# Description of the biology and an assessment of the fishery for adult longfinned eels in NSW

Edited by B.C. Pease

Cronulla Fisheries Centre
P.O. Box 21, Cronulla, NSW, 2230
Australia

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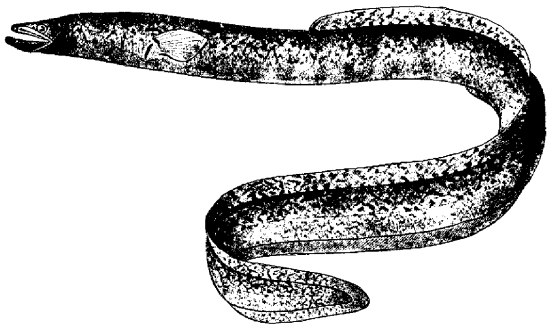

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# NON-TECHNICAL SUMMARY

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|---|---|
| 98/127 | Description of the biology and an assessment of the fishery for adult longfinned eels in NSW. |

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**OBJECTIVES:**

1. Compile all available survey data on longfinned eels in NSW to provide a quantitative summary of their distribution and relative abundance in coastal catchments.
2. Compile and cross-check all available historic catch and effort data for the commercial fishery on longfinned eels in NSW from all sources (monthly catch returns, permit logs, and export records) into a database of catch and effort information.
3. Conduct a literature review of fishery-dependent techniques for assessing adult anguillid eel stocks.
4. Describe the size, age, reproductive status and stock structure of the commercial catch of longfinned eels and their populations in representative fished and unfished catchments of NSW.
5. Assess the magnitude of the recreational fishery and the magnitude and cultural significance of the traditional fishery for freshwater eels in NSW.
6. Develop a preliminary fishery dependent model for stock assessment of longfinned eels which incorporates relevant catch, effort, recruitment and growth information.
7. Develop a strategy for monitoring the commercial fishery for longfinned eels and associated impacts related to glass eel harvest in the future.
8. Provide advice to fishery managers on the status of the stocks of longfinned eels in NSW, along with an assessment of the adequacy of existing management restrictions.
9. Provide advice to the Australia – New Zealand Eel Reference Group about the development and implementation of fishery dependent techniques for assessing other anguillid eel stocks of eastern Australia.

**NON TECHNICAL SUMMARY:**

Freshwater eels have a long history as a food source in Australia, firstly as part of the subsistence diet of aboriginal people and then as a commercial fishery developed by European settlers since 1912. In the late 1980s a high-value Asian market developed for live longfinned eels. In response to the new market, statewide catches of longfinned eels in the early 1990s increased dramatically to a peak of 388 tonnes in fiscal year 1992/93. Since 1992/93, statewide catches of longfinned eels have declined to approximately half the peak value. This decline in commercial catch in conjunction with continuing interest in the harvest of juvenile eels for aquaculture and a general lack of biological and ecological knowledge about longfinned eels highlighted the need to study the biology of this species. The primary objective of this study was to determine key aspects of the population biology of longfinned eels relevant to assessing the stocks of this species.

All available information about the distribution and abundance of the two river eel species in NSW was compiled into a single geographic information system. The presence/absence data from this spatial database was then summarised to provide an insight into the occurrence of these species within and among catchments. It was concluded that longfinned eels probably occur in virtually every coastal waterbody in NSW and they are among the most ubiquitous fish species within the coastal catchments of eastern Australia. They are known to occur in every aquatic habitat within this region, from marine and occasionally hypersaline waters at the mouth of the estuaries to montane streams, freshwater lakes and isolated freshwater impoundments. In many of the habitats they occupy, they are the largest or "top' carnivore. Due to their ubiquity and trophic status, they play a key role in the ecological structure and function of aquatic communities in the coastal catchments of eastern Australia.

Sex and stage of gonadal development of longfinned eels from a range of catchments and habitats were macroscopically and histologically examined to determine their reproductive biology. Typical of other river eel species, testes were found to be lobed in structure, and ovaries were frilled. Histology showed that sex identification by macroscopic observation was justifiable. However, to accurately define stages of gonadal development, particularly in individuals less than 600mm in total body length, it was found that histological preparation and microscopic examination were essential. Gamete development was not synchronous in males and females, indicating that the timing of sexual maturity and spawning migrations may differ between sexes. However, there was no evidence of lobed (male) organs containing oocytes, or gonads containing both male and female sex cells, indicating that this species does not change sexes. Gonadal development stages were positively correlated with body size in both sexes. However, female eels were significantly larger than males and their gonads matured over a broader size range. Size at sexual differentiation (42-60cm for males and 50-76cm for females) was much larger than for most other river eel species that have been studied, with the exception of the New Zealand longfinned eel. All of the evidence indicates that this species spawns only once before dying, similar to other river eels that have been studied. The most advanced cells present in migrating male and female eels were spermatocytes and pre-vitellogenic oocytes, respectively, indicating that the spawning site for this species is a relatively long distance from the nursery estuaries compared to most of the other river eel species that have been studied. Corresponding with its large range in size at sexual differentiation was a relatively large range in the size of sexually mature eels prior to migration to the oceanic spawning grounds (44-62cm for males and 74-142cm for females). Therefore, most males reach sexual maturity before reaching the marketable size of 58 cm or 500 g.

The annual nature of growth rings in otoliths of "yellow eel stage" (fully pigmented, pre-migratory) longfinned eels was validated using a combination of laboratory and field experiments. Eels were injected with oxytetracycline (OTC) and tagged with external "T-bar" tags. Microscopic examination of thin transverse sections of the sagittal otoliths from recaptured eels showed that one opaque annulus was typically formed in the otolith during each year subsequent to OTC marking. The seasonal timing of opaque annulus formation was highly variable, but generally occurred between May and October. Supernumerary (false or incomplete) rings were observed in many of the otoliths. Examination of otolith sections from a sample of very small, untagged, yellow eels verified the age at first annual increment formation. Marked and tagged longfinned eels did not have a significantly higher mortality rate than controls in the laboratory experiment but tag loss rates may be high.

The field tagging studies were also used to evaluate the movement patterns of yellow-stage longfinned eels within the coastal catchments of NSW. Of the original 865 tagged eels, there was an overall recapture rate of 19%. One individual was recaptured in the same location after 720 days at liberty. All except two of the recaptured eels were found close to their original tagging site, indicating that the home range of longfinned eels is generally less than approximately 300m. Both

eels that moved greater distances were females that moved downstream from the freshwater zone, possibly in anticipation of the spawning migration.

Sex ratios, catch per unit of effort (CPUE) and population age and length structure were examined in three zones (fresh water, upper tidal, and lower tidal) in the Hacking, Hawkesbury and Clarence River catchments. Females were found in relatively high proportions in all zones, ranging from 97% in a freshwater (non-tidal) site down to 59% at a tidal site. Males were found primarily in tidal zones (only two of the 677 eels caught in non-tidal fresh water were males), with the greatest proportions being found in the brackish upper tidal areas. The mean number of eels captured per trap were significantly higher in the freshwater and upper tidal zones than in the lower tidal zones. The mean age (17.9 years ± 0.29 S.E.) and age range (5-52 years) for females were significantly higher than those of males (12.2 years ± 0.39 S.E.; range 5-22 years), which is typical of other river eel species. Eels captured in fresh water were found to be significantly larger and older than those in tidal zones due to the almost exclusive predominance of females in the freshwater zone. Therefore, the existing closure of non-tidal fresh waters provides significant refugia for female spawning stock. Male spawning stock in the heavily fished upper tidal zone could be effectively protected by increasing the minimum size limit to 58 cm or 500g (mean size of sexual differentiation for females). Yield per recruit modelling of the eel fishery as part of collaborative studies by the Queensland Department of Primary Industries also indicate that the increased size limit would result in an increase in the relative yield per recruit to the estuarine and impoundment large yellow eel fisheries, as well as an increase in the relative egg production of females in these habitats, while decreasing the harvest of males.

Growth rates of long-finned river eels among the three zones and coastal catchments were also examined. Mean annual growth rates for the total population of sampled eels were calculated through age-length analysis (42mm/yr$^{-1}$) and individual tag-recapture (35mm/yr$^{-1}$). Both methods showed high intra and inter-population variability in growth rates of eels, even within the same sex at similar sites. Growth rates (based on body length) were found to be significantly faster in younger (5-15 years) eels than older (>15 years) eels with females growing an average 10 mm/yr$^{-1}$ faster than males of similar ages. These differences may be attributed to the different life history strategies employed both within and between sexes. The mean growth rate of eels in tidal areas was found to be significantly higher than in freshwater areas, with eels in the tidal areas of the Clarence River showing the greatest growth. Consistently faster growth of longfinned eels in tidal areas of catchments through a wide latitudinal range may be attributed to a longer growing season in the highly productive estuarine habitats. Other factors influencing variability in growth rates include sex ratios, density and fishing pressure.

Genetic samples from 447 glass and adult eels were collected from nine geographically distinct locations throughout NSW, Qld and New Caledonia. These samples were screened using six polymorphic dinucleotide microsatellite nuclear loci and allelic diversity at all six microsatellite loci was high. Both Chi-squared and $F_{ST}$ testing indicated moderate but highly significant levels of genetic structuring that are comparable with other fish species with high dispersal ability. Importantly, the level of genetic differentiation reported here for Australian longfinned eels is an order of magnitude higher than previously shown for other freshwater eel species. However, the level of genetic structuring reported here is also based on incomplete data sets and should be treated as preliminary. If genetic structuring is verified by further analysis, this result will have significant management implications. Based on the “precautionary principle”, these preliminary results indicate that the NSW population of longfinned eels should be managed as a discrete unit, independent of recruitment from spawning stocks in other parts of the extensive geographic range.

Four different commercial fisheries for longfinned eels (glass eel, small yellow eel, estuarine large yellow eel and impoundment large yellow eel fisheries) were described and summarised. Glass eels (post-larvae) are harvested for aquaculture grow-out from the upper tidal reaches of the estuary by

fishers with special permits using fine meshed fyke nets. The estuary and impoundment fisheries for large yellow eels have similar biological (females) and method (trap) characteristics but distinct fishing areas and management controls. The small yellow eel fishery has identical management characteristics to the estuarine large yellow eel fishery but targets the smaller male and undifferentiated yellow eels which are often in different areas from the larger female eels. Only the catch and effort data from the estuarine large yellow eel fishery is currently stored in the centralised catch and effort corporate database and reported on annually. Catch and effort data for all four eel fisheries should be stored in the corporate database and reported on annually.

The glass eel fishery has remained a very small-scale (annually much lower than the 40,000 longfinned glass eel peak), experimental fishery since its inception in 1995. Along with the problems associated with sourcing and identifying glass eel seedstock, aquaculturists have encountered problems with weaning then finding appropriate diets for the subsequent life-history stages. Mortality rates of these early life-history stages are often high. Therefore, aquaculturists have turned their attention primarily to small yellow eels from the yellow eel trap fishery for seedstock in the late 1990's. Unfortunately, the landings of these small yellow eels for aquaculture are not reported separately from the landings of the larger yellow eels that are harvested for the export market. Therefore, we only have anecdotal evidence from commercial fishers and aquaculturists that annual landings of small yellow eels have been less than 20,000 eels in recent years and we have no associated fishing effort information. The low level of harvest in both the glass eel and small yellow eel fisheries is primarily related to limited demand by the aquaculture industry rather than limitations of stock size or CPUE.

The impoundment trap fishery for large yellow eels has remained a small, limited-entry fishery since permits were first issued in 1992. The number of fishers and total annual landings in this fishery have declined since the mid 1990's but the catch per unit of effort has remained high since the fishery began. It is estimated that 30 to 40 thousand eels have been harvested annually by this fishery in recent years. The high CPUE and stability of the annual landings since the mid 1990's indicate that this fishery is operating within sustainable limits. However, stability and sustainability of this fishery are dependent on a complex mixture of factors related to the number of fishers and how often they harvest the isolated stocks with variable recruitment and growth rates from a large number of small impoundments.

The majority of eels that are commercially landed in NSW are harvested by the estuarine trap fishery for large yellow eels. This fishery has operated since at least 1970 and the number of fishers has remained stable since at least 1984. Annual landings and catch per fisher-month increased through the 1980's to a peak in the early 1990's when the high-value export market developed. Fishing effort, as measured by catch per fisher-month, has remained high since then but annual landings and catch per unit of effort (CPUE) declined in the mid 1990's, then levelled off. This temporal pattern in CPUE indicates that harvest prior to the early 1990's was having little impact on eel stocks, but increased effort in the early to mid 1990's rapidly reduced the level of available surplus production. This is typical of a new fishery. The stable nature of annual landings (estimated at 150 to 170 thousand eels in recent years) and catch per unit of effort since the mid 1990's, indicates that this fishery is now operating within sustainable limits.

Annual harvest rates and market values are not necessarily the only indicator of the importance of a fishery. Some harvested species may have special cultural or social significance to ethnic segments of the population. There is considerable archaeological and anthropological literature on Aboriginal use of eels in New South Wales. In this study, the nature and cultural significance of the indigenous fishery for eels in New South Wales was evaluated based on the available literature. Eels are often depicted in Dreamtime stories and rock engravings. Information from early European settlers depicts indigenous fishers capturing eels with a wide range of methods. More recent literature indicates that eels remain a popular food item with the indigenous population.

The magnitude of the indigenous and recreational eel fisheries in NSW were assessed using data from the 2000/01 national recreational survey and relevant tag/recapture data from our study. The two independent methods produced very similar estimates for both the total annual indigenous and recreational harvests of longfinned eels, which each ranged from 1748 to 2897 eels or from 2185 to 3677 kg, respectively. It is not feasible to estimate the variance associated with these estimates. Estimates from the tagging study were based on simplistic assumptions of proportionality between harvest and tag return rates while estimates from the national recreational survey were based on spatial sampling frames smaller than the state level. However, the consistency of these independent estimates verifies that the indigenous and recreational harvests of longfinned eels from NSW are each low (probably less than 3000 eels or 4 tonnes per year) compared to commercial harvests. Therefore, the total non-commercial harvest is probably in the order of 4000 to 6000 eels or 6 to 8 tonnes per year, which is less than 3% of the recent average annual commercial harvest of large yellow eels.

Strategies for monitoring longfinned eel stocks in NSW are discussed. Existing commercial catch and effort monitoring programs should be continued, as specified by the Estuary General Fishery Management Strategy. Long-term trends in catch and CPUE have been useful in assessing the status of stocks. This report also demonstrates that it is feasible to monitor size and age structure of fishery independent and fishery dependent catches. However, ongoing monitoring of size and age structure may not be cost effective because of the high variability of sex ratios, size and age among habitats and catchments. Monitoring of spawning stocks (out-migrating silver eels) is not technically feasible at this time. However, cost-effective techniques for monitoring annual glass eel recruitment have recently been developed. A glass eel recruitment monitoring program would provide useful information about the long-term status of yellow eel stocks, as well as the annual status of glass eel stocks for the glass eel fishery.

**Outcomes Achieved**

1. All available survey data on longfinned eels in NSW up through the year 2000 have been compiled into an Access database called Eel Distribution. Based on the information in this database and the available literature, a quantitative summary of the distribution of longfinned and shortfinned eels in NSW is provided in Chapter 2.2. The Eel Distribution database has been archived at NSW Fisheries for future reference.
2. All available catch and effort data for the commercial yellow eel fisheries in NSW have been cross-checked and compiled into an Access database called Lcatch Eels. Based on the information in this database, a quantitative summary of the catch and effort of the commercial eel fisheries of NSW are provided in Chapter 3. The Lcatch Eels database has been archived at NSW Fisheries for future reference.
3. An international workshop was held at the Fisheries Research Institute, Cronulla to assess fishery independent and fishery dependent strategies for sampling adult eels. The proceedings of the workshop were published in a report by Walford and Pease (1999).
4. Estimates of the magnitude of the indigenous and recreational fisheries for longfinned eels in NSW are provided for the first time.
5. Fishery independent and fishery dependent samples of longfinned eels were collected from a range of habitats, in a number of coastal catchments in NSW over a three-year period. The environmental, morphometric, age, gonad condition and sex data from this study has been compiled into an Access database called Adult Eels. After using this database for the analyses summarised in this report, it has been archived at NSW Fisheries for future reference.
6. Many of the biological and ecological results of this study, including aspects of anaesthesia, reproduction, age, movement and demography of longfinned eels, have been published in a

series of four journal publications (Walsh and Pease 2002; Walsh, Pease and Booth 2003; Pease, Reynolds and Walsh 2003; Walsh, Pease and Booth 2004).
7. Data from this study have been used in the collaborative development of a yield per recruit model for longfinned eel populations by the Queensland Department of Primary Industries in a study funded by FRDC.
8. Bycatch data from fishery independent eel trapping for this study were used in the Environmental Impact Statement for the Estuary General Fishery (NSW Fisheries 2001) and a journal publication on freshwater turtle bycatch in trap fisheries by Lowry, Pease, Graham and Walford (2004).
9. Advice on the status of longfinned eel stocks and the adequacy of existing management strategies for eel stocks was presented to the Australia-New Zealand Eel Reference Group at a meeting in Melbourne on 12 July 2002 and to the NSW Estuary General Management Committee at a meeting in Cronulla on 20 September 2002.
10. Based on the results of this study, a recommendation to increase the minimum legal size of longfinned eels from 30 cm to 58 cm was proposed in a discussion paper on the longfinned eel fishery of NSW that was sent to all commercial eel fishers in December 2003.

**KEYWORDS:**
Longfinned Eels, *Anguilla rienhardtii*, Reproduction, Age, Growth, Stock Structure, Stock Assessment

# 1. INTRODUCTION

## 1.1. Background

Freshwater eels belong to the genus *Anguilla* and four of the 16 known species occur in Australia. The two most common species in eastern Australia are the Australian longfinned eel (*Anguilla reinhardtii* Steindachner, 1867) and the Australian shortfinned eel (*Anguilla australis australis* Richardson, 1841). Both of these species are commercially harvested from the coastal catchments of eastern Australia. The widely distributed longfinned eel (also known locally in NSW and Victoria as the spotted or conger eel) is a predominantly tropical species that occurs along the entire east coast of Australia from Cape York south to Tasmania, west to Melbourne and east to Lord Howe Island.

Freshwater eels are catadromous fishes that spawn in the ocean. The exact location of the spawning grounds of the East Australian species is unknown but it is believed that they spawn in depths greater than 400 metres in the Coral Sea. The leaf-shaped larvae, called leptocephali metamorphose into transparent eel-shaped "glass eels". As the eels migrate up the estuaries they become pigmented and are then called elvers. As one of the primary apex carnivores in the upper parts of coastal catchments in Eastern Australia, adult longfinned eels are extremely important components of these ecosystems. Longfinned eels are reported to be relatively long-lived species, Tasmanian studies indicate that they reach sexual maturity after 10 to 40 years, when they migrate out of the estuary and return to their oceanic spawning grounds. They may attain a length of 1.6 metres and a weight of over 20 kg.

Freshwater eels have a long history as a food source in Australia, firstly as part of the subsistence diet of Aboriginal people and then as a commercial fishery developed by European settlers since 1912. The first commercial eel fishery developed in Victoria and has been based primarily on the Australian shortfinned eel, producing between 200 and 350 tonnes per year since 1976. In NSW and Queensland the commercial fisheries are based primarily on longfinned eels. The Queensland fishery started in the 1980s and has remained small (less than 50 tonnes per year). The commercial fishery in NSW started in the late 1960s. Reported catches remained relatively low (less than 100 tonnes per year) until the early 1990s. Most of the catch during this period was obtained from the Clarence River catchment and the northern region of the state. During this period both longfinned and shortfinned eels were primarily exported as frozen product. In the late 1980s a high-value Asian market developed for live longfinned eels. In response to the new market, statewide catches of longfinned eels increased dramatically to a peak of 388 tonnes in fiscal year 1992/93. Most of the increased catches came from Port Stephens and the Hawkesbury River in the central region and a new fishery for eels from impoundments and farm dams. Since 1992/93, statewide catches of longfinned eels have declined to approximately half the peak value. Despite this decline, the 1996/97 eel catch ranked fifth by weight and third by value (approximately one million dollars) of commercial estuarine finfish in NSW. Therefore, the longfinned eel fishery is a significant component of the estuarine fisheries in NSW.

The number of fishers reporting eel catches in NSW has remained relatively stable at 180 to 260 fishers per year since 1984. In 1997, access to the fishery was limited by requiring an endorsement to use eel traps and the number of estuarine eel fishers has declined. Since the inception of the fishery in NSW, trapping has been the only legal commercial harvest method for freshwater eels. Fish and eel trapping during this period has been restricted to tidal waters, except for a few large impoundments since 1989 and some small coastal farm dams since 1992, where eels have been harvested by special permit. Since 1989 a maximum size limit has been imposed by the

specification of a maximum entrance tunnel diameter of 10 cm for eel traps. In 1997 a minimum legal length of 30 cm was introduced.

Information on the magnitude of either the traditional or recreational catch of freshwater eels in NSW is not readily available, but these catches are believed to be small in comparison with the commercial catch. However, eels may be totemically significant within the culture of Aboriginal people. There is also very little information on the magnitude of the by-catch in other estuarine fisheries, but this component is also believed to be very limited.

Eels have been extensively cultured in Victoria since the early 1970's. Culturists are still unable to spawn any of the freshwater eel species in captivity so Victorian lakes are stocked with undersized eels and elvers from the commercial fishery and a commercial fishery for glass eels has developed in Queensland for supplying local aquaculture facilities. As a result, there is growing interest in all the eastern states of Australia in the potential for intensive and extensive culture of eels using wild caught glass eels and elvers. Export of glass eels and elvers (less than 30 cm) from NSW is currently prohibited but a limited number of permits have been issued for harvest of glass eels to provide seed for experimental eel culture facilities within the state. Expansion of the harvest of glass eels may be possible but the level of exploitation should be determined using appropriate information on all relevant life history stages and their interaction. Therefore, uncertainty about the impact of glass eel harvest on adult eel stocks makes it even more important to gain an understanding of the status and dynamics of adult eel populations.

## 1.2. Need

Internationally, the demand and resulting value of glass eels has increased tremendously in recent years. Live glass eels have been sold for over $15,000 per kilo. This international demand results from over-fishing of adult and glass eels in Asia, North America and Europe. This world experience indicates that recruitment over-fishing of long-lived freshwater eels can be catastrophic. Because of the increasing significance of adult eels in the estuarine fisheries of NSW, decreased catches in recent years and the prospect of increased future catches of glass eels for aquaculture, it is important to undertake research which will lead to an understanding of the current status of adult stocks in NSW. Stocks of adult eels must be managed properly to ensure continued production of the commercial fishery for adult eels, continued recruitment of glass eels and elvers for aquaculture and stability of coastal catchment ecosystems.

Limited research into the basic biology and ecology of longfinned eels has been carried out in Victoria and Tasmania, but there have been no biological studies conducted in NSW. The only published age and growth information for this species comes from one catchment in Tasmania and indicates that they are relatively long-lived (40 years), but this age data has not been validated. The available literature indicates that growth rates of freshwater eel species are highly variable among habitats and distributional ranges. Therefore, there is need to determine the basic biological parameters of NSW longfinned eels stocks, including validated age structure, growth and mortality rates, and reproductive characteristics for use in stock assessment modelling.

Since there is a significant commercial fishery for adult eels in NSW, fishery-dependent techniques based on sampling of commercial catches may represent the most cost effective stock assessment and monitoring methodology. Age and growth monitoring of many commercial finfish species in NSW is currently carried out by sampling fish at the Sydney Fish Markets and regional fisherman's co-operatives. Most of the commercial eel catch in NSW is exported live through a few (currently four) specialised processors. Therefore, it may be necessary to establish a specialised monitoring regime and fishery-dependent model which will provide data on which to base advice for the future sustainable management of exploitation of the resource.

## 1.3. Achievement of Objectives

1. Achieved - All available survey data on longfinned eels in NSW up through the year 2000 have been compiled into an Access database called Eel Distribution. Based on the information in this database and the available literature, a quantitative summary of the distribution of longfinned and shortfinned eels in NSW is provided in Chapter 2.2. The Eel Distribution database has been archived at NSW Fisheries for future reference.

2. Achieved - All available catch and effort data for the commercial yellow eel fisheries in NSW have been cross-checked and compiled into an Access database called Lcatch Eels. Based on the information in this database, a quantitative summary of the catch and effort of the commercial eel fisheries of NSW are provided in Chapter 3. The Lcatch Eels database has been archived at NSW Fisheries for future reference.

3. Achieved – All literature relevant to stock assessment of anguillid eels has been compiled into a Procite database of eel literature with over 500 references. This database (Eel Refercnces) has been archived at NSW Fisheries for future reference.

4. Achieved – Fishery independent and fishery dependent samples of longfinned eels were collected from a range of habitats, in a number of coastal catchments in NSW over a three-year period. The environmental, morphometric, age, gonad condition and sex data from this study has been compiled into an Access database called Adult Eels. After summarising this information in Chapter 2, it has been archived at NSW Fisheries for future reference. Many of the biological and ecological results of this study, including aspects of anaesthesia, reproduction, age, movement and demography of longfinned eels, have been published in a series of four journal publications (Walsh and Pease 2002; Walsh, Pease and Booth 2003; Pease, Reynolds and Walsh 2003; Walsh, Pease and Booth 2004). Detailed information about the reproductive biology, ecology and demographics and genetic stock structure are presented for the first time.

5. Achieved – Based on a review of available literature, the cultural significance of the indigenous fishery is discussed in Chapter 4. The magnitude of the indigenous and recreational fisheries for longfinned eels in NSW is estimated for the first time in Chapter 5, using the national recreational survey and tag recapture data.

6. Not achieved – A model for assessing longfinned eel stocks based on fishery dependent data was not developed because a modeller was not available at NSW Fisheries during the contract period. However, information from this NSW study was provided to Simon Hoyle for collaborative development of a yield per recruit model for longfinned eels. This model will be presented in the final report to FRDC on the collaborative study of longfinned eels by the Queensland Department of Primary Industries.

7. Achieved – Methods for monitoring longfinned eel stocks are discussed in Chapter 5 and final recommendations for monitoring are given.

8. Achieved – Advice on the status of longfinned eel stocks is provided in Chapter 3 and recommendations for improving the management of eel fisheries in NSW is provided in Chapter 5. A summary of the management recommendations from this report were presented to the Estuary General Management Advisory Committee on 20 September 2002. Based on the results of this study, a recommendation to increase the minimum legal size of longfinned eels from 30 cm to 58 cm was proposed in a discussion paper on the longfinned eel fishery of NSW

that was sent to all commercial eel fishers in December 2003 and endorsed by the Estuary General Management Committee in July 2004.

9. Achieved – Based on the findings of this study, recommendations on the development and implementation of fishery dependent techniques for assessing anguillid eel stocks were presented to ANZERG at a meeting in Melbourne on 12 July 2002.

# 2. BIOLOGY AND STRUCTURE OF LONGFIN POPULATIONS

## 2.1. Overview of Biological Studies

Bruce Pease – NSW Dept of Primary Industries

### *2.1.1. Introduction*

This chapter provides an overview of the sampling areas, method of capture and processing of eels in both the field and laboratory for the entire biological study. More detailed descriptions of methods relevant to specific aspects of the biological studies will be given separately in subsequent chapters. The term 'eels' in this study refers to freshwater eels of the genus *Anguilla* unless otherwise stated. The term 'yellow' eel will be used when referring to fully pigmented, pre-adult stage eels that are feeding and have not yet taken on the silvery appearance and morphological changes associated with maturation. The term 'silver' eel will be used when referring to eels that have generally ceased feeding, have undergone distinctive morphological changes associated with metamorphosis and are commencing their migration to sea to spawn.

### *2.1.2. Methods*

#### *2.1.2.1. Study Areas*

The majority of the field sampling in this study was carried out in the Hacking, Hawkesbury, and Clarence River catchments (Fig. 2.1.1). These three rivers were the focus of a major study of longfinned eel biology (Walford & Pease, 2000), where most of the fishery independent and fishery dependent samples were collected from a wide range of freshwater and tidal locations. For additional reproductive and ageing information a smaller number of eels were collected from freshwater locations in a number of other catchments during separate fishery independent surveys of freshwater fishes (Fig. 2.1.1). Also, a few additional silver eels were supplied by commercial fishers in the Hunter, Pambula, and Wollamba catchments. For the purposes of this study sampling within the three primary rivers was divided into three zones - freshwater, upper tidal and lower tidal.

The Clarence is the largest of all NSW coastal rivers in terms of both catchment area (22400km$^2$) and discharge (Bell and Edwards, 1980), with the mouth being located approximately 550kms north of Sydney (Fig. 2.1.1). The length of the river is approximately 250km, with the limit of tidal influence being Smith Falls near Copmanhurst, approximately 108km from the mouth. The upper catchment is well forested and remains relatively undisturbed with agricultural land dominating the lower reaches. The Clarence River supports the largest eel fishery in NSW (see Chapter 3). Sites sampled in the Clarence River are shown in Figure 2.1.2.

The Hawkesbury/Nepean catchment is the second largest in NSW (catchment area of 21500 km$^2$) (Bell & Edwards, 1980), with the mouth being located approximately 38kms north of Sydney (Fig. 2.1.1). The estuary (also a drowned river valley) is the largest in the state with the tidal limit being near Yarramundi - a distance of 145 km upstream of the mouth. As well as several national parks and state recreation reserves, a large area of the upper estuary alluvial flats is dominated by market gardening, turf farming, and animal husbandry. The Hawkesbury River supports a significant eel fishery (see Chapter 3). Sites sampled in the Hawkesbury River are shown in Figure 2.1.3.

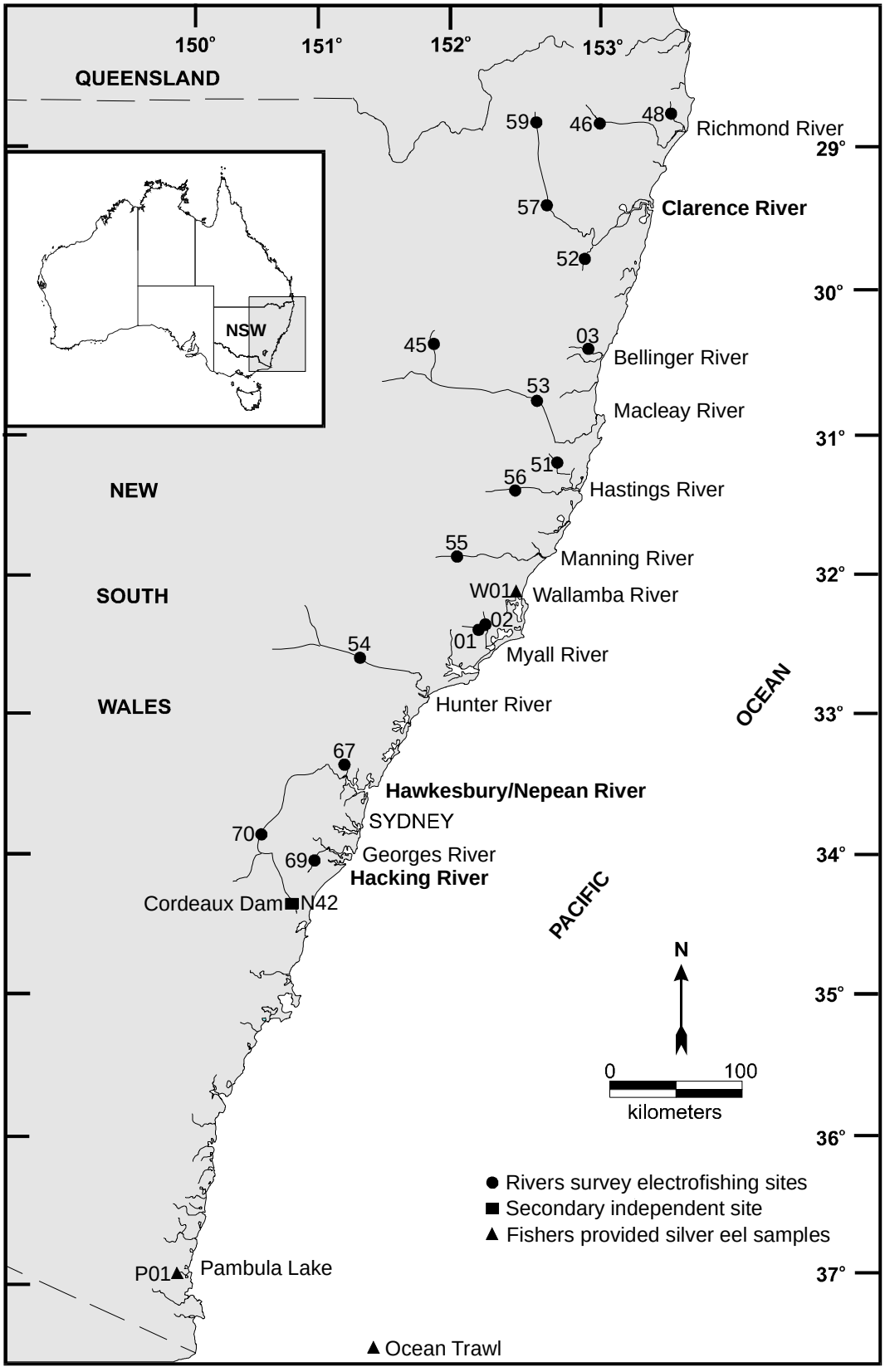


**Figure 2.1.1.** Map showing the location of catchments where eels were sampled. The primary catchments for fishery independent and dependent trap sampling are shown with bold font.

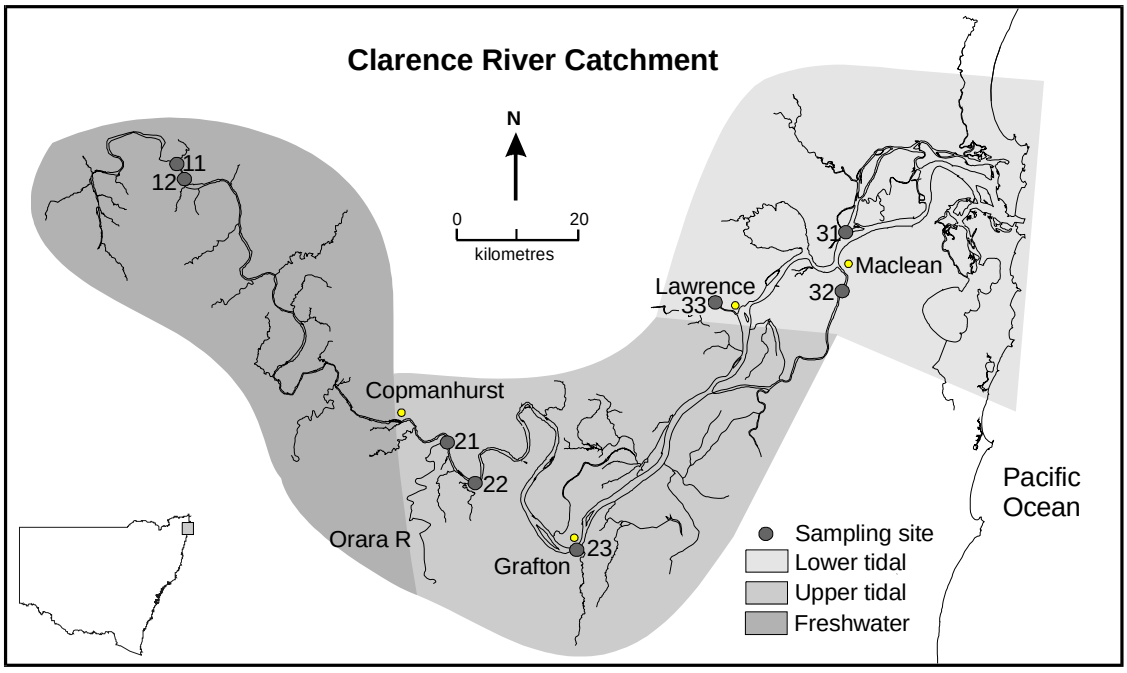


**Figure 2.1.2.** Map showing the location of the primary fishery independent trap sampling sites in the Clarence River catchment. Shaded areas show catchment zones.

The Hacking River is a relatively small catchment (area-180 km$^2$) (Bell & Edwards, 1980) in NSW with the mouth located approximately 24km south of Sydney (Fig. 2.1.1). Most of the catchment lies within the Royal National Park with the northern shore forming the southern boundary of the city of Sydney. The estuarine portion of this catchment consists of a small, drowned-river valley (Roy, 1984) called Port Hacking. The estuary extends 12km upstream to a causeway (Audley weir), which forms a tidal barrier across the Hacking River. As a result there are only two zones associated with this catchment (freshwater and lower tidal). The major differences between this river and the Hawkesbury and Clarence Rivers are a smaller catchment area; the presence of a estuary/freshwater interface; and the fact that this system is closed to commercial fishing. Sites sampled in the Hacking River are shown in Figure 2.1.4.

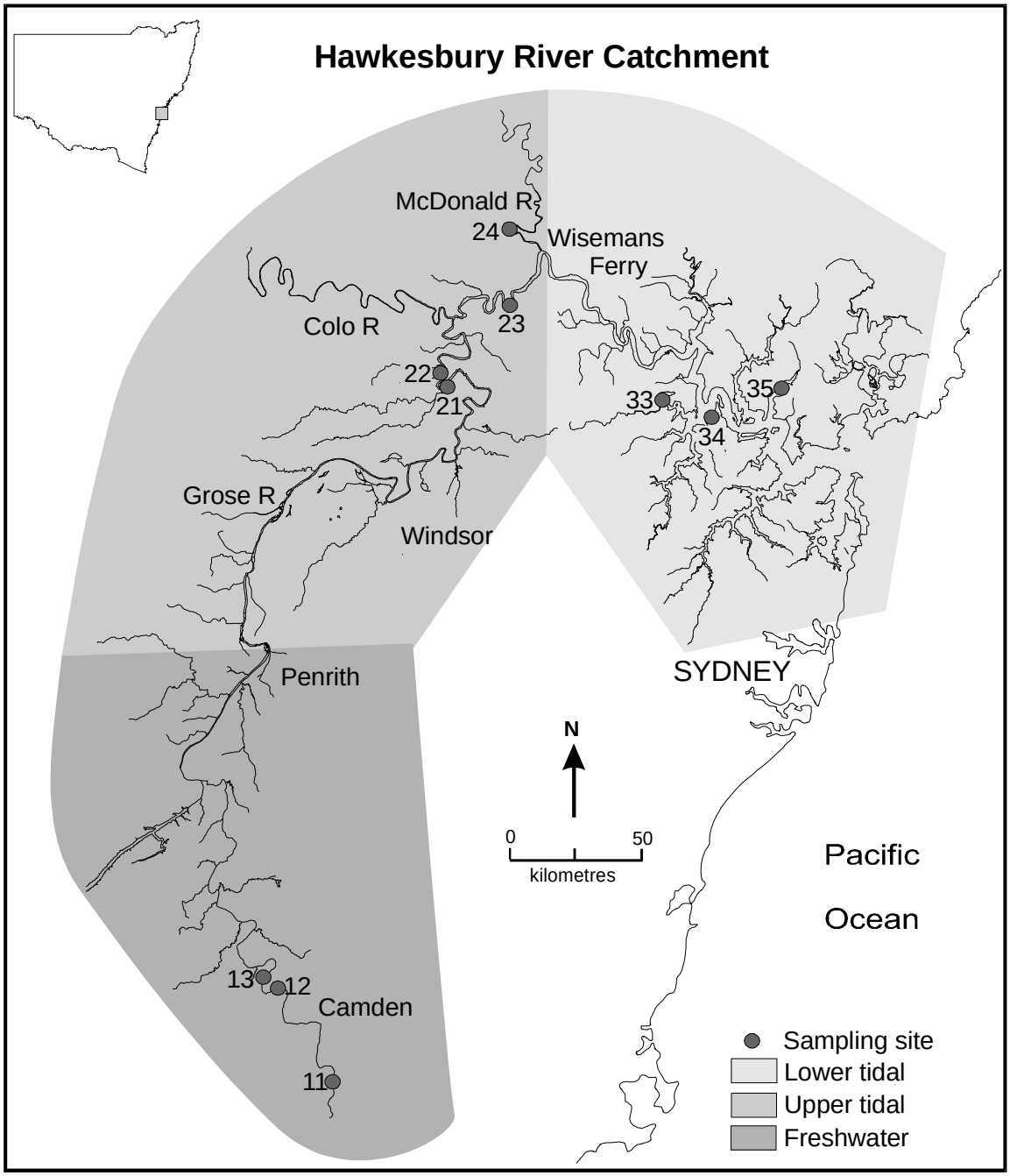


**Figure 2.1.3.** Map showing the location of the primary fishery independent trap sampling sites in the Hawkesbury/Nepean River catchment. Shaded areas show catchment zones.

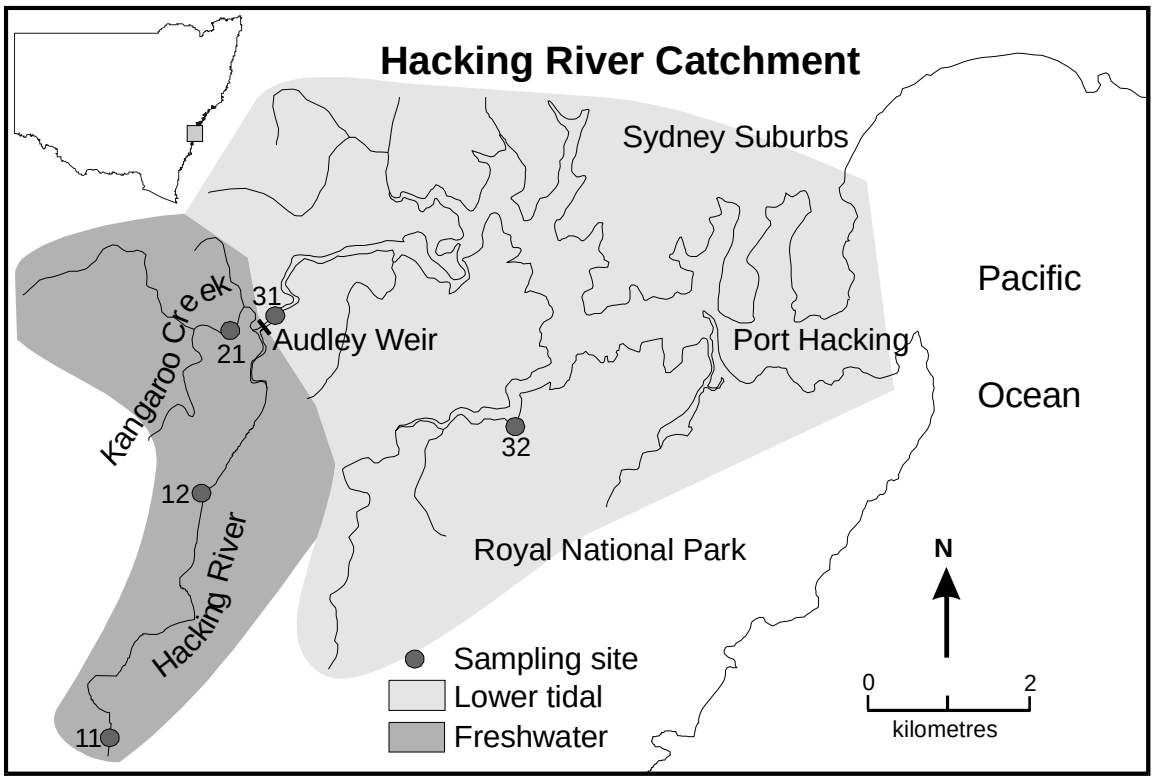


**Figure 2.1.4.** Map showing the location of the primary fishery independent and dependent trap sampling sites in the Hacking River catchment. Shaded areas show catchment zones.

*2.1.2.2. Zones*

In this study the 'freshwater zone' is defined as the area above the tidal limits of the main riverine channel which is always fresh. This waterbody is generally quite narrow relative to the other zones in the rest of the catchment. The substrate is generally rocky, often with undercut banks, snags, and overhanging vegetation on the outside bends of the river. The inside bends often consists of a shallow sandy substrate.

The 'upper tidal zone' is defined as the area of predominantly fresh water below the upper tidal limits which therefore has some saline influence (0-2ppt). The waterbody in this zone is generally quite wide in these areas and consists of a more muddy substrate. While there are still rocky areas, terrestrial vegetation cover and aquatic macrophytes, the cover is significantly less, often the result of human practices.

The 'lower tidal zone' is defined as the brackish to marine dominated (3-35ppt.) areas found near the mouths of the estuaries. This more expansive part of the waterbody is even less influenced by terrestrial habitat types than the upper tidal areas, however channels, backwaters and swamps provide suitable refuge for *A.reinhardtii*.

In this study the term 'tidal' (on its own) refers to the body of water within a coastal catchment which includes both the upper and lower tidal zones.

### *2.1.2.3. Capture Methods*

The majority of eels sampled in this study were captured using commercial eel traps. The traps used for fishery independent sampling were of identical design to those used by local commercial fishers for both river and static water use. Each trap consisted of a rectangular steel frame (900mm length, 500mm width and 400mm depth) with a mesh size of 25mm and an inward opening funnel of 100mm diameter. The two types of traps used in this study were the estuarine and freshwater traps. The only difference in the two traps being the length of the cod ends (1 and 5 metres respectively). The longer cod end in the freshwater trap reaches the surface and contains a float which allows air-breathing vertebrates (freshwater turtles, water rats, platypuses etc.) to breath at the surface, ensuring their survival and subsequent release.

Often the freshwater habitat areas favoured by eels were located in sandy shallow sub strates close to the banks of the rivers or in the backwaters. In these situations fyke nets were considered to be more effective than traps. The fyke nets consist of a 5 metre long wing attached to a 3 metre long funnel net with a mesh size of 25mm. The fyke nets were attached to a star picket above the surface to allow for air breathers and were not baited. Fyke nets were not used at sites in the tidal zones.

To provide additional size, reproductive and age information for *A. reinhardtii*, eels were sampled from a wider range of catchments (Fig. 2.1.1) using an aluminum electrofishing boat (FRV Electricus) in collaboration with the NSW Rivers Survey conducted by NSW Fisheries (see Harris and Gehrke 1997 for detailed methods). Electrofishing sites are shown in Figure 2.1.1. The sites were sampled each summer during the study period.

### *2.1.2.4. Fishery Independent Sampling Strategy*

Trapping was the primary method of fishery independent sampling carried out at the sites in each zone (along with fyke netting only in freshwater zones) in autumn and spring (2000 to 2001) for the Hacking, Hawkesbury and Clarence (spring only) Rivers. Water temperatures at these times of year were comparable and discussions with commercial fishers indicated that catch rates of eels may be seasonally higher at these times. During the first year of the study (1999-2000), most eels were tagged then released while only recaptured eels were euthanased and processed. Details of the tagging program are given in Chapter 2.4. To detect any temporal differences in eel population characteristics in this study, all captured eels were euthanased and processed during all seasons (2000-2001) at sites within the Hacking (freshwater and lower tidal zones) and Hawkesbury (upper tidal zone) Rivers. During the third year of the study (2001) all captured eels were euthanased and processed.

Two to four trap sampling sites were established in each zone of each catchment (Figures 2.1.2-2.1.4). Each site consisted of a 100-300m section of the river or tributary. Independent sampling was carried out in each site in each season over three nights with approximately 10 traps (and up to three fyke nets if deemed appropriate for the habitat) being set. The traps or fykes were emptied each day and then rebaited (traps only) for the next 24 hrs with either pilchard (*Sardinops neopilchardus*) or mullet (*Mugil cephalus*). Environmental variables such as water temperature, salinity, and depth were recorded after each trap and fyke was emptied. Location and habitat details of all fishery independent sites are summarised in Appendix I.

#### *2.1.2.5. Fishery Dependent Sampling Strategy*

Eel samples were collected from commercial eel fishers whenever they were available throughout the study period. Commercial fishing is banned in the Hacking River as well as in flowing non-tidal freshwater rivers and their tributaries in all other catchments in NSW. As mentioned previously this is primarily to prevent the incidental capture of air-breathing vertebrates. Fishery dependant samples were collected at sites associated with independent sampling sites in the tidal (both upper and lower) zones from the Hawkesbury and Clarence Rivers. Samples were collected at each fisher's residence, rather than at a processing facility so that the source location of the eels was known. A representative sub-sample of approximately 15 to 20 eels was collected for processing from each of the commercial fishers' catches. Silver eels were occasionally supplied from commercial fishers for additional reproductive and age information. Location, habitat and method details of all fishery dependent sampling sites are summarised in Appendix I.

#### *2.1.2.6. Processing of Eel Samples*

The processing of eels for both methods of sampling (fishery independent and dependent) were identical. To ensure accuracy in determining the body weight and length measurements of eels they were first anaesthetised. Clove oil at a recommended concentration of 100mg/l (Walsh and Pease, 2001) was used to anaesthetise the eels for weighing and measuring before placing them in a concentration of 200mg/l clove oil for approximately 30 minutes. This was sufficient to ensure the animal was killed. The total body length of each eel (from top jaw to the tip of the tail) was measured to the nearest mm, the girth at the pectoral fins was measured to the nearest mm and total weight was recorded to the nearest 10 grams. The eels were then either processed for their otoliths and gonads that particular day or frozen until they could be processed at a latter date. A more detailed description of the methods involved for the reproductive, age and movement analyses will appear in their appropriate chapters.

All environmental data at the sampling sites as well as morphometric, age, gonad condition and sex data was stored in an Access database called Adult Eels. The table structure of this relational database is summarised in Appendix II.

### *2.1.3. Results and Discussion*

A summary of the eel samples collected during the fishery independent trapping and fyke netting operations is given in Table 2.1.1. The numbers of measured, sexed and aged eels were generally similar from both the freshwater and tidal zones. More eels were sampled from the Hacking and Hawkesbury catchments because the seasonal habitat sampling in 2000-2001 was carried out in these catchments. A high proportion of the eels from these samples (approximately 30%) were sexed and aged. We believe that these samples provide the least biased and most representative biological information about eels in the three primary catchments.

**Table 2.1.1.** Summary of the number of eels sampled at the primary fishery independent trap sites. Fyke nets were also used at the freshwater sites.

| Catchment | Zones | Sexed | Aged | Measured |
|---|---|---|---|---|
| Clarence | Freshwater | 52 | 55 | 148 |
| Clarence | Tidal | 55 | 75 | 245 |
| Hawkesbury | Freshwater | 58 | 72 | 198 |
| Hawkesbury | Tidal | 103 | 134 | 460 |
| Hacking | Freshwater | 113 | 102 | 297 |
| Hacking | Tidal | 90 | 77 | 176 |
| Total | Freshwater | 223 | 229 | 643 |
| Total | Tidal | 248 | 286 | 881 |
| Total | All | 471 | 515 | 1524 |

A summary of the eel samples collected during the electrofishing surveys is given in Table 2.1.2. Numbers of eels captured during these surveys were relatively low and only about 10% of the samples were aged and sexed. Electrofisher eel sampling is biased by a range of factors. Varying water depths and turbidity affect the ability of samplers to see stunned eels. The area fished is also dependent on a range of factors including: depth, conductivity and electrical output characteristics. All stunned eels could not be reached with the dip nets and they occasionally escaped from the nets once they were lifted from the water.

