ASSESSMENT OF JUVENILE EEL RESOURCES IN SOUTH EASTERN AUSTRALIA AND ASSOCIATED DEVELOPMENT OF INTENSIVE EEL FARMING FOR LOCAL PRODUCTION

G. J. Gooley, L. J. McKinnon, B. A. Ingram, B. Larkin, R.O. Collins and S.S. de Silva.

Final Report
FRDC Project No 94/067

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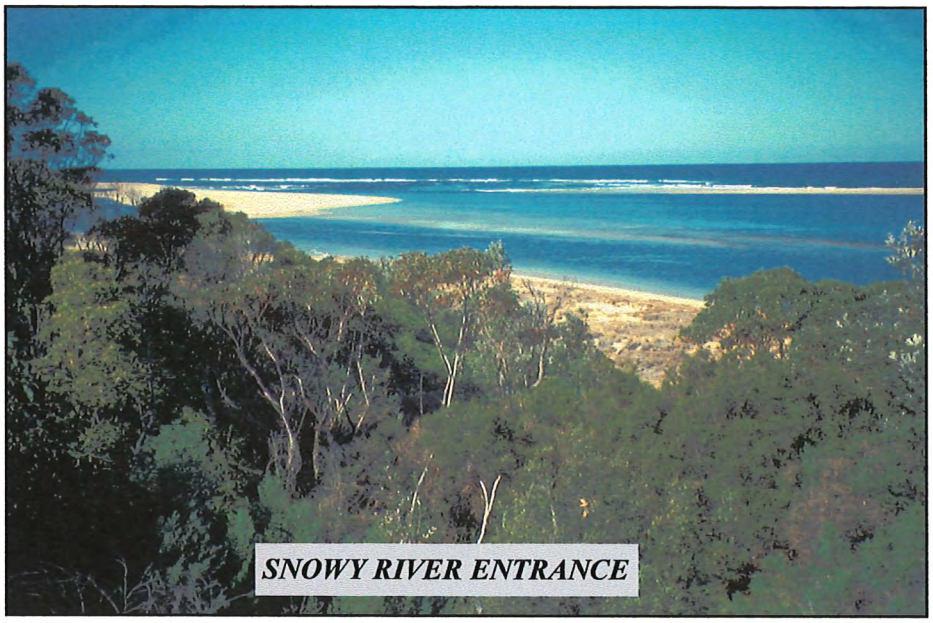

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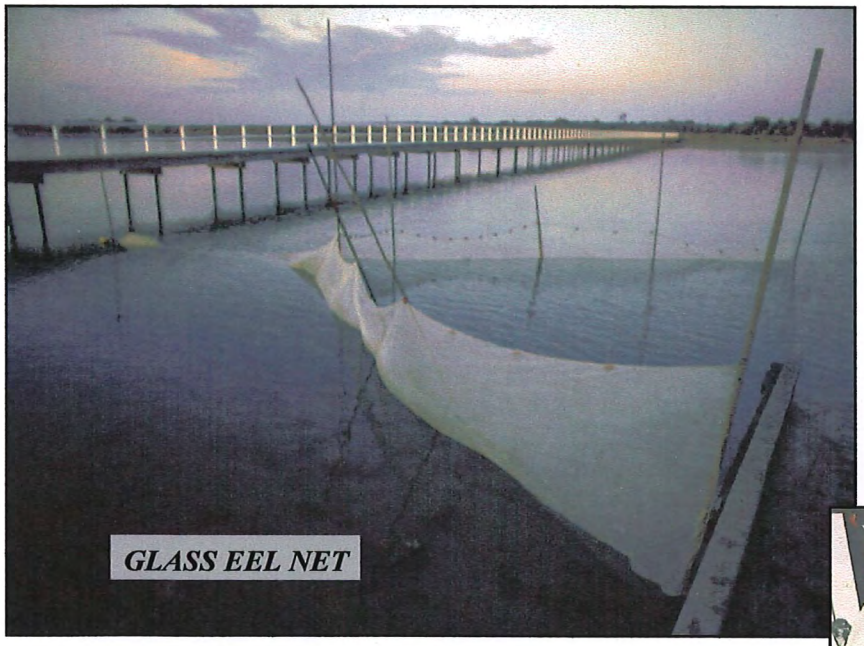

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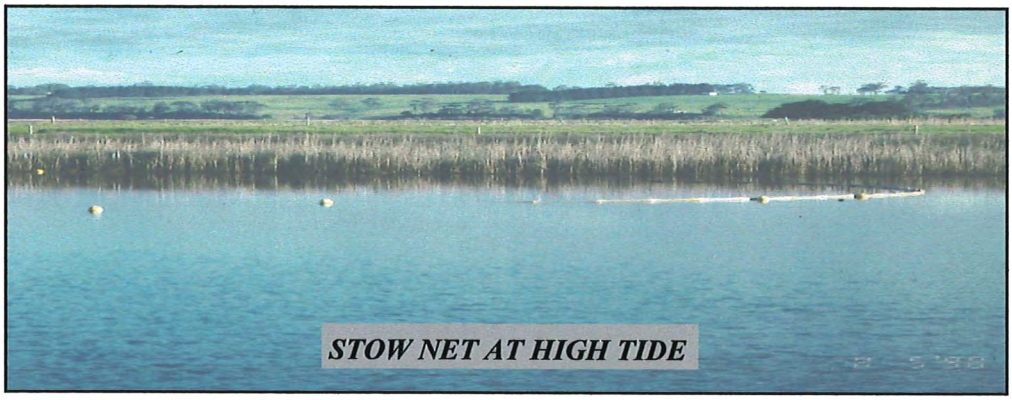

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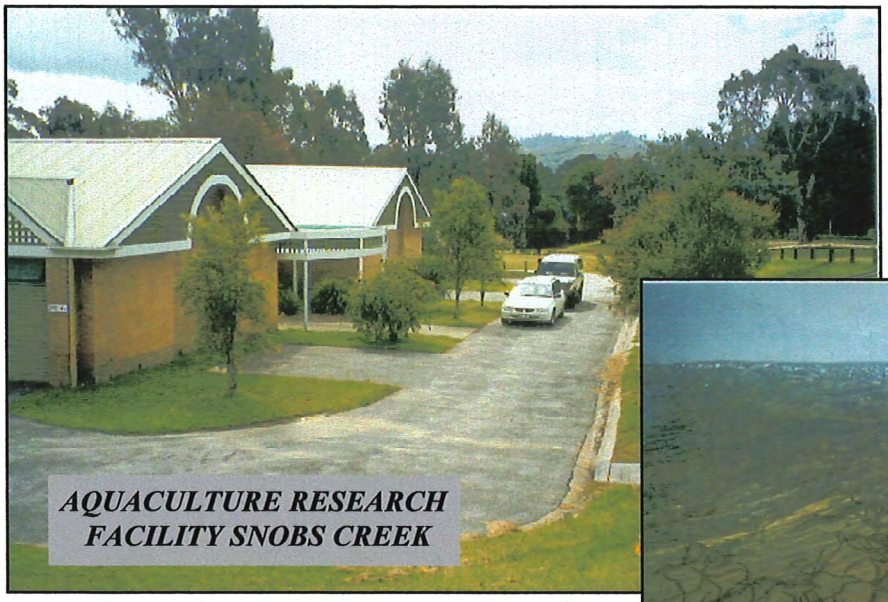

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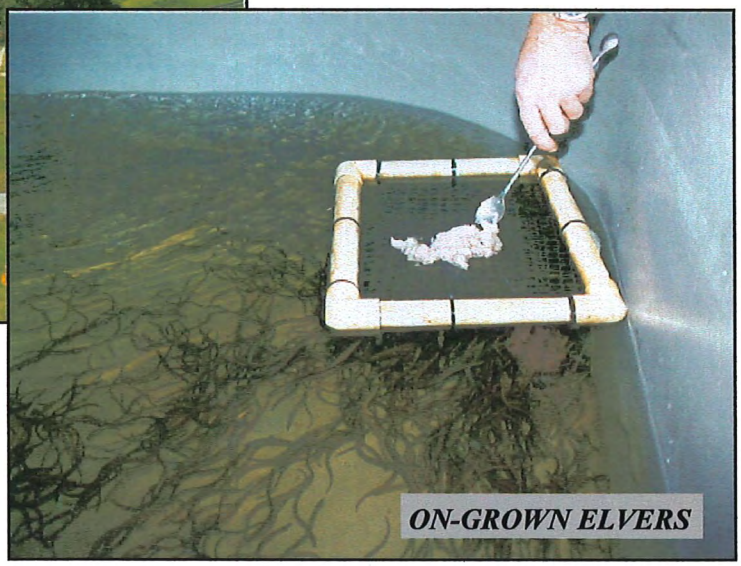

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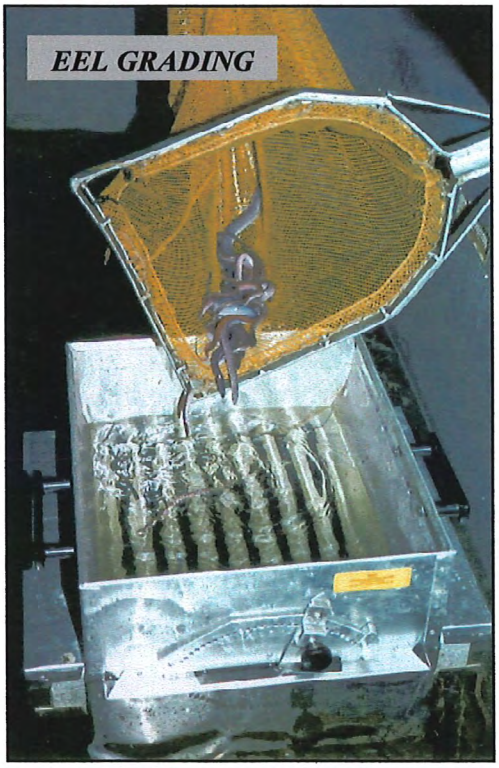

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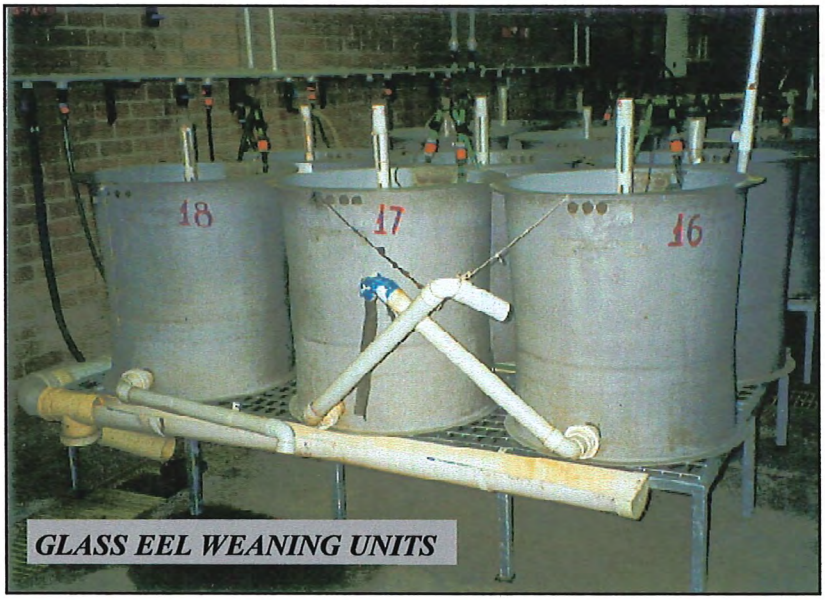

GLASS EEL WEANING UNITS

INTENSIVE EEL CULTURE UNIT

MARKET SIZED EEL

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3 NON-TECHNICAL SUMMARY

94/067 *Assessment of juvenile eel resources in SE Australia and associated development of intensive eel farming for local production*

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OBJECTIVES

1. To characterise and qualitatively assess *A. australis* glass eel migrations into coastal catchments of southern NSW, Victoria and Tasmania for the purpose of investigating potential for commercial exploitation of glass eels on an ecologically sustainable basis:
2. To adapt intensive/semi-intensive, pond/tank culture technology for the purpose of enhancing survival and viability of translocated juvenile eels, including glass eels, to be used in restocking/extensive production and/or intensive production to market size.

SUMMARY

In the face of declining world production of freshwater, anguillid eels, together with largely unsatisfied export market demand for such eels and eel produce, a commercial premium is being placed on the development of intensive eel culture technology and the associated utilisation of glass eel seedstock. For the purposes of this study it is assumed that any significant increase in Australian shortfin eel production over current levels will primarily occur with the adoption of intensive aquaculture practices based on the sustainable use of wild glass eel seedstock. Based on this rationale, the need for the present study is succinctly summarised as:

1. Glass eel assessment
- Do we have an accessible shortfin glass eel resource in Australia, and if so,
- Where, when and how can we efficiently and effectively harvest glass eels sustainably?

2. Glass eel culture
- Can we commercially culture shortfin glass eels in Australia, and if so,
- Where, when and how can this best be done in an economically viable way?

Key research methods employed during the Project include:

- a systematic schedule of glass eel surveys undertaken over a range of estuarine locations in Victoria, southern NSW and northern Tasmania to identify location and timing of significant glass eel invasions; measurement of a suite of key environmental parameters at sample locations to identify relevant criteria/cues associated with these invasions; measurement of total catch, effort, developmental stage, size and condition of glass eels and selected by-catch at a range of sites using a range of purpose built fishing equipment and associated techniques to determine the best methods for collecting glass eels at these locations, and to identify the relative size of the glass eel resource which can potentially be collected from these locations.
- a series of replicated tank trials at the Marine and Freshwater Resources Institute (MAFRI), Snobs Creek, investigating various husbandry and system requirements for shortfin glass eel culture under controlled environment conditions; a series of replicated pond trials at Deakin University, Warrnambool, investigating various husbandry and environmental requirements for shortfin glass eel culture under ambient conditions.

Key results and conclusions include:

- The invasion of shortfin glass eels into southeastern Australian estuaries is highly variable, spatially and temporally. A total of 30 waters were surveyed over three years in Victoria, NSW and Tasmania with glass eels being collected at 22 locations. The greatest catch-effort (CPUE) was recorded in the Snowy R. in Victoria. Glass eel invasions are typically seasonal, with peak catches occurring during winter and early spring. If certain assumptions are made about the potential market value of glass eels, "break even" quantites in Australia, in terms of covering collection costs for commercial fishers, are likely to be in the order of 1.0 kg/net/night (4,500-6,000 pieces, depending on mean weight of glass eels). Such catches were achieved in the Snowy River in the final year of the Project over the main invasion period (mid July-mid September), where glass eel CPUE was in the order of 1000-4000 pieces/net/hour (max. up to 3 kg in one night), and in the Tarwin River in 1995 (1-2 kg/night). Actual quantities of glass eels collected during the study were relatively small in commercial terms (<20 kgs over three years), most of which were caught in the final year of the project (approximately 17kg).
- The key environmental criteria for shortfin glass eel invasion of estuaries appear to include temperature, salinity and lunar-tidal cues involving moon phase and tidal bore. European style "stow" nets consistently produced the best catch when compared to more conventional glass eel nets, with bycatch a significant issue. A short-term database of catch rate indices has been established which shows that at any given location, early harvested glass eels tend to be larger than later arrivals, and at any given time, smaller glass eels tend to be harvested at the northerly extreme of the range compared with larger glass eels further south.
- Shortfin glass eels are readily transported and acclimated to freshwater, utilising basic handling and fish health protocols. Initial weaning to artificial diets can be variously achieved using a range of live or wet biomass feeds. The weaning phase to artificial diets was critical to successful culture, with key parameters being diet type and rate of wean. For initial intensive production, diet type, water temperature and feed rate were considered to be critical factors although stocking density, at the tested levels, was not. No major fish health problems were experienced during the trials. Pond culture generally produced growth rates consistent with tank culture, albeit on a seasonal basis only. Survival under pond culture was however significantly less than in tanks.
- Relatively high survival can be achieved (>80-90%) during the initial production stages, although growth under such production protocols is likely to be variable (up to 3.6% body weight/day). At such rates, commercially viable production of marketable eels (eg. 150-200g live weight) from glass eels within 12-24 months is conceivable. Wet feeds tended to result in very high FCR's and poor water quality within the culture tanks. Other recommended production parameters include water temperatures (>25^{0}C), and feeding and stocking rates during weaning (9-12% body weight/day and >10kg/m^3 respectively). It is estimated that for every 100 kg of Australian shortfin glass eels harvested annually, an additional value of up to AUD$100,000 or more could be added to the wild fishery and total aquaculture productivity likewise could increase by 50-100 tonnes worth approximately AUD$0.75-1.5 million (farm gate price).

Future R&D needs to focus on testing additional glass eel fishing techniques at fixed sites over a longer temporal scale for both shortfin and longfin glass eels in order to establish greater harvest efficiencies and a suitable catch-effort index of productivity. Bycatch reduction techniques also require attention. Development of glass eel culture techniques should focus on intensive tank systems, for both species, with an emphasis on species specific diet development. These issues are presently being addressed as part of FRDC Project No. 97/312: *"Assessment of eastern Australian glass eel stocks & associated eel aquaculture"*. This is a three year project, commencing in 1997/98, and is being managed by the Marine and Freshwater Resources Institute (Fisheries Victoria, Department of Natural Resources and Environment)

KEY WORDS
Australia, Anguilla, glass eels, assessment, aquaculture

4 BACKGROUND

World Production

The world aquaculture production of freshwater anguillid eels currently exceeds an estimated 130,000 tonnes per annum, worth over US$1.3 billion. The bulk of this production occurs in Asia, with China producing approximately 50,000 tonnes per annum, (mostly farmed), Japan 35,000 tonnes per annum and Taiwan 34,000 tonnes per annum, and to a lesser extent Europe (10,000 tonnes per annum). The two most commonly cultured species are the European eel, *Anguilla anguilla*, and the Japanese eel, *A. Japonica*.

Approximately 70% of the Asian production is for the Kabayaki market (150-200g eels, steamed, grilled and consumed whole), whereas the majority of the European market is for smoked fish, either whole or filleted. The major producers are commonly, but not exclusively, the major consumers of eels and eel products eg. Japan and several European countries. However, it is notable that at the present time production in Japan, the biggest consumer, does not meet its domestic demand; the latter estimated to exceed 100,000 tonnes per annum. China, as the major world eel producer, now exports the majority of its production to Japan to meet much of the shortfall in supply..

Despite the widespread global demand for cultured eels, worldwide eel production is declining, particularly in several Asian countries. A decline in Asian and, to a lesser extent, European glass eel stocks due to the combined effects of overfishing (for both glass eels and adult stocks) and environmental change impacting on recruitment is thought to be the main reason. Opportunities for utilising glass eel stocks of other non-exploited species, such as some of the Australian and North American anguillids, are now apparent.

Production methods

Eel farming industries around the world employ a variety of reliable, well established systems and technologies for intensive production purposes, ranging from relatively low density (< 5-10 kg/m^3), flow through pond culture under ambient conditions, to semi-intensive (10-100 kg/m^3) pond and tank culture under semi-controlled conditions, and super high density (>100 kg/m^3) in closed loop (recirculation), tank culture under completely controlled environment conditions. Culture tanks and ponds vary in size from small nursery tanks (eg. 1-10m^3 capacity) to large grow out ponds (eg. 0.05-0.2 Ha surface area). Water supplies for culture systems also vary from fresh to brackish, and from surface waters at ambient temperatures, to heated industrial effluent and geothermal artesian aquifers. The use of greenhouses is also common in some Asian countries, primarily as a cost-effective means of increasing water temperature and therefore growth rates.

Culture systems utilised for different species in Europe and Asia, and associated performance in terms of productivity, varies due to the different species specific requirements. Specific production methods are therefore modified and adapted accordingly. Typically, European systems tend to rely on super-intensive production in tank-based, closed loop/recirculation systems (eg. in the Netherlands), although the more traditional , semi-intensive pond systems are still practiced also (eg. Italy). Asian farming methods tend to be intensive, pond-based (both earthen and concrete), under ambient climatic conditions, albeit often with supplementary heat from use of greenhouse structures over ponds. More recently, the use of super-intensive, closed loop systems is also now gaining prominence.

In general, it is agreed that high density culture of eels in purpose built systems, of whatever type, can lead to a higher rate of survival and overall production compared with extensive culture at lower densities resulting from harvesting wild populations and/or re-stocking of translocated juveniles into surface waters (eg. lakes, farm ponds, natural wetlands etc).

Glass Eel Seedstock

Glass eels (post-larval juvenile eels) are the seedstock of choice for the Asian and European commercial eel aquaculture industry, which relies on the associated wild glass eel fishery for *A. anguilla* in Europe (250-1000 tonnes pa) and *A. japonica* in Asia (100-150 tonnes pa)(note that glass eels range from approximately 5000-8000 individuals or "heads/pieces" per kg at harvest). *A. japonica* is the preferred and therefore higher priced species in the Asian market, with prices reported to have recently exceeded AUD$10,000/kg. *A. anguilla* is the preferred species in the European market, with prices ranging from about AUD$300-800/kg. It should be noted that although the glass eel fishery in Europe far exceeds the Asian fishery in actual tonnage, only about 5% of the total catch in the former is used for aquaculture, compared with closer to 100% for the latter.

Due to the limited supplies to date, the Australian glass eels have no "accepted" market value at this stage, however, in the short term, a nominal value in the order of AUD$500-1000/kg is considered reasonable. It is also apparent that the unit value of all imported glass eels may achieve a premium in the Asian market over domestic prices in source countries, as the Asian industry endeavours to meet the increasing shortfall in domestic supply of *A. japonica* glass eels. Such prices for imported glass eels are thought unlikely to be as high as for *A. japonica.*

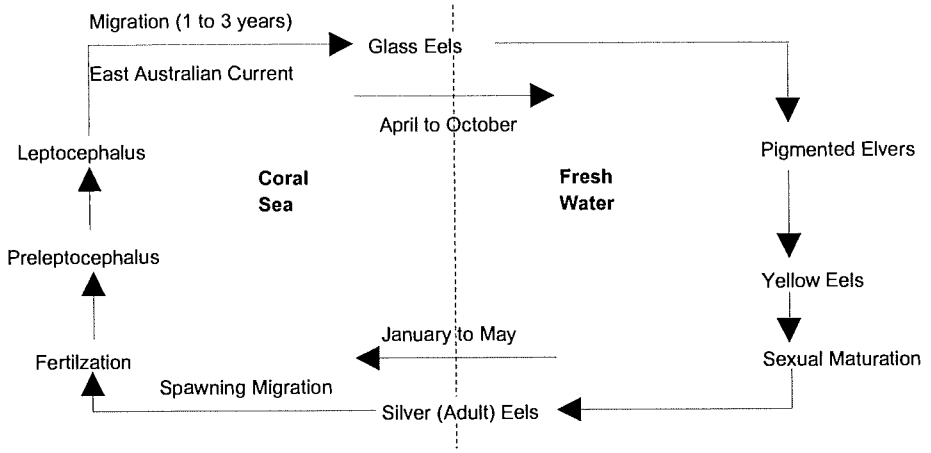
Anguillid eels are generally long-lived animals exhibiting extremely variable growth, and eel populations, both in Australia and other countries, also exhibit extremely variable recruitment. Large-scale glass eel migrations into estuaries are typically episodic events, often preceded by one or more years of recruitment failure in any one catchment . A number of environmental factors largely determine the frequency and viability of juvenile eel migrations . For these reasons, population estimates of recruitment and natural mortality are extremely difficult and therefore there are few documented reports, particularly in relation to juveniles.

