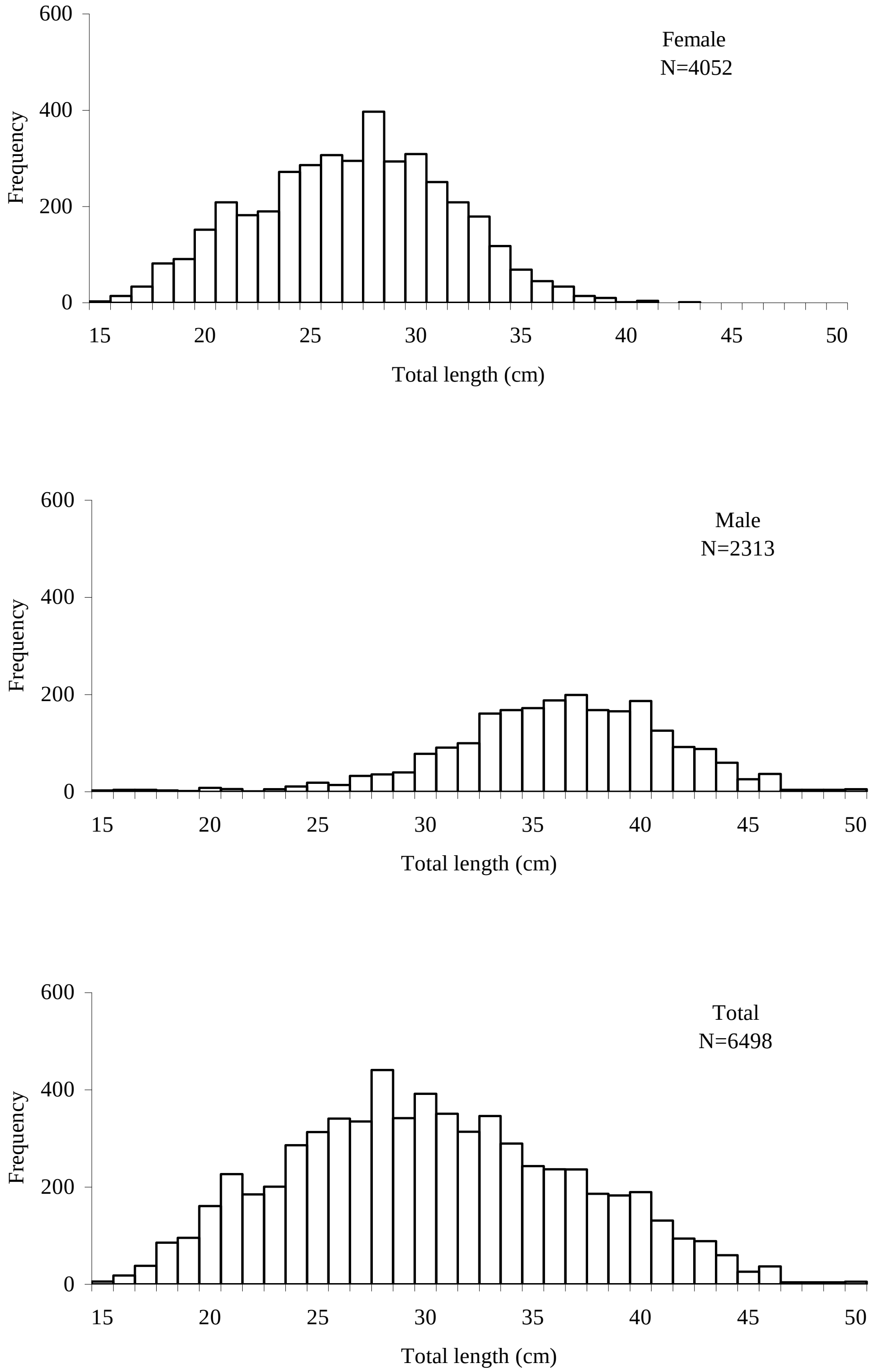


Figure 21 Length-frequency distributions by sex for bluethroat wrasse, October 1997 – February 1999.

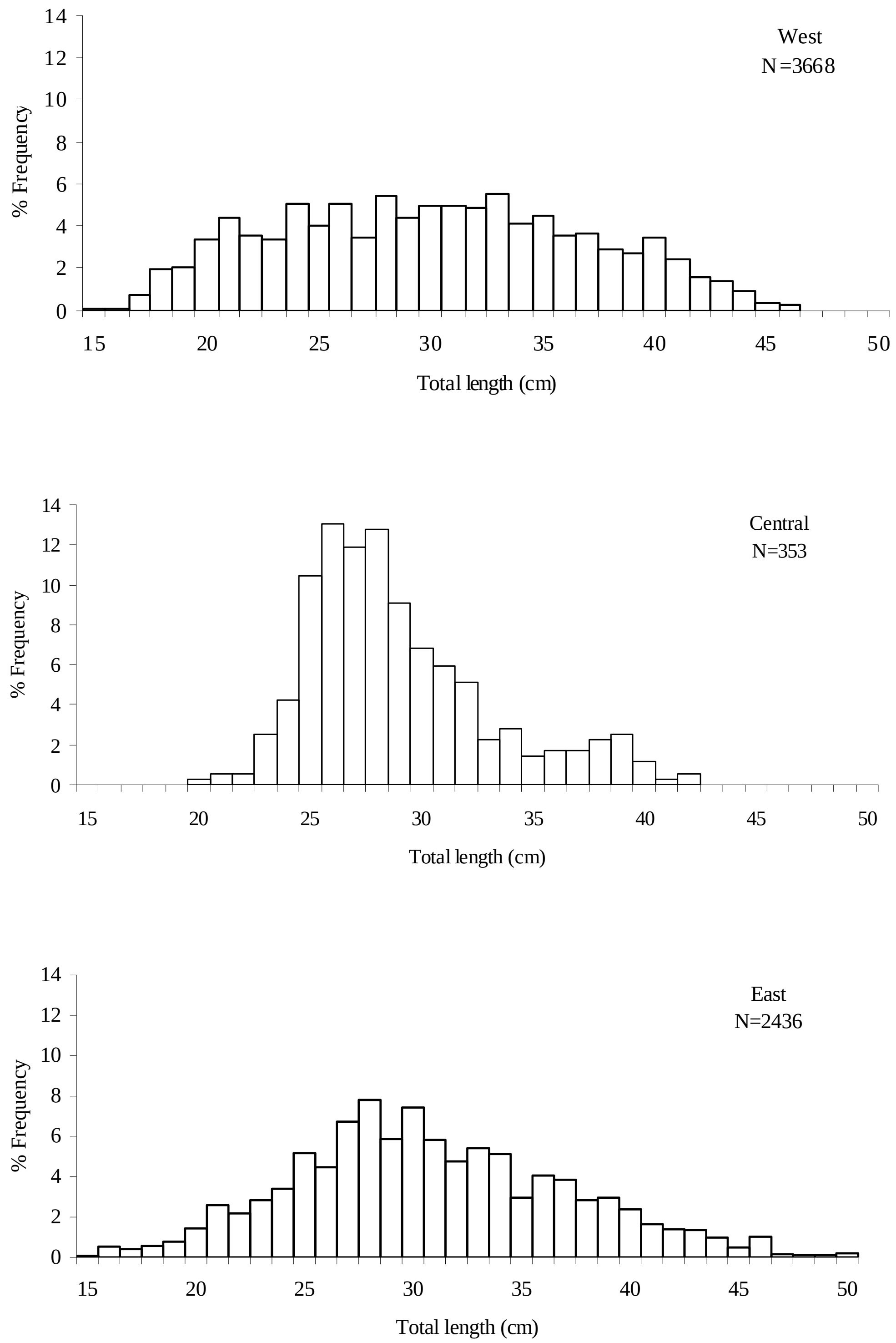


Figure 22 Percentage length-frequency distributions for blue throat wrasse by area, October 1997 – February 1999.

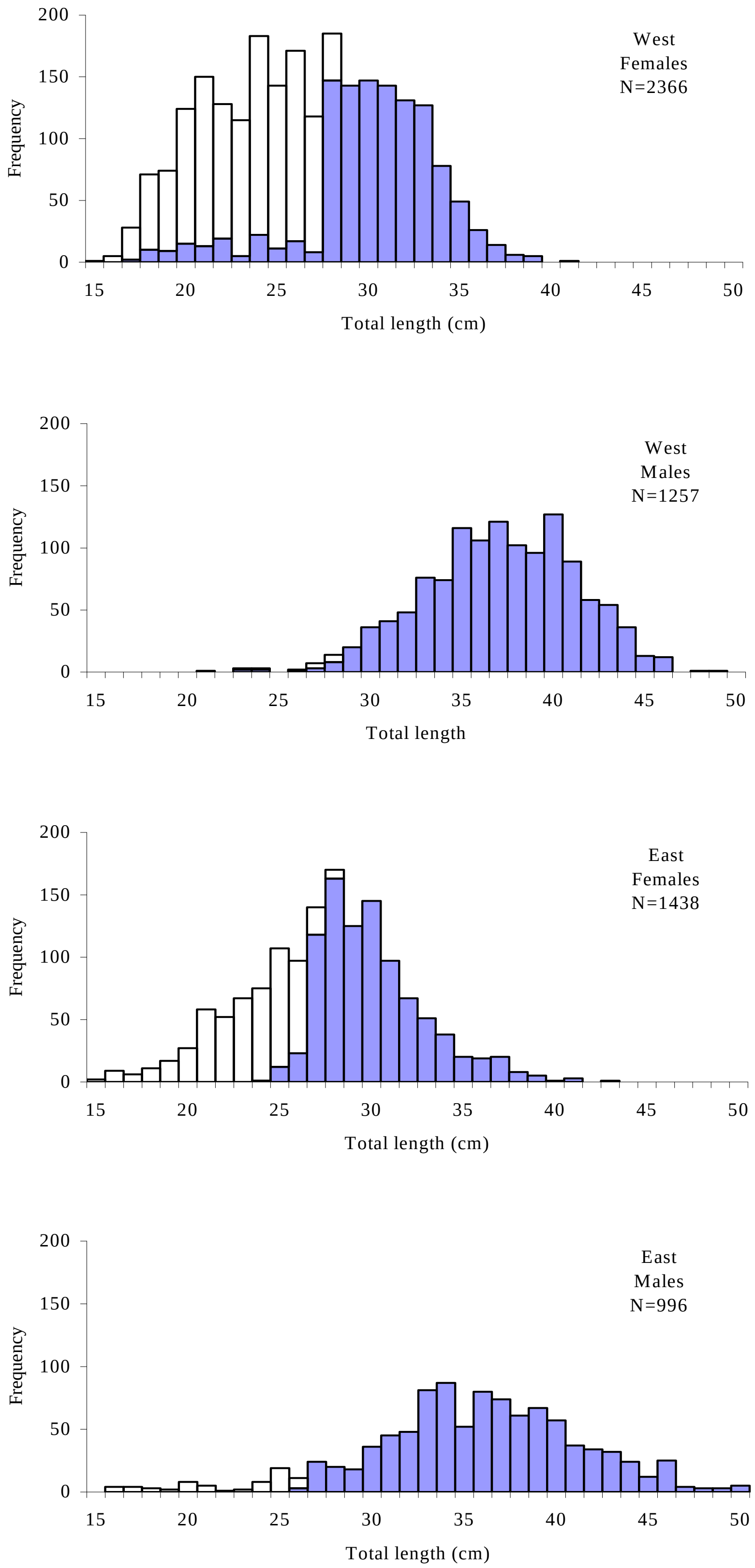


Figure 23 Length-frequency distributions for retained (solid bars) and discarded (clear bars) bluethroat wrasse by sex and area, October 1997-February 1999.

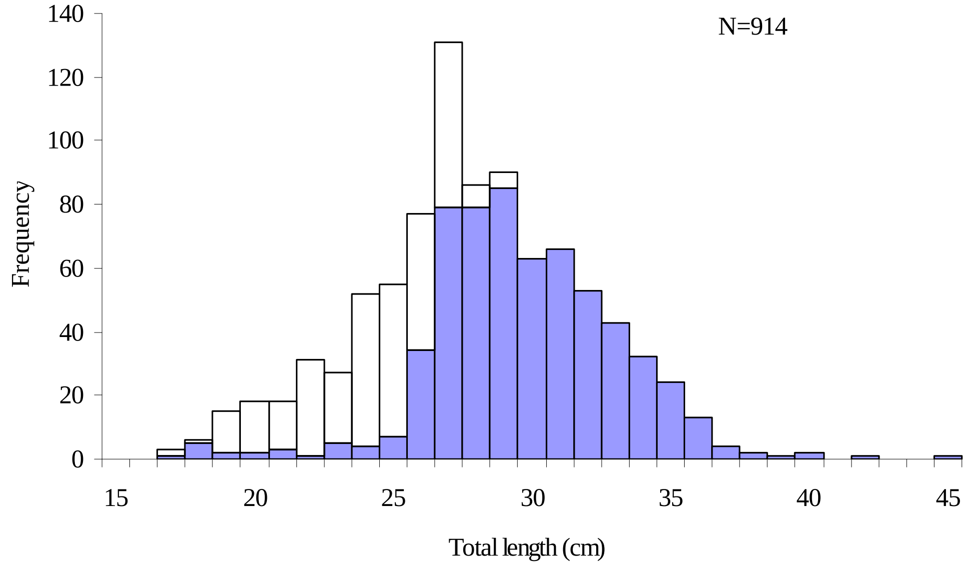


Figure 24 Length-frequency distributions for retained (solid bars) and discarded (clear bars) saddled wrasse, October 1997-February 1999.

Age, growth and mortalities

Age determination

During the project, 1475 bluethroat wrasse were aged using sectioned saggital otoliths. Examples of sectioned otoliths are shown in Figure 25. Fish ranged in age from 3 to 19 years for females (N=864) and from 5 to 23 years for males (N=590). Note 21 were of unknown sex.

a) Estimated age 14 years. Length 36.2 cm, Warrnambool 28/11/97.

Figure 25. Examples of transverse sectioned bluethroat wrasse sagittal otoliths. b) Estimated age 16 years. Length 41.3 cm. Warrnambool. 28/11/97.

As indicated in the methods, whole otoliths cannot be used for ageing bluethroat wrasse. Up to about age 6, estimates from the two methods are similar but after this they diverge with whole otolith estimates significantly underestimating age (Figure 26).