**Table 2.1.2.** Summary of the number of eels sampled by electrofishing at Rivers Survey sites.

| Catchment | Sexed | Aged | Measured |
|---|---|---|---|
| Richmond | 0 | 0 | 8 |
| Clarence | 14 | 18 | 88 |
| Macleay | 10 | 14 | 59 |
| Bellinger | 0 | 0 | 20 |
| Hastings | 2 | 2 | 25 |
| Myall | 3 | 9 | 99 |
| Hunter | 0 | 0 | 2 |
| Hawkesbury | 0 | 0 | 13 |
| Georges | 0 | 0 | 9 |
| Total | 29 | 43 | 323 |

A summary of the eel samples collected during the fishery dependent surveys is given in Table 2.1.3. The vast majority of this data was collected from tidal waters, because flowing fresh waters are closed to commercial eel fishing. Only one sample of eels harvested from freshwater farm dams was collected. Most of the samples were collected from the Clarence River because it supports the largest commercial eel fishery of all catchments in NSW. Approximately 10% of the eels were sexed and aged. Size grading by commercial fishers is common, so the size and age distributions may be biased. Eels in one sample may have come from a wide range of locations within the target catchment and in some cases may have come from different catchments. However, we believe these samples provide biological information that is generally representative of the estuarine commercial eel fishery in NSW.

**Table 2.1.3.** Summary of the number of eels sampled using fishery dependent techniques.

| Catchment | Zones | Sexed | Aged | Measured |
|---|---|---|---|---|
| Clarence | Tidal | 215 | 236 | 2231 |
| Wallamba | Tidal | 10 | 4 | 10 |
| Hawkesbury | Freshwater | 16 | 17 | 103 |
| Hawkesbury | Tidal | 112 | 155 | 1112 |
| Pambula | Tidal | 1 | 1 | 1 |
| South Coast | Marine | 1 | 1 | 1 |
| Total | Tidal | 338 | 396 | 3354 |
| Total | Freshwater | 16 | 17 | 103 |
| Total | Marine | 1 | 1 | 1 |
| Total | All | 355 | 414 | 3458 |

## 2.2. Geographic Distribution

Bruce Pease and Trudy Walford – NSW Dept of Primary Industries

### *2.2.1. Introduction*

Two species of catadromous anguillid eels occur in abundance and are harvested commercially on the east coast of Australia. As shown in Figure 2.2.1, *Anguilla reinhardtii*, known locally as the long-finned eel or simply longfin, is a predominantly tropical species found in the coastal catchments of eastern Australia from Cape York to Tasmania (Beumer 1996). It is also known to occur in New Guinea, Solomon Islands, New Caledonia, Lord Howe Island and New Zealand (Schmidt 1928; Ege 1939; Allen 1991; Jellyman *et al.* 1996a). *Anguilla australis*, known locally as the short-finned eel or simply shortfin, is a predominantly temperate species found in the coastal catchments of eastern Australia from southern Queensland (Caboolture River) to Tasmania (Beumer 1996). This species also occurs in New Caledonia, Norfolk Island, Lord Howe Island, and New Zealand (Schmidt 1928; Ege 1939; Dijkstra and Jellyman 1999).

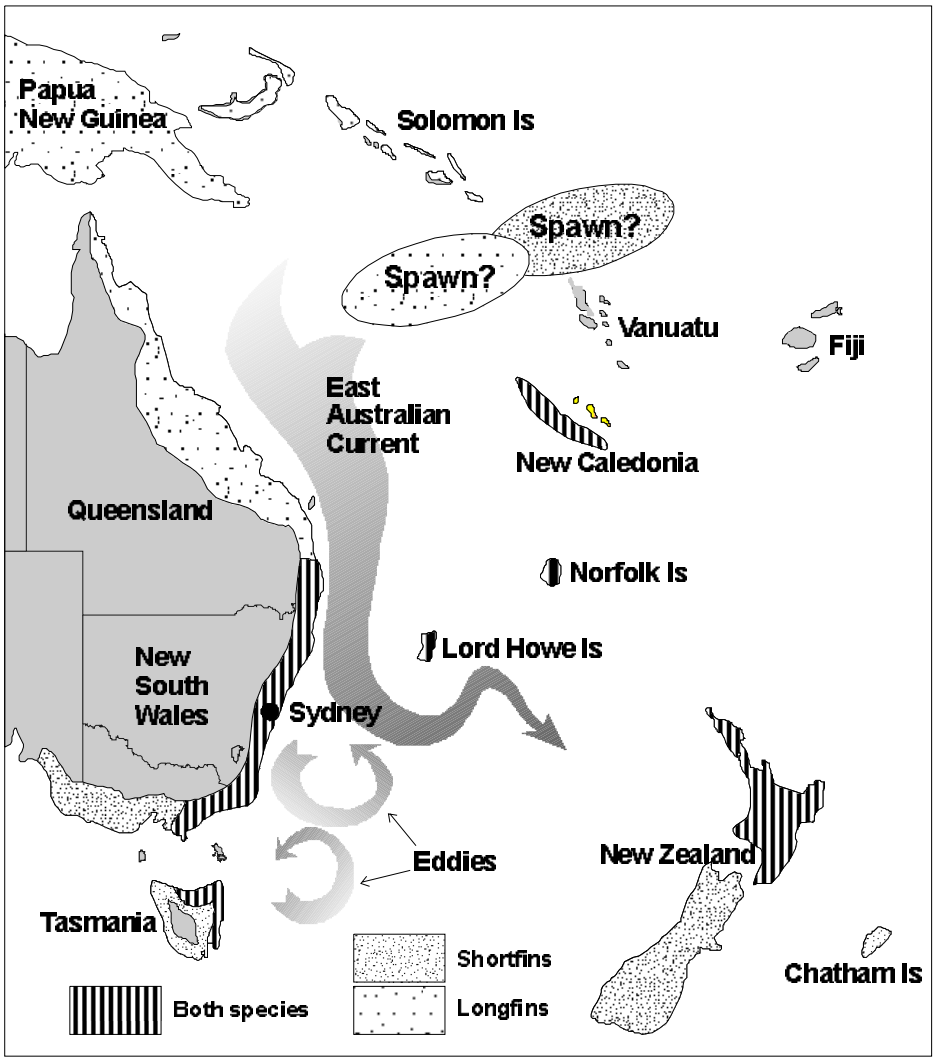


**Figure 2.2.1.** Geographic distribution of long and short-finned eels in the southwestern Pacific.

Both species are believed to spawn in the south-western Pacific north of New Caledonia (Aoyama *et al.* 1999). The leptocephalus larvae are carried to the east coast of Australia by the East Australian Current (Jespersen 1942; Castle 1963; Jellyman 1987; Beumer and Sloane 1990), where they metamorphose into post-larval glass eels which recruit to eastern Australian estuaries. In Australia, juvenile and adult longfins are most abundant in the coastal catchments of Queensland and New South Wales (NSW), while shortfins are most abundant in Victoria and Tasmania. Geographic distributions of the two species overlap in NSW but very little is known about their relative abundances and habitat preferences in this overlap zone.

Previous to this study, a wide range of more general freshwater and estuarine fish surveys and studies have been carried out in New South Wales. Many of the fish samples collected during these studies included anguillid eels. The most extensive surveys have been done by NSW Fisheries and much of the data from these surveys is still available in electronic databases. Eel samples collected by NSW Fisheries, universities, other government agencies and the public are also lodged with the Australian Museum as voucher and reference specimens and information about the specimens and capture sites is also stored in an electronic database.

The objective of this part of the study was to compile all available information about the distribution and abundance of the two eel species in NSW into a single geographic information system. The presence/absence data from this spatial database was then summarised to provide an insight into the occurrence of these species through catchments. This study focused primarily on longfinned eels, therefore the distribution of this species through habitats in the region was also summarised.

### *2.2.2. Methods*

Records containing catch and effort data relating to *Anguilla reinhardtii* and *A. australis* in NSW waters were extracted from a number of NSW Fisheries databases (including this study) and the Australian Museum database, as listed in Table 2.2.1. These records were then compiled in an Access (Microsoft Office 97 version) database called "Eel Distribution". All associated sampling and biological data were compiled into tables that are described in Appendix III. The spatial reference and species occurrence data from this database was then loaded into an Arcview (version 8.1) geographical information system (GIS) in order to analyse and display the geographical distribution information. These databases are now archived at NSW Fisheries. Occurrence of longfinned eels in habitats within coastal catchments was then reviewed using the results of this study (FRDC 98/127) and studies based on the other NSW Fisheries databases.

**Table 2.2.1.** Sources of eel distribution and abundance data in the Eel Distribution database. Number of records designates occurrence of shortfins or longfins at a sampling site on one date, not number of eels.

| Data Source | No. of Records | Period |
|---|---|---|
| Rivers Survey (Harris & Gerhke 1997) | 1205 | Aug 1994 – Jun 1999 |
| Adult Eel Study (FRDC 98/127) | 897 | Jan 1998 – Feb 2001 |
| Hawkesbury Study (Gerhke & Harris 1996) | 889 | Oct 1992 – Sep 1995 |
| Eastern Cod Survey (Ian Wooden, NSW Fisheries database) | 184 | May 2000 – Nov 2001 |
| Northern Rivers Study (West 1993) | 102 | Feb 1988 – Jun 1990 |
| Australian Museum Collection (Ichthyology database) | 183 | May 1905 – Oct 1996 |

### *2.2.3. Results*

The geographical distribution of longfinned and shortfinned eels in fish samples collected throughout NSW is summarised in Figure 2.2.2. The boundaries of the Pease (1999) estuarine bioregions at 32$^o$ and 35$^o$ south latitude are also shown. Longfins occurred more frequently in the northern and central bioregions than in the southern bioregion. Shortfins occurred more frequently in samples from the southern and central bioregions than from the northern bioregions. Therefore, the greatest distributional overlap occurred in coastal catchments within the central bioregion. A higher proportion of shortfins than longfins were found greater than 100 km inland from the coast, particularly in the southern and central bioregions.

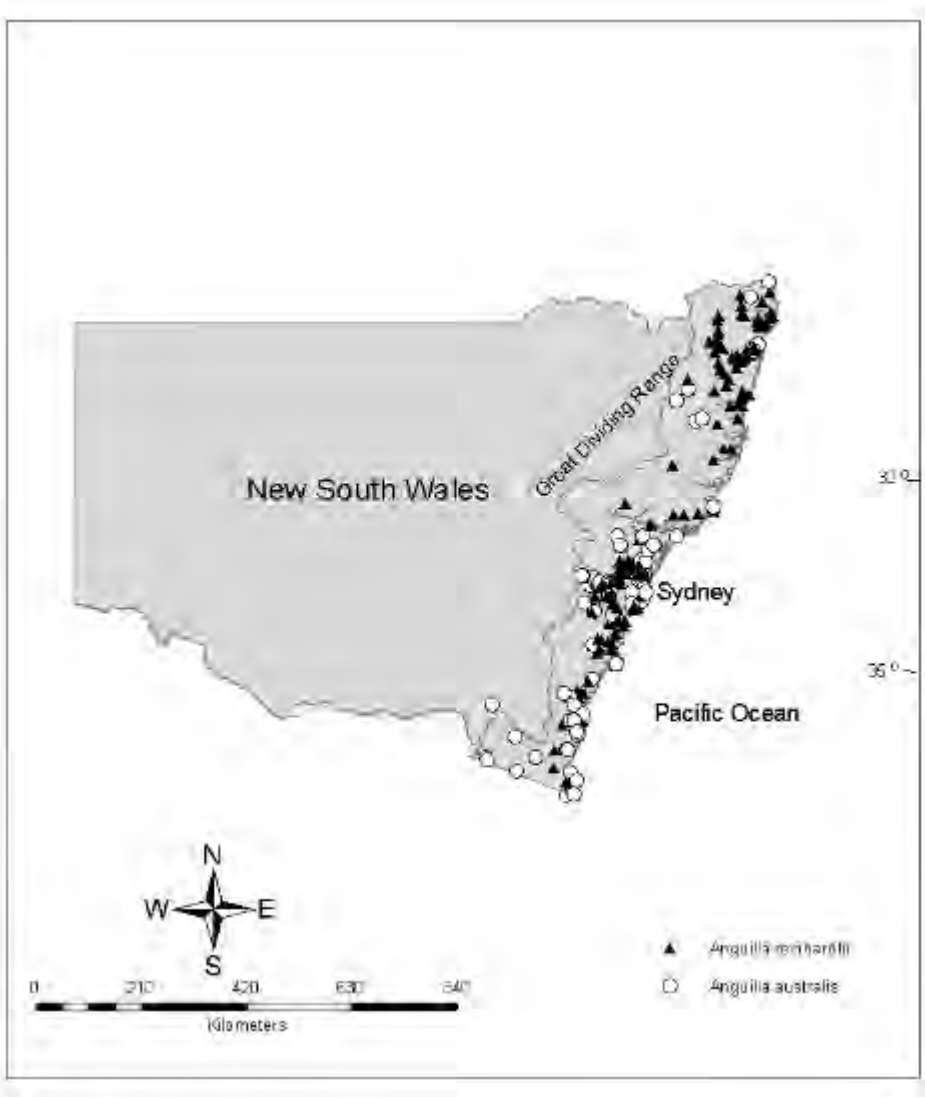


**Figure 2.2.2.** Distribution of longfinned (*A. reinhardtii*) and shortfinned (*A. australis*) eel samples in NSW from all surveys.

Within the present study, only three habitat zones (fresh water, upper tidal and lower tidal) were defined within catchments. Longfinned eels were present in all three zones. The relative abundance of longfins in these habitat zones can be compared using catch per unit of effort data because eels were the target species using standard units of effort. Within the three primary study catchments, they were most abundant in the fresh water and upper tidal habitats and least abundant in the lower tidal zone (Fig. 2.2.3). These zones were primarily defined by salinity. Figure 2.2.4 shows that longfins were found in tidal waters ranging from fresh to marine, but were most abundant in oligohaline waters having a salinity of less than six parts per thousand. The distribution of longfins within the three habitat zones is summarised in greater detail in Chapter 2.5.

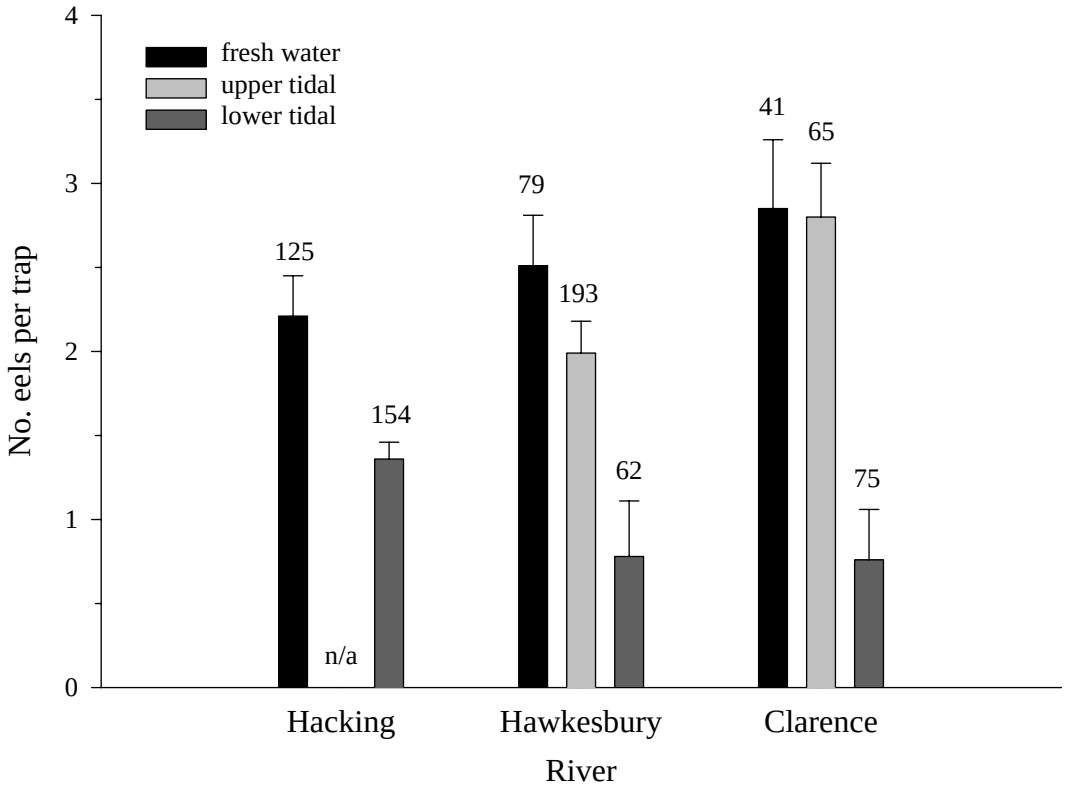


**Figure 2.2.3.** Mean number and standard error of *A. reinhardtii* captured per fishery independent trap sample in the different zones of the Hacking (upper tidal zone absent), Hawkesbury and Clarence Rivers.

Most of the sampling sites for this study were located in the main river channel or in the channel of a smaller tributary. However, during the course of this study longfinned eels were also sampled from small farm dams, yabbie aquaculture ponds, large dam impoundments, lowland streams, as well as freshwater and estuarine wetlands.

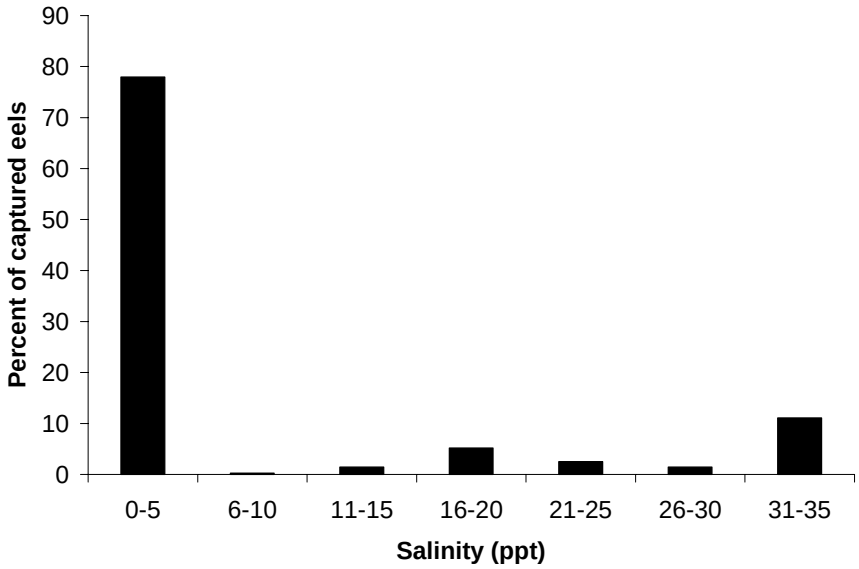


**Figure 2.2.4.** Percent of eels captured in fishery independent traps at a range of salinities.

Within the other surveys and studies listed in Table 2.2.1., longfins were sampled in a wide range of habitats. West and Walford (2000) found them in estuarine communities of the Clarence and Richmond Rivers which were defined as marine, brackish and tidal freshwater. They were also found in all three bioregions in a wide range of fluvial freshwater habitats defined by Harris and Gerhke (1997) which are summarised in Table 2.2.2. Gerhke *et al.* (1999) found them in all of the regulated freshwater habitats within the Hawkesbury River catchment in the central bioregion which were defined as: 1) regulated lowland rivers (Table 2.2.2), 2) slope rivers below dams, 3) within dam impoundments, and 4) streams above dams. Wooden (Pers. Comm) also found them at all of the montane and slope sampling sites for Eastern freshwater cod, including dam impoundments within the Clarence and Richmond River catchments.

**Table 2.2.2.** Fluvial freshwater habitats defined by Harris and Gerhke (1997). Sampled by: 1 = Harris and Gerhke (1997), 2 = Gerke and Harris (2000), 3 = Gerhke *et al.* (1999), 4 = Wooden (NSW Fisheries eastern freshwater cod database).

| Habitat | Definition | Sampled by: |
|---|---|---|
| Montane | > 700 m | 1, 2 & 4 |
| Slope | < 700 m and > 40 m | 1, 2, 3 & 4 |
| Unregulated Lowland | < 40 m with natural, unrestricted upstream flow | 1, 2 & 3 |
| Regulated Lowland | < 40 m with flow modified by upstream dam | 1, 2 & 3 |

### *2.2.4. Discussion*

Longfins occur from Cape York to Tasmania and are among the most widely distributed commercial fish species found in the coastal catchments of eastern Australia. As evidenced by the Eel Distribution Database (Fig. 2.2.2) and the commercial catch data (Chapter 3), this species undoubtedly occurs in every coastal catchment in New South Wales, which is in the centre of its geographic range. However, as a predominantly tropical species (Schmidt 1928) it appears to be more prevalent in the northern and central bioregions than in the southern bioregion. However, this conclusion may be biased by the much higher sampling intensity of multiple fish surveys conducted in the Hawkesbury and Clarence River catchments. Despite this sampling bias, longfins probably occur in virtually all of the 952 coastal waterbodies connected to the Tasman Sea (Williams *et al.* 1998) and most of the uncatalogued large and small isolated freshwater impoundments in NSW.

Within NSW, shortfins are near the northern end of their geographic range (southern Queensland). This was reflected in the generally lower occurrence of shortfins than longfins and the decreased occurrence of this species in the northern bioregion, despite the high sampling intensity in the Clarence River catchment. Gerkhe and Harris (2000) found that they were the dominant fish species in montane streams in southern NSW but did not contribute significantly to any of the other coastal freshwater habitats sampled. Jellyman (1977) and Beumer (1996) indicate that they occur primarily in still, fresh waters. During our study, shortfins were observed in swampy backwaters, yabby ponds and farm dams, which have not been sampled extensively during previous freshwater fish surveys. They were not caught in any of the highly brackish or marine-dominated tidal habitats.

Longfins are probably the most ubiquitous fish species in coastal catchments of NSW. They are known to occur in every aquatic habitat within this region, from marine and occasionally hypersaline waters at the mouth of the estuary to montane streams, freshwater lakes and isolated freshwater impoundments. During recent surveys of aquatic habitats in coastal dunes within the northern bioregion, Knight (2003) also found longfins in a large perched lake and a range of dystrophic, ephemeral streams, lakes and swamps within the coastal dune ecosystem. Within many of these habitats, they are among the dominant fish species in terms of abundance and biomass.

A range of sampling methods was used to sample fish in the various surveys and studies that are summarised in this chapter. Our Adult Eel Study was the only one that targeted eels using specialised eel traps. The other studies used a range of sampling techniques including prawn trawling, gill netting, minnow trapping and electrofishing. Growns *et al.* (1996) showed that electrofishing was much more effective and efficient for sampling fish (and particularly eels) in freshwater habitats than gill netting. Therefore, the following inferences about the dominance of eels in freshwater fish habitats are based on studies that primarily sampled with electrofishing methods.

Longfins were the only fish species that Wooden (NSW Fisheries eastern cod database) found at a wide range of sampling sites in montane and slope freshwater habitats in the Clarence and Richmond River catchments. Gerkhe and Harris (1999) found that longfins were the most widespread freshwater fish species in their study of flow alteration in the Hawkesbury-Nepean River, forming a significant component of the unregulated fish assemblages in upper and slopes reaches, the regulated fish assemblage below dams and combined fish assemblages in lowland reaches. In their survey of riverine fish communities in NSW, Gerkhe and Harris (2000) found that longfins were consistently among the numerically dominant fish species in all north coast freshwater habitats (montane, slope, unregulated lowland and regulated lowland) and all south coast freshwater habitats except for montane (the only habitat that shortfins were dominant in).

This apparent decline in abundance with increasing distance from the sea associated with increasing latitude is consistent with the findings of Sloane (1984a and b) at the southern end of the range in Tasmania.

Longfins are carnivorous predators which feed primarily on teleost fish, including other anguillid eels (Beumer 1979). In many of the habitats they occupy, they are the largest or "top' carnivore. Due to their ubiquity and trophic status, they play a key role in the ecological structure and function of aquatic communities in the coastal catchments of eastern Australia.

## 2.3. Reproductive Biology

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### *2.3.1. Introduction*

Like other members of the family Anguillidae, *A. reinhardtii* is believed to be both catadromous and semelparous (Beumer 1983). Because of this life history strategy, eels have small, poorly developed gonads during most of their long residence period in coastal catchments. This has made it difficult for researchers to discriminate between the sexes. There are no definitive external characteristics for distinguishing the sex of anguillid eels and early researchers believed them to be viviparous, or even the product of spontaneous generation (Stead 1906). In 1777 Mondini described the frilled female ovary and in 1874 Syrski described the lobulate testes, which was later to be known as the organ of Syrski (Tesch 1977). Even to this day accurate macroscopic assessment of sex and gonad stage of anguillid eels remains problematic.

In early studies concentrating on gonad morphology and development of eels, staging was almost entirely based on the external appearance of the gonads. This is the simplest and fastest method of assessing the sexual development of most fish species but is subjective, and can be completely inaccurate when applied to eels (Sinha and Jones 1966; Gray and Andrews 1970; Wenner and Musick 1974; Tesch, 1977; Dolan and Power 1977; Harrell and Loyacano 1982). For example, studies of the European eel (*Anguilla anguilla*) have shown that a lobed organ is generally diagnostic of maleness, but some have been found to contain oocytes (D'ancona 1960; Sinha and Jones 1966; Colombo and Grandi 1996). Therefore, many researchers may have incorrectly sexed small undifferentiated eels with gonads resembling the organ of Syrski as males. Many researchers studying sex ratios and gonadal development now depend on histological examination for accuracy, particularly with small immature individuals. Histological preparation and analysis is expensive and time-consuming but is by far the most accurate technique for assessing gonadal development in fish (West 1990).

For all fish, the early stages of sexual development are characterised by an undifferentiated phase. Grandi and Colombo (1997) describe eels as undifferentiated gonochorists which display juvenile rudimentary hermaphroditism before final sex differentiation. They found germ cells of both sexes in gonads of *A. anguilla* that were up to 22cm in body length. Helfman *et al.* (1984) were the first to describe gonads of the American eel (*Anguilla rostrata*) containing both oogonia and spermatogonia, but these were uncommon (only 6 out of 418 specimens examined). Huver (1966) found that the organ of Syrski appeared histologically as an immature testes in *A. rostrata*, but that it developed into an ovary as the eel increased in size. In contrast, Satoh *et al.* (1962) found no stages of precocious feminization or juvenile hermaphroditism in the Japanese eel (*Anguilla japonica*) and Todd (1974) found that none of the gonads of the New Zealand longfinned (*Anguilla dieffenbachii*) or Australian shortfinned (*Anguilla australis*) eels in his study possessed both oocytes and spermatogonia.

Studies of the European and the American eels have concluded that critical life history events such as differentiation of the sexes and sexual maturity are more closely correlated with body length rather than age (Tesch 1977; Bieniarz *et al.* 1981; Helfman *et al.* 1987; Colombo and Grandi 1996). The sex of European (Sinha and Jones 1966), American (Helfman *et al.* 1987) and Japanese (Satoh *et al.* 1962; Chiba *et al.* 1993) eels may remain indistinguishable up to a length of 35cms, whereas Harries (1974) examined *A. dieffenbachii* and found that 50% of the sample within the 46-50cm size class was sexually indeterminate. It is only during the later stages of sexual maturity in these

four species that there is a well-defined size difference between males and females. Coinciding with larger maximum lengths of indeterminacy in comparison with other temperate anguillids, Todd (1980) found that the mean lengths at migration for *A. dieffenbachii* were much larger than for European (Colombo *et al.* 1984) and American eels (Helfman *et al.* 1987; Barbin & Mcleave 1997; Krueger & Oliveira 1997).

In the present study, both macroscopic and microscopic (histological) techniques were used to describe the sexual differentiation and gonadal development of Australian longfinned river eels in New South Wales, Australia. The accuracy of macroscopic sex determination and gonad staging is evaluated against microscopic analysis of histologically prepared samples. Key characteristics of sexual development in this species are defined and compared with the available information for other species in the family Anguillidae.

### *2.3.2. Methods*

The yellow (adult) and silver (migrating) eels examined in this study were captured from a number of coastal catchments (Table 2.3.1). Details of the experimental design are given in Chapter 2.1.

**Table 2.3.1.** Number of eels caught and capture method used at each locality.

| **Locality** | **Method of capture** | **No. eels** | |
|---|---|---|---|
| | | **Freshwater** | **Tidal** |
| Hacking River | Trap/fyke net | 90 | 69 |
| Hawkesbury River [1] | Trap/fyke net | 56 | 232 |
| Clarence River [1,2] | Trap/fyke net/electro. | 52 | 270 |
| Other catchments (Hastings, Myall, and Macleay rivers)[2] (Wollamba, Hunter, Pambula rivers) [3] | Trap/fyke net/electro. | 39 | 0 |
| Oceanic (offshore) [4] | Trawl | 0 | 2 |

[1] Samples also from commercial trap fishery

[2] Samples from fishery independent (electrofishing) surveys

[3] Silver eel samples supplied by commercial trap fishers

[4] One female silver eel supplied by a NSW commercial trawl fisher and one male silver eel supplied by a Queensland commercial trawl fisher

Shortly after capture, eels were euthanased with 300mg/L clove oil solution. Total length was measured to the nearest millimetre and total weight was recorded to the nearest 10 grams. Eels were either processed on the day of capture or frozen for later analysis. Silver eels were externally identified by coloration, increased eye diameter, and fin shape (Wenner and Musick 1974; Tesch 1977; Todd 1981; Pankhurst 1982).

As sexual dimorphism of external morphological characteristics was not apparent, sex was identified by internal examination. A small section of gonadal tissue (approx. 0.5cm$^3$) was removed

at the point of its attachment by making a longitudinal incision along the mid-section of the body wall. In smaller individuals, where gonads were difficult to locate, an abdominal segment of gut and attached mesentery tissue was removed. The whole gonad of eels that had taken on a 'silver' appearance was extracted, weighed, then preserved in two fixatives. Firstly the tissue was fixed in a buffered formalin fixative (10% strength FACC) for 30 days. This enabled samples to retain their fresh colour and texture for macroscopic examination. They were then transferred into 70% ethanol for histological preparation and long term storage (Virgona *et al.* 1998).

#### *2.3.2.1. Macroscopic Observations*

Gonadal tissue was examined on a black background under a binocular microscope using a reflected light source. The structure, shape, and size of the gonad was described and it was then categorised into the appropriate developmental stage. The classification of gonads was based on macroscopic examinations done previously for other species of *Anguilla* (Satoh *et al.* 1962; Todd 1974; Harrell and Loyacano 1982; Beullens *et al.* 1997). Specific criteria for defining gonadal stages in this species were developed after examining a number of individuals. The maximum width of the gonad was measured with a micrometer eyepiece and these measurements were later converted to millimetres.

#### *2.3.2.2. Microscopic Observations*

A representative sample of the macroscopically staged gonads were also examined histologically. These included all of the gonads that were identified as undifferentiated, male, or silver eels of either sex, along with a random sample of macroscopically assigned Stage 1 (n=79) and Stage 2 (n=193) females. Tissue was dehydrated and embedded in paraffin wax using standard procedures. Paraffin sections 5 microns thick were cut on a rotary microtome, mounted on slides, stained with haematoxylin, counterstained with eosin, then examined at 40-100x under a compound microscope.

The classification system used in this study is adopted from terminology standardised by West (1990), and incorporates specific observations relevant to the genus *Anguilla* by Harries (1974), Todd (1974), Takashima and Hibiya (1995), Colombo and Grandi (1996), and Beullens *et al.* (1997). Testicular development was assessed on the appearance and abundance of spermatogonia, spermatocytes and interconnective tissue. Oocyte maturation was classified by assessing the comparative development of the nucleus, cytoplasm and the surrounding connective tissue. In sections where more than one stage was apparent, the sample was categorised according to the most dominant cell type present (West 1990). For gonadal tissue where the sex could not be determined, an undifferentiated stage was designated. Mean germ cell diameter was determined by measuring five of the most dominant cells from each section using a micrometer eyepiece. Measurements were later converted to millimetres. Images of gonad samples representative of each development stage were recorded using a digital video camera mounted to the photo eyepiece of an Olympus BHA compound microscope.

#### *2.3.2.3. Size and Maturity*

Relationships between body length and gonad stage characteristics were analysed using analysis of variance (ANOVA) for general linear models within the Statistica 6 (Statsoft) software package.

### *2.3.3. Results*

The gonads of 810 eels were examined, including 774 yellow eels ranging from 340 to 1149mm in length, and 36 silver eels ranging from 446 to 1423mm in length. The gonads of both sexes are comprised of a ribbon-like structure extending longitudinally along each side of the gut for the entire length of the body cavity. Undifferentiated gonads and testes extend equally along both sides. However, the ovaries are of unequal length, with the right ovary commencing further forward of the left ovary, anterior to the gall bladder. The left ovary extends posteriorly beyond the right ovary and terminates posterior to the urogenital opening. Testes are smooth on both sides and distinctly lobed, while ovaries are frilled.

As a result of macroscopic and microscopic observations, gonadal development was divided into an undifferentiated stage and three differentiated stages for both males and females. Macroscopic assessment of the developmental stage was based on the appearance, size and structure of the gonad. Figure 2.3.1 schematically illustrates the representative characteristics of each macroscopic stage. Key macroscopic characteristics of each gonad stage are summarised in Table 2.3.2. All gonads from eels that displayed morphological characteristics typical of a 'silver' eel were macroscopically classified at the final stage of development (Stage 3). While the silver eels examined in this study have 'paddle-like' tails and larger eye diameters, similar to other *Anguilla* species, the body of *A. reinhardtii* becomes more metallic bronze in appearance offset by fins displaying a dark black colouration.

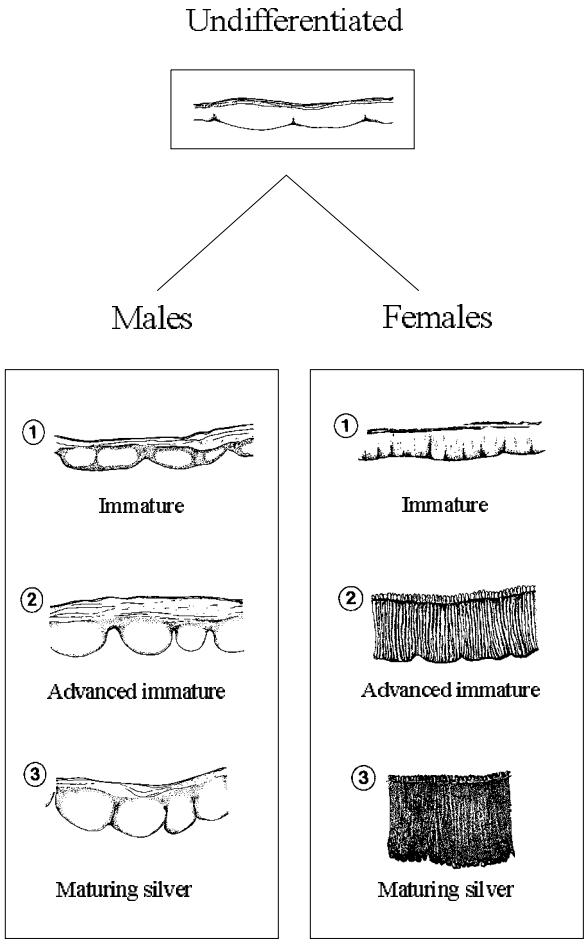


**Figure 2.3.1.** Schematic representation of macroscopic gonad stages (modified from Todd 1974;Buellens et al. 1997).

**Table 2.3.2.** Macroscopic features delineating the stages of gonad development.

| STAGE | DESCRIPTION |
|---|---|
| **Sexually** Undifferentiated | The gonad is a translucent ribbon, smooth on both sides and generally thin but variable in width. The gonad is generally uniform in density, however undulations may occur, often giving a slightly lobed appearance. However, these lobes are never distinct. Gonad width ranges from 0.6 to 2.5mm. |
| **Male** | |
| Stage 1 Immature | The gonad is a lobed ribbon, dense in structure, with distinct white opaque zones joined by clear webs of tissue. Gonad width ranges from 0.8 to 2.2mm. |
| Stage 2 Advanced Immature | The lobes are more distinct than at earlier stages. In less developed individuals the lobes may still be joined at the base, while in the more advanced individuals the lobes are separate and white in appearance. Gonad width ranges from 0.7 to 3.3mm. |
| Stage 3 Maturing Silver | This gonad conforms to the description of the organ of Syrski (Tesch, 1977), with all lobes being distinct and separate. The gonad is often pinkish to red in appearance and has an extensive vein network. At this stage of development the eels have taken on the characteristic external morphology of a 'silver' eel. Gonad width ranges from 3.6 to 6.5mm. |
| **Female** | |
| Stage 1 Immature | This gonad is an undulating ribbon, white in colour. It has a network of vein-like structures on the inner (medial) face of the gonad, with transverse ridges or ovarian lamellae on the outer (lateral) face. The gonad may be slightly lobed but lobes are never distinct. Gonad width ranges from 0.5 to 5.3mm |
| Stage 2 Advanced Immature | The gonad is a frilled ribbon, cream in colour, and pleated in larger individuals. The ovarian lamellae are very distinct and readily identify the gonad as an ovary. Gonad width ranges from 0.9 to 25mm. |
| Stage 3 Maturing Silver | This gonad is similar in appearance to a stage 2 gonad, except the features are more pronounced and the width is greater. The gonad is white to cream in colour with the pleated tissue consisting of deep folds. At this stage of development the eels have taken on the characteristic external morphology of a 'silver' eel. Gonad width ranges from 4.6 to 40.6mm. |

A total of 435 gonads were histologically prepared and examined microscopically. Changes in microscopic structure associated with gonadal differentiation and development were consistent with the macroscopically delineated undifferentiated stage and three differentiated stages for both males and females. There was no evidence of both male and female sex cells present in the same gonadal tissue, nor was there evidence of degenerating testicular tissue in the ovaries of female eels. The maximum gonadal development observed for both sexes were spermatocytes in the testes and pre-vitellogenic oocytes in the ovaries. No spermatids or spermatozoa were found in any of the Stage 3 male gonads, and no yolk globule formation was observed in any Stage 3 female gonads. Microscopic characteristics of each development stage are summarised in Table 2.3.3.

**Table 2.3.3.** Histological features delineating the stages of gonad development.

| STAGE | DESCRIPTION |
|---|---|
| **Sexually** Undifferentiated | The gonad is composed of a dense surrounding matrix of connective tissue containing primary germ cells. These cells are distinguished by their large size, faint staining, low nucleocytoplasmic ratio, and have a prominent, more darkly-staining nucleolus and clear cytoplasm. These cells either appear singularly or in clusters of up to eight cells. Cell width ranges from 4.7 to 23.5 microns. |
| **Male** | |
| Stage 1 Immature | The gonad is dominated by the presence of primary germ cells but is lobed and spermatogonia are present. The number of germ cells have increased since the first stage and now appear in crypts or cysts of up to eight cells (in section) surrounded by a less dense irregular network of connective tissue. In some gonads at an advanced state of development, light tubular structure may be developing. Cell width ranges from 1.8 to 28.2 microns. |
| Stage 2 Advanced Immature | The gonad is dominated by the presence of spermatogonia. These cells, although smaller than germ cells, are recognisable by the more compact and darker staining nucleus and cytoplasm. As opposed to the more cyst-like arrangement of germ cells, spermatogonia are found within a tubular arrangement. Cell width ranges from 1.8 to 14.1 microns. |
| Stage 3 Maturing Silver | The gonad has well defined tubules with clear lumina which have spermatocytes on their inner margin. Spermatocytes were recognised by their smaller nuclear size and darkly staining chromatin material. Cell width ranges from 1.8 to 4.4 microns. |
| Female | |
| Stage 1 Immature | The gonad is dominated by oogonia, although primary germ cells and a few isolated primary oocytes may also be present. Smaller oogonia are faintly staining and it is difficult to distinguish between them and primary germ cells, however larger oogonia have a darker coloured basophilic cytoplasm with a prominent, darkly staining nucleolus. Cell width ranges from 4.7 to 94 microns. |
| Stage 2 Advanced Immature | The gonad is dominated by primary or growing oocytes. These cells are larger in size than oogonia and are easily distinguished by their basophilic cytoplasm which is stained deeply by haematoxylin. Also attributable to this stage of cell development is the migration of multiple nucleoli to the peripheral nucleoplasm. Cell width ranges from 11.8 to 129 microns. |
| Stage 3 Maturing Silver | The gonad is dominated by the presence of vacuolated oocytes. An increase in oocyte size is associated with cytoplasm that is less basophilic and is stained blue-grey by the haematoxylin. In less mature cells small vacuoles are first observed at the periphery of the oocyte. As the gonad matures, the vacuoles gradually move towards the nucleus. Cell width ranges from 59 to 329 microns. |

*2.3.3.1. Macroscopic vs Microscopic Observation*

Table 2.3.4 summarises the accuracy of macroscopic staging, showing the proportion of samples with matching macroscopically and microscopically determined stages. Of the 435 eels that were macroscopically and histologically examined, 83 (19%) were mismatched. Immature females (Stage 1) showed the highest probability of misidentification. Upon histological examination, 64% of these were found to exhibit a more advanced stage of cell development typical of Stage 2 females. The other significant mismatch was that 33% of Stage 2 males were histologically identified as Stage 1 (immature) males. Only 10% of eels macroscopically determined as undifferentiated were later found to be male or female, but this also increased the probability of misidentifying Stage 1 males. No macroscopically determined gonads were incorrectly identified as being of the opposite sex. Neither did any of the distinctly lobed gonads contain oocytes.

It should also be noted that of the 30 female eels displaying morphological characteristics typical of a 'silver' eel, 28 contained ovaries with pre-vittellogenic cells. These cells were the most advanced found in ovarian tissue. Only eight macroscopically determined immature eels (3%) displayed pre-vitellogenic oocytes on histological examination.

**Table 2.3.4.** Accuracy in sex determination comparing macroscopic versus microscopic (histological) stages of development.

| Gonad stage | n | % non match |
|---|---|---|
| Undifferentiated | 70 | 10 |
| **Male** | | |
| Stage 1 | 44 | 4 |
| Stage 2 | 12 | 33 |
| Stage 3 | 7 | 0 |
| **Female** | | |
| Stage 1 | 80 | 64 |
| Stage 2 | 192 | 8 |
| Stage 3 | 30 | 7 |
| Total/mean | 435 | 19 |

*2.3.3.2. Size and Maturity*

There was a high degree of overlap of body size ranges between each stage of development, particularly between the undifferentiated and Stage 1 male eels. Figure 2.3.2 illustrates the relationship between mean body length and stage of gonadal development for males and females. A factorial analysis of variance (ANOVA) showed that mean lengths are significantly different between sexes and among development stages ($F=33.42$, $p < 0.001$). A post-hoc HSD multiple comparison test showed that mean lengths of females increased significantly with each developmental stage ($p<0.001$), but mean lengths of males were not significantly different among stages ($p>0.5$).

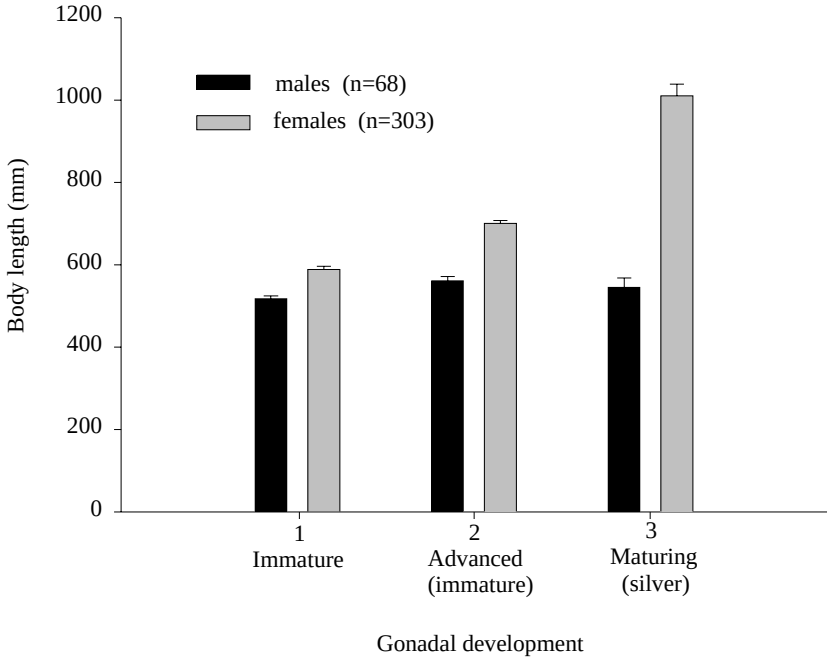


**Figure 2.3.2.** Mean body size (± standard error) for each histologically determined gonad development stage.

Table 2.3.5 compares the size and gonad stage data of both undifferentiated and female eels between freshwater and tidal areas. Males were not included as they were not found in significant numbers in the freshwater areas. A factorial analysis of variance (ANOVA) showed that both mean body lengths (F=0.38, p=0.77) and mean cell widths (F=0.41, p=0.74) of each development stage did not differ significantly between freshwater and tidal areas. However, mean lengths at each development stage were consistently higher in the freshwater samples.

**Table 2.3.5.** Comparison of body length and cell size of each development stage for freshwater and tidal areas (undifferentiated individuals and females only).

| Gonad stage | Body length (mm) | | | Cell width (mm) | |
|---|---|---|---|---|---|
| | Range | Mean | n | Range | Mean |
| **Freshwater** | | | | | |
| **Undiff.** | 500-584 | 543 | 8 | 9-14 | 12 |
| **Stage 1** | 568-590 | 632 | 9 | 7-21 | 14 |
| **Stage 2** | 548-1153 | 735 | 54 | 14-235 | 42 |
| **Stage 3** | - | 810 | 1 | 117- 145 | 129 |
| **Tidal** | | | | | |
| **Undiff.** | 379-606 | 516 | 53 | 4-20 | 12 |
| **Stage 1** | 469-632 | 574 | 29 | 4-20 | 16 |
| **Stage 2** | 510-1139 | 684 | 171 | 11-129 | 42 |
| **Stage 3** | 735-1070 | 844 | 5 | 94-148 | 144 |

The upper end of the length frequency distribution for males overlaps with the lower end of the female length frequency distribution in the length range of 47 to 62cm (Figure 2.3.3). The mean size of Stage 1 females (59cm) and males (52cm) appears to provide a reasonable estimate of mean size at differentiation. The value for females provides a good reference point for separating the sexes, with 87% of the females being larger, and 94% of the males being smaller in length. The minimum size of Stage 3 males (44cm) and females (74cm) is our best approximation of the smallest size at migration. However, the indication is that maturation occurs over a wide size range and given a sufficiently large sample size, the minimum size at migration would probably decrease further.

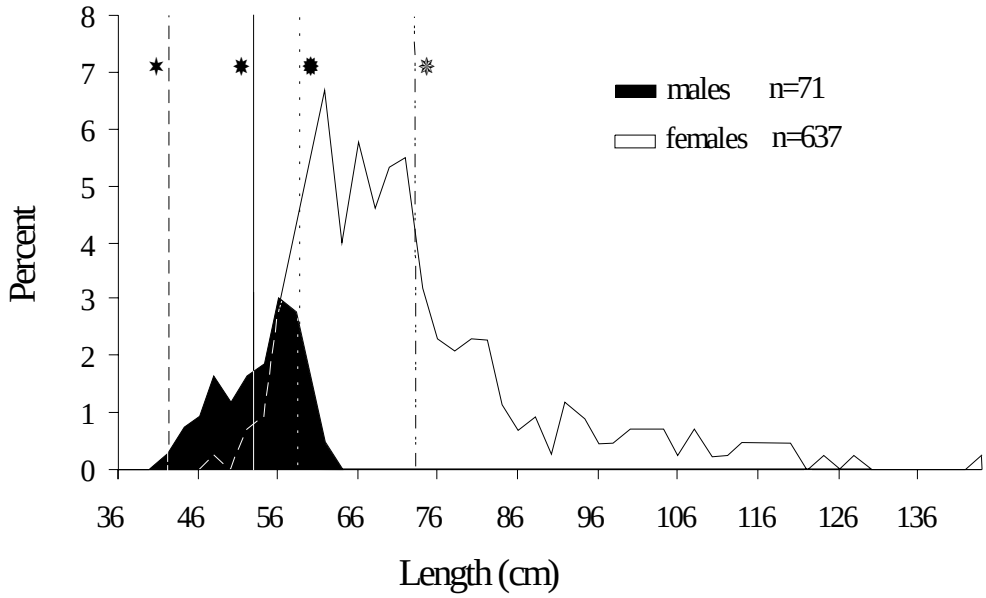


**Figure 2.3.3.** Length frequency distribution of male and female *A reinhardtii*, where sex was determined macroscopically. ① mean length (S1 males) = 52cm; ② minimum length (S3 males) = 42cm; ③ mean length (S1 females) = 59cm; ④ minimum length (S3 females) = 74cm.

### *2.3.4. Discussion*

The developmental stages for the testes and ovaries of *A. reinhardtii* were typical of those observed for other species of anguillid eels (Satoh *et al.* 1962; Todd 1974; Tesch 1977; Krueger and Olvieira 1997; Beullens *et al.* 1997). Macroscopically, all male eels contained gonads which appeared as a lobed organ of Syrski. These lobes were contiguous, with no overlap except for migrating (silver) individuals. A dissecting microscope proved necessary for accurate sex identification, particularly for smaller individuals. There were many gonads that displayed a slightly lobed appearance and texture similar to that of males; however, as these attributes were not distinct, they were macroscopically assessed as undifferentiated. The gonadal morphology displayed by silver eels was different from that of immature eels, with appearance and size being more accentuated. Histologically, males were assessed on the presence of male sex cells - spermatogonia and spermatocytes. This study found no evidence of spermatid formation in *A. reinhardtii*, including a migrating specimen captured in the ocean offshore from Queensland. Spermatids have been found in wild silver males of *A. anguilla* and *A. dieffenbachii* (Boetius and Boetius 1967; Todd 1980). This indicates that *A. reinhardtii* males may migrate at an earlier stage of gonadal development than some of the other anguillid species.

Macroscopically, all females had gonads which appeared as frilled ribbons, which are characteristic of anguillid ovaries (Tesch 1977). In the ovaries of smaller individuals (<600mm) these features were not as pronounced; however, they were slightly pleated, with a network of veins similar to that found in immature female *A. dieffenbachii* ovaries (Todd 1974). Ovaries that displayed no signs of pleating were assessed as undifferentiated. Most ovaries were readily identifiable with the naked eye, and like the male testes, the morphology of the silver stage eel ovaries demonstrated more accentuated features. As with the males, most of the gonads contained representations of all sex specific cell types at varying stages of development. Females were assessed on the presence of the female sex cells: oogonia, primary oocytes, and pre-vittellogenic oocytes.