The most relevant glass eel stock assessment studies have been undertaken in Europe where the glass eel fishery appears to have been declining steadily over recent years. It is also recognised however that extensive observations over many years are needed to verify any perceived trends and that the effects of physical conditions on elver recruitment reduces the reliability of simple catch data as an estimate of population viability. Nonetheless, it is generally agreed that there are many factors influencing glass eel migration and that any decline in the Asian and/or European glass eel fisheries could be as a result of any one or a combination of factors, including numerous environmental factors, habitat degradation, overfishing, climate change and associated natural fluctuations.

Australian Anguillid species

There are four species of freshwater eels endemic to Australian coastal catchments, all belonging to the Anguillidae family. The two species with most potential for commercial farming are the shortfin eel, *Anguilla australis* Richardson and the longfin eel, *A. reinhardtii* Steindachner. The shortfin eel is typically a temperate species but with a natural range which extends from southeast Queensland through to Victoria, Tasmania and the Murray River in South Australia. In contrast, the longfin eel is a typically more sub-tropical species but also has a broad natural distribution extending from northern Queensland through to eastern Victoria and northeastern Tasmania.

Anguillid eels, including Australian shortfin and longfin eels, have a relatively unique life-cycle in which the sexually mature adult eels migrate out to sea to spawn at depths of >300m. The tiny larval eels, or "leptocephali", are then thought to be carried in large numbers (hundreds of millions) by oceanic currents back to the continental shelf before they metamorphose into the next developmental stage known as "glass" eels (up to 12-18 months of age). The glass eels are carried by tides into estuaries of coastal rivers where they undergo further development to become "elvers" (up to 1-3 years of age), which have adopted the adult form in all respects other than size. The elvers then undertake a more active secondary migration into the freshwater, upper reaches of the catchment where they grow and develop into sexually mature adults before returning to the sea to spawn (average 10-25 years of age, although varies with species and location). A schematic summary of the life-cycle of the Australian shortfin eel is provided below.



Life Cycle of *Anguilla australis*. After Beumer (1983)

All Anguillid eels are thought to spawn only once. Australian shortfin and longfin eels are thought to spawn in the Coral Sea. The overall trip from spawning grounds to freshwater and back for any one eel can cover several thousands of kilometres. Because anguillid eels cannot be successfully bred artificially, all aquaculture seedstock is obtained by harvesting natural stocks of glass eels and the larger elvers on an annual basis during their respective migrations.

Australian Eel Production and Industry Status

Production of Australian shortfin and longfin eels currently is in the order of 500-600 tonnes pa, worth approximately AUD$4-6 million. The vast majority of this production comes from "stock enhanced" wild fisheries (also referred to in the industry as "cultured" eels), in which wild elvers and sub-adult eels are translocated from coastal rivers to lakes, swamps, wetlands etc., where they are left to grow to marketable size under natural conditions. Elvers are the preferred seedstock for such practices, and most translocated elvers presently are sourced primarily from Tasmania. When available, Tasmanian elver prices typically range from AUD$200-350/kg. Victoria has the largest annual production based on this practice, estimated to be approximately 250-400 tonnes pa. Market prices for wild and farmed eels (adults and sub adults) currently range from $10-17/kg (wholesale).

Internationally, market prices for cultured eels and eel products vary with species, country and product type and quality. The majority of existing Australian production is exported to European (Germany, The Netherlands) and Asian markets (Hong Kong, Taiwan and Japan) as adult size (> 1kg), fresh, chilled or frozen whole fish. Larger longfin eels are sometimes exported live into selected Asian markets (Taiwan and Hong Kong), and some value-added smoked products are also supplied to the local market.

At the commencement of this study in 1993/94 there was no commercial supply of Australian glass eels and no significant, commercial-scale intensive aquaculture production of Australian eels. Commercial intensive production was being attempted on a pilot scale only with state agencies in Victoria, Queensland and NSW providing access to limited quantities of glass eels (from 50 to 200 kg/state) and intensively cultured elvers (Victoria only) on a trial basis. Efforts to increase production at this time were largely focused on securing additional surface waters for grow-out of translocated "re-stock".

In Victoria at least, such waters are restricted to coastal catchments within the natural range of the target species for conservation reasons. More recently, the availability and use of re-stock, including elvers from Tasmania, has been limited due to variable supply and, in the case of the Tasmanian elvers, significant elver price increases. The cost of these eels has increased over the course of the

present study from about AUD$10/kg to about AUD$200-350/kg, as a result of the Tasmanian Government moving to a public tender system for the annual sale of harvested elvers to industry.

Australian glass eel resource

Consistent with other countries around the world, and for much the same reasons, little is known of the state of glass eel stocks in Australia. Studies undertaken in Victoria and Tasmania have reported distribution and relative abundance of *A. australis* glass eels in relation to physical and environmental variables, however there are no estimates of absolute abundance, recruitment or natural mortality. Returns from commercial fishers do not document glass eel catches, although much anecdotal information exists to suggest that substantial, commercial-scale glass eel resources do exist along the Victorian, NSW and Tasmanian coasts. Commercial operators have reported periodic, large-scale glass eel invasions of a number of coastal streams in Victoria and fishing activities targeted at these invasions can yield viable quantities of seedstock with relatively little effort. It is also suggested that natural mortality of these glass eel stocks is typically very high, with many large migrations occurring in very small streams with a relatively low standing stock of adult/sub-adult eels.

The apparently large natural mortality on glass eels and, to a lesser extent, subsequent post-larval stages over the first few months of entering estuaries, suggests that there are likely to be fewer conservation problems with harvesting glass eels in comparison to later juvenile, sub-adult and adult stages. The biggest problem is in determining the timing and location of mass glass eel migrations in the first place. Whilst acknowledging the significance of natural mortality of glass eel stocks to conservation values of estuarine ecosystems, it is still generally agreed that significant potential exists for the exploitation of glass eel stocks to sustain a commercial eel aquaculture industry without detrimentally impacting on either standing stock or other aquatic biota.

Significant glass eel migrations may occur every 2-3 years in some Australian river systems, and in Europe and the USA perhaps every 3-5 years. In all cases these migrations are extremely difficult to quantify in terms of total abundance and natural mortality, even with long-term and detailed monitoring programs. However, even in the absence of reliable, quantifiable stock assessment data, Australian glass eel runs could possibly be exploited for commercial purposes without any significant risk of depleting stocks to a non-recoverable stage, simply by using a practical, common sense and conservative approach to management of the resource. In all probability, the harvest of commercial-scale quantities of glass eels may not be significant to the population in absolute terms, and the effects on the wild fishery of any resultant reduction in recruitment levels could be effectively masked by existing natural variability.

Australian eel industry trends

Accordingly, the demand for Australian glass eels, elvers and cultured eel produce in general is deemed to be increasing, and any subsequent increase in Australian production is therefore thought likely to be readily absorbed by the world market. This is also largely due to the relatively unpolluted nature of Australian waters and the perceived high quality of the cultured and wild-caught eels grown therein.

Due to the lack of an Australian intensive eel industry, actual marketability and benchmark prices of cultured shortfin and longfin eels are unknown. The greatest potential appears to be in the production of smaller eels for the Japanese Kabayaki market. Value-adding through local processing is another means by which profitability and marketability can be enhanced. Presently there is little processing of eels in Australia, although appropriate processing infrastructure and expertise exists for other seafood products. Potential also exists for the intensive production of 5-10g shortfin elvers from glass eel seedstock for commercial stock enhancement purposes within existing wild fisheries eg. Victoria.

Moreover, the development of intensive eel culture technology has the potential for significantly increasing eel production over existing practices without any nett increase in environmental impact on natural ecosystems. Whereas it is generally agreed that of the native Australian eels, *A. australis*, has

the greatest potential for intensive aquaculture, and that the European and Asian technology could in part be readily adapted for use in Australia, experience suggests that it will be necessary to develop a "customised" system for Australian production, due to likely biological differences with the other species.

Such technology can potentially provide the means by which the commercial eel farming industry may expand in Australia without the need for further translocation of eels into public waterways. Although there may yet be some debate within the Australian aquaculture/eel industry as to the most appropriate level and means of intensification for local commercial eel production, the existing practice by fishermen of extensive farming is already producing significant quantities of eels, albeit perhaps somewhat inefficiently, due to the relatively low survival of translocated juveniles. If through adaptation of some relatively low cost, semi-intensive farming methods, the growth and survival of translocated juveniles for restocking purposes can be enhanced then this would provide immediate benefits to the industry.

In part, such methodologies already exist and are routinely and successfully used within other sectors of the Australian finfish aquaculture industry. Semi-intensively on-grown juvenile eels could then be restocked at a larger size for extensive rearing or made available by the fishermen to specialist growers to take to a market size under fully intensive conditions (once the necessary intensive aquaculture technologies are established). Coupled with the increased availability of seedstock through the harvest of glass eels, instead of elvers, such a development towards greater intensification could see a rapid and significant expansion in eel fishing/farming productivity.

5 NEED

In the face of unsatisfied market demand and declining world production, a commercial premium is therefore being placed on the development of intensive culture technology and the utilisation of glass eel seedstock. For the purposes of this study it is assumed that any significant increase in Australian eel production over current levels will only occur with the adoption of intensive aquaculture practices based on the sustainable use of wild glass eel seedstock. A corollary to this assumption is that ultimately, limited availability of such seedstock is likely to be the major constraint to further development of the Australian industry.

Based on the above rationale, the need for the present study can be succinctly summarised as:

1. Glass eel assessment
- Do we have an accessible shortfin glass eel resource in Australia, and if so,
- Where, when and how can we efficiently and effectively harvest glass eels in a sustainable manner?

2. Glass eel culture
- Can we commercially culture shortfin glass eels in Australia, and if so,
- Where, when and how can this best be done in an economically viable way?

Gaining access to significant glass eel stocks and associated improvement in culture technologies for enhancing quality and survival of seedstock would potentially provide a huge boost to productivity for the Australian industry, provide the opportunity for value-adding to an Australian natural resource and substantially increase the competitiveness of the Australian industry in the major European and Asian export markets. Pending the availability of suitable seedstock, and the development of associated culture technology, the potential exists to increase Australian production by approximately 100% over the next 3-5 years.

This project will therefore assess the status of the juvenile glass eel fishery in south-eastern Australia with the aim of developing the intensive culture of Australian glass eels for both domestic and export markets.

6 OBJECTIVES

Objective 1.

To characterise and qualitatively assess *A. australis* glass eel migrations into coastal catchments of southern NSW, Victoria and Tasmania for the purpose of investigating potential for commercial exploitation of glass eels on an ecologically sustainable basis:

- identify/establish location and timing of major glass eel "runs"
- identify/define and measure, where appropriate, relevant environmental variables/conditions associated with these "runs"
- determine/refine/adapt, where appropriate, best methods for collecting glass eels at these locations
- measure quantity of glass eels which can potentially be collected from these locations, together with an estimate of associated effort, as part of a commercial fishing operation

Objective 1 will be dealt with under Section VI, entitled Assessment Component.

Objective 2.

To adapt intensive/semi-intensive, pond/tank culture technology for the purpose of enhancing survival and viability of translocated juvenile eels, including glass eels, to be used in restocking/extensive production and/or intensive production to market size.

- adapt and evaluate methods for handling, holding and transporting glass eels
- adapt and evaluate methods of intensive tank and semi-intensive pond rearing of glass eels to pigmented elver stage for extensive and/or intensive grow-out
- adapt and evaluate methods of semi-intensive pond rearing of pigmented elvers to stocker stage for extensive and/or intensive grow-out

Objective 2 will be dealt with under Section VII, entitled Culture Component.

7 ASSESSMENT COMPONENT

7.1 INTRODUCTION

7.1.1 MECHANISMS OF GLASS EEL INVASION AND MIGRATION

The life-history of all anguillid eel species is both similar and relatively complex. Although spending most of its life in freshwaters, the sexually mature adult eel makes an extensive journey seaward to spawn. For *Anguilla anguilla* (European eel) and *A. rostrata* (American eel), spawning takes place in the Sargasso Sea, up to 6000km from the European coast and 2-4000km from the North American coast respectively (Tesch 1977). The Japanese eel, *A. japonica*, spawns off the north-east coast of The Philippines, some 3000km from where it is found in the freshwaters of northern Asia. The spawning ground(s) of the Australian and New Zealand shortfin eel, *A. australis,* the Australian longfin eel, *A. reinhardtii* and the New Zealand longfin eel, *A. dieffenbachii*, are not precisely known. Spawning is thought to take place in the Coral Sea, up to 2000km from their freshwater habitat along the eastern and south-eastern coast of Australia and in New Zealand (Schmidt 1925; Jespersen 1942; Jellyman 1987). But the evidence for the exact location of spawning grounds for these species is sparse and highly tentative.

Ocean currents carry the eel larvae, called leptocephali, to their various destinations. The Gulf Stream, North Atlantic and Florida Streams transport *A. anguilla* and *A. rostrata*, the Kuroshio or "Black" Current transports *A. japonica*, and the East Australian Current is the proposed vehicle for the transport of both *A. australis* and *A. reinhardtii* from the Coral Sea to the Australian continent. The transport of *A. australis* to New Zealand is also thought to be facilitated by the East Australian Current while the transport of *A. dieffenbachii* to New Zealand is considered to be facilitated by the Trade Wind Drift (Sloane 1984a).

The recent description of *A. reinhardtii* from northern New Zealand (Jellyman *et al.* 1996), and the recruitment of at least eight consecutive year classes of this species, have posed some interesting questions regarding the transport mechanisms of anguillid eels (McDowall *et al.* 1998). Reasons for the recent, but sustained recruitment of *A. reinhardtii* to New Zealand waters may include changes in oceanic currents which may be related to the El Niño Southern Oscillation, whereby *A. reinhardtii* glass eels become entrained within anticyclonic eddies which break off the East Australian Current and migrate across the Tasman Sea to the west coast of New Zealand (Jellyman *et al.* 1996; McDowall *et al.* 1998). The most probable reason for the occurrence of *A.reinhardtii* however, is transoceanic dispersal, probably from subtropical oceanic spawning grounds north of New Zealand (McDowall *et al.* 1998).

As leptocephali, eels feed and grow but in the vicinity of the continental shelf commence metamorphosis into the glass eel phase and temporarily cease feeding (Deelder 1970; Tesch 1977). Age at metamorphosis varies considerably from species to species, largely in relation to distance travelled from spawning grounds (Tzeng 1990; Guérault 1992).

The mechanisms of invasion and migration of glass eels of the genus *Anguilla* are well documented for many countries. Typically, the initial invasion by anguillid glass eels, including *A.australis*, into estuaries and their subsequent active upstream migration into freshwater habitats is seasonal and is facilitated by tidal movement, using flood tides and generally at night (Creutzberg 1961; Deelder 1970; Tesch 1977; Jellyman 1977, 1979; Beumer and Harrington 1980; McCleave and Kleckner 1982; Gascuel 1986; McCleave and Wippelhauser 1987; McCleave *et al.* 1987). Specific observations on the invasion and migration of *A. australis* glass eels in Australian estuaries have been reported, including reference to distribution and abundance and suitability for aquaculture, by Beumer and Harrington (1980), Beumer (1983a,b), Sloane (1984a) and Beumer and Sloane (1990).

For the purposes of this report, glass eel invasion is defined as the flow-carried transport of unpigmented (Stage VB; Strubberg 1913) glass eels into and within the estuary, including flow-assisted movement via tidal bore. This is distinct from the active swimming phase of upstream glass eel and later-stage pigmented elver migration, which is generally considered to commence at or near the upper limit of the tidal zone (Jellyman 1979; Sloane 1984a; Gascuel 1986). A summarised description of terms used in the present study is provided in Table 1. Glass eels represent a single year class whereas pigmented elvers may comprise multiple year classes of young eels in their secondary migration phase.

Table 1 Descriptions of developmental stages of Anguillid eels.

Developmental Stage	Description
Leptocephalus	Larval form. Narrow, deep-bodied, shaped like a willow leaf; primarily oceanic distribution
Glass eel	All stages from metamorphosed larva to early pigmented elver (Stages VA-VIB; Strubberg 1913). Initially transparent juvenile found between region of continental shelf and freshwater interface; term typically referring to estuarine juvenile eel stages
Pigmented elver	Fully pigmented juvenile, typically found in freshwater. Less than 30cm long. Larger elvers often referred to as "snigs" or brown elvers
Yellow eel	Eel which has completed its migratory phase into freshwater. Generally over 30cm long
Silver eel	Mature, adult eel migrating downstream to spawning grounds

7.1.2 GLASS EEL INVASION AND MIGRATION CUES

Several environmental cues are thought to influence the invasion and migration patterns of anguillid glass eels. Tosi *et al.* (1990) concluded that salinity is the most important factor directing *A. anguilla* glass eels toward fresh water. Tongiorgi *et al.* (1986) demonstrated that temperature, although not the sole cue, is an important factor in glass eel orientation as thermal gradients between fresh and sea water often exist, the direction of which depends on latitude. Chen *et al.* (1994) showed that a direct relationship exists between catches of *A. japonica* glass eels and rainfall, which consequently results in an indirect relationship between sea water temperature and glass eel abundance in the commercial catch. However, the effect of rainfall on other environmental variables, such as decreased salinity, increased terrestrial runoff and increased flow, is also thought to confound the specific response of glass eels to temperature change (Chen *et al.* 1994). Domingos (1992) demonstrated that glass eel abundance is favoured by high river flow and that rainfall increases the ascent of glass eels, although it was noted that heavy rainfall can have a negative effect on migration by producing river flows which retard tidal flows upstream, and are therefore too high for successful upstream migration of glass eels.

It has been reported that natural fresh water contains organic chemoattractants that act as cues for *A. anguilla* glass eels at sea to locate estuaries (Creutzberg 1961). Such chemoattractants are thought to originate largely from decaying vegetation (Sorensen 1986), and from soil as chemical compounds which produce odours similar to that of geosmin (Sola 1995). The attraction of *A. anguilla* glass eels to organic chemicals has been found to be related to decreasing salinity (Sola and Tongiorgi 1996). Lunar phase, in terms of light level, is thought to also influence the migration of glass eels (de Casamajor *et al* 1996) with greatest commercial catches occurring during new moon periods when

light level is low. It was also noted by de Casamajor *et al* (1996) that light has an increasingly repellent effect on glass eels as pigmentation increases.

Glass eel invasion and migration in estuaries also appears to show a relationship with lunar phase, in terms of tide height, with many commercial glass eel fisheries operating only around new and full moon periods (e.g. Antunes 1994). This is thought to be due to the effect of lunar phase on tidal magnitude, with the higher spring tides occurring at new moon and full moon (Jellyman 1979). Using preliminary data from the first two years of the present project, McKinnon and Gooley (1998) found that low (<10000 µS/cm) electrical conductivity, medium (10-14°C) water temperature and high (>0m AHD) tide height showed significant correlation with abundance of *A. australis* glass eels, measured as catch per unit effort (CPUE), but lunar phase (as moon age in days) did not. These results were presented at the European Inland Fisheries Advisory Commission and International Council for the Exploration of the Sea (EIFAC/ICES) Working Group on Eel meeting in IJmuiden, The Netherlands, 23-27 September, 1996. A copy of the published paper detailing this work is included in the appendices.

7.1.3 PIGMENTATION AND ASSOCIATED DEVELOPMENTAL STAGES

The term "glass eel" refers to the transparent nature of the post-larval juvenile, and is due to the lack of sub-epidermal pigmentation. Progress of initial invasion, and subsequent active migration, and associated physiological development can be measured by the rate of change of pigmentation seen in glass eels (Tesch 1977). The development of pigment enables the classification of different ontogenetic stages in the eel (Tesch 1977), in particular, throughout the larval/glass eel/elver stages (Deelder 1970). Strubberg (1913) developed a pigmentation classification table for *A. anguilla* which is still widely used (see Table 2) and which can be used to describe the development of pigment in *A. australis* (Jellyman 1977) during glass eel invasion and migration.

Strubberg (1913) found that temperature is important in pigmentation development of *A. anguilla* and, as pigmentation progresses, a concomitant reduction in length and weight occurs (Deelder 1970; Tesch 1977; Guérault *et al.* 1992) until Stage VIAIII2 (Tesch 1977). There is some evidence to suggest that *A. anguilla* glass eels up to Stage VIAIII2 do not eat, but may commence feeding at Stage VIAIV1 in the wild (Tesch 1977). Length and weight reduction and a decrease in condition have also been found for pigmenting *A. australis* glass eels (Jellyman 1977; Sloane 1984a). Sloane (1984a) found that mean length of *A. australis* glass eels decreased from Stage VB to Stage VIAIII and Jellyman (1979) found that the mean length of *A. australis* glass eels at Stage VIAIII was always greater than that at Stage VIAII, suggesting growth and therefore feeding commences at or prior to Stage VIAIII in *A. australis*.

A. australis glass eels increase in pigmentation stage as the season progresses (Jellyman 1977, 1979; Sloane 1984a) and glass eels at the estuary mouth are less pigmented than those found further upstream (Sloane 1984a). Early studies of *A. australis* and *A. reinhardtii* suggested that pigmentation of glass eels was induced on contact with fresh water (Cairns 1941) but it has since been determined that pigmentation of glass eels proceeds at equal rates in seawater and freshwater (Jellyman 1977). As such, pigmentation stage of invading glass eels thus would reflect the length of post-metamorphic sea life, and therefore late season glass eels are often more pigmented than early season glass eels (Jellyman 1977). Glass eels as early as Stage VA have been recorded previously in Victoria (Beumer and Sloane 1990) but Stage VB is the earliest pigmentation stage previously reported for *A. australis* in Tasmania (Sloane 1984a) and New Zealand (Jellyman 1977). Stage VA glass eels have also been recorded in northern NSW and Queensland (Beumer and Sloane 1990; Russell 1995).