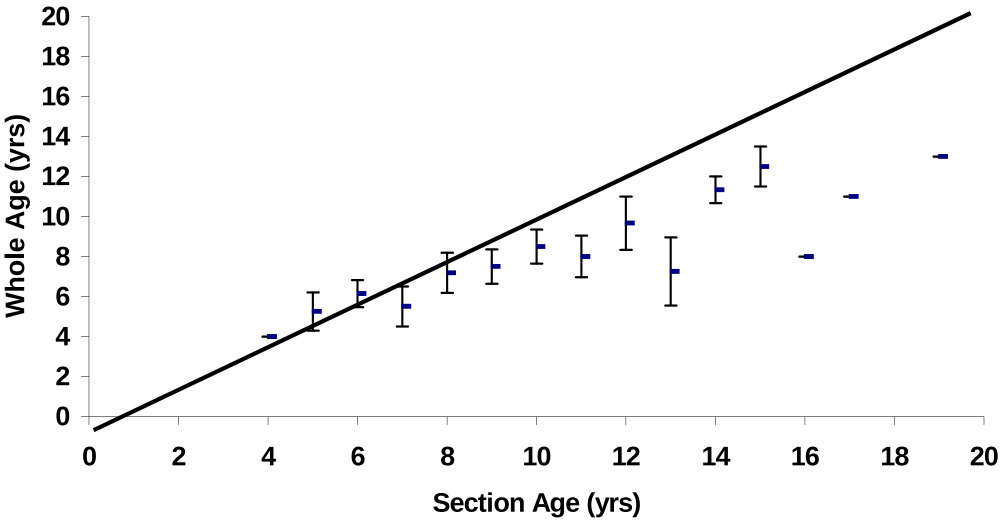


Figure 26 Comparison of bluethroat wrasse ages estimated from whole and sectioned otoliths (N=65).

The Central Ageing Facility has found that the relationship between otolith weight and age is linear (or a "broken-stick", ie a double linear relationship) for most species examined (Morison *et al.* 1998). By itself this is not validation but it does provide a useful diagnostic for determining the efficacy of a particular ageing method and does enable outliers to be identified. For bluethroat wrasse, the relationship is generally linear but quite variable (Figure 27). Relationships were also linear for males and females separately.

Otoliths were collected opportunistically from saddled wrasse and ages were also estimated from sectioned otoliths. Age estimates ranged from 4 to 16 years.

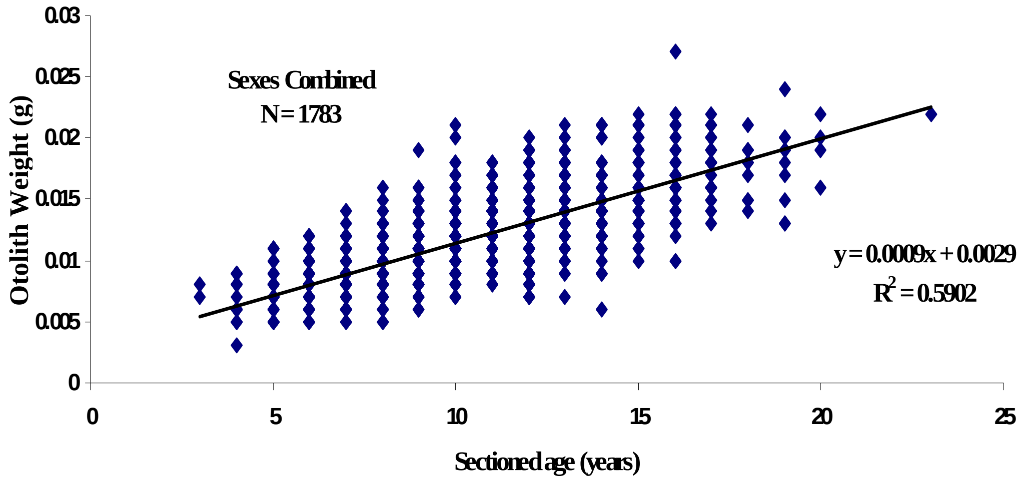


Figure 27 Relationships between otolith weight and age estimated from sectioned otoliths for bluethroat wrasse.

Precision

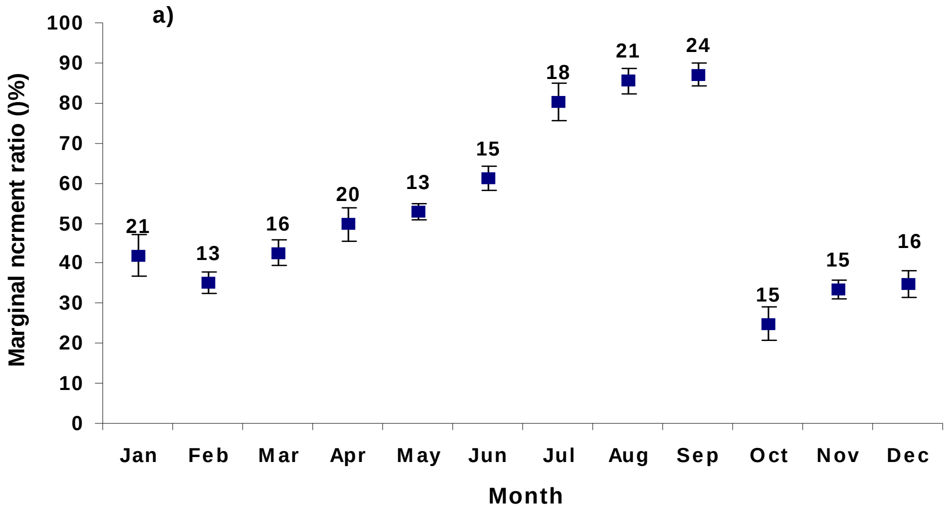
Detailed results of within and between reader comparisons are shown in Appendix 3. The within reader APE was 3.7% (N=270) and the between reader APE was 3.65% (N=91). There was no significant bias in ages from repeat readings (Appendix 3). Generally, APE values less than 5% are regarded as acceptable (Morison *et al*. 1998). However, only about 50% of second readings provided the same age estimate, 85% were within 1 year and 97% within 2 years.

Overall this indicates that bluethroat wrasse are relatively difficult to age but estimated ages are reproducible.

Validation

Results of the marginal increment analysis indicates there is a clear pattern of annual zone formation in bluethroat wrasse otoliths (Figure 28). The figure shows the monthly marginal increment ratio (MIR) for ages 6 to 8 years in aggregate, chosen because of consistent sample sizes and the clarity of the incremental structure. Also shown is the monthly MIR for age group 8 only to show the pattern in a single age group. Note age 8 was also the most numerous in the aged sample.

The results indicate that the opaque zone begins to be formed during autumn and is completed by the end of winter. The translucent zone is formed during spring giving rise to the rapid drop in the MIR.



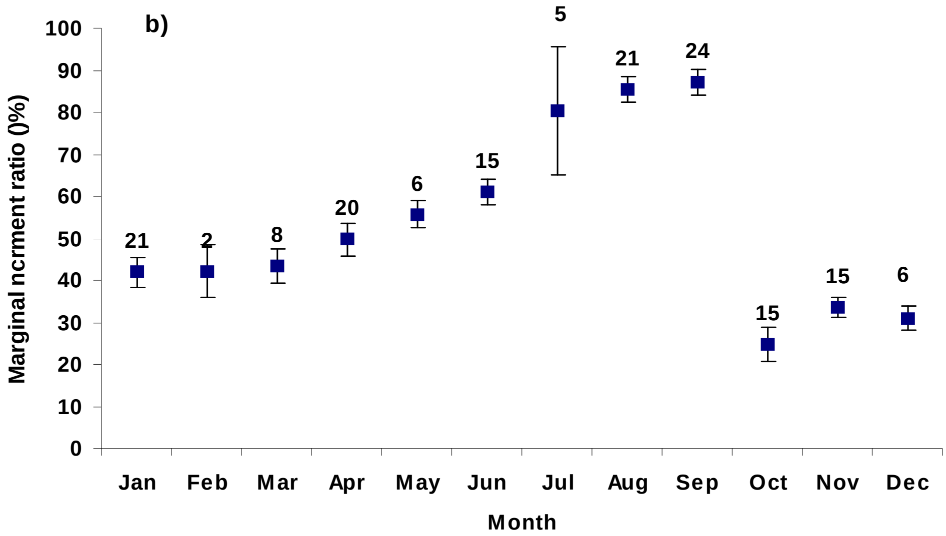
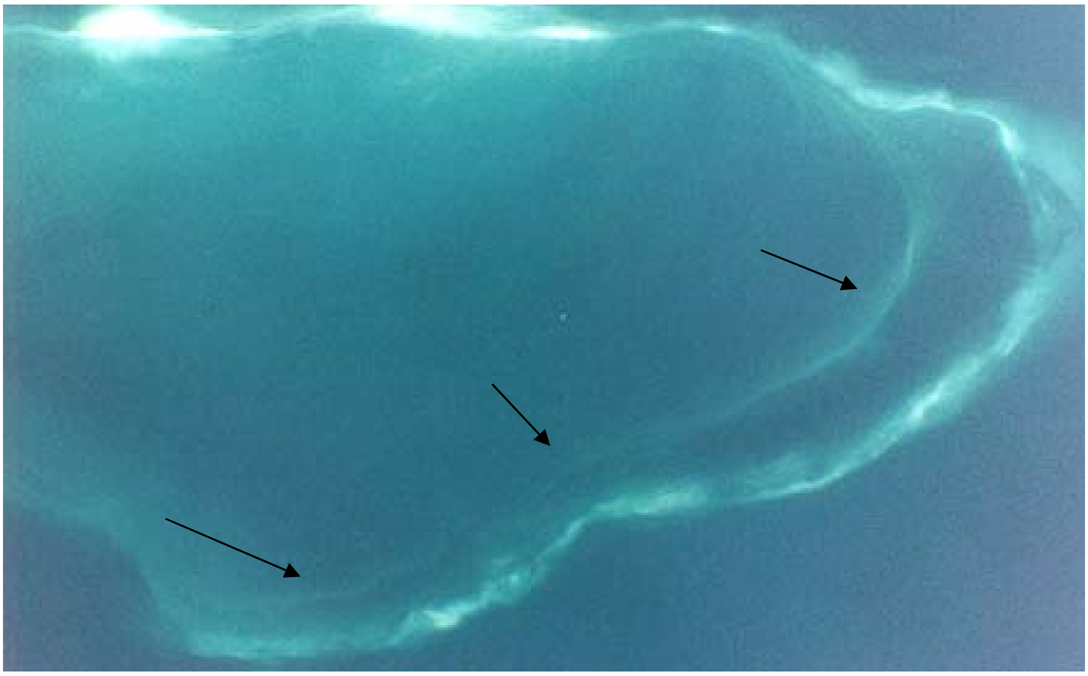
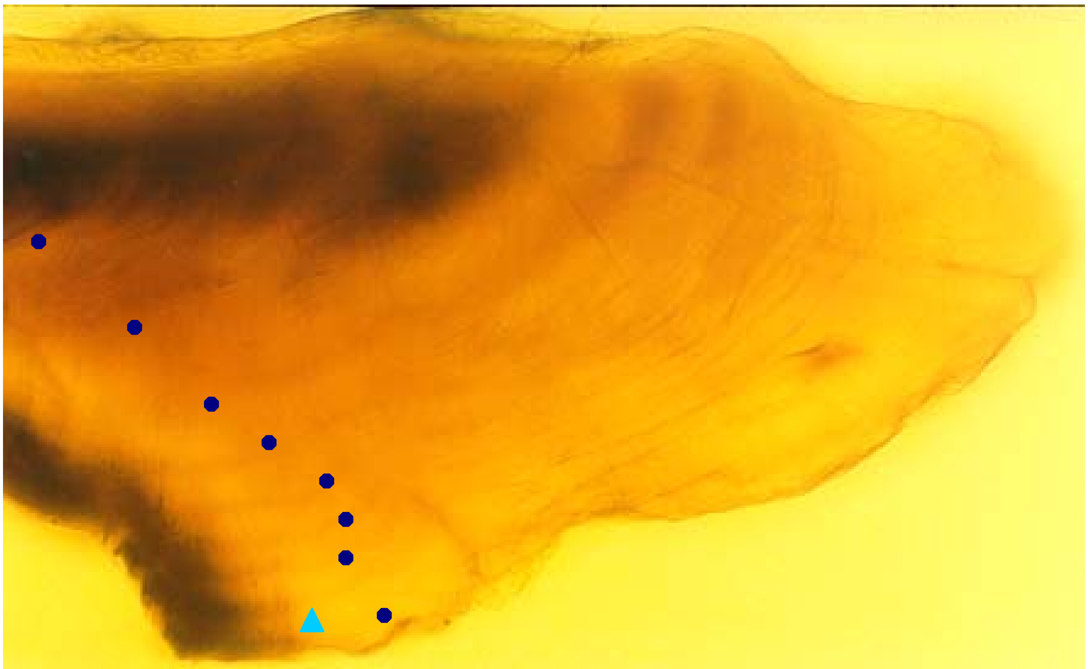


Figure 28 Mean (+/- 1 standard error) marginal-increment ratio (as a percentage of previous growth by month for bluethroat wrasse for a) ages 6,7,8 and 9 combined and b) age 8 only

OTC injected wrasse held in cages at MAFRI Queenscliff for periods more than one year corroborated the MIR results. An example is shown in Figure 29. One opaque zone was formed after the OTC mark and the otolith has a translucent edge.



a) Tag 189, time at large 420 days. Arrows indicate position of OTC mark.



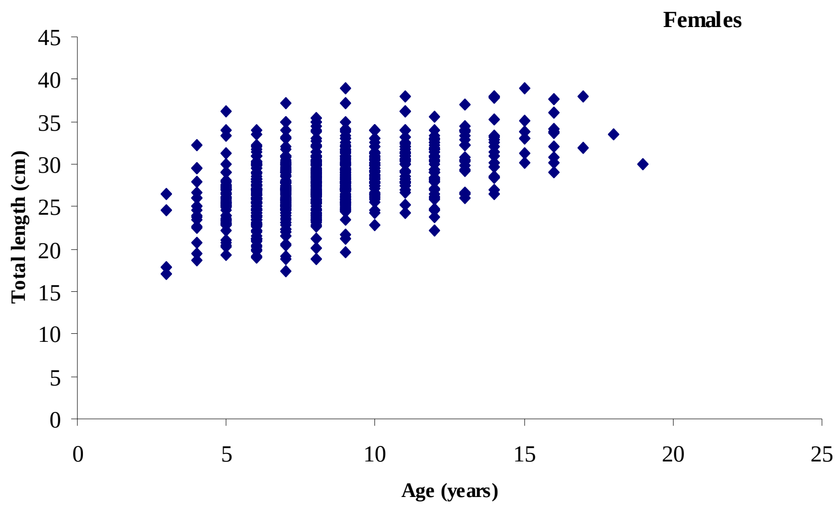
b) Circles indicate annual marks. Triangle indicates annual band highlighted by the flourescent OTC in the above figure.