There was no evidence of females with ovaries in the yolk (vittellogenic oocyte) stage, even in a migrating specimen caught several kilometres offshore in the ocean. This indicates that a considerable amount of further sexual development is needed before spawning can take place. Egg diameters and histological examination of the gonads showed that female *A. reinhardtii* were significantly less sexually developed than either *A. rostrata* or *A. dieffenbachii* at the silver eel stage (Wenner and Musick, 1974; Todd 1981; Lokman *et al.* 1998). Studies of these latter two species have revealed significant numbers of female silver eels with oocytes at the early to mid vitellogenic stage. The degree of difference in sexual development between angullid species at migration may be related to the distance which needs to be travelled to reach the spawning grounds (Wenner 1973; Tesch 1977). The relatively early development stage of both male and female *A. reinhardtii* migrating from New South Wales, may indicate that these individuals need to travel further or take longer to reach their spawning grounds than some of the other anguillid species. Further studies comparing the histology, egg size, and gonosomatic index (GSI) between populations of *A. reinhardtii* at both southern and northern latitudes may provide more evidence in relation to this hypothesis.

Validation of macroscopic observations using histological techniques showed that sexes were accurately identified when eels were larger than 600mm in body length. For smaller eels, particularly those under 600mm in length, a dissecting microscope is necessary. Another alternative is to determine their sex using the aceto-carmine squash technique (Guerrero and Shelton 1974). Krueger and Oliviera (1997) used this technique successfully on *A. rostrata*, although these specimens were larger migrating silver eels.

Assessing gonadal development at the level of Stage 1 and 2 was much less accurate. There was evidence of some gonads, in particular those of some immature females (64%), exhibiting a more advanced stage of development when determined histologically. This was attributable to the similarity in external appearance of the gonad between the three stages of female sexual development. Gonad widths and extent of pletation were highly variable for each stage and thus may not be precise indicators of sexual development. The high probability of error in macroscopically identifying the first two stages of development, particularly Stage 2 females (Table 2.3.4), indicates that determination of some sex-related characteristics, such as size at sexual differentiation, should be based on histological examination. However, size at migration for both males and females can be accurately assessed using macroscopic observations.

Of the 75 lobed gonads examined in this study, none contained oocytes. There was also no evidence of both male and female sex cells being found in the same gonad tissue of either male or female type gonads. The lobed organ being diagnostic of maleness, and the lack of an intersexual stage is consistent with findings for the Japanese (Satoh *et al.* 1962) and the New Zealand eel species (Todd 1974). However, the European (Sinha and Jones 1966; Buellens 1997; Grandi and Colombo 1997) and American (Dolan and Power 1977) eel species have been shown to exhibit intersexual characteristics. This indicates that the basic nature of sexual development probably differs among anguillid species.

Evidence from this study could be interpreted superficially to indicate that *A. reinhardtii* is protandrous, with mature males reaching a certain size and then changing sex. However, the most conclusive evidence for protandry is the occurrence of transitional individuals with gonads containing degenerating testicular tissue and developing ovarian tissue (Sadovy and Shapiro 1987). No such evidence of this type of gonadal structure has been found in other anguillids or amongst the eels examined in this study.

Body length varied greatly within each development stage (Table 2.3.5). For undifferentiated eels this is probably due to the large difference between the mean size at sexual differentiation of males compared to females. Also, both males and females reach Stage 3 of maturation over most of the length range between the size at differentiation and the maximum length of the males and females in the populations, respectively. Gonadal development in females increased significantly with average body length, while those of males did not (Fig. 2.3.2). A proportion of the females in the population continue to grow to a maximum size of almost three times the mean size at sexual differentiation, whereas males attain a maximum size which is only about 1.2 times the mean size at sexual differentiation.

Some of the variability in sizes associated with developmental stages may be associated with variable growth in the huge range of habitats that this species occupies. The samples for this study were collected from a wide range of freshwater and tidal estuarine habitats. However, there were no significant differences in gonadal development characteristics apparent when eels from freshwater habitats were compared with eels from tidal habitats (Table 2.3.5).

The mean size of Stage 1 individuals appears to be a useful indicator of size at sexual differentiation for both sexes. The estimated size for males may be a little higher than the actual size at sexual differentiation because of the under-sampling of the bottom end of the size range, due to selectivity of meshes in the traps and fyke nets used for most of the sample collections. This selectivity may also be one factor responsible for the extremely low ratio of males to females observed in this study. However, the consistent results of the relatively unbiased electrofishing method indicate that selectivity is probably not the primary cause of the low proportion of small eels in this study. We believe the low numbers of small eels (including males) are due mostly to size-related habitat preferences, and that they are more abundant in shallower habitats than the larger eels (Cairns 1941; Chisnall 1996; Glova 2001).

The almost complete separation of the sizes between males and females (Fig. 2.3.3) indicates that size is a reliable indicator of sex. This is typical of other anguillid species that have been studied extensively (Table 2.3.6). Bimodal size distributions may be attributable to differences in migration and/or growth rates, as well as spatial segregation of the sexes (Sadovy and Shapiro 1987). There is a common belief in anguillid research that the female reproductive strategy is to promote size rather than to minimise generation time (Svedang *et al.* 1996; Helfman *et al.* 1987). In contrast, Helfman *et al.* (1987) suggested that males may maximise fitness by growing rapidly to a sufficient size ready for migration. The literature suggests that skewed sex ratios at any one location, and hence the spatial distributions of males and females of most anguillids studied may be a result of environmental factors associated with different habitat preferences (Helfman *et al.* 1987; De Leo and Gaetto, 1996; Peterson *et al.* 1996; Krueger and Oliviera 1999).

Table 2.3.6 summarises the general size range of individuals examined at both differentiation and migration for five species of anguillids, including the data for *A. reinhardtii* generated from this study. The two temperate species from the northern hemisphere, *A. anguilla* and *A. rostrata*, as well as the Australasian shortfin species, *A. australis*, show similar lengths at both differentiation and migration. Our results show that biological attributes of *A. reinhardtii* are most similar to those of the New Zealand longfinned eel (*A. dieffenbachii*). This is reflected in the fact that these two

species do not sexually differentiate and migrate until they reach lengths considerably larger than those attained by most of the other anguillids that have been studied.

**Table 2.3.6.** Comparative lengths at sexual differentiation and migration for various species of *Anguilla*.

| Species | Sex | Body length (cm) at | | References |
|---|---|---|---|---|
| | | Differentiation | Migration | |
| *A. anguilla* | m | 25 - 33 | 32 - 46 | Colombo et al. (1984) |
| | f | 20 - 52 | 42 - 65 | |
| *A. rostrata* | m | 21 - 32 | 30 - 40 | Helfman et al. (1987) |
| | f | 16 - 35 | 50 - 80 | Barbin & McCleave (1997) |
| *A. australis* | m | 27 - 48 | 38 - 55 | Todd (1974), Todd (1980) |
| | f | 32 - 49 | 56 - 93 | |
| *A. dieffenbachii* | m | 33 - 65 | 48 - 72 | Harries (1974), Todd (1980) |
| | f | 42 - 64 | 73 - 157 | |
| *A. reinhardtii* | m | 42 - 60 | 44 - 62 | Present study |
| | f | 50 - 76 | 74 - 142 | |

In his early studies on the phylogenetic relationships between anguillid eels, Ege (1939) postulated that species with a short dorsal fin, and those without variegated markings on their bodies, were derived from a common ancestor. However, recent molecular phylogenetic studies presented on anguillid eels by Aoyama *et al.* (2001), suggest that, although morphological features are suitable for species classification, they are not a reflection of phylogenetic relationships. These two studies show that *A. reinhardtii* is the least related ancestrally amongst the other eel species represented in Table 2.3.6. The differences in sexual development and size at differentiation and migration found between *A. reinhardtii* and other anguillids may be a reflection of these phylogenetic relationships.

This study clearly demonstrates the similarities and differences in sexual development between *A. reinhardtii* and other anguillid species. For this species there are significant differences between the sexes in relation to gonadal development and body size. Males are much smaller and mature over a narrower size range than females. Males were found almost exclusively in tidal estuarine habitats, while females were found in all freshwater and estuarine habitats sampled during the study.

## 2.4. Tagging, Age Validation and Movement

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### *2.4.1. Introduction*

Age and growth rate are key life history characteristics controlling the productivity of fish populations and estimates of these parameters are needed for assessing stocks of longfinned eels in the coastal catchments of eastern Australia (Walford and Pease 2000). Estimates of age are essential, because growth and mortality rate estimates are based on age information. It is generally acknowledged that analysis of otoliths provides the best estimate of age for many teleost fish species (Campana and Thorrold 2001) and otoliths have been used to age anguillid eel species for at least eighty years (Jellyman 1979). Sloane (1984a) used otoliths to age Australian longfinned eels in Tasmania, Australia, the southern limit of the known range for this tropical species (Schmidt 1928). Annual periodicity of otolith structures in this species was inferred from marginal increment formation.

Aging techniques must be validated for each species and life history stage that they are applied to (Beamish and McFarlane 1983; Campana 2001). This is particularly true for anguillid eels because age validation studies have shown that supernumerary (sometimes called “false” or “incomplete”) growth checks are often present in the otoliths of European, *Anguilla anguilla* (Deelder 1981; Berg 1985; Vero *et al.* 1986); American, *A. rostrata* (Liew 1974; Oliviera 1996); African, *A. mossambica* (McEwan and Hecht 1984); Japanese, *A. japonica* (Guan *et al.* 1994); Australian shortfinned, *A. australis* and New Zealand longfinned, *A. dieffenbachii* (Graynoth 1999) eels. Environmental and population factors may also cause growth characteristics and associated otolith microstructure to differ greatly among individuals, as observed for the European eel (Panfili *et al.* 1994; Holmgren 1998).

An understanding of mobility in eel populations is also important when evaluating growth characteristics. Most growth studies assume that yellow eels are resident in one habitat for most of their lives, however there is no available information on home range and movement of this species.

The primary aim of this component of the study was to validate otolith age estimates of yellow-phase Australian longfinned eels using both laboratory and field marking and tagging techniques. A secondary aim of the laboratory study was to estimate mortality and tag loss rates for marked and tagged eels. A secondary aim of the field study was to investigate movement of this species within and between flowing freshwater and tidal estuarine habitats based on recapture of tagged eels during the age validation study.

### *2.4.2. Methods*

#### *2.4.2.1. Laboratory Study*

Two size ranges of yellow-phase longfinned eels were used in the laboratory experiment to examine otolith increment periodicity under controlled conditions. Twenty-seven small eels ranging from 420 to 650 mm in total length (382 mm mean length) were obtained from an aquaculture facility at Repton, NSW. The eels had been captured as elvers and small, pigmented yellow eels then reared in fiberglass tanks using recirculated tidal water from the Bellinger River.

A second batch of 35 larger eels ranging from 452 to 971 mm in total length (676 mm mean length) were obtained from a commercial eel fisher. The eels had been recently captured in tidal waters of the Macleay River. The two batches of eels were transported to the experimental fish holding and

rearing facilities at the Fisheries Research Institute (FRI), Cronulla, NSW. At FRI, the two batches of eels were placed in two separate 5000 litre fibreglass tanks and slowly acclimated to ambient water from Port Hacking over a 48 hour period. Water in the flow-through system at FRI varies in salinity from 30 to 35 parts per thousand and temperatures vary seasonally from 15 to 24 degrees centigrade. Both tanks were outside under a sheltering roof so that the eels were exposed to reduced sunlight in the local diurnal cycle. Throughout the experiment the eels in each tank were fed a maintenance diet of commercially manufactured (Kinta Proprietry Limited) pellets and frozen pilchards (*Sardinops neopilchardus*).

After acclimating and holding the eels with no mortalities for 3 weeks, 22 of the cultured and 30 of wild eels were randomly selected and removed from the holding tanks on October 8, 1998. These eels were individually anaesthetised in 20 liters of ambient water containing 100 mg/l benzocaine (ethyl-p-amino benzoate). Each eel was weighted and measured (total body length), then injected intraperitoneally with 100 mg of oxytetracycline (OTC) per kilogram of body weight. The OTC was injected as buffered liquid Engemycin 100 (manufactured by Intervet Proprietry Limited, Castle Hill, NSW, with 100 mg/l oxytetracycline hydrochloride) in order to mark the otoliths.

Each eel was tagged externally with one T-bar anchor tag before putting it into 20 litres of ambient water in a recovery tank. Tags were inserted through the base of the dorsal fin rays, several centimeters from the anterior end, using a Dennison tagging gun. Hallprint fine T-bar anchor tags (TBF) with a 15 mm filament length were used on eels weighing less than 500 g. Hallprint standard T-bar anchor tags (TBA) with a 19 mm filament length were used on eels weighing more than 500 g. Both tags terminated with a 1 mm diameter orange marker 30 mm long with a unique, printed alphanumeric code.

After each marked and tagged eel recovered from the anaesthetic, it was replaced in the 5000 litre tank it had been removed from. The five eels which remained in each tank without any marks or tags were considered to be experimental controls for assessing mortality rates. There were no mortalities on the day that the eels were marked and processed, but all subsequent mortalities were frozen for later processing along with information about the mortality date and tank of origin. The number of eels which had shed their tags was recorded every two months for the first eight months (12/9/98, 2/16/99 and 4/27/99), every 3 months for the second six month period (9/7/99 and 12/9/99) and for the final time 18 months from the start of the experiment (4/7/00). One of the large tagged eels and two of the small tagged eels were processed after 8 months. All of the small eels and all but four of the large eels remaining after 18 months were processed. The three remaining large eels were finally processed on June 6, 2001, 32 months after the experiment started.

Live eels to be processed were euthanased in 200 mg/l benzocaine. Recently euthanased eels and thawed mortalities were processed as follows: 1) total body length and weight were measured 2) sex and reproductive development stage were estimated from macroscopic examination of the gonads (Chapter 2.3), 3) a sample of the gonad was removed, fixed in a buffered formalin fixative (10% strength FACC) then preserved in 70% ethanol solution for later histological examination (Chapter 2.3) and 4) the sagittal otoliths were removed, cleaned with fresh water and stored dry with no exposure to UV light.

### *2.4.2.2. Field Study*

Longfinned eels were also marked, tagged and recaptured in the field in order to verify annual periodicity of otolith growth intervals across the entire age range of commercially captured eels. Yellow eels from a wide range of freshwater and tidal estuary habitats were tagged and recaptured in the Hacking, Hawkesbury, and Clarence River catchments from November 1998 to February 2002 as described in Chapter 2.1.

The marking, tagging and releasing of eels in the field occurred at the capture location. Because of the potential for human consumption, these eels were anaesthetized in 20 l of ambient water with 100 mg/l clove oil (Walsh and Pease 2002) rather than benzocaine. Other than the anaesthetic, the marking and tagging procedure was the same as that used in the laboratory experiment. Along with the unique identification code, contact details were printed on all anchor tags so that eels recaptured by commercial and recreational fishers could be returned. All eels recaptured by our fishery independent sampling or by commercial or recreational fishers were processed in the same manner as those in the laboratory experiment.

In order to look at the size of eels when the first otolith increment is formed, we examined otoliths from a sample of 14 fully pigmented longfinned eels ranging in size from 66 to 187 mm in total length. These eels were incidentally captured in habitat collectors (Silberschneider *et al.* 2001) placed below tidal barriers in the Illawarra, Hacking, Manning and Tweed catchments from 1998 through 2001 as part of a major study of glass eel recruitment in New South Wales (Pease *et al.* 2003a). The eels were euthanased in 100 mg/l benzocaine then placed in 95% ethanol at the capture location. In the laboratory, total length of each eel was measured to the nearest millimeter, weighed to the nearest thousandth of a gram, then both sagittal otoliths were removed, cleaned and stored dry.

### *2.4.2.3. Otolith Preparation*

The best (undamaged) available otolith of each pair from eels greater than 187 mm in length was selected and weighed. The otolith was placed on a light box and the location of the opaque nucleus was marked on the convex side using a 0.1 mm felt pen then embedded in an Epofix resin block. An Isomet circular saw fitted with a single diamond blade was used to produce a 1 mm thick section by making two transverse cuts on either side of the nucleus. The resulting transverse section was attached to a glass slide with thermoplastic glue then ground to the nucleus with 1200 grit wet polishing paper using a Struers “Labopol” polishing machine. Once the interior of the nucleus was reached, the section was polished with 400 grit wet polishing paper then 9 micron lapping film in the polishing machine. The slide was then heated and the section was turned over and affixed to a slide with the polished face down. The exposed face was then ground to the nucleus and polished as described above. The thickness of the resulting sections ranged between 0.1 and 0.3 mm. Otoliths that had been marked with OTC were not etched and were stored in a dark place to ensure maximum intensity of the fluorescent mark. Unmarked otoliths were etched for one minute in 5% ethylenediaminetetraacetic acid (EDTA). All sections were then mounted with a cover slip in Safety Mount.

Otoliths from small eels 74 to 187 mm long were attached to a glass slide with thermoplastic glue then ground to the nucleus in the sagittal plane using the grinding techniques described above. These sagittal sections were not etched before attaching a cover slip. Whole otoliths from small eels less than 74 mm long were simply mounted in glycerine under a cover slip on a glass slide.

#### *2.4.2.4. Otolith Reading*

In order to determine periodicity of growth intervals, the outer margin and last 3-4 suspected annual growth increments of all OTC marked otoliths were examined with a compound microscope under a combination of UV and reflected light using 40-100x magnification. A computer-based image capturing system was used to measure the distances between the margin, each opaque (white) annulus and the fluorescent OTC mark. The readability of opaque annuli was graded from 0 to 3, where 0 was no confidence that opaque annuli could be distinguished, 1 was readable but ambiguous, 2 was readable with no ambiguity and 3 was excellent readability suitable for reference pictures. The intensity of the fluorescent mark was graded from 0 to 2, with 0 indicating no evidence of a fluorescent mark, 1 indicating the mark was faint and/or discontinuous and 2 indicating that the mark was distinct and continuous. Evidence of an opaque ring forming on the margin was also noted. During all otolith reading operations, readers were not supplied with information about where and when the eel was captured.

In order to study the formation of the first annulus in relation to body length, opaque (white) zones between the marine nucleus and the outer margin of otoliths from the small eels (66-187 mm in length) were examined using a compound microscope under reflected and transmitted light with magnifications of 40-100x. In order to assess further otolith growth in relation to body size, a regression analysis of otolith weight versus body length was conducted for all eels from fishery independent and dependent sampling in the Hacking, Hawkesbury and Clarence River catchments, where otoliths were collected and weighed.

Further experiments were conducted to determine whether reading with reflected or transmitted light provides the most precise age estimates and to compare the precision of multiple readers. The OTC marked otoliths described above along with additional otoliths sampled from eels in commercial catches from the Hacking, Hawkesbury and Clarence Rivers (Chapter 2.1) were aged by two readers. In the first test, one reader used reflected light and the other used transmitted light to read the same set of otoliths. In the second test, both readers used reflected light to read the same set of otoliths. Bias plots and coefficients of variation (CV's) (Campana *et al.* 1995) were used to analyse the reader precision during each test. A t test was used to compare mean coefficients of variation. The data was normalized with a $\log_{10}(x+1)$ transformation, however it was not possible to equalize the variances. The analysis was done anyway because numerous studies have shown that the t test is robust enough to stand considerable departures from its theoretical assumptions, especially if the sample sizes are equal and a two-tailed hypothesis is considered (Zar 1974). In order to further assess the variability of age estimates and to determine whether otolith growth is constant throughout the age range of eels sampled during this study, a regression analysis of otolith weight versus age was conducted for all eels from fishery independent and dependent sampling in the Hacking, Hawkesbury and Clarence River catchments, where otoliths were collected and weighed. All of the statistical analysis was done using Statistica version 6 (Statsoft, Inc.) with $p < 0.05$ considered significant for all hypothesis testing.

### ***2.4.3. Results***

#### *2.4.3.1. Otolith Characteristics*

Figure 2.4.1a shows the features of a transverse otolith section as seen under reflected light against a dark background. The marine nucleus appears as an opaque (white) mass at the central core of the otolith. The transition ring, sometimes referred to as the freshwater check, often appeared as the first complete opaque ring outside but near the marine nucleus. It was not visible on all otoliths. Annual increments outside the nucleus and transition check were composed of a relatively broad

translucent (dark or black in color under reflected light) growth zone followed by a narrower, continuous, opaque (pale or white in color under reflected light) ring which was counted as a winter annulus. Under transmitted light the growth zones became clear and the annuli became black. Counts were generally made along the numbered axis in Figure 1a. Opaque (pale or white in color under reflected light) supernumerary checks were often observed in the summer growth bands, usually near the winter annuli. The supernumerary checks were less distinct and generally narrower than winter annuli and did not extend continuously around the otolith (often not visible on the dorsal axis).

Figure 2.4.1b shows the white OTC mark on the proximal margin at the ventral end of the otolith in Figure 2.4.1a under reflected UV and visible light. The margin in this example appears to be opaque (white) and is considered to be a marginal annulus, and will be referred to as AM. The increment from the margin to the previous annulus A(M-1) is referred to as M. The first annual increment inside M (toward the marine nucleus) is referred to as M-1 and the annual increment inside M-1 is referred to as M-2. Distances between the margin (AM in this example), annuli (A(M-1) and A(M-2)) and the OTC mark were measured along the dashed line, generally perpendicular to each of these structures.

*2.4.3.2. Laboratory Study*

Mortality and tag loss rates of eels during the first six month period (October 1998 to April 1999) and a second six month period (June to December 1999) are summarized in Table 2.4.1. Mortality rates for each treatment group were calculated simply as the proportion of eels at the start that died during the six month period. Mortality rates of the small eels remained constant at about 0.2-0.25. Mortality rates of the large eels were lower, varying from 0 to 0.2. There was no significant difference between mortality rates of tagged eels and control eels (Chi-square = 0.02;P>0.05). Tag loss rates for each size of tagged eels were calculated as the percent of eels at the start that lost tags during the six month period. Tag loss rates of the small eels were generally higher than loss rates of the larger eels. Tag loss rates of both large and small eels were high (0.27-0.33) during the first six months but were much lower (0.06-0.14) during the second period. However, these differences were not significant (Chi-square=0.39;P>0.05 for size groups and Chi-square=2.39;P>0.05 for periods).

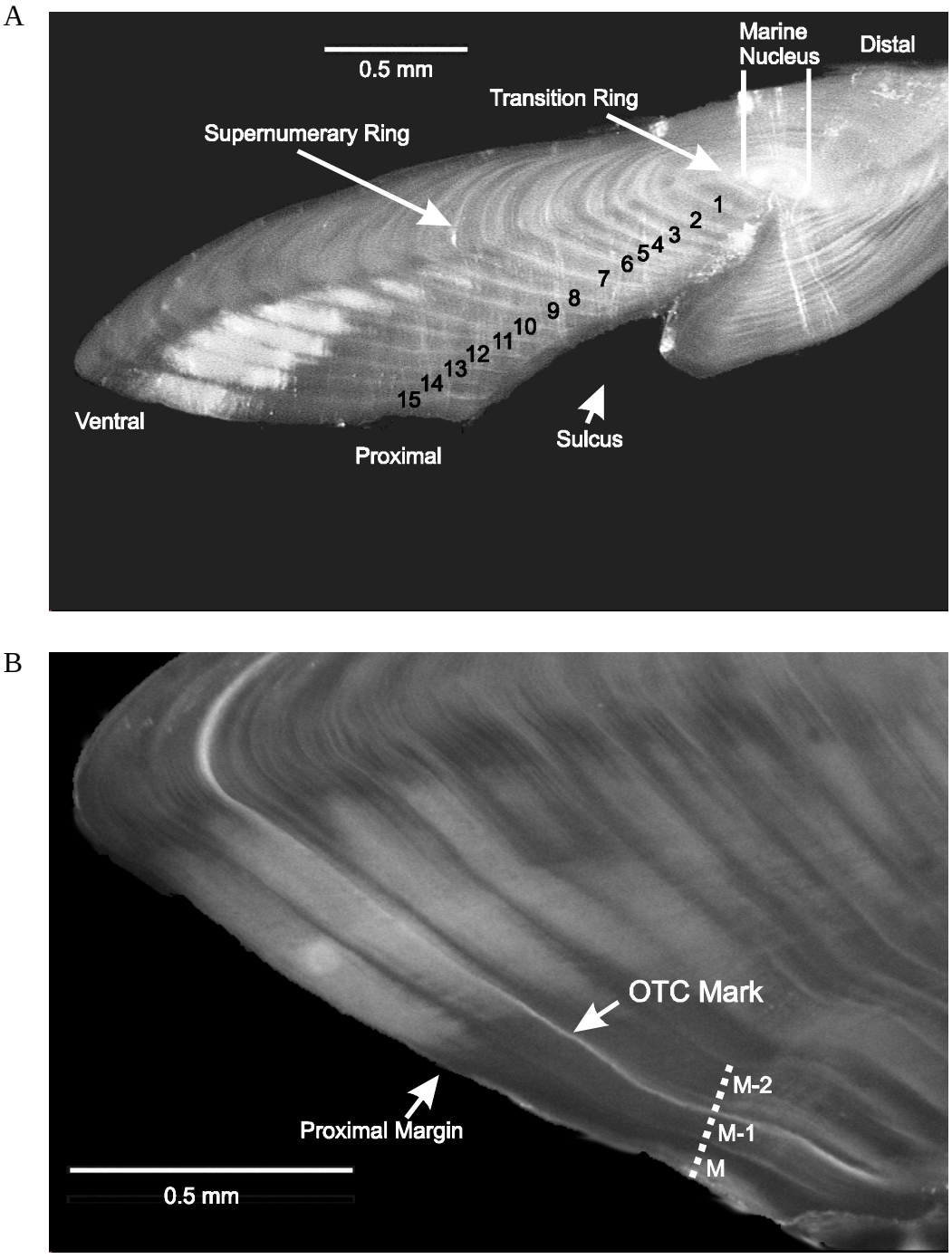



**Figure 2.4.1.** A) Etched, thin section of a longfinned eel otolith viewed under reflected light. Black numbers on opaque, white annuli indicate estimated age with alignment showing axis which ages were read along. B) Further magnified view of proximal margin of otolith shown in 1a with OTC mark visible under UV light. Dotted line shows axis for measuring distances between the margin, annuli, and the OTC mark within annual increments M, M-1 and M-2. Note that opaque, white margin indicates annulus formation.

**Table 2.4.1.** Mortality and tag loss (proportion) of eels in each treatment during Period 1 (10/8/98-27/4/99) and Period 2 (6/16/99-12/9/99) of the laboratory experiment.

| | Period 1 | | Period 2 | |
|---|---|---|---|---|
| Treatment | Mortality | Tag loss | Mortality | Tag loss |
| Small tagged eels | 0.23 | 0.33 | O.23 | 0.14 |
| Small control eels | 0.20 | NA | 0.25 | NA |
| Large tagged eels | 0.00 | 0.27 | 0.18 | 0.06 |
| Large control eels | 0.20 | NA | 0.00 | NA |

The marginal area of all otoliths from the laboratory experiment were readable but there was no sign of an OTC mark on 23% of them. Figure 2.4.2 summarizes formation of opaque annuli in relation to otolith growth subsequent to OTC marking. The linear regression was significant ($R^2$ =0.79, F=120, p<0.001). With the exception of one otolith that had not yet formed an annulus 14 months after tagging, one annulus was formed on all other otoliths each year subsequent to the tagging event. The otoliths collected during the first two years of the study show that annuli apparently formed between August and November. Further evidence that most annuli are generally formed during this period is that 20% of the OTC marks occurred on the 1998 annulus, indicating that these annuli were being formed during the October tagging event. The other 80% of OTC marks occurred within the first 38% of the 1999 annual increment, indicating that the 1998 annulus was formed during the three or four month period prior to the tagging event.

All of the eels in the small treatment were found to be males. Eels in the large treatment were found to be females, except for one male and one undifferentiated individual. There was no obvious difference in growth characteristics between the two sexes.

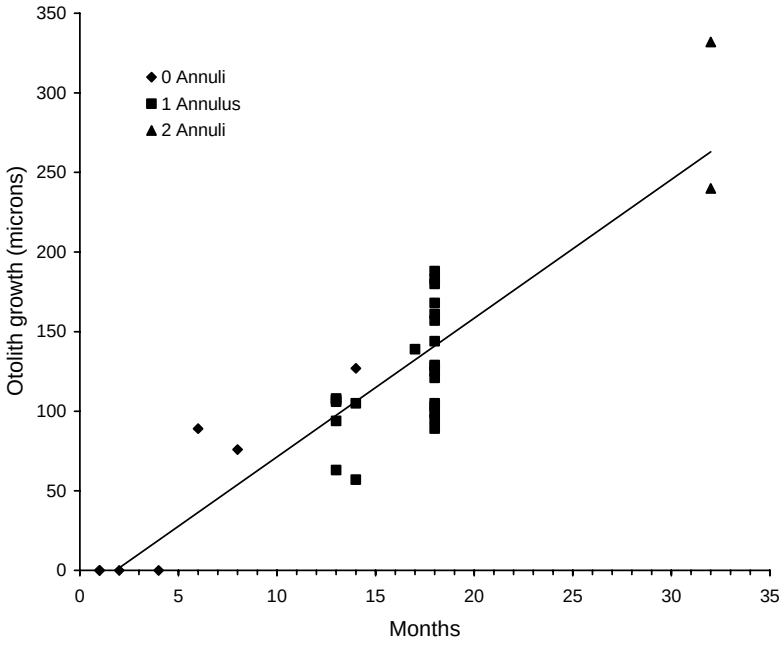



**Figure 2.4.2.** Otolith growth measured as the distance along the axis shown in Figure 2.4.1b, from the OTC mark to the margin in otoliths from the laboratory experiment. Month 0 is the start of the experiment on 8/10/98 and month 32 is the end of the experiment on 6/4/01.

*2.4.3.3. Field Study*

The numbers of eels tagged and recaptured in each catchment during each year of the study period are summarized in Table 2.4.2. A total of 161 of the 877 tagged eels were recaptured, giving an overall recapture rate of 18%. The recapture rate varied considerably between catchments, from a high of 26% in the Hacking to a low of 7% in the Clarence. Most (111) of the recaptured eels were collected during our fishery independent sampling operations. All of the recaptures in the Hacking catchment were collected in this manner, but 49% of the recaptures from the commercially fished Hawkesbury and Clarence catchments were collected by commercial fishers or recreational fishers.

**Table 2.4.2.** Number of eels tagged and percent recaptured within catchments and zones.

| | Hacking | | Hawkesbury | | Clarence | |
|---|---|---|---|---|---|---|
| Zone | No. Tagged | % Recaptured | No. Tagged | % Recaptured | No. Tagged | % Recaptured |
| Fresh water | 165 | 27 | 127 | 10 | 93 | 11 |
| Upper tidal | NA | NA | 218 | 32 | 129 | 5 |
| Lower tidal | 75 | 24 | 20 | 0 | 38 | 3 |
| All zones | 240 | 26 | 365 | 22 | 260 | 7 |

All of the tagged eels that were recaptured during fishery independent sampling were recaptured at the sites where they were originally tagged, which indicates that they had not moved more than 100-300 m. In the case of recaptures by commercial and recreational fishers we can be confident about which zone they were recaptured in but not the specific recapture location. All except two of the tagged eels that were recaptured by commercial and recreational fishers were recaptured in the same zones where they had been tagged. One immature female that had been tagged at a freshwater site in the Hawkesbury River was recaptured seven weeks later by a commercial fisher in the upper tidal zone, indicating that this eel had moved downstream at least 65 km. Another immature female was tagged at a freshwater site in the Clarence River and was recaptured 67 weeks later by a commercial fisher in the upper tidal zone, also indicating that this eel had moved downstream at least 45 km from the tag site.

Table 2.4.3 summarizes the otolith growth of all recaptured eels which had been at large for at least six months, had a visible OTC mark on the otolith, an otolith readability greater than zero and had not moved between zones subsequent to tagging. Twenty percent of the otoliths had no visible mark and 3% were unreadable. The table displays growth information for the three annual increments at the margin as shown in Figure 1b. Each annual increment is divided into four zones from left to right, where the first three zones (G1 to G3) are three equal sections of the translucent growth zone. For the marginal increment (M) the size of each growth zone (G1 to G3) is estimated to be the same as the size of each growth zone in the previous increment (M-1). For annual increments M-1 and M-2, the three growth zones are followed by the location of the opaque annulus. For the marginal increment, the growth zones are followed by the location of the marginal annulus (AM) if the margin was opaque or the location of the margin when it is at least as wide as the previous annual increment (M-1) if it was not opaque.

**Table 2.4.3.** Month and year eels were marked (left hand column) and recaptured (right hand column) in columns indicating location on the otolith within annual increments M-2 to M (Fig. 1), listed by catchment and zone (FW = fresh water, UT = upper tidal and LT = lower tidal). Locations within increments are shown in three growth zones (G1-G3), annuli (A(M-2) to AM) or estimated complete annual margin (AI M-1). Month/year eels marked or recaptured during annulus formation is given in parentheses. Number of otoliths with identical data is given in column labelled "No.".

| | | | Annual Increment M-2 | | | | Annual Increment M-1 | | | | Annual Increment M | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Catchment | Zone | No. | G1 | G2 | G3 | A(M-2) | G1 | G2 | G3 | A(M-1) | G1 | G2 | G3 | AM/AI M-1 |
| Hacking | FW | 1 | | | | | | | | | 11/98 | | 10/99 | |
| Hacking | FW | 1 | | | | | | | | (11/98) | | 10/99 | | |
| Hacking | FW | 3 | | | | | | | | (11/98) | | | 10/99 | |
| Hacking | FW | 1 | | | | | | | | | | 10/99 | | 04/00 |
| Hacking | FW | 1 | | | | | | | | (10/99) | | 04/00 | | |
| Hacking | FW | 1 | | | | | | | | (10/99) | | | 04/00 | |
| Hacking | FW | 1 | | | | | | | | (03/99) | | | 04/00 | |
| Hacking | FW | 5 | | | | | | | | (10/99) | | | | (04/00) |
| Hacking | FW | 1 | | | | | | | | | 03/99 | | | (04/00) |
| Hacking | FW | 2 | | | | | | | | (10/99) | | | 04/00 | |
| Hacking | FW | 1 | | | | | | | 03/99 | | | 04/00 | | |
| Hacking | FW | 1 | | | | | | | | | 11/98 | | | (04/00) |
| Hacking | FW | 1 | | | | | | | | (10/99) | | | 06/00 | |
| Hacking | FW | 3 | | | | | | | | | | | 04/00 | (11/00) |
| Hacking | FW | 1 | | | | | | | | | | | 04/00 | 11/00 |
| Hacking | FW | 1 | | | | | | | | (10/99) | | | | (11/00) |
| Hacking | LT | 2 | | | | | | | | | | 02/99 | | (11/99) |
| Hacking | LT | 3 | | | | | | | | | | 02/99 | | 11/99 |
| Hacking | LT | 1 | | | | | | | | | | | 03/00 | (10/00) |
| Hacking | LT | 1 | | | | | | 03/99 | | | | 10/00 | | |
| Hacking | LT | 1 | | | | (02/99) | | | | | | | 05/01 | |
| Hacking | LT | 1 | | | | | 11/99 | | | | | | | (09/01) |
| Hawkesbury | FW | 2 | | | | | | | | | | | 04/99 | 11/99 |
| Hawkesbury | FW | 1 | | | | | | | | | | | 04/99 | (11/99) |
| Hawkesbury | FW | 1 | | | | (04/99) | | | | | | | | 04/01 |
| Hawkesbury | FW | 1 | | | 04/99 | | | | | | | | 04/01 | |
| Hawkesbury | FW | 1 | | | | (11/99) | | | | | | | | (04/01) |
| Hawkesbury | FW | 1 | | 04/99 | | | | | | | | | | 04/01 |
| Hawkesbury | FW | 1 | | | | (04/99) | | | | | | | 04/01 | |
| Hawkesbury | FW | 1 | | | | | | | | (05/00) | | | | (12/01) |
| Hawkesbury | UT | 1 | | | | | | | | | | | 06/99 | (11/99) |
| Hawkesbury | UT | 1 | | | | | | | | (06/99) | 12/99 | | | |
| Hawkesbury | UT | 4 | | | | | | | | | 12/99 | | 05/00 | |
| Hawkesbury | UT | 4 | | | | | | | | | 12/99 | | | (05/00) |
| Hawkesbury | UT | 1 | | | | | | | | | | 12/99 | | (05/00) |
| Hawkesbury | UT | 1 | | | | | | | | (06/99) | | | | (05/00) |
| Hawkesbury | UT | 1 | | | | | | | | | 12/99 | | | (06/00) |
| Hawkesbury | UT | 1 | | | | | | | | | 12/99 | | | 06/00 |
| Hawkesbury | UT | 1 | | | | | | | | (10/99) | | | | (11/00) |
| Hawkesbury | UT | 3 | | | | | | | | | | | 05/00 | (12/00) |
| Hawkesbury | UT | 1 | | | | | | | | | | 05/00 | | (12/00) |
| Hawkesbury | UT | 2 | | | | | | | | (05/00) | | 02/01 | | |
| Hawkesbury | UT | 1 | | | | | | 05/00 | | | | 03/01 | | |
| Hawkesbury | UT | 1 | | | | | | | | (05/00) | | | 03/01 | |
| Hawkesbury | UT | 1 | | | | | | | 05/00 | | | 03/01 | | |
| Hawkesbury | UT | 2 | | | | | 12/99 | | | | | | | (12/01) |
| Hawkesbury | UT | 4 | | | | | | | | (05/99) | 11/99 | | | |
| Hawkesbury | UT | 1 | | | | | | | | (05/99) | | 11/99 | | |
| Hawkesbury | UT | 1 | | | | | | | | | 12/99 | | | 05/00 |
| Hawkesbury | UT | 1 | | | | | | | | | 12/99 | | | (05/00) |
| Clarence | FW | 1 | | | | | | | | | | 01/99 | | 09/99 |
| Clarence | FW | 1 | | | | | | | 02/00 | | 10/00 | | | |
| Clarence | FW | 1 | | | | | | | | | | 02/00 | 10/00 | |
| Clarence | FW | 2 | | | | | | | | | | | 02/00 | (10/00) |
| Clarence | FW | 1 | | | | | | | | | | | 02/00 | 10/00 |
| Clarence | FW | 1 | | | | | | | | | | 02/00 | | (10/00) |
| Clarence | FW | 1 | | | | | | | | (02/00) | | 10/00 | | |
| Clarence | FW | 1 | | | | | | | | | 02/00 | 10/00 | | |
| Clarence | FW | 1 | | | | | | | | | | | 02/00 | 10/00 |
| Clarence | FW | 1 | | | | | | 02/00 | | | | | | 05/01 |

Each row in the table summarises the mark and recapture information for one or more otoliths from a given catchment and zone. Each row has two numbers in the incremental zone columns. The left-hand number is the month and year that the otolith was marked and is shown within the incremental zone it was observed. The right-hand number is the month and year that the eel was recaptured and is shown in the marginal increment zone where the margin was observed. Where marks occurred on annuli (A(M-2) and A(M-1)) the month and year of marking is shown in parentheses. Where margins occurred at the expected marginal annulus location and showed signs of opaqueness, they are considered to be marginal annuli and the recapture month and year is shown in parentheses. Where margins occurred at the expected marginal annulus location but did not show signs of opaqueness, they were not considered to be marginal annuli and the recapture month/year is not shown in parentheses.

Table 2.4.3 shows that even though marking events for different otoliths may have occurred within the same month and year, there was some variability in the incremental zone they were observed in. Similar variability was observed for the location of the margin within the marginal increment when recapture occurred within the same month and year. However, the relative location of marking and recapture events within the increments of each otolith was consistent with the hypothesis that one increment and associated annulus was formed each year after marking. This pattern was consistent among catchments and habitat zones.

When an OTC mark was observed on the annulus of an otolith, it was assumed that OTC marking had occurred during a month when the annulus was being formed (Fig. 2.4.3). The monthly proportion of otoliths from all recaptured eels with evidence of annulus formation increased from February to June, then peaked in October. Monthly annulus formation was not correlated with the total recapture of eels which had been marked during respective months ($r = 0.05$, $p > 0.05$). None of the eels that had been marked and tagged during winter (14 in July, 55 in August and 186 in September) were subsequently recaptured.

No opaque annuli were visible on otoliths from very small yellow eels less than 88 mm in length (Fig. 2.4.4). The significant linear regression of the minimum length at age of the very small yellow eels ($F = 618$, $p < 0.01$) indicates that the number of annuli visible on otoliths from eels larger than 87 mm was consistent with their increasing length. They-intercept of the regression line provides an estimate of 58 mm for the size at recruitment to the estuary.

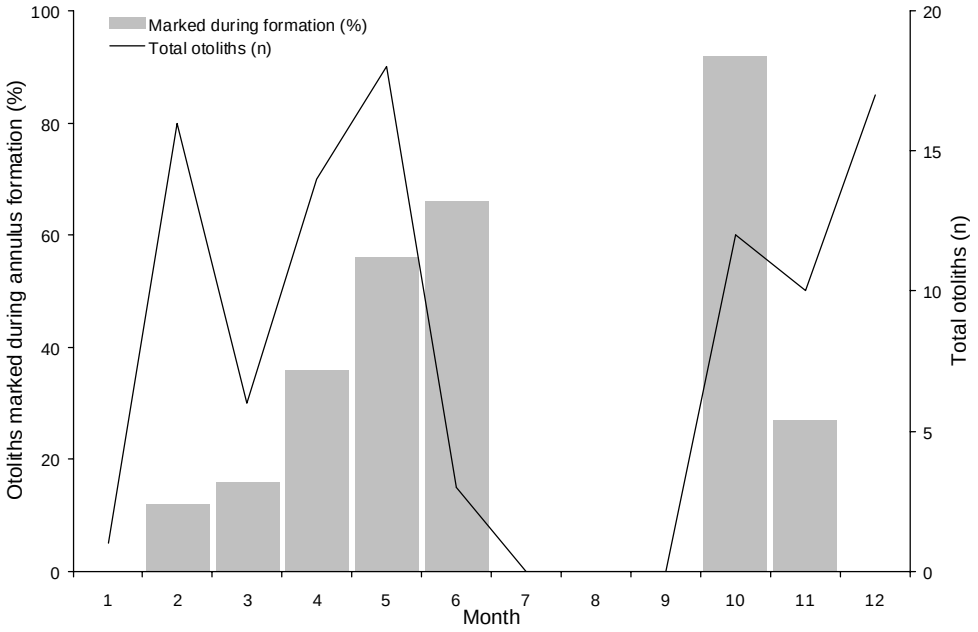



**Figure 2.4.3.** Bars show the percent of all otoliths recaptured each month of the year during the field study, with a visible OTC mark observed on an annulus (otolith marked during annulus formation). The line shows the monthly total number of otoliths recaptured which had been marked and tagged on each respective month of the year.

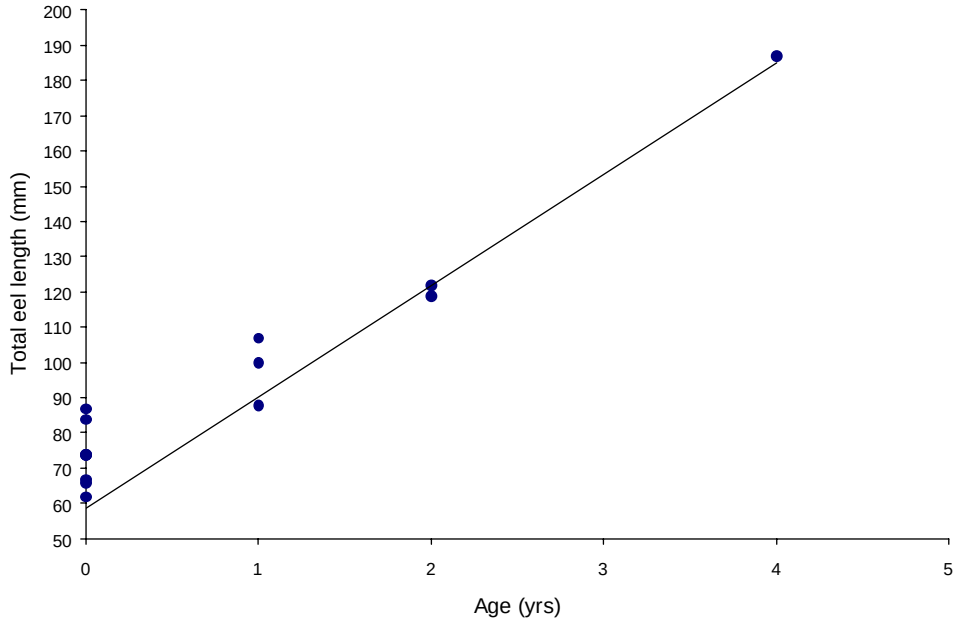
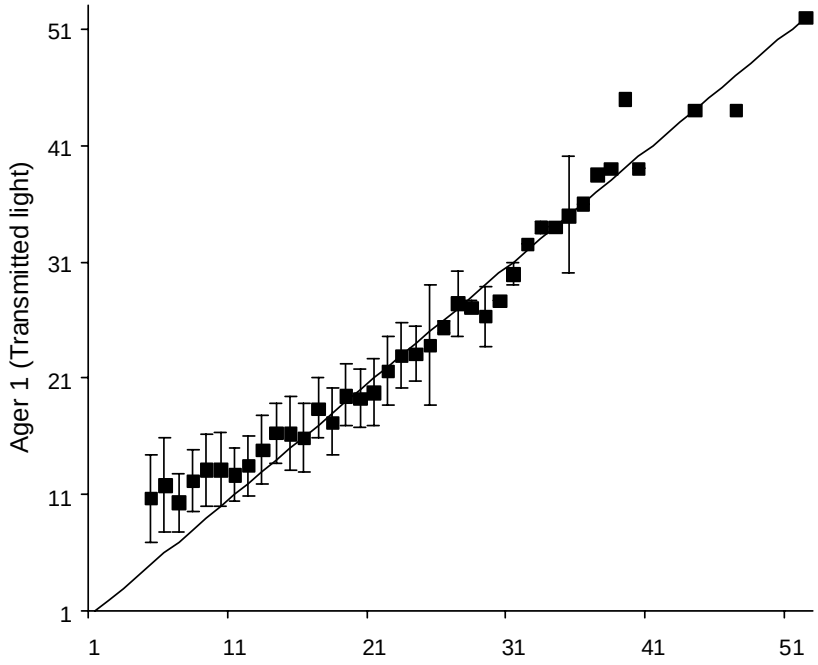



**Figure 2.4.4.** The length and estimated age of each very small yellow eel is plotted. The line (Y = 31.5X + 58.8) has been fitted to the observed minimum length at each age using least squares regression.

### *2.4.3.4. Otolith Aging of Adult Eels*

Two agers aged all of the otoliths for this study. Initial observations by both agers were primarily done using reflected light. However, before the final aging of otoliths commenced, Ager 1 aged 261 otoliths using transmitted light then Ager 2 aged the same set of otoliths using reflected light. An age bias graph comparing transmitted light readings with reflected light readings (Fig. 2.4.5a) shows that 95% confidence intervals were relatively high and there was evidence of over-aging bias of 5-10 year old eels by Ager1 using transmitted light. Ager1 complained that reading along the entire aging axis often became confusing because minor growth checks are emphasized and possibly consolidated under transmitted light. The same set of otoliths was then aged again by both agers using reflected light. An age bias graph comparing the two reflected light readings (Figure 2.4.5b) shows that confidence intervals were generally lower and there was no indication of over-aging bias by Ager 1 when using reflected light. The mean and standard deviation of the CV's for the two reflected light readings ($8.54 \pm 6.80$) were much lower than those for the transmitted versus reflected light readings ($14.53 \pm 14.05$). The t test of the transformed CV values showed that the two means were significantly different ($t=5.60$, $P<0.001$). As a result of these comparisons it was decided to use reflected light readings for all otolith aging. Of course, transmitted light was still used to observe and evaluate specific zones and structures that were unclear under reflected light.

*A.*




*B.*

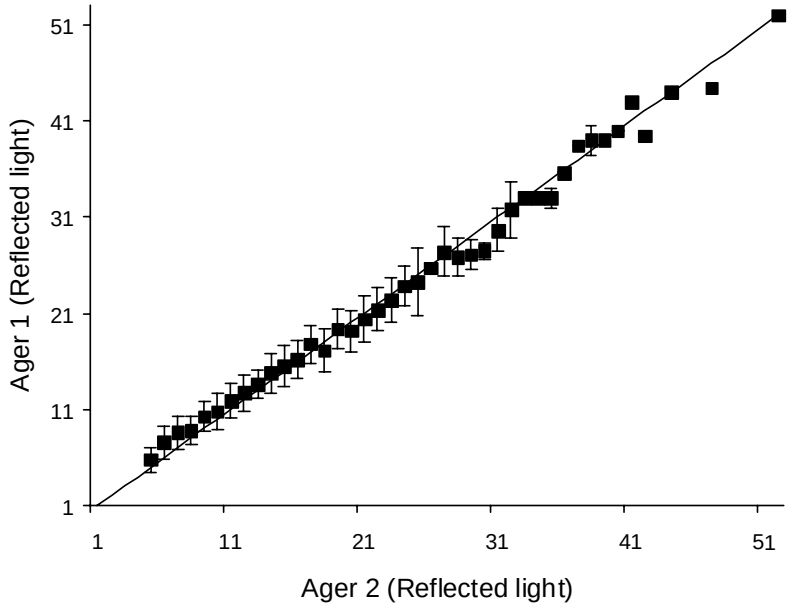



**Figure 2.4.5.** A) Age bias plot with 95% confidence intervals for Ager 1 reading with transmitted light versus Ager 2 reading with reflected light. B) Age bias plot with 95% confidence intervals for Ager 1 and Ager 2 both reading with reflected light.

Ages of eels in the laboratory experiment ranged from 5 to 33 years old and eels recaptured during the field validation study ranged from 7 to 52 years old. Figure 2.4.6 illustrates the significant linear relationship ($F = 1108$, $p < 0.001$) between age and otolith weight, showing that these two variables were significantly correlated ($r = 0.74$, $p < 0.05$) despite increasing variability with age. This indicates that estimated ages were generally consistent with increasing otolith weight and that otolith growth is continuous throughout the age range of yellow eels sampled for our studies associated with the commercial eel fishery.