In Tasmania, Stage VB glass eels in the north-east of the State had higher condition (K) factors than in other parts of the State, and were heavier than glass eels at other pigmentation stages (Sloane 1984a). Waters nearer the region of the onset of metamorphosis from the leptocephalus to the glass eel acquire glass eels earlier and in best condition (Sloane 1984a). In *A. anguilla*, the longest glass eels arrive earlier and are older than the smaller glass eels, suggesting that the size of a glass eel

entering the estuary is determined by the size of the former leptocephalus at metamorphosis (Guérault *et al.* 1992). From the literature it appears, therefore, that a combined spatial and temporal effect exists whereby larger glass eels, which are older and more vigorous than smaller glass eels, arrive earlier at a given location. In addition, glass eels arriving at locations relatively close to spawning grounds are smaller than those arriving at locations far from spawning grounds. This is because the latter glass eels presumably spend more time as leptocephali, thus feeding and consequently growing larger. Once metamorphosis occurs however, feeding ceases and condition of glass eels decreases until entry into freshwater and recommencement of feeding occurs.

7.1.4 WORLD FISHERY

Anguillid glass eels form the basis of an important fishery in many parts of the world. Commercial catches of *A. anguilla, A. rostrata* and *A. japonica* are taken annually from Europe, North America and northern Asia (Japan, Taiwan and China) respectively. The majority of glass eels are used as seedstock for aquaculture, however some quantities are used directly for human consumption in some parts of Europe and some quantities are used for restocking purposes (Tesch 1977). In 1924 France exported 750 tonnes of glass eels to Spain; the commercial catch including 12-15 tonnes from one short section of the Loire River (Tesch 1977). More recently, catches of 350-500 tonnes of *A. anguilla* glass eels were taken from European waters in 1993 and 1994 (Moriarty 1996) and 3-10 tonnes of *A. rostrata* from the USA and Canada in 1996 (B. Jessop, Dept. Fisheries and Oceans, Canada, *pers. comm.*). Catches of *A. japonica* in Taiwan, China and Japan are presently between 100 and 150 tonnes per annum (K. Matsunobu, Manager, Osumi Eel Farm, Japan, *pers. comm.*). In New Zealand a commercial glass eel fishery for *A. australis* operated between 1970 and 1974 in the Waikato River to supply local and Japanese eel farms. Total annual catches ranged from 0.7 tonnes-6.4 tonnes (Jellyman 1979).

Commercial catching methods are many and varied, often limited by local licensing laws. For example, the glass eel fishers in the Severn River, England, are restricted to using hand held dipnets, whereas those in the Vilaine River, France, use boat-operated trawl nets, and in the Rio Miñho, Portugal, large stow nets, or "hamennets" are used. In Taiwan and Japan, the Japanese glass eel net, or "Hell" net was commonly used however, because of its highly efficient catching ability, commercial glass eel fishers in Japan are now generally restricted to the use of hand-held dipnets. The 25,000 licensed glass eel fishers in Japan however, still catch an average 2kg per fisher annually. In the USA and Canada, the Japanese glass eel net is commonly used, as are hand held-dipnets and elver traps (Sheldon 1974; Jessop 1998).

The value of glass eels ranges widely between species and location and over time. In 1995, glass eel fishermen on the Severn and Wye Rivers in the UK received between $A125-and $A143 per kg of *A. anguilla* glass eels, while French glass eel fishermen working the Vilaine estuary received up to $A250 per kg of *A. anguilla* glass eels during the same period. Currently, UK glass eel fishermen fishing the Severn River are receiving over $A500 per kg. In 1987, *A. japonica* glass eels fetched up to $A6000 per kg (Gousset 1992). More recently *A. japonica* glass eels have fetched up to $A12000 per kg (K. Matsunobu, Manager, Osumi Eel Farm, Japan, *pers. comm.*). At the time of this study, no Australian glass eel fishery existed.

7.1.5 PRESENT STUDY

Rationale

The invasion of Australian shortfin (*A. australis*) glass eels into south-eastern Australian estuaries was investigated for the purpose of characterising the primary environmental cues associated with such invasions and subsequent migration of glass eels. It was considered feasible to undertake relevant biological and resource assessment investigations of shortfin glass eels, ultimately to achieve the following:

- Establish monitoring sites to develop a recruitment/production index for management of glass eel stocks
- Establish suitable locations for collecting commercial quantities of glass eels
- Identify biological and environmental parameters associated with the invasion and migration of glass eels

Objective

The primary objective of the Assessment Component of the project was to characterise and qualitatively assess *A. australis* glass eel migrations into coastal catchments of southern NSW, Victoria and Tasmania for the purpose of investigating potential for commercial exploitation of glass eels on an ecologically sustainable basis.

Strategy

The project strategy was to:

- Identify/establish location and timing of major glass eel "runs"
- Identify/define and measure, where appropriate, relevant environmental variables/conditions associated with these "runs"
- Determine/redefine/adapt, where appropriate, best methods for collecting glass eels at these locations
- Measure quantity of glass eels which can potentially be collected from these locations, together with an estimate of associated effort, as part of a commercial fishing operation

7.2 MATERIALS AND METHODS

7.2.1 SITE SELECTION AND GEAR USED

Glass eel surveys were conducted in south-eastern Australian estuaries for three successive seasons during the June-November period from 1994 to 1996. Waters were initially selected largely on the basis of distribution information from previous studies (e.g. Sloane 1984b, Beumer and Sloane 1990) and anecdotal evidence provided by commercial eel fishers in Victoria and Tasmania. As it became progressively evident which waters were likely to yield the greatest quantities of glass eels, subsequent assessment surveys were concentrated on these waters, resulting in fewer waters being sampled more frequently in the second and third years of the project. A total of 18 waters (16 in Victoria, 2 in Tasmania) were sampled with glass eel nets in the first year, 13 waters (3 in NSW, 5 in Victoria, 5 in Tasmania) were sampled with both glass eel nets and stow nets in the second year and 8 waters (1 in NSW, 4 in Victoria, 3 in Tasmania) were sampled in the final year using glass eel nets and stow nets (Figure 1). Summaries of glass eel surveys are given in Table 5. The Snowy River in Victoria was surveyed to the greatest extent during the study, and is shown in detail in Figure 2.

Limited use of a trawl net was also undertaken for experimental purposes in Tasmania in the final year of the study. Elver traps were also trialed on barriers (artificial and natural) in a number of Victorian estuaries in the first year of the project, however the use of these was abandoned due to poor glass eel catches, instability during periods of high flow and their vulnerability to theft and vandalism. Consequently the data from this gear type are not included in the analyses.

Glass eel nets were 3m in length, had two, 3m wings of 1m drop attached, providing an estimated effective fishing area of 5.2m^2, and were constructed of 2mm (stretched) nylon mesh. A detachable cod-end, constructed of <0.5mm mesh, was fitted to each net (Figure 3). Stow nets, also constructed of 2mm mesh, were as described by Weber (1986), providing an estimated effective fishing area of 86.7m^2, with the exception that a 3m cod-end was attached (Figure 4).

7.2.2 FISHING METHODS AND DATA COLLECTED

Glass eel nets were set in estuaries on either bank and stow nets were set in the main channel of the estuary. Both gear types were set at low slack water occurring at or after dusk. Catch was cleared at regular intervals, usually hourly, until high slack water occurred when fishing was terminated. Fishing generally occurred between 2-3 days before and 2-3 days following new and full moons with the exception of a number of waters sampled during the first and second years of the project. These latter sites were assessed on an *ad hoc* basis for 1-2 nights only to provide general information on the spatial distribution and relative abundance for the purpose of identifying potential long-term glass eel monitoring and harvest sites.

Catch was sorted using stacked plastic (530mm long x 350mm wide x 185mm deep) crates fitted with mesh screen floors graduated in size from largest (at the top) to smallest (10mm, 3.25 or 2.5 mm and <0.5mm mesh size respectively). Glass eels typically collected in the bottom tray and, depending on quantity, were counted individually or enumerated by weighing the total catch. A subsample of 50 glass eels from each sampling period at each site was taken and individual lengths and weights were recorded. This sample was used for ageing purposes and pigmentation staging.

Environmental data collected from each sampling trip included water temperature and electrical conductivity (salinity), recorded at 15 min. intervals using TPS 90FL dataloggers throughout the sampling period, time and height of low and high water, tidal range, stream discharge and lunar phase.

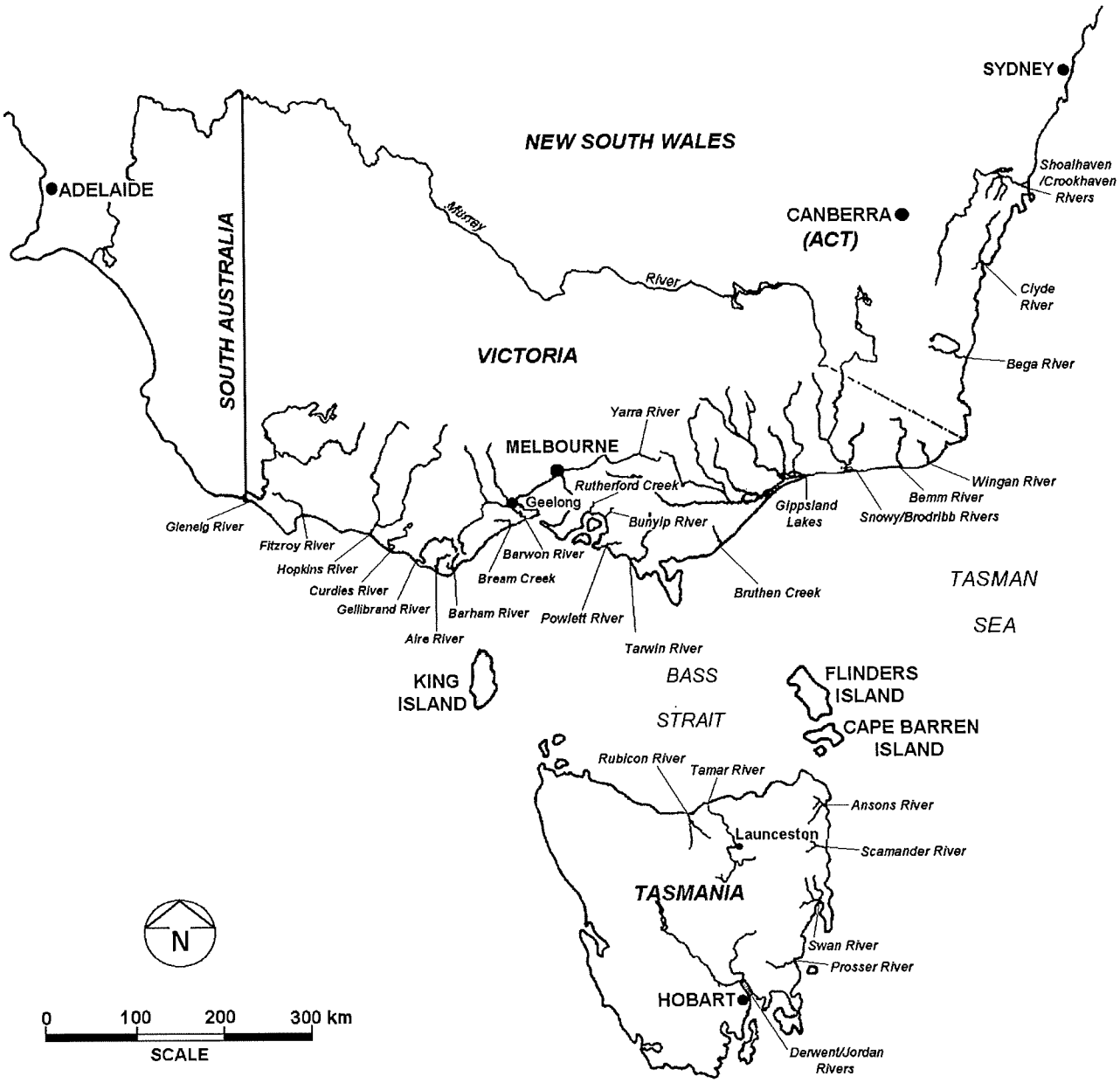


Figure 1 **Map of study area indicating waters sampled during the project using glass eel and/or stow nets**

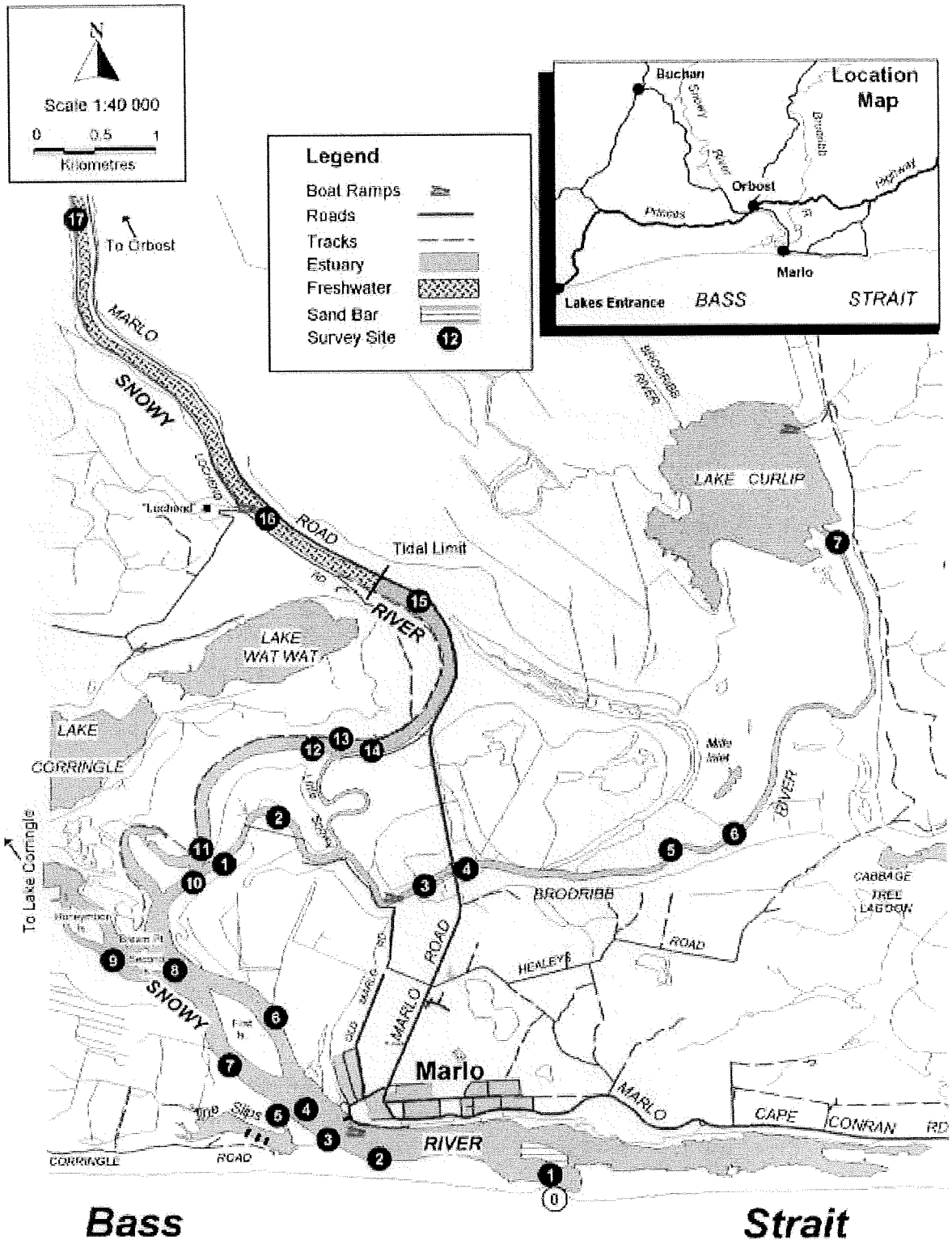


Figure 2. Detailed map of the Snowy River estuary indicating sites sampled in this study

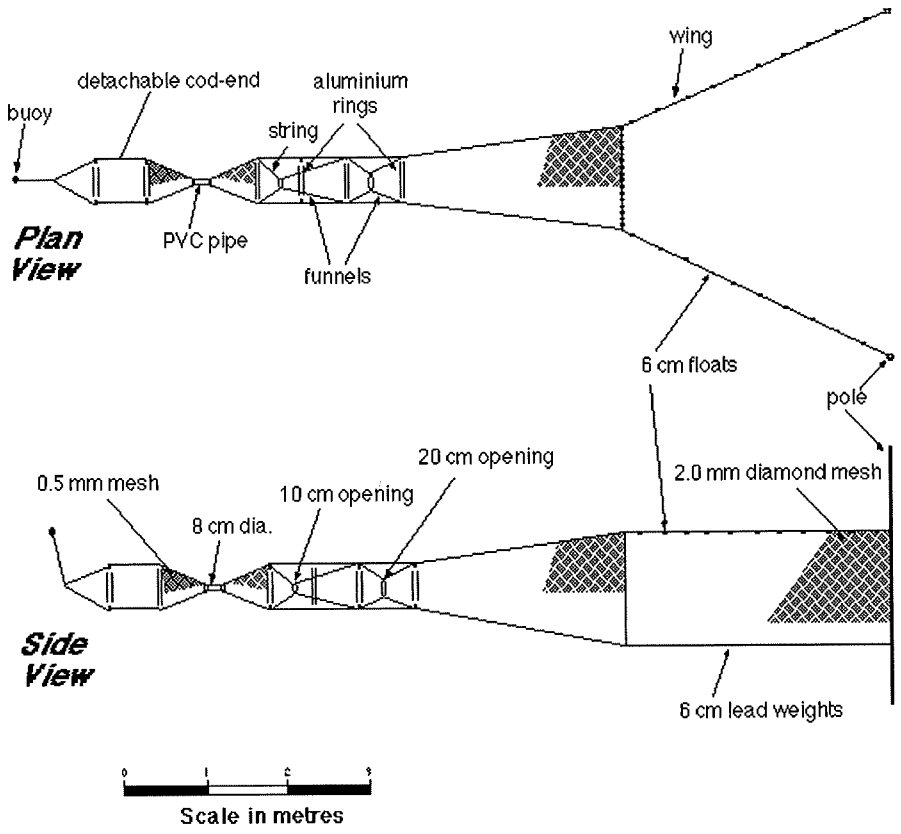


Figure 3 Schematic diagram of a glass eel net used during present study.

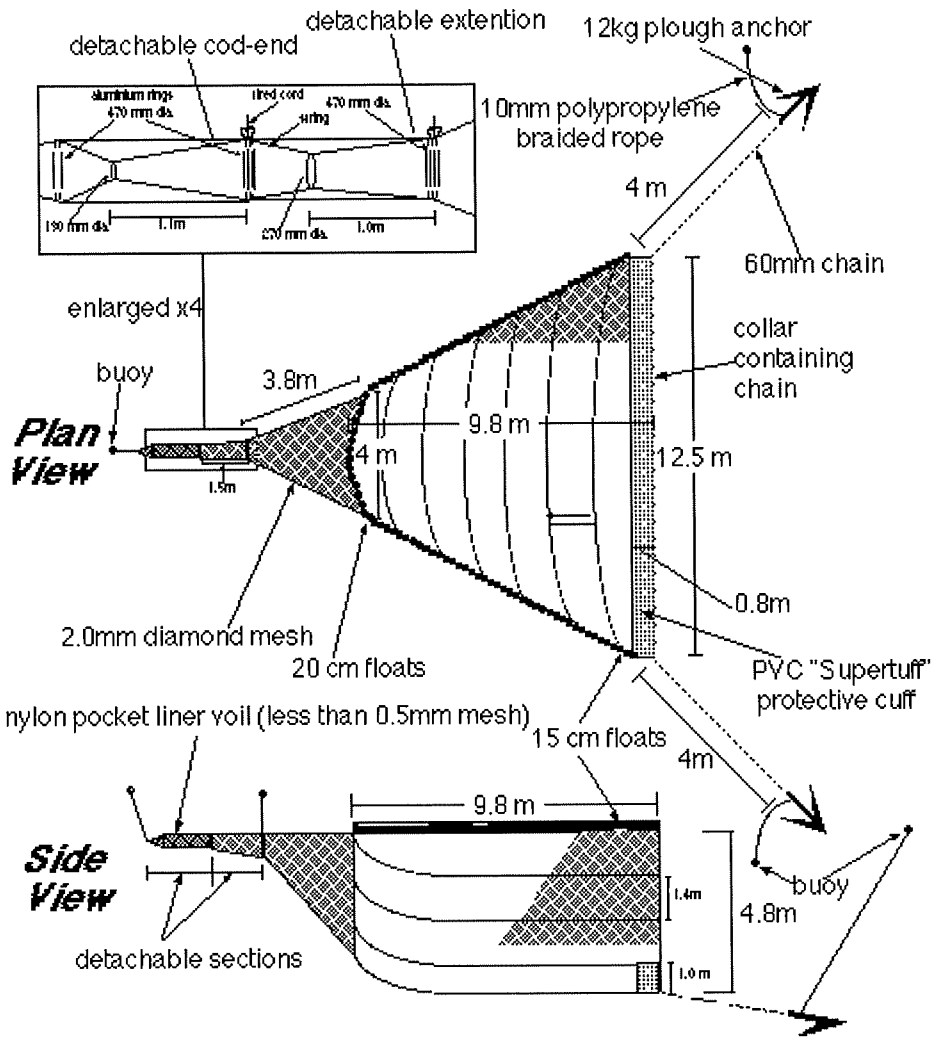


Figure 4 Schematic diagram of a stow net used during present study.

Depending on quantities caught beyond the project's subsampling requirements, glass eels were either kept for culture trials, or released at the point of capture. Retained glass eels were stockpiled in aerated tanks filled with estuary water throughout each sampling trip. At the conclusion of each sampling trip, stockpiled glass eels were packed into plastic bags at the rate of 1-2kg glass eels per bag. Bags were filled at the ratio of 1/3 water and 2/3 oxygen, and packed in cardboard boxes. These were then delivered to Snobs Creek for acclimation to freshwater and weaning for culture trials.

7.2.3 DATA ANALYSIS

Detailed analyses were conducted on data from the Snowy River collected over the three years of the project. The Snowy River was sampled on 7 nights in 1994, 12 nights in 1995 and 39 nights in 1996. Data from all other sampling sites and locations were summarised separately and are presented in both tabular and graphical forms where appropriate. Data from the Snowy, Tarwin and Tamar Rivers in 1994 and 1995, were analysed separately and results were presented to the EIFAC/ICES Working Group on Eel Conference in The Netherlands, September, 1996. A detailed description of the data presented is given in McKinnon and Gooley (1998) (see Appendices). In essence, selected environmental variables were classified into several categories which were typically encountered during glass eel surveys. These were: electrical conductivity (salinity), 'low', 'medium' and 'high'; temperature, 'low', 'medium' and 'high'; moon age, 'low', 'medium' and 'high' and height of high tide, 'low' and 'high'. General Linear Modelling (GLM) Procedure (SAS/STAT Release 6.12 Edition) was used to determine relationships between electrical conductivity, temperature, moon age and height of high tide and catch per unit effort (CPUE) of glass eels (no. glass eels/net/hour) from the Snowy, Tarwin and Tamar Rivers during 1994 and 1995.