Figure 29 a) OTC marked otolith under flourencent light at 450 um b) the same otolith under transmitted light

Although not all assigned ages for each age group have been validated these results provide strong evidence that the incremental structure is formed annually and the zones counted represent the age of the fish in years.

Growth

The growth of bluethroat wrasse is initially rapid up to ages 3-4 years but then relatively slow, particularly for females (Figure 30). Growth is more rapid for males; they reach a greater size and are generally longer lived than females (Figures 30, 31). Growth is variable for both sexes with considerable overlap between age groups.



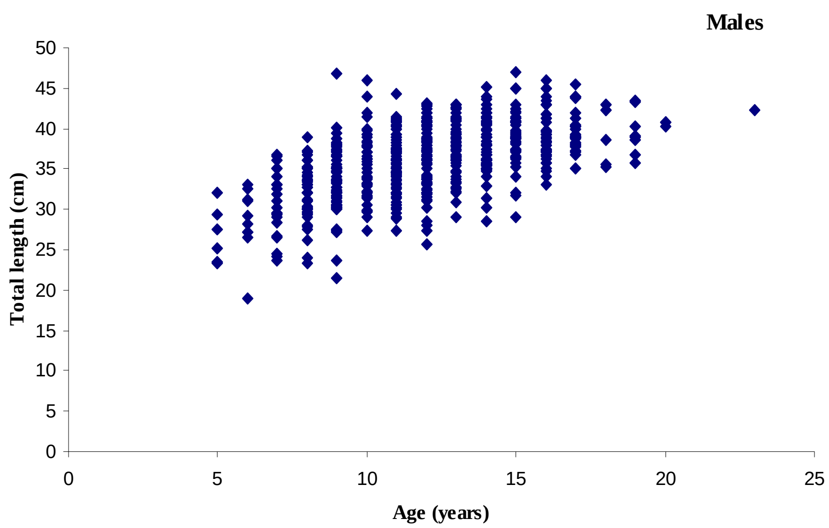
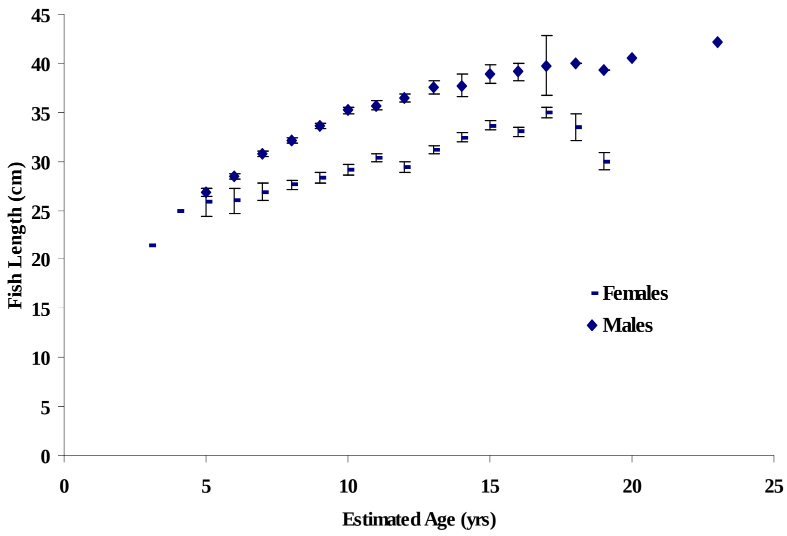


Figure 30 The relationship between total length and age for female and male bluethroat wrasse.



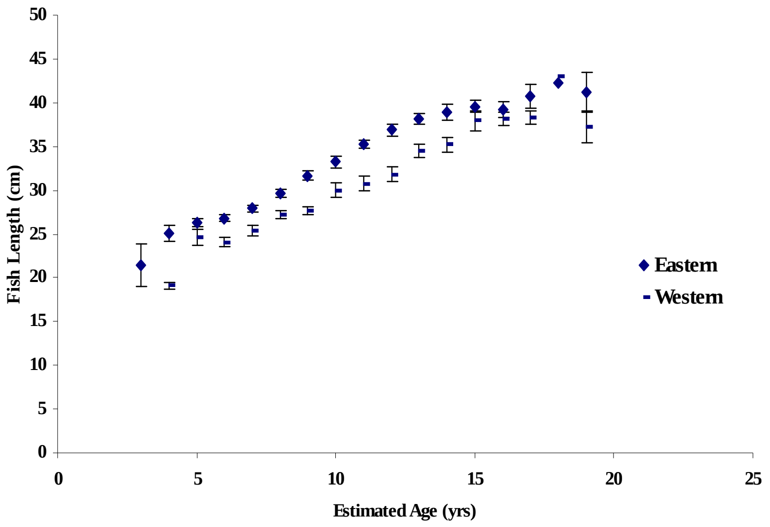


Figure 31 Comparison of mean lengths-at-age (+/- 1 se) by sex and area for bluethroat wrasse

It also appears that growth is faster for fish off the east of Victoria compared to the west (Figure 31). This pattern is not uncommon and is repeated for a number of quite diverse species where growth (eg southern rock lobsters [Hobday and Punt 2002] and blue warehou [Smith 2003]) and productivity (gummy, saw and elephant sharks [Walker *et al.* 2002]) are higher in eastern Bass Strait than Western Bass Strait. The reasons are likely to reflect different oceanographic conditions

Length-weight relationships for bluethroat wrasse were as follows:

females	weight = 0.0118length $^{3.13}$	N= 878, R^2=0.94
males	weight = 0.0089length $^{3.21}$	N= 518, R^2=0.94
combined	weight = 0.0102length $^{3.17}$	N= 1397, R^2=0.97

Fits to the von Bertalanffy growth curve were poor, particularly for females and the sexes combined leading to a high L_{inf}, low Ks and large negative t_os. This was because of the flat pattern of growth. For males the fit was better, especially for the younger age groups with estimates of 41.80, 0.15 and –1.79 for L_{inf}, K and t_o, respectively. However, the curve did not fit older ages at all well and hence the L_{inf} is low compared to observed maximum lengths. Consequently, for the per-recruit modelling, parameters for the von Bertalanffy growth curve were estimated by fitting curves to mean weight-at-age data separately for males and females by least squares, giving:

	female	male
t_o	-4.10	-0.39
K	0.12	0.17
W_{inf} (Kg)	0.84	1.27
L_{inf} (cm)	35.53	40.33

L_{inf} was estimated by back-calculation using the length-weight relationships given above.

These parameters gave the best fit with SSQ of the residuals of 0.04654 and 0.12055, respectively. The values of L_{inf} and W_{inf}, however, were considered to be too low given the data and the curves were refitted using biologically more realistic values of L_{inf} of 37.0 (females) and 43.4cm (males):

	female	male
t_o	-4.20	-1.13
K	0.11	0.13
W_{inf} (kg)	0.956	1.61

This gave a good fit with SSQ of the residuals of 0.06007 (female) and 0.20567 (male). The L_{inf} for males is probably still a little low compared to the observed size distributions but higher values resulted in less satisfactory fits to mean weight at age data.

Although the sample size was small, the growth of saddled wrasse appears to follow a similar patter to that of bluethroat wrasse (Figure 32). Growth is variable with considerable overlap in length between age groups.

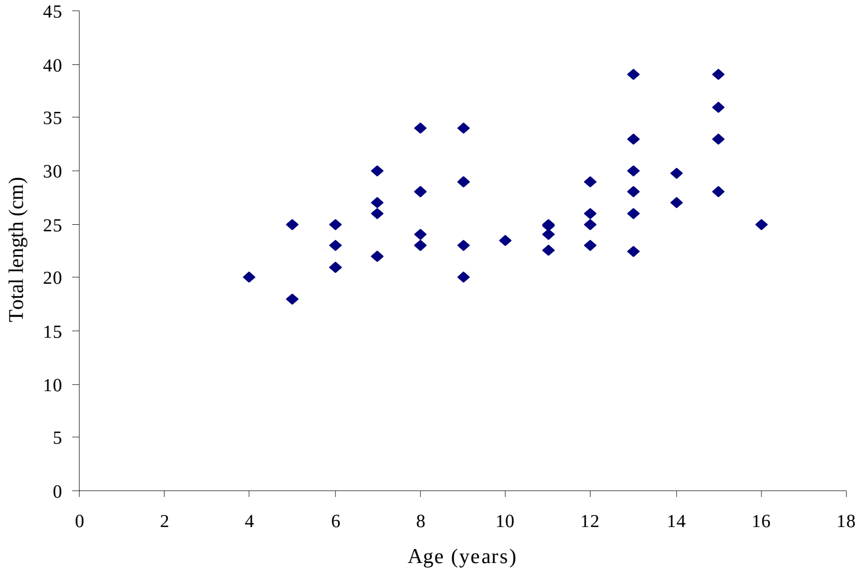


Figure 32 Relationship between length and age for saddled wrasse, sexes combined.

Age-composition and mortality rates

Bluethroat wrasse ranged in age from 3 to 23 years (Figure 33). For females, catches were dominated by fish between 5 and 9 years. Males were more numerous in the older age groups with age 8-17 years the dominant age groups. Generally, the age composition for combined sexes was similar across Victoria (Figure 33).

The maximum ages for wrasse were in the range of 20 to 25 years. This gives estimates of M from 0.18 to 0.23. On this basis, a value of M of 0.2 was chosen for subsequent analyses.

The catch curve for combined sexes is shown in Figure 34. The slope of the right-hand limb, equivalent to Z, is 0.32. With an M of 0.2, an F of 0.12 is obtained. Although there are uncertainties in these estimates, it does appear that total mortality is relatively low and that fishing mortality is less the natural mortality.

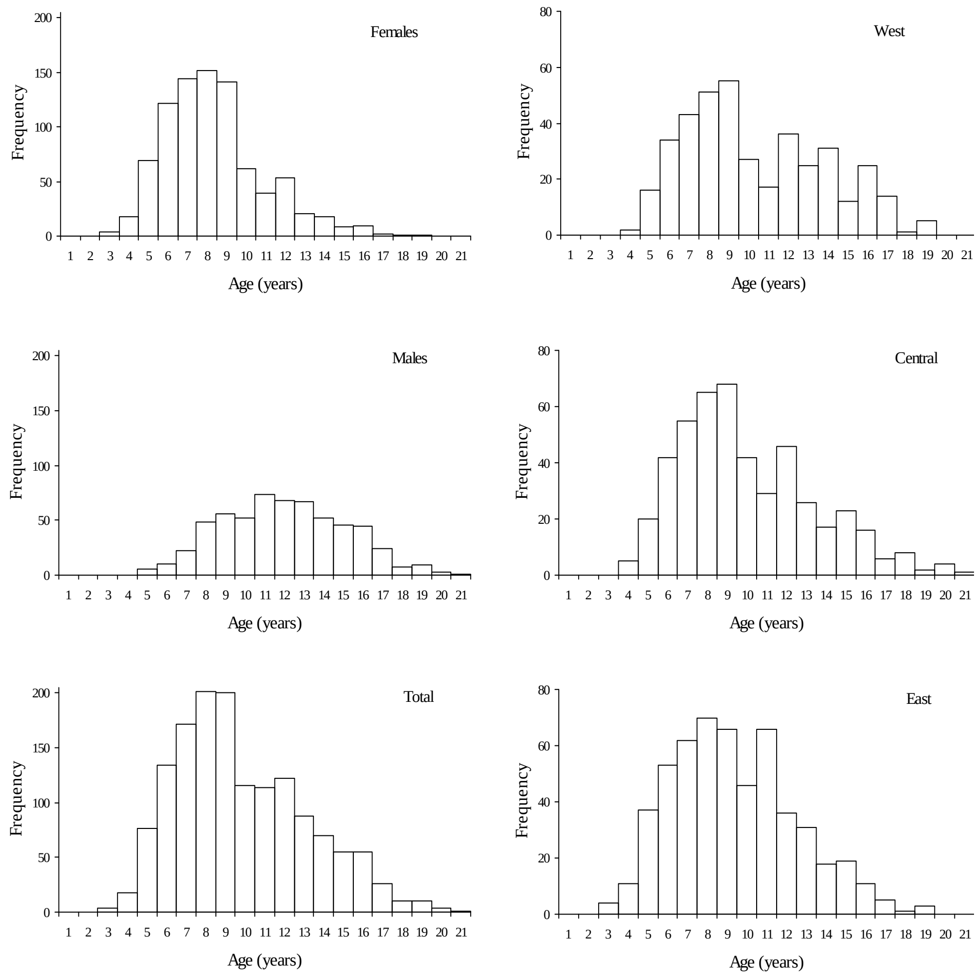


Figure 33 Age composition of bluethroat wrasse by sex and area.

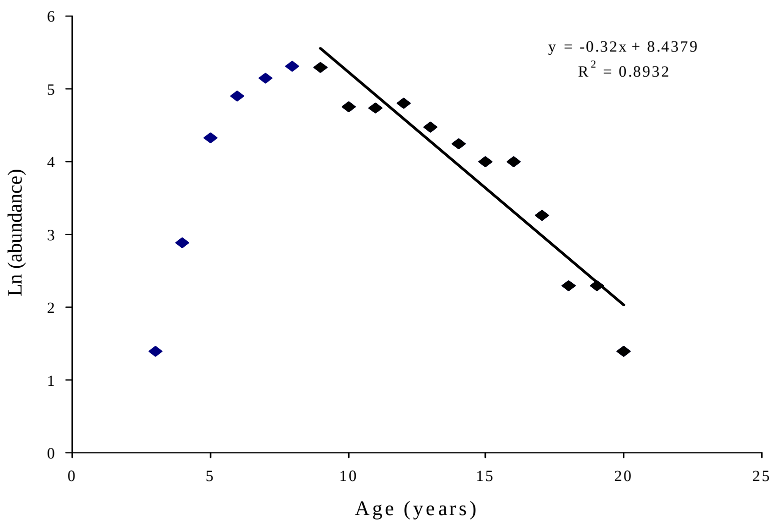


Figure 34 Catch curve for bluethroat wrasse, sexes and areas combined

Tagging studies

A total of 1898 bluethroat wrasse and 601 saddled wrasse were tagged and released during the project. Of these the greatest number were tagged by the commercial sector in collaboration with project staff (Table 8). These covered the full size range of bluethroat wrasse but the greatest number were relatively small fish, reflecting the LML of 28 cm (Figure 35). Similarly, the size of tagged saddled wrasse was dominated by small fish (Figure 34). Fish tagged by recreational fishers covered a broader size range (Figure 36) but small fish were still numerous.