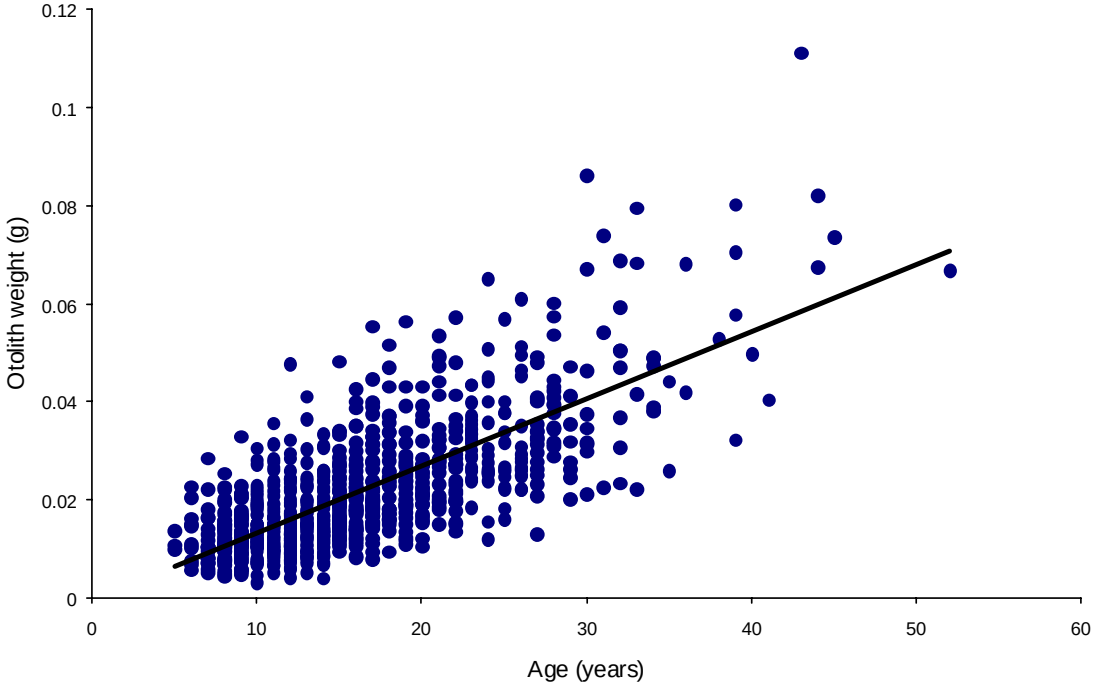



**Figure 2.4.6.** Estimated age in years plotted against available otolith weight in grams for all otoliths collected during fishery independent and fishery dependent field studies. The line has been fitted by least squares linear regression.

### *2.4.4. Discussion*

Both the laboratory and field validation studies show that one opaque white annulus (as viewed under reflected light) is formed per year in the age range of longfinned eels harvested by the commercial eel fishery in New South Wales (5-52 years old). Annuli were apparently formed during the cold-water period during winter and early spring in the otoliths of eels used in the laboratory study. Time of annulus formation was much more variable in recaptured eels from the field study (Table 2.4.3). Marks and recaptures coincided with annulus formation primarily in June and October (Fig. 2.4.3), but annulus formation apparently occurred during all months except January, July, August and September. However, this evidence is biased by the fact that no eels were recaptured July through September. High variability in the timing of annulus formation is probably related primarily to inter-annual variability in winter temperatures within the wide range of habitats sampled.

Timing of marks observed immediately before and after annuli support the hypothesis that marks are formed primarily during the winter and spring. Observation of otolith marginal increments for

this species by Sloane (1984a) in Tasmania also support this hypothesis. One explanation for lack of recaptures during annulus formation from July through September in our field study, despite relatively high numbers of eels captured during this period, may be that mortality of tagged eels from handling stress was very high during this cold water period. We observed several incidences of high mortality after anaesthetizing and measuring live eels that had been commercially harvested during winter months. Longfinned eels are a tropical species with a range that extends into temperate regions (Schmidt 1928). The catchments sampled during this study are located at the boundary between subtropical and temperate regions (Pease 1999) where the eels may be more sensitive to colder winter temperatures than they are within the tropical regions of their extensive geographic range. In the laboratory study, there was no difference between the mortality rates observed during the first and second six month periods (Table 2.4.2), despite the fact that Period 2 included several winter months. However, all of the handling stress related to anaesthetizing, measuring, marking and tagging was incurred at the start of Period 1, with none during Period 2.

Annulus formation during February and March coincided only with marking events, not recapture events. One explanation for the observed annulus formation during late summer and autumn is that the marking and handling stress may cause annuli to be formed earlier than usual. Berg (1985) found that tagging often caused supernumerary rings to form in European eels and Oliviera (1996) observed a similar phenomenon in American eels associated with OTC marking and tagging.

Supernumerary rings were observed on many of the otoliths examined in this study. They were easily distinguished from annuli by their relative thinness and lack of continuity. They were generally most prevalent in eels from the freshwater zone of the more temperate Hacking and Hawkesbury catchments, indicating that they may result from stresses associated with cooler water temperatures. Deelder (1981) and Liew (1974) suggested that temperature extremes are a source of supernumerary ring formation in European and American eels, respectively. Supernumerary rings have been reported by numerous researchers who have aged temperate (European, American, Japanese, African, Australian shortfinned, and New Zealand longfinned) eel species, but have not been previously reported for a tropical species such as the Australian longfinned eel.

This is also the first time that annual increment periodicity has been verified in otoliths from this species using mark and recapture techniques. Similar OTC marking and tagging techniques have been used to successfully verify the annual increment periodicity in European (Bagliniere *et al*. 1994), American (Oliveira 1996), Australian shortfinned and New Zealand longfinned (Chisnell and Kalish 1993) eels. All of the abundant literature examining annual periodicity of otolith increments in anguillid eel otoliths using a wide variety of techniques indicate that one increment is formed per year and each broad summer growth zone is followed by a typically narrower winter annulus. However, there is considerable confusion in this literature over terminology (such as translucent, hyaline, or opaque) associated with the appearance of these structures, which varies with preparation (crack and burn, unstained section, stained section, or acetate peel) and light conditions for viewing (reflected or transmitted). After comparing age readings under transmitted and reflected light, we determined that the most precise readings of our etched and unstained slides were made under reflected light. The structure of Australian longfinned eel otoliths appears to be consistent with the ultrastructure of European eel otoliths as described by Lecompte-Finiger (1992) with "(1) Hyaline zone: wide and optically dark under reflected light, corresponding to an increasing calcification rate and large crystals of aragonite; (2) Opaque zone: wide or narrow, optically pale under reflected light, corresponding to a decreasing calcification rate".

The early life history of this species (as with all anguillid eels) is complex. Shiao *et al.* (2002) showed that the marine nucleus of longfinned glass eels from the Hacking River catchment contained daily increments which indicate that they had spent 130-157 days at sea as leptocephali before metamorphosing into glass eels which spent an average of 35 days on the continental shelf. Glass eels entered the estuary at an age of 160-203 days and a size of 51.0 $\pm$ 1.4 mm (mean $\pm$ sd).

The outer edge of the marine nucleus is assumed to be a growth check formed on entry to the estuary. They found that 83% of the longfinned glass eels in their study had also formed a secondary transition check between the outer edge of the marine nucleus and the margin. They propose that the transition check may reflect further physiological adjustment to the estuarine environment in preparation for movement to fresh water. However, Cieri and McCleave (2001) argue that the transition check is not linked to a reduction in salinity because it formed in 61 of 126 otoliths from American glass eels while they were held in marine waters.

Few publications describing eel aging studies clearly define how the first annual increment (age 0 to age 1) is determined. In this study, agers counted the outer edge of the marine nucleus as age 0 and the first annulus outside the transition ring (if present) as age 1 (Fig. 2.4.1a). Therefore, ages represent the number of years that eels have spent in the catchment since entering the estuary from the ocean. This is an acceptable assumption because most studies are concerned with the biology, ecology or population dynamics of eels within coastal catchments. Determination of the time they spend in the ocean as leptocephali and glass eels (almost a year in some species) requires very specialized recruitment sampling and otolith preparation techniques and may not have direct relevance to the study of life history stages in coastal catchments.

The size of 58 mm at age 0 (entry to the estuary) estimated in this study (Fig. 2.4.4), is similar to the estimate of 51 mm by Shiao et al. (2002). In fact, if 51 mm is used as the minimum length at age 0, the linear regression fit is significantly improved ($F = 3229$, $P < 0.0005$). This fit helps to validate the first annual increment and shows that our age estimates are very consistent with the known information about age 0 recruits. Pease *et al.* (2003a) showed that longfinned glass eels recruit to Port Hacking primarily during the summer and autumn, therefore the age 1 annulus is probably formed during their second winter in the catchment.

Annual growth of otoliths in the laboratory was relatively constant (Fig. 2.4.2). However, the shape of each otolith and the width of annual increments at all ages were highly variable in eels sampled from the wild. These factors are probably related to different growth characteristics in each of the wide range of habitats sampled. However, otolith growth was continuous throughout the period of estuarine residence as indicated by the linear relationship between otolith weight and age (Fig. 2.4.6).

All of the eels that were recaptured during fishery independent sampling, had not moved appreciably from their capture site, indicating that the home range of yellow-stage longfinned eels is generally less than 300 m in the wide range of fluvial and tidal habitats which were sampled. All except two of the fishery dependent recaptures were recaptured within the zone in which they were tagged. There was no indication of frequent movement between sites within zones (1-25 km) or between habitats. Therefore, it is believed that the otolith age and growth characteristics of tagged and recaptured eels during the study period were generally representative of each of the habitats sampled. The only exceptions were the two eels that were tagged in the freshwater zone and recaptured by commercial fishers in the upper tidal zone over 65 km downstream in the Hawkesbury River and 45 km downstream in the Clarence River. Both were immature females that may have moved downstream in preparation for sexual maturation (silvering) and the subsequent spawning migration.

There is no comparative movement data for a tropical anguillid species, but these findings are generally similar to findings for temperate anguillid species in the southwestern Pacific region. Chisnell and Kalish (1993) found that Australian shortfinned and New Zealand longfinned eels were recaptured after 1 to 3 years within 20 m of their tagging sites in a New Zealand pastoral stream. Beumer (1979) found that yellow stage Australian shortfinned eels in a slightly brackish swamp in Victoria had a home range of approximately 400 m but two of the eels moved up to 3.7 km. Jellyman *et al.* (1996b) showed that most Australian shortfinned eels that were tagged in a

New Zealand coastal lagoon (Lake Ellesmere) were recaptured at their tagging site, but 39% moved an average distance of 5 km. It appears that anguillid eels in fluvial and tidal waters within this region generally have a restricted home range but are capable of periodic extensive movements.

This study shows that there are potential problems with the use of OTC marking and tagging techniques for Australian longfinned eels. The field and laboratory studies both indicate that intraparitoneal injection of OTC did not mark the otoliths in 20-23% of the recaptured eels. We believe that this may have resulted from occasional accidental injection of OTC into the gut and recommend that future studies investigate the success of intramuscular injection of OTC.

Loss rates of t-bar anchor tags were also relatively high during the laboratory study, particularly during the first six month period (27-33%). However, loss rates dropped to a more acceptable 6-14% during the second six month period. We believe that high initial tag loss rates were at least partially due to inexperience at handling and tagging live eels. We also believe that our handling and tagging techniques improved by the time we commenced tagging eels for the field study. This is indicated by the high recapture rates in the Hawkesbury and Hacking Rivers (22 and 26% respectively), which were higher than the 18.5% recapture rate of Australian shortfinned eels reported by Beumer (1979).

The mortality rates of eels in all treatments were relatively high during the laboratory study (0-25% during the two six month periods). However, the mortality rates of marked and tagged eels were very similar to the mortality rates of the controls, indicating that mortality rates were probably influenced primarily by the holding conditions rather than the OTC marking and tagging process.

In conclusion, this study provides validation of initial annual increment formation and annual periodicity of subsequent annuli over the age range of Australian longfinned eels harvested by the commercial trap fishery in New South Wales. This information, along with clarification about formation and associated terminology for otolith structures such as the initial annual increment, transition rings and supernumerary rings in this species, provides a solid basis for the analysis of age structure in subsequent chapters.

## 2.5. Variation in Sex Ratio, Size and Age Within and Among Catchments

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### *2.5.1. Introduction*

As with many teleost fishes, the spatial distribution of the sexes in anguillid populations varies considerably, with sex ratios in most rivers being highly skewed (Gray and Andrews 1970; Harrell and Loyacano 1982; Helfman *et al.* 1987; Krueger and Oliveira 1997). It has often been suggested that distribution of anguillids within a catchment may be a function of sex (Huver 1966). This topic has been actively debated for the European (*Anguilla anguilla*) (Parsons *et al.* 1977; Wiberg 1983), American (*Anguilla rostrata*) (Helfman *et al.* 1984; Hansen and Eversole 1984), Japanese (*Anguilla japonica*) (Tzeng *et al.* 1995) and New Zealand eels (*Anguilla australis* and *Anguilla dieffenbachii*) (Harries 1974; Todd 1974). Generally, males live in estuaries and brackish lagoons, while females are found in fresh water and, as a consequence, the ratio of females to males increases with increasing distance from the sea (Bertin 1956).

In the last 30 years, studies have shown that the sex ratios of American eels may differ regionally as well as within a given catchment (Helfman *et al.*1984; Helfman *et al.* 1987; Oliveira *et al.* 2001). High proportions of females have been found within estuaries in some catchments, while males apparently dominate the sex ratios in entire river systems and freshwater lagoons in other catchments (Winn *et al.* 1975; Todd 1980; Krueger and Oliveira 1997). Several hypotheses have been proposed for explaining the asymmetry of sex ratios throughout the distribution of the species. It is now believed that environmental factors, as well as life history strategies (such as sex related differences in age at maturity, mortality and migration) may drive this process (Girondot and Pieau 1993; Oliveira *et al.* 2001).

A basic requirement in the assessment of fish populations is the determination of the age and size composition of the species being studied, from which estimates of growth rates can be made (Pawson 1990). However inferences about the geographic distribution of age and size characteristics of anguillids is often based on data sets which combine habitats and life history stages. When Helfman *et al.* (1987) combined information from different authors for studies on *A. rostrata* on the Atlantic coast, they found the magnitude of age and size differences between regions was significant. Apart from Oliveira and McCleave (2000), the examination of sex ratios as well as age and size structure has been limited to a single river or sampling location, making conclusions regarding larger scale geographical and intra-river distribution of population characteristics problematic.

The only available size and age information for *A. reinhardtii* comes from one study conducted in Tasmania (the southern limit of the species distribution) by Sloane (1984a). This study was based on samples from freshwater habitats in one catchment, with no discrimination of sexes. Therefore, the aim of this study was to determine sex ratios and their impact on size and age characteristics of *A. reinhardtii* in fresh water and tidal habitats among three rivers (Hacking, Hawkesbury and Clarence) in NSW, Australia. Variation in age characteristics between the sexes and gonadal development stages of this species was then compared with available information for other species of anguillids.

### *2.5.2. Methods*

Eels were collected through fishery independent and fishery dependent sampling from sites within each of the zones in the Hawkesbury and Clarence Rivers, and through fishery independent sampling in the Hacking River as described in Chapter 2.1. Data were pooled in zones where multiple sites were sampled due to their close proximity to each other and similar riverine characteristics. Commercial eel traps with a mesh size of 25mm were used to collect all fishery independent samples at all sampling sites. Fishery dependent sampling involved measuring commercial eel trapping catches from tidal zones in both the Hawkesbury and Clarence Rivers. Shortly after capture eels were anaesthetised with 100mg$L^{-1}$ clove oil solution (Walsh and Pease 2002). Total length was measured to the nearest millimetre and total weight was recorded to the nearest 10 grams. A subsample of 50-100 eels of the total catch was measured and a further representative subsample of eels (approximately 15-20) were obtained for processing of otoliths and gonads. For the fishery independent sampling the first year of sampling involved the measuring, tagging and releasing of eels (for age validation studies). In the final year all eels captured were measured, euthanased and the otoliths and gonads processed for each eel. Of the eels processed 815 (yellow and silver eels) were sexually identified as either undifferentiated, males or females based on both macroscopic and histological examination as described in Chapter 2.3. Otoliths were processed and aged as described in Chapter 2.4.

#### *2.5.2.1. Spatial Distribution of the Sexes*

A chi-square contingency test was used to determine if there was a significant difference in sex ratios between fishery dependent and fishery independent trapped eels. After determining that there was no significant difference, Chi-square contingency tests of pooled trapping data were then used to determine whether there were significant differences in the sex ratios between the zones and among the rivers.

#### *2.5.2.2. Temporal Distribution of the Sexes*

Fishery independent data from the Hacking River was used to determine the temporal distribution of the sexes within freshwater and lower tidal zones. As there was no upper tidal area in the Hacking River, the upper tidal area of the Hawkesbury River was examined temporally. Therefore zones were analysed independently of each other. Fishery independent samples were collected from these three zones in spring, summer, autumn and winter between 2000 and 2001. Chi-squared contingency tests were used to determine whether there were significant differences in the sex ratios for each zone among the seasons.

#### *2.5.2.3. Spatial and Temporal Distribution of Catch per Unit of Effort (CPUE)*

The numbers of eels caught in each fishery independent trap for each day of sampling were recorded as the CPUE in each of the three zones (fresh water, upper tidal and lower tidal) for the Hacking, Hawkesbury and Clarence Rivers. Assumptions of normality and homogeneity of variance could not be met, even with transformation of the CPUE data. Therefore, non-parametric Kruskal-Wallis analysis of variance (ANOVA) tests were used to determine whether there were significant differences in the mean numbers of eels captured per trap day between the zones and among the rivers. A Kruskal-Wallis ANOVA was also done to determine whether there were any significant differences in the mean number of eels captured per trap day for each zone among the four seasons (2000 to 2001). Fishery independent data from both the Hacking (fresh water and lower tidal) and Hawkesbury River (upper tidal) were used in this analysis.

#### *2.5.2.4. Length/Weight Relationships*

To determine the length/weight relationship of eels among the sexes, rivers and zones a least squares regression line was fitted to the lengths and weights of eels in the study. The linear relationship of length to weight was calculated from the logarithmic expression of the exponential equation: $\log_{10} w = \log_{10} a + b\log_{10} l$ (where w = weight in grams, l = length in mm, b= slope of the regression line, a = intercept). Analysis of covariance (ANCOVA) tests of log transformed data were used to test whether there were any significant differences in the slopes of the linear length/weight relationships among sexes, rivers and zones.

#### *2.5.2.5. Age and Size Structure*

A one-way ANOVA was used to determine if there was any significant difference in mean age and length between fishery dependent and independent data. Mean ages for each sex and stage of gonadal development (Chapter 2.3) were determined for *A. reinhardtii*. Age and size distribution of eels were determined in the freshwater and tidal (pooled upper and lower) zones in the Hacking, Hawkesbury and Clarence Rivers. Differences in mean age and body length (sexes pooled) between zones and among rivers were compared using two-factor ANOVA. All length and age data were log transformed to meet the assumptions of normality and homogeneity of variance. Analyses were done using the Statistica 6 (Statsoft) software package with a p value of less than 0.05 considered significant (Zar, 1974).

### ***2.5.3. Results***

#### *2.5.3.1. Spatial Distribution of the Sexes*

The distribution of undifferentiated, male and female *A. reinhardtii* varied considerably both between zones and among rivers (Table 2.5.1). No males were found in the freshwater zones of either the Hacking or the Hawkesbury Rivers and only two males (4%) were captured in the freshwater zone of the Clarence River. The proportion of males within each river increased to 13-19% of the eels captured in both the upper tidal and lower tidal reaches of each catchment. The only exception was the lower tidal area in the Hawkesbury River where only one male (4%) was captured.

A chi-square contingency test showed there was no significant difference in sex ratios when tidal data for both fishery dependent and fishery independent sampling was compared ($\chi^2$=1.62, p=0.2), therefore data were pooled. Chi-square contingency tests revealed that there were no significant differences in the sex ratios of males and females for the upper tidal ($\chi^2$= 1.94, p=0.16) (Hawkesbury and Clarence rivers only) and lower tidal zones ($\chi^2$= 4.68. p=0.1) for the three rivers. The significant difference being in the freshwater zone ($\chi^2$=8.08, p=0.02) due to the occurrence of males in the Clarence River. There were also significant differences in sex ratios found between zones among the three rivers due exclusively to the predominance of females in the freshwater zone (Hacking: $\chi^2$=24.52, p<0.01; Hawkesbury: $\chi^2$=11.51, p<0.01; Clarence: $\chi^2$=6.21, p=0.03).

**Table 2.5.1.** Percentages (bold) and numbers (in brackets) of undifferentiated (UD), male and female *A. reinhardtii* captured in the Hacking, Hawkesbury and Clarence Rivers.

| Zone | Sex | River | | |
|---|---|---|---|---|
| | | **Hacking** | **Hawkesbury** | **Clarence** |
| **Freshwater** | % male | **0** | **0** | **4** (2) |
| | % female | **96** (108) | **97** (56) | **75** (39) |
| | % (UD) | **4** (5) | **3** (2) | **21** (11) |
| **Upper** | % male | n/a | **13** (24) | **19** (17) |
| **tidal** | % female | n/a | **75** (138) | **67** (60) |
| | % (UD) | n/a | **12** (21) | **14** (23) |
| **Lower** | % male | **16** (14) | **4** (1) | **13** (22) |
| **tidal** | % female | **59** (53) | **96** (27) | **75** (128) |
| | % (UD) | **25** (23) | **0** | **12** (20) |

*2.5.3.2. Temporal Distribution of the Sexes*

Table 2.5.2 shows the sex ratios within each of the three zones (Hacking River – freshwater and lower tidal, Hawkesbury River – upper tidal) for spring, summer, autumn, and winter between 2000 and 2001. On average, lower numbers of eels were captured in the months corresponding with the lowest water temperatures (winter). As no males were captured in the freshwater area, a chi-square contingency test could only be done using female and undifferentiated eels in this zone. The analysis showed that there were no significant differences in the sex ratios for each zone among the four seasons (freshwater: $\chi^2$= 3.22, p=0.36; upper tidal: $\chi^2$= 3.2, p=0.78; lower tidal: $\chi^2$= 7.53, p=0.27).

**Table 2.5.2.** Percentages (bold figures) of undifferentiated (UD), male and female *A. reinhardtii* captured in the Hacking (freshwater, lower tidal) and Hawkesbury (upper tidal) Rivers from spring 2000 to winter 2001.

| Zone | Sex | Season | | | |
|---|---|---|---|---|---|
| | | **Spring** | **Summer** | **Autumn** | **Winter** |
| **Freshwater** | % male | **0** | **0** | **0** | **0** |
| | % female | **94**(33) | **97**(32) | **100**(24) | **89**(16) |
| | % (UD) | **6**(2) | **3**(1) | **0** | **11**(2) |
| **Upper** | % male | **13**(3) | **13**(6) | **20**(11) | **11**(4) |
| **tidal** | % female | **71**(17) | **60**(27) | **67**(36) | **80**(28) |
| | % (UD) | **16**(4) | **27**(7) | **13**(7) | **9**(3) |
| **Lower** | % male | **19**(5) | **17**(4) | **12**(3) | **15**(2) |
| **tidal** | % female | **74**(20) | **57**(13) | **52(**13) | **46**(6) |
| | % (UD) | **7**(2) | **26**(6) | **36**(9) | **39(5)** |

### *2.5.3.3. Spatial and Temporal Distribution of CPUE*

Figure 2.5.1 summarises the mean CPUE in the fresh water, upper tidal and lower tidal areas of the Hacking, Hawkesbury and Clarence Rivers. The highest number of eels captured per trap day was 19, from the upper tidal area in the Clarence River. While the mean number of eels captured per trap day varied from 2 to 3 in the freshwater and upper tidal zones for each river, this average decreased significantly to less than 1.3 eels per trap in the lower tidal areas. When only the freshwater and tidal zones (both upper and lower pooled) were compared a Kruskal-Wallis ANOVA showed that the mean number of eels captured per trap/day was significantly higher in the freshwater zone than the tidal zones for the three rivers (Hacking: $H=7.38$, $p<0.01$; Hawkesbury: $H=5.43$, $p=0.02$; Clarence: $H=12.80$, $p<0.01$). There was no significant difference found when the mean number of eels per trap/day was compared between the three rivers ($H=8.91$, $p=0.16$).

A similar result was obtained when the three different zones (fresh water, upper tidal and lower tidal) of the Hawkesbury and Clarence Rivers were compared. A Kruskal-Wallis ANOVA showed that there were significant differences in mean number of eels per trap/day between the three zones for each river (Hawkesbury: $H=25.40$, $p<0.01$; Clarence: $H=42.29$, $p<0.01$). Multiple comparison tests revealed that there were no significant differences between the fresh water and the upper tidal zones. However the mean numbers per trap/day in these zones were significantly higher than those for the lower tidal zones in both rivers ($p<0.01$ for all tests).

A Kruskal-Wallis ANOVA showed that there were no significant differences in the mean number of eels per trap/day when zones in the Hacking (fresh water and lower tidal) and Hawkesbury (upper tidal) Rivers were compared among the seasons (fresh water: $H=3.58$, $p=0.28$, upper tidal: $H=2.24$, $p=0.53$; lower tidal: $H=5.89$, $p=0.12$).

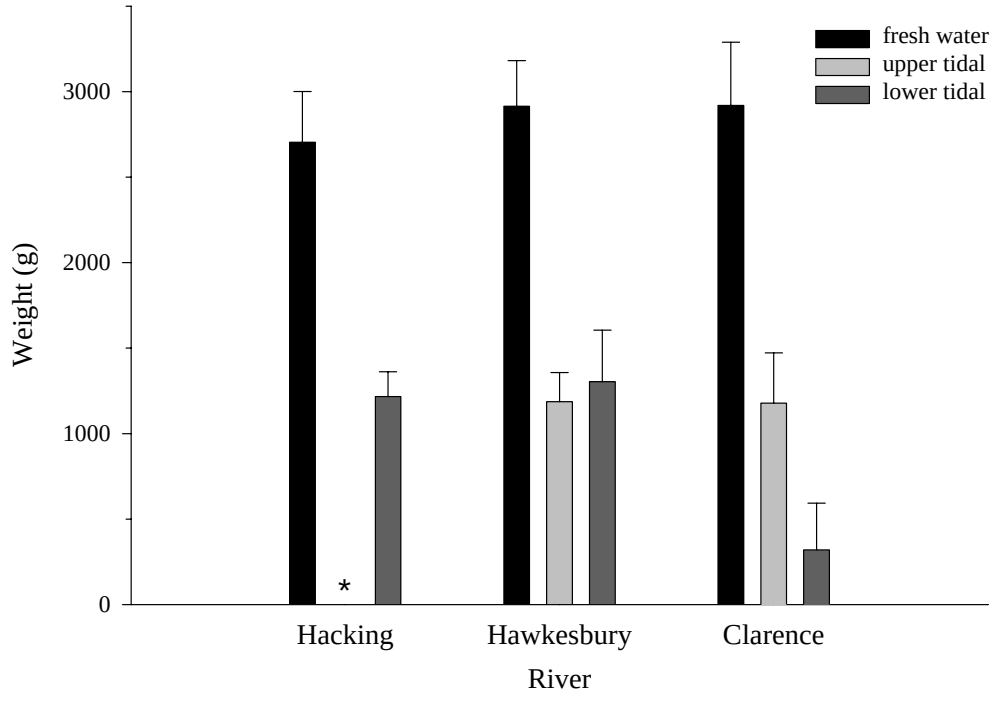


**Figure 2.5.1.** Mean weight and standard error of *A. reinhardtii* captured per trap in the different zones of the Hacking (* upper tidal zone absent), Hawkesbury and Clarence Rivers.

*2.5.3.4. Length/Weight Relationships*

Regression analysis of length/weight (rivers pooled) showed that slopes of the log linear fits were significantly different from zero for undifferentiated, male and female eels ($p<0.01$), and coefficients of determination for each fit were >0.8 (Table 2.5.3). An analysis of covariance (ANCOVA) revealed that the slopes did not differ significantly among the sexes ($F=1.49, p=0.22$). Therefore, sexes were pooled in all further statistical tests. An ANCOVA showed that the slopes of the length/weight relationship for the Hacking, Hawkesbury and Clarence Rivers were not significantly different ($F=1.74$, $p=0.18$). Therefore, eels in the Hacking, Hawkesbury and Clarence Rivers gained mass equally according to the gains in total length. However, slopes of the length/ weight relationship in tidal areas (upper and lower pooled) were significantly lower ($F=12.22$, $p=0.01$) than slopes in freshwater areas in all three rivers.

**Table 2.5.3.** Intercepts and slopes of the equation $\log_{10}\text{weight} = \log_{10} a + b\log_{10}\text{length}$ with pooled length and weight data for each sex, river and zone.

| Sex | Intercept (a) | Slope (b) | Coefficient of determination ($r^2$) |
|---|---|---|---|
| undifferentiated | -5.39 | 2.94 | 0.81 |
| male | -5.36 | 2.93 | 0.8 |
| female | -5.55 | 3 | 0.91 |
| **River** | | | |
| Hacking | -6.49 | 3.34 | 0.95 |
| Hawkesbury | -6.15 | 3.22 | 0.97 |
| Clarence | -5.88 | 3.12 | 0.95 |
| **Zone** | | | |
| freshwater | -5.39 | 2.94 | 0.81 |
| tidal | -5.36 | 2.93 | 0.8 |

*2.5.3.5. Age and Size Structure*

An ANOVA showed that the mean age and length of eels captured by the fishery dependent sampling were not significantly different from those of the eels captured by fishery independent sampling (age: $F= 0.44$, $p=0.5$; length: $F=1.04$, $p=0.3$). Therefore, fishery dependent and fishery independent data were pooled as required in the following statistical analyses. Table 2.5.4 shows the frequencies of different age groups for undifferentiated, male and female eels from the study. The youngest and oldest sexually identifiable eels caught in the study were 5 years and 52 years respectively. The ages ranged from 6 to 27 years for undifferentiated eels; 5 to 22 years for male eels; and 5 to 52 years for female eels. The age frequencies were similar for both male and undifferentiated eels with up to 98% of each sample population falling within the ages of 6 to 20 years.

The mean age of undifferentiated (12.54 ± 0.37 s.e) eels was similar to the mean age of male eels (12.2 ± 0.39 s.e). The females exhibited a larger age range with 95% of the sample population aged between the ages of 6 and 30 years. A one-way ANOVA showed that the mean age of females (17.9 ± 0.29 s.e) was significantly higher than the mean age of both undifferentiated and male eels ($F=49.06$, $p<0.01$). Table 2.5.5 summarises the relationship between age and stage of gonadal development for both males and females. A one-way ANOVA showed that mean ages of females increased significantly with each stage ($F= 7.77$, $p<0.01$), but mean ages of males were not significantly different among stages ($F=0.06$, $p=0.93$).

A summary of age frequency of the sample population with sexes pooled (Fig. 2.5.2) showed that there was a general shift in the age frequency of the total number of eels from younger age classes in the tidal (upper and lower pooled) zones to older age classes in the freshwater zone. A two-factor ANOVA showed that mean ages were significantly different between zones ($F=228.26$, $p<0.01$) and among rivers ($F=36.31$, $p<0.01$), with no significant interaction of the two factors ($F=2.00$, $p=0.131$). A post-hoc HSD multiple comparison test showed that mean ages of eels were significantly older in the freshwater zones for all three rivers ($p<0.01$), with the youngest mean age being found in the tidal zone of the Clarence River.

**Table 2.5.4.** Age frequencies (percentages in bold) for undifferentiated, male and female *A. reinhardtii*.

| **age range** | **undiff.** n = 102 | **male** n = 84 | **female** n = 629 |
|---|---|---|---|
| 0-5 | | **1**(1) | **0.5**(2) |
| 6-10 | **28**(29) | **32**(27) | **16**(104) |
| 11-15 | **54**(55) | **49**(41) | **25**(158) |
| 16-20 | **14**(14) | **17**(14) | **26**(163) |
| 21-25 | **3**(3) | **1**(1) | **17**(105) |
| 26-30 | **1**(1) | | **10**(62) |
| 31-35 | | | **3**(22) |
| 36-40 | | | **1**(8) |
| 41-45 | | | **1**(4) |
| 46-50 | | | |
| 50-55 | | | **0.5**(1) |

**Table 2.5.5.** Mean age and standard error for each gonadal development stage (histologically determined in Chapter 2.3) for *A. reinhardtii.*

| Gonad stage | n | Age (years) | | |
|---|---|---|---|---|
| | | Range | Mean | S.e |
| Undifferentiated. | 62 | 6 - 22 | 12.8 | 0.46 |
| immature male | 51 | 5 - 22 | 12.5 | 0.5 |
| advanced male | 9 | 7 - 18 | 12.6 | 1.26 |
| silver male | 7 | 7 - 19 | 13.0 | 1.7 |
| immature female | 38 | 8 - 25 | 13.8 | 0.74 |
| advanced female | 231 | 5 - 38 | 17.0 | 0.44 |
| silver female | 34 | 10 - 30 | 19.7 | 0.92 |

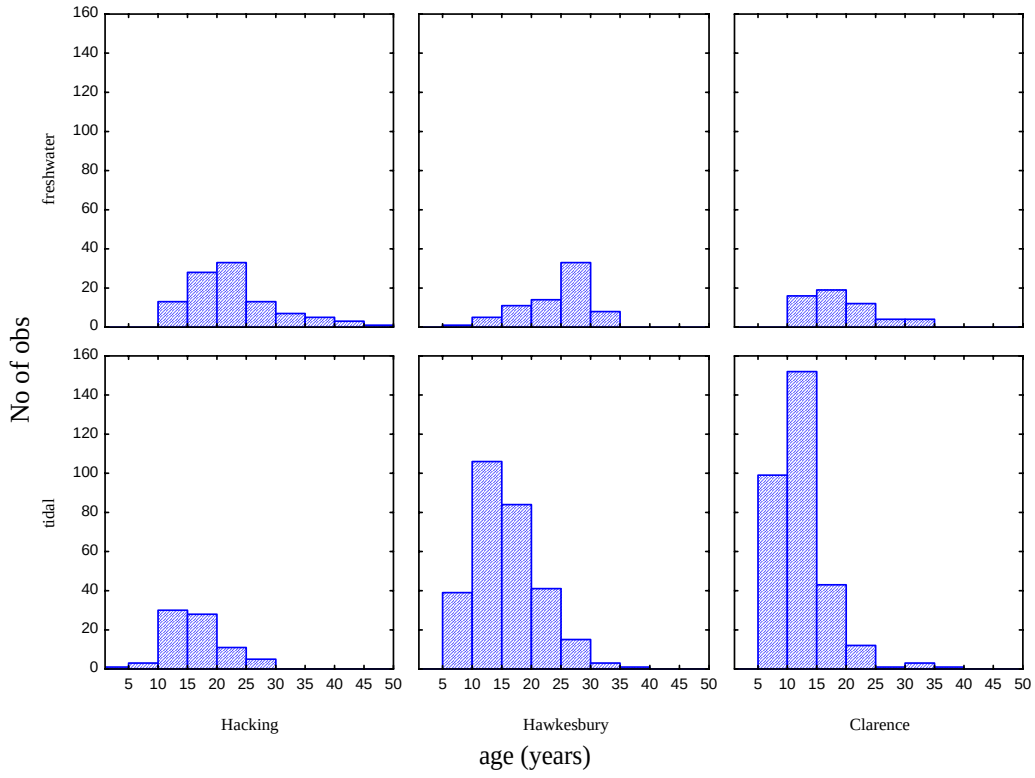


**Figure 2.5.2.** Age frequencies of *A. reinhardtii* in freshwater and tidal (upper and lower pooled) zones in the Hacking (n=181), Hawkesbury (n=362) and Clarence Rivers (n=366).

Mean total body lengths (sexes pooled) were compared between the freshwater and tidal (upper and lower pooled) zones and among rivers (Fig. 2.5.3). A two-factor ANOVA showed that eels in freshwater zones were significantly larger than those in the tidal zones ($F=34.74, p<0.01$), with a post-hoc HSD multiple comparison test revealing the significance was due to the smaller eels found in the tidal areas of the Hacking River. There was no significant interaction between the effects of both factors ($F=1.46$, $p=0.20$) neither were there any significant differences among the rivers ($F=2.70$, $p=0.67$).

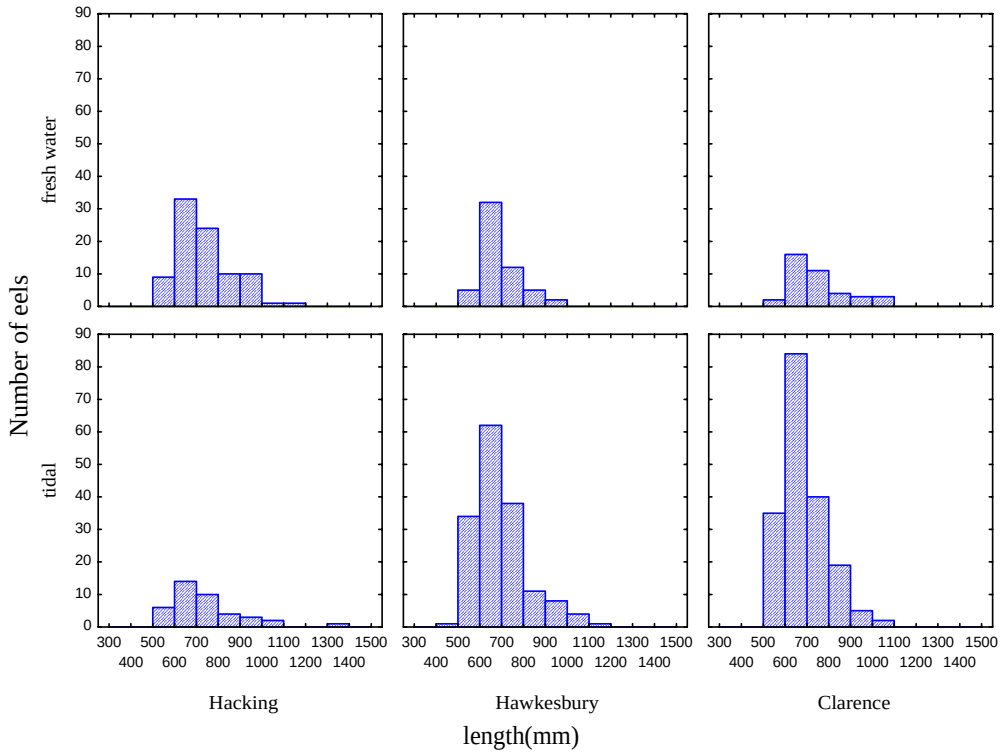


**Figure 2.5.3.** Length frequencies of *A. reinhardtii* in freshwater and tidal (upper and lower pooled) zones in the Hacking (n=181), Hawkesbury (n=362) and Clarence Rivers (n=366).

### *2.5.4. Discussion*

The distribution of the sexes differed significantly between the three zones as well as among the three rivers (Hacking, Hawkesbury and Clarence). Females occurred in significant numbers in all three zones (freshwater, upper tidal and lower tidal), while the males were predominantly found in the upper and lower tidal areas closer to the sea. While males accounted for only 10% of the eels sampled, the proportion in tidal zones was much higher (up to 19% in the upper tidal zone of the Clarence River). The relatively low number of *A. reinhardtii* males along with their occurrence in tidal habitats was consistent with previous studies of other anguillids. Olivieria and Mcleave (2000) found the proportion of females in two rivers to be positively correlated with distance upstream, and like this study the overall sex ratios differed in each river. While other studies have shown that large proportions or even exclusively males have been found in freshwater areas (Huver 1966; Sinha and Jones 1966; Todd 1980), these studies were limited to a single river or sampling location making the analysis of geographical and intra river distribution difficult.

There have been many hypotheses regarding the factors determining the distribution of sexes in anguillids both geographically and within regions. Helfman *et al.* (1987) examined the frequencies of occurrence of yellow male *Anguilla rostrata* in relation to latitude and distance from the

spawning grounds. They found that at higher latitudes (4000km from the spawning grounds) males are relatively abundant in brackish water and absent from collections made in freshwater habitats (Gray and Andrews 1970; Dolan and Power 1977). Whereas in the lower latitudes, closer to the spawning grounds, males represented up to 36% of the estuarine population, and were increasingly found in freshwater (up to 26% in some areas). The results of our study showed that there was a significant difference in the sex ratios found in the freshwater zones among the three rivers. This was primarily due to the occurrence of males (4%) found in the upper Clarence River. While the Clarence River is 800km closer to the suspected spawning grounds of *A. reinhardtii* than the other rivers in this study, there was insufficient data to support the proposed hypothesis of Helfman *et al.* (1987).

Other biological and environmental factors that can influence sex distribution amongst angullids include different life history strategies, sampling bias and trap selectivity. In this study the average river life span of *A. reinhardtii* females was shown to be almost 6 years longer than that of males. Studies of other anguillids have shown that the female strategy is to live longer to maximise fecundity, with the inherent risk of increased mortality (Parsons *et al.* 1977; Vollestad 1992; Helfman *et al.* 1987; Jennings *et al.* 2001). The opposite trend is apparent in males that reach maturity at a younger age and smaller size. Therefore, the male strategy is apparently to differentiate and reach maturity rapidly over a small size and age range, with a lower risk of mortality. This may explain why males occur in productive areas such as estuaries and are scarce upriver, with females preferring less productive habitats further from the sea (Dolan and Power 1977; Helfman *et al.* 1984; Tzeng *et al.* 1997).

There were no significant differences in the sex ratios, mean age, or mean size between eels in the fishery dependent samples and those in the fishery independent samples. Commercial catches were sampled representatively but gear and fisher selectivity may have occurred. The minimum legal size for commercial or recreational capture of *A. reinhardtii* in NSW is 30cm, while the preferred size for the live export trade to Asia is >500grams (S. Fernie pers. comm.) or approximately 58cm (based on length/weight regression). Many fishers release eels between the minimum and preferred sizes. Also commercial fishers may target specific areas within habitats known to be occupied by larger eels. As a result, males may have been under-represented in the commercial catch in this study.

The mesh size of traps used in both fishery dependent and independent sampling may well be size and hence sex selective. Size frequencies relating to this study show that there were relatively few eels below 40cm caught in any of the zones or catchments (Fig. 2.5.3). Size selectivity of the sampling gear could be a factor contributing to the relatively low number of undifferentiated and male eels in the study. Another factor may be the presence of larger eels (probably females) in a particular area which enter the traps first and subsequently deter the smaller eels from entering the traps. Small *A. dieffenbachii* (including males) have been found to be more abundant in shallower habitats than the larger eels (Cairns 1941; Chisnall 1996; Glova 2001). Therefore, differential habitat preferences by smaller individuals may be the primary factor causing the relatively low proportion of small eels found in this study. The absence of males in the freshwater zones indicates that habitat factors are probably more important than gear selectivity in determining sex ratios within the samples collected in this study.

It has long been suggested that population density is one of the major factors determining the sex and distribution of anguillid eels (Petersen *et al.* 1996). Degani and Kushnirov (1992) and Kreuger and Oliveira (1999) found that high population densities of anguillid eels, relative to available habitat area and quality, would result in male dominated sex ratios. Parsons *et al.* (1977) suggested that *A. anguilla* elvers reaching the coast were asexual and dispersed in a random manner. Overcrowding and associated competition for food would give rise to male eels, while low population densities and less competition for food would favour females. This explains why female

European (Tesch 1977, Vollestad and Jonsson 1986) and American (Helfman *et al.* 1984; Krueger and Oliveira 1999; Oliveira and McCleave 2002) eels have been shown to have faster growth rates than males.

The findings of this study do not support the general view that population densities of eels are higher in tidal estuarine areas than the low food production areas of freshwater habitats (Helfman *et al.* 1987). In this study CPUE was used as an index of abundance to examine relative differences in abundance between the zones and among the rivers. It was found that the CPUE in the freshwater and upper tidal zones were significantly higher than in the lower tidal areas. Tesch (1977) states that population density is relatively low in the lower areas of the estuaries near the sea because relatively few of the invading glass eels remain in the region, with most moving further inland. As low population densities are often associated with female dominated sex ratios, this may explain the decrease in proportion of females from the lower tidal to the upper tidal areas in the Hawkesbury and Clarence Rivers. Studies have shown that eels may delay their upstream migration in upper tidal areas for up to several years before entering freshwater (Naismith and Knights 1988; Jessop *et al.* 2002). Therefore, the highest densities may actually occur in shallow habitats in the upper tidal zone, but the trap method used in this study may not have sampled this habitat representatively.

Eel population densities have been found to vary greatly between seasons and sites (Barak and Mason 1992). Sloane (1984a) and Jellyman *et al.* (1996b) found that in the winter months eels retreated to the deeper tidal areas, while in summer, population densities increased in the shallow freshwater habitats. The numbers of eels caught in winter in this study were also significantly lower than in other seasons. However, tag and recapture information for both *A. dieffenbachii* and *A. reinhardtii* show that there is no significant short-term movement between habitats for these river eels (Chisnall and Kalish 1993; Pease *et al.* 2003b). In addition, this study showed no evidence that sex ratios or CPUE differed significantly among zones over the four seasons.

The growth of *A. reinhardtii* was determined to be allometric, with the intercepts and slopes of the length/weight relationship for the sexes and rivers typical of other anguillid eels (Sinha and Jones 1967; Todd 1980; Hansen and Eversole 1984; Oliveira and Mcleave 2000). The growth exponent (slope) has often been found to differ among areas, as well as the eels life history stages (Tesch 1977). Todd (1980) found a significant difference in length/weight relationships between yellow and migrant longfin eels (*Anguilla dieffenbachii*) as a result of the development of ovaries during the maturation process in females. Due to the small number of silver eels caught in this study, only yellow eels were used in the length/weight analysis. However, there was a significant difference in the slopes when comparing the relationships between freshwater and tidal zones. This may be related to different growth characteristics in areas with differing productivity and food availability.

Like other anguillids, *A. reinhardtii* is a long-lived species which spends the majority of its life span in coastal catchments. This is particularly the case with yellow females, with at least 30% of the sampled population greater than 20 years old (oldest caught – 52 years). Similar to the relationship between mean body length and maturity (Walsh *et al.* 2003), ages for each sex, as well as the stages of gonadal development varied greatly (Table 2.5.5). This is due to the fact that the mean age at sexual differentiation (Stage 1) of males is significantly lower than the mean age at differentiation of females, and the fact that both sexes reach maturity over most of the age range between sexual differentiation and migration. While there is significant overlap between the age ranges of the sexes, males mature over a much smaller age range and migrate at a much earlier age than females. Due to the selectivity of trap meshes within this study the mean age of males in our samples may be a little higher than the mean age of the actual male population. Table 2.5.6 summarises the general age range at both differentiation and migration from available data on four temperate anguillid species for comparison with our data for the more tropical *A. reinhardtii*. The fact that males are significantly smaller and younger than females is typical of other anguillid

species and is attributable to a generalised male life history strategy of minimising mortality by growing rapidly to a sufficient size for migration (Helfman *et al.* 1987; Vollestad 1992).

**Table 2.5.6.** Comparative ages at sexual differentiation and migration for various species of *Anguilla*. Age range for differentiation calculated as youngest to cummulative age frequency of 50% determined. Age range for migration calculated as the youngest silver eel to the oldest yellow or silver eel captured.

| Species | Sex | Age (years) | | References |
|---|---|---|---|---|
| | | Differentiation | Migration | |
| *A. anguilla* | m | 2 - 3 | 10 - 33 | Poole & Reynolds (1996) |
| | f | 3 - 7 | 8 - 57 | Sinha & Jones 1967 |
| *A. rostrata* | m | 2 - 7 | 3 - 10 | Helfman et al. (1987) |
| | f | 3 - 7 | 4 - 18 | Hansen & Eversole (1984) |
| *A. australis* | m | 5 - 10 | 8 - 22 | Todd (1974), Todd (1980) |
| | f | 6 - 13 | 12 - 35 | |
| *A. dieffenbachii* | m | 12 - 18 | 12 - 35 | Todd (1974), Todd (1980) |
| | f | 10 - 19 | 25 - 48 | |
| *A. reinhardtii* | m | 6 - 14 | 7 - 19 | Present study |
| | f | 8 - 20 | 10 - 52 | |

It is apparent from this study that age and size structure of eel populations may be dependent on habitat and geographical differences. Analysis of eel samples from different zones in the Hacking, Hawkesbury and Clarence Rivers revealed that there were significantly higher mean age and body lengths of eels found in freshwater as opposed to the tidal areas (Figs. 2.5.2 and 2.5.3). This is predominantly due to the increasing proportions of females upstream and their longer residence in fresh water, thus increasing the proportion of older age classes in the population (Helfman *et al.* 1987; Tzeng *et al.* 1995; Oliveira and McCleave 2000). Other less influential factors include the greater distances travelled from areas of estuarine recruitment to fresh water with younger smaller eels found predominately in tidal areas, and the early migration of younger, smaller males out of tidal areas.

Clarence River eels of similar mean lengths to eels from the other rivers were younger on average in both the freshwater and tidal zones. This may be due to faster growth by this tropical species in warmer waters at a lower latitude, as evidenced by the higher percentage of undifferentiated and male eels captured in both freshwater and upper tidal areas (Table 2.5.1). The Clarence River also supports the largest commercial eel fishery of any catchment in NSW (Chapter 3). Selective removal of larger females from the upper tidal areas may further shift the sex ratios in favour of males, and alter age and size structures of both male and female populations. Jellyman and Todd (1998) hypothesised that commercial fishing pressure in Lake Ellesmere since the 1960s caused sex

ratios of *A. australis* to shift from dominance by females (4.6:1) in 1947 to dominance by males (235:1) in 1996.

It is apparent that each sex has a distinct habitat preference, making habitat availability a prime management concern. Currently in NSW, nontidal, flowing freshwater areas are closed to commercial eel trapping (Chapter 3). This study shows that it is important to maintain this closure in order to provide a refuge for the generally older, larger and potentially highly fecund female spawning stocks in these coastal catchments. However, this closure in fresh water increases the fishing pressure in the tidal areas where the males are primarily found. An increase in the size limit for legal capture from 30cm to the mean size of female differentiation (58cm) and implementation of specific habitat closures would enhance the protection of male spawning stocks (Chapter 2.3). Yield per recruit modelling (Hoyle 2002) of the eel fishery as part of collaborative studies by the Queensland Department of Primary Industries also indicate that the increased size limit would result in an increase in the relative yield per recruit to the estuarine yellow eel fishery, as well as an increase in the relative egg production of female spawning stock in NSW, while decreasing the harvest of male spawning stocks.

In summary, this is the first time that the distribution of the sexes as well as the age and size structure of a tropical anguillid species such as *A. reinhardtii* has been studied, and was found to be associated with both tidal zone and river. We believe that recruiting eels accumulate in the upper tidal reaches of catchments resulting in relatively high densities in these habitats. Males were found primarily in tidal habitats where they mature faster and migrate sooner than females. It is recommended that the minimum size limit for the recreational and commercial fisheries for longfinned eels be increased to 58 cm to allow a higher proportion of males mature and contribute to the spawning population. Females were found to be significantly larger and older than males. They were relatively abundant in all the habitats examined but were consistently most abundant in the non-tidal freshwater zone. Therefore, the existing closure of non-tidal fresh waters to eel trapping effectively protects a proportion of the female spawning stock.

## 2.6. Variation in Growth Within and Among Catchments

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### *2.6.1. Introduction*

For species that can be aged, growth can be estimated directly from size at age data, or back-calculated from otolith measurements (Francis 1990). Other methods include the calculation of individual growth through tag and recapture as well as length frequency analysis (Francis 1988; Jennings *et al.* 2001). Studies in European (*Anguilla anguilla*) (Moriarty 1983; Vollestad 1985), American (*A. rostrata*)(Gray and Andrews 1971; Harrell and Loyacano 1982), New Zealand (*A. dieffenbachii* and *A. australis*) (Harries 1974; Todd 1980) and more recently the Japanese (*Anguilla japonica*) eels (Guan *et al.* 1994; Tzeng *et al.* 2000), have shown that even within the same environment the age and growth structure of populations exhibit large variability.