For the purposes of this report the data from the Snowy River only, from 1994 to 1996, is analysed using GLM Procedure and is used as a 'case study' for a preliminary description of glass eel migration in south-eastern Australia.

The dependent variable, CPUE, measured as No. glass eels/net/hour (accumulated soak time of total number of nets in the water at each site on each survey) was taken as an index of relative shortfin glass eel abundance. Analysis of variance using GLM procedure was undertaken for all environmental variables as major effects. Significant difference of CPUE at $P < 0.05$ showed dependence. Tukey's Studentized Range Test was used to compare means of significant effects. The variables tested were: mean salinity (measured as electrical conductivity), mean temperature, moon phase (as age in days) and stream discharge. Lagged stream discharge was also included when analysing the data from 1996 only. Table 2 summarises the categories assigned to the variables for each year. The model: CPUE = Salinity + Temperature + Moon Phase + Discharge + Error was then tested for each year and for each gear type.

Mean length and weight of glass eel samples were also analysed using GLM procedure with the main effects being spatial (different sites) and temporal (individual sites over time) and between years. Pigmentation staging was undertaken on glass eel samples from each sampling trip. Different pigmentation stages were classified according to Strubberg (1913) (Table 3).

Table 2 Values of class levels applied to variables for analysis using General Linear Modelling for each year of the project for the Snowy River only.

YEAR	LEVELS	CLASSES				
		Mean Salinity ($x10^3\mu S/cm$)	Mean Temperature (°C)	Moon phase	Discharge (ML/Day)	Lagged Discharge (ML/Day)
1994	LOW	0-8	7-9	NEW[1]		
	MEDIUM	8-20	9-11	OTHER[2]		
	HIGH	>20	11-16	FULL[3]		
1995	LOW	8-20		NEW	800-1400	
	MEDIUM			OTHER		
	HIGH	>20	9-11	FULL	1400-2200	
1996	LOW	8-20	7-9	NEW	800-1400	800-1400
	MEDIUM		9-11	OTHER	1400-2200	1400-2200
	HIGH	>20	11-16	FULL	>2200	>2200

1. New = From 3 days before to 3 days after the new moon (days 26-3).
2. Other = First quarter (days 3-12) and third quarter (days 18-26) of the moon.
3. Full = From 3 days before to 3 days after the Full moon (days 12-18).

Table 3 Pigmentation stages in glass eels, from Strubberg (1913), used in the project.

Stage	Progression of pigmentation
VA	Only on extreme tip of tail and along spinal cord
VB	Only on head and rostrum
VIAI	In formation along dorsal ridge
VIAII (1)	Progress of medio-lateral pigment in rear half of tail
VIAII (2)	Medio-lateral pigment reaches middle of tail
VIAII (3)	Medio-lateral pigment advances, but not over anus
VIAII (4)	Medio-lateral pigment reaches over anus
VIAIII (1)	Medio-lateral pigment reaches below front edge of dorsal fin
VIAIII (2)	Medio-lateral pigment reaches out over liver
VIAIII (3)	Medio-lateral pigment reaches out over pectoral fins. Little or no pre-anal ventro-lateral pigment
VIAIV (1)	Scattered ventro-lateral pigment present pre-anally
VIAIV (2)	Ventro-lateral pigment more distinct pre-anally
VIAIV (3)	Ventro-lateral pigment developed along myosepta pre-anally. No inter-myoseptal pigment present
VIAIV (4)	Development of inter-myoseptal pigment
VIB	Myoseptal pigment arrangement, both dorsally and ventrally, becomes indistinct

7.3 RESULTS

7.3.1 CATCH-EFFORT

Catch of glass eels (actual numbers of glass eels) per unit effort (net hours) was used to estimate relative abundance of glass eels at all sites. After the commencement of the second year of the project it became clear that consistently higher catch returns were being achieved from the Snowy River than from the other sites sampled. The results from the Snowy River were therefore analysed and discussed separately.

Snowy River

CPUE and length-weight data of glass eels from all surveys with both gear types in the Snowy River are summarised in Table 4. CPUE of glass eels was significantly different (adjusted for effective fishing area of each gear type) between gear types ($F_{1,1356} = 98.14$, $P < 0.0001$), and between years ($F_{2,1226} = 5.40$, $P < 0.005$, $F_{1,1023} = 73.06$, $P < 0.0001$), for glass eel nets and stow nets respectively (Figure 5 and Figure 6). CPUE in glass eel nets was higher in 1994 than in other years (Figure 5) but CPUE in stow nets in 1996 greatest for all years and gear types (Figure 6).

In 1994 using glass eel nets only, the effects of different salinity, temperature and moon phase intervals on CPUE were highly significant ($F_{9,830} = 60.65$, $P = 0.0001$, $R^2 = 0.39$). CPUE was greater at high and medium salinity intervals than at the low salinity interval ($F_{2,830} = 38.32$, $P = 0.0001$, $R^2 = 0.39$) (Figure 7). CPUE was also greater at medium and high temperature than at low temperature ($F_{2,830} = 6.12$, $P = 0.0004$, $R^2 = 0.39$), and during the Full Moon phase, rather than during New, First or Last Quarter phases ($F_{2,830} = 205.20$, $P = 0.0001$, $R^2 = 0.39$) (Figure 7). There was also a strong interaction effect of temperature and moon phase on CPUE ($F_{1,830} = 29.98$, $P = 0.0001$, $R^2 = 0.39$).

In 1995 using glass eel nets, only the effect of moon phase on CPUE was significant ($F_{2,241} = 8.17$, $P < 0.005$, $R^2 = 0.31$) with high CPUE occurring during the First and Last Quarters of the moon, rather than during Full or New Moon periods (Figure 8). However, in stow nets in 1995, highly significant effects of salinity and temperature on mean CPUE occurred ($F_{15,312} = 28.53$, $P = 0.0001$, $R^2 = 0.58$) with greater CPUE occurring at low salinity ($F_{1,312} = 31.08$, $P = 0.0001$, $R^2 = 0.58$) and at high temperature ($F_{2,312} = 43.41$, $P = 0.0001$, $R^2 = 0.58$) ranges (Figure 9). There was also a strong interactive effect on CPUE from salinity with each of temperature ($F_{1,312} = 11.28$, $P = 0.0009$, $R^2 = 0.58$), moon phase ($F_{1,312} = 31.87$, $P = 0.0001$, $R^2 = 0.58$) and discharge ($F_{1,312} = 27.69$, $P = 0.0001$, $R^2 = 0.58$).

No significant effects of any of the variables on CPUE were determined from the data obtained using glass eel nets in the Snowy River for 1996, however CPUE in stow nets was significantly affected by temperature, moon phase and discharge ($F_{29,584} = 30.54$, $P = 0.0001$, $R^2 = 0.60$). CPUE was higher at medium temperature range than at low or high temperature range ($F_{3,584} = 3.82$, $P = 0.009$, $R^2 = 0.60$), higher during the New Moon phase ($F_{2,584} = 3.67$, $P = 0.026$, $R^2 = 0.60$), and higher at low discharge range ($F_{3,584} = 98.56$, $P = 0.0001$, $R^2 = 0.60$) (Figure 10).

Other Sites

Catch effort data from the Tarwin River (Victoria), Barwon (Victoria), Clyde (NSW) and Tamar (Tasmania) Rivers are summarised in Figure 11, Figure 12, Figure 13. Figure 14 and Table 5. These rivers, like the Snowy River, were either sampled over a relatively large temporal scale, or, as in the case of the Tarwin River, CPUE of glass eels was comparatively high. These data show the high degree of variability in glass eel abundance both spatially and temporally. The figures also show the great differences in CPUE between the two major gear types used during the project, with stow nets generally returning far greater catches than glass eel nets (Figure 12, Figure 13 and Figure 14). Data from other sites sampled less frequently are summarised in Table 5. A summary of temperature and electrical conductivity (salinity) data for major sampling sites and trips is presented in Table 6.

7.3.2 LENGTH-WEIGHT ANALYSIS

Length-weight data were recorded from 12 of the 18 rivers sampled over 17 surveys in 1994, (Figure 15, Figure 16). Mean length varied significantly between rivers ($F_{16,656} = 12.31$, $P < 0.0001$), but over three separate trips to the Snowy River in August, 12 and 7 days apart respectively, there was no significant difference in mean length of glass eels ($F_{2,103} = 0.93$, $P = 0.397$). Likewise, mean weight of glass eels differed significantly between rivers in 1994 ($F_{16,657} = 9.13$, $P < 0.0001$), but again, there was no significant difference in mean weight between trips to the Snowy River ($F_{2,104} = 1.81$, $P = 0.169$). Numbers of glass eels per kg varied from 6600/kg in the Gellibrand, Tamar and Rubicon Rivers to 9000/kg in the Wingan River (Figure 16).

In 1995, length-weight samples were taken from 9 rivers over 14 sampling trips (Figure 17 and Figure 18). Again, mean length differed significantly between rivers ($F_{13,663} = 26.43$, $P < 0.0001$). Mean weight also differed significantly between rivers ($F_{13,663} = 23.03$, $P < 0.0001$), although over three sampling trips to the Barwon River in Victoria, 13 and 16 days apart respectively, neither length nor weight differed significantly ($F_{2,147} = 1.81$, $P = 0.1667$ and $F_{2,147} = 2.08$, $P = 0.1281$ respectively). Numbers of glass eels per kg ranged from approximately 5000/kg in the Crookhaven River to 9000/kg in the Bemm River (Figure 18).

Length - weight samples were taken from five rivers over 15 trips in 1996 (Figure 19 and Figure 20). Mean length differed significantly between sites ($F_{14,708} = 19.55$, $P < 0.0001$) and mean weight also differed significantly between sites ($F_{14,708} = 13.85$, $P < 0.0001$). Numbers of glass eels per kg ranged from 5500/kg in the Tamar River to 8300/kg in the Snowy River (Figure 20). Within the sampling regime for 1996, seven sampling trips, 12.5 days apart on average, were made to the Snowy River between mid July and late September. Both mean length and mean weight differed significantly between trips over this time ($F_{6,343} = 2.22$, $P < 0.05$ and $F_{6,343} = 10.29$, $P < 0.0001$ respectively) and a weak but significant negative correlation was found between mean weight of glass eels and time ($R^2 = 0.10$, $P < 0.0001$), although no correlation was found between mean length of glass eels and time ($R^2 = 5.7\text{x}10^{-3}$, $P = 0.1579$).

Similar results were obtained from the Tamar River in 1996 where four sampling trips, 16, 8 and 15 days apart respectively, were undertaken between mid September and late October. Mean weight of glass eels differed significantly between trips ($F_{3,189} = 14.43$, $P < 0.0001$) and a weak but significant correlation between mean weight of glass eels and time was observed ($R^2 = 0.17$, $P < 0.0001$). Conversely, mean length between trips did not differ significantly ($F_{3,189} = 0.87$, $P = 0.4564$), nor was any correlation observed between mean length of glass eels and time ($R^2 = 1.0\text{x}10^{-4}$, $P = 0.9044$).

The model equation $W=0.7L^3/10^3$, where W is the mean weight of glass eels (g) and L is the mean length of glass eels (mm) was found to describe the length-weight relationship of glass eels in both the Snowy and Tamar Rivers ($R^2 = 0.98$, $P < 0.0001$; $R^2 = 0.99$, $P < 0.0001$ respectively) from samples taken in 1996. Condition, K, of glass eels was calculated from each of these rivers over the entire sampling period in 1996, using $K=(W/L)\text{x}1000$. Regressions of K over time show a significant negative correlation for both the Snowy ($R^2 = 0.13$, $P < 0.0001$) and Tamar Rivers ($R^2 = 0.22$, $P < 0.0001$) in each case (Figure 21). Using data from consecutive trips to the Snowy River in 1994, a very weak, and only just significant ($R^2 = 0.04$, $P = 0.05$) positive correlation between K and time was observed (Figure 21). Calculated K values from length-weight data from consecutive sampling trips to the Barwon River in 1995 showed a weak but significant ($R^2 = 0.04$, $P = 0.017$) negative correlation with time (Figure 21), supporting observations made from the Snowy and Tamar Rivers' data from 1996.

7.3.3 PIGMENTATION

Glass eels collected from most sites across the geographical sampling range in Victoria from August to mid-September, 1994, were predominantly at pigmentation stage VB (Figure 22). As the season progressed, and as sampling extended into Tasmania, pigmentation stage of glass eels progressed with predominantly VIAII(1) glass eels found in the Yarra River, Victoria, and VIAII(3) and VIAIII(3) glass eels found in the Tamar River, Tasmania, in mid-October (Figure 22). In the Snowy, Tamar and Rubicon Rivers, where sampling was repeated 7, 11 and 14 days apart respectively, distinct progression of pigmentation of glass eels was observed (Figure 22). Within one week, the proportion of stage VB glass eels in the Snowy River had decreased from over 80% to less than 50%, with increased proportions of later pigmentation stages, up to stage VIAIII(3) occurring (Figure 22). Likewise, pigmentation stage of glass eels in the Tamar River progressed from predominantly VIAII(1) in early October to VIAII(3) and VIAIII(3) by mid October (Figure 22). Glass eels from the Rubicon River were predominantly at stages VIAII(1) and VIAII(2) in early October, and had progressed to stages VIAIII(3) and VIAIV(1), with small numbers observed at stage VIB, 2 weeks later (Figure 22).

The greatest proportion of stage VA glass eels was seen in samples taken from the Crookhaven River, NSW, in 1995 (Figure 23). Small numbers of stage VA glass eels were found in the Clyde, Bega and Snowy Rivers up to late July 1995, and in the Tarwin and Barwon Rivers as late as mid and late August respectively (Figure 23). With few exceptions, the vast majority of invading glass eels at all sites on all sampling occasions in 1995 were at stage VB (Figure 23). Samples taken from sites later in the season and in Tasmania showed later stages of pigmentation with modes occurring at stages VIAII(1) from the Derwent and Tamar Rivers which were sampled on 29 September and 7 October respectively, and at stage VIAII(2) from the Tamar River on 23 October (Figure 23). Progression of pigmentation was seen in samples taken from the Tarwin and Tamar Rivers during August and October respectively (Figure 23). Samples taken from the Barwon River showed no progression in pigmentation between late August and early September, where 100% of glass eels sampled were stage VB, but pigmentation had progressed by late September with some individuals at stage VIAII(4) (Figure 23). Likewise, little progression in pigmentation occurred in samples from the Snowy River between late July and early August (Figure 23) suggesting glass eels may have been invading over a protracted period at this time of year.

In 1996, glass eels at advanced pigmentation stages were caught earlier in the season than in previous years at all sites fished (Figure 24). By mid July the majority of glass eels from the Snowy River were at stage VIAI, however most glass eels had not advanced past pigmentation stage VIAII(1) by mid September (Figure 23). No VA or VB glass eels were found in the Clyde River in mid June, but ranged from stage VIAI to VIAIV(1), which was in contrast to that seen the previous year (Figure 23). Glass eels from the Bruthen Creek were between VB and VIAI in mid August, thus more advanced than samples from similar areas, eg the Snowy River, in previous years (Figure 23). Likewise, glass eels sampled from the Prosser River, Tasmania were at later pigmentation stages earlier in the sampling period than those sampled from nearby sites such as the Derwent River in the previous year (Figure 23).

7.3.4 BYCATCH

The most commonly caught bycatch species at each site surveyed during the present project are listed in Table 7. Overall, the mysid opossum shrimp, (*Haplostylus dakini*) was the most prevalent bycatch species in Victorian and New South Wales waters, in terms of both biomass and numbers. Juvenile galaxiids, or whitebait, (*Galaxias* spp.) were also common in most waters surveyed, and were particularly common in Tasmanian waters as was Tasmanian whitebait (*Lovettia sealii*) (Table 7). Other species regularly caught as bycatch at most sites include sandy sprat (*Hyperlophus vittatus*), Australian smelt (*Retropinna semoni*), flat-headed gudgeon (*Philypnodon grandiceps*), gobies (Gobiidae), isopods and amphipods (Table 7).

The composition of the bycatch from any one river varied with distance upstream and with time of year. At sites closer to the river mouth, consequently experiencing higher salinities, larger numbers of euryhaline or marine species such as opossum shrimp, sandy sprat and anchovies (*Engraulis australis*) were recorded. Conversely, further upstream, or when river flows were high, species considered to be essentially freshwater inhabitants, such as Australian smelt and flat-headed gudgeons, were more common. Earlier in the season such as during July and early August, galaxiid whitebait and adult short-headed lampreys (*Mordacia mordax*) were often recorded. During late August and September however, larger numbers of adult galaxiids occurred in the bycatch and lampreys were virtually absent.

The majority of bycatch species were small fish or juveniles of larger species, and crustaceans. Most larger finfish species were expected to avoid capture in the nets used, however in some circumstances large individuals such as adult eels (*A. australis*), black bream (*Acanthopagrus butcheri*) and estuary perch (*Macquaria colonorum*) were caught as bycatch. In New South Wales waters, jellyfish (Hydrozoa) were also commonly encountered, often excessively fouling nets. The capture of Tasmanian whitebait over two consecutive years in the Tarwin River, Victoria (Table 7) confirms this site as the only mainland water in which a self-maintaining population of this species occurs (T. Raadik, Marine and Freshwater Resources Institute, *pers. comm.*).

On occasion, particularly when glass eel catches were high, total quantities of bycatch were in the order of 10-15kg per net per hour. Following sorting of the catch, bycatch mortality often reached 100%, posing important implications for the management of a potential commercial glass eel fishery.

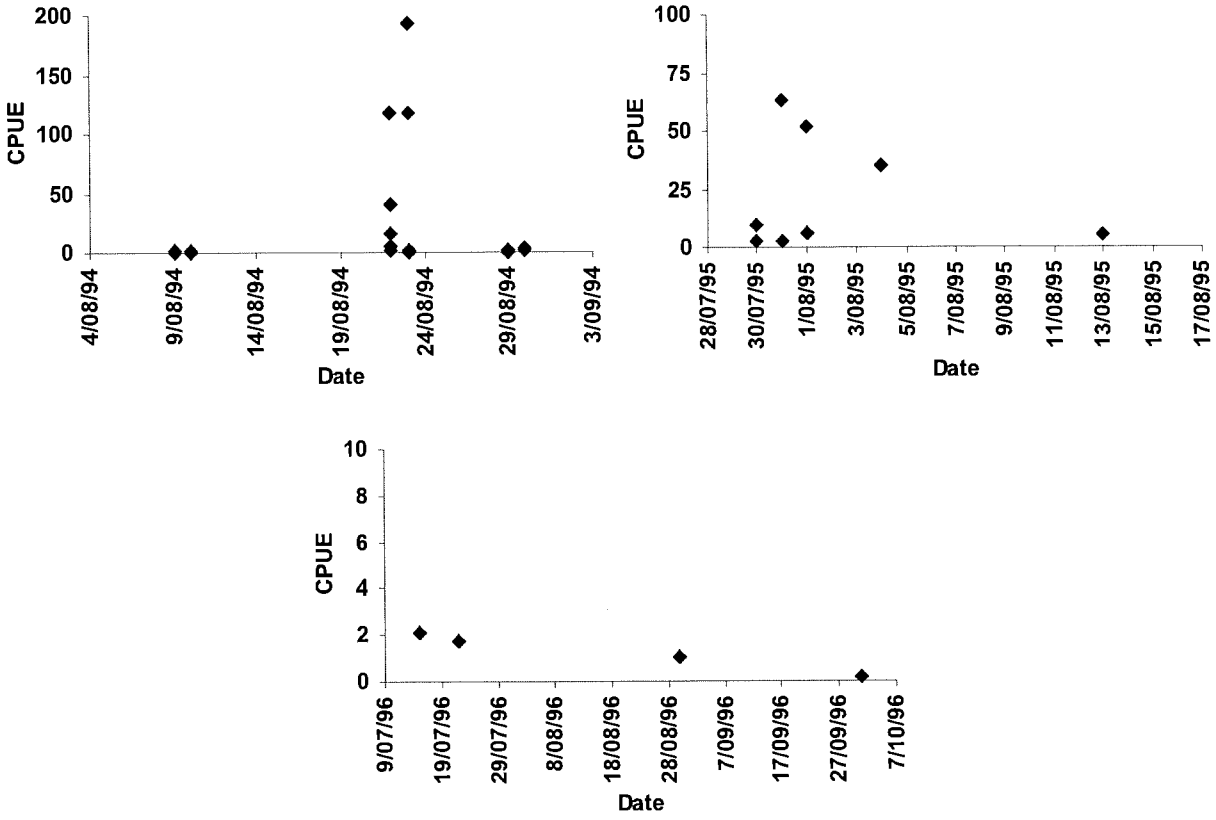


Figure 5 CPUE (No. glass eels/net/hour) in glass eel nets in the Snowy River from 1994-1996.

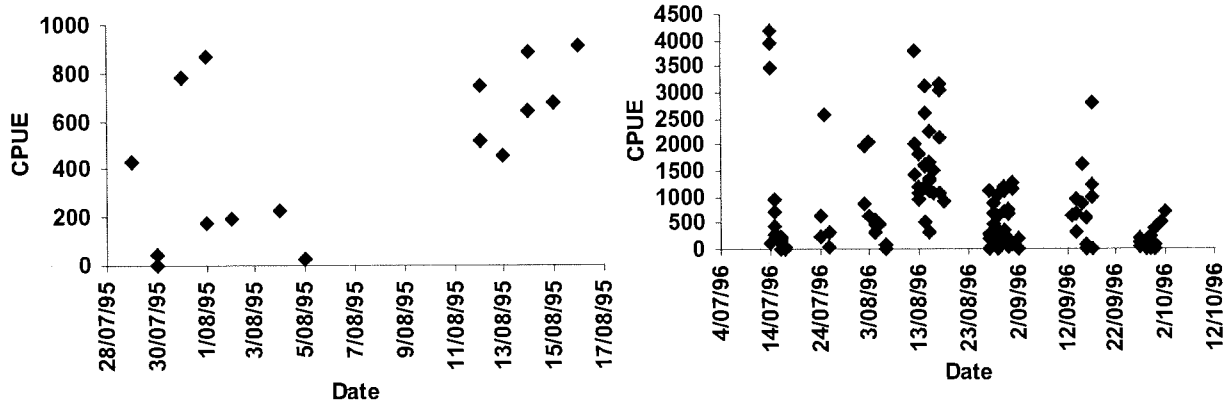


Figure 6 CPUE (No. glass eels/net/hour) in stow nets in the Snowy River from 1995-1996.