Table 8 Summary of released and recaptured bluethroat and saddled wrasse.

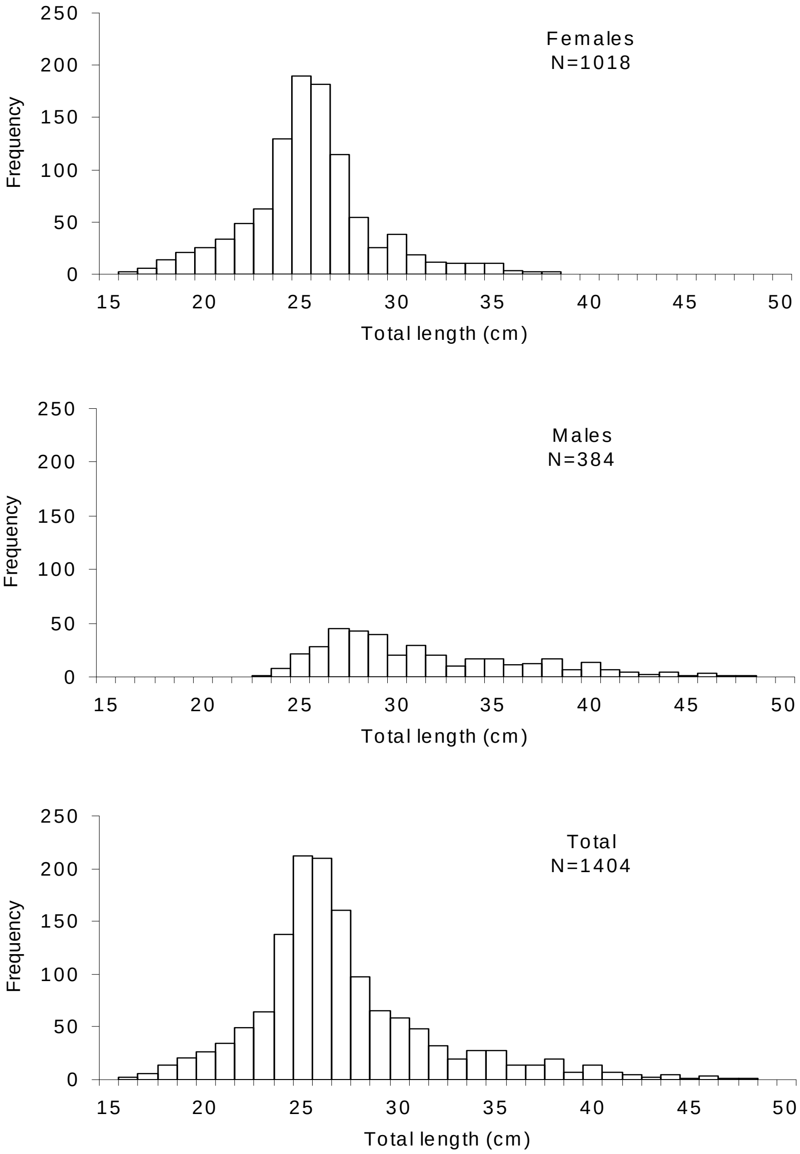
	Bluethroat wrasse			Saddled wrasse		
	Released	Recaptured	%	Released	Recaptured	%
Commercial	1404	23	1.6	483	6	1.2
Recreational	494	22	4.5	118	2	1.7
Total	1898	45	2.4	601	8	1.3

Bluethroat wrasse were tagged and released across the State with the highest numbers at the mouth and offshore of Port Phillip Bay, and off Portland (Figure 37). Most of the saddled wrasse were tagged and released off western Victoria, around Portland.

Recaptures were low, 45 bluethroat and 8 saddled wrasse, respectively, and generally reflected release numbers (Table 8, Figure 37). The recapture rate for both species was higher for fish tagged by recreational fishers than for fish tagged by commercial operators and project staff. However, as the numbers are low it is unclear whether this difference is significant. One reason for the disparity may be due to some commercial fishers not returning tags. There was some anecdotal information that this may have occurred but at the workshop, industry participants reported seeing few tagged fish.

The low recapture rate did not appear to be due to the type of tag used. Barrett (1995) also used anchor tags for a number of reef species, including bluethroat and saddled wrasse, and had relatively high recapture rates. In addition, no fish tagged and released with both dart and anchor tags and with a proportion fin-clipped were recaptured, despite repeated sampling in the area where they were released.

a) Bluethroat wrasse



b) Saddled wrasse

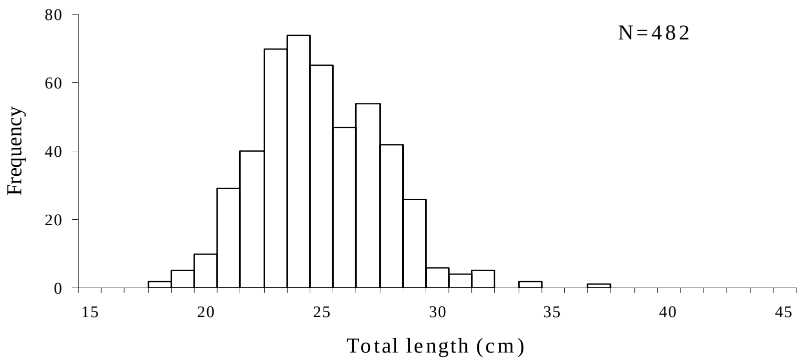


Figure 35 Length-frequency distributions of tagged and released by commercial fishers and project staff: a) bluethroat wrasse by sex, and b) saddled wrasse.

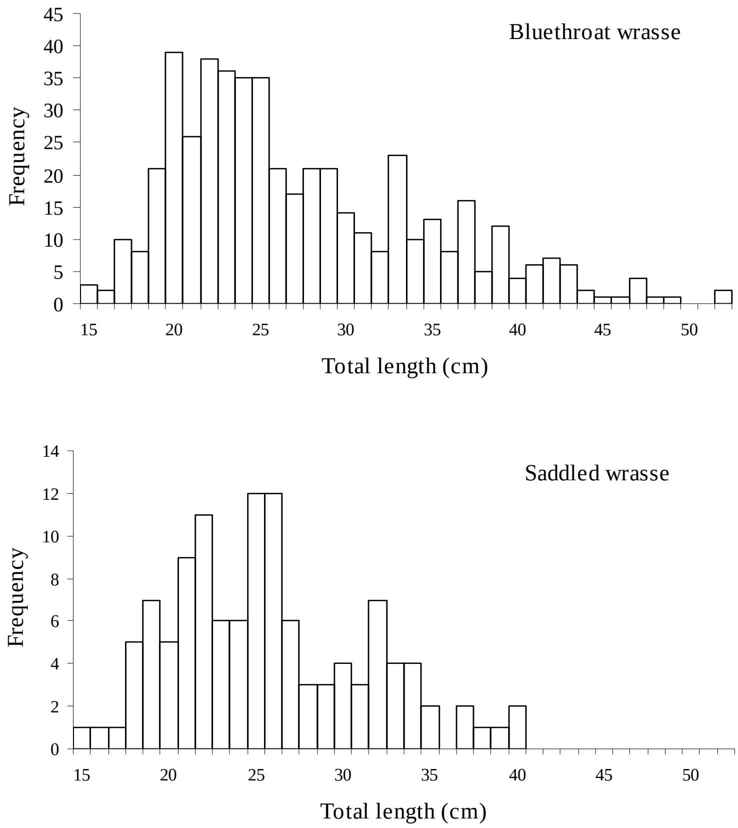


Figure 36 Length-frequency distributions of tagged and released by recreational fishers: a) bluethroat wrasse, and b) saddled wrasse.

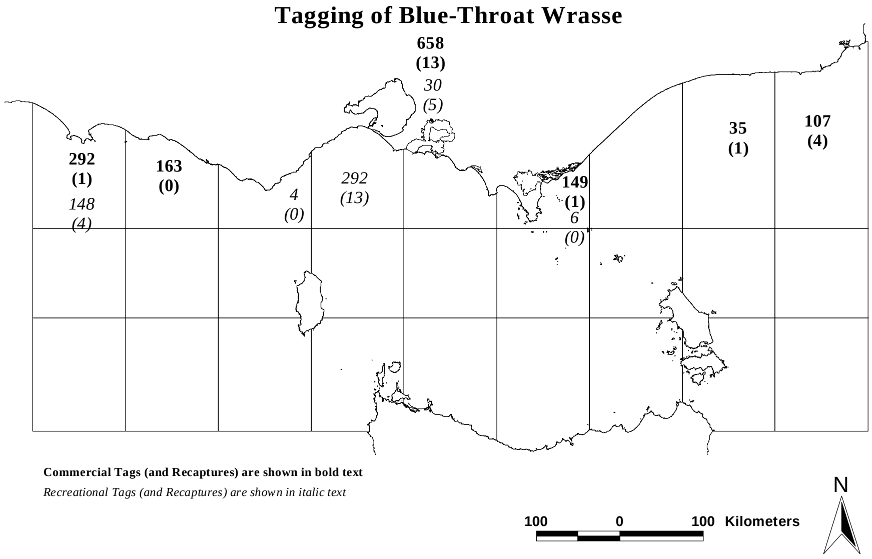
It is appears that smaller fish may have had a higher tagging mortality or lost tags at a greater rate than larger fish. Table 9 shows percentage of tagged and released bluethroat wrasse in three length groups compared to the size of recaptured fish at release. It is clear that, even allowing for growth, the recapture of small fish was considerably less than would be expected relative to the numbers tagged. This was true for both sectors. In addition, there was a higher proportion of recaptures in the 30+ cm size classes for fish tagged by recreational fishers.

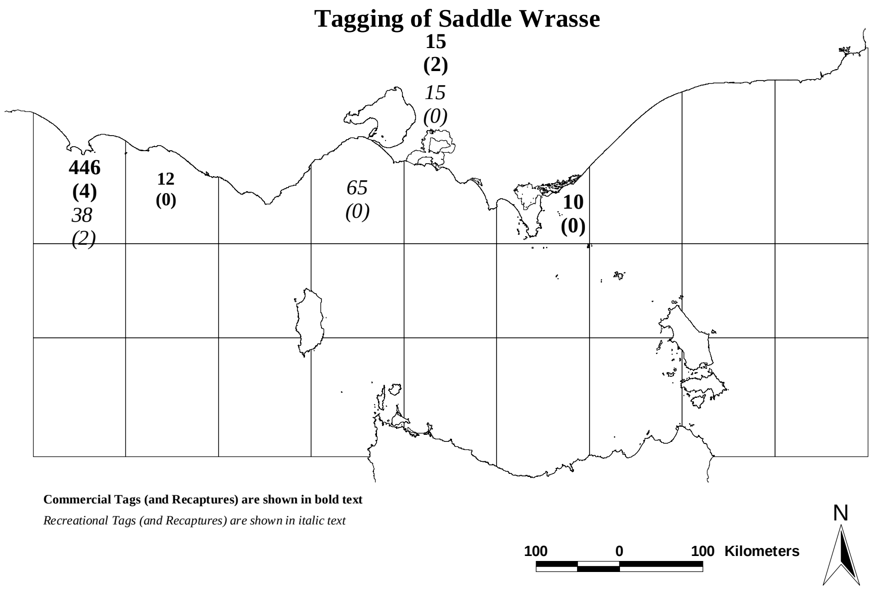
Table 9 Comparison of size-at-release of all tagged and recaptured bluethroat wrasse.

Length Groups (cm)	Commercial size-at-release (%)		Recreational size-at-release (%)	
	tagged	recaptures	tagged	recaptures
<25	25.0	5.0	22.3	4.5
25-29	53.1	70.0	33.8	22.7
30+	21.7	25.0	43.9	72.7

Therefore, the greater proportion of small fish tagged by the commercial sector and project staff may also account for the lower overall recapture rate.

For saddled wrasse, the number of fish <25 cm made up 48% of the total tagged compared to 48% and 4% for the 25-29 and 30+ cm size classes, respectively. However, no fish were recaptured from the smallest size classes. Similar to bluethroat wrasse, it appears that there may be a higher mortality or tag loss for small saddled wrasse.





Figure

Figure 37 Location of tagged and released bluethroat and saddled wrasse by sector.

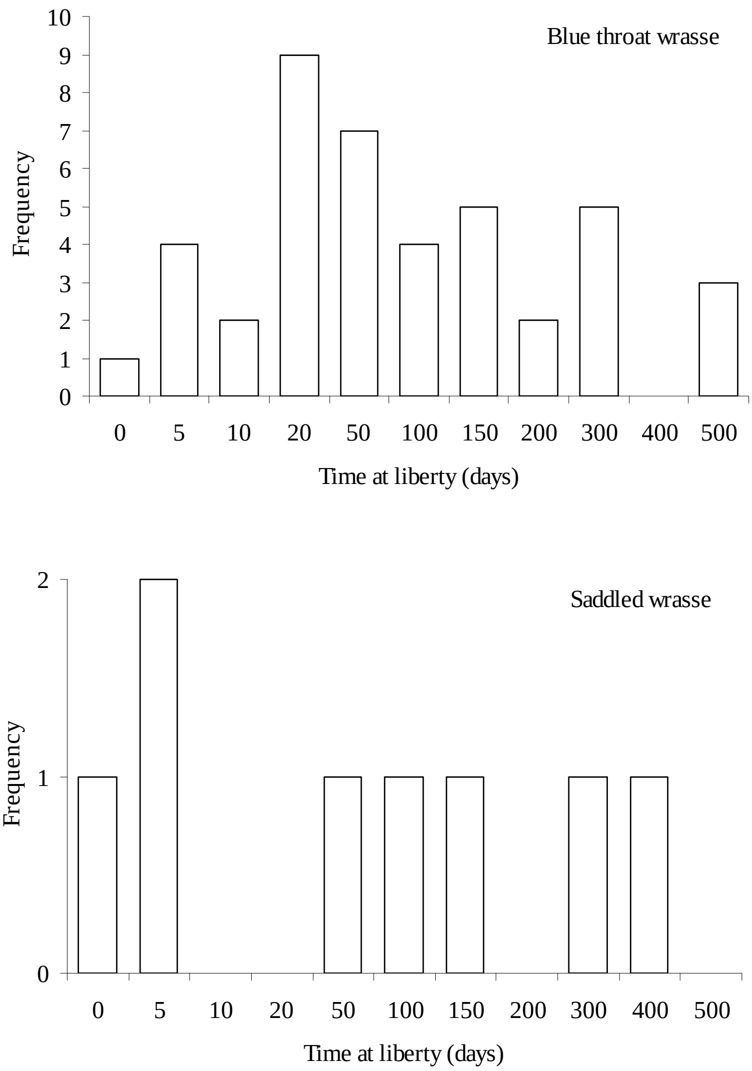


Figure 38. Time at liberty for tagged and recaptured bluethroat and saddled wrasse.