Helfman *et al.* (1987) and Vollestad (1992) postulated that sexually differentiated eels develop and mature according to different life history strategies. Males develop and mature using a time-minimising life-history strategy while females use a size-maximising strategy. Therefore, it is expected that each of these strategies is based on a different growth rate. Earlier studies of *A. rostrata* growth rates have showed that males grow faster than females (Helfman *et al.* 1987), although this study was confounded because males occurring in the more productive estuarine habitats were compared with females from a wide range of habitats. Other anguillid studies have shown that growth rates of female eels are generally faster than those of males in European (Poole & Reynolds 1996), American (Oliviera 1999) and New Zealand (Harries 1974; Todd 1974) eels in similar habitats. Growth rates determined from age-length and tag-recapture analyses of eels have also been shown to differ both between and within river catchments. These results suggest an inverse relationship between growth rates and latitude (Hansen and Eversole 1984; Helfman *et al.* 1984); as well as growth rates and distance from the sea (Chisnall and Hicks 1993; Oliveira and McCleave 2002).

There have been no tag and recapture studies of *Anguilla reinhardtii* and only one previous growth study (Sloane 1984a). However this study did not distinguish between the sexes and was restricted to one catchment (Douglas River) at the southern most end of the species distribution. For yellow stage Australian longfinned eels the aims of this chapter were to: 1) assess differences in age-length based growth rates between sexes and age groups; 2) compare growth rates between the freshwater and tidal areas of the Hacking, Hawkesbury and Clarence Rivers using both age-length and tag-recapture data; and 3) compare variation in life history and habitat specific growth characteristics with available information for other anguillid species.

### *2.6.2. Methods*

#### *2.6.2.1. Sampling*

Yellow eels were captured through fishery independent and fishery dependent sampling at sites within each of the zones in the Hacking (fresh water and lower tidal zones only), Hawkesbury and Clarence River catchments (Chapter 2.1). Growth data were pooled in zones where multiple sites were sampled due to their close proximity to each other and the similar riverine characteristics. For tag- recapture analysis, the first year of fishery independent sampling involved the measuring,

tagging and releasing of eels not previously tagged. In the final year, all eels captured were measured, euthanased and their otoliths and gonads processed (Chapter 2.1). Eels were identified as either undifferentiated, males or females based on both macroscopic and histological examination (Chapter 2.3). Ages were estimated by examining sectioned otoliths (Chapter 2.4).

#### *2.6.2.2. Growth Analysis*

Mean annual growth rates were determined from the age and total length of each eel. These were calculated by dividing the total length of individuals minus the mean size of juvenile *A. reinhardtii* at the onset of annulus formation (Shiao *et al.* 2002), by the number of annuli present on the otolith (Oliveira 1997). Mean annual growth rates were determined for all eels in the study by sex (where represented), river and zone. Differences in growth rates between age groups, sexes, rivers and zones were investigated using one-way and two-way analysis of variance (ANOVA) and analysis of covariance (ANCOVA).

Annual growth rates for recaptured tagged eels were calculated by dividing the difference between the initial tagging and recapture total lengths (mm) by the time at liberty (days), multiplied by 365. Mean annual growth rates were then determined for eels of different size and age groups as well as those in each river and zone. Differences in growth rates (tag to recapture) between rivers and zones were investigated using one-way and two-way ANOVA tests and GROTAG analysis (Francis 1988) using a linear growth model. Growth of sexes could not be compared from the tagging data because of an insufficient sample size of recaptured males.

Data presented in this study are expressed as mean ± SE. When required, growth data were log transformed to satisfy normality assumptions prior to parametric analysis. ANOVA and ANCOVA analyses used the Statistica 6 (Statsoft) software package with a significance (p) value of less than 0.05 considered statistically significant (Zar, 1974).

### ***2.6.3. Results***

#### *2.6.3.1. Age-Length Growth*

Ages were determined from the otoliths of 740 individuals. Longfinned eels 380 to 1389mm in total length ranged from 5 to 52 years of age. Figure 2.6.1 shows the age-length regression plot of data (sexes combined) from the Hacking, Hawkesbury and Clarence Rivers ($y=473.\ 95 + 10.64x$, $r^2=0.26$, $p<0.01$). While there is relationship between age and total body length there are substantial differences in length for a given age (eg. 80cm length range for the 25 year old eels). Large variability was also found when the combined data were divided up into zones within each catchment. For example eels from the lower tidal zone of the Clarence River varied up to 62cm in length at a given age, while eels from the freshwater zone of the Hacking River varied by as much as 34cm. When the data from Figure 2.6.1 was divided up into sexes there was a significant relationship between age and length for both undifferentiated ($y=467.28 + 3.17x$, $r^2=0.04$, $p=0.03$) and female eels ($y = 589.12 + 6.42x$, $r^2 = 0.15$, $p<0.01$) but not for the males ($y = 520.12 + 0.43x$, $r^2 = 0.03$, $p=0.79$). The low coefficients of determination indicate that the age-length relationship was weakened by the high variability between individuals.

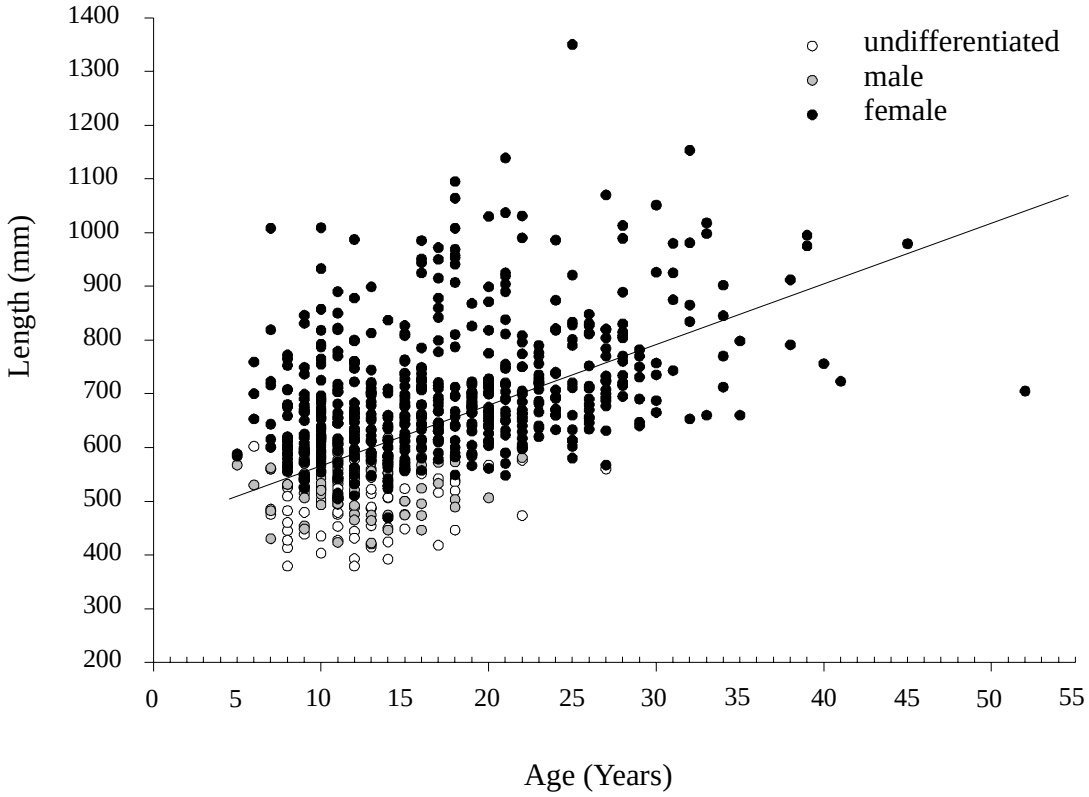


**Figure 2.6.1.** Age-length relationship for undifferentiated (n=98), male (n=75) and female (n=567) *A. reinhardtii* captured in the Hacking, Hawkesbury and Clarence Rivers.

For the age range of eels sampled in this study, the estimated mean annual growth rate for *A. reinhardtii* (all sexes pooled) was 42.32 ± 0.54 mm/yr$^{-1}$. Mean annual growth rates of undifferentiated (39.31 ± 1.7 mm/yr$^{-1)}$, male (42.59 ± 1.95 mm/yr$^{-1}$) and female eels (42.97 ± 0.71mm/yr$^{-1}$) were not significantly different (ANOVA, $F_{(2, 737)}$=1.06, p=0.34). However significant differences were found between the sexes when age groups (≤15 and >15 years) of eels were compared. Figure 2.6.2 shows that there was a rapid decline in mean annual growth rates from age 5 (106mm/yr$^{-1}$) to age 15 (34mm/yr$^{-1}$). For eels aged 15 and over the rate of decline in growth rate was lower, with high variability in the older age groups (>30). This variability was probably due to small sample sizes of older age groups. Mean annual growth rates of 5 to 15 year old males from tidal areas were compared with growth rates of females from the same age group and areas in Figure 2.6.3. Both the sexes showed a decline in growth rate with age. An analysis of covariance (ANCOVA) showed that these females had a significantly higher mean growth rate than the males ($F_{(1, 312)}$=80.35, p<0.01).

An ANOVA showed that the female eels aged between 5 and 15 had significantly higher mean growth rates than female eels aged greater than 15 years (rivers and zones combined) ($F_{(1, 566)}$=673.6, p<0.01). Therefore to accurately compare the effects of the different rivers and zones on estimated mean growth rates only sampled female eels from the two age groups were analysed. This eliminated any confounding effects of sex and sample size (sample sizes of undifferentiated and male eels in the >15 age group were much smaller than those in the <15 age group).

The estimated mean annual growth rates of female eels in the two different age groups (5-15 and >15 years) within the freshwater, upper tidal and lower tidal zones in the Hacking, Hawkesbury

and Clarence Rivers are summarised in Table 2.6.1. There were no significant differences in growth rates between upper and lower tidal areas for the two age groups in the Hawkesbury and Clarence Rivers. Therefore analyses were done using only freshwater and tidal (upper and lower pooled) zones. A two-way ANOVA showed that mean annual growth rates for female eels aged 5 to15 were not significantly different between zones, and not significantly different among rivers (zones: $F_{(1, 247)}$= 2.84, p=0.01; rivers: $F_{(2, 247)}$ =2.05, p=0.13). For female eels greater than 15 years there were significant differences in growth rates both between zones ($F_{(1, 304)}$=35.90, p<0.01) and among rivers ($F_{(2,304)}$= 9.65, p<0.01). Post-hoc multiple comparison tests revealed that mean annual growth rates were significantly higher in the Clarence River than those in the other two rivers for both age groups (p<0.01), and mean annual growth rates in the tidal zones were significantly higher than those in the freshwater zone for both age groups (p<0.01).

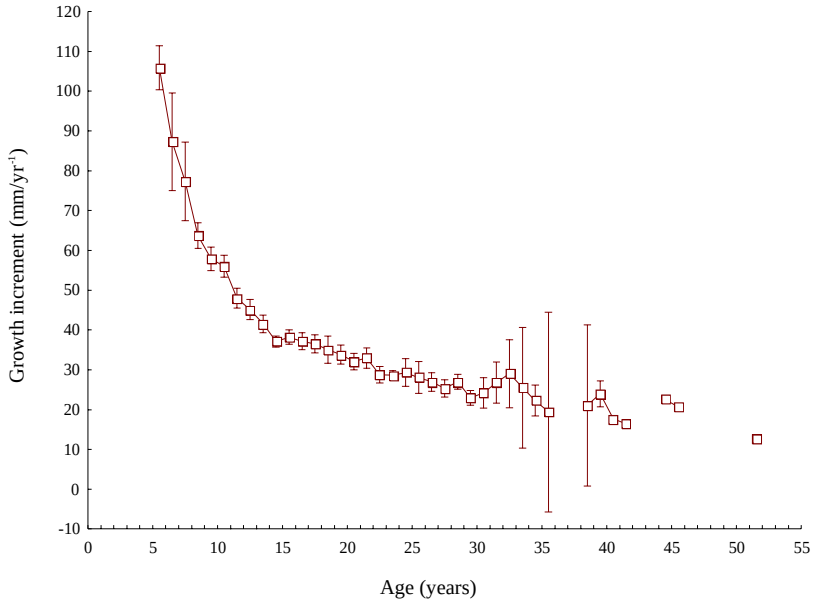


**Figure 2.6.2.** Mean calculated growth increment ± standard error of aged *A. reinhardtii* (n=740).

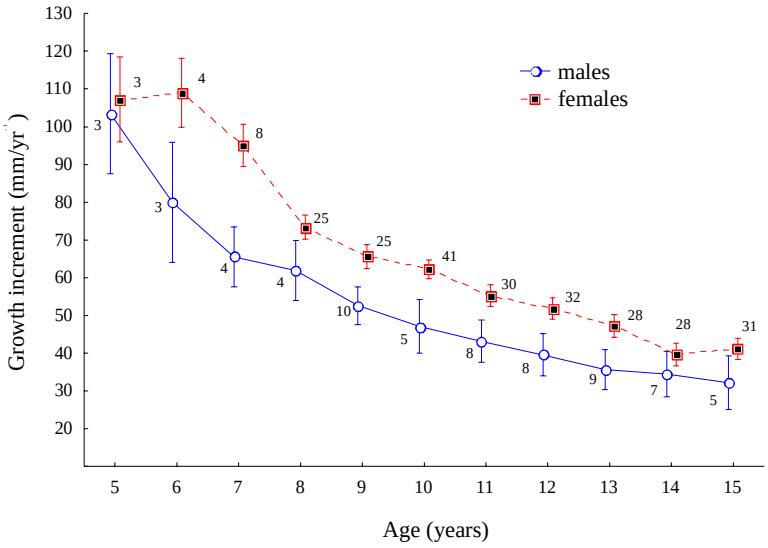


**Figure 2.6.3.** Mean calculated growth increment ± standard error (number of replicates beside each data point) for male and female *A. reinhardtii* in the 5 to 15 age group.

**Table 2.6.1.** Mean annual growth rates ± standard error (mm/yr-1) for female *A. reinhardtii* eels (aged 5-15 and > 15 years), in the freshwater and tidal zones of the Hacking, Hawkesbury and Clarence Rivers.

| | River | | | | | |
|---|---|---|---|---|---|---|
| **Zone** | **Hacking** | | **Hawkesbury** | | **Clarence** | |
| | 5-15 | >15 | 5-15 | >15 | 5-15 | >15 |
| **Fresh** | 42.40±4.39 | 30.36±0.85 | 46.63±6.81 | 25.89±1.05 | 41.86±5.76 | 33.24±1.32 |
| **n** | 12 | 76 | 5 | 51 | 7 | 32 |
| **Upper** | N/A | N/A | 49.70±2.20 | 31.59±0.80 | 65.49±2.64 | 34.91±1.53 |
| **n** | | | 52 | 81 | 36 | 22 |
| **Lower** | 45.46±3.93 | 36.94±1.50 | 52.75±4.40 | 33.46±1.91 | 62.08±3.03 | 35.39±1.99 |
| **n** | 15 | 25 | 13 | 14 | 113 | 13 |

### *2.6.3.2. Tag-Recapture Growth*

Figure 2.6.4 illustrates the relationship between individual growth and days at liberty. While the average days at liberty for recaptured eels was 255 days one individual from the Hawkesbury catchment was at liberty for 720 days. The highest growth rate of 269 mm/yr$^{-1}$ was achieved by a female eel that was at liberty in the lower tidal zone of the Hacking River. In examining the tag-recapture growth rates between rivers and among zones only female eels were analysed due to the insufficient numbers of male eels. Only the eels that were recaptured in the zone they were originally tagged in were used. An ANOVA determined that there was no significant differences in growth rates between age (5-15 and >15) ($F= 0.59$, $p=0.44$) or size (>400, >600, >800, >1000) ($F=0.34$, $p= 0.79$) groups. Therefore all age and size group data for females were pooled for growth rate comparisons between rivers and among zones. The stress of collecting and tagging has been shown to affect growth in European (Berg, 1986) and American (Oliveira, 1996) eels. Therefore, recaptured eels with a period of liberty (<90 days) were not included in the growth data analysis.

The mean growth rate for recaptured female eels (rivers and zones combined) in this study was 35.42 ± 4.51 mm/yr$^{-1}$ for the ≤15 age group and 31.42 ± 0.75 mm/yr$^{-1}$ for the >15 age group, based on age/length analysis. A two-way ANOVA showed that growth rates in tidal zones (upper and lower pooled) were significantly higher than those of the freshwater zones ($F_{(1, 77)}=14.99$, $p<0.01$). GROTAG analysis (Fig. 2.6.5) also resulted in different linear models for the growth data from each zone, indicating that growth rates were highest in the lower tidal zone and lowest in the freshwater zone.

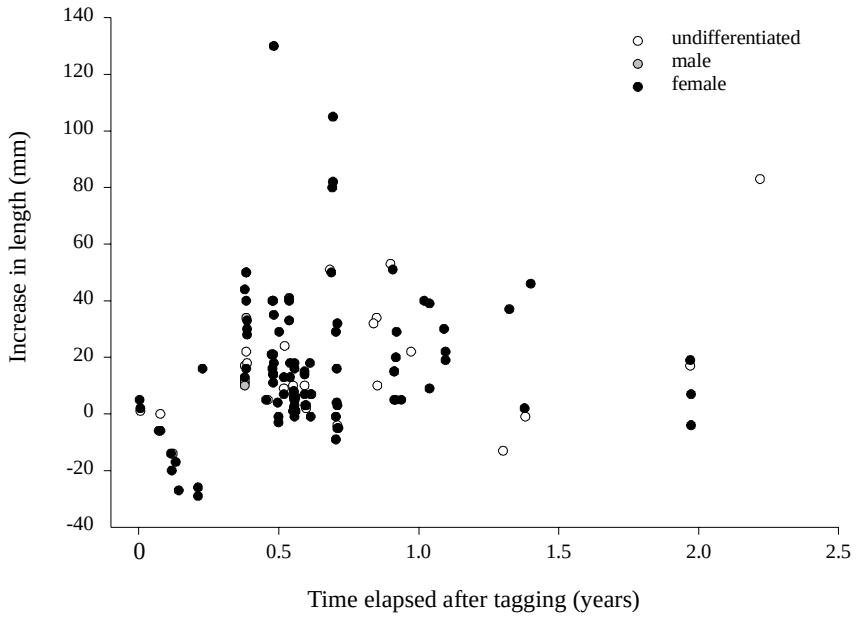


**Figure 2.6.4.** Growth rates (increase in length) of tagged and recaptured undifferentiated (n=26), male (n=3) and female (n=132) *A. reinhardtii* from the Hacking, Hawkesbury and Rivers.

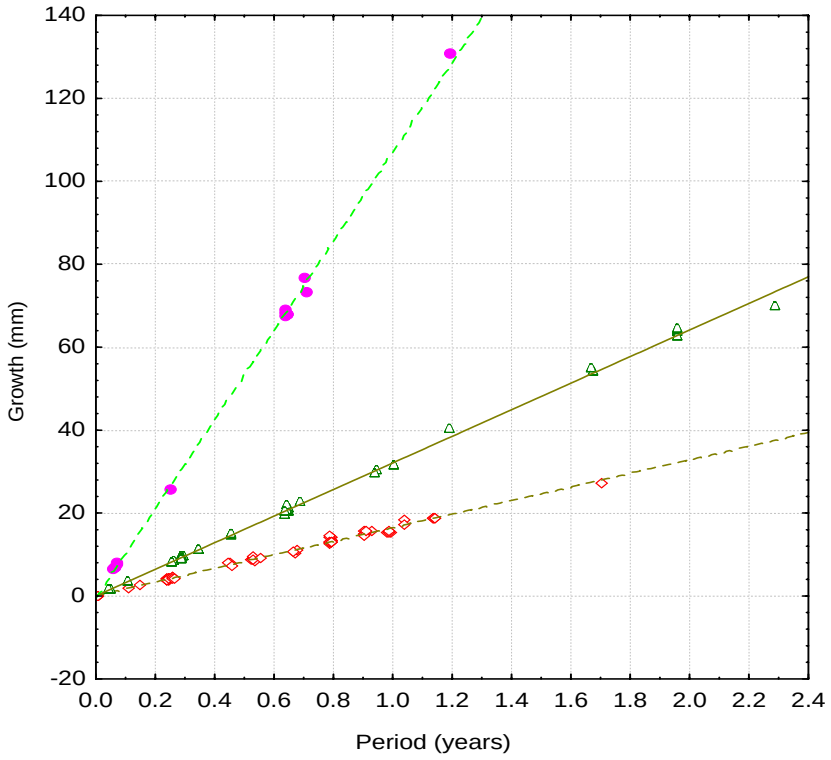


**Figure 2.6.5.** Growth data generated by the GROTAG model of tag-recapture data. Diamonds = recaptures from the freshwater zone, triangles = recaptures from the upper tidal zone and circles = recaptures from the lower tidal zone.

### *2.6.4. Discussion*

Growth rates for eels have traditionally been calculated through age at length analysis (Tesch 1977; Moriarty 1983) or from individual growth based on tag-recapture data (Francis 1988). From age-length analysis, studies have assumed linear growth for the European (Sinha and Jones 1967; Barak and Mason 1992; Gordo and Jorge 1991) American (Hansen and Eversole 1984) and New Zealand (Chisnall and Hayes 1991) eels. Linear growth is at variance with the classical growth models of fish, where growth rate declines as the asymptotic length is approached (Jennings *et al.* 2001). Jellyman (1997) found that linear growth rates examined in *A. dieffenbachii* and *A. australis* resulted from the use of fyke nets rarely collecting individuals less than 30cm, and the fact that anguillids migrate to spawn as maximum length is approached. Thus linear growth seems more suitable for describing the course of growth in these species. In this study there were no eels captured below 340 mm in total body length or <5 years of age. This may be due to selectivity of the traps and fyke nets and/or habitat preferences by smaller individuals.

For tag-recapture growth analysis some of the eels at liberty for a considerable amount of time (>90days) achieved relatively low growth rates. In particular there were four eels from the freshwater zone of the Hawkesbury River that grew less than 20mm after being at liberty for approximately two years. Negative growth may be attributed to measurement error, shrinkage and/or stress at tagging and recapture (Berg 1986). The eels long cylindrical shape and extensive mucous covering as well as the two separate measurements (tagging and recapture) collected from different workers may have resulted in measurement error. In regards to the effect of stress on growth, eels were handled quickly and as little as possible and were held in recovery bins of fresh water after tagging, allowing full recovery before being returned to the water. Clove oil was used as an anaesthetic in this study as it has been shown to have a wider safety margin at different concentrations than other prescribed anaesthetics (Walsh and Pease 2002). Therefore apart from possible measurement error it is more than likely that minimal growth rates achieved by eels in this study were the result of differences in habitat and/or life history stages of individuals.

The average annual growth of *A. reinhardtii* calculated from age-length analysis (42.32 ± 0.54 mm) was typical of other anguillids. A significant feature of the sampled population was the high longevity (up to 52 years) and the highly variable growth rates, even for individuals within the same habitat. Chisnall and Hicks (1993) found mean annual growth rates for *A. dieffenbachii* ranged from 12 to 36mm, while mean annual growth rates for *A. anguilla* (Poole and Reynolds 1996) and *A. rostrata* (Helfman *et al.*, 1984) were 20-46mm and 34-62mm respectively. The mean annual growth rates of the sampled *A. reinhardtii* population based on both age-length and tag-recapture data was 31.42±0.75 and 35.42 ± 4.51mm/yr$^{-1}$ respectively. Both Burnet (1969) and Chisnall and Kalish (1993) reported similarities and differences in mean growth rates between absolute growth (tag-recapture) and growth estimated from length at age. No attempt in this study was made to quantitatively compare these two methods as growth calculated from length at age includes growth over the entire life span of the eel, whereas growth determined by tag-recapture is limited to just one portion of an extremely variable life history (Francis 1988). However these two different analyses did provide estimates of grow that varied consistently among catchments and zones.

Growth rates based on age-length data for *A. reinhardtii* in the younger age group (5 to 15 years) were significantly higher than growth rates in the older age group (>15 years). The rapid decline of growth rates within the younger age group may be attributed to the loss of faster growing eels that migrate out from the population at earlier ages (Helfman *et al.* 1987); and the shift in energy away from somatic growth in favour of gonadal development when eels metamorphose to the migratory silver phase (Oliveira and Mcleave 2002). This may explain why no significant differences in

growth rates were found between age and size groups sampled from tag-recapture data, due to the low representation of eels younger than 15 years and less than 600mm in length.

For eels aged 5 to 15 years, the estimated growth rate for females was 57mm/yr$^{-1}$, an average of 10mm/ yr$^{-1}$ faster than male eels of similar ages (Fig. 5.3). Many previous studies based on age/length analysis and back-calculation of otolith measurements have shown that females achieve a faster growth rate than the males in the European (Panfili *et al.* 1994; Aprahamian 1988; Poole and Reynolds 1996), American (Oliviera 1997; Oliviera and McCleave 2002) and New Zealand longfinned (Harries 1974; Todd 1974) eels. Through back-calculation, Oliveira and McCleave (2002) showed that female American eels grew faster than males after age 4 and had a slower reduction in growth rate with age. These authors hypothesised that female eels benefit from growing rapidly to a larger size (increased fecundity and niche breadth) while males use a risk-averse strategy which maintains sub-maximum growth rates to enhance survival to a smaller size at maturity and migration.

A difference in sex ratios or age structure is often associated with the growth rate of a population (Oliveira and McCleave 2002). Due to the lack of males found in freshwater areas, only female eels from the two different age groups (5-15 and >15) were assessed independently to determine any differences in mean annual growth rates between rivers and among zones. Analysis of age-length data showed that female eels from the Clarence River had a significantly higher mean growth rate than the Hacking or Hawkesbury Rivers, with the tidal zones having the highest growth rate of all zones in all rivers. Along with sex ratios and age structures other factors such as geographical distribution and habitat preferences may also affect individual growth rates. When rivers were compared, the age-length data suggested that the mean annual growth rate of female eels (>15 years) decreased with increasing latitude. In studies of American eels, it was found that eels from the southern latitudes (Hansen and Eversole 1984; Harrell and Laycano 1984; Helfman *et al.* 1984) grew faster than their northern counterparts in similar bodies of water due to the former being subjected to longer growing seasons, primarily as a result of higher annual mean water temperatures (Harrell and Laycano 1984).

Water temperature is one of the most important factors causing differences in habitat-specific growth in eels (Chisnall and Hicks 1993). Low water temperatures have been shown to reduce eel mobility, foraging and feeding, hence lowering growth rates (Sinha and Jones 1967; Jellyman 1991; Holmgren 1996; Graynoth and Taylor 2000). Sloane (1984a) found that the main period of growth for both *A. australis* and *A. reinhardtii* coincided with an increase in water temperatures (15-22°C) with little growth below <10°C. Mean temperatures in the tidal zones of the three rivers in this study rarely fell below this lower limit. However, in the freshwater zones winter water temperatures often decrease below this minimum, particularly in the Hacking and Hawkesbury Rivers.

For both methods of estimating growth the results generally agree with other studies that have compared anguillids in different habitats showing that high growth rates are often associated with tidal or estuarine areas (Paulovits and Biro 1986). Hansen and Eversole (1984) found that annual growth rates of *A. rostrata* from the brackish water areas of Cooper River were 5-11cm greater at ages 1-4 than in the freshwater areas (Harrell and Laycano 1982). Helfman *et al.* (1984) also found that American eels from the Altamaha river, Georgia, had higher growth rates in brackish water than in fresh water.

A brackish water environment generally leads to fast growth rates, due to stable water temperatures and more abundant food supplies. Chisnall & Hicks (1993) found that the growth rates of *A. dieffenbachii* in the forested streams of the upper catchments were considerably less than the lower pastoral rivers. Streams in native forests tend to have lower food availability (low fish and invertebrate biomass) than pastoral streams (Hanchett 1990). In particular, relatively low

abundances of fish in the upper catchments may limit piscivory, and could impair growth of larger eels compared with lower catchments where fish are more plentiful (Chisnall & Hicks 1993).

As well as food biomass, lower growth rates may also be associated with density-dependent factors such as intraspecific competition and fishing pressure. Jellyman (1997) in comparing two series of lakes with hydro-electric dams in New Zealand found that the differences in growth rates of *A. anguilla* and *A. dieffenbachii* between these lakes were principally due to differences in eel density. He argued that the most likely mechanism for high densities to affect growth is through the reduction in food availability, and that this factor would probably not be limiting at low densities. Vollestad and Jonnson (1986) found that an increase in the density of European eels in a system decreased the growth rate of both sexes. Walsh *et al.* (2004) found that more *A. reinhardtii* were caught per trap/day in freshwater and upper tidal areas of the Hacking, Hawkesbury and Clarence Rivers than the lower tidal areas. In these areas, high concentrations of larger older eels in the less productive areas of the upper catchment may reduce overall growth rates.

Fishing pressure has been found to be associated with changes in anguillid growth rates, both by altering sex ratios within catchments, and by lowering biomass density. Removing the larger, typically older and therefore slower growing females from tidal areas over time may result in the selection of a population of fast growing individuals (Helfman *et al.* 1987). Chisnall and Hayes (1991) suggested that growth rates of *A. australis* in areas of increased fishing pressure (up to four times higher) were likely to be the result of decreased eel densities. The lowest mean number of *A. reinhardtii* caught per trap/day were recorded in the lower tidal areas of the Clarence River, which coincides with the highest mean growth rates determined in this study. Therefore, commercial eel fishing in the Clarence River, the most heavily fished catchment in NSW (Chapter 3), may be associated with these faster growth rates. However it is likely that fishing pressure is only one of many complex interactive factors contributing to the highly variable growth of this species.

## 2.7. Genetic Stock Structure

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### *2.7.1. Introduction*

Knowledge of population subdivision is necessary for the development of more precise management strategies and to predict whether locally depleted stocks will be recolonised by connected populations (Shacklee 1983; Stephenson 1999). Additionally, it has become clear that few marine species exist as single discrete populations, which may react differently to exploitation (Carvalho and Hauser 1994) or have developed distinct evolutionary trajectories with unique adaptive potentials (Phillips and Moore 2003). Indeed it has been shown that there are many forces that shape marine populations, including oceanographic currents, climate, hydrodynamics and topolography of natural barriers (Cowen *et al.,* 2000), together with life-history factors comprising length of larval stage, physiological tolerances, swimming ability and location of spawning ground (Ruzzante *et al*. 1996; Shulman 1998; Ruzzante *et al*. 1998).

The role of population genetics in defining heterogeneity in fisheries resources is well documented (Ovenden 1990; Utter 1991; Carvalho and Hauser 1994; Ward and Grew 1994; Furguson 1994). Genetic techniques allow for the non-lethal collection and delineation of reproductive isolation and gene flow among populations using naturally occurring genotypes, eliminating the costs of physical tags (Shaklee and Bentzen 1998). Neutral genetic markers also eliminate problems associated with local environmental conditions and regional selective forces. In the absence of such information, management strategies may not achieve long-term sustainability or conservation goals (Ovenden 1990).

#### *2.7.1.1. Molecular Markers*

Many molecular markers have been used to delineate population structuring in fish populations, however all have drawbacks. Allozyme electrophoresis is hampered by a limited number of polymorphic loci that can be screened (Ferguson 1994) and the absolute amount of accessible genetic variation is low, therefore resolution may be insufficient to detect subtle population structuring (Ward and Grew 1994). Mitochondrial DNA (mtDNA) is extensively used in marine stock assessment, and remains a useful tool in delineating structuring. Due to its mode of inheritance (maternal) mtDNA has one quarter the effective population size of nuclear DNA, thereby accentuating the effects of genetic drift and leading to greater genetic differences between populations. Additionally the mutation rate of the mtDNA control region is thought to be five to ten times higher than that of single copy nuclear DNA. However, mtDNA has a limitation in that it represents a single locus and due to its maternal inheritance, significant gene flow may be indistinguishable if it is primarily paternally dispersed.

#### *2.7.1.2. Microsatellite Markers*

Microsatellites exhibit attributes that make them particularly suitable as genetic markers in fisheries research (O'Connell and Wright 1997). Microsatellite loci are numerous throughout eukaryotic genomes, allowing the development of a potentially unlimited supply of markers (Wright and Bentzen 1994). Microsatellites also exhibit extremely high levels of polymorphism, which can increase the power of analysis (Jarne and Lagoda 1996; Estoup and Angers 1998). Additionally,

new statistical techniques (assignment tests) allow the comparison of genotype frequencies instead of single locus comparisons, significantly increasing the power of analysis (Paetkau *et al*. 1995; Roques *et al*. 1999).

#### *2.7.1.3. Eel Population Structuring World Wide*

All anguillids conform to a single life-history strategy, that is long distance catadromous migration from freshwater and estuarine nursery and adult habitats to oceanic spawning grounds near abyssal sea-mounts (Schmidt 1925; Fricke and Kaese 1995; Fricke and Tsukamoto 1998). These migrations may be up to 7000km from origin to spawning ground, with individuals from multiple river systems or islands converging on a common spawning location. By comparison, most other fish have life-histories or dispersal patterns which limit gene-flow to some degree. The dispersal capabilities of many species are far less than their geographic distribution, resulting in gene-flow only between populations of close proximity. Equally, geographically distant populations are likely to become isolated purely by distance alone, while proximate populations are more likely to be genetically similar. The level of genetic subdivision between populations will depend on the amount and rate of gene-flow.

Due to their considerable dispersal ability, it was assumed that eels would conform to genetically uniform populations with high levels of gene-flow. This hypothosis has been supported by studies of North Atlantic eels including *Anguilla rostrata* (Avise *et al*. 1986), *Anguilla anguilla* (Pantelouris and Payne 1968; Pantelouris *et al*. 1970; Pantelouris *et al*. 1971; Williams *et al*. 1973; Koehn and Williams 1978; Avise *et al*. 1986; Lintas *et al*. 1998; Avise *et al*. 1990) and the Japanese eel *Anguilla japonica* (Sang *et al*. 1994). However, the hypothesis of panmixia (no genetic structuring) has been challenged with the development of more sensitive genetic markers (microsatellites) (Daemen *et al*. 2001; Wirth and Bernatchez 2001; Maes and Volckaert 2002). Although the genetic differences demonstrated for eels so far are weak compared to some species, they are significant and suggest that eel populations are likely to be structured. Moreover, several studies have highlighted what appear to be clines shaped by natural selection (Williams, *et al*. 1973; Koehn and Williams 1978; Maes and Volckaert 2002). These latitudinal variant frequency clines suggest that there may be significantly different selectional forces operating between populations.

It is currently assumed that longfinned eels (*Anguilla reinhardtii*) conform to a single discrete panmictic stock throughout their geographic range. However, given the species is widely dispersed throughout the south Pacific, with all spawning adults expected to migrate to abyssal, oceanic sea mounts near New Caledonia (Aoyama *et al.* 1999) to reproduce at a similar time, it is likely that the differences in migration timing and spawning location may create population subdivision. This hypothesis is supported by the long duration of recruiting glass eels into coastal estuaries (Beumer and Sloane 1990; Shiao *et al.* 2002; Silberschneider In preparation). The aim of this component of the study is to determine whether *Anguilla reinhardtii* has any spatial or temporal genetic structure based on analysis of microsatellite DNA.

## 2.8. Methods

### *2.8.1. Sampling Strategy*

A total of 447 glass and adult eel samples were collected from nine sites along the east coast of Australia and from New Caledonia between 1998 and 2000 (Figure 2.7.1 and Table 2.7.1). Australian sampling locations were well spaced along the east coast, covering the geographic range of *A. reinhartii* in Australia. Glass eels were sampled from the Pambula, Port Hacking and Bellinger Rivers in New South Wales by Pease *et al.* (2003), and from the Albert, Burnett, Fitzroy,

Barron, Haughton and Mulgrave Rivers in Queensland by Adrian Collins (McKinnon et al 2002). Samples were collected for three years from the Bellinger River and Port Hacking to determine temporal variation in spatial structuring of *A. reinhartii.* All other sampling was conducted in 1998 unless specified. Tissue samples were collected from yellow-stage *A. reinhartii* in New Caledonia during 2000 by Christine Poellabauer as part of a larger ecological study of the freshwater fish fauna of New Caledonia. These samples were used in our study to assess longitudinal structuring across the South Pacific. All specimens were identified morphologically.

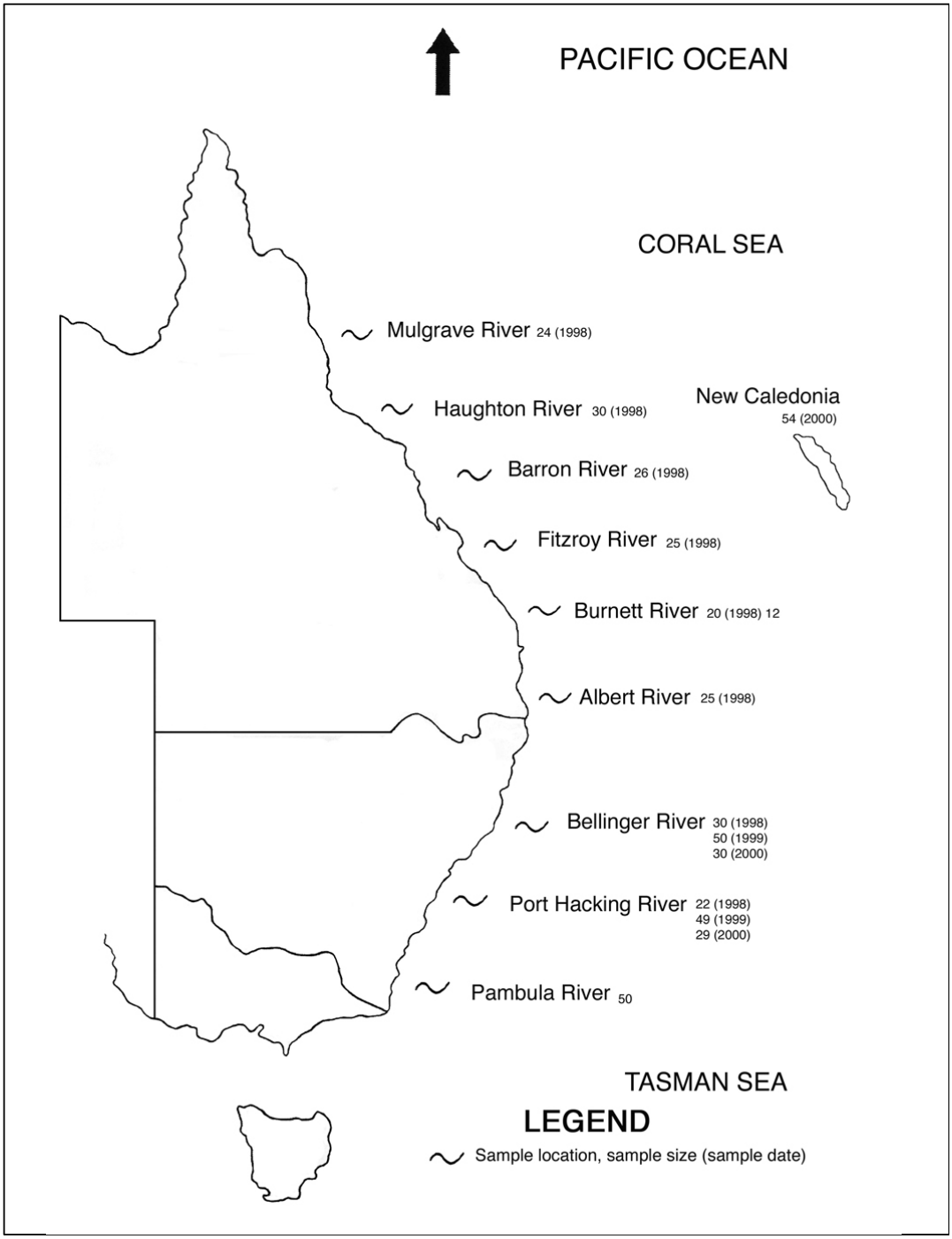



**Figure 2.7.1.** Map showing sample locations along with sample size and date at each location.

**Table 2.7.1.** Sample sizes per location for each sampling year.

| Sample sites | 1998 | 1999 | 2000 |
|---|---|---|---|
| Mulgrave River | 24 | | |
| Haughton River | 30 | | |
| Barron River | 26 | | |
| Fitzroy River | 25 | | |
| Burnett River | 20 | 12 | |
| Albert River | 25 | | |
| Bellinger River | 30 | 50 | 30 |
| Port Hacking | 22 | 49 | 29 |
| Pambula River | 50 | | |
| New Caledonia | | | 54 |

*2.8.1.1. Genomic DNA Extraction*

Glass eels, fin clips and tissue samples were stored in 70% ethanol and maintained in a -20 $^{o}$C freezer for the duration of the study. Total DNA was extracted from all samples using the high-throughput silica binding technique (Elphinstone 2003). Digestion buffer 500µl, (100 mM NaCl, 50 mM Tris. Hcl, pH 8, 10 mM EDTA, 0.5% sodium dodecyl sulphate and 200 µg proteinase K (Roche Diagnostics, Germany) was added to each sample and digested with regular mixing for 3-4 hours at 55 $^{o}$C. Digests were centrifuged for 1 min at 12,000 *g* to precipitate cellular debris and reduce blockage in the filtration membrane. Aliquots of 50 µ*l* were transferred to 96 well microtitre trays (Millipore MAHV S45-10) and mixed with 150 µ*l* of binding buffer (6 M sodium iodide saturated with 0.2 M sodium sulphate) and 20 µ*l* etched silica solution (silica fines (Merck) etched in nitric acid and eluted in milliQ $H_20$). The solution was filtered through the filtration plates via a vacuum manifold system (MAVM0960R, Millipore) to remove cellular debris. The filtrate was washed with ice-cold buffer (200 µ*l* 50% ethanol, 50 mM NaCl, 10 mM Tris. Hcl pH 7.4, and 0.5 mM EDTA). The wash step was repeated with the vacuum applied for 5 minutes. 200 µ*l* elution buffer (10 µ*l* mM Tris. HCl pH8, 1mM EDTA) was filtered into a fresh collection 96 well plate. However, due to problems associated with PCR inhibitors in eel skin and mucus (see section 4.2.3), the method was abandoned and no samples extracted using the silica technique were used in PCR reactions for this study.

Total genomic DNA (gDNA) was extracted from all tissues using standard phenol-chloroform purification adapted from (Bothwell 1990). Tissue was digested in 20µ*l* proteinase K (10mg/ml) in 0.5ml proteinase K digestion buffer (100mM NaCl, 50mM Tris, 10mM EDTA, 0.5% sodium dodecyl sulphate - SDS) over 3-4 hours at 55 $^{o}$C with regular mixing.

Two phenol-chloroform purification steps with 0.5ml phenol:chloroform (1:1) were completed before a single 0.5ml chloroform extraction (Sambrook 1989). gDNA recovery consisted of standard ethanol precipitation. 3M sodium acetate (1/10 volume) and absolute ethanol (2 volumes) were added and incubated at –20 for 15 minutes before centrifugation at 10, 500 rpm for five minutes at 5 $^{o}$C (Beckman J21M/E). The DNA pellet was washed by vortex in 0.5 ml 70% ethanol and eluted into 0.5 ml Te buffer (10mM Tris.Cl, 1mM EDTA, pH 8.0). gDNA was visualised on 1% EBTR stained agarose gel using a Novaline GDS Gel Documentation System.

A negative control was included in each extraction run of 24 samples. All gDNA was transferred to master trays consisting of 96 well microtitre trays, with 2µ*l* aliquots placed into 96 well trays for PCR. DNA extractions were performed by the author and Laura Homer. DNA for all the PCR amplification used in this study was extracted using phenol-chloroform protocol outlined above.

#### *2.8.1.2. PCR Inhibitors in Eels*

Amplification through polymerase chain reaction (PCR) was inconsistent in gDNA samples where the silica binding method of DNA extraction was used. Amplification across all primers was affected, causing reactions to fail. Samples that amplified in one reaction, failed in repeat reactions. These results may be due to the amount of inhibitor present in the reaction at the time. However, dilution trials whereby a volume of gDNA was eluted by a factor of ten for each dilution for a total of 8 dilutions, failed to amplify consistently for all samples trialed. Eel tissue was then extracted using standard phenol-chloroform procedures. Samples extracted using phenol-chloroform worked consistently in trials and all samples used for the rest of this study were extracted using this technique. The high throughput silica binding technique was abandoned due to its inability to remove PCR inhibitors.

#### *2.8.1.3. Microsatellite Primers*

A total of six microsatellite primer sets produced bright resolvable bands. Of the six resolvable primer pairs, four pairs (AjTR-27, AjTR-37, AjTR-42, AjTR-45) (GenBank accession numbers AB051092, AB051094, AB051097, AB051100) were characterised for the Japanese eel *Anguilla japonica* (Ishikawa *et al.* 2001) and two pairs (Aro054 and Aro095) for the American eel *Anguilla rostrata* (Wirth and Bernatchez 2001) (GenBank accession numbers AF237896-AF237897). Both Aro054 and Aro095 were modified from the original primers of (Wirth and Bernatchez 2001) to increase annealing temperature and provide a more robust PCR product. The forward primer Aro054 was extended by five bases at the five prime end, while the reverse primer was extended by eight bases at the five prime end. The forward primer of Aro095 was extended in the five prime end by five bases and in the reverse primer by five bases again at the five prime end. The extension of both primer pairs increased annealing temperature from 55$^{o}$C to 60$^{o}$C. Primer design was conducted using NAR oligo software (Rychlik 1989).

#### *2.8.1.4. Statistical Analysis*

Conformity to Hardy Weinberg equilibrium was calculated using Genepop version 3.4 (Raymond and Rousset 1995) for each sample at every locus using Fisher's exact test, including heterozygote deficiency, heterozygote excess and global tests. Markov-chain parameters included 1000 dememorization, with 100 batches and 1000 iterations per batch. Linkage disequilibrium was also calculated using Genepop 3.4 using the same Markov-chain parameters. Observed heterozygosity ($H_{obs}$), expected heterozygosity ($H_{exp}$), and number of alleles per locus were also calculated. Genetic structure was assessed using pair-wise Chi-squared comparisons (Zar 1974) of $F_{ST}$ (Weir and Cockerham 1984) to test for conformity to Hardy-Weinberg equilibrium (Haldane 1954), where $F_{ST}$ is a standard measure of genetic diversity based on the frequency of alleles within and between populations. All Chi-squared significance values were adjusted for multiple tests using the Bonferroni technique as per Rice (1989).

### ***2.8.2. Results***

#### *2.8.2.1. Level of Polymorphism and Hardy-Weinberg Equilibrium (HWE)*

A significant number of samples could not be reliably genotyped and are currently being re-genotyped and analysed, thus were not ready to be included in this report. Allelic diversity varied for all six loci, from 10 alleles for locus (AjTR-27), 12 (Aro095), 15 (AjTR-42), 19 (Aro054), to 21 (AjTR-37) and 28 for locus (AjTR-45) (Table 2.7.2). Tests for Hardy-Weinberg equillibrium of observed and expected genotypic proportions suggested a homozygous excess (heterozygote deficit) at five out of six loci (AjTR-37, AjTR-42, AjTR-45, Aro054 and Aro095), which is

reported in many studies using microsatellite loci on wild populations (Ovenden and Street 2003). The phenomenon is still poorly understood, though Lessios (1992) and Bagley *et al.*, (1999) provide insights into the principles of the problem and its relevance to microsatellite loci. Homozygous excess may be an indicator for the presence of null alleles and further testing for null alleles is planned after the present genotyping is complete. Heterozygous deficit may also be caused by a Wahlund effect, where one sampling event may have sampled several populations. Heterozygous excess was not demonstrated for any loci or any population. Exact tests for linkage disequilibrium (locus independence) demonstrated no significant locus comparisons. It is concluded therefore that there is no significant association among all six loci.

*2.8.2.2. Genetic Differentiation*

Out of 45 pair-wise Chi-squared comparisons for all loci, 22 demonstrated highly significant differences ($P \leq 0.0002$) between locations after sequential Bonferroni tests of significance (Rice 1998) at the 5% level (Table 2.7.3). Highly significant differences were shown between locations Pambula-Port Hacking, Albert-Port Hacking, Albert-Bellinger, Albert-New Caledonia, Albert-Barron, Albert-Burnett, Mulgrave-Port Hacking, Mulgrave-Pambula, Mulgrave-Bellinger, Mulgrave-New Caledonia, Mulgrave-Barron, Mulgrave-Burnett, Haughton-Port Hacking, Haughton-Pambula, Haughton-Bellinger, Haughton-New Caledonia, Haughton-Barron, Haughton-Burnett, Fitzroy-Port Hacking, Fitzroy-Bellinger, Fitzroy-New Caledonia and Fitzroy-Barron. Another seven locations showed significant differences ($P \leq 0.05$) before adjustment for multiple tests. This heterogeneity was also supported by 45 pairwise $F_{ST}$ comparisons ($F_{ST} \geq 0.05$; 1000 iterations), demonstrating concordance with ten out of the 22 tests. Concordance between both tests suggests that moderate but highly significant heterogeneity may be present.