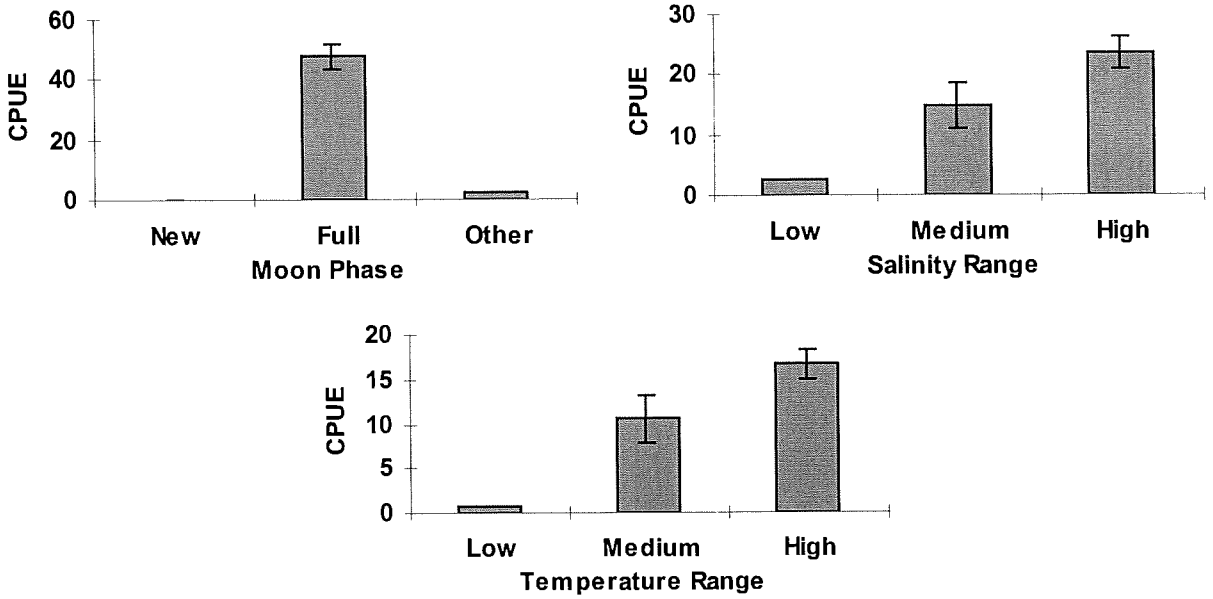


Figure 7 Mean CPUE (No. glass eels/net/hour) in glass eel nets Vs. Moon Phase, Salinity Range and Temperature Range from the Snowy River in 1994.

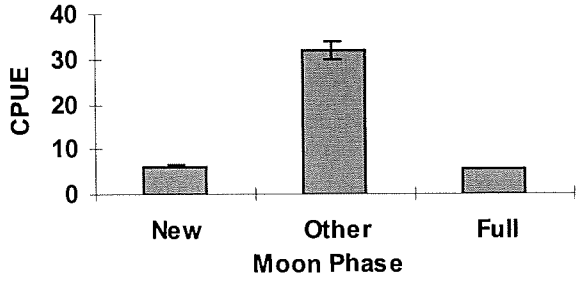


Figure 8 Mean CPUE (No. glass eels/net/hour) in glass eel nets Vs. Moon Phase from the Snowy River in 1995.

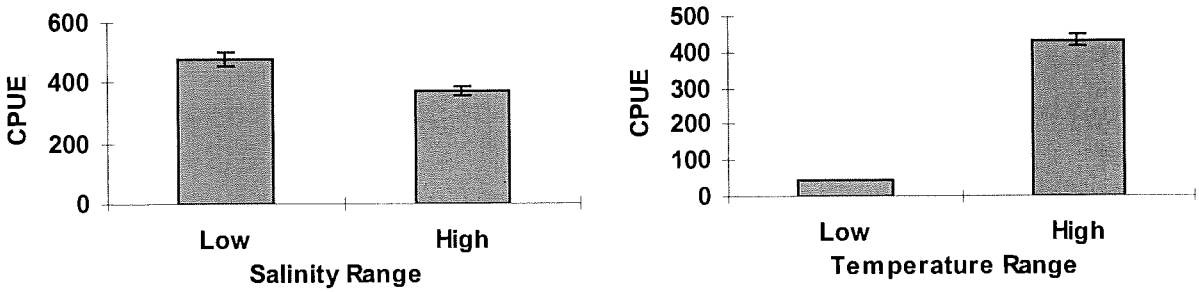


Figure 9 Mean CPUE (No. glass eels/net/hour) in stow nets Vs. Salinity Range and Temperature Range from the Snowy River in 1995.

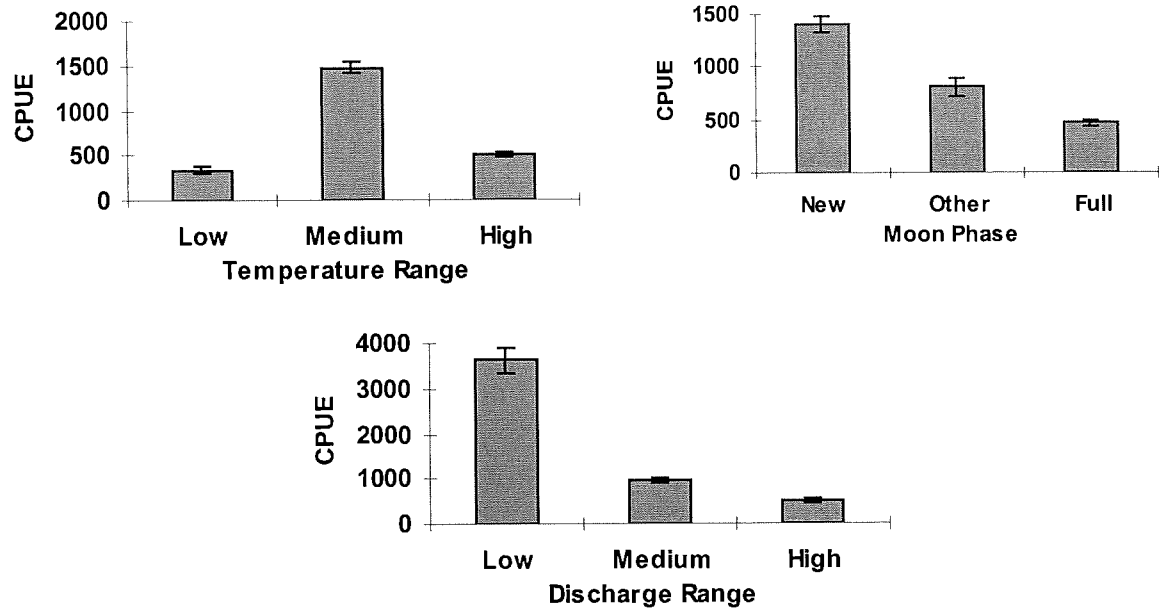


Figure 10 Mean CPUE (No. glass eels/net/hour) in stow nets Vs. Temperature Range, Moon Phase and Discharge from the Snowy River in 1996.

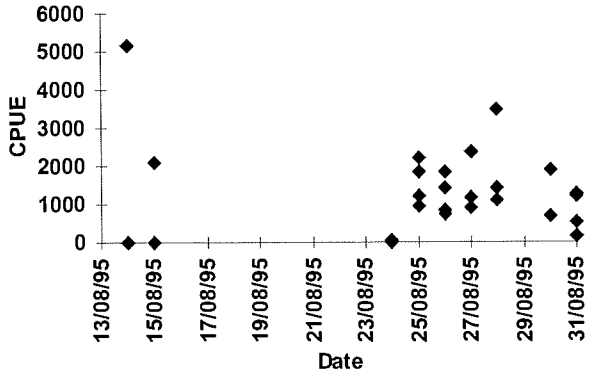


Figure 11 CPUE (No. glass eels/net/hour) in stow nets from the Tarwin River in 1995.

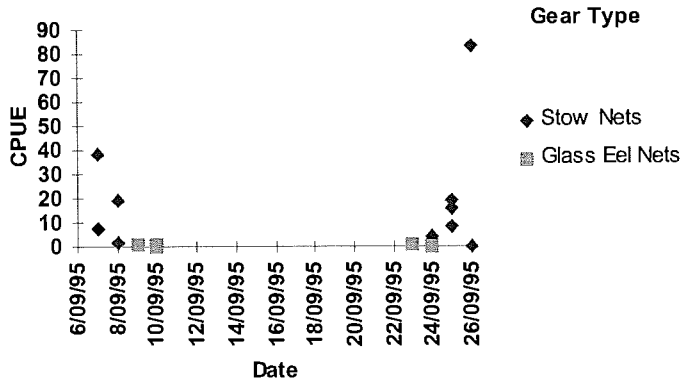


Figure 12 CPUE (No. glass eels/net/hour) in stow nets and glass eel nets from the Barwon River in 1995.

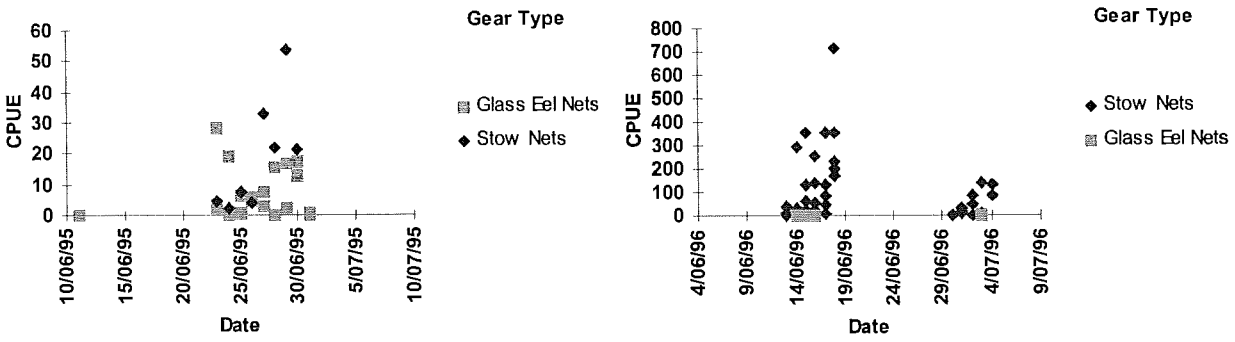


Figure 13 CPUE (No. glass eels/net/hour) in stow nets and glass eel nets from the Clyde River in 1995 and 1996.

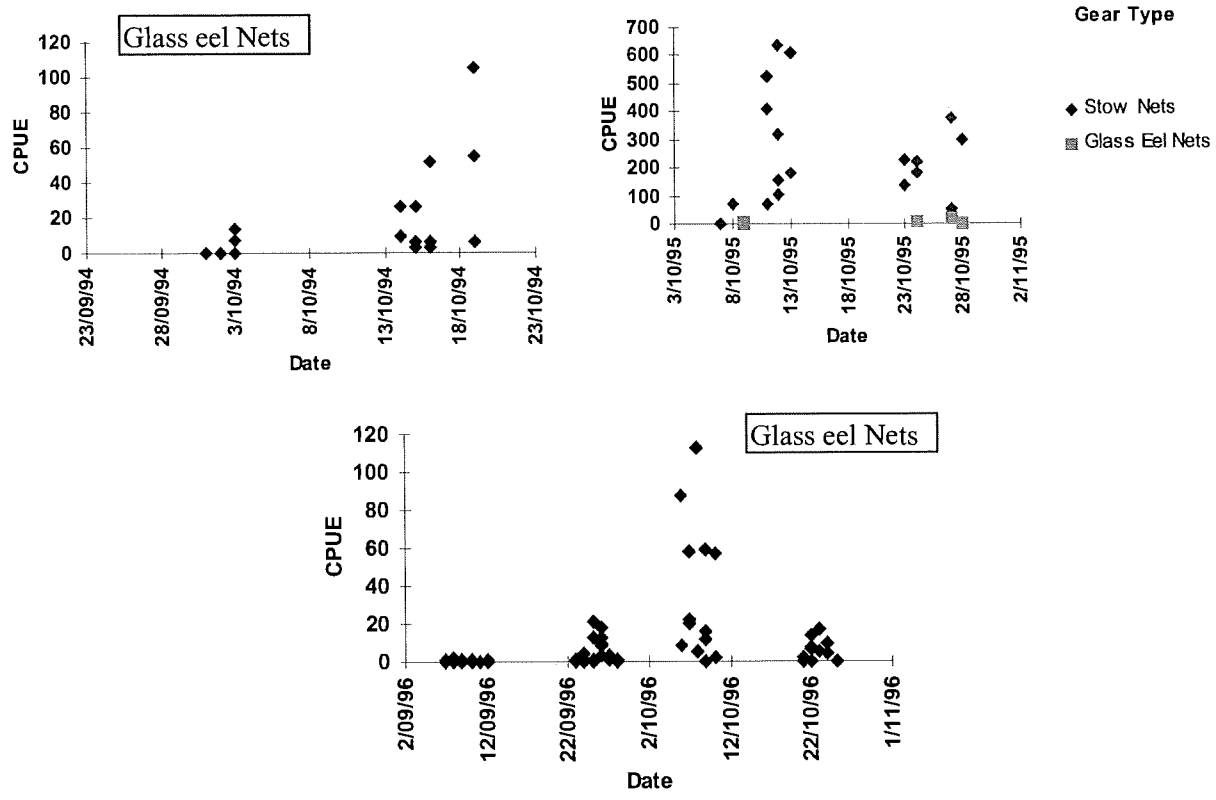


Figure 14 CPUE (No. glass eels/net/hour) in stow nets and glass eel nets from the Tamar River from 1994 to 1996.

Table 4. CPUE and Length and Weight Data for the Snowy River during the present study, August 1994-October, 1996.

Date	Net Type	CPUE	No.	Length (mm)			Weight (g)			No/kg
			eels	Min.	Max.	Mean	Min.	Max.	Mean	
9-10/8/94	Glass eel net	0.33	9	56.8	91.25	69.21	0.12	0.17	0.15	6667
22-23/8/94	Glass eel net	57.67	1309	53.5	65.15	59.03	0.07	0.19	0.14	7143
29-30/8/94	Glass eel net	1.95	115	53.2	63.10	58.93	0.07	0.22	0.15	6667
29/7-2/8/95	Stow net	344.15	8948	52.30	65.10	58.02	0.10	0.22	0.14	7143
29/7-2/8/95	Glass eel net	20.97	585	52.30	65.10	58.02	0.10	0.22	0.14	7143
12-16/8/95	Stow net	669.35	12952	52.30	64.90	58.56	0.09	0.21	0.14	7143
12-16/8/95	Glass eel net	5.56	25	52.30	64.90	58.56	0.09	0.21	0.14	7143
14-17/7/96	Stow net	961.94	14910	53.50	68.10	60.37	0.11	0.23	0.18	5555
14-17/7/96	Glass eel net	2.14	9	53.50	68.10	60.37	0.11	0.23	0.18	5555
22-26/7/96	Stow net	973.33	7008	53.10	67.20	61.32	0.09	0.24	0.17	5882
22-26/7/96	Glass eel net	1.75	17	53.10	67.20	61.32	0.09	0.24	0.17	5882
2-4/8/96	Stow net	901.18	8381	52.30	66.10	59.40	0.08	0.24	0.16	6250
12-17/8/96	Stow net	1680.85	45719	54.40	66.20	60.27	0.10	0.23	0.15	6667
27/8-1/9/96	Stow net	500.12	16254	53.00	64.20	60.29	0.07	0.25	0.16	6250
27/8-1/9/96	Glass eel net	1.08	4	53.00	64.20	60.29	0.07	0.25	0.16	6250
13-17/9/96	Stow net	824.31	10139	54.40	66.70	60.24	0.07	0.23	0.15	6667
27/9-1/10/96	Stow net	166.00	2822	54.30	64.70	59.73	0.08	0.18	0.13	7692
27/9-1/10/96	Glass eel net	0.18	3	54.30	64.70	59.73	0.08	0.18	0.13	7692

Table 5. CPUE and Length and Weight Data for all other sites sampled during the project.

Water	Date	Net Type	CPUE	No. eels	Length (mm)			Weight (g)			No/kg
					Min.	Max.	Mean	Min.	Max.	Mean	
Victoria											
Wingan River	7-8/08/94	Glass eel net	20.10	224	43.2	82.5	55.8	0.05	0.17	0.11	9090
Bruthen Creek	15-16/08/94	Glass eel net	1.30	12	55.7	80.5	61.2	0.07	0.15	0.12	8333
Powlett River	19/08/94	Glass eel net		0							
Tarwin River	17-18/08/94	Glass eel net	14.10	232	54.95	66.95	60.04	0.10	0.20	0.14	7143
Gippsland Lakes	21/08/94	Glass eel net	0.27	4	58.8	96.8	74.7	0.10	0.23	0.14	7143
Yarra River	27-28/08/94	Glass eel net		0							
Bruthen Creek	31/8-1/09/94	Glass eel net		0							
Barwon River	3-6/09/94	Glass eel net	24.98	863	55.4	65.4	60.6	0.10	0.18	0.14	7143
Barwon River	28-29/10/94	Glass eel net	4.50	6							
Gellibrand River	5-9/09/94	Glass eel net	2.45	328	56.3	65.0	61.0	0.11	0.22	0.15	6667
Aire River	11,14/09/94	Glass eel net	0.30	18	56.6	65.4	59.9	0.09	0.16	0.12	8333
Barham River	12,14/09/94	Glass eel net	4.79	140	58.0	66.8	62.5	0.11	0.18	0.15	6667
Curdies River	15-16/09/94	Glass eel net	3.86	188	57.1	67.7	61.2	0.08	0.18	0.13	7692
Hopkins River	17-18/09/94	Glass eel net	0.05	1	61.3	61.3	61.3	0.12	0.12	0.12	8333
Glenelg River	17-18/09/94	Glass eel net		0							
Fitzroy River	19/09/94	Glass eel net		0							
Gellibrand River	20/09/94	Glass eel net	0.03	1							
Yarra River	9-13/10/94	Glass eel net	0.49	20	54.5	65.9	61.4	0.10	0.17	0.13	7692
Bream Creek	28-29/10/94	Glass eel net	0.07	2	56.6	58.8	57.7	0.10	0.11	0.11	9090
Hopkins River	31/10-2/11/94	Glass eel net	0.01	1	60.4	60.4	60.4	0.18	0.18	0.18	5555
Hopkins River	13-15/11/94	Glass eel net		0							
Fitzroy River	16/11/94	Glass eel net		0							
Bemm River	15-19/7/95	Stow net	118.89	107	50.4	62.2	55.1	0.08	0.16	0.11	9090
Bemm River	15-19/7/95	Glass eel net	11.86	325	50.4	62.2	55.1	0.08	0.16	0.11	9090
Rutherford Creek	11/08/96	Stow net	0.77	2							
Yarra River	7-8/10/95	Glass eel net		0							
Tarwin River	12-15/08/95	Stow Net	1208.96	13903	54.95	66.95	60.04	0.10	0.20	0.14	7143
Tarwin River	12-15/08/95	Glass eel net	12.56	98	54.95	66.95	60.04	0.10	0.20	0.14	7143
Tarwin River	24-31/08/95	Stow Net	1280.92	31895	54.10	65.20	59.61	0.11	0.23	0.15	6667
Tarwin River	24-31/08/95	Glass eel net	178.33	856	54.10	65.20	59.61	0.11	0.23	0.15	6667

Table 5. Continued.

Water	Date	Net Type	CPUE	No. eels	Length (mm)			Weight (g)			No/kg
					Min.	Max.	Mean	Min.	Max.	Mean	
Victoria											
Barwon River	24-28/08/95	Stow net	10.21	96	56.6	67.6	61.5	0.11	0.23	0.16	6250
Barwon River	24-28/08/95	Glass eel net		0							
Barwon River	7-10/09/95	Stow net	15.21	73	54.6	64.7	61.0	0.11	0.23	0.16	6250
Barwon River	7-10/09/95	Glass eel net	0.89	7	54.6	64.7	61.0	0.11	0.23	0.16	6250
Barwon River	24-26/09/95	Stow net	17.85	141	53.5	67.2	61.9	0.11	0.21	0.15	6667
Barwon River	24-26/09/95	Glass eel net	0.59	6	53.5	67.2	61.9	0.11	0.21	0.15	6667
Bunyip River	12/08/96	Stow net		0							
Bruthen Creek	13/08/96	Stow net	30.32	94	53.3	66.4	58.8	0.08	0.19	0.14	7143

Table 5. Continued

Water	Date	Net Type	CPUE	No. Eels	Length (mm)			Weight (g)			No/kg
					Min.	Max.	Mean	Min.	Max.	Mean	
Tasmania											
Tamar River	30/09-1/10/94	Glass eel net		0							
Tamar River	2-3/10/94	Glass eel net	8.38	68	56.6	66.25	60.9	0.11	0.24	0.16	6250
Tamar River	14-19/10/94	Glass eel net	28.73	1923	53.05	65.35	60.68	0.11	0.18	0.14	7143
Rubicon River	4-6/10/94	Glass eel net	1.50	35	55.6	65.6	60.4	0.10	0.19	0.15	6667
Rubicon River	17-18/10/94	Glass eel net	1.47	32	53.0	66.8	60.6	0.12	0.23	0.16	6250
Derwent River	29/9-4/10/95	Stow net	3.51	54	56.0	66.6	62.6	0.13	0.23	0.18	5555
Derwent River	29/9-4/10/95	Glass eel net	1.60	4	56.0	66.6	62.6	0.13	0.23	0.18	5555
Tamar River	7-13/10/95	Stow net	234.49	2509	56.1	66.5	61.23	0.13	0.24	0.17	5882
Tamar River	7-13/10/95	Glass eel net	3.05	16	56.1	66.5	61.23	0.13	0.24	0.17	5882
Tamar River	23-28/10/95	Stow net	224.57	2111	51.2	64.9	59.8	0.11	0.22	0.17	5882
Tamar River	23-28/10/95	Glass eel net	11.03	86	51.2	64.9	59.8	0.11	0.22	0.17	5882
Scamander River	14-15/10/95	Glass eel net		0							
Ansons River	16-17/10/95	Glass eel net		0							
Swan River	17-18/10/95	Glass eel net		0							
Derwent River	30/10-2/11/95	Stow net		0							
Derwent River	30/10-2/11/95	Glass eel net		0							
Jordan River	12/10/96	Glass eel net		0							
Prosser River	13-15/10/96	Glass eel net	0.26	2	54.6	62.8	59.1	0.09	0.17	0.13	7692
Prosser River	13-15/10/96	Trawl net	13.64	30	54.6	62.8	59.1	0.09	0.17	0.13	7692
Tamar River	7-12/9/96	Glass eel net	0.49	45	57.0	66.2	61.29	0.13	0.24	0.18	5555
Tamar River	23-28/9/96	Glass eel net	3.90	402	55.5	65.9	61.1	0.13	0.23	0.17	5882
Tamar River	23-28/9/96	Trawl net	2.05	16	55.5	65.9	61.1	0.13	0.23	0.17	5882
Tamar River	6-10/1096	Glass eel net	36.78	1166	58.1	65.7	61.7	0.11	0.20	0.16	6250
Tamar River	21-25/10/96	Glass eel net	4.16	212	56.7	66.8	61.2	0.12	0.19	0.15	6667
Tamar River	21-25/10/96	Trawl net	5.00	5	56.7	66.8	61.2	0.12	0.19	0.15	6667