The longest time-at-liberty was 596 days and 449 days for bluethroat and saddled wrasse, respectively. The results indicate that tags were potentially retained well (Figure 38); 19% of recaptured bluethroat and 25% of recaptured saddled wrasse were at liberty for a year or more.

Both bluethroat and saddled wrasse are regarded as permanent reef residents with a limited home range (Barrett 1995). The results for saddled wrasse supported this with all fish recaptured in the vicinity where they were released. The results for bluethroat wrasse, however, were less clear. About 87% were caught in the general vicinity of release but there were a number of significant movements. Five fish were recaptured more than 10 km from the release site, including one fish moving about 20km and one fish about 40 km. It is possible that movements like these could be due to incorrect positions being recorded but it is unlikely that this could account for all, ie. 5 out of 45 fish (11%). Barrett (1995) found that range size increased with fish size. There was no clear relationship here. The longer movements were by fish ranging from 23 to 36 cm, whereas recaptured fish greater than 40 cm TL were caught within the area of release. Barrett recorded one longer movement for the reef dwelling monocanthid *Penicipelta vittiger* and suggested that longer movements maybe restricted to only a small percentage of the population quoting Bohnsack's (1990) work on tropical species. Eitherway, the results of the current project suggest that, at least in Victorian waters, some bluethroat wrasse move further than was previously thought.

Table 10 Mean growth cm (X) and number (N) of recaptured blue throat wrasse after three time periods and for four length groups.

Length Group (cm)	Time at liberty(days) 0-100		100-300		>300	
	N	X	N	X	N	X
<25	1	0	0	0	0	0
25-29	7	0.04	3	1.5	4	3.6
30-39	5	-0.1	7	2.1	2	4.5
40+	5	0.2	1	1		

The low number of recaptures precluded estimation of growth using standard methods. However, Table 10 summarises the mean growth-increments for recaptured bluethroat wrasse. Generally these are consistent with growth estimated from otolith sections.

Results for saddled wrasse were similar but for the small number recaptured, growth was slower. These are summarised below:

Time at Liberty (d)	Size group	N	mean growth cm
<100	25-29	4	0.08
100-300	25-29	2	1.60
>300	25-29	2	1.90

Per recruit analyses

At recruitment all individuals are female. When the recruits are older than 4 years, some of them change sex, from female to male, each year so that the proportion of males in the cohort, originally zero, gradually increases with age. If it is assumed that the proportion of females changing sex each year thereafter, p, is constant, then a value of p = 0.12 gives an estimated percentage of males which approximates the observed percentage (Figure 39)

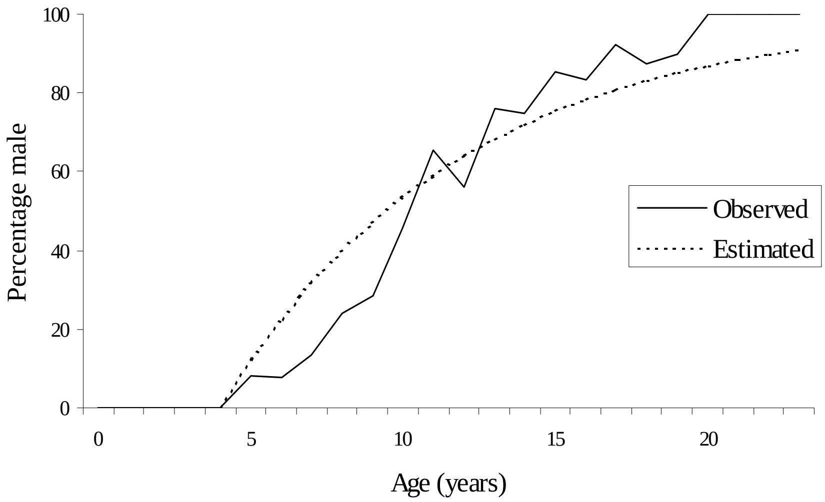


Figure 39. Observed and estimated percentage of males bluethroat wrasse.

M and F are the instantaneous rates of natural and fishing mortality, respectively, and N_t^g is the probability of a recruit surviving as gender g in time period t. The effect of natural and fishing mortality on a recruit in the time period Δt between age t and age $t + \Delta t$ is given by:

$$N_{t+\Delta t}^g = N_t^g e^{-(M+F)\Delta t}.$$

F = 0 if t is less than the age at first capture and a Δt of 1/6 year was used.

The proportion of females assumed to change sex at the end of each time period is p/6 after age 4 is reached. $N_t^f e^{-(M+F)\Delta t} p$ is then the probability of a recruit surviving as a female from age t to $t + \Delta t$ and changing sex within that time period. A value of 0.12/6 = 0.02 was used for p after age 4.

The combined effect of mortality and sex change on the probability of a recruit surviving as a female at age $t + \Delta t$ is given by:

$$N_{t+\Delta t}^{f} = N_t^f e^{-(M+F)\Delta t} - N_t^f e^{-(M+F)\Delta t} p$$

The probability of a recruit surviving as a male is zero until age 4. After that it becomes

$$N_{t+\Delta t}^{m} = N_t^m e^{-(M+F)\Delta t} + N_t^f e^{-(M+F)\Delta t} p$$

For simplicity, and in the absence of evidence to the contrary, it is assumed that the natural mortality of males and females is the same and independent of age (Figure 40). The equations could be generalised by applying sex and age subscripts to M.

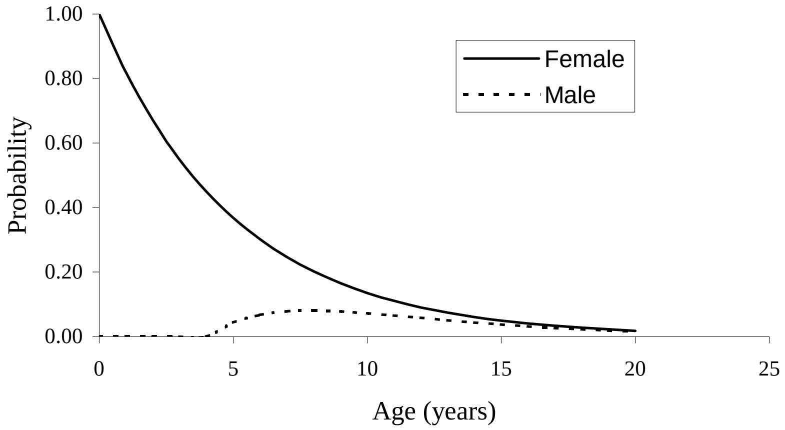


Figure 40. The probability of individual survival by age and sex.

Multiplying the probability of a recruit surviving as a particular sex by the mean weight of an individual of that age and sex, w_t^g gives the predicted biomass by sex per recruit:

$$B_t^g = w_t^g N_t^g$$

Plotting biomass per recruit against age (Figure 41) we observe the relative effects of growth of individuals and mortality. This is called the yield trade-off and plot of biomass per recruit against age usually gives a humped curve with the maximum biomass per recruit occurring at an intermediate age. Here the changing of females into males complicates the situation.

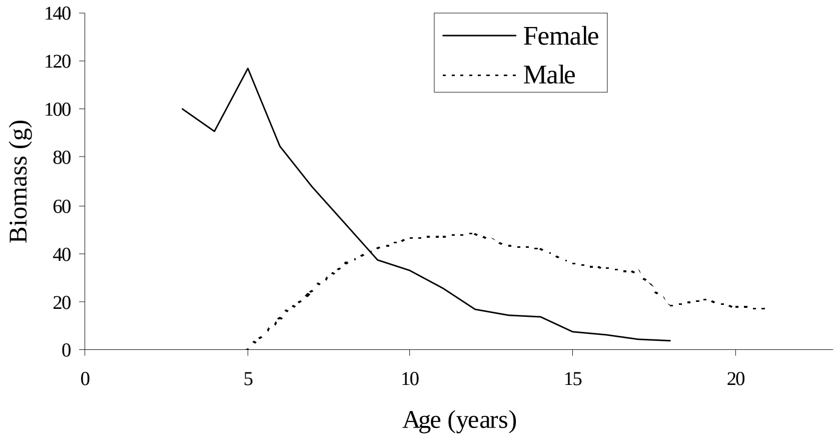


Figure 41. The expected biomass against age of female and male bluethroat wrasse in the absence of fishing (F=0)

Figure 41 uses observed mean weight-at-age values. However, for the per recruit analyses, von Bertalanffy parameters were estimated by fitting curves to mean weight-at-age data separately for males and females by least squares as described in the previous section.

The normal yield equation is given by:

$$Y = \int_{t_c}^{t_{\max}} F w_t N_t dt \ .$$

If N_t is used to denote probability of individual survival at time t, as has been done here, then Y is yield per recruit. The yield per recruit was calculated by numerical integration of the fished biomass of males and females using Simpson’s Composite Rule.

Parameter values used in the per recruit analyses are summarised in Table 11.

Table 11. Parameters values used in the per recruit analyses.

Parameter	Female	Male
W_∞	0.96	1.61
K	0.11	0.13
t_0	-4.20	-1.13
b	3.13	3.21
a	0.012	0.009
Proportion females changing sex p	0.12	
M	0.2	0.2

The interactive per recruit model uses a GUI that allows the age at first capture and the fishing mortality to be varied by dragging sliders with the mouse and the graphs to be recalculated by clicking the mouse on the background of the graph. In addition, there are markers that approximate total lengths of 26, 28 and 30 cm, so implications of changing the LML can be quickly examined.

The model displays the mean lengths of males and females corresponding to the age at first capture and the yield per recruit for that age at first capture and fishing mortality.

Screen dumps (Figures 42 and 43) are shown for the current LML of 28 cm with F values of 0.15, 0.4 and 0.8, and for sizes at first capture of 26 and 30 cm with an F = 0.15.

The results for yield per recruit (YPR) and the proportion of biomass that are males (Figure 44) show that for the current LML of 28cm there is a trade-off between YPR and proportion of biomass that are males. A LML of 26cm would give a higher YPR but a LML of 30 cm gives a higher proportion of males in the biomass. This is important in a sex-change species like bluethroat wrasse where it is the number of males in the population that are most affected by exploitation rather than egg production which is normally the case. In fact eggs per-recruit calculations indicate that the female population achieved maximum reproductive potential at age 5 (Figure 45). This is below the current LML of 28 cm.

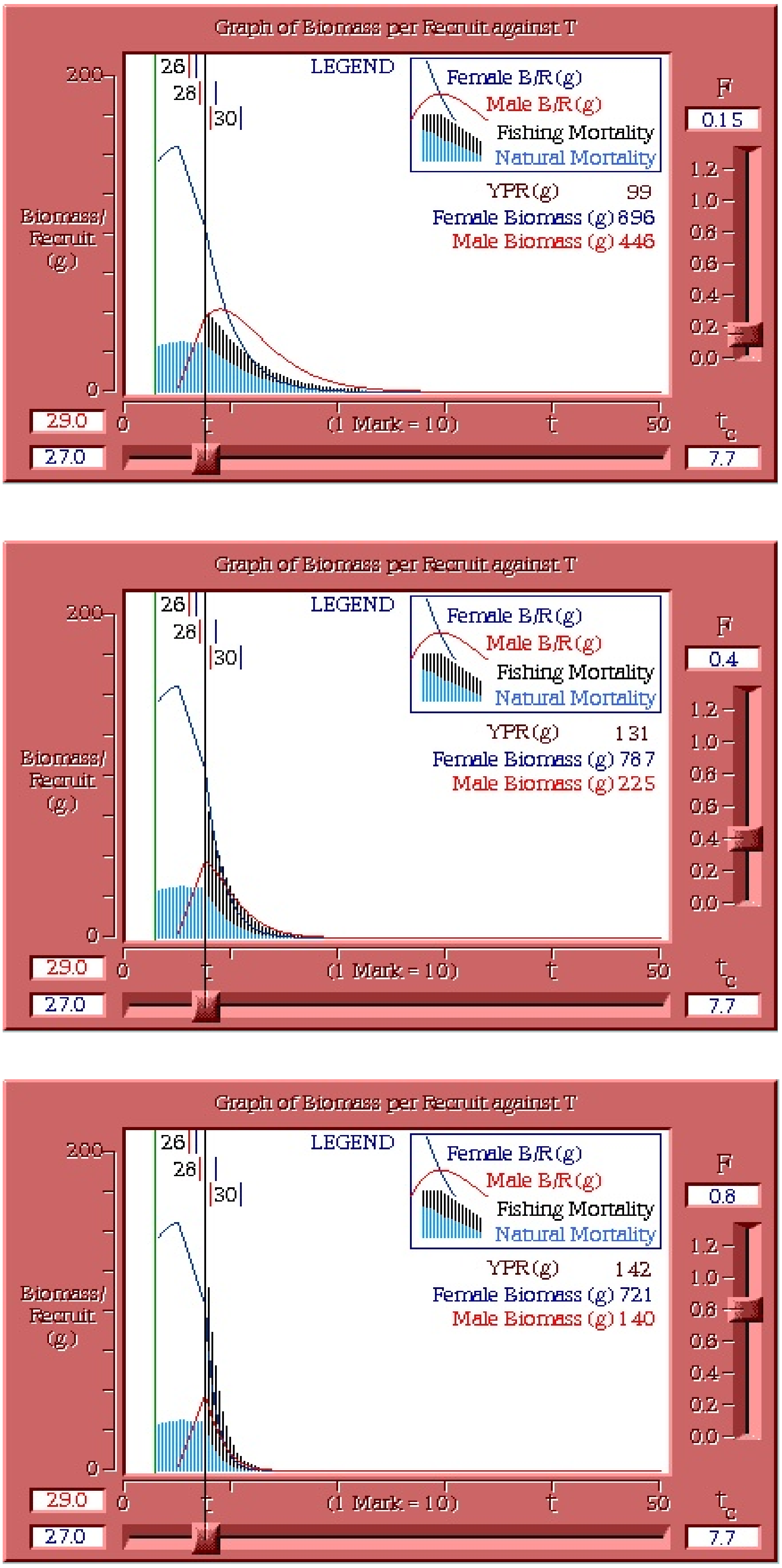
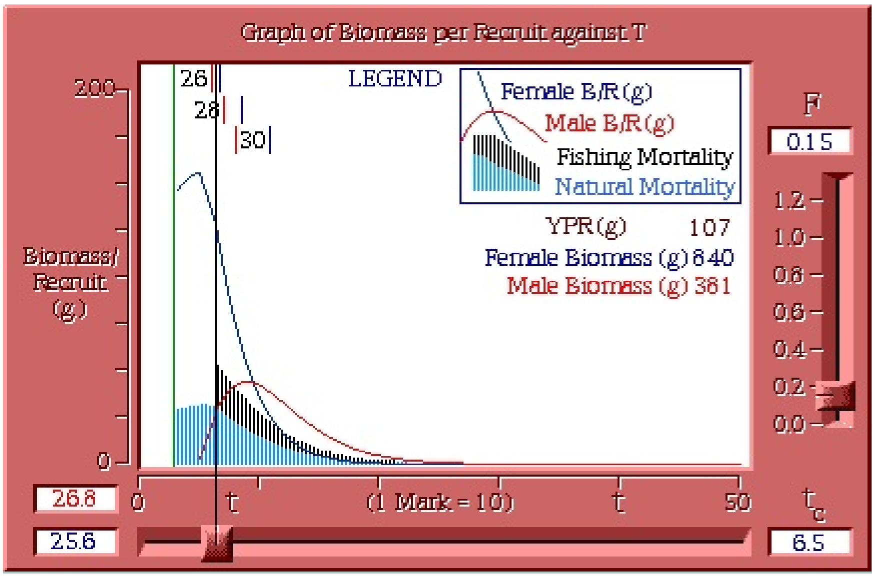


Figure 42. Screen dumps from the interactive per recruit model with approx current LML, with three fishing mortalities.