**Table 2.7.2.** Sample size (n), number of alleles, observed hereozygosity (Ho), expected heterzygosity (He) and number of samples that genotyped for each locus and population (Ng).

| | AjTR-27 | AjTR-37 | AjTR-42 | AjTR-45 | Aro054 | Aro095 |
|---|---|---|---|---|---|---|
| **Port Hacking** | *n = 100* | | | | | |
| $N_g$ | 93 | 80 | 81 | 77 | 66 | 92 |
| $H_o$ | 35 | 69 | 29 | 54 | 58 | 46 |
| $H^e$ | 35.19 | 72.42 | 35.94 | 67.54 | 58.45 | 46.17 |
| No. of Alleles | 5 | 20 | 12 | 15 | 16 | 3 |
| **Pambula** | *n* = 50 | | | | | |
| $N_g$ | 18 | 14 | 45 | 46 | 43 | 46 |
| $H_o$ | 12 | 13 | 21 | 37 | 40 | 20 |
| $H^e$ | 11.88 | 12.51 | 18.31 | 40.37 | 37.36 | 28.26 |
| No. of Alleles | 5 | 10 | 6 | 15 | 13 | 6 |
| **Bellinger** | n = 110 | | | | | |
| $N_g$ | 44 | 71 | 97 | 92 | 97 | 99 |
| $H_o$ | 20 | 65 | 37 | 56 | 80 | 43 |
| $H^e$ | 19.78 | 65.74 | 38.06 | 82.42 | 83.93 | 58.35 |
| No. of Alleles | 5 | 17 | 4 | 17 | 12 | 5 |
| **New Caledonia** | n = 54 | | | | | |
| $N_g$ | 42 | 36 | 52 | 37 | 48 | 52 |
| $H_o$ | 26 | 31 | 15 | 28 | 38 | 24 |
| $H^e$ | 22.66 | 32.97 | 15.02 | 33.02 | 42.92 | 28.57 |
| No. of Alleles | 6 | 13 | 6 | 14 | 9 | 3 |
| **Barron** | *n* = 26 | | | | | |
| $N_g$ | 19 | 23 | 19 | 23 | 20 | 21 |
| $H_o$ | 6 | 19 | 6 | 16 | 18 | 9 |
| $H^e$ | 5.43 | 20.53 | 8.21 | 20.35 | 17.46 | 9.75 |
| No. of Alleles | *3* | 12 | 5 | 10 | 9 | 3 |
| **Burnett** | *n* = 20 | | | | | |
| $N_g$ | 29 | 26 | 29 | 27 | 28 | 29 |
| $H_o$ | 14 | 22 | 16 | 16 | 22 | 17 |
| $H^e$ | 15.57 | 23.39 | 16.21 | 23.50 | 23.14 | 15.35 |
| No. of Alleles | 4 | 11 | 4 | 8 | 7 | 4 |
| **Albert** | *n* =25 | | | | | |
| $N_g$ | 15 | 9 | 25 | 10 | 24 | 25 |
| $H_o$ | 3 | 8 | 12 | 6 | 16 | 11 |
| $H^e$ | 6.86 | 7.17 | 11.93 | 8.35 | 18.44 | 16.89 |
| No. of Alleles | 6 | 7 | 5 | 9 | 7 | 5 |
| **Mulgrave** | *n* =24 | | | | | |
| $N_g$ | 17 | 5 | 23 | 5 | 21 | 22 |
| $H_o$ | 9 | 5 | 6 | 5 | 17 | 9 |
| $H^e$ | 9.27 | 4.66 | 5.53 | 4.66 | 17.36 | 12.34 |
| No. of Alleles | 5 | 7 | 3 | 5 | 7 | 3 |
| **Haughton** | *n* =30 | | | | | |
| $N_g$ | 28 | 5 | 29 | 7 | 28 | 29 |
| $H_o$ | 9 | 4 | 11 | 4 | 22 | 14 |
| $H^e$ | 11.05 | 3.77 | 9.40 | 6.46 | 23.38 | 17.36 |
| No. of Alleles | 4 | 5 | 4 | 7 | 10 | 5 |
| **Fitzroy** | *n* =25 | | | | | |
| $N_g$ | 20 | 4 | 25 | 18 | 24 | 25 |
| $H_o$ | 7 | 4 | 8 | 14 | 12 | 14 |
| $H^e$ | 10.84 | 3.57 | 9.44 | 15.42 | 19.34 | 18.14 |
| No. of Alleles | 5 | 5 | 5 | 7 | 10 | 6 |

**Table 2.7.3.** Chi-squared tests for heterogeneity (above diagonal) with pairwise FST estimates (below diagonal) for all ten populations of *Anguilla reinhardtii*. Chi-squared and FST estimates were calculated and the significance tested from 1000 randomisations using GenePop 3.4 (Raymond and Rousset 1995). Chi-squared tests were corrected for significance $\alpha < 0.05$ using sequential Bonferroni as per Rice (1995).

| Population | Port Hacking | Pambula | Bellinger | New Caledonia | Barron | Burnett | Albert | Mulgrave | Haughton | Fitzroy |
|---|---|---|---|---|---|---|---|---|---|---|
| **Port Hacking** | - | $\chi^2_{12} = 37.1$ $P = 0.0002^{sig}$ | $\chi^2_{12} = 29.6$ $P = 0.0028^{Bonf}$ | $\chi^2_{12} = 16.3$ $P = 0.1766^{not\ sig}$ | $\chi^2_{12} = 10.5$ $P = 0.5653^{not\ sig}$ | $\chi^2_{12} = 28.4$ $P = 0.0047^{Bonf}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ |
| **Pambula** | 0.0096 | - | $\chi^2_{12} = 20.1$ $P = 0.0650^{not\ sig}$ | $\chi^2_{12} = 29.0$ $P = 0.0038^{Bonf}$ | $\chi^2_{12} = 16.4$ $P = 0.1698^{not\ sig}$ | $\chi^2_{12} = 14.2$ $P = 0.2858^{not\ sig}$ | $\chi^2_{12} = 27.6$ $P = 0.0062^{Bonf}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = 29.7$ $P = 0.0030^{Bonf}$ |
| **Bellinger** | 0.0013 | 0.0027 | - | $\chi^2_{12} = 8.5$ $P = 0.7438^{not\ sig}$ | $\chi^2_{12} = 10.4$ $P = 0.5762^{not\ sig}$ | $\chi^2_{12} = 19.2$ $P = 0.0837^{not\ sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ |
| **New Caledonia** | 0.0023 | 0.0060 | 0.0006 | - | $\chi^2_{12} = 15.4$ $P = 0.2200^{not\ sig}$ | $\chi^2_{12} = 30.4$ $P = 0.0023^{Bonf}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ |
| **Barron** | -0.0015 | 0.0113 | 0.0021 | 0.0124 | - | $\chi^2_{12} = 18.5$ $P = 0.1000^{not\ sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ |
| **Burnett** | 0.0083 | -0.0003 | 0.0082 | 0.0201 | 0.0066 | - | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} = \infty$ $P = 0.0000^{sig}$ | $\chi^2_{12} =$ $P = 0.0000^{sig}$ | $\chi^2_{12} = 29.4$ $P = 0.0033^{Bonf}$ |
| **Albert** | 0.0377 | 0.0372 | 0.0390 | 0.0295 | 0.0442 | 0.0443 | - | $\chi^2_{12} = 14.4$ $P = 0.2708^{not\ sig}$ | $\chi^2_{12} = 13.7$ $P = 0.1831^{not\ sig}$ | $\chi^2_{12} = 8.4$ $P = 0.7524^{not\ sig}$ |
| **Mulgrave** | 0.0646* | 0.0499 | 0.0501* | 0.0436 | 0.0849* | 0.0731* | 0.0155 | - | $\chi^2_{12} = 10.8$ $P = 0.5435^{not\ sig}$ | $\chi^2_{12} = 12.4$ $P = 0.4065^{not\ sig}$ |
| **Haughton** | 0.0708* | 0.0681* | 0.0639* | 0.0559* | 0.0761* | 0.0836* | 0.0180 | 0.0182 | - | $\chi^2_{12} = 8.3$ $P = 0.7540^{not\ sig}$ |
| **Fitzroy** | 0.0371 | 0.0202 | 0.0287 | 0.0238 | 0.0403 | 0.0350 | -0.0089 | -0.0001 | 0.0018 | - |

* denotes departures from panmixia (no population structuring); $_{12}$ denotes degrees of freedom (df); $^{sig}$ denotes significance at the level of $\alpha < 0.05$ after Bonferroni correction (Rice, 1989); $^{Bonf}$ denotes no significance at the level of $\alpha < 0.05$ after Bonferroni correction (which would have been significant prior to correction); $^{not\ sig}$ denotes no significance at the level of < 0.05.

### *2.8.3. Discussion*

Preliminary analysis of *A. reinhartii* microsatellites from different geographic locations indicates that there is significant genetic structuring of the population. Chi-square tests indicated modest, but highly significant ($P \leq 0.0002$) levels of structuring between 22 pairwise comparisons for all loci. Estimates of $F_{ST}$ were moderate (0.050 - 0.0849) (Wright, 1978), and are comparable with other fish species with high dispersal ability. However, when these results are compared to other studies of genetic heterogeneity in eels, our results are significantly higher. Wirth and Bernatchez (2001) reported weak but highly significant genetic structuring in the European eel *Anguilla anguilla* (pair-wise $F_{ST} \neq 0.003$ - 0.005) and concluded that the common hypothesis of panmixia in eels must be refuted. Daemen *et al*., (2001), also reported concordant $F_{ST}$ values (0.004 - 0.007), concluding that the paradigm of a single panmictic population for the European eel is difficult to maintain. The level of genetic differentiation reported here for Australian longfinned eels is an order of magnitude higher than previously shown for other eel species ($F_{ST} \neq 0.050$ - 0.0849). Additionally these measures are concordant with highly significant Chi-squared results ($P \leq 0.0002$).

Comparisons with other fish with high dispersal ability such as Atlantic cod show similar levels of genetic partitioning (Ruzzante 1996). In a meta-analysis Ward *et al.* (1994) reported average genetic subpopulation differentiation (GST) across marine fishes of (0.062), levels that are similar to those reported here.

The level of genetic structuring reported here should be treated as preliminary. The results are based on incomplete data sets, with many samples currently being re-genotyped for final analysis and publication in a PhD thesis (Moore In preparation) and scientific journals. Several of the Queensland samples are small ($n$ = 24-30) for Albert, Burnett, Fitzroy, Barron, Haughton and Mulgrave Rivers, which may be responsible for some of the significant tests of differentiation. An important challenge in studies where genetic differentiation is likely to be low is to discriminate between minor but ecologically important heterogeneity and artefacts due to sampling error (Waples 1998). It is hoped that we have overcome the problems associated with small sample size by using at least six loci. Additionally, we propose to analyse the data using assignment testing techniques (Paetkau *et al*. 1995) that utilize all loci as a genotypic test, compared to tests that analyse data for one locus at a time. Assignment testing has provided a far more powerful tool for analysing population structure in fish populations than previous genetic tests (Roques *et al*. 1999). Additional analysis will also comprise estimates of RST, tests for isolation by distance (Wright 1943) and Pearson's correlation and a linear regression with geographic distance.

If genetic structuring is verified by further analysis, this result will have significant management implications. Where there is uncertainty regarding the role of stock substructure in preserving specific genes and genetic variations, the "precautionary principle" dictates that sub-units of the population should be treated as discrete and conserved (Stephenson 1999). Therefore, genetic structuring indicates that the NSW population of longfinned eels should be managed as a discrete unit of spawning stock, independent of recruitment from spawning stocks in other parts of the extensive geographic range.

# 3. COMMERCIAL FISHERIES

Bruce Pease and Trudy Walford - NSW Dept of Primary Industries

## 3.1. Introduction

In this report, the harvest of any life history stage of naturally occurring longfinned eels for commercial profit is considered to constitute a commercial fishery. The eels may be sold for direct consumption or may be sold to the aquaculture industry for further grow-out and value-adding. Any translocation of naturally occurring eels for further growth and later harvest for commercial profit is also considered to be a commercial activity. Harvest of a range of life-history stages for an increasing range of markets has lead to a complex set of commercial fisheries and related catch and effort reporting systems for river eels in NSW.

Based on the following comments by Roughley (1955), who was Superintendant of NSW Fisheries from 1939 to 1952, it is apparent that there were no commercial eel fisheries in NSW prior to 1955: "In view of the fact that there is so little demand for eels in Australia they can be viewed only as being in the nature of pests, for they destroy large quantities of fish that are appreciated by the public and, when occurring in streams containing trout, they prey on these valuable sporting fish extensively. In North Gippsland farmers who endeavour to raise ducks are pestered by eels, which bite off the legs of the ducklings when swimming or drag them to the bottom to consume them. Although found in greatest abundance in fresh water, eels sometimes occur in considerable concentrations in the brackish water of estuaries, where they may interfere seriously with the operations of net fishermen."

The first reported commercial landings of eels in NSW appear in the annual Report of the Chief Secretary on Fisheries in New South Wales for the Year Ended 30th June, 1970 (Pease and Grinberg 1995). It is highly likely that commercial landings of eels occurred before this time but fishers recorded this information on monthly catch returns (reporting forms) under the heading of "Other species". "Eels" were added to the list of species provided on the monthly catch returns for collecting catch data from coastal estuaries (Form 49) and inland fresh waters west of the Dividing Range (Form 51) in 1969/70. Therefore, a specific space was provided for recording eel catches separately from other species for the first time. Annual landings have been reported from tidal waters every year since then.

Very low eel catches (probably bycatch in mesh nets, hoop nets and fish traps) have been reported intermittently from inland areas west of the Dividing Range since 1970. Based on the known distribution of freshwater eel species in Australia (Chapter 2.2), landings from these inland areas were probably shortfinned eels and will not be considered further in this report.

Since 1970, most of the eel landings have been reported from tidal waters (estuaries) east of the Dividing Range and this fishery will be referred to as the "estuarine large yellow eel fishery". NSW Fisheries Commissioners began closing non-tidal fresh waters east of the Range to commercial fishing in 1902 to protect trout (Fisheries Commissioners 1903). By 1970, all of these waters were closed to commercial fishing in order to protect trout as well as air-breathing animals, such as platypuses and freshwater turtles.

Prior to 1983, eels were captured in estuarine waters using a range of methods including, mesh nets, lines and fish traps. An "eel trap" was specified in the *Fisheries and Oyster Farms (General) Regulations 1983* for the first time and subsequently modified in the *Fisheries Management (General) Regulation 1995* and now 2002 (see Appendix IV). Since 1983, commercial fishers have

only been allowed to target yellow eels in estuarine waters using the specified eel trap. The reported bycatch of eels by other methods of fishing is not significant. Within the Estuary General Fishery approximately 6% of the reported eel landings are retained in mesh nets and outside the Estuary General Fishery approximately 1% are retained in prawn trawl nets (NSW Fisheries 2001).

With the expansion of lucrative new markets for live eels in Asia in the early 1990's, a new fishery to harvest large yellow eels from freshwater impoundments (hereafter referred to as the "impoundment large yellow eel fishery") commenced in 1992. Eel trapping in this fishery is allowed by two types of special permits. Type I permits are issued automatically to fishers who have been tendered by relevant authorities to harvest eels from large impoundments under their control. Type II permits allow fishers to harvest eels from farm dams and small, publicly-owned, off-stream storages. Both permit types must be renewed annually and stipulate a number of terms and conditions (Appendix V).

In 1995, a small fishery to harvest glass eels/elvers for aquaculture (hereafter referred to as the "glass eel fishery) also commenced. This has remained a very small-scale experimental fishery controlled by another type of permit. The current terms and conditions of this permit are listed in Appendix (VI). There was also an initial quota of 100 kg for the maximum annual harvest of glass eels. In 1999, this quota was increased to 300 kg per year in an effort to add capacity and stimulate eel aquaculture in NSW.

Under the *Fisheries and Oyster Farms Act of 1935*, a single commercial fishing license allowed fishers to trap eels in most of the tidal waters in NSW and provided eligibility to obtain a permit to trap eels in freshwater farm dams and impoundments. The new *Fisheries Management Act of 1994* provided a framework to restrict access, thus turning the estuarine eel trap fishery into a restricted or limited entry fishery. Each fisher must possess one of a limited number of eel trapping endorsements, as well as a commercial fishing license and an Estuary General Fishery endorsement. In 2002, a new fishery management strategy (NSW Fisheries 2003) was implemented for the Estuary General Fishery. This strategy imposes a system of rolling performance trigger points on the annual catch of eels from each estuary in NSW. If the trigger points are activated, a review of the eel fishery must be conducted and an appropriate action plan must be developed in order to maintain sustainable harvest levels.

Prior to 1997 there was no minimum legal size limit for eels. A minimum legal size limit of 30 cm was implemented for the commercial and recreational eel fisheries in 1997 to provide consistency with size limits for river eels in Victoria and Queensland. The 30 cm limit was originally based on the marketable size of shortfinned eels in Victoria, where the commercial river eel catch consists primarily of shortfins (Hall *et al.* 1990).

Historically, an unknown (probably small) proportion of the trapped eels under the minimum marketable size (approximately 500 grams for longfins) were translocated (often illegally) to small privately owned impoundments for grow-out and subsequent re-harvest. Since the minimum size limit was implemented, a significant legal aquaculture market has developed for eels larger than the minimum legal size but smaller than the minimum acceptable market size. This "small yellow eel fishery" is a sub-component of the estuarine large yellow eel fishery.

Submission of monthly and in some cases daily catch returns summarizing fishing catch and effort is a mandatory requirement of all permit, restricted and share managed fisheries in NSW. An array of catch return forms have been designed to capture catch and effort data in the estuarine commercial fisheries since 1970 (Pease and Grinberg 1995; Tanner and Liggins 1999). A separate daily logbook for recording catch and effort in the farm dam and impoundment fishery was implemented in 1995 and has recently (2001) been revised as a monthly catch return form (Appendix VII). Separate recording systems for estuarine and freshwater impoundment catches has

led to confusion and some double reporting. Data for separate catch and effort recording systems are stored in separate databases and some databases are held in different locations, depending on whether the data are considered to be aquaculture or commercial fisheries information collected from fishers holding permits or restricted fishery endorsements.

The use of ambiguous and confusing common names for eel species on catch and effort return forms prior to 1997 has also made it difficult to accurately interpret commercial catch statistics for this group of fish species. Spaces for identifying recorded landings were provided on the monthly return forms for estuarine catch and effort as follows: 1) 1970 to 1990 - "eels", 2) 1990 to 1992 - "eel, short finned" and "eel, other (specify)", 3) 1992 to 1997 – "eel, short finned or river", "eel, southern conger" and "eel, other (specify)", and 4) 1997 to present – "eel, shortfin river" and "eel, longfin river" (Appendix VIII). The available choices prior to 1997 were obviously confusing when it is considered that conger eel is another popular common name for longfinned river eels, as well as eels belonging to the genus *Conger*. It is doubtful that fishers accurately specified longfinned eels by correctly writing the name on forms prior to 1997.

The commercial fishery for longfinned eels in NSW (173 tonnes in 1999/00 (Tanner and Liggins 2001)) is the largest fishery for this species in Australia (Kailola 1993). Commercial landings in 2000 were only 42 and 25 tonnes from Queensland (data provided by Queensland Department of Primary Industries) and Victoria (Department of Natural Resources and Environment 2002), respectively. No commercial catches of this species have been published for Tasmania. Most of the commercial longfinned eel catch is exported live to international markets and the Australian Quarantine and Inspection Service (AQIS) maintains a database of the quantities of all eel products exported from Australia.

Under the *Fisheries Management Act 1994*, NSW Fisheries is responsible for the conservation and management of the State's aquatic resources by conserving fish stocks and protecting key aquatic species, communities and habitats within a framework of ecologically sustainable developmnent (ESD). Wild harvest eel fisheries are also subject to recent Commonwealth legislation under the *Wildlife Protection (Regulation of Exports and Imports) Act 1982*. This is because most of the eel catch is exported and spawning of these species occurs in international waters. Under this Commonwealth Act, it must be demonstrated that the commercial river eel fisheries of NSW are managed within an ecologically sustainable framework.

The objectives of this chapter are to: 1) define and characterise each commercial fishery for longfinned river eels in NSW, 2) summarise spatial and temporal trends in available catch and effort data from the NSW eel fisheries and 3) validate NSW catch return data for all eel trap fisheries against AQIS export data.

## 3.2. Methods

Biological and management related characteristics were summarized for each of the four fisheries identified in the introduction. Biological characteristics of yellow eels were based on the biological findings in this report (Chapter 2) and the biological characteristics of glass eels were based on the findings of Pease *et al.* (2003a). The management related characteristics are based on current management regulations and information in our catch and effort databases.

Glass eel harvest was summarized using the logbook information submitted monthly by glass eel permit holders. Glass eel catches include both longfins and shortfins and are not sorted to species. Annual number of permit holders and estimates of total annual landings were obtained from the logbook data held by the Aquaculture Division of NSW Fisheries, which administers this permit system. Spatial and temporal details of catch and effort are not readily available for this fishery because the logbook data are not entered into the primary corporate database of fisheries catch and

effort data. However, most of the logbook information from glass eel permit fishers, along with additional information about catches they obtained for research purposes, has been put into an Access database of glass eel research data and simple spatial and temporal summaries of glass eel catches were obtained from that database.

The trap fisheries for yellow-stage eels were summarised by putting data from the monthly catch returns for the estuary general fishery, logbook data from the impoundment fishery, together with AQIS export data and Queensland state catch data into a Microsoft Access database called "Lcatch Eels". The table structure of this database is summarised in Appendix IX.

There are three types of tables in Lcatch Eels: 1) the primary table of consolidated and cross-checked estuary general catch return and impoundment logbook catch and effort data (table - Catch Data Estuaries and Dams), 2) raw data extracted from all databases external to Lcatch Eels (tables - Historic Eel Data, Catch Data, Farm Dams, AQIS Export Data, Yearly Queensland Catch), and 3) Look-up or reference tables for areas, species, periods, etc. The first step in building the database was to extract the raw data for all "eel" species codes from external databases. Annual estuarine catch records in the Historic Eel Data table were extracted from the corporate database of historic (1940 -1992) fisheries catch and effort data called "Hcatch". Monthly records of eel catch and effort in the Catch Data table were extracted from the corporate database of monthly catch and effort data for all share managed and restricted fisheries (1984 – present) called "Comcatch". Logbook data for the impoundment fishery is not entered into the corporate database system, so catch and effort records in the Farm Dams table were manually entered from the logbooks submitted by farm dam and impoundment permit holders. The AQIS Export Data table was compiled from a monthly summary of export data for eels during the 1995 to 2000 period that was purchased from AQIS. The Yearly Queensland Catch table consists of annual eel catches during the 1996 to 2000 period that were extracted from the primary corporate database of fisheries catch and effort in Queensland which is administered by the Queensland Department of Primary Industries (QDPI).

The Catch Data Estuaries and Dams table was compiled by consolidating data from the Catch Data and Farm Dam tables. During this process, incidences of duplicate reporting were rectified and catch weights under multiple species codes for "eel, southern conger" and "eel, other (specify)" were consolidated into catch weights for the longfinned eel species code. Therefore, each catch record in this table is identified as either the longfinned or shortfinned species wherever possible.

Spatial and temporal catch and effort summaries of the yellow eel trap fisheries were extracted from the Lcatch Eels database. Species (longfins and shortfins) were pooled in all summaries of yellow eel catch and effort that include the period prior to fiscal year 1997/98 because longfinned eels were not listed separately on catch return forms during that period. Our fishery independent eel trap samples, as well as anecdotal evidence from fishers, both indicate that very few shortfinned eels are caught in the eel trap fishery. Average monthly landings of longfinned yellow eels were calculated using recent data from fiscal years 1997/98 to 1999/2000, when landings for each species could be separated with some confidence. Effort and related catch per unit of effort (CPUE) data are only available for the period from fiscal years 1984/85 to 1999/00.

Annual summaries of longfinned eel landings reported in the NSW Fisheries catch and effort return system (Catch Data Estuaries and Dams table) were validated against corresponding annual summaries of Commonwealth export data for live eels (AQIS Export Data table) for the calendar years 1996 to 2000. A significant proportion of the NSW longfinned eel catch is actually exported from Brisbane, along with some of the commercial eel landings from Queensland (Qld). Therefore, it is necessary to use the reported longfinned eel landings from Qld in validation comparisons. State landings were compared with Commonwealth exports by combining State landings (NSW + Qld) and comparing them with the combined AQIS exports of live eels from NSW and Qld.

Finally, the reported annual landings of all four fisheries were compared. Maximum estimated annual weight and number of eels landed during the respective reporting period of each fishery were compared. Species data were pooled for maximum estimates because of uncertainty about recording of species during the reporting period. The mean and standard error of the annual landings of longfins by weight and number in each fishery during the period from 1996/97 to 1999/00 were also estimated and compared. This period was chosen for comparison because most of the yellow eel landings during this recent period were recorded relatively accurately by species and validated against Commonwealth export data. Weight and number estimates of longfinned glass eels during this period were obtained by multiplying annual glass eel (mixed species) landings by 0.5. Pease *et al.* (2002) showed that the species ratios of recruiting glass eels may vary annually among different sampling locations within a catchment but the average annual species ratio of longfins to shortfins in the Port Hacking estuary was 50/50. Both the maximum and mean number of eels was estimated by dividing the estimated mean weight of individual eels in each fishery by the estimated maximum and mean weight of annual landings.

### 3.3. Results

Characteristics of the four longfinned eel fisheries identified in the introduction are summarized in Table 3.1. Both the biological and management related characteristics of the glass eel fishery are distinctly different from all three of the trap fisheries for later life history stages. Glass eels are harvested from the upper tidal reaches of the estuary by fishers with special permits using fine meshed fyke nets. The juvenile eels are captured in the nets as they travel upstream with the incoming tide. Live glass eels may be held by fishers until a prescribed quantity is accumulated before they are delivered to the aquaculture facility. Fishing effort (number of fishers) is limited by an annual selective tender process which also links individual quotas to specific aquaculture markets.

**Table 3.1.** Biological and management characteristics of the four commercial fisheries for longfinned eels in NSW. Biological characteristics of glass eels from Pease *et al.* (2002) and characteristics of yellow eels from Chapters 2.3 and 2.5 of this report. Management characteristics from the *Fisheries Management Act* 1994.

| | Fishery | | | |
|---|---|---|---|---|
| | **Glass eel** | **Small yellow eel** | **Estuarine large yellow eel** | **Impoundment large yellow eel** |
| **Life history stage** | Glass eel / elver | Male / undifferentiated yellow | Female yellow | Female yellow |
| **Length (mm)** | < 80 | 300 < L < 600 | > 600 | > 600 |
| **Average weight (g)** | 0.2 | < 500 | 1,000 | 1,000 |
| **Area/habitat fished** | Estuary | Estuary | Estuary | Freshwater Impoundments |
| **Start date** | 1995 | 1997? | 1970 | 1992 |
| **Fishing method** | Fyke | Trap | Trap | Trap |
| **Effort control** | Permit | Endorsement | Endorsement | Permit |
| **Output control** | Quota | None | None | None |
| **Market** | Domestic aquaculture | Domestic aquaculture | Live export to Asia | Live export to Asia |

The estuary and impoundment fisheries for large yellow eels have identical biological characteristics but distinct fishing areas and management controls. The small yellow eel fishery has identical management related characteristics to the estuarine large yellow eel fishery but targets the smaller male and undifferentiated yellow eels which are often in different areas from the larger female eels. These targeted catches of small yellow eels are accumulated and held by the fisher until the aquaculturist picks them up. Because the management related characteristics and reporting requirements are identical, there is no way of separating the catch and effort statistics for the small yellow eel fishery from those for the estuarine large yellow eel fishery. Therefore, catch and effort

summaries of the yellow eel trap fishery can be separated into impoundment and estuarine components but not small and large yellow eel components.

Fishers in the estuarine yellow eel fishery must hold an Estuary General fishery entitlement with an attached "eel trapping" endorsement. Fishers in the impoundment fishery hold a farm dam or impoundment trapping permit that must be renewed annually. In both the estuary and impoundment fisheries, the fishers use baited traps that are set overnight. Traps used in the impoundment fishery must have netting cod ends long enough to reach the surface in order to provide an air-space for air-breathing vertebrates such as platypuses and freshwater turtles. Fishers generally accumulate and hold their daily catches of live eels at their premises until the exporter picks them up (usually weekly) and transports them to their holding facilities before the eels are finally exported to Asia.

The annual landings of glass eels reported from 1995 to 2000 are summarized in Figure 3.1. Landings remained below 20 kg per year with no sharp peaks or declines during the period. Ninety percent of these landings were obtained from the Bellinger River catchment and five percent were obtained from the Wallis Lake catchment. Glass eel catches obtained by permit fishers for commercial and research purposes were primarily obtained from January through July, and the highest catches were obtained in May (Fig. 3.2).

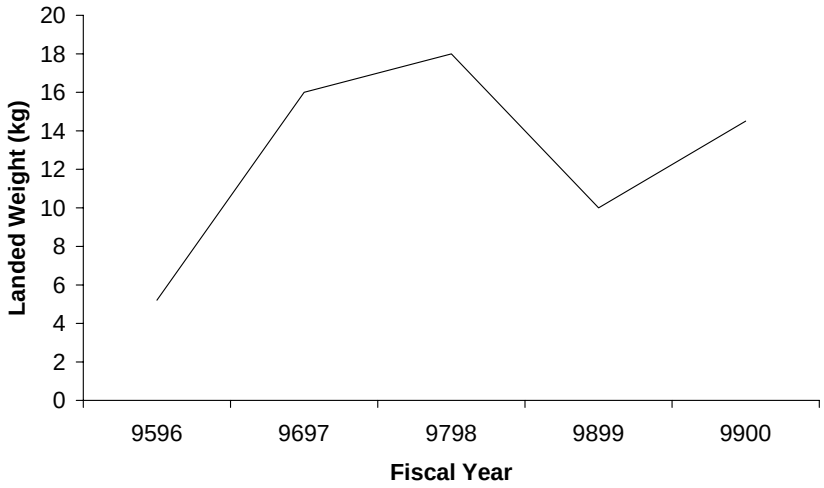



**Figure 3.1.** Annual commercial landings of glass eels reported by fishers holding glass eel fishing permits for fiscal years 1995/96 to 1999/00. Landed weights in kilograms include both longfinned and shortfinned eel species.

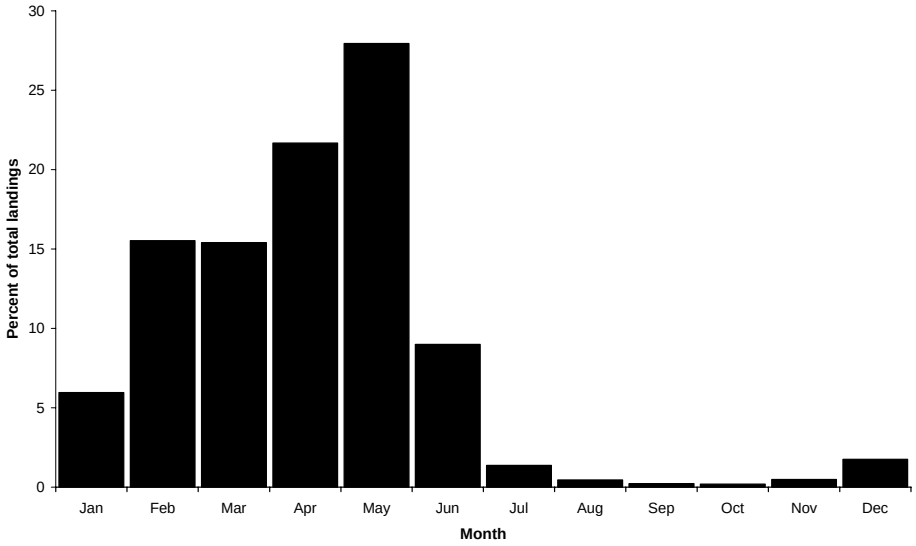



**Figure 3.2.** Monthly proportion of glass eel landings (both species) reported by glass eel permit fishers between 1997 and 2000 for commercial and research purposes.

Total annual landings of yellow eels in the trap fisheries remained below 100 tonnes until the early 1990's (Fig. 3.3), when the export market for live eels developed. Landings then increased rapidly to over 400 tonnes with large increases in landings reported from the impoundment fishery and estuaries in the central bioregion (Pease 1999). Total annual landings then decreased until fiscal year 1996/97 and have remained relatively stable at 170-210 tonnes per year since that time. A large proportion of the total landings were reported from the northern bioregion throughout the entire period, while landings from the southern region remained relatively low.

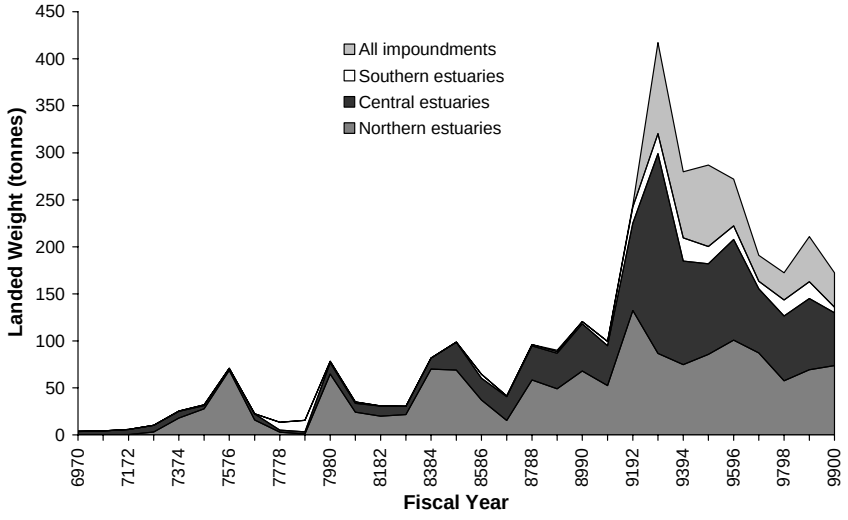



**Figure 3.3.** Landed weight of yellow eels from all estuarine and impoundment trap fisheries during fiscal years 1969/70 to 1999/00. Estuarine landings divided into the three estuarine bioregions defined by Pease (1999).

More detailed spatial analysis of the yellow eel landings (Fig. 3.4) shows that most of the landings from the northern bioregion during the last three decades have been obtained from the Clarence River catchment, which has also consistently provided some of the highest landings of any catchment basin in NSW. During the first two decades since 1970, very few landings were reported in any catchment other than the Clarence River. During the 90's, higher landings were distributed through most of the catchment basins and landings in the Great Lakes (mostly Myall Lakes and River) and Hawkesbury River basins increased significantly.

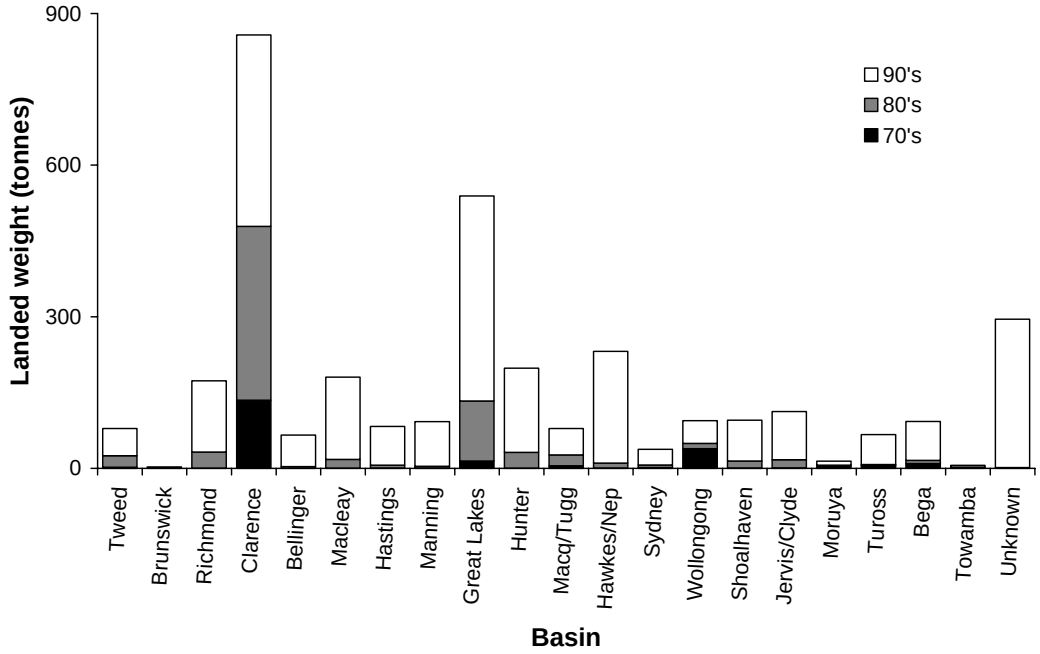
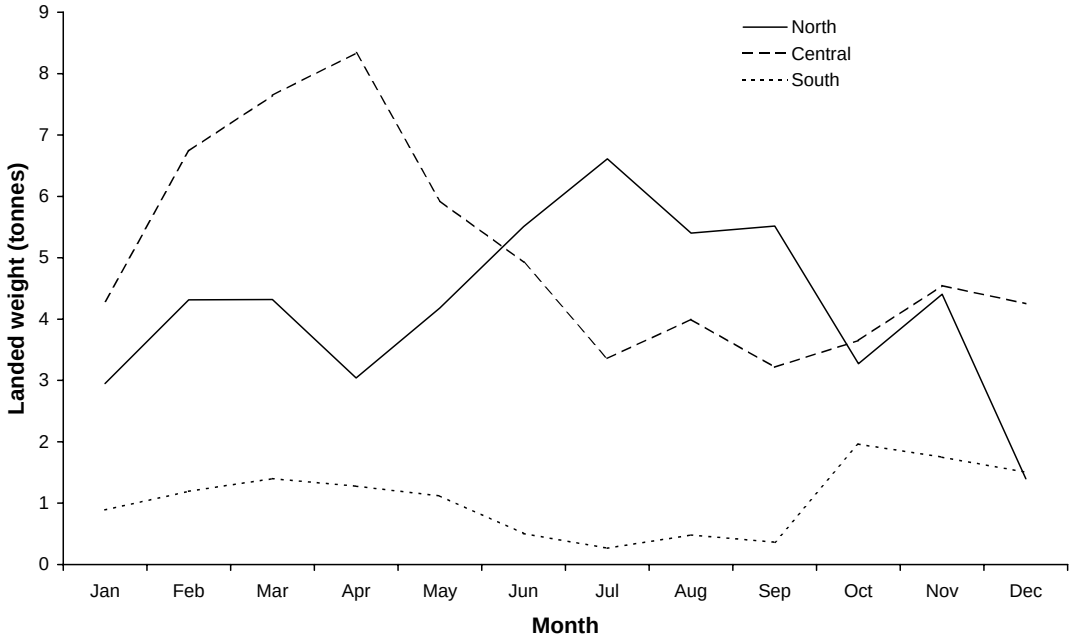



**Figure 3.4.** Landed weight of yellow eels from all estuarine and impoundment trap fisheries from each of the coastal drainage basins used for recording impoundment catches (Appendix IV) during the last three decades.

Landings in both the estuarine and impoundment yellow eel fisheries show seasonal peaks and troughs that differ among regions (Fig. 3.5). Average monthly landings in the estuary and impoundment fisheries were at their highest in the winter and late autumn, respectively, and at their lowest in summer. Landings in both fisheries had their highest peaks during autumn in the central region and spring in the southern region. Landings in both fisheries were lowest during the winter in both the central and southern regions.

The annual number of fishers reporting eel catches from estuaries remained relatively stable (approx. 200-250) during the entire 1984 to 2000 period (Fig. 3.6a), while the annual number of estuarine fisher-months (monthly catch returns reporting eel catches) doubled from approximately 500 to 1000 fisher-months in the early 90's when the export market developed (Fig. 3.6b). The number of estuarine fisher-months has remained high (approx. 800-1000) in the 90's. Estuarine CPUE increased from a low of less than 100 kg per fisher-month in the mid 80's to a peak of 330 kg per fisher-month in the early 90's then declined in the mid 90's and remained very stable at approximately 200 kg per fisher-month in the late 90's (Fig. 3.7).

*A.*




*B.*

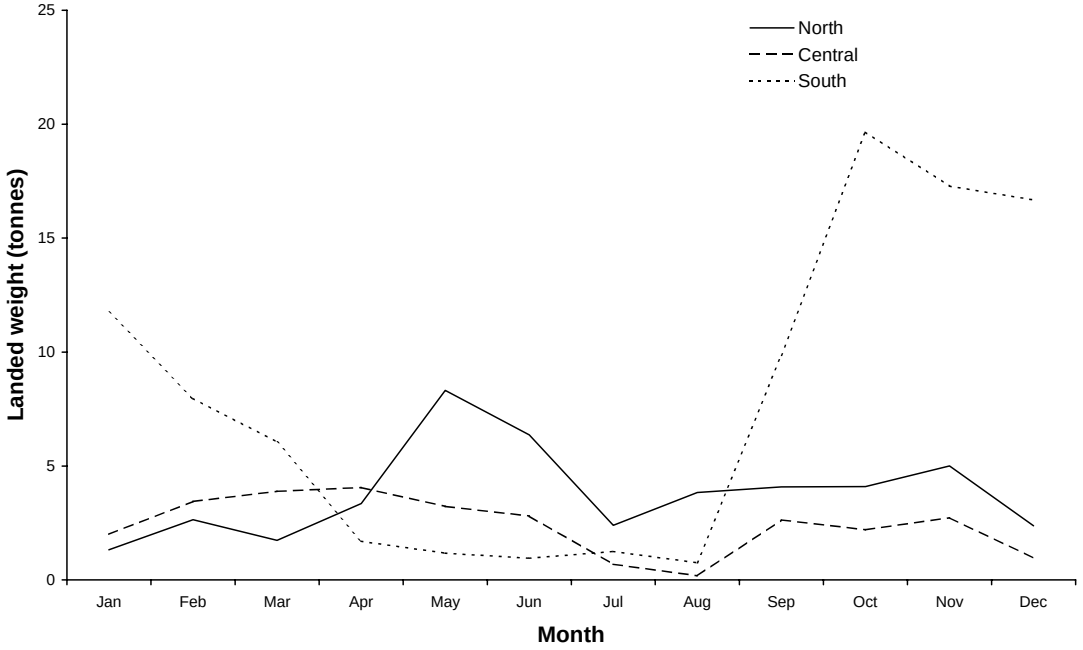
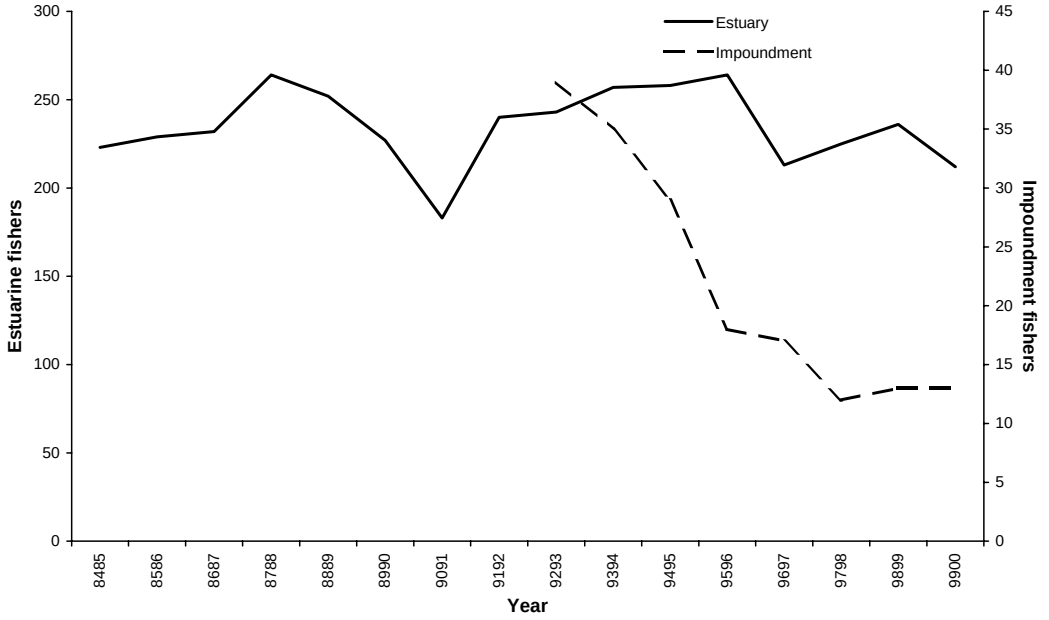



**Figure 3.5.** Average monthly landed weight of longfinned eels in the estuarine (A.) and impoundment (B.) yellow eel trap fisheries during fiscal years 1997/98 to 1999/00. Landings from each fishery divided into northern, central and southern bioregions (Pease 1999).

*A.*




*B.*

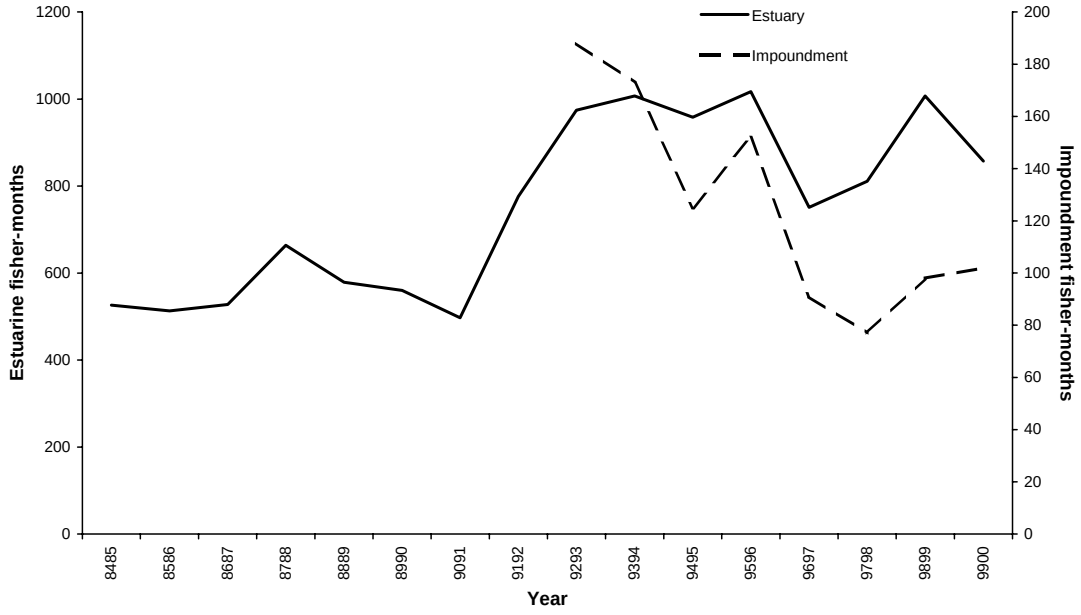



**Figure 3.6.** Fishing effort in the estuary and impoundment yellow eel trap fisheries during fiscal years 1984/85 to 1999/2000, expressed as: A) total annual number of fishers reporting eel catches and B) annual cumulative total number of months that fishers reported eel catches. Note different scales on y-axes.

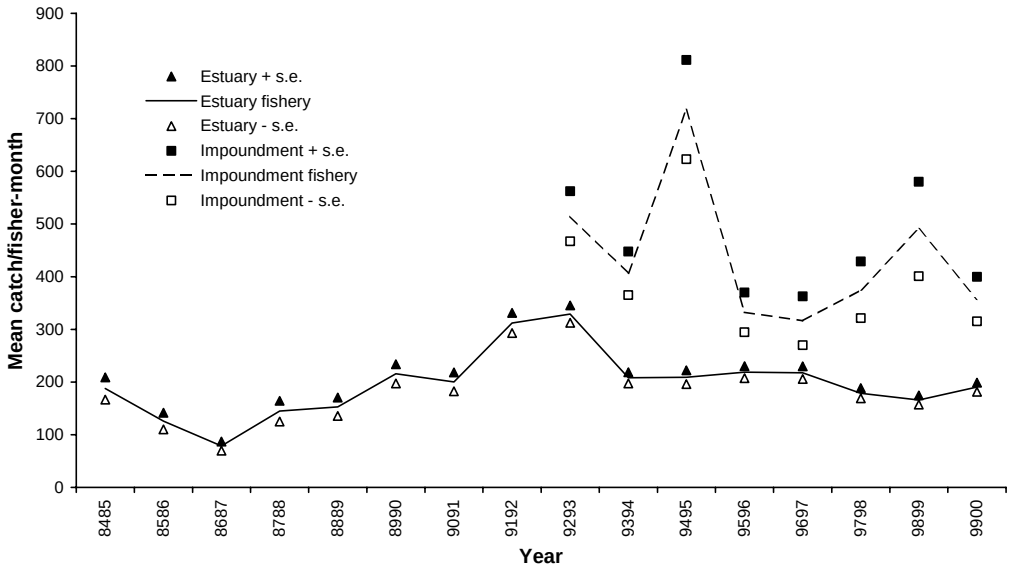



**Figure 3.7.** Annual mean eel catch (kg) per fisher-month within one standard error (s.e.) for the estuary and impoundment fisheries for fiscal years 1984/85 to1999/00.

Both the number of fishers (Fig. 3.6a) and the number of fisher-months (Fig. 3.6b) in the impoundment fishery peaked in 1992/93, when permits were first issued for this fishery. The number of impoundment fishers and fisher-months both declined until 1996/97 and has remained relatively stable since that time. Note that no new fishers have been issued permits since 1992/93 and existing permits are forfeited if they are not renewed annually. CPUE in the impoundment fishery was much more variable (due to the low number of fishers) with no observable trend during the period (Fig. 3.7). However, the average CPUE of the impoundment fishery was consistently much higher than the CPUE in the estuary fishery.

A comparison of reported annual landings of longfinned eels on State (NSW and Qld) catch returns with annual exports of live eels reported to AQIS (Fig. 3.8) shows that the two sources of information generally agreed within 5-19 tonnes annually. Longfin landings reported on State catch returns were consistently higher than the AQIS export values. Shortfin landings reported after 1996, when both species were listed on the catch return forms, were relatively low (24-40 tonnes). Shortfin landings are not generally exported live and during this period they constituted only 18% of the estuarine landings and 3% of the impoundment landings recorded on State catch returns.

A final summary of the estimated annual landings of each fishery is provided in Table 3.2. Annual landed weights of glass eels have remained low. However, these low landed weights translate into relatively high numbers of harvested eels. Estimated numbers of harvested glass eels were similar in magnitude to the numbers of estimated large yellow eels landed in the impoundment fishery. Landings of small yellow eels for aquaculture have not been recorded separately from the landings of large yellow eels in the estuary fishery and official estimates of small yellow eel landings are unavailable. The estimates of small yellow eel harvest in Table 3.2 are based on anecdotal evidence from commercial fishers and assumes that only longfinned eels are harvested. Reported landings of large yellow eels have remained stable during the period that average landings were calculated, at less than half the maximum levels recorded prior to that period. Fishers in the estuarine large yellow eel fishery harvest approximately five times more eels than the fishers in any of the other eel fisheries.

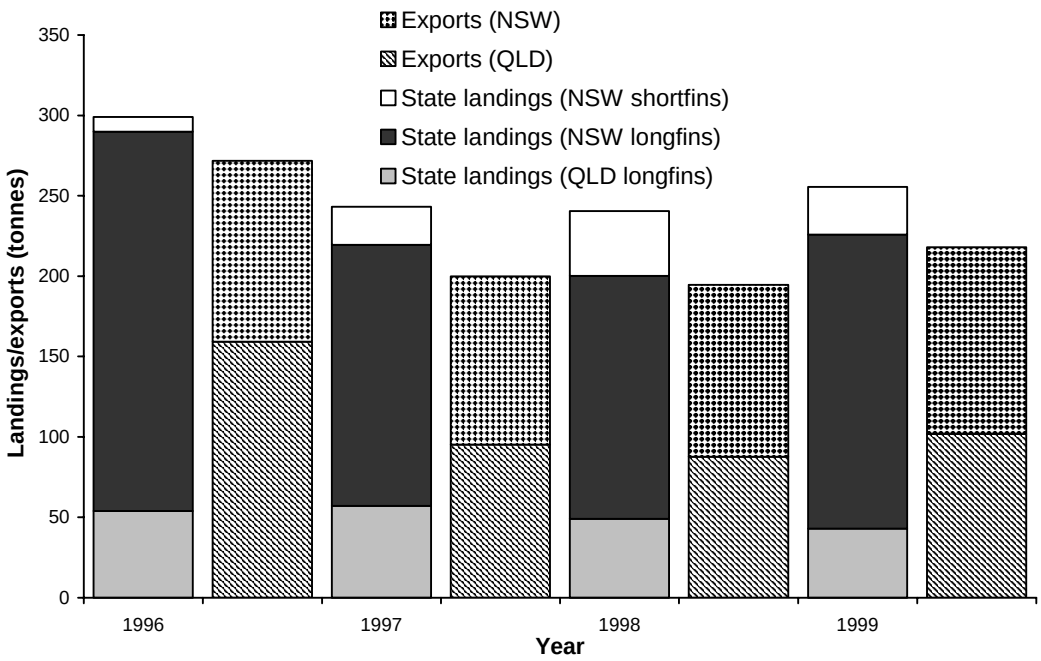



**Figure 3.8.** Comparison of annual eel landings reported on state (NSW and QLD) catch returns with AQIS live eel exports from NSW and QLD for calendar years 1996 to1999.