Table 5 Continued

Water	Date	Net Type	CPUE	No.	Length (mm)			Weight (g)			No/kg
				Eels	Min.	Max.	Mean	Min.	Max.	Mean	
New South Wales											
Crookhaven River	7-10/6/95	Stow net	6.18	17	53.3	65.0	59.8	0.13	0.27	0.20	5000
Crookhaven River	7-10/6/95	Glass eel net	0.57	2	53.3	65.0	59.8	0.13	0.27	0.20	5000
Clyde River	11/06/95	Stow net		0							
Clyde River	11/06/95	Glass eel net		0							
Clyde River	23/06-1/07/95	Stow net	21.31	503	49.7	65.9	59.1	0.11	0.23	0.18	5555
Clyde River	23/06-1/07/95	Glass eel net	7.46	573	49.7	65.9	59.1	0.11	0.23	0.18	5555
Bega River	3-5/7/95	Glass eel net	3.39	77	48.9	63.3	56.1	0.09	0.21	0.14	7143
Clyde River	12-18/06/96	Stow net	36.08	1447	48.7	64.4	56.5	0.08	0.23	0.14	7143
Clyde River	12-18/06/96	Glass eel net	0.19	24	48.7	64.4	56.5	0.08	0.23	0.14	7143
Clyde River	12-18/06/96	Trawl net	3.53	6	48.7	64.4	56.5	0.08	0.23	0.14	7143
Clyde River	30/06-4/07/96	Stow net	59.94	1049	49.0	62.5	55.7	0.08	0.24	0.14	7143
Clyde River	30/06-4/07/96	Glass eel net	0.06	1	49.0	62.5	55.7	0.08	0.24	0.14	7143

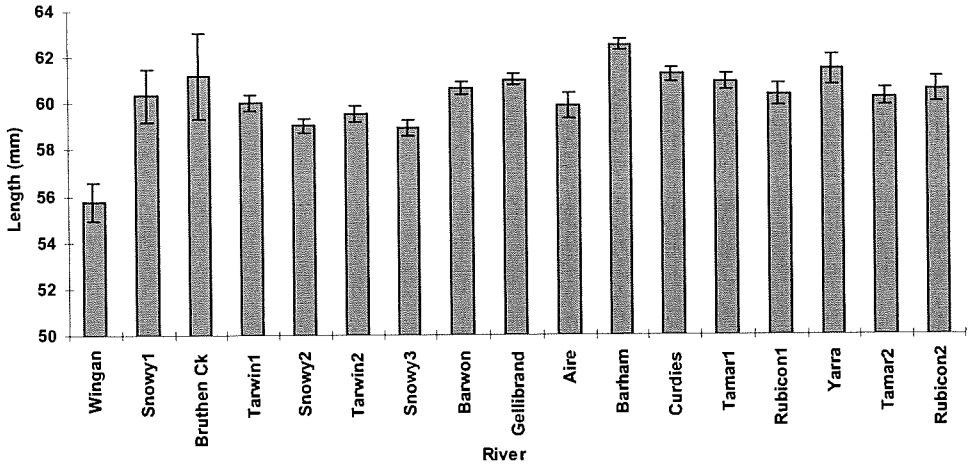


Figure 15 Mean length of *A. australis* glass eels ± standard error from sites sampled in chronological order in 1994.

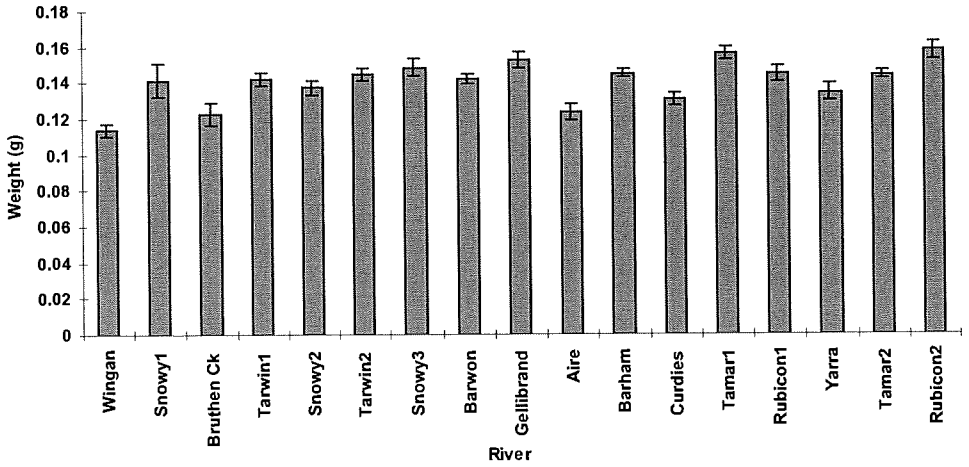


Figure 16 Mean weight of *A. australis* glass eels ± standard error from sites sampled in chronological order in 1994.

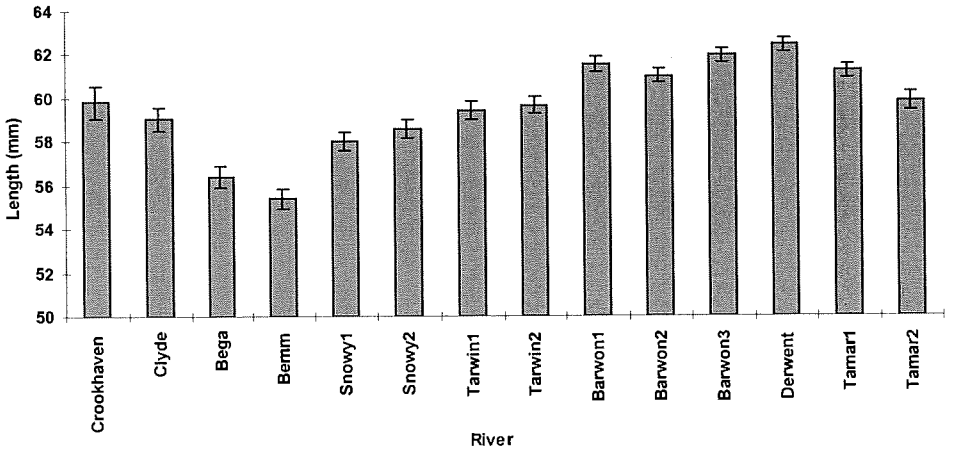


Figure 17 Mean length of *A. australis* glass eels ± standard error from sites sampled in chronological order in 1995.

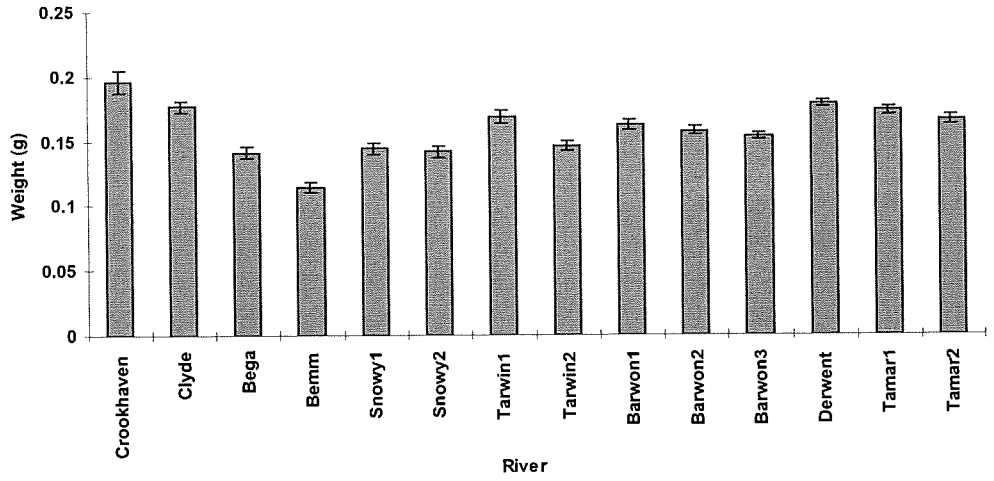


Figure 18 Mean weight of *A. australis* glass eels ± standard error from sites sampled in chronological order in 1995.

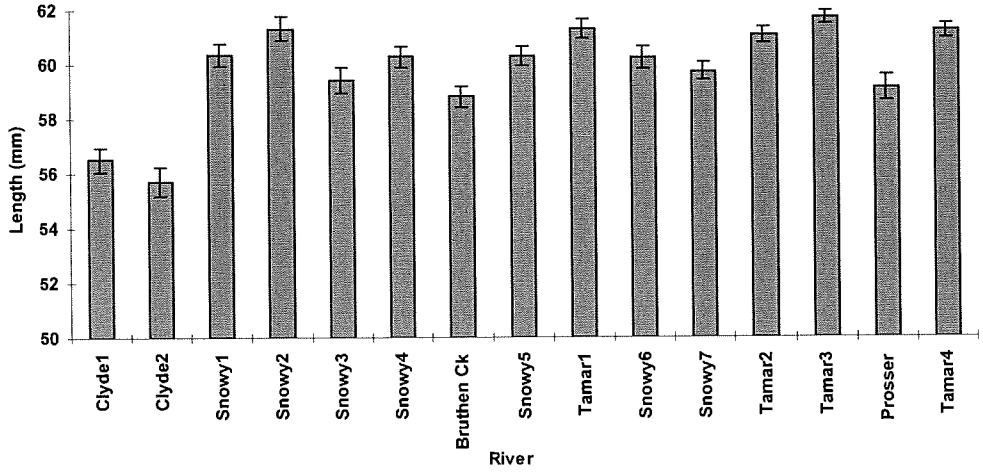


Figure 19 Mean length of *A. australis* glass eels ± standard error from sites sampled in chronological order in 1996.

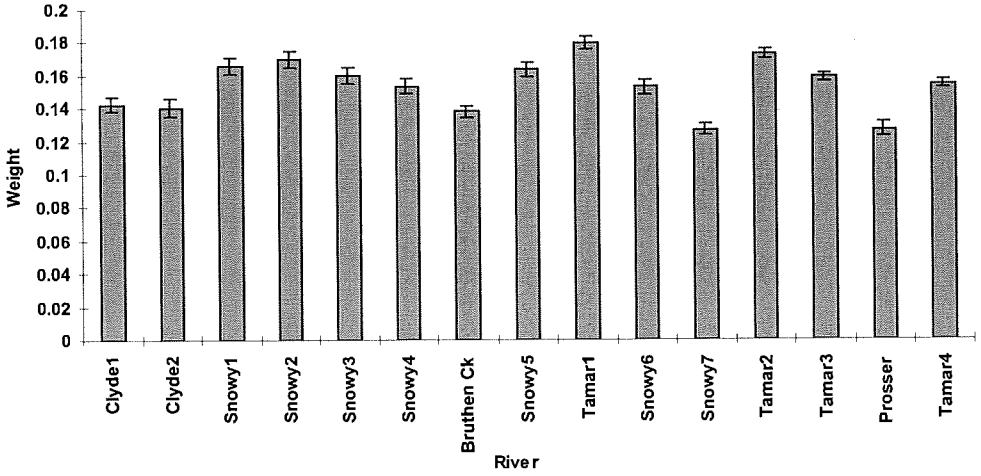


Figure 20 Mean weight of *A. australis* glass eels ± standard error from sites sampled in chronological order in 1996.

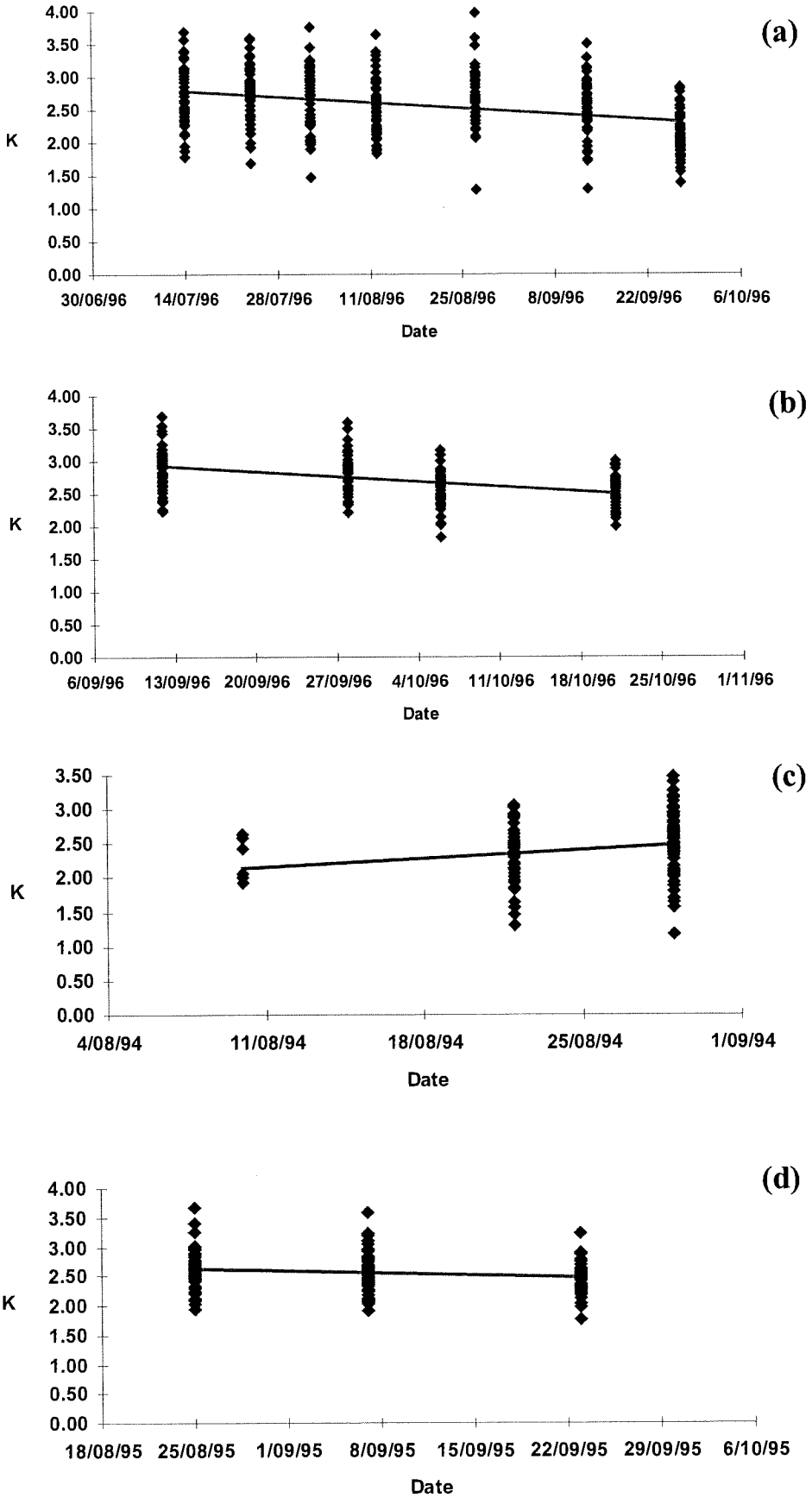


Figure 21 Condition (K) of glass eels from the (a) Snowy River 1996, (b) Tamar River 1996, (c) Snowy River 1994, and (d) Barwon River 1995.

Table 6. Summary of water quality at major sites.

River	Trip Date	Electrical (µS/cm)	Conductivity		Temperature (°C)		
New South Wales		**Min.**	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**
Clyde	10/6/95	46400	48400	47350	15.60	16.00	15.90
Clyde	22-23/6/1995	15550	45900	36307	11.90	13.40	12.50
Clyde	25/6-1/7/1995	65	39400	28057	9.50	13.10	12.00
Clyde	14-18/6/1996	7170	25560	11119	12.10	14.00	12.80
Clyde	30/6-4/7/1996	22060	35400	25846	11.90	13.10	12.50
Victoria							
Snowy	9-10/8/1994	14140	52900	36840	8.60	11.30	9.90
Snowy	22-23/8/1994	7840	45000	26373	10.60	11.90	11.40
Snowy	29-30/8/1994	422	1819	1316	15.10	17.30	16.30
Tarwin	17-18/8/94	420	42200	8474	9.30	11.20	9.80
Snowy	29/7-4/8/1995	14800	53700	24074	7.30	10.70	9.20
Snowy	13-16/8/1995	13950	30900	19284	9.60	10.70	10.20
Tarwin	12-14/8/1995	351	9050	2272	9.00	10.20	9.70
Tarwin	24-30/8/1995	520	21100	5253	9.80	13.60	11.70
Snowy	14-16/7/1996	3870	47500	24861	7.80	10.90	9.30
Snowy	23-25/7/1996	6270	18010	11716	8.80	10.00	9.60
Snowy	2-5/8/1996	5970	45400	18130	9.60	11.90	11.00
Snowy	12-17/8/1996	473	49300	14308	8.80	11.10	10.40
Snowy	27/8-1/9/1996	577	24790	6006	11.50	13.20	12.10
Snowy	13-15/9/1996	755	8350	4309	11.70	13.20	12.10
Snowy	27/9-1/10/1996	243	5540	2119	13.00	15.30	14.00
Barwon	3-5/9/1994	1968	50700	12929	10.90	12.40	11.80
Barwon	25-28/8/1995	29	26410	9248	11.70	13.50	12.80
Barwon	7-10/9/1995	2124	31200	9933	9.50	11.90	10.60
Barwon	24-25/9/1995	3500	14470	6342	11.40	12.60	12.00
Tasmania							
Tamar	30/9-3/10/1994	67	37200	19064	10.30	11.80	11.00
Tamar	14-19/10/1994	8	6600	1071	11.20	15.20	13.20
Tamar	7-12/10/1995	55	33400	7058	13.10	13.90	13.40
Tamar	23-27/10/1995	1980	5160	3876	14.00	15.60	14.90
Tamar	7-12/9/1996	82	125	98	9.00	9.50	9.30
Tamar	23-28/9/1996	85	194	106	9.60	11.10	10.20
Tamar	6-10/10/1996	93	138	116	12.20	13.20	12.90

Table 7. Five most common bycatch taxa caught at each site.

VICTORIA

TAXA	Bream Creek	Wingan River	Snowy River			Gipps-land Lakes	Bruthen Creek		Tarwin River		Bunyip River
	1994	1994	1994	1995	1996	1994	1994	1996	1994	1995	1996
CRUSTACEANS											
Crabs (Brachyura)						X					
Amphipods (Amphipoda)											
Prawns (*Macrobrachium* spp.)											
Sea-lice (Isopoda)			X	X	X				X		
Shrimp (*Paratya* spp.)	X	X	X	X		X	X	X	X		
Opossum shrimp (*Haplostylus dakini*)			X	X	X		X	X			
OTHER INVERTEBRATES											
Jellyfish (Hydrozoa)							X				
Sandworms (Nereidae)											
Snails (Gastropoda)						X					
FISHES											
Cobbler (*Gymnapistes marmoratus*)								X			
Australian anchovy (*Engraulis australis*)											
Climbing galaxias (*Galaxias brevipinnis*)										X	
Common galaxias (*Galaxias maculatus*)				X	X			X		X	
Spotted galaxias (*Galaxias truttaceus*)											
Juvenile galaxias (*Galaxias* spp.)		X	X						X		X
Tasmanian mudfish (*Galaxias cleaveri*)											
Tasmanian Whitebait (*Lovettia sealii*)									X	X	
Glassfish (*Ambassis* spp.)											
Port Jackson glassfish (*A. jacksoniensis*)											
Sand mullet (*Mugil elongatus*)											
Glass goby (*Gobiopterus semiver*)											
Tamar River goby (*Afurcagobius tamarensis*)										X	
Flat-headed gudgeon (*Philypnodon grandiceps*)	X	X									

Table 7. Continued.