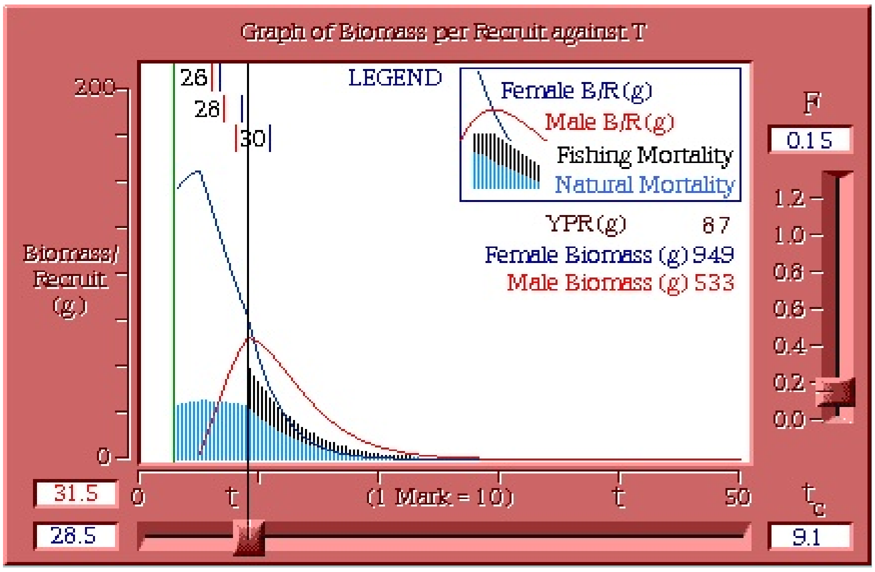
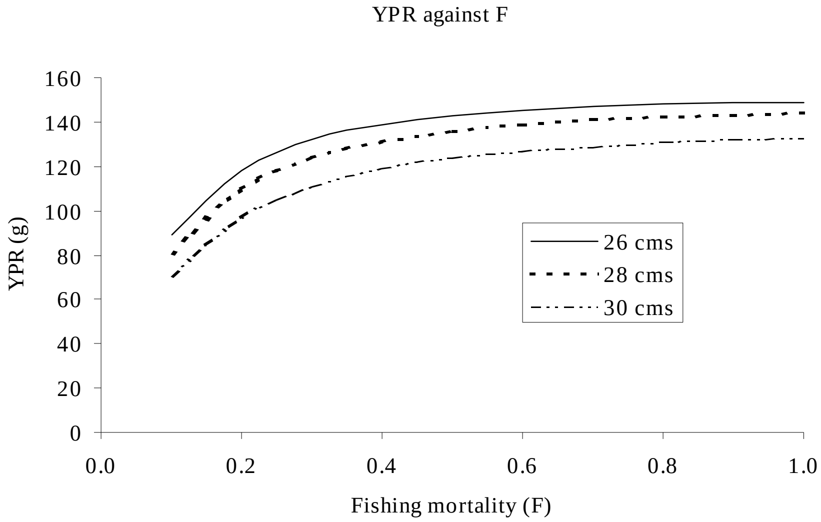


Figure 43 Screen dumps from the interactive per recruit model with approximate size of first capture at 26 and 30 cm. F=0.15.



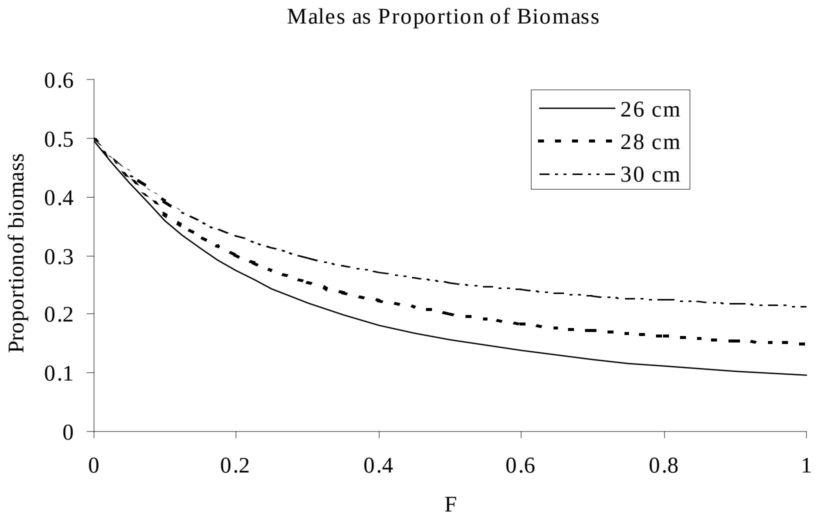


Figure 44 Yield per recruit and proportion of male biomass for a range of fishing mortalities and three sizes at first capture.

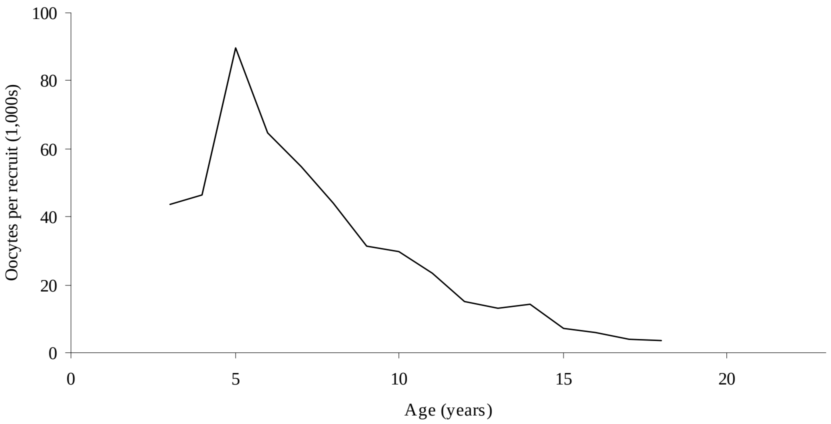


Figure 45 Eggs per recruit for female bluethroat wrasse in the absence of fishing.

Several previous studies have examined the effect of harvesting in protogynous hermaphrodites (Buxton 1992; Punt *et al*. 1993; and Armstrong 2001).

Buxton (1992) applied YPR models to two South African sparid reef species, *Chrysoblephus laticeps* and *Chrysoblephus cristiceps*. He varied the growth parameters by species and location, but not by sex and assumed knife-edged sex change in both species. Consequently his yield per recruit and spawning biomass per recruit calculations did not take gender into consideration though he did calculate the ratio of number of males in the total population at different ages. He concluded that harvesting would skew the sex ratio towards females. The observed size distribution of males and females in areas of low and high fishing mortality supported this conclusion.

The model used by Punt *et al*. (1993) kept track of different cohorts of males after change of sex and used a finer time scale of 0.1 year to separate these cohorts. A growth model developed by Garatt was used which had different growth rates for males and females. This model has a $t_0^{\alpha,m}$ parameter, analogous to the t_0 parameter of the Von Bertalanffy growth equation, to allow continuous growth of males at α, the age of sex change. The model allowed for age-specific selectivity but, because data were lacking to take advantage of this, knife-edged selectivity at recruitment was assumed. Fecundity did not vary with age as knife-edged maturity was used for both males and females. This model included a Beverton-Holt stock-recruitment relationship. As in the Buxton study, a severe effect of fishing mortality on the percentage of males in the population was predicted. However, the particular fishery under study, in Natal, was unexpectedly robust. It was concluded that this robustness could be explained by three scenarios:

a) Recruitment is not dependent on only the number of males in the stock;

b) There is sufficient immigration of recruits; or

c) Recruitment is related to stock size by the Ricker relationship.

The population model used by Armstrong (2001) was an age-structured with separate cohorts for males and females. Change of sex was handled in two ways. In option 1, it was assumed to be endogenous and related to age. In option 2, it was assumed to be exogenous and influenced by social factors such as the number of males in the population. He calculated production in the population from the probability of interactions between males and females, weighted by age-dependent fertility. Recruitment was governed both by a local Beverton-Holt stock-recruitment relationship and by larval immigration. Stochastic larval immigration was enacted using a Monte Carlo simulation. Again, Armstrong found a severe effect of fishing on the sex ratio but found little difference between endogenous and exogenous modelling of sex change. Immigration of larvae again played an important role in sustaining populations. In particular, the model showed dynamic behaviour (cusp catastrophe) which Armstrong was able to interpret in terms of source and sink characteristics of different regions of parameter space. Population simulations showed that populations could collapse to sink status following a string of years of poor local recruitment, and that these populations did not recover subsequently.

In the YPR model developed for the current study, it was assumed that sex change was endogenous and a function of size and different growth parameters were used for each sex. The main purpose of the model, in addition to the YPR calculations, was the visual presentation of the effects of various combinations of age at first capture and fishing mortality on the profiles of the female and male populations. The shapes of the biomass curves indicate the distribution of biomass by age, while the area under the curves is a measure of the total biomass. The shape of the female curve was used to judge the effects of fishing and LMLs on maturing females while the area under the male curve gave a clear indication of the effect of fishing mortality on the size of the male population.

The effect of different LMLs and fishing mortalities on this age cohort could be observed directly. The effect of these factors on the male population could be observed in the same way. This made it possible to judge the likely impact of current legal size limits and the current level of fishing effort.

The effect on males can be judged by examining the effect of the LML and instantaneous fishing mortality on ratio of female to male biomass. In the absence of fishing mortality, the biomass ratio appears to be about 1:1. This is made up of a greater number of smaller females and a smaller number of larger males, females achieving maximum biomass per recruit at about 24 cm, and males at about 36 cm. Thus it would appear that in a natural state the numbers of females and males are not in 1:1 ratio. Increasing fishing mortality has a severe effect on the biomass ratio, particularly at high levels, eg > 0.5. It is not known what the minimum proportion of males is required to maintain reproductive output and the effect of changes in biomass ratio on reproductive success and subsequent recruitment. The results indicate that raising the minimum legal size would reduce the effect of fishing mortality on male bluethroat wrasse in this species but there is a trade-off with reduced yield.

Implications for Management

The implications of the research on the wrasse fishery were discussed at length at the wrasse workshop held at MAFRI, Queenscliff, on 11 May 2001. Key points were:

- Catches peaked in 1998 at about 90 tonnes and have subsequently declined to around 50 tonnes. Effort in terms of both the number of vessels and days fished also declined after 1998. Overall, standardised catch rates have exhibited a slight decline since peaking in the mid-1990s. However, standardised catch rates that include an area*year interaction suggest that catch rates are being maintained by fishing effort moving to different areas.

- There is considerable latent effort in the fishery. With quotas introduced into the rock lobster fishery, concern was expressed that this may lead to increased targeting of wrasse.

- The catch of by-product in the fishery is relatively small but discarding (by-catch) can be quite high. Because the majority of by-catch is returned to the water live, discard mortality is considered to be low. However, tagging results a relatively higher mortality for released small fish.

- Fish are moderately long-lived (approximately 20 years) and slow growing. The current LML appears appropriate for the current estimated fishing mortality. Maximum egg production occurs at a size lower than this limit. However, maintaining the number of males could be an issue with greatly increased harvest.

- Industry has requested a LML for saddled wrasse. This should be estimated from similar per-recruit analyses as those undertaken for bluethroat wrasse.

- Correct reporting of each species on catch and effort returns remains an issue. The bulk of wrasse reported by fishers continues to be recorded as unspecified wrasse. It was suggested that species identification guides should be included in logbooks.

- The commercial sector has expressed concern about recreational fishing practices in some areas.

Benefits

This project has provided real benefits to the management of the wrasse fishery in Victoria. It is the first time that the wrasse fishery and the biology of bluethroat wrasse have been studied in Victoria.

This project will directly benefit wrasse fishers, both commercial and recreational, who utilise the resource. The results have provided the basis for assessing the current status of the resource and future management of the fishery.

The project has demonstrated that joint industry-science collaborations are a cost-effective means of assessing low value fisheries.

The results of this project will assist Fisheries Victoria in ensuring the wrasse fishery is managed in a manner consistent with the principles of ecologically sustainable development.

Further Development

Research and monitoring needs identified as a result of this work to increase our knowledge of bluethroat and saddled wrasse and improve assessment of the fishery include:

- Ensuring correct identification of species in catch returns.
- Undertaking ongoing monitoring of the length-frequency distributions of the catches of both species; retained and discards. Such monitoring could be undertaken with a large industry component.
- Periodic “snapshots” of the age composition of catches should be undertaken to provide a means of assessing changes in mortalities and recruitment.
- Per recruit analyses for saddled wrasse should be undertaken to enable the optimum size at first capture to be estimated.
- Additional information should be collected on the recreational fishery. The current project has focussed mostly on the commercial fishery.