**Table 3.2.** Summary of estimated annual landings for the four commercial eel fisheries in NSW. Maximum estimates are for shortfinned and longfinned eel species combined. Average and standard error estimates are for longfinned eels. Number of eels is based on the average weight of individual eels from Table 5.3.1.

| | Estimated annual landings | | | |
|---|---|---|---|---|
| | Maximum (eels) | | Average 1996/97 to 1999/00 (longfins) | |
| **Fishery** | **Weight (kg)** | **Number (eels)** | **Weight (kg) ± s.e.** | **Number (longfins) ± s.e.** |
| **Glass eel** | 18 | 90,000 | 7 ± 2 | 36,000 ± 4,000 |
| **Small yellow eel** | ? < 10,000 | ? < 20,000 | ? < 10,000 | ? <20,000 |
| **Impoundment large yellow eel** | 97,000 | 97,000 | 33,000 ± 5,000 | 33,000 ± 5,000 |
| **Estuarine large yellow eel** | 320,000 | 320,000 | 161,000 ± 8,000 | 161,000 ± 8,000 |

## 3.4. Discussion

Based on biological characteristics of longfinned eels, the commercial fisheries for glass eels, small yellow eels and large yellow eels are distinctly different. Based on management characteristics, the glass eel, estuarine yellow eel and impoundment yellow eel fisheries are distinct. The two types of characterizations overlap with the capture of small yellow eels in the estuary and result in the definition of four fisheries for: 1) glass eels, 2) estuarine small yellow eels, 3) estuarine large yellow eels and 4) impoundment large yellow eels.

The aquaculture industry for longfinned eels in NSW has not developed much beyond the experimental phase since it began in the mid 1990's. Glass eels were initially viewed as the primary source of seedstock for the industry. However, glass eel landings have remained low (Fig. 3.1) for a number of reasons. We estimate that less than 40,000 longfinned glass eels were harvested annually in the late 1990's and the annual harvest has declined further since 2000. Few sites have been located where glass eels can be dependably captured in large quantities. Both eel

species are often captured together and there is no easy way of separating them. Based on the findings of Pease *et. al.* 2003, most of the commercial glass eel landings between January and April (Fig. 3.2) are probably longfins but in April and May landings are mixed and most of the landings after April are probably shortfins.

Along with the problems associated with sourcing and identifying glass eel seedstock, aquaculturists have encountered problems with weaning then finding appropriate diets for the subsequent life-history stages. Mortality rates of these early life-history stages are often high. Therefore, aquaculturists have turned their attention primarily to small yellow eels from the yellow eel trap fishery for seedstock in the late 1990's. Unfortunately, the landings of these small yellow eels for aquaculture are not reported separately from the landings of the larger yellow eels that are harvested for the export market. Therefore, we only have anecdotal evidence from commercial fishers and aquaculturists that annual landings of small yellow eels have been less than 10 tonnes or 20,000 eels in recent years and we have no associated fishing effort information. The low level of harvest in both the glass eel and small yellow eel fisheries is primarily related to limited demand by the aquaculture industry rather than limitations of stock size or CPUE.

The impoundment trap fishery for large yellow eels has remained a small, limited entry fishery since permits were first issued in 1992. The number of fishers and total annual landings in this fishery have declined since the mid 1990's but the catch per unit of effort has remained high since the fishery began. It is estimated that 30 to 40 thousand eels have been harvested annually by this fishery in recent years. The high CPUE and stability of the annual landings since the mid 1990's indicate that this fishery is operating within sustainable limits. However, stability and sustainability of this fishery are dependent on a complex mixture of factors related to the number of fishers and how often they harvest the isolated stocks with variable recruitment and growth rates from a large number of small impoundments.

The majority of eels that are commercially landed in NSW are harvested by the estuarine trap fishery for large yellow eels. This fishery has operated since at least 1970 and the number of fishers has remained stable since at least 1984. Annual landings and catch per fisher-month increased through the 1980's to a peak in the early 1990's when the high-value export market developed. Fishing effort, as measured by catch per fisher-month, has remained high since then but annual landings and CPUE declined in the mid 1990's, then leveled off. This temporal pattern in CPUE indicates that harvest prior to the early 1990's was having little impact on eel stocks, but increased effort in the early to mid 1990's rapidly reduced the level of available surplus production. The stable nature of annual landings (estimated at 150 to 170 thousand eels in recent years) and catch per unit of effort since the mid 1990's, indicates that this fishery is also operating within sustainable limits.

All non-tidal flowing freshwaters remained closed to commercial fishing during the entire period that eel landings have been reported. However, the total number of fishers in the estuarine large yellow eel fishery and the number of estuaries open to commercial fishing have recently decreased due to the declaration of Recreational Fishing Havens and Marine Protected Areas and an associated buy-back of commercial fishing businesses. The restricted fishery process in 1997 resulted in the allocation of 252 eel trapping endorsements. At the time of finalizing this report (2004), the number of eel fishers had been reduced by 25% to 188. During this period (1997 to 2004), the number of estuaries open to eel trapping was reduced by approximately 23% with a concurrent 21% reduction in the total water area of estuaries open to commercial eel trapping. Therefore, fishing effort as measured by the ratio of fishers to area of fishable estuaries has remained relatively unchanged during this period (0.186 fishers/sq km in 1997 to 0.175 fishers/sq km in 2003).

Most of the large yellow eels in these trap fisheries are harvested from the northern and central bioregions of NSW. The Clarence River catchment in the northern bioregion consistently provides the greatest landings, followed by the Great Lakes and Hawkesbury/Nepean catchments in the central bioregion. This spatial pattern is consistent with the geographic distribution of longfinned eels and the belief that they are primarily a tropical species.

Large yellow eels are trapped all year round but there are seasonal peaks in landings and seasons vary among bioregions. In the central bioregion, monthly landings are highest in the autumn. In the northern bioregion, peak landings occur during winter months, while landings in the southern bioregion peak in the spring. Peak seasonal landings in each region are related primarily to seasonal patterns of fishing activity using a range of methods rather than catchability of eels. The eel trap fishers all hold endorsements within the Estuary General fishery and generally use a range of methods to catch a wide range of species during different seasons. Therefore, periods of eel trapping activity may occur primarily when other fishing methods are not being used, rather than when eels are more abundant or catchable. The diversity of fishing methods and associated patterns of fishing activity are known to vary among bioregions (Pease 1999). However, low landings during the winter in both the central and southern bioregions may be related to decreased catchability of eels due to inactivity during periods of low water temperature in these bioregions which are closer to the southern end of the longfinned eel's range.

Landings from state catch returns were in very good agreement with the AQIS export figures. It is assumed that the export data are more accurate than the state catch return data because the export data are rigorously recorded at a few tightly controlled departure sites (primarily Sydney and Brisbane airports), whereas the catch return data are submitted by each individual fisher. Therefore, this validation exercise indicates that the state catch return data are generally accurate. Another indication of the validity of this data is the result that the state landings are consistently 5-17 tonnes higher than the live export data. This consistent difference is an expected result of the small yellow eel harvest for domestic aquaculture and the limited local market for eels that die while being held by fishers and processors.

The value of the fishery is difficult to estimate because live eels are marketed through several export processors which pay the fishers variable prices. A small but unknown proportion of the catch dies and is put through other markets at a much lower value. Most of the exported eels in Figure 3.8 were live and during the 1997-99 period processors were paying approximately $8-10 per kilo for live eels. Therefore, the fishery during those years may be valued at approximately two million dollars per year. However, Tanner and Liggins (2000) list the value of the longfinned eel landings in fiscal year 1998/99 as $1.3 million. Therefore, the NSW eel landings in recent years have probably been worth between one and two million dollars per year.

The process of summarizing and analyzing commercial eel landings from state catch and effort returns was difficult. Catch return data for the glass eel and impoundment fisheries are not kept in corporate databases and summaries are not reported annually in Departmental reports. In order to estimate the total catch of yellow-stage longfinned eels, catch and effort records for the impoundment fishery must be manually entered into a database and cross-checked with the estuarine catch return data. To enable future monitoring of catch and effort in the commercial longfinned river eel fisheries, it is recommended that catch and fishing effort data from all four longfinned eel fisheries be entered into the corporate catch and effort database system. It is recommended that glass eel landings should be summarized annually in the aquaculture production report series (ISSN 1444-8440). After landed weights of yellow eels have been validated against AQIS export figures, it is recommended that official reports summarizing New South Wales commercial fisheries statistics annually (ISSN 1320-3371) should provide landed weights from each catchment for all three yellow eel fisheries.

# 4. CULTURAL SIGNIFICANCE OF THE INDIGENOUS FISHERY

Bruce Pease[1] and Helen Carpenter[2]

1. NSW Dept of Primary Industries
2. NSW Fisheries – now NSW Dept of Infrastructure Planning and Natural Resources

## 4.1. Introduction

Annual harvest rates and market values are not necessarily the only indicator of the importance of a fishery. Some harvested species may have special cultural or social significance to ethnic segments of the population. Eels appear in the art and traditional legends of Aboriginal people in New South Wales. Giant eels are implicated in the creation of both the Clarence and Parramatta Rivers. A plaque on the headland at Yamba tells of how the largest river system in NSW, the Clarence River was created: *"In the hills near Woodenbong lived a spiteful old Diringan woman. The woman was angry with her son-in-law, Balungan and hid all the drinking water from him. Balungan had two clever dogs that found the hidden water while chasing a kangeroo one day. The dogs led Balungan to the hiding place. Balungan thrust his spear into the hidden water. The water spurted out in a great spring that became the Clarence River. The Dirangan woman was swept away by the waters. As the waters of the river flowed from the spring at Woodenbong a giant eel swam downstream. As far as Copmanhurst the eel was thin and swam a straight path. Then he grew big and fat and began to thrash about making the river wide, deep and winding as it flowed to the sea. This great eel now lives under the bridge at Grafton"*.

There is considerable archaeological and anthropological literature on Aboriginal use of eels in New South Wales. The primary aim of this part of the study was to describe the nature and cultural significance of the indigenous fishery for eels in New South Wales based on the available literature.

## 4.2. Cultural significance of eels

Eels appear regularly in aboriginal artwork. Parramatta Council uses some of these artistic depictions of eels as artwork and logos on many of its publications. The traditional legends implicating eels in the creation of the Clarence, Hawkesbury and Parramatta Rivers are regularly recounted and have been incorporated into dance performances.

Archaeological sites in the form of rock engravings provide the strongest evidence of pre-colonial and ancient Aboriginal use of eels. Rock engraving sites are considered to have served a number of purposes including representation of clans or totems, story telling, or to pass on knowledge, laws, and beliefs (Lampert 1969).

In New South Wales, there are a number of rock engraving sites depicting eels alongside of other fish, people, ancestor beings, and other animals (Stanbury and Clegg 1990). The sites reflect use of eels by Aboriginal groups of those areas. Rock engraving sites depicting eels within New South Wales have been documented at places including Botany Bay, Manly Cove, Willoughby, Patonga, the Ku-ring-gai Chase National Park as well as inland areas.

## 4.3. Catching eels

Historical sources reveal that Aboriginal people employed a variety of methods for catching eels. These include use of hooks and lures, line fishing, traps and natural poisons.

Pollard (1969) describes how hooks and lures were used to catch eels. Generally, hooks were fashioned from shell, bone, or bird talons. Roughly (1955) also describes a method whereby earthworms were threaded onto a string with a sliver of cane. Once an eel had fixed its teeth into the bait, it was pulled from the water on the string. Lawrence (1968) documents the use of these methods in the Sydney and Port Stephens areas. Line fishing for eels was known to be practiced by women from canoes in the open sea below South Head in the Sydney area.

Eels were also captured using traps or cages. Thompson (1893) suggests that basket traps were the primary method for catching eels and Roughly (1955) describes basket traps measuring approximately three to four feet in length, and six to ten inches in diameter. Traps were used either alone or in conjunction with fences. Fishers would drive eels upstream into traps and secure remaining eels by raised fences covered with river grass (Roughly 1955). Hollow log traps for eels have also been documented for Aboriginal groups using the inland freshwater lagoons of Sydney (Lawrence 1968).

The natural poisons of certain native plants were used to stupefy, stun or kill eels. Pollard (1969) identifies use of *Tephrosia purpurea* and *Duboisia myoporoides* (related to the pituri tree) in eastern Australia and New South Wales for poisoning eels. For poisoning, the leaves, stems, roots or seeds of appropriate plants were pounded and scattered in the water or swirled in the water in nets. Poisons had the affect of killing the eels but were not dangerous for consumers (Pollard 1969). Thompson (1893) also refers to use of poisons for capture of eels, and Lawrence (1969) records the use of this method by Aboriginal groups in ponds in Twofold Bay.

Lawrence (1968) notes that Aboriginal women in the Sydney area were also known to spit chewed oysters, mussels and fish into the water as burley for catching eels.

Collection of eels was not necessarily always a haphazard pursuit by Aboriginal people. Gilmore (1934), for example, writing about the 1800s, notes that "All billabongs, rivers and marshes were treated as food reserves and supply depots by the natives [sic]…Thus storage never failed. But besides birds and plants there were the fish - yabbies, freshwater lobsters [sic], eels, catfish, cod and other varieties peculiar to Australia."

## 4.4. The continuing importance of eels

Aboriginal use of eels for food in inland waters has been documented as early as 1802. Considerable evidence of use of eels by Aboriginal people comes from South West Victoria (Lake Condah) where eels are associated with large ceremonial gatherings (Flood 1995). Flood also documents extensive use of eels as a major food source for Aboriginal groups along coastward flowing rivers throughout southeastern Australia (Flood 1995).

Merriman (1993) provides considerable anthropological evidence of use of eels within the staple diets of the Dharug and Gundungurra Aboriginal groups of the Blue Mountains. The Dharug word for eel is burra, and the Gundungurra refer to eels as cunark (Stockton 1993). According to Merriman (1993), the Dharug and Gundungurra peoples used short-finned eels (*Anguilla australis*) and long-finned eels (*Anguilla reinhardtii*) for food. Eels were caught in rivers and lagoons using spears, nets and poisons. The migratory nature of eels meant that they often travelled in large

numbers to spawning grounds making them a reliable, predictable food source and one with the potential to support large group gatherings.

Use of eels is also recorded for Aboriginal groups in the broader Hawkesbury-Nepean areas which were used by the Dharug (mentioned above) and the Gurringai or Eora peoples. Eels were caught by these groups around the Broken Bay and Port Jackson areas and in waters up to Lake Macquarie (Ross 1990).

South coast groups are also known to catch and use eels. Cane (1992) broadly documents use of eels by the Dharrawal (Tharrawal) and Yuin Aboriginal groups. People of the south coast have regional words for eels including dumbi (Browns Flat), bumbie (Nowra), and bambi (Wallaga Lake) (Cane 1992; Chittick and Fox 1997). Micky the Cripple, an Aboriginal man of Ulladulla in the late 1800s, drew pictures of many fishing scenes. His drawings are often considered to be an Aboriginal view of economic resources at the turn of the last century and they include eels (Cane 1992).

Chittick and Fox (1997) recorded oral histories of the south coast from a respected Elder of Wallaga Lake. Eels were an important part of the food of south coast groups and studies show that sharing eel tucker is part of place. In the following excerpt of Chittick and Fox (1997), the way eels are shared is described.

*That's the Aboriginals' tucker, the eels. That bambi, that's their dangang. Dangang, that's their tucker. See, dangang, that's in the language of our people. We never say, 'Well, give us a bit of that there eel there. Give us a bit of that eel to eat'. See, it's too plain. It don't sound in the language at all. We'd say, 'Give me a bit of that bambi, my dangang. Bambi for my dangang'. Perhaps, 'You want a bit of dangang? Bambi dangang?'*

# 5. HARVEST BY NON-COMMERCIAL FISHERIES

Bruce Pease - NSW Dept of Primary Industries

## 5.1. Introduction

In this report non-commercial fisheries are defined as fisheries composed of fishers who do not profit financially from the harvest of eels. In New South Wales this includes the indigenous fishery and the non-indigenous recreational fishery (hereafter referred to simply as the recreational fishery). Unfortunately, these two sectors are difficult to separate. Most indigenous fishers harvest eels for subsistence, as well as cultural and ceremonial requirements (see Chapter 4). However, some may harvest eels simply for recreation in a manner similar to non-indigenous recreational fishers. Under the current *Fisheries Management Act* (1994) indigenous and non-indigenous non-commercial fishers are only allowed to catch eels with a hook and line. The minimum legal size is 30 cm and the bag limit is 20 eels per day. Non-indigenous fishers require a licence to fish in both fresh and salt water. However, the *NSW Fisheries Indigenous Fisheries Strategy* (NSW Fisheries 2002b) recognises that fishing has been an important source of food, a basis for trade and an important part of cultural and ceremonial life. Aboriginal fishers do not require a recreational fishing licence for fishing in fresh waters and limited exemptions apply to aboriginal fishers in tidal waters with respect to paying a recreational fishing fee.

The non-indigenous recreational fishery for eels is the least documented of the three eel fishery sectors (commercial, indigenous and recreational). Unlike the indigenous fishery, eels have no special historical or cultural significance to recreational fishers. Unlike the commercial fishery sector, there is no long-term source of state-wide catch and effort estimates for any fish species harvested by non-commercial fisheries sectors.

Anecdotal information (Beumer 1996, Kailola *et al*. 1993), indicates that longfinned eels are harvested by recreational fishers in eastern Australia using hook and line methods. Angling references, such as Starling (2001), often contain information about the edibility of eels, favoured baits and fishing rigs. Guided eel fishing charters in eastern Australia can be arranged via the internet. In 1993, the Australian Anglers Association record for a freshwater eel was an 8.9 kg longfin from northern New South Wales (Kailola *et al*. 1993). A recreational fishing trophy consisting of a stuffed eel that weighed in at 14.75 kg is mounted on the wall of the Guyra (NSW) pub.

Estimates of non-commercial fish harvesting in Australia are usually made from angler creel surveys. These surveys have historically been temporally and spatially limited (McGlennon 1994) and have generally included the indigenous and recreational fisheries as one sector. Most recreational surveys in NSW have only been done during one time period (typically one to two years) in one water body. In eastern drainages, most surveys have been conducted in estuaries rather than throughout the entire catchment. McIlgorm and Pepperell (1999) summarised the available catch data from creel surveys conducted in NSW estuaries since 1979 and found that longfinned eels comprised 0.01% of the total number of fish caught.

The first state-wide omnibus survey of recreational fishing catch and effort in New South Wales was done in 2000-01 as part of a broader initiative to obtain fisheries statistics on non-commercial sectors of Australian fisheries (Henry and Lyle 2003). Eel catches were recorded but annual catch and effort estimates were not calculated for minor species such as eels in the final report. However, the raw data are available on the project database. The objective of this chapter is to assess the

magnitude of the indigenous and recreational eel fisheries in NSW using data from the 2000-01 National Recreational Survey and relevant tag/recapture data from this Adult Eel Study.

## 5.2. Methods

### *5.2.1. Estimates from the Tagging Study*

The tagging component of this Adult Eel Study was designed primarily to provide information for the age validation, growth and movement studies (Chapter 2.4). However, along with the fishery independent tag recaptures, tagged eels were also recaptured by indigenous, recreational and commercial fishers. Assuming that recapture rates of each fishery sector were directly proportional to their respective harvest rates, tag recapture rates by each fishery sector provide a gross estimate of the relative harvest of longfinned eels that is attributable to each respective sector. If we assume that the number of tagged eels recaptured by each sector ($R_n$ for the non-commercial sector and $R_c$ for the commercial sector) is similarly proportional to the total catch by each respective sector ($C_n$ for the non-commercial sector and $C_c$ for the commercial sector) during the study period , then $C_n/R_n = C_c/R_c$. Based on the recorded commercial landings we can estimate the non-commercial harvest during the study period as: $C_n = (C_c \cdot R_n)/ R_c$. Tags were recaptured from river and estuary habitats during the three year study period from November 1998 to November 2001. Therefore, commercial landings from the estuarine yellow eel fishery during this period were used as the recorded commercial landings in the above calculations and were divided by three in order to estimate the annual non-commercial harvest. The estimate of $C_n$ does not include the non-commercial harvest from impoundments because eels were not tagged in that habitat. Based on the assumption of proportionality of harvest rates, indigenous and recreational catches were estimated as $C_i = (R_i / R_n) C_n$ and $C_r = (R_r / R_n) C_n$ , respectively (where $C_i$ is indigenous catch, $R_i$ is indigenous recaptures, $C_r$ is indigenous catch and $R_r$ is recreational recaptures).

### *5.2.2. Estimates from the National Recreational Survey*

The survey used remote (telephone and diary) survey methods as the primary source of information from recreational fishers. A clustered stratified random sample of household telephone numbers was drawn from electronic white page directories. Researchers rang each household and conducted an interview with respondents to obtain information on their fishing and boating activities and demographic profile. Each respondent who indicated that a member of the household was likely to go fishing in the coming 12 months was invited to participate in a diary survey. Fishing households were issued with survey kits containing a diary or memory jogger, fish identification booklet and a letter of confirmation from the relevant fishery management agency. Fishing households were contacted each month (whether fishing was anticipated or not) to obtain the details of their fishing activity and expenditure on fishing related items. A number of calibration/validation (refusals, non-contact, intending non-fisher, on-site creel) surveys were conducted at the end of the diary survey to correct for non-response and other sources of bias. A detailed account of the survey methodology is available in the final report by Henry and Lyle (2003). A separate survey of indigenous fishers was done in Northern Australia (Queensland and Northern Territory) but the primary survey did not identify ethnic groupings of respondents in the other states, including New South Wales. Therefore, the survey results for New South Wales actually combine the indigenous and recreational sectors.

Within New South Wales household surveys were regionally stratified using the 12 Australian Bureau of Statistics statistical divisions. This allowed results to be reported by north, central and south coastal regions. Fishing effort and catch were also stratified into five habitat types (Offshore oceanic, coastal oceanic, estuary, river and lake or dam. Eel catch and effort data for this report was only extracted from the estuary, river and lake or dam habitats. Eels were not considered to be a

key species category and they are not easy for the general public to identify so they were not reported as separate species. It was assumed that eel catch from the estuary, river and lake or dam habitats was comprised primarily of longfinned and shortfinned river eels.

## 5.3. Results

### *5.3.1. Estimates from the Tagging Study*

During the tagging study period, one tagged longfinned eel was recaptured by a non-indigenous recreational fisher, one tagged eel was recaptured by an indigenous fisher and 45 tagged eels were recaptured by commercial fishers. Based on the Lcatch Eels database, the reported estuarine catch of longfinned eels during the three year study period was 439,987 kg. The average weight of all legal sized eels caught during this study was 820 g. Therefore, 0.8 kg per eel was used to convert commercial catch weight to number of eels. Based on these values, estimated annual non-commercial estuarine catch was calculated as: $C_n = (C_c \cdot R_n)/ R_c / 3 = (351{,}990 \text{ eels} \cdot 2)/ 45/ 3 =$ 5215 longfinned eels. Using a mean weight of 0.8 kg per eel, the estimated annual non-commercial catch was 6619 kg. Therefore, the annual indigenous and recreational harvests of longfinned eels from estuaries (not including impoundments) were each estimated to be 2607 eels or 3309 kg ($1/2 \cdot C_n$).

### *5.3.2. Estimates from the National Recreational Survey*

It was estimated that the annual non-commercial retained catch from rivers, estuaries and impoundments was 2145, 985 and 733 eels, respectively. This results in a total estimated non-commercial catch of 3863 eels (both species) or 4829 kg, assuming an average weight per eel of 0.8 kilogram. We assume that virtually all of the eels caught in the rivers and estuaries were longfins, based on the fact that only 8 of the 5361 eels captured during our eel study in rivers and estuaries were shortfins. Beumer (1996) indicates that shortfins are found predominantly in slow flowing or static water. Therefore, we estimate that half of the recreational catch from impoundments may have been shortfins, resulting in a total estimated non-commercial catch of 3496 longfinned eels or 4370 kg. Based on the findings of the tagging study, the annual indigenous and recreational harvests of longfinned eels were each estimated to be 1748 eels or 2185 kg ($1/2 \cdot C_n$).

The regional estimates indicated that 44%, 25% and 31% of the total retained recreational eel catch were obtained from the northern, central and southern coastal regions, respectively. Based on our knowledge of eel species distributions in NSW (Chapter 2) the northern and central estimates probably reflect the regional distribution of longfins but the southern estimate may be inflated by a greater (but unknown) proportion of shortfins.

Estimates of non-commercial fishing effort for eels were low. It was estimated that 2678 fishers in NSW kept eels and only 675 fishers targeted eels.

## 5.4. Discussion

The final estimates of indigenous and recreational harvests are not directly comparable between methods because the tagging method did not incorporate estimated catches from impoundments. Based on the estimated impoundment catch from the national survey (approximately 10% of the non-commercial catch of longfins), the total annual indigenous and recreational catch of longfinned eels from the tagging study were each estimated to be 2897 eels (2607/0.90) or 3677 kg.

The two independent methods produced very similar estimates for both the total annual indigenous and recreational harvests of longfinned eels, which each ranged from 1748 to 2897 eels or from 2185 to 3677 kg. It is not feasible to estimate the variance associated with these estimates. Estimates from the tagging study were based on simplistic assumptions of proportionality between harvest and tag return rates while estimates from the national recreational survey were based on spatial sampling frames smaller than the state level. However, the consistency of these independent estimates verifies that the indigenous and recreational harvests of longfinned eels from NSW are each low (probably less than 3000 eels or 4 tonnes per year) compared to commercial harvests. Therefore, the total non-commercial harvest is probably in the order of 4000 to 6000 eels or 6 to 8 tonnes per year, which is less than 3% of the recent average annual commercial harvest of large yellow eels.

# 6. STRATEGY FOR MONITORING EEL STOCKS IN NSW

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## 6.1. Introduction

There are many different methods for monitoring the status of exploited fish stocks. Sources of monitoring information may be collected independently from commercial fisheries or may be dependent on information gathered from them. Adequate monitoring may require information on specific or multiple life history stages. The type of information collected may range from simple catch and effort data to structured sex, size and age data. The adequacy and appropriateness of the monitoring methods vary for different species, depending on their biology, economic value and characteristics of their associated fisheries.

As discussed in Chapter 3, basic catch and effort data from the commercial fisheries for glass eels and large yellow eels currently provide the only means of monitoring the status of longfinned eel stocks in NSW. This valuable species has a complex life history and a range of life history stages are exploited by associated fisheries. The aim of this chapter is to assess the practicality and desirability of monitoring longfinned eels at each of the major life history stages that occur in the coastal catchments of NSW.

## 6.2. Discussion

### *6.2.1. Silver eels*

Populations of semelparous species that are vulnerable to fishing for many years before spawning once then dying, may not show signs of recruitment failure as readily as a species that spawns annually upon reaching sexual maturity. An estimate of spawning biomass provides the earliest warning of impending recruitment failure of a long-lived species. The best way to monitor the stock status of a long-lived, semelparous species, such as longfinned eels, is to estimate the annual spawning biomass. This could be accomplished by conducting annual surveys of out-migrating silver eels as they leave the estuaries. However, there are no commercial fisheries for silver-stage longfinned eels in Australia, so fishery independent techniques would have to be employed. There have been no quantitative surveys of silver eel out-migration in Australia, so extensive research into sampling and survey techniques would have to be conducted. Techniques have been developed for sampling European (Vollestad and Jonsson 1988; Holmgren, Wickstrom and Clevestam 1997), American (Caron, Verreault and Rochard 2003) and New Zealand (Jellyman 2001) silver eels, however their application to Australian conditions would need to be tested. The techniques generally involve the use of weirs and large traps, therefore a fishery independent sampling program is likely to be resource intensive and expensive.

### *6.2.2. Glass eels*

Monitoring of glass eel recruitment to coastal catchments probably provides the next best way to monitor the stock status of a long-lived, semelparous species such as longfinned eels (Tesch 2001; Dekker 2002). In the short term, it provides an indicator of the spawning success of each individual year class, which is useful as an index of potential glass eel stocks available for harvest by the aquaculture industry. Consistent trends during monitoring programs of at least 20 years provide a useful index of yellow eel stock status. Consistent declines of glass eel stocks during long-term recruitment monitoring of European (Dekker 1998), American (Castonguay *et al.* 1993) and

Japanese (Tzeng 1997) eels provided most of the evidence for significant declines in worldwide eel resources recently documented in the Quebec Declaration of Concern (Dekker *et al.* 2003).

Glass eel recruitment can be sampled with a wide range of methods (Dekker 2002). However, all methods must be used in an experimental design that is spatially and temporally consistent. Sampling must be spatially consistent in order to isolate variability associated with delivery by regionally variable currents (Pease 1999, Pease *et al.* 2003a). Sampling must be temporally consistent in order to account for seasonal recruitment patterns (Pease *et al.* 2003a).

The glass eel fishery has thus far operated at an experimental level and glass eels have not been collected in a spatially and temporally consistent manner. Therefore, the existing fishery dependent catch and effort data cannot be used to monitor glass eel recruitment. However, if the glass eel fishery develops further and fishing effort becomes spatially and temporally consistent it may be possible to implement a fishery dependent monitoring program in the future.

A purpose designed fishery independent sampling program would provide the best means of monitoring glass eel recruitment. Flow traps (Jessop 2000) and artificial habitat collectors (Silberschneider *et al.* 2001) provide the most cost-effective means of sampling. Silberschneider (In preparation) has developed and trialed an effective experimental design for sampling glass eel recruitment in NSW. Replicate artificial habitat collectors were deployed monthly for 1.5 years at sampling sites in two estuaries in each of the three estuarine bioregions delineated by Pease (1999). This monitoring program can be carried out by one technician with associated travel expenses. The only laboratory analysis required is the observation of each glass eel (or a subsample of glass eels from large samples) under a dissecting microscope to determine the species. It then provides annual recruitment indices for both shortfinned and longfinned eel species. These annual indices would provide a useful method of monitoring the short term status of the glass eel fishery. Long term information collected over at least 10 to 20 years would provide a good indication of yellow eel stock status. A long time series is required to determine background inter-annual variation.

### *6.2.3. Yellow eels*

As discussed in the introduction, basic catch (landed weight) and effort (fisher months per catchment) data have been collected from the commercial yellow eel fishery since 1970 (Chapter 3). This information may provide some indication that commercial fishing pressure is having an impact on longfinned eel stocks and the Estuary General Fishery Management Strategy (NSW Fisheries 2003) specifies its use as a performance indicator to trigger a review of the fishery if established trigger points are breached. However, landed weight does not provide a good indicator of stock status. As one component of the complex Estuary General fishery, changes in fishery landed weight may be the result of changes in market demand and associated value of eels, or redirection of fishing effort from eel trapping to one of the many other fishing methods employed by Estuary General fishers. Changes in landed weight and catch per unit of effort may be attributed to either changes in population size (eel numbers) or size/age structure of the population. This does not allow us to assess whether the changes are due to recruitment or growth overfishing. Because the modal age of females (primarily targeted by the fishery) is 16 to 20 years (Table 2.5.4), recruitment overfishing will not be detected in the yellow eel fishery for many years. Finally, all fishery dependent catch and effort data may be affected by deliberate misreporting as well as errors associated with changing recording systems (Pease and Grinberg 1995).

Fishery dependent monitoring of size and age structure of the yellow eel population would provide a significant improvement over the existing catch and effort monitoring system. This study (Chapter 2.1) demonstrated that it is possible to sample the size and age structure of commercial catches from individual catchments. However, an ongoing monitoring program would require a

high level of resource commitment (probably the equivalent of at least one full time technician) to carry on sampling in both the Clarence and Hawkesbury catchments as well as otolith aging in the laboratory. The program requires extensive liaison with fishers in order to arrange sampling of catches in the holding facilities of their private residences and also requires a high level of consistent cooperation from the industry. Our studies revealed that sex ratios and associated size structure (Chapter 2.5) varied significantly between zones (habitats) and catchments. Francis and Jellyman (1999) also found a high level of variation in the size structure of commercial eel (*Anguilla australis* and *A. diefenbachii*) catches in New Zealand and determined that a similar size structure monitoring program would not detect a significant change until the biomass of eel stocks declined by at least 40%. They concluded that size data are not likely to provide good indicators for use in year-to-year management of eel stocks, but could possibly be useful for detecting large, long-term changes in stock status.

Our studies revealed that age and growth also varied significantly among zones (habitats) and catchments. Francis (1999) also found that age structure varied significantly between eel populations in different New Zealand catchments. He determined that sample precision is dependent more on the number of landings sampled than the number of eels sampled, so that temporal and spatial point estimates must be based on samples from at least 5 landings. This level of sampling would require a relatively high resource commitment in terms of travel expenses.

The greatest limitation of the fishery dependent data is that it only provides information about the eel populations in tidal waters and impoundments. Our fishery independent sampling revealed that a significant proportion of the female eel stocks reside in non-tidal, flowing fresh waters (Chapters 2.2 and 2.5) that are closed to commercial fishing. Therefore, the fishery dependent data for yellow eels cannot be used to estimate the most important population parameter, spawning biomass of the NSW eel stocks, without associated fishery independent monitoring of yellow eel size and age structure in non-tidal, flowing fresh waters.

Fishery independent monitoring of yellow eel size and age structure would require a more significant commitment of resources. This level of commitment would require a second full-time technician and additional travel expenses, along with the full-time technician required for fishery dependent monitoring of yellow eel size and age structure. However, due to the large variation in sex ratios, size and age structure among habitats and rivers it is possible that the combined fishery dependent and independent monitoring programs may not detect short term changes in stock status. Further cost-benefit studies would be required to determine whether the high cost of the program could be justified based on the value of the fishery and the potential benefits of additional yellow eel monitoring (Francis 1999).

## 6.3. Conclusions

Catch and effort of all eel fisheries should continue to be monitored, as specified by the Estuary General Fishery Management Strategy (NSW Fisheries 2003). Large-scale, long-term changes in landings of the yellow eel fisheries will trigger a review of each eel fishery. However, because of the longevity and relatively low growth rates of longfinned eels, recruitment failure may not be detected for many years.

It is technically feasible to implement additional programs to monitor size and age structure of yellow eels but they would be very costly (probably in the order of 10% of the one to two million dollar value of the fishery annually). These costly programs cannot be recommended due to the high variability of eel demography among habitats and catchments which results in a high level of uncertainty about the ability to detect short-term changes in stock status.

Monitoring of out-migrating silver eel biomass would probably supply the best information about short-term changes in stock status. However, there is insufficient knowledge of Australian silver eel ecology and appropriate sampling techniques to even assess the feasibility of implementing a monitoring program for silver-stage longfinned eels.

Based on overseas experience (Tesch 2001, Dekker 2002, Dekker *et al.* 2003), monitoring of glass eel recruitment has provided the earliest and most consistent indicator of recruitment failure in American, European and Japanese eel stocks. Based on our existing knowledge of glass eel recruitment in NSW (Silberschneider *et al.* 2001, Pease *et al.* 2003a, Silberschneider In preparation) a cost effective (probably less than 5% of the value of the yellow eel fishery annually) glass eel recruitment monitoring program could be easily implemented. It is recommended that a glass eel recruitment monitoring program be implemented in order to provide useful long-term information about the status of yellow eel stocks, as well as short term recruitment information for the glass eel fishery.

# 7. MANAGEMENT RECOMMENDATIONS AND IMPLICATIONS

Bruce Pease – NSW Dept of Primary Industies

## 7.1. Benefits

This project has provided the following information about longfinned eels in NSW:

- A summary of their distribution, indicating that they are probably the most ubiquitous fish species in the coastal catchments of eastern Australia.
- Development and validation of otolith ageing techniques for this species.
- Preliminary knowledge of the home range and movement of yellow eels within catchments.
- Estimates of the size and age at sexual differentiation and maturity, demonstrating the extent of sexual dimorphism.
- An understanding of the reproductive ecology and demography of populations within and among coastal catchments, demonstrating the importance of non-tidal fresh waters as refugia for female spawning stocks and the importance of upper tidal habitats for male spawning stocks.
- Preliminary knowledge of genetic stock structure, indicating that it may be necessary to apply the precautionary principle and manage NSW populations as a regional stock.
- A validation and summary of catch and effort data from all of the commercial fisheries, demonstrating the importance of maintaining the existing catch and effort reporting systems and validating state landings against Commonwealth export records.
- A time series of catch and catch per unit of effort data for commercial yellow eel fisheries, indicating that the commercial fisheries have been operating within sustainable limits.
- An understanding of their significance to the indigenous culture.
- Estimates of the annual harvest by recreational and indigenous fishers, demonstrating that annual non-commercial harvest is less than 3% of the recent average annual commercial harvest.
- An understanding of existing and potential methods for monitoring stock status, indicating the importance of maintaining existing catch and effort monitoring programs and developing a long-term recruitment monitoring program.

## 7.2. Intellectual Property

No intellectual property of any commercial value arose from this project, however the results of the research will be utilised in stock assessment fora at both the state and Commonwealth level, to improve the sustainable management of Australian longfinned eels. The results will also be published in scientific journals and industry magazines.

## 7.3. Further Developments

Analysis of the information in this report has lead to the following recommendations for improvement in the sustainable management of longfinned eels in NSW:

- The minimum size limit for the recreational and commercial fisheries for longfinned eels be increased to 58 cm to protect estuarine male spawning stocks (Chapter 2.5).
- The catch and fishing effort data from all four commercial longfinned eel fisheries (glass eels, estuarine small yellow eels, estuarine large yellow eels and impoundment large yellow eels) be entered into the corporate catch and effort database system (Chapter 3).

- Glass eel landings be summarised annually in the aquaculture production report series (ISSN 1444-8440) (Chapter 3).
- Official reports summarising New South Wales commercial fisheries statistics annually (ISSN 1320-3371) should provide landed weights from each catchment for all three commercial yellow eel fisheries (Chapter3).
- A glass eel recruitment monitoring program be implemented in order to provide useful information about the status of both glass eel and yellow eel stocks (Chapter 6).

The recommendation to increase the size limit is particularly important and is being progressed with industry and the public through a discussion paper. The recommendation to implement a glass eel recruitment monitoring program will be progressed within a new framework for the assessment of harvested fish resources in NSW (James Scandol, personal communication). The rest of the recommendations regarding storage and reporting of data will be progressed internally.

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# APPENDICES

**Appendix I.** Location and habitat details at the sampling sites.

1. Location and habitat details at the primary fishery independent trap sampling sites.

| Catchment | Site | Zone | Water/habitat | Longitude | Latitude |
|---|---|---|---|---|---|
| Clarence | 11 | Freshwater | Fluvial | 152.57 | 29.38 |
| Clarence | 12 | Freshwater | Back swamp | 152.59 | 29.40 |
| Clarence | 21 | Upper tidal | Tidal freshwater | 152.82 | 29.61 |
| Clarence | 22 | Upper tidal | Tidal freshwater | 152.84 | 29.64 |
| Clarence | 23 | Upper tidal | Tidal freshwater | 152.94 | 29.70 |
| Clarence | 31 | Lower tidal | Brackish | 153.20 | 29.44 |
| Clarence | 32 | Lower tidal | Brackish | 153.20 | 29.49 |
| Clarence | 33 | Lower tidal | Brackish | 153.08 | 29.49 |
| Hawkesbury | 11 | Freshwater | Fluvial | 150.74 | 34.12 |
| Hawkesbury | 12 | Freshwater | Fluvial | 150.69 | 34.02 |
| Hawkesbury | 13 | Freshwater | Fluvial | 150.68 | 34.01 |
| Hawkesbury | 21 | Upper tidal | Tidal freshwater | 150.88 | 33.50 |
| Hawkesbury | 22 | Upper tidal | Tidal freshwater | 150.88 | 33.49 |
| Hawkesbury | 23 | Upper tidal | Tidal freshwater | 150.95 | 33.42 |
| Hawkesbury | 24 | Upper tidal | Tidal freshwater | 150.94 | 33.36 |
| Hawkesbury | 33 | Lower tidal | Brackish | 151.12 | 33.52 |
| Hawkesbury | 34 | Lower tidal | Brackish | 151.17 | 33.53 |
| Hawkesbury | 35 | Lower tidal | Brackish | 151.25 | 33.50 |
| Hacking | 11 | Freshwater | Fluvial | 151.03 | 34.15 |
| Hacking | 12 | Freshwater | Fluvial | 151.06 | 34.07 |
| Hacking | 21 | Freshwater | Fluvial | 151.05 | 34.08 |
| Hacking | 31 | Lower tidal | Brackish | 151.07 | 34.07 |
| Hacking | 32 | Lower tidal | Brackish | 151.1 | 34.09 |

2. Location details of the fishery independent electrofishing samples collected from the freshwater zone at Rivers Survey sites.

| Catchment | Site | Longitude | Latitude |
|---|---|---|---|
| Richmond | 46 | 153.02 | 28.87 |
| Richmond | 48 | 153.52 | 28.80 |
| Clarence | 52 | 152.57 | 28.86 |
| Clarence | 57 | 152.89 | 29.82 |
| Clarence | 59 | 152.63 | 29.44 |
| Macleay | 45 | 151.82 | 30.42 |
| Macleay | 53 | 152.53 | 30.82 |
| Bellinger | 3 | 152.90 | 30.45 |
| Hastings | 51 | 152.47 | 31.45 |
| Hastings | 56 | 152.67 | 31.25 |
| Myall | 1 | 152.20 | 32.41 |
| Myall | 2 | 152.21 | 32.42 |
| Hunter | 54 | 151.35 | 32.63 |
| Hawkesbury | 67 | 151.15 | 33.35 |
| Hawkesbury | 70 | 150.63 | 33.87 |
| Georges | 69 | 151.00 | 34.05 |

3. Location, habitat and method details of the fishery dependent samples.

| Catchment | Site | Zone | Water/habitat | Life stage | Method | Source |
|---|---|---|---|---|---|---|
| Clarence | 20 | Upper tidal | Tidal freshwater | Yellow | Trap | Sampled |
| Clarence | 30 | Lower tidal | Brackish | Yellow | Trap | Sampled |
| Wallamba | 1 | Upper tidal | Tidal freshwater | Silver | Prawn Set Pocket | Supplied |
| Hawkesbury | 41 | Freshwater | Impoundment | Yellow | Trap | Sampled |
| Hawkesbury | 20 | Upper tidal | Tidal freshwater | Yellow | Trap | Sampled |
| Pambula | 1 | Upper tidal | Tidal freshwater | Silver | Trap | Supplied |
| South Coast | 1 | Offshore | Marine | Silver | Southeast Trawl | Supplied |

**Appendix II.** Table structure and description of fields in the Adult Eels database.

**By-catch**

| Field Name | Description |
|---|---|
| By-CatchID | Autonumber |
| SampleID | Linked to Sampling data table |
| SpeciesCode | **Linked to Species Codes table** |
| SpWeight | Weight of species sample in grams |
| SpNo | Number of individuals in sample |

**Eel Details**

| Field Name | Description |
|---|---|
| EelID | Autonumber |
| EelIDupdate | Number used to label otolith slide, may be different to EelID |
| SampleID | Linked to Sampling data table |
| SpeciesCode | Species code 1=A. reinhardtii, 2=A. australis |
| Stage | Sexual maturity |
| Tag | Tag number |
| Weight | Weight of individual in grams |
| Length | Length of individual in mm |
| Girth | Girth of individual measured in front of pectoral fins in mm |
| Recap | Whether individual was recaptured |
| Otolith | Whether otoliths were taken |
| Gonads | Whether gonads were taken |
| Finclip | Whether finclip was performed |
| Process | Tag number for processing |
| Sex | Sex of individual J=juvenile, F=female, M=male |

**Fishers**

| Field Name | Description |
|---|---|
| Name | Name of commercial fisher where sample came from |
| FisherCode | Linked to Sampling data table |
| Street | Street address |
| Suburb | Suburb |
| PostCode | Post code |
| State | State |
| Mobile Ph | Mobile phone number |
| Contact | Home phone number |

**Gear**

| Field Name | Description |
|---|---|
| GearCode | Linked to Sampling data table |
| Type | Description of type of gear |

**Otoliths**

| Field Name | Description |
|---|---|
| OtolithID | Autonumber |
| EelID | Linked to Eel Details table |
| Recap | Whether individual was recaptured |
| Otolith_wt | Weight of otolith in grams |
| Age1 | Estimate of age as read by Reader1 |
| Readability1 | Quality of reading as read by Reader1, 0=bad to 3=excellent, clear marks |
| Comments1 | Comment on quality of slide |
| Reader1 | Name of reader |
| Date Read1 | Date read by Reader2 |
| Age2 | Estimate of age as read by Reader2 |
| Readability2 | Quality of reading as read by Reader2, 0=bad to 3=excellent, clear marks |
| Comments2 | Comment on quality of slide |
| Reader2 | Name of reader |
| Tage2 | ? |

**Recap data**

| Field Name | Description |
|---|---|
| EelID | Linked to Eel Details table |
| DateFished | Date sampled Day/Month/Year |
| Tag | Tag number |
| SiteNo | Linked to Sites table |
| Waterbody | Linked to Sites table |
| Zone | Linked to Sites table |
| Recap | Whether individual was recaptured |

**Sampling**

| Field Name | Description |
|---|---|
| SampleID | Autonumber |
| SiteNo | Linked to Sites table |
| Snag | 0 = absent, 1 = present |
| UndercutBank | 0 = absent, 1 = present |
| AquaticMacros | Aquatic plants - 0 = absent, 1 = present |
| TerrGrass | Terrestrial grass 0 = absent, 1 = present |
| Rocks | 0 = absent, 1 = present |
| TerrVeg | Terrestrial riparian vegetation 0 = absent, 1 = present |
| SideCreek | 0 = absent, 1 = present |
| Sector | Industry sector C=commercial, R=rivers survey, I=independent |
| FisherCode | Commercial fisher where sample came from |
| GearCode | Type of gear used to sample |
| DateSet | Date gear was set DayMonthYear |
| TimeSet | Time gear was set |
| Water Temp1 | Degrees Celsius at time of setting |
| Salinity1 | In ppm at time of setting |
| DepthofGear1 | Depth in metres gear was set |
| DateFished | Date gear was recovered DayMonthYear |
| TimeFished | Time gear was recovered |
| WaterTemp2 | Degrees Celsius at time of recovery |

| | |
|---|---|
| Salinity2 | In ppm at time of recovery |
| DepthofGear2 | Depth in metres gear was recovered |
| Person1 | Sampling personnel |
| Person2 | Sampling personnel |
| Person3 | Sampling personnel |
| TotNoLFEels | Total number of long finned eels caught in sample |
| TotWtLFEels | Total weight of long finned eels caught in sample |
| WeightBycatch | Weight of by catch |
| Comments | |

**Sites**

| Field Name | Description |
|---|---|
| SiteNo | Site number linked to Sampling table |
| Catchment | Name of catchment |
| Waterbody | River, Lake or Creek |
| Zone | Waterbody divided into 1=upper, 2=middle, 3=lower |
| Site | Zone divided into replicates |
| Site Description | Specific detail of site |
| Longitude | Decimal degrees |
| Latitude | Decimal degrees |

**Species Codes**

| Field Name | Description |
|---|---|
| CSIROCde | Code derived from CSIRO list of species |
| Species Name | Scientific name |
| Species Code | Abbreviated code used in Adult Eels database |

**Gonad Details**

| Field Name | Description |
|---|---|
| GonadID | Autonumber |
| EelID | Linked to Eel Details table |
| Macrostage | Macroscopic stage of gonad development where 1=undiff and 7=silver female |
| Micrometer | Measurement of gonad width for macrostage as measured from micrometer |
| Scale | Magnification of dissecting microscope lens for macrostage, linked to Magnification table |
| Gonad weight | Weight of gonad in grams |
| Gonad width | Width of gonad measured at widest point in mm |
| Eye size (vertical) | Vertical measurement in mm |
| Eye size (horizontal) | Horizontal measurement in mm |
| Comments | |
| Dominant cell | Description of cell type linked to development microstages (gonads) table |
| Microstage | Microscopic stage of gonad development, where 1=undiff and 7=silver female |
| Scale2 | Magnification of compound microscope lens for microstage, linked to Magnification2 table |
| Micrometer2 | Measurement of gonad width for microstage cell width1 as measured from |

| | |
|---|---|
| | micrometer |
| Cell width1 | Cell diameter in mm Replicate 1 |
| Micrometer3 | Measurement of gonad width for microstage cell width2 as measured from micrometer |
| Cell width2 | Cell diameter in mm Replicate 2 |
| Comments2 | |

**Development microstages (gonads)**

| Field Name | Description |
|---|---|
| Microstage | Microscopic stage of gonad development 1 to 7 |
| Dominanat cell | Description of cell type linked to Gonad Details table |
| Description | |

**Magnification**

| Field Name | Description |
|---|---|
| Scale | Magnification of dissecting microscope lens for macrostage, linked to Magnification table |
| Actual scale | Measurement used to multiply micrometer by actual scale |

**Magnification2**

| Field Name | Description |
|---|---|
| Scale2 | Magnification of compound microscope lens for microstage, linked to Magnification table |
| Actual scale2 | Measurement used to multiply micrometer by actual scale2 |

**Appendix III.** Table structure and description of fields in the Eel Distribution database.

**Adult eel details table**

| Field Name | Description |
|---|---|
| EelID | Autonumber |
| SampleID | Linked to Sampling data table |
| SpeciesCode | Species code 1=A. reinhardtii, 2=A. australis |
| Stage | Sexual maturity |
| Tag | Tag number |
| Weight | Weight of individual in grams |
| Length | Length of individual in mm |
| Girth | Girth of individual measured in front of pectoral fins in mm |

**Adult eel sampling table**

| Field Name | Description |
|---|---|
| SampleID | Autonumber, Linked to Eel Details table |
| SiteNo | Linked to Adult Eel Sites table |
| Sector | Industry sector C=commercial, R=rivers survey, I=independent |
| FisherCode | Commercial fisher where sample came from |
| GearCode | Type of gear used to sample |
| DateFished | DayMonthYear |
| Comments | Comments related to sample |

**Adult eel sites table**

| Field Name | Description |
|---|---|
| SiteID | Autonumber, Linked to Adult Eel Sampling table |
| SiteNo | Linked to Adult Eel Sampling table |
| Catchment | Name of Catchment |
| Waterbody | River , Lake or Creek |
| Zone | Waterbody divided into 1=upper, 2=middle, 3=lower |
| Site | Zone divided into replicates |
| Site Description | Specific details of site |
| Longitude | Decimal degrees |
| Latitude | Decimal degrees |

**Biological data table**

| Field Name | Description |
|---|---|
| BiolID | Autonumber |
| SampleID | Linked to Sampling Data table |
| SpeciesCode | Species code 1=A. reinhardtii, 2=A. australis |
| Length | Length of individual in mm |
| MinLength | Minimum length of sample |
| MaxLength | Maximum length of sample |

**Eastern freshwater cod sites table**

| Field Name | Description |
|---|---|
| ID | Autonumber |
| SiteName | Description of sampling site |
| River | Name of River , Lake or Creek |
| Catchment | Name of Catchment |
| SiteNo | Linked to 'catch data E cod survey' table |
| Lat | Latitude in decimal degrees |
| Long | Longitude in decimal degrees |
| ECCapture | Whether Eastern Cod were captured at this site |

**Eel catch data from eastern freshwater cod survey table**

| Field Name | Description |
|---|---|
| ID | Autonumber |
| Date | DayMonthYear |
| SiteNo | Linked to Eastern Cod Sites table |
| Bank | Left or Right side of river |
| SectNo | ? |
| OpNo | Operation number ie number of replicates |
| Fish No | Number of each individual caught at each site |
| Species | Six digit name of species caught |

**GIS eel sites table**

| Field Name | Description |
|---|---|
| Region | Regional sector within State |
| Stream | Name of River, Lake or Creek |
| Catchment | Name of catchment |
| State | Name of State |
| SpeciesCode | Species code 1=A. reinhardtii, 2=A. australis |
| Long1 | Longitude in decimal degrees |
| Lat1 | Latitude in decimal degrees |
| Species | Number of individuals caught |

**Hawkesbury survey sites table**

| Field Name | Description |
|---|---|
| ID | Linked to Sampling Data table |
| Date | DayMonthYear |
| Collector | Name of fisher |
| SiteNo | Number of replicate within the site |
| Trudys SiteNo | Linked to Trudys Hawk Codes table |
| Location | Description of site |
| Stream | Name of River, Lake or Creek |
| DWR | Drainage Basin Number given by Water Resources |
| Town | Nearest town |
| Bedrock | Substrate A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Boulder | Substrate A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Cobble | Substrate A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Gravel | Substrate A=Abundant, R=Rare, F=Frequent, O=Occasional |

| | |
|---|---|
| Sand | Substrate A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Mud/Silt | Substrate A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Clay | Substrate A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Unknown | Substrate A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Native Trees | Plants A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Exotic Trees | Plants A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Shrubs | Plants A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Terrestrial Grasses | Plants A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Rushes/Sedges | Plants A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Littoral Grasses | Plants A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Floating Macrophytes | Plants A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Submerged Macrophytes | Plants A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Algae | Plants A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Rock | Cover A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Timber | Cover A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Undercuts | Cover A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Plant Litter | Cover A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Level | ? |
| Turbidity | Water clarity |
| Surface Temp | Surface temperature |
| Migration | ? |
| Barriers | ? |
| Stream Flow | ? |
| Type | ? |
| Velocity | S=Slow, M=Medium, F=Fast |
| Pool | Stream Habitat A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Run | Stream Habitat A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Riffle | Stream Habitat A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Rapid | Stream Habitat A=Abundant, R=Rare, F=Frequent, O=Occasional |
| Av Width | Average width of stream in metres |
| Tidal | Level of tide in metres where applicable |
| Depth | ? |
| Still Water | ? |
| Storage Level | Of still water |
| Max Depth | Maximum water depth of still water |
| Platypus | Were platypus sited |

**Method codes table**

| Field Name | Description |
|---|---|
| Method Codes | Method code |
| Description | Description of method and boat used |
| Combined Method Code | Type of method used |

**Sampling details table**

| Field Name | Description |
|---|---|
| SampleID | Autonumber |
| SiteID | Linked to Sites table |
| Date | DayMonthYear |
| Survey | Survey number, Rivers survey only |
| OpNo | Operation number ie number of replicates |
| Replicate | Number of replicate at site |
| Method | Method code, linked to Method Codes table |
| Temp | Temperature degrees C |
| Salinity | Salinity in ppm |
| NoEelsCaught | Number of eels caught in sample |
| NoEelsObs | Number of eels observed but not caught in sample |
| TotalNoEels | Total number of eels caught and observed in sample |
| MinLength | Smallest length in sample, Museum samples only |
| MaxLength | Longest length in sample, Museum samples only |
| Data Source | Source of dataset |

**Sites table**

| Field Name | Description |
|---|---|
| SiteID | Site number linked to Sampling Data table |
| RiverType | Type and nature of stream |
| Region | Regional sector within State |
| Stream | Name of river, lake or creek |
| DWR | Drainage Basin Number given by Water Resources |
| Catchment | Catchment |
| Nearby Town | Nearest town |
| State | State |
| LatDeg | Degrees of latitude |
| LatMin | Minutes of latitude |
| LongDeg | Degrees of longitude |
| LongMin | Minutes of longitude |
| Lat | Latitude in degrees and minutes |
| Long | Longitude in degrees and minutes |
| Long1 | Longitude in decimal degrees |
| Lat1 | Latitude in decimal degrees |
| MapGrid | Map grid reference number |
| ID | ? |
| SiteNo | Original dataset site number |
| HawkSiteNo | Replicate number, Hawkesbury/Nepean dataset only |
| TrudySiteNo | Site number, linked to Trudys Hawk Codes, Hawkesbury/Nepean dataset only |
| NRSampleNo | Sample number of original Northern Rivers dataset |

| | |
|---|---|
| NRSiteNo | Site number of original Northern River dataset |
| AESiteNo | Site number of original Adult Eel Project dataset |
| SiteDescription | Description of sampling site |

**Trudys Hawk Codes**

| **Field Name** | **Description** |
|---|---|
| Siteno | Site number of Hawkesbury/Nepean dataset |
| Dam/riv | Name of dam or river |
| Reach | Description of type of river reach |
| Site | Site name |
| Bioreg | Bioregion, based on Pease (1999) |
| DWR | Drainage Basin Number given by Water Resources |
| Study | Name of study within Hawkesbury/Nepean Project |
| Catchment | Catchment |

**Appendix IV.** Definition of an eel trap in the *Fisheries Management (General) Regulation* 2002.

## Fisheries Management (General) Regulation 2002

### 65 Eel trap

**(1) It is lawful for a commercial fisher to use a trap for taking eels in the waters specified in the Table to this clause if the trap complies with the description as set out in relation to those waters in that Table and the following conditions are complied with:**

(a) the eel trap is not set or used unless its position is indicated by a buoy which:

(i) is moored so as to be positioned above the trap, and

(ii) has a diameter above the water of not less than 100 mm, and

(iii) has a weight of not less than 50 gm suspended not less than 1 metre under the float so that no rope is floating on the surface of the water, and

(iv) displays "LFB" followed by the licence number of the boat used to set the trap and "E" at the end of that number, in clearly visible letters and figures which are not less than 50 mm in height and are of a colour which contrasts with that of the buoy,

(b) the commercial fisher does not set or use more than 10 eel traps at any one time.