VICTORIA

TAXA	Bream Creek	Wingan River	Snowy River			Gipps-land Lakes	Bruthen Creek		Tarwin River		Bunyip River
	1994	1994	1994	1995	1996	1994	1994	1996	1994	1995	1996
Yellow-eyed mullet (*Aldrichetta forsteri*)		X					X				
Small-mouthed hardyhead (*Atherinosoma microstoma*)											
Pipefish (Syngnathidae)						X					
Australian smelt (*Retropinna semoni*)			X		X					X	
Tasmanian smelt (*Retropinna tasmanica*)											
Sandy sprat (*Hyperlophus vittatus*)				X	X						
Gobies (Gobiidae)											
Toadfish (Tetraodontidae)								X			
Tupong (*Pseudaphritis urvilli*)	X	X				X	X				

Table 7 Continued

VICTORIA

TAXA	Rutherford Creek 1996	Yarra River 1994	Barwon R. 1994	Barwon R. 1995	Barham River 1994	Aire River 1994	Gellibrand River 1994	Curdies River 1994	Hopkins River 1994	Fitzroy River 1994	Glenelg River 1994
CRUSTACEANS											
Crabs (Brachyura)							X				
Amphipods (Amphipoda)									X		
Prawns (*Macrobrachium* spp.)											
Sea-lice (Isopoda)			X		X				X	X	X
Shrimp (*Paratya* spp.)	X	X	X	X	X	X	X	X	X	X	
Opossum shrimp (*Haplostylus dakini*)	X			X	X						
OTHER INVERTEBRATES											
Jellyfish (Hydrozoa)											
Sandworms (Nereidae)	X										
Snails (Gastropoda)											
FISHES											
Cobbler (*Gymnapistes marmoratus*)											
Australian anchovy (*Engraulis australis*)											
Climbing galaxias (*Galaxias brevipinnis*)											
Common galaxias (*Galaxias maculatus*)			X	X					X	X	
Spotted galaxias (*Galaxias truttaceus*)											
Juvenile galaxias (*Galaxias* spp.)		X			X	X	X	X			X
Tasmanian mudfish (*Galaxias cleaveri*)											
Tasmanian Whitebait (*Lovettia sealii*)											
Glassfish (*Ambassis* spp.)											
Port Jackson glassfish (*A. jacksoniensis*)											
Sand mullet (*Mugil elongatus*)											
Glass goby (*Gobiopterus semiver*)											
Tamar River goby (*Afurcagobius tamarensis*)										X	
Flat-headed gudgeon (*Philypnodon grandiceps*)		X				X	X		X	X	
Yellow-eyed mullet (*Aldrichetta forsteri*)			X		X			X			X

Table 7 Continued

VICTORIA

TAXA	Rutherford Creek 1996	Yarra River 1994	Barwon River 1994	Barwon River 1995	Barham River 1994	Aire River 1994	Gellibrand River 1994	Curdies River 1994	Hopkins River 1994	Fitzroy River 1994	Glenelg River 1994
Small-mouthed hardyhead (*Atherinosoma microstoma*)											
Pipefish (Syngnathidae)											
Australian smelt (*Retropinna semoni*)						X		X			
Tasmanian smelt (*Retropinna tasmanica*)											
Sandy sprat (*Hyperlophus vittatus*)											
Gobies (Gobiidae)	X					X		X			
Australian salmon (*Arripis* spp.)				X							
Toadfish (Tetraodontidae)	X		X	X							
Tupong (*Pseudaphritis urvilli*)							X				

Table 7 Continued

TASMANIA AND NEW SOUTH WALES

TAXA	Rubicon River	Tamar River			Ansons River	Scaman-der River	Swan River	Prosser River	Jordan River	Der-went River	Bega River	Shoal-haven River	Clyde River	
	1994	1994	1995	1996	1995	1995	1995	1996	1996	1995	1995	1995	1995	1996
CRUSTACEANS														
Crabs (Brachyura)										X	X			
Amphipods (Amphipoda)	X											X		
Prawns (*Macrobrachium* spp.)											X			X
Sea-lice (Isopoda)	X			X	X	X	X	X		X	X		X	
Shrimp (*Paratya* spp.)	X							X					X	X
Opossum shrimp (*Haplostylus dakini*)						X								
OTHER INVERTEBRATES														
Jellyfish (Hydrozoa)														
Sandworms (Nereidae)														
Snails (Gastropoda)														
FISHES														
Cobbler (*Gymnapistes marmoratus*)														
Australian anchovy (*Engraulis australis*)			X										X	X
Climbing galaxias (*Galaxias brevipinnis*)		X												
Common galaxias (*Galaxias maculatus*)		X	X	X	X	X		X		X		X		
Spotted galaxias (*Galaxias truttaceus*)		X												
Juvenile galaxias (*Galaxias* spp.)														
Tasmanian mudfish (*Galaxias cleaveri*)		X		X				X						
Tasmanian Whitebait (*Lovettia sealii*)	X									X				
Glassfish (*Ambassis* spp.)														
Port Jackson glassfish (*A. jacksoniensis*)											X	X	X	X
Sand mullet (*Mugil elongatus*)											X			
Glass goby (*Gobiopterus semiver*)												X		
Gobies (Gobiidae)	X	X	X				X	X		X				

Table 7 Continued

TASMANIA AND NEW SOUTH WALES

TAXA	Rubicon River	Tamar River			Ansons River	Scaman-der River	Swan River	Prosser River	Jordan River	Der-went River	Bega River	Shoal-haven River	Clyde River	
	1994	1994	1995	1996	1995	1995	1995	1996	1996	1995	1995	1995	1995	1996
Tamar River goby (*Afurcagobius tamarensis*)				X										
Flat-headed gudgeon (*Philypnodon grandiceps*)			X		X									
Yellow-eyed mullet (*Aldrichetta forsteri*)														
Small-mouthed hardyhead (*Atherinosoma microstoma*)					X		X							
Pipefish (Syngnathidae)							X							
Tasmanian smelt (*Retropinna tasmanica*)			X	X										
Sandy sprat (*Hyperlophus vittatus*)									X			X	X	X
Toadfish (Tetraodontidae)														
Tupong (*Pseudaphritis urvilli*)							X							

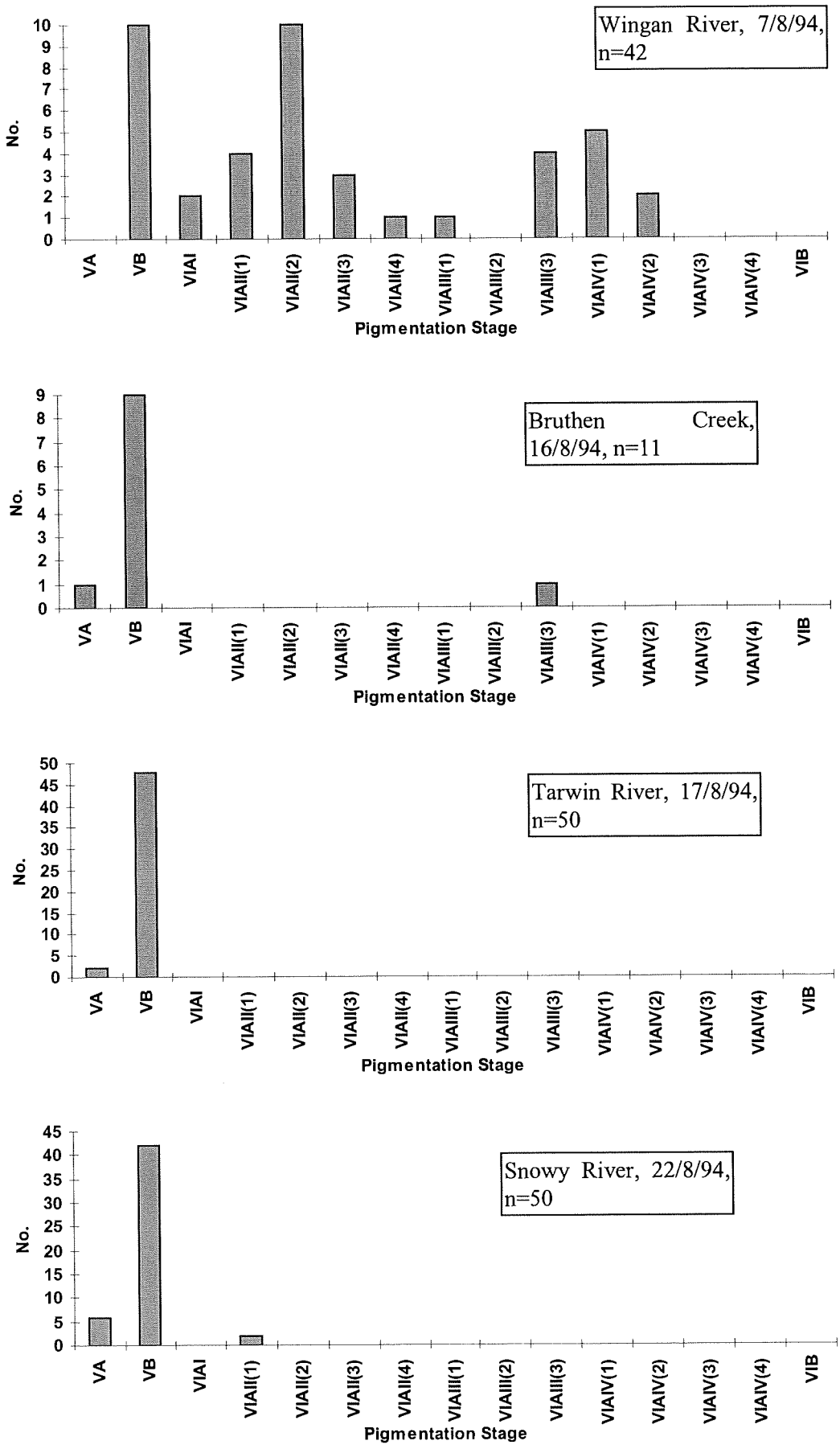


Figure 22 Pigmentation stages of glass eels sampled from sites in Victoria and Tasmania in 1994. Plots are presented in chronological sampling order.

Figure 22 Continued

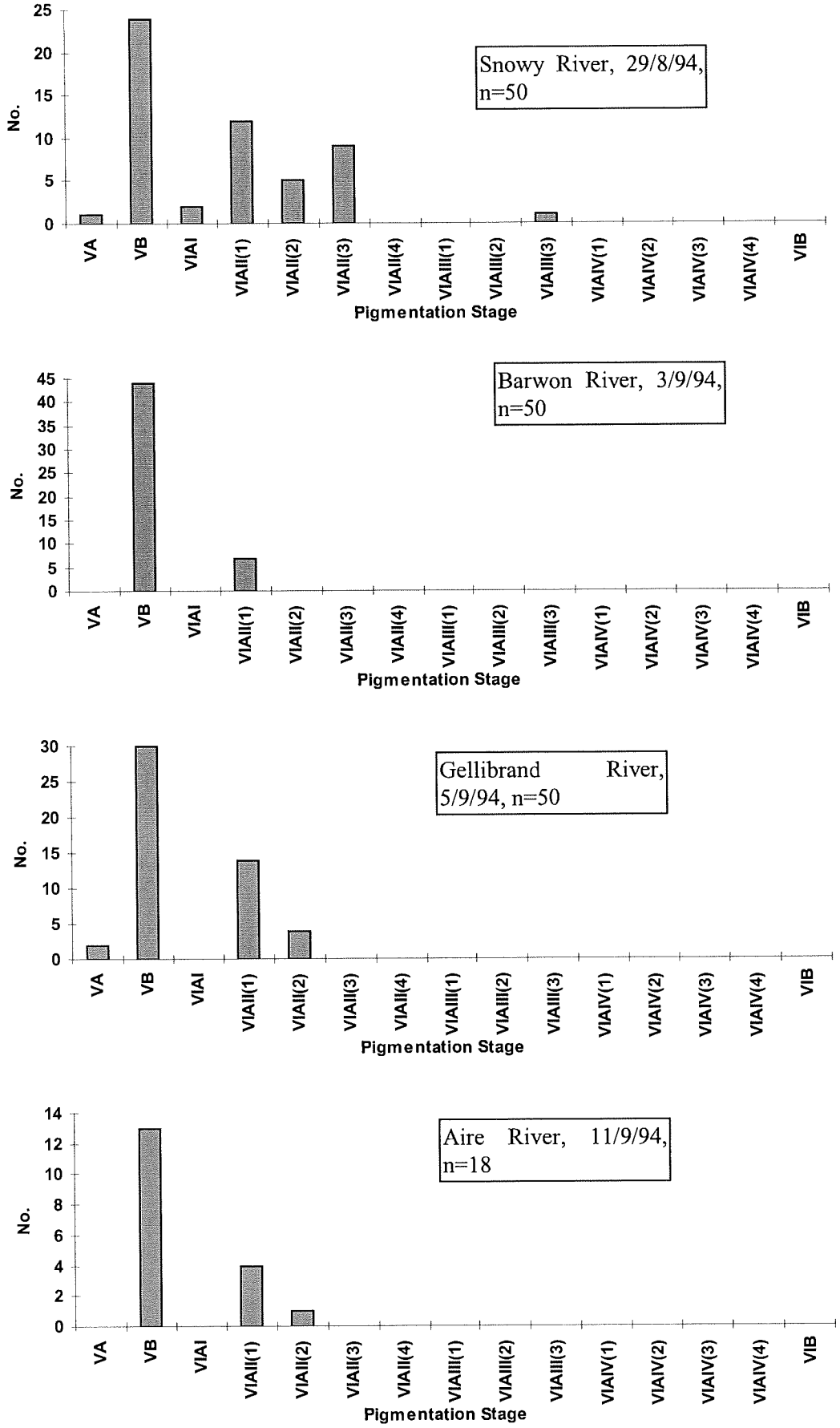


Figure 22 Continued

Figure 22 Continued

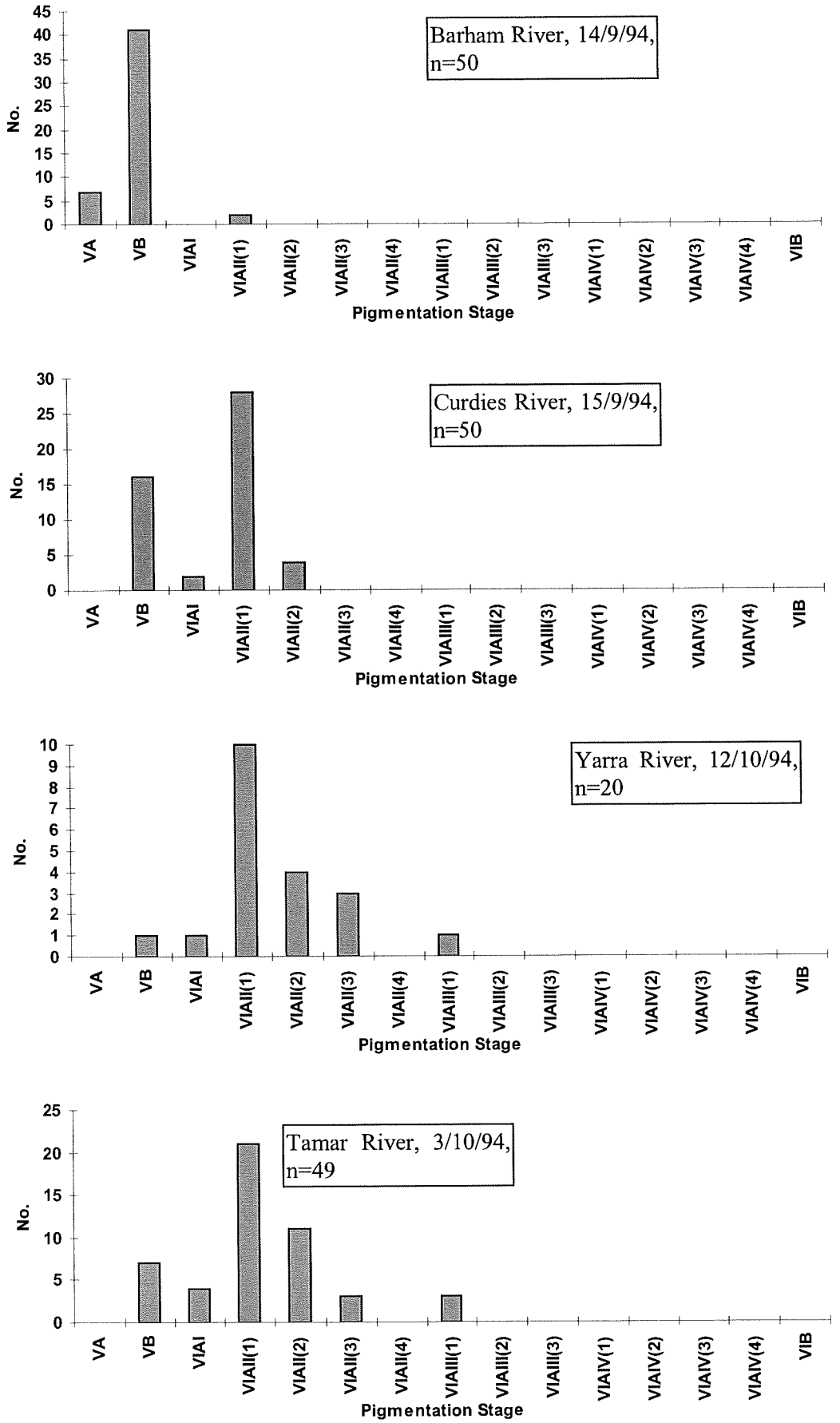


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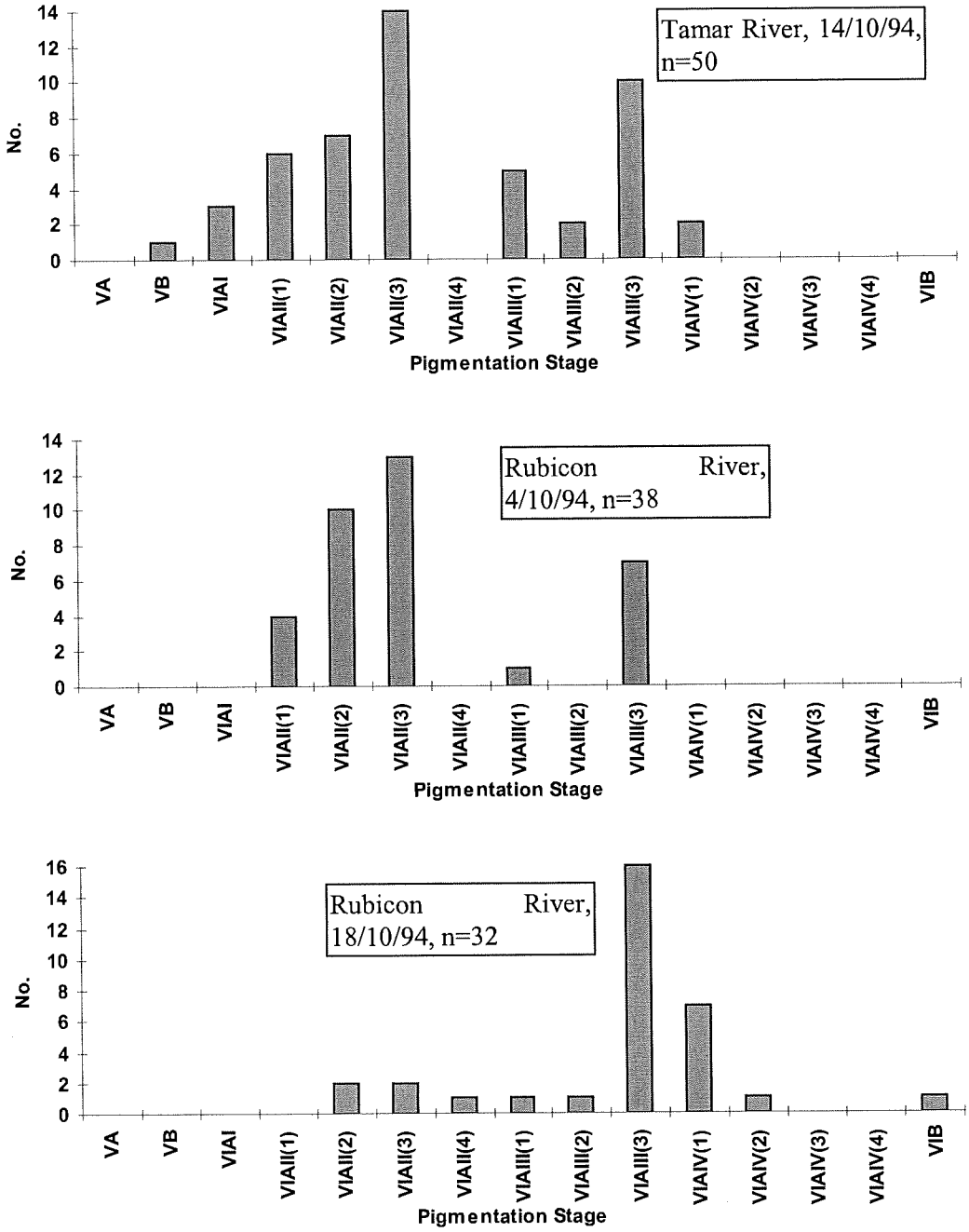
Figure 22 Continued



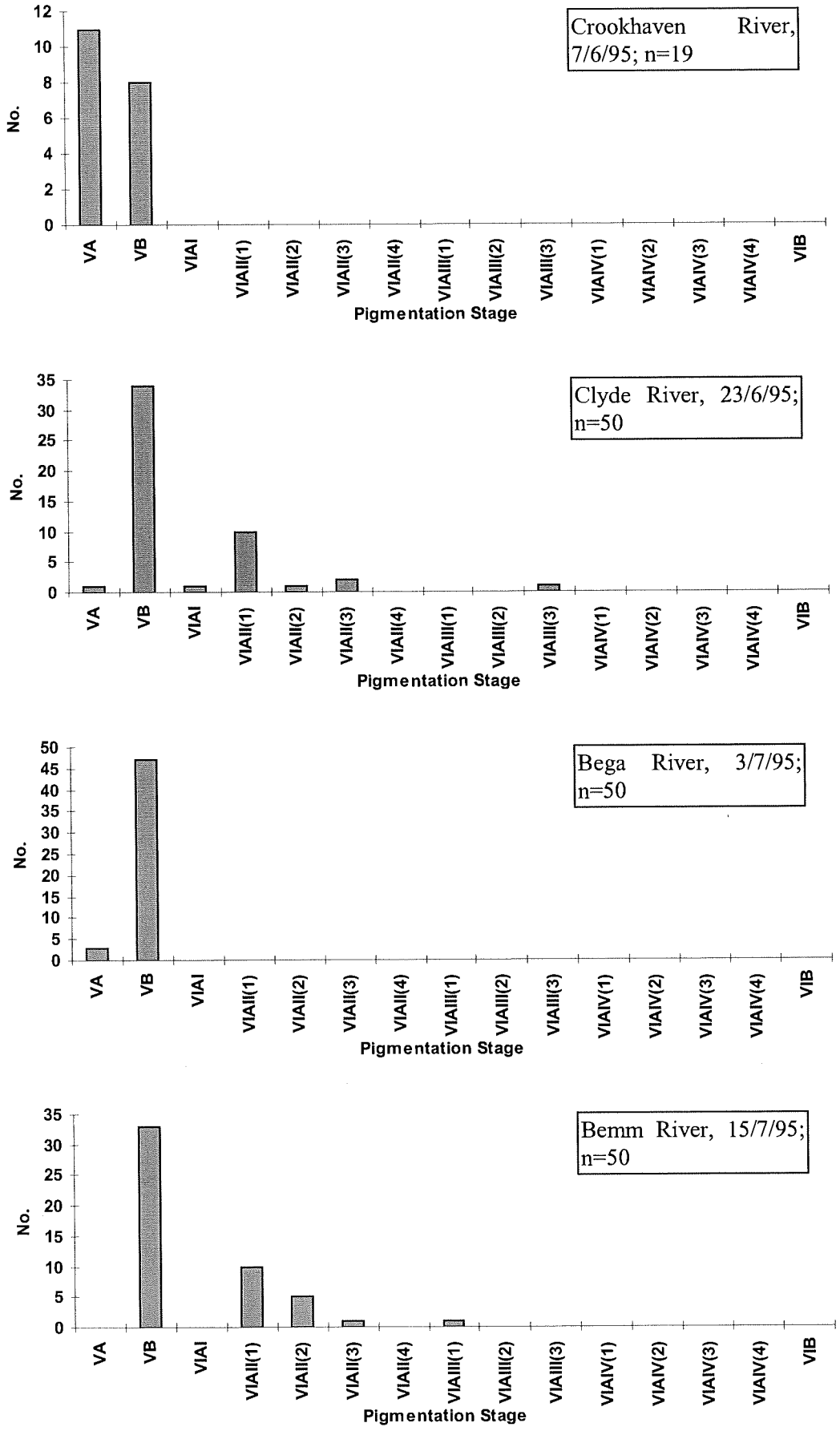


Figure 23 Pigmentation stages of glass eels sampled from sites in NSW, Victoria and Tasmania in 1995. Plots are presented in chronological sampling order.