- It is assumed that discard mortality is relatively low. However, this should be assessed explicitly for both the commercial and recreational sectors.
- The minimum proportion of males required to maintain reproductive output is not known, nor is the effect of changes in biomass ratio on reproductive success and subsequent recruitment.
- The current assessment assumes that the response of bluethroat wrasse to changes in fishing mortality is “linear”. However, given the complex reproductive and social behaviour this may not be the case and may have important implications for the response of the population to fishing pressure. A better understanding of the biology at reef level and how populations respond to removals would be needed to assess this. Such a study would provide an appropriate topic for postgraduate research.
- As for many low value fisheries, developing cost-effective formal stock assessment methods that deal explicitly with uncertainty and present results in a risk assessment framework is a high priority.

Planned Outcomes

The objectives of the project were to describe the biology of and fishery for bluethroat wrasse in Victorian waters and provide the scientific data necessary for rational management of the resource. These were largely met. This project has provided the first comprehensive study of the biology of and fishery for bluethroat wrasse in Victorian waters. Recent annual catches appear to be sustainable but the study identified considerable latent effort in the fishery. The results suggest that the current legal minimum length for the species is appropriate given current fishing mortality but also highlight in a sex-change species, such as this, the importance of maintaining the number of males in the population.

The project has demonstrated that joint industry-science collaborations are a cost-effective means of assessing low value fisheries. Management implications of the study were discussed and agreed at a workshop held at the end of the project. Fisheries Victoria is using the results of this study in developing management arrangements for the fishery.

Conclusions

This project provides the first comprehensive study of the biology of and fishery for bluethroat wrasse in Victorian waters. Information was also collected on saddled wrasse. Through a collaborative arrangement between industry and scientists, the fishery was extensively sampled over a two-year period.

Catches in the fishery rose rapidly to a peak of over 90 tonnes in 1998 but have subsequently declined to about 50 tonnes. Much of this decline was due to a reduction in fishing effort. Wrasse are taken along the entire Victorian coast but were highest off central Victoria and off the west coast. Catches of saddled wrasse were higher in the west. Catch rates peaked in the mid 1990s. It appears that high catch rates have been maintained by the industry fishing new areas. The fishery is relatively “clean” with low catches of by-product species. Discards can be relatively high but discarded species are returned to the water live. However, the potential impact of hooking mortality has yet to be assessed.

Spawning of bluethroat wrasse occurs during spring. The size-at-maturity for females occurs at 20-25 cm TL. Histological examination provided the basis for staging gonads. All males were secondary and transition gonads were characterised by proliferating testicular tissue in the presence of degenerating ovarian tissue. It was estimated that about 12% of females change sex annually after age 4.

Ages estimated from sectioned otoliths were validated by MIR, flourochrome marks and the growth of tagged individuals. Fish ranged in age from 3 to 23 years. The youngest male was 5 years. Growth was initially fast then relatively slow. There were indications that growth was faster in the east than the west. The growth of saddled wrasse was similar to bluethroat wrasse but the maximum age was 16 years.

The catches of female and male bluethroat wrasse were dominated by ages 5 and 9, and 8-17 years, respectively. Total mortality was estimated, by catch curve analysis, to be 0.32. Natural mortality was estimated to be about 0.2.

Recaptures of tagged and released fish were low for both species (2.4 and 1.3%) but the recapture rate of wrasse tagged by recreational fishers was slightly higher. The results suggest that small fish had a higher tag loss and/or tagging mortality. As there was a greater proportion of small fish tagged by commercial fishers, this may account for lower overall recapture rate by this sector. Most recaptured fish were taken in the same area where they were released, particularly saddled wrasse. However, for bluethroat wrasse there were a number of movements > 10 kms that suggest that some fish, at least in Victorian waters, move further than was previously reported.

Per recruit analyses shows that when setting LMLs there is a trade-off between YPR and the proportion of biomass that are males. The current LML (28 cm TL) appears appropriate for the estimated fishing mortality. A LML of 26 cm would give a higher YPR but a LML of 30 cm gives a higher proportion of males in the biomass. This is important in a sex-change species like bluethroat wrasse where it is the number of males in the population that are most affected by exploitation rather than egg production which is normally the case. In fact eggs-per-recruit calculations indicate that the female population achieves maximum reproductive potential at age 5, below the current LML.

References

Anderson, J. R., Morison, A. K., and Ray, D. J. (1992). Age and growth of Murray cod, *Maccullochella peelii* (Perciformes: Percichthyidae), in the lower Murray-Darling Basin, Australia, from thin-sectioned otoliths. In ‘Age Determination and Growth of Fish and Other Aquatic Animals’. (Ed. D.C. Smith.) *Australian Journal of Marine and Freshwater Research.* **43**, 983-1013.

Armstrong, P. R., 2001. Effects of fishing on a protogynous hemaphrodite. *Canadian Journal of Fisheries and Aquatic Science* **58**, 568-578.

Atz, J.W. (1964). Intersexuality in fishes. In. ‘Intersexuality in vertebrates including man’. (Eds C.N. Armstrong and A.J. Marshall), pp 145-232. Academic Press, London and New York.

Bagenal, T.B. (1978). Aspects of fish fecundity.. *In* ‘Methods of assessment of ecology of freshwater fish production’. (Ed S.D. Gerking) pp. 75-101, Blackwell, Oxford**.**

Barrett, N. S. (1995). Short and long-term movement patterns of six temperate reef fishes (families Labridae and Monocanthidae). *Marine and Freshwater Research*. **46**, 853-860.

Barrett, N. S. (1999). Food availability is not a limiting factor in the growth of three Australian temperate reef fishes. *Environmental Biology of Fishes*. **56**, 419-428,

Beamish, R. and Fournier, D.A. (1981). A method for comparing the precision of a set of age determinations. *Journal of the Fisheries Research Board of Canada* 36, 1395-400.

Beamish, R.J. and McFarlane, G.A. (1983). The forgotten requirement for age validation in fisheries biology. *Transactions of the American Fisheries Society* **112**, 735-743

Buxton, C.D. (1992). The application of pre-recruit models to two South African sparid reef species with special consideration of sex change. *Fisheries Research* **15**, 1-16.

Cailliet, G.M., Love, M. and Ebeling, A.W. (1986.) Fishes: a field and laboratory manual on their structure, identification, and natural history. Wadsworth Press, Belmont, CA, U.S.A. 194 pp

Campana, S.E. (2001). Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology* **59**, 197-242.

Choat, J.H. and Robertson, D.R. (1975). Protogynous hermaphroditism in fishes of the family Scaridae. In 'Intersexuality in the animal kingdom' (Ed R.Reinboth), pp 263-283. Springer-Verlag, Berlin, Heidelberg and New York.

Edmunds, M. (1990). Ecology of fishes on Tasmanian rocky coasts. BSC Hons Thesis, University of Tasmania, Hobart.

Ferreira, B.P. (1993).Reproduction of the inshore coral trout *Plectropomus maculatus* (Perciformes: Serranidae) from the central Great Barrier Reef, Australia. *Journal of Fish Biology* **42**, 831-844.

Ferreira, B.P. (1995). Reproduction of the common coral trout *Plectropomus leopardus* (Serranidae: Epinephelinae) from the central and northern Great Barrier Reef, Australia. *Bulletin of Marine Science* **56**, 653-669.

Gomon, M.F., Glover, J.C.M., and Kuiter, R.H. (Eds) (1994). The Fishes of Australia's South Coast. (State Print, Adelaide) 992 pp.

Hastings, P.A. (1981). Gonad morphology and sex succession in the protogynous hermaphrodite *Hemanthias vivanus* (Jordan & Swain). *Journal of Fish Biology* **18**, 443-454.

Hobday, D.K. and Punt, A.E. (2001). Size-structured population modelling and risk assessment of the Victorian southern rock lobster, *Jasus edwardsii*, fishery. *Marine and Freshwater Research* **52**, 1495-1508.

Hunter, J.R. and Macewicz, B.J. (1985). Measurement of spawning frequency in multiple spawning fishes. In 'An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*'. (Ed. R. Lasker,). pp. 79-94, U.S. Department of Commerce.

Knuckey, I.A. and Sivakumaran, K.P. (2001). Reproductive characteristics and per-recruit analyses of blue warehou (*Seriolella brama*): implications for the South East Fishery of Australia. *Marine and Freshwater Research* **52**, 575-587.

Moe, M. A., Jr (1969). Biology of the red grouper *Epinephelus morio* (Valenciennes) from the eastern gulf of Mexico, Fla. Department of Natural Resources, Marine Research Laboratoire. Professional Paper Series vol 10, pp. 1-95.

Morison, A.K., Robertson, S.G., and Smith, D.C. (1998). An integrated system for production fish ageing: image analysis and quality assurance. *North American Journal of Fisheries Management* **18**, 587–98.

Nagahama, Y. (1983). The functional morphology of teleosts gonads. In Fish Physiology, IX (Part A) (Hoar, W. S., Randall, D. J. & Donaldson, E. M., eds), pp. 223-275. London: Academic Press.

Nakazono, A. (1979). Studies on the sex reversal and spawning behavior of five species of Japanese labrid fishes. Rep. Fish Res Lab., Kyushu Uni., 4:1-64.(In Japanese with English abstract.)

Punt, A. E., Garratt, P. A. and Govender, A., 1993. On an approach for applying per-recruit methods to a protogynous hermaphrodite, with an illustration for the Slinger *Chrysoblephus puniceus* (Pisces: Sparidae). *South African Journal of Marine Science*, **13** 109-119.

Reinboth, R. (1970). Intersexuality in fishes Pages 515-543 In ‘Hormones and the environment’ (Eds G.K.Benson and J.G.Phillips), pp 515-543 Cambridge University Press, Cambridge.

Shibuno, T., Chiba, I., Gushima, K., Kakude, S. and Hashimoto, H. (1993). Reproductive behaviour of the wrasse, *Halichoeres marginatus* at Kuchierabu-jima. *Japanese Journal of Ichthyology* **40**, 351-359.

Shepherd, S.A. and Hobbs, L.J. (1985). Age and growth of the blue-throated wrasse *Psuedolabrus tetricus. Transactions of the Royal Society of Southern Australia.* **109**, 177-178.

Smith, D.C. (1992). Introduction. In ‘Age Determination and Growth in Fish and Other Aquatic Animals’. (Ed. D. C. Smith.) *Australian Journal of Marine and Freshwater Research* **43**, vii-viii.

Smith, D.C. (2003). *Blue Warehou 2002,* Stock Assessment Report, Blue Warehou Assessment Group, South East Fishery Assessment Group. (Australian Fisheries Management Authority: Canberra.)

Thresher, R.E. (1984). Reproduction in reef fishes. T.F.H. Publ., Neptune City, New Jersey. 399 pp.

Walker, T. I., Taylor, B. L., and Hudson, R. J. (2002). Southern shark catch and effort 1970– 2001 report to Australian Fisheries Management Authority. 47 pp. July 2002. (Marine and Freshwater Resources Institute: Queenscliff, Victoria, Australia.)

Warner, R.R. (1975) The reproductive biology of the protogynous hermaphrodite *Pimelometopon pulchrum* (Pisus: Labridae). *Fishery Bulletin,* **73**, 262-283

Warner, R.R. and Robertson, D.R. (1978). Sexual patterns in the labroid fishes of the western Caribbean, 1:the wrasses (Labridae). Smithson. Contr. Zool., 254: 1-27.

Yamamoto, K. O., Takano, K. and Ishikawa, T. (1965). Studies on the maturing process of the rainbow trout *Salmo gairdneri irideus. Bulletin of the Japanese Society of Scientific Fisheries* **31**, 123-132.

Yogo, Y. (1987). Hermaphroditism and the evolutionary aspects of its occurrences in fishes. In 'Sex change in fishes'. (Eds A. Nakazono and T. Kuwamura), pp 1-47. Tokai University Press, Tokyo.

Appendix 1: Intellectual Property

No intellectual property has arisen from the research that is likely to lead to significant commercial benefits, patents, or licences. Intellectual property associated with information produced from the project will be shared equally by the Fisheries Research and Development Corporation, the Victorian Department of Primary Industries and Seafood Industry Victoria.

Appendix 2: Staff and Acknowledgements

Mr Ross Hodge	Principal Investigator	SIV
Dr David Smith	Co-investigator	MAFRI
Dr K. P. Sivakumaran	Reproductive biology	MAFRI
Dr Ian Montgomery	Modelling	MAFRI
Mr Kyne Krusic-Golub	Age determination	CAF, MAFRI
Mr Ken Smith	Field coordination	MAFRI

Karen Clifton and Steve Shanks of the (then) Victorian Fishing Industry Federation helped develop the original project proposal and gain industry support.

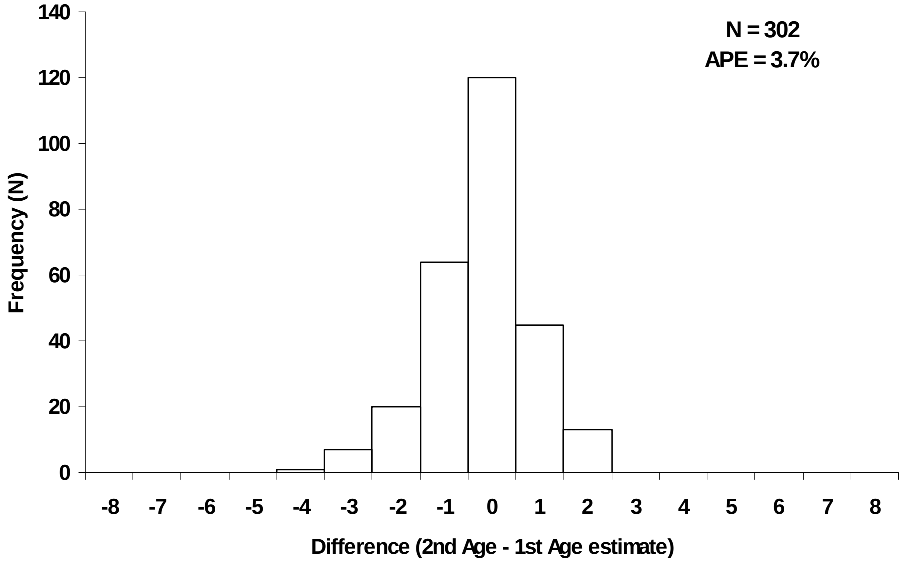
We would like to acknowledge the contribution of the following MAFRI staff: Ann Gason performed the GLM analyses, David Ball and Alistair Coots did the GIS work, Pam Oliveiro managed the data, David McKeown, Ian Duckworth and Sue Smith carried out much of the field work. The editorial comments of Terry Walker and Sandy Morison are much appreciated.