(2) For the purposes of this Regulation or any other instrument under the Act, a trap referred to in this clause may be referred to as an eel trap.

### Table Eel trap

| | |
|---|---|
| 1 | (a) *Waters*—Any waters (other than inland waters, ocean waters or sea beaches).<br><br>(b) *Description of trap*—Not exceeding 2 metres in length, 0.5 metre in width and 0.5 metre in depth or not exceeding 1 metre in length, 1 metre in width and 0.5 metre in depth; consists of mesh not less than 20 mm diagonal nor more than 40 mm diagonal; has an entrance funnel not exceeding 100 mm. |

**Appendix V.** Terms and conditions for a permit to trap eels in freshwater farm dams.

# PERMIT UNDER SECTION 37
# FISHERIES MANAGEMENT ACT 1994

**Eel Trapping Farm Dams**

IN accordance with the provisions of section 37 of the *Fisheries Management Act 1994*, licensed commercial fisherman **Mr X** of X, is hereby authorised to trap eels in farm dams located within NSW and east of the Great Dividing Range, subject to the following conditions.

**Conditions:**

1. The permit holder is restricted to taking eels in farm dams on private property only. The permit holder shall not attempt to take eels in publicly owned impoundments or in farm dams constructed on any water course or in any tidal stream.
2. The design and dimensions of eel traps shall be as prescribed by clause 64 of the Fisheries Management (General) Regulation 1995. Mesh netting (not wire netting) only shall be used in the eel traps. The size of the mesh shall be not less than 25mm.
3. The permit holder shall use a maximum number of 25 eel traps at any one time. The location of the traps must be marked with a float. All gear and floats must carry the name of the permit holder and the permit number in legible characters.
4. *The traps shall be set so that any cod-end is partially out of the water to enable trapped mammals to breathe.*
5. All traps must not be left unchecked for a period exceeding 24 hours.
6. This permit does not give right of access to farm property. To harvest eels from farm dams, permission must be obtained from the owner.
7. Monthly farm dam catch returns are required to be forwarded to: NSW Fisheries Catch Records, PO Box 21, CRONULLA NSW 2230. Returns must include details of the number of fishing days, localities, weight of daily catches, and number of gear used each day (whether eels have been captured or not).
8. The permit holder shall only take eels. Any other finfish or platypus captured shall be returned to the water with the least possible injury.
9. The permit holder shall carry this permit at all times when fishing for eels in farm dams.
10. The permit holder shall contact the local Fisheries Officer at least five days prior to trapping for eels in a particular district, to advise of the areas proposed to be fished.
11. This permit does not authorise fishing activities in contravention of any notification issued under section 8 of the *Fisheries Management Act 1994*.
12. The permit holder shall abide by any instruction relating to the operation of this permit, given by an Officer of NSW Fisheries. This may involve the inspection of eel traps at any time.
13. The issue of this permit in no way implies or guarantees future rights in any fishery.
14. Failure to comply with any of the conditions may result in a prosecution under the Fisheries Management Act 1994, and the cancellation of this permit.
15. This permit may be varied, suspended or cancelled at any time by the Director of NSW Fisheries.
16. Unless sooner suspended or cancelled, this permit shall remain in force from **1 July 2002 to 30 June 2003.**

X

**Principal Manager, Fisheries Services**

Date:

**Appendix VI.** Terms and conditions of a permit to collect glass eels from coastal estuaries.

# GLASS EEL COLLECTION PERMIT

*TERMS AND CONDITIONS*

A. *Harvests of Juvenile Eels*

1. There will be no interstate or overseas export of eels harvested under this permit.

2. Eel elvers must not be taken from NSW waters, see I(2).

3. The main commercial fishing catchments for market size eels (Clarence River catchment, Port Stephens catchment and the Hawkesbury River catchment) are closed for glass eel collection.

4. Sustainability of the glass eel fishery will be reviewed each year based on the reports submitted by glass eel collection permit holders and any other source of glass eel recruitment information.

5. NSW Fisheries reserves the right to terminate glass eel collection permits or review the 300kg maximum allowable catch at any time.

B. *Maximum Allowable Catch of Glass Eels*

1. The maximum allowable catch of glass eels (long and short finned combined) is 300kg/year in total.

2. Along the NSW coast, a maximum of 30kg/year of glass eels (long and short finned combined) may be caught per catchment drainage basin, excluding the 3 listed in A3.

3. The total catch of glass eels approved by NSW Fisheries for each year will be based on the demand from the NSW eel aquaculture industry. Demand will be based on a farms carrying capacity (pond/tank area), and intensity of the production facility. Only NSW eel aquaculture permit holders will be eligible to acquire NSW glass eels from selected collectors.

4. NSW Fisheries shall act as the controlling authority for approval and allocation of glass eels. Aquaculture permit holders must apply to NSW Fisheries for glass eel stock on a regular basis and receive an approved allocation.

5. In-principal agreement to source NSW glass eel stock shall be granted to proponents applying for an eel aquaculture permit, however, no stock shall be collected for the farm until the facilities are constructed and operational.

C. *Collection Permits*

1. There will be a limited number of glass eel collection permits granted. Consideration will be given to the geographic spread of the permit holders in relation to estuaries and catchments in NSW.

2. A permit under section 37 of the Fisheries Management Act 1994, will be available to the successful applicants. They will be issued on an annual basis, dependant upon negotiations with eel permit holders with approved glass eel allocations. The permit will prescribe conditions relating to the collection, possession and sale of glass eels.

3. This arrangement will remain in force, unless cancelled, for 5 years. Following this time, the arrangements described for selection of glass eel collectors will be reviewed.

4. A permit does not concern any future access right to take glass eels.

5. NSW Fisheries will review the permits and permit conditions annually and reserves the right to vary or cancel the permits.

6. At no time is it guaranteed that the maximum allowable catch will remain at 300kg.

7. Permits to collect glass eels are not transferable in any form or manner.

D. *Glass Eel Collectors*

1. Selected glass eel collectors may not nominate any other person to undertake collecting activities for them. They must be present during collection activities.

2. Any persons assisting the permitted fisher to undertake collection activities will need to be registered on the permit. The decision to register other persons rests with NSW Fisheries.

E. *Permit Tenure*

1. Given the experimental nature of the fishery, collection permits will have a short tenure and be reviewed after 5 years.

2. NSW Fisheries will review the permits and permit conditions annually and reserves the right to vary or cancel the permits.

3. At no time is it guaranteed that the maximum allowable catch will remain at 300kg.

*4.* Permits to collect glass eels are not transferable in any form or manner.

F. *Authorised Fishing Areas*

1. Collectors may collect glass eels in most estuarine waters of NSW.

2. Closed waters, National Parks and Federal Lands must not be fished.

3. No freshwater areas may be fished unless varied by the permit.

4. NSW Fisheries reserves the right to allocate refuge areas in parts or whole of estuaries to protect juvenile stocks from overfishing.

5. Collectors must avoid conflict with other resource users, avoiding commercial fishing grounds, recreational fishing and recreational boating areas.

6. Holders of the permit are expected to avoid conflict with other resource users, avoiding commercial fishing grounds, recreational fishing and recreational boating areas.

7. The permit shall not be used in any way for the collection of glass eels for the purposes of personal consumption, sale (other than to the stated aquaculture facilities), trade, barter or giving glass eels away. Any excess glass eel catch or bycatch caught must be immediately returned to the waters where caught and not removed from the immediate vicinity.

G. *Fishing Times*

1. Collectors may collect glass eels at any time of the day.

2. Collectors must not undertake collection activities on public holidays. Fishing must cease before 6am on the day the holiday commences and not recommence until 6am on the day after the holiday.

H. *Fishing Gear*

1. NSW Fisheries must approve fishing gear. Nets typically include Elton type fyke nets, with 1.5mm knotless mesh wings, a 0.7mm mesh cod-end and a 25mm mesh exclusion device, dip nets (max diameter 0.3m) or flow traps.

2. The permit number must be prominently displayed at all times during collection activities in letters no smaller than 150mm, on the side of the boat used to set nets, on an accompanying vehicle where hand dipping glass eels and on the side of flow traps.

3. Nets must have exclusion devices and any by-catch must be returned to the water.

4. Set nets and flow traps do not need to be attended at all times but must be cleared at a maximum of 12 hourly intervals.

5. No boat trawling for glass eels will be allowed.

I. *Eel Species*

1. The collection permit will authorise for both long and short finned glass eels to be collected. Glass eels are defined as a young eel recently metamorphosed that have not yet commenced feeding. Cylindrical in shape and devoid of body pigment, 40-70mm and weighing 0.1-0.2g.

2. Elvers will not be authorised to be collected until there is a better understanding of the fishery. Elvers are glass eels that have undergone pigmentation and commenced feeding, 60-200mm and weighing 0.3-1.0g.

J. *Glass Eel Collectors Obligations*

1. Collectors will notify the local Fisheries office 24 hours prior to undertaking collection activities.

2. Collectors will carry a copy of their permit at all times during collecting activities.

3. Collectors will maintain logbooks to assist in stock assessment describing collecting activities including such details as: date, moon phase, tides, weather, water temperature, catch, by-catch, mortalities, methods of fishing and a sketch of location. Also outline any problems encountered and successes in sourcing and handling of glass eels.

4. Logbooks are to be completed for each day of fishing whether or not there is any catch.

5. Copies of logbooks will be submitted to NSW Fisheries on a monthly basis.

K. *Sales Agreement*

1. Collectors will enter into a sales agreement with eel aquaculture permit holders for the purchase of glass eels to meet an approved allocation.

2. The sales agreement will include such details as: price/kg, agreed survival rates, collection or transport responsibilities and proof of stock species.

3. A copy of the sales agreement is to be lodged with NSW Fisheries prior to a permit being issued to allow the collection of that allocation.

M. *Disagreements*

Disagreements shall be handled by arbitration.

N. Royalties

Royalties demanded per kilogram of glass eels caught will be mandatory after a two year period. During this time an independent assessment can be made of their true royalty value.

**Appendix VII.** Current version of monthly catch and effort return for farm dam eel fishers.

NSW FISHERIES

## EEL FARM DAM/IMPOUNDMENT MONTHLY RETURN

An eel farm dam/impoundment monthly return must be completed by every fisher with a permit to access these waters (even for months in which there was no fishing). **The catch details reported on this form must not be recorded on any other monthly catch return.**

**Section A -Must be completed**

Permit Holder's Name | Permit Holder's FL

Month | Year | No. of days worked in farm dams or impoundments

**Section B - Complete if you fished in the farm dam fishery this month**

Complete a new group (1, 2, 3 or 4) for each different drainage basin in which you fished

| Group → | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Drainage basin fished (see map) | | | | | |
| No. of days in this drainage basin | | | | | |
| No. of dams/impoundments fished | | | | | |
| Total no. of trap pulls this month (refer to instructions for definition of trap pulls) | | | | | |

**Please record details of the catch from each drainage basin reported above.**

| Group → | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Longfin river eel weight (kg) | | | | | |
| No. Longfin river eel (estimated) | | | | | |
| Shortfin river eel weight (kg) | | | | | |
| No. Shortfin river eel (estimated) | | | | | |
| Total catch (kg) | | | | | |

**Section F - Complete if you caught species other than eels (e.g. turtles, platypus, finfish)**
Please record details of other species which you caught, include the name/s of the species caught, number caught and condition when released.

**Section C - Complete if you fished in farm dams or impoundments this month**

For each dam or impoundment worked, please record the basin number, the name of dam/impoundment (or property), property owner's name, address of property and a contact phone number for the property owner.

| Details (see above) of Dam/Impoundment (or property) | Basin No. |
|---|---|
| | |
| | |
| | |
| | |
| | |

**Section D - Complete if you produced catch from farm dams or impoundments**

Please record first receiver of your catch only

| Name/Number of Fish Receiver | Weight (kg) |
|---|---|
| | |
| | |
| | |
| TOTAL | |

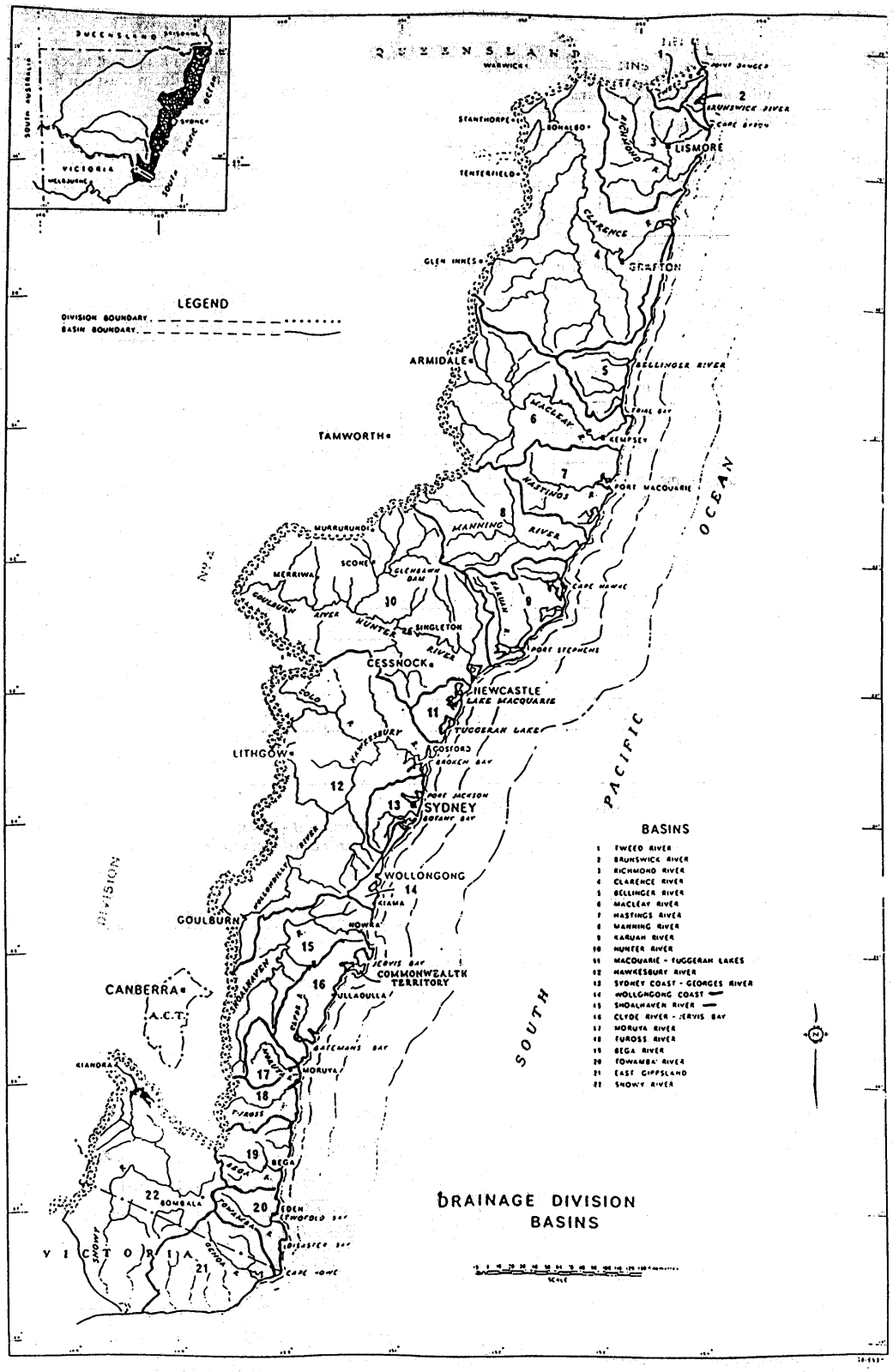
**Section E- Permit holder must complete this section**

I certify the information I have provided on this return is a complete and accurate record and that to the best of my knowledge none of the recorded catch has been claimed by any other fisher or is recorded on any other catch return.

Permit Holder's Signature: | Date:

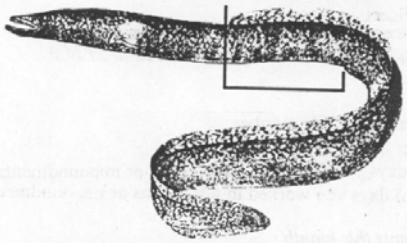
Please return original to your local NSW Fisheries office or to NSW Fisheries, Catch Records Section, Locked Bag 6, Cronulla NSW 2230. Keep duplicate (pink copy) for your own records.

EEL01 - 200107


QUEENSLAND
NEW SOUTH WALES
VICTORIA
SOUTH AUSTRALIA
SOUTH PACIFIC OCEAN
LEGEND
DIVISION BOUNDARY
BASIN BOUNDARY
WARWICK
STANTHORPE
BONALBO
TENTERFIELD
GLEN INNES
ARMIDALE
TAMWORTH
MURRURUNDI
SCONE
MERRIWA
SINGLETON
CESSNOCK
NEWCASTLE
LAKE MACQUARIE
TUGGERAH LAKE
GOSFORD
BROKEN BAY
LITHGOW
SYDNEY
BOTANY BAY
WOLLONGONG
KIAMA
NOWRA
GOULBURN
JERVIS BAY
COMMONWEALTH TERRITORY
CANBERRA
A.C.T.
ULLADULLA
BATEMANS BAY
MORUYA
TUROSS
BEGA
BOMBALA
EDEN
TWOFOLD BAY
CAPE HOWE
GRAFTON
LISMORE
BRUNSWICK RIVER
CAPE BYRON
BELLINGER RIVER
KEMPSEY
PORT MACQUARIE
CAPE HAWKE
PORT STEPHENS
BROKEN BAY
BOTANY BAY
BASINS
1 TWEED RIVER
2 BRUNSWICK RIVER
3 RICHMOND RIVER
4 CLARENCE RIVER
5 BELLINGER RIVER
6 MACLEAY RIVER
7 HASTINGS RIVER
8 MANNING RIVER
9 KARUAH RIVER
10 HUNTER RIVER
11 MACQUARIE - TUGGERAH LAKES
12 HAWKESBURY RIVER
13 SYDNEY COAST - GEORGES RIVER
14 WOLLONGONG COAST
15 SHOALHAVEN RIVER
16 CLYDE RIVER - JERVIS BAY
17 MORUYA RIVER
18 TUROSS RIVER
19 BEGA RIVER
20 TOWAMBA RIVER
21 EAST GIPPSLAND
22 SNOWY RIVER
DRAINAGE DIVISION BASINS

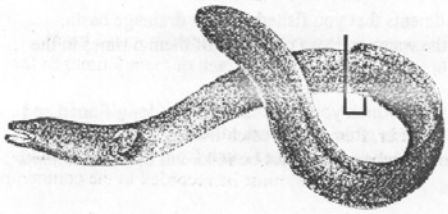
## Identifying your Eels

**LONG-FINNED RIVER EEL**
Max: 1.6m NSW



- Dorsal fin begins well in front of anal fin
- Colour is olive-green to brownish becoming lighter ventrally, dorsal areas with darker blotches and mottling

**SHORT-FINNED RIVER EEL**
Max: 1.2m NSW



- Dorsal fin begins slightly in front of anal fin
- Colour is olive green to olive brown with greyish white ventrally; lacks blotches and mottling

## Provisions for providing an airspace

- The trap must have a cod end long enough to reach the surface of the water and a float with a minimum diameter of 100 mm must be placed inside the end of the cod end.
- At least one hoop with a minimum diameter of 0.5 metre must be fastened to the inside of the cod end within 1 metre of the draw string end.
- The cod end must be extended to the surface in a manner that provides animals in the trap with unrestricted access to the airspace. To avoid twisting and bunching, the cod end should be stretched tight and fastened to an object on the bank.
- No additional funnels or valves should be allowed in the trap other than the single entrance funnel.

## NSW Fisheries Monthly Catch Return Instructions
Eel Farm Dam/Impoundment – Form EEL01-200107

A record of fishing activities in farm dams or impoundments is required from every fisher with a permit to access these waters (even if there has been no fishing). If you did not work in farm dams or impoundments in the month, complete Sections A and E only. Details of fishing activities (e.g. catch) from farm dams or impoundments must only be reported on this form. Do not include such details on any other type of return. The original copies (orange copy) of completed returns must be received by NSW Fisheries within 28 days of the end of the month. The duplicate copy (pink) should be kept as your own record. Please also retain any records in relation to your fish sales as you may be required to produce such documents to Fisheries Officers.

Please note, fishers operating in farm dams or impoundments must work in accordance with the provisions of Section 37 of the *Fisheries Management Act 1994* and the conditions outlined on their permit.

*SECTION A: Must be completed*
**Permit Holder's Name/ File Number (FL):** Record the name of the permit holder and their file number.
**Month/Year:** Record the month and calendar year to which this return applies.
**Number of days worked in farm dams or impoundments:** Record the number of days you worked in farm dams or impoundments during this month.

*SECTION B: To be completed only if the fisher worked in farm dams or impoundments this month*
Record details of effort and catch resulting from fishing activities in farm dams or impoundments in this section of the return. There are five columns labeled Groups 1 to 5. Please complete a separate Group for each different drainage basin you fished during the month. Locations of drainage basins are shown on the reverse side of this return. Only one drainage basin is to be listed in each Group/box and catch and effort from each different drainage basin MUST be shown in a separate column.

**Drainage basin fished:** Record the code number/s of each drainage basin (see map) fished during the month. A map showing drainage basins is provided on the reverse. If you fished in more than one drainage basin during the month, please record details of each basin and the associated catch and effort in a different Group.
**No. of days in this drainage basin:** Record the number of days fished in each drainage basin. Include days when you went fishing and did not catch anything.
**Number of dams/impoundments fished:** Record the number of dams/impoundments that you fished in each drainage basin.
**Total number of trap pulls this month:** For example, if you have 10 traps in the water and you pull each of them 5 times in the month, you would record 50 traps pulls (10 traps x 5 pulls).

**Catch Details:** Please record details of the catch for each different drainage basin in which you worked. Catch of long-finned and short-finned eels must be recorded as both a weight (in kg) and as an estimated number. Remember catch from different drainage basins needs to be divided and shown in separate columns. Any by-catch (e.g. platypus, turtles) must be recorded in the comments section.

*SECTION C: Complete if worked in the farm dams or impoundments this month*
Please record the drainage basin number (see map) and the names of the dams or impoundments (or the name of the property/s containing such) in which you worked.

*SECTION D: Complete if you produced catch from farm dams or impoundments*
Record the name or registration number of the first receiver/s of your catch (e.g. co-op, processor) along with the quantity of fish disposed at each. Record the total of all fish disposed in the 'total box'. This total should equal the sum of totals in Section B of your return. If you are a restricted registered fish receiver, record your name and registration number together with the total weight of catch disposed.

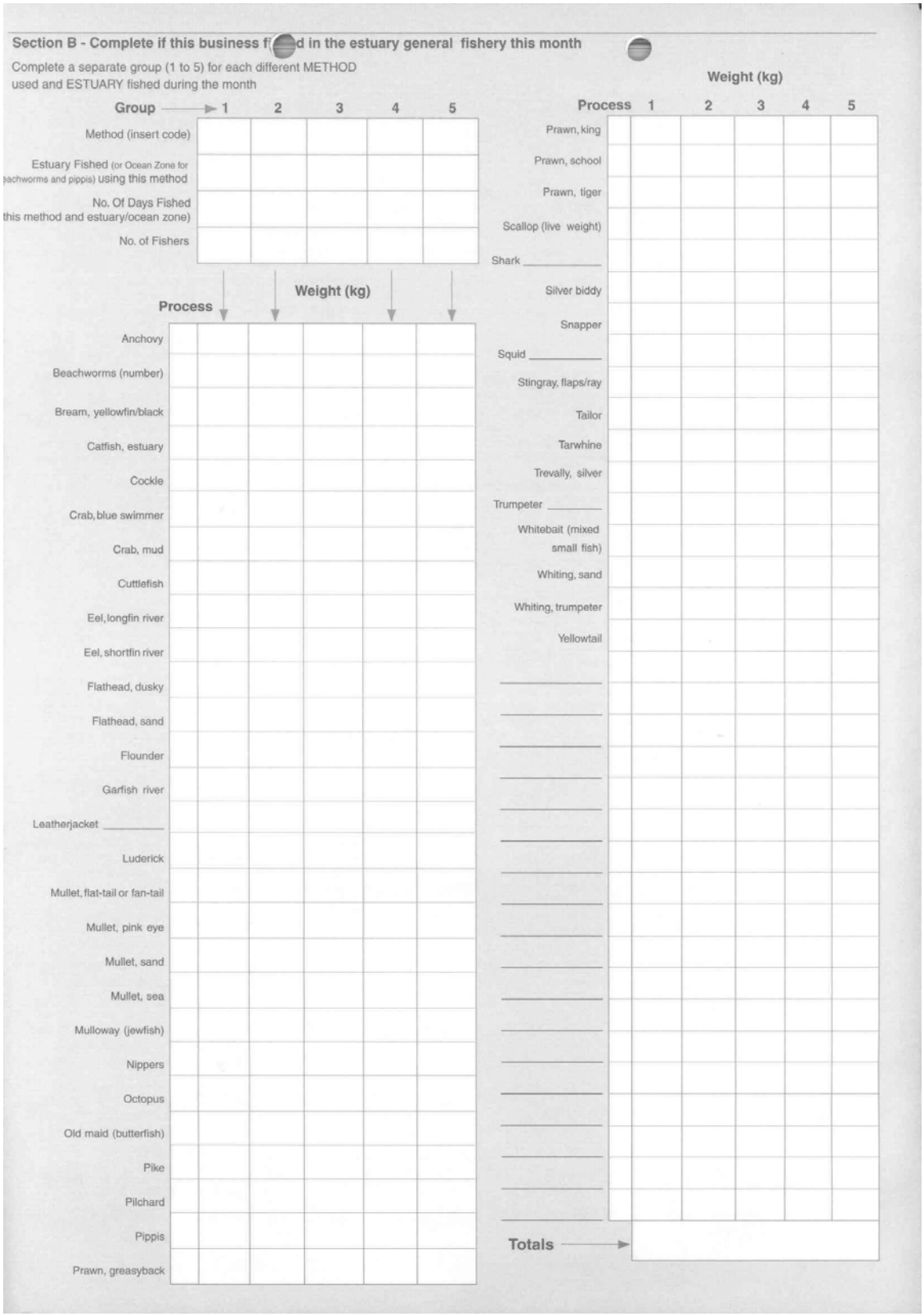
*SECTION E: All fishers must complete this section*
The fisher must sign and date the return to verify it is a complete and accurate record of his/her fishing activities.

*SECTION F: Complete if you caught species other than eels*
Record catch of all species you caught other than eels (e.g. finfish, platypus or turtles). Remember such species must be returned to the wild with the least possible injury.

**Please submit completed returns to either your local NSW Fisheries office or to:**
**NSW Fisheries, Catch Records Section, Locked Bag 6, Cronulla 2230. New forms are available from your local NSW Fisheries office or by calling the Catch Records Section on 02 9527 8511.**

**If you have any questions about these monthly catch returns, please contact the Catch Records Section at NSW Fisheries on (02) 9527 8511.**

**Appendix VIII.** Current version of the catch and effort return for the Estuary General Fishery.



**Section B - Complete if this business fished in the estuary general fishery this month**

Complete a separate group (1 to 5) for each different METHOD used and ESTUARY fished during the month

| Group → | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Method (insert code) | | | | | |
| Estuary Fished (or Ocean Zone for beachworms and pippis) using this method | | | | | |
| No. Of Days Fished this method and estuary/ocean zone) | | | | | |
| No. of Fishers | | | | | |

| Process | Weight (kg) 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Anchovy | | | | | |
| Beachworms (number) | | | | | |
| Bream, yellowfin/black | | | | | |
| Catfish, estuary | | | | | |
| Cockle | | | | | |
| Crab, blue swimmer | | | | | |
| Crab, mud | | | | | |
| Cuttlefish | | | | | |
| Eel, longfin river | | | | | |
| Eel, shortfin river | | | | | |
| Flathead, dusky | | | | | |
| Flathead, sand | | | | | |
| Flounder | | | | | |
| Garfish river | | | | | |
| Leatherjacket _____ | | | | | |
| Luderick | | | | | |
| Mullet, flat-tail or fan-tail | | | | | |
| Mullet, pink eye | | | | | |
| Mullet, sand | | | | | |
| Mullet, sea | | | | | |
| Mulloway (jewfish) | | | | | |
| Nippers | | | | | |
| Octopus | | | | | |
| Old maid (butterfish) | | | | | |
| Pike | | | | | |
| Pilchard | | | | | |
| Pippis | | | | | |
| Prawn, greasyback | | | | | |

| Process | Weight (kg) 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Prawn, king | | | | | |
| Prawn, school | | | | | |
| Prawn, tiger | | | | | |
| Scallop (live weight) | | | | | |
| Shark _____ | | | | | |
| Silver biddy | | | | | |
| Snapper | | | | | |
| Squid _____ | | | | | |
| Stingray, flaps/ray | | | | | |
| Tailor | | | | | |
| Tarwhine | | | | | |
| Trevally, silver | | | | | |
| Trumpeter _____ | | | | | |
| Whitebait (mixed small fish) | | | | | |
| Whiting, sand | | | | | |
| Whiting, trumpeter | | | | | |
| Yellowtail | | | | | |
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| Totals → | | | | | |

NSW FISHERIES

# NSW Fisheries Monthly Catch Return Instructions

## Estuary General – Form EG05- 2001/07

A record of fishing activities in the estuary general (EG) fishery is required from every fishing business (FB) with endorsements in this fishery (even if there has been no fishing). If more than one fisher is involved in the fishing operations it is now possible to list the names and details of all fishers on just one return page. Fishers who are listed on a return do not need to submit a separate EG return (unless they participated in activities independently of those fishers listed on the return). If it is impractical to list the details of all fishers on one return, each fisher can still submit separate monthly catch returns. In such cases however, it is important that each fisher only records his/her share of the catch and effort (e.g. days fished). The endorsement holder is responsible for submitting the monthly record of the FBs activities. Record details of fishing done in NSW estuaries only. If the FB did not work in the EG fishery, complete Section A only. Please note there is now a separate return for estuary prawn trawling. The original copies of completed returns must be received by NSW Fisheries within 28 days of the end of the month. Please retain any records in relation to your fish sales as you may be required to produce such documents to Fisheries Officers.

### SECTION A: Must be completed

**Month/Year:** Record the month and calendar year to which this return applies.
**Date return completed:** Record the date of completing the return in the format day/month/year.
**Page no. this month (estuary general only):** If the FB/s listed on this return is/are submitting more than one estuary general return page for the month please number each page, otherwise record '1'.
**Fisher's Name/ File Number (FL)/Fishing Business No:** If you worked alone you will only need to use line 1 to record your details. If however more than one fisher worked to produce the catch, it is now possible to record the names and details of all these fishers on one return. Fishers should keep other related records (e.g. sales dockets) showing their actual share of the catch. Please record the name of the fisher to be contacted should there be a problem with the return at position 1. Most FBs should have a fisher nominated to hold the endorsements for the fishery. This person is responsible for submitting a record of the FBs activities in the estuary general fishery. Contact NSW Fisheries Licensing on (02) 9527-8411if you wish to make or confirm the nomination of a fisher.
**Fishing Business No. (FB):** This number should be printed on your fishing licence. If you are uncertain of your number, please contact the Catch Records Section on (02) 9527 8511.
**No. of days:** Record the number of days each fisher worked to produce the catch reported on this return.
**Signature:** Each fisher is required to sign the return to verify it is a complete and accurate record of the month's fishing activities.

### SECTION B: To be completed only if the FB/s fished in the estuary general fishery this month

Record details of effort and catch in the estuary general fishery in this section of the return. There are five columns labeled groups 1 to 5. Please complete a separate group for each different method used and estuary fished during the month. For example, during the month you working in Wallis Lake using both a prawn running net and a mesh net. In the same month you also work in Smiths Lake using a mesh net and a handline. You will need to complete 4 groups/ columns on the return page (prawn running net/Wallis Lake, mesh net/Wallis Lake, mesh net/Smiths Lake, handline/Smiths Lake), with catch and effort for each different method and estuary divided. Only one method and estuary is to be listed in each group/box. Catch from different estuaries or using different methods MUST be shown in separate columns. Remember include details of effort and catch taken from NSW estuaries only.
**Method:** Estuary general method codes are listed on the code sheet on the reverse of this return. Record the codes for each fishing method used during the month. You must use a separate group/box for each different method and catch must be split accordingly.
**Estuary:** Estuary codes are listed on the reverse side of this return. Record the codes of the estuary in which you fished. If you fished in more than one estuary during the month, record each estuary and the associated catch in a different group.
**No. of Days Fished:** For each different method and estuary record the number of days worked (note: the number of fishers operating is no longer relevant). If you trap for 5 days in the Clarence River and 4 days in the Richmond River, you would record Clarence River, Trapping, 5 days and Richmond River, Trapping 4 days. Only include days when there was actual fishing and not days when you were maintaining your gear.
**No. of Fishers:** Record the average number of fishers who worked (for each given method and estuary) to produce the catch reported on this return.
**Catch:** Record the catch of each species in kilograms (kgs). Remember catch produced from different estuaries and methods needs to be divided and shown in separate columns. If a species of fish is not listed on the return, record in space given at the end of list. If a species of fish is followed by a line (e.g. leatherjacket and shark), you should specify the type if possible. Please try to limit reports of 'mixed fish' to less than 5% of your total catch. Record the total catch in each column in the area marked 'totals'. It is important that a particular catch of fish is only recorded once. Total catch from an operation can be recorded on one return (listing all fishers involved), OR if this is not practical each fisher can complete a separate return recording his/her split of the catch and effort only.
**Process:** If you process (e.g. gut, head) any of your fish before marketing, record appropriate process code (listed on the code sheet) in the process box next to the fish name. If fish is marketed whole, leave this box blank. If fish was used for bait, record a '9' in the process box.

### SECTION C: Complete if the FB/s disposed of catch taken in the estuary general fishery

Receivers of fish are now referred to as Registered Fish Receivers (RFRs) and MUST have an RFR number. Your fish receiver should be able to advise you of their RFR number or for a list of all RFRs please contact either the Registered Fish Receivers Branch on 02 4333 7134 or the Catch Records Section on 02 9527 8511. For each RFR to which you disposed of catch this month please record the RFR number, name of the receiver and the total weight of catch disposed. Please supply only the RFR number of the FIRST receiver to whom you supplied your catch. For example, if you supply your catch to a co-op who then passes it to the Sydney Fish Market, you must only record the details of the co-op. Record the total of all fish disposed in the 'total box'. If you are a Restricted Registered Fish Receiver, please supply your RRFR number in the space provided and DO NOT record details of where catch was disposed.

### SECTION D: Complete this section only if you wish to indicate nil returns for other fisheries in which the FB/s holds endorsements.

If no fishing was done in other fisheries in which a FB holds endorsements you may indicate a 'nil' return for the fishery in this section. Record the FB number next to the fishery in which a nil return is required. Separate returns (for each of the fisheries indicated) are not required from the FBs listed in this section.

**Please submit completed returns to your local NSW Fisheries office or to: NSW Fisheries, Catch Records Section, Locked Bag 6, Cronulla 2230.**
**New forms are available from your local NSW Fisheries office or by contacting the Catch Records Section on (02) 9527 8511.**

**If you have any questions about monthly catch returns, please contact the Catch Records Section at NSW Fisheries on (02) 9527 8511.**

# Estuary General Monthly Catch Return Code Sheet - EG05 - 2001/07

## Estuary Codes

**Please record appropriate estuary code/s (from the list given below) on your monthly return. If you fish in more than one estuary during the month show details (catch and effort) in a separate group/column on your return.**

**2810** Tweed River
**2833** Brunswick River
**2852** Richmond River
**2907** Evans River
**2926** Clarence River
**2941** Sandon River
**2953** Wooli River
**2959** Corindi River, Redbank Creek
**3006** Woolgoolga Lake
**3013** Moonee Creek
**3018** Coffs Harbour Creek
**3021** Boambee Creek
**3023** Bonville Creek
**3030** Bellinger River, Kalang Creek
**3036** Deep Creek
**3039** Nambucca River
**3052** Macleay River
**3126** Hastings River
**3133** Lake Innes, Lake Cathie
**3138** Camden Haven River, Queens Lake
**3153** Manning River
**3211** Wallis Lake
**3223** Smiths Lake
**3226** Myall Lakes, Myall River, Port Stephens, Karuah River
**3255** Hunter River
**3305** Lake Macquarie
**3321** Tuggerah Lakes
**3334** Hawkesbury River
**3345** Narrabeen Lake
**3350** Sydney Harbour, Parramatta River
**3401** Botany Bay, Georges River
**3404** Port Hacking
**3433** Lake Illawarra
**3434** Benson's Creek
**3438** Minnamurra River
**3453** Shoalhaven & Crookhaven Rivers
**3457** Lake Wollumboola
**3506** Jervis Bay
**3510** St Georges Basin
**3512** Swan Lake
**3516** Lake Conjola
**3518** Narrawallee Inlet
**3524** Burrill Lake
**3527** Tabourie (Toubouree) Lake
**3528** Termeil Lake
**3529** Meroo Lake
**3538** Durras Lake
**3545** Batemans Bay, Clyde River
**3550** Tomaga River
**3555** Moruya River
**3557** Congo Creek
**3559** Meringo Creek
**3603** Coila Lake
**3605** Tuross Lake
**3606** Lake Brunderee
**3607** Brou Lake
**3610** Dalmeny (Mummuga) Lake
**3612** Kianga Lake
**3613** Wagonga Lake
**3615** Nangudga Lake
**3617** Corunna Lake
**3620** Tilba Tilba Lake
**3621** Dry Lake (Little Lake, Tilba)
**3622** Wallaga Lake
**3625** Bermagui River
**3628** Barragoot Lake
**3629** Cutagee Lake
**3632** Murrah Lake
**3638** Wapengo Lake
**3639** Middle Lake (Bega)
**3641** Nelson Lake
**3642** Bega River
**3647** Wallagoot River
**3653** Back Lake, Merimbula
**3654** Merimbula Lake
**3657** Pambula Lake
**3703** Curalo Lake
**3705** Twofold Bay
**3706** Nullica River
**3707** Towamba River, Kiah River
**3715** Womboyn River
**3716** Merrica River
**3731** Other estuary

## Fishing Method Codes

**Please record appropriate method code/s (from the list given below) on your monthly return. Show catch and effort for each different method in a separate group/column.**

**Prawn Methods**
Note: Estuary prawn trawl now has a separate return. No estuary prawn trawl details are to be recorded on estuary general returns

**12** Prawn set pocket net
**14** Prawn haul net
**16** Prawn seine (snigger)
**18** Prawn running net

**Hauling Nets**
**53** General purpose, trumpeter whiting, garfish

**Bait Nets**
**56** Bait net
**57** Pilchard and anchovy bait net
**58** Lampara net
**61** Bullringing (garfish)
**65** Hoop or lift net

**Mesh Nets**
**66** Mesh net, flathead
**69** Mesh net - top set, bottom set or splashing

**Traps**
**40** Lobster pot/trap
**41** Crab trap
**42** Fish trap
**43** Eel trap
**46** Bait trap

**Lines**
**34** Trolling
**36** Handline/rod & reel
**39** Jigging
**94** Set line

**Other**
**80** Skindiving
**82** Hand gathering

## Processing Codes

**If you process any of your fish before marketing, please record appropriate process code in the column labeled 'process' on your catch return.**
**If fish is marketed whole, leave the process box blank.**

**1** Gutted
**2** Headed
**3** Gilled and Gutted
**4** Headed and Gutted
**5** Headed, Gutted and Skinned
**6** Filleted
**7** Heads
**8** Cooked
**9** Bait for personal use
**10** Live
**11** Roe
**12** Headed, gutted and finned - cleaned shark
**20** Female
**30** Male

**Confidentiality of Information**
Information supplied to NSW Fisheries will only be released in summarised form which does not identify individual fishers. This includes information supplied under the terms of the *Freedom of Information Act*. The Department may have to release data relating to specific returns under over- riding State or Commonwealth legislation such as the *Income Tax Assessment Act*.

**Legal Requirements**
You are required by law to complete monthly catch returns. Under the *Fisheries Management Act 1994*, complete and accurate returns must be submitted to NSW Fisheries. Whilst there is provision for penalties for failing to complete appropriate returns, it is in your interest to comply and thereby assist with the management of our fisheries.

**Appendix IX.** Table structure and description of fields in the Lcatch Eels database.

**Catch Data Estuaries and Dams**

| Field Name | Description |
|---|---|
| FL | Fishers File Number |
| Period | YearMonth |
| Area Code | Waterway or zone |
| Basin Code | All major waterways divided into drainage basins |
| Method Code | Method of capture |
| Lcatch/hcatch Species Code | Old code name from corporate historic and pre 2000 databases |
| New Species Code | Name of species |
| Species Weight | Weight of catch in kilos |

**Historic Eel Data**

| Field Name | Description |
|---|---|
| Year | Fiscal year |
| Code Hregion | Region code form corporate historic database |
| Category | Estuary or Inland |
| Weight | Total weight of catch |

**Catch Data**

| Field Name | Description |
|---|---|
| FL | Fishers File Number |
| Period | YearMonth |
| Area Code | Waterway or zone |
| Method Code | Method of capture |
| Process Code | Processing Method |
| Days of Effort | Number of days fished in the month |
| Species Code | Name of species |
| Species Weight | Weight of catch in kilos. |
| Port Code | Port of landing |

**Farm Dams**

| Field Name | Description |
|---|---|
| Period | YearMonth |
| Type | Type of impoundment: N=nil, C=coastal, I=impoundment |
| FL | Fishers File Number |
| Date | Day/Month/Year |
| No_Longfin | Total number of longfin eels caught |
| Wt_Longfin | Total weight of longfin eels caught |
| No_Shortfin | Total number of shortfin eels caught |
| Wt_Shortfin | Total weight of shortfin eels caught |
| No_Traps_Used | Number of traps used in 24 hr period |
| No_Traps_Lifted | Number of traps lifted in 24 hr period |
| Hours_Fished | Number of hours each trap fished |
| Dams_Fished | Number of dams fished in 24 hr period |
| Basin_Code | All major waterways divided into drainage basins |

**AQIS Export data**

| Field Name | Description |
|---|---|
| Month | Month |
| Year | Calendar Year |
| Loaded | City of export |
| State | State of export |
| Preservation | Live or frozen |
| Treatment | Smoked or natural |
| Style | Gutted or whole |
| Species | Name of species |
| Discharged | City of import (destination) |
| FinalCountry | Country of import (destination) |
| Total Weight | Total weight of species exported |

**Yearly Queensland Catch**

| Field Name | Description |
|---|---|
| Year | Calendar year |
| Number of licences | Number of licenced fishers contributing to catch |
| Number of trap checks | Number of traps fished contributing to catch |
| Export total adults (kg) | Total weight (kg) of adult eels exported |
| Export Total glass eels (g) | Total weight (g) of glass eels exported |

**Codes Areas**

| Field Name | Description |
|---|---|
| Area Code | Area Code |
| Area Name Short | Short name |
| Area Name Laong | Full name |
| Report | For status reports |
| Ocean Zone | Ocean zone, Estuary or Inland |
| Class of Water | Ocean, Estuary, Inland, Dam |
| Source | Data sourced from |
| Area Code Old | Pre 2000? |
| Hregion codes | Historic region codes |
| Bioregion | Based on Pease (1999) |
| Basin Codes | All major waterways divided into drainage basins |

**Codes Basins**

| Field Name | Description |
|---|---|
| Basin Code | All major waterways divided into drainage basins |
| Description | Name of drainage basin (catchment) |

**Codes Fishers**

| Field Name | Description |
|---|---|
| FL | Fishers File Number |
| Report | For status reports |
| Surname | Surname |
| Given Names | Given Names |
| Address1 | Address1 |
| Address2 | Address2 |
| Address3 | Address3 |
| Postcode | Postcode |
| Phone | Phone |
| Licence Status | Licensing section information |
| District Code | Licensing section information |
| District | Licensing section information |

**Codes Fishery**

| Field Name | Description |
|---|---|
| Fishery Code | Fishery Code |
| Fishery | Type of fishery |
| Class of Water | Area of fishery |

**Codes Methods**

| Field Name | Description |
|---|---|
| Method Code | Method Code |
| Method Name | Type of method |
| Report | For status reports |

**Codes Period**

| Field Name | Description |
|---|---|
| Period | YearMonth |
| Month | Month |
| Financial Year | Financial Year |
| Calendar Year | Calendar Year |
| Old Code | 2 digit year and month |

**Codes Port**

| Field Name | Description |
|---|---|
| Port Code | Port Code |
| Port Name Long | Full port name |
| Port Name Short | Short port name |
| Port Zone | Ocean zone where port is located |
| Report | For status reports |

**Codes Process**

| Field Name | Description |
|---|---|
| Process Code | Processing code |
| Process | Type of processing |
| Report | For status reports |

**Codes Species**

| Field Name | Description |
|---|---|
| Species Code | Species Code |
| Report | For status reports |
| Species Name Short | Short species name |
| Species Name Long | Long species name |
| Class Species | Phylum |
| Freshwater | Freshwater or saltwater species |
| Protected | Whether protected or not |
| Deleted | Reporting information |
| Jurisdiction | Reporting information |
| Added to returns | Reporting information |
| Class for Report | Reporting information |

**Eel Fisher Endorsements**

| Field Name | Description |
|---|---|
| Fullfishery | Eel endorsement code |
| Endorsement Holder | Fishers File Number |

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