Funding was provided by the Fisheries Research and Development Corporation with support from Fisheries Victoria and Seafood Industry Victoria.

Finally, we would like to thank those commercial wrasse fishers who participated in the project and the recreational fishers who tagged and released fish as part of the VicTag program.

Appendix 3. Within and between reader comparisons of ages estimated for bluethroat wrasse

Within



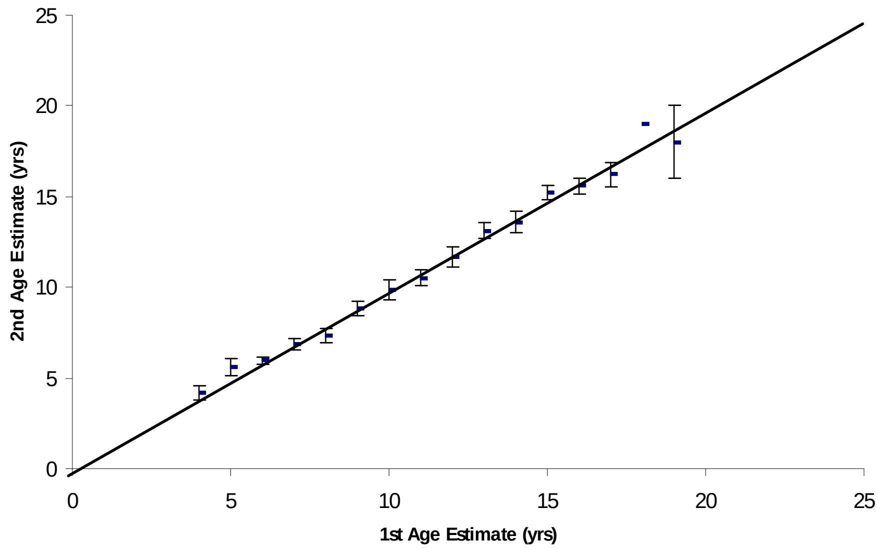
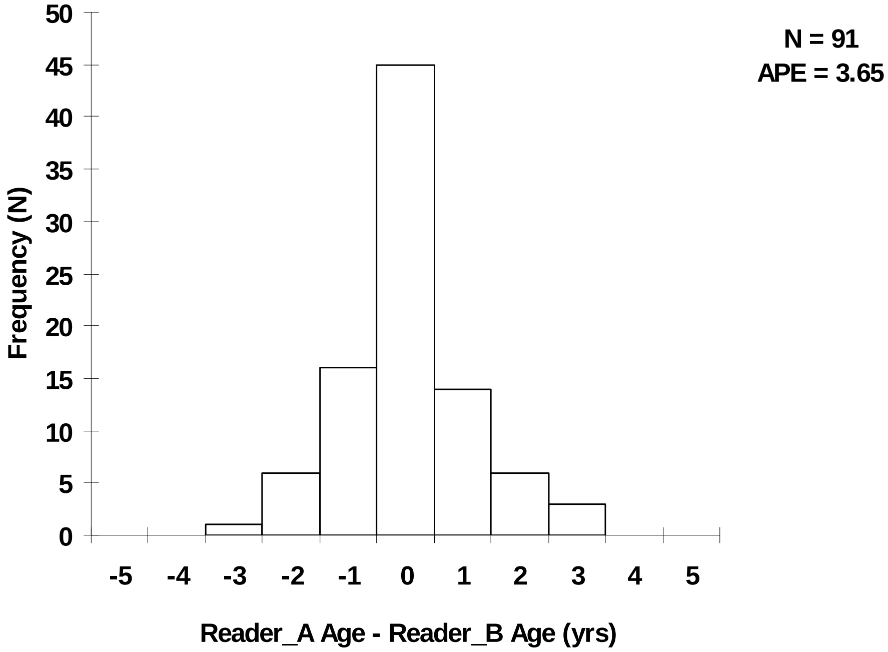


Figure 1. Within reader age determination variability for blue throat wrasse. In the lower plot, mean values +/- 2se are shown by horizontal and vertical bars, respectively. The solid line represents equal age estimates.

Table 1 Within reader age-reading error matrix for bluethroat wrasse

	Age2																					
Age1	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**N**
0	**0**																					**0**
1		**0**																				**0**
2			**0**																			**0**
3				**0**																		**0**
4					**4**	1																**5**
5						**5**	4	1														**12**
6						7	**17**	3														**25**
7						1	8	**9**	4													**20**
8							1	6	**5**													**12**
9								2	8	**9**	6	1										**26**
10								1	3	3	**9**	5	2									**23**
11									1	3	8	**10**	1	2								**25**
12									1	3	1	5	**12**	6	2							**30**
13												1	1	**10**	3	1						**16**
14												1	4	2	**8**	3	1					**19**
15															5	**9**	6	2				**22**
16															2	7	**9**	1	1			**20**
17																2	4	**2**	1			**9**
18																			**0**	1		**1**
19																	1			**2**		**3**
20																					**0**	**0**
N	**0**	**0**	**0**	**0**	**4**	**14**	**30**	**22**	**22**	**18**	**24**	**23**	**20**	**20**	**20**	**22**	**21**	**5**	**2**	**3**	**0**	**270**

Between readers



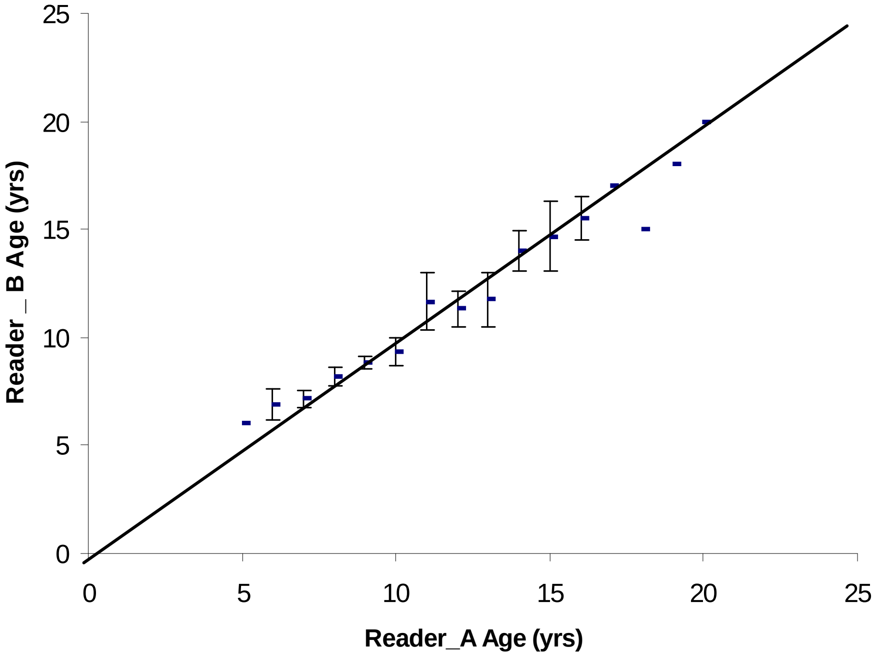
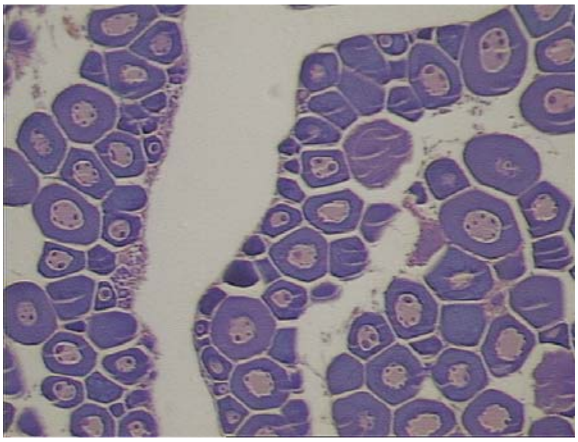


Figure 2. Between reader age determination variability for blue throat wrasse. In the lower plot, mean values +/- 2se are shown by horizontal and vertical bars, respectively. The solid line represents equal age estimates.

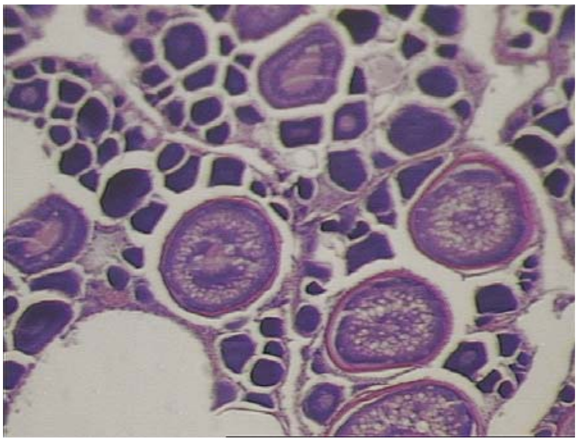
Table 2. Between reader age-reading error matrix for bluethroat wrasse

	Reader_B Age																					
Reader_A Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	N
0	**0**						1															0
1		**0**																				0
2			**0**																			0
3				**0**																		0
4					**0**																	0
5						**0**	1															1
6							**4**	3	1	1												9
7						1	2	**11**	5	1												20
8								2	**8**	3	1											14
9									1	**6**												7
10									1	2	**3**											6
11												**2**		1								3
12											2		**4**									6
13											1		2	**1**								4
14													1	2	**2**	2	1					8
15													1	1	1	**0**	2	1				6
16																1	**1**					2
17																		**2**				2
18																1			**0**			1
19																			1	**0**		1
20																					**1**	1
N	0	0	0	0	0	1	7	17	16	14	7	3	8	5	3	4	4	3	1	0	1	91

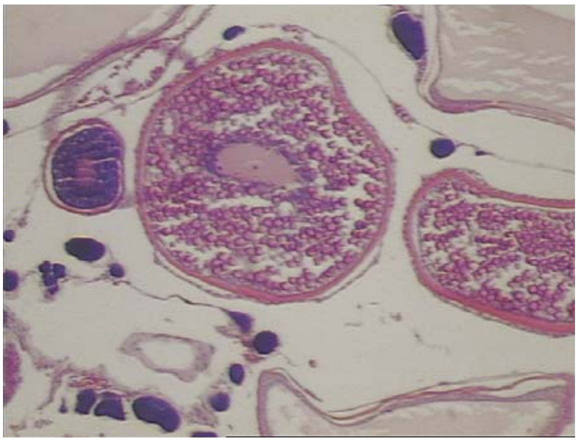
Figure 18. Histological sections showing the maturation of bluethroat wrasse oocytes from stage 1 to VI



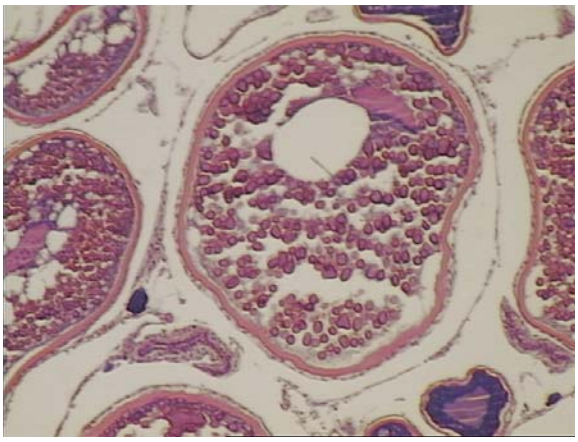
Stage 1. Unyolked stage: Oocyte size increases slightly as dark-blue-stained cytoplasm thickens, nucleoli appear at the periphery of nucleus.



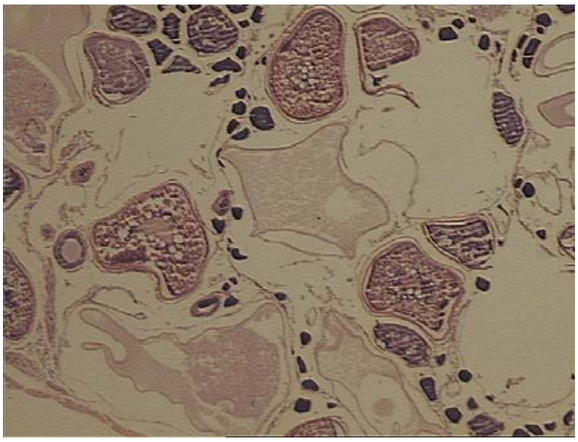
Stage 2. Partially yolked stage: Appearance of yolk vesicle in pale-blue stained cytoplasm, pink-stained zona radiata distinguishable and oil vesicles present.



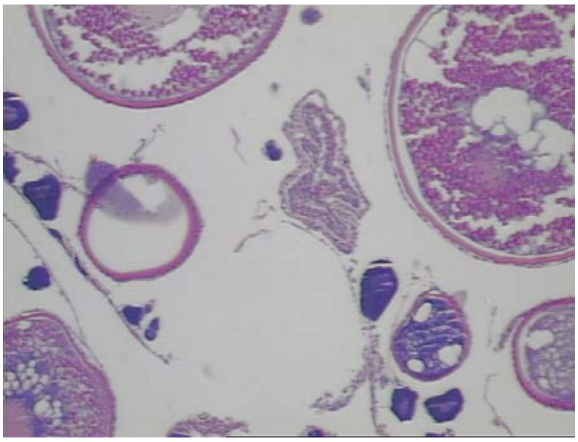
Stage 3. Advanced yollked stage: Marked increase in oocyte size, cytoplasm filled with pink-stained yolk granules, yolk vesicles and oil vesicles.



Stage 4. Nuclear migration stage: Migration of nucleus to periphery of oocyte, fusion of yolk granules into yolk plates.



Stage 5. Hydration stage: Further increase in size of oocyte, all yolk granules fused into a few plates.



Stage 6 Spent stage: After spawning the postovulatory follicles are clearly visible.

Figure 19. a) Secondary testis: Note the distinct remnant ovarian lumen (ovarian cavity), a characteristic feature of secondary males.

b) Secondary testis: Secondary spermatocytes, and spermatids and spermatozoa present.