Figure 23 Continued

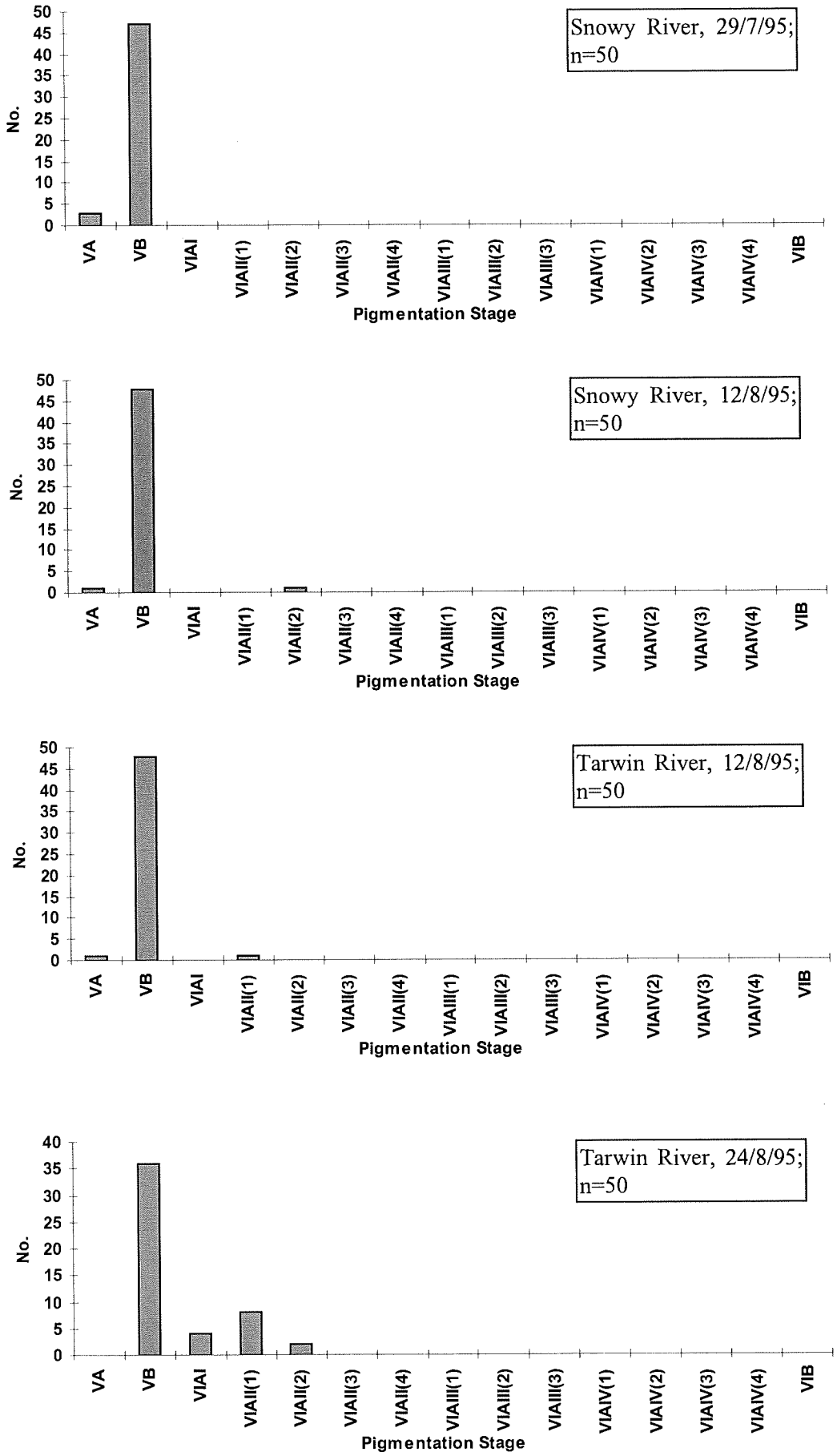


Figure 23 Continued

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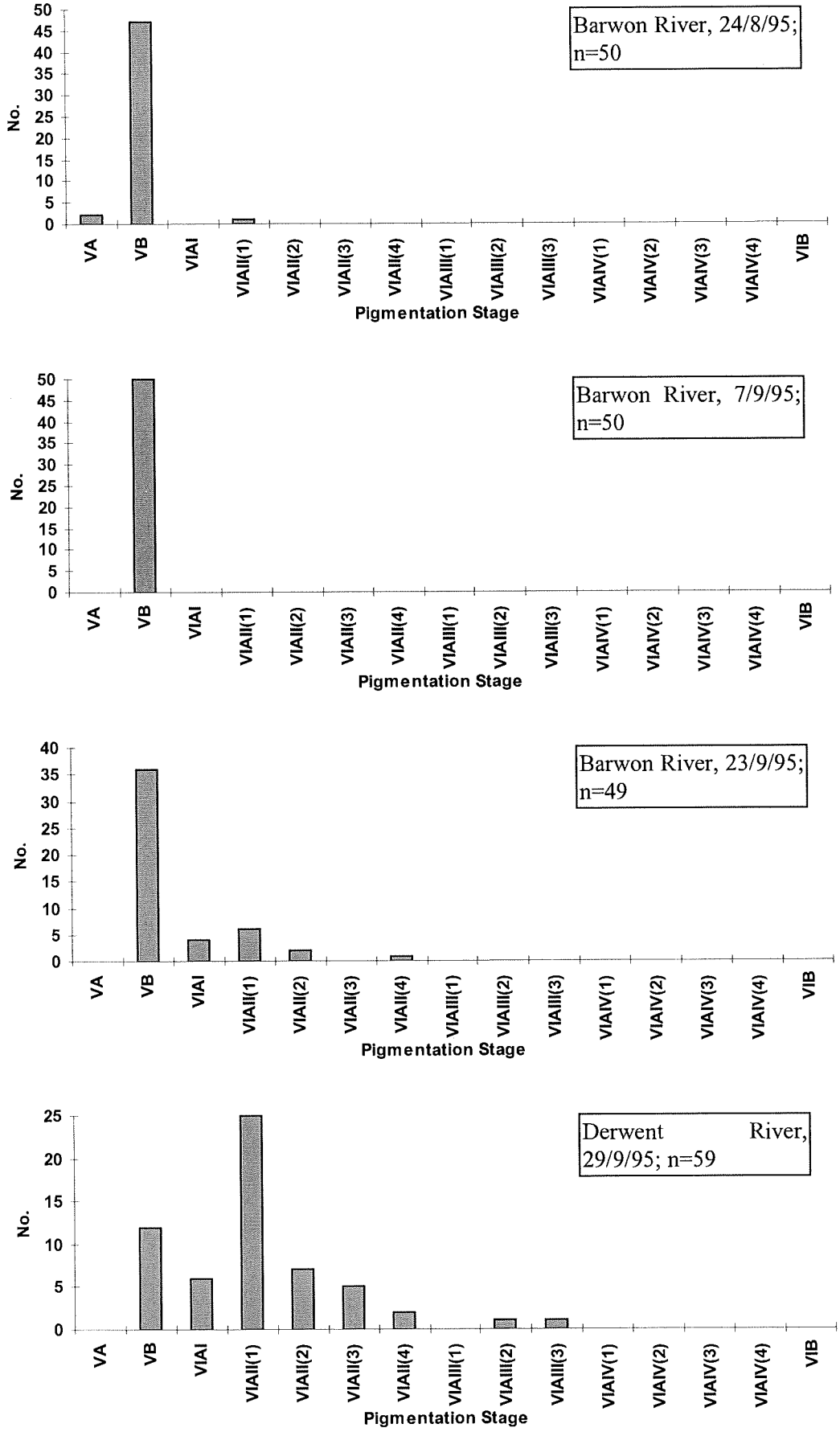
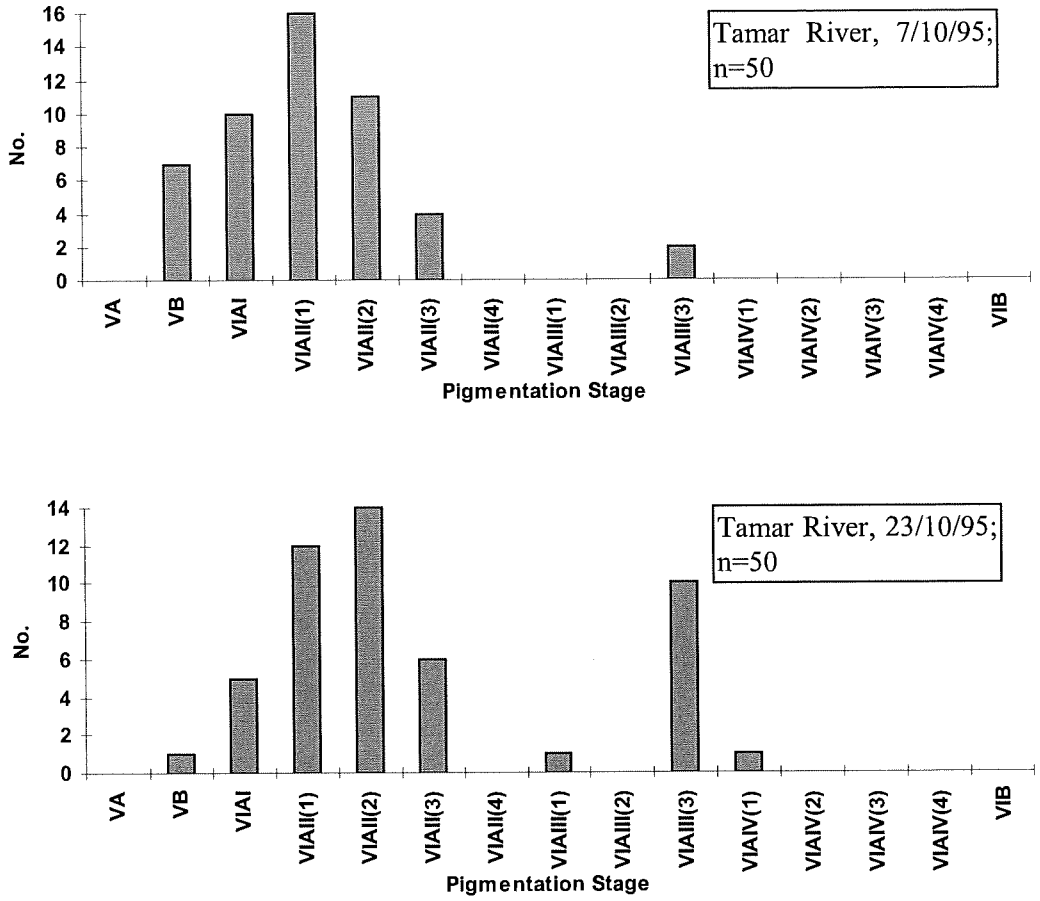


Figure 23 Continued

Figure 23 Continued



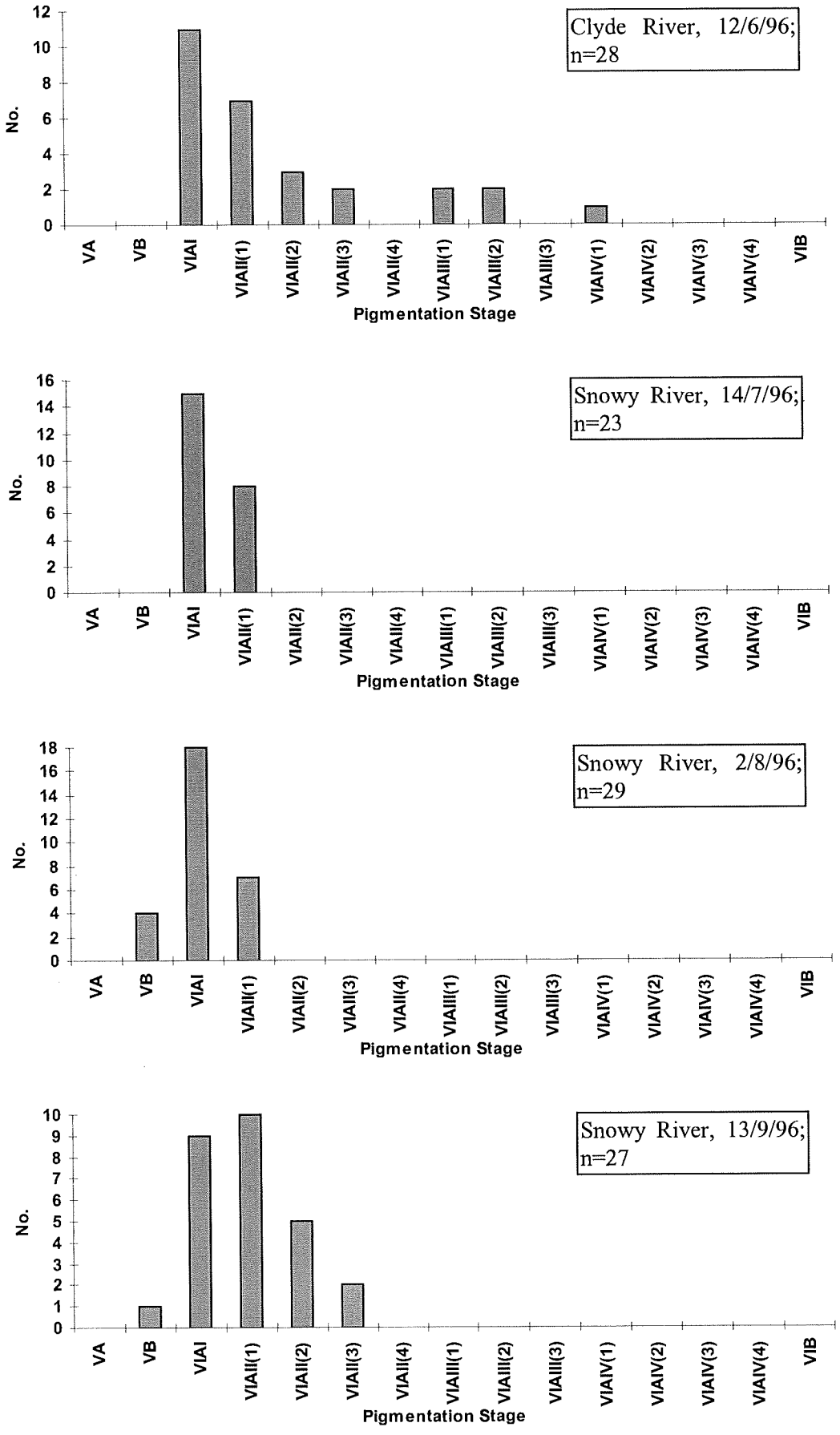
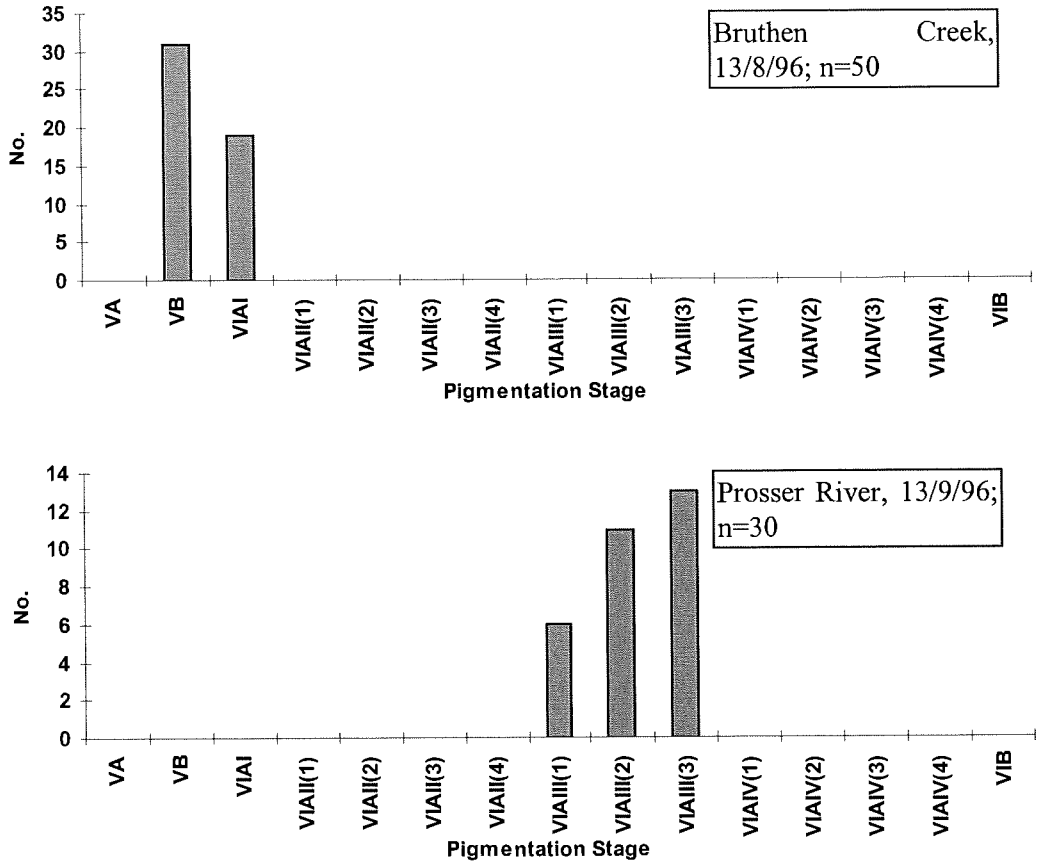


Figure 24 Pigmentation stages of glass eels sampled from sites in NSW, Victoria and Tasmania in 1996. Plots are presented in chronological sampling order.

Figure 24 Continued



7.4 DISCUSSION

7.4.1 CATCH-EFFORT

The invasion of *A. australis* glass eels into south-eastern Australian estuaries is highly variable, both spatially and temporally. Of the 30 waters in Victoria, NSW and Tasmania sampled on at least one occasion over the three years of the project, *A. australis* glass eels were found in 22. Of the waters which did not produce any, or very small numbers of glass eels, the entrances to six (Bream Creek, Powlett, Aire, Glenelg, Fitzroy and Bunyip Rivers) were substantially closed at the time of sampling. Such closures restricted penetration of seawater through the mouth of the estuary to the latter part of the flood tide, thus allowing very little upstream tidal bore. Consequently the opportunities for glass eel invasion into these waters were limited. The waters which produced the greatest numbers of glass eels with at least some degree of consistency during the present study were the Snowy, Tarwin, Tamar, Clyde and Barwon Rivers, with the greatest CPUE of glass eels occurring in the Snowy River in stow nets in 1996.

The degree of spatial and temporal variability in shortfin glass eel abundance observed during the present study is common in other anguillid eel species (Moriarty 1987; Domingos 1992; Jessop 1998; Dekker 1998). Recruitment of *A. anguilla* glass eels to the Baltic Sea is thought to be significantly affected by the presence or absence of westerly winds during the main period of arrival of glass eels to northern Europe (January-February) (Westerberg, 1998). Although the possible effects of anthropogenic chemical contamination, habitat modification and commercial fishing have been considered as adversely affecting recruitment, changes in oceanographic conditions are seen as being one of the most likely causes of recruitment variability in *A. anguilla* (Dekker 1998). Castonguay *et al.* (1994) could not conclude exactly what has caused the decline in *A. rostrata* recruitment in the St. Lawrence River and Gulf, Canada, however possible synergism of the above postulated causes, including changes in oceanographic conditions, may exist. Geographic differences in *A. rostrata* glass eel catches are thought to be linked to oceanographic current patterns between the Gulf Stream and the Canadian/North American coast (Jessop 1998). Changes in the East Australian and Tasman Currents, possibly due to fluctuations in the El Niño Southern Oscillation Cycle, have been suggested as being accountable for the recent occurrence of the Australian longfin eel, *A. reinhardtii*, in New Zealand waters (Jellyman *et al.* 1996; McDowall *et al.* 1998), further emphasising the high degree of spatial variability of glass eel abundance. Early information from investigations into glass eel stocks in Queensland indicates that, with *A. australis*, major migration periods may coincide in different areas throughout the entire range of the species, with peak catches of shortfin glass eels occurring in southern Queensland and Victoria at the same time (A. Collins, QDPI, *pers. comm.*).

It is clear that stow nets were far more effective in catching glass eels than conventional glass eel nets, although stow nets were not introduced into the sampling regime until the 1995 sampling season. When glass eel nets were used concurrently with stow nets, CPUE of glass eels was consistently higher in stow nets than in glass eel nets. Stow nets were also shown to be more efficient in catching glass eels per square metre of effective fishing area of net. Stow nets can more easily be set in deeper water within the main channel, whereas the use of glass eel nets is limited largely to the littoral zone in shallower water, often out of the main flow of the flood tide. Large nets, such as stow nets, are therefore more effective when targeting the invasion phase of glass eel migration, whereas glass eel nets may have greater application when targeting pigmented glass eel migration when glass eels tend to swim upstream close to the river bank, particularly during ebb tides (Jellyman 1979).

Stow nets are used in the Portuguese and Spanish commercial glass eel fisheries (Weber 1986; Domingos 1992; Antunes and Weber 1993), and the methods employed in these fisheries were considered to be suitable for fishing conditions encountered in south-eastern Australia. However, under the conditions experienced at most sites, stow nets were found to endure extreme flood tide flows which occasionally caused the nets to drag anchor and move upstream with the tidal bore. This generally resulted in the wings of the net straightening out and the entrance to the net closing up to as little as 2-3m. In some cases only one anchor would drag, sometimes straightening the entire net out

almost completely. In extreme cases the net would tear. These limitations of stow nets partly restricted their use in glass eel fishing to areas of lower flow, such as shallower (<3m) or relatively wide sections of the estuary. As a result, optimum fishing sites could not always be accessed using stow nets. Modifications to the stow nets were made to address these problems. These included reducing the amount of flotation, using plough anchors instead of sand anchors and sewing 'stop-rip' nylon along the lead line of the net to prevent tearing. Each of these design modifications improved the fishing efficiency of the stow nets significantly, however under high flow conditions, movement of the net still occurred due to the large surface area which the net covered.

No clear trend in eel recruitment was evident from the three years of data collected during this project, using CPUE as an index of relative abundance of glass eels. It is expected that a minimum of 10-15 years of recruitment data is needed to identify inherent annual variability. While recognising the high degree of spatial variability in glass eel recruitment, it would be necessary to limit long term monitoring to strategic locations for logistic reasons and for consistency in data collection and methods. The results of the work suggest that the Snowy River would be a likely site for long term glass eel recruitment monitoring in south-eastern Australia for logistic reasons and due to the relatively consistent catches of glass eels made there during the project.

The low catches of glass eels in waters west of Cape Otway, Victoria, and in eastern and southern Tasmania, suggest that shortfin glass eels may invade these streams on a less than annual basis, as appears to be the case for eastern Victorian (Gippsland) streams. Although it is reasonable to assume that the East Australian Current acts as the predominant vehicle for the transportation of glass eels from the supposed spawning grounds in the Coral Sea to the eastern Australian and New Zealand coasts, the predominant flow in Bass Strait is from west to east (Middleton and Black1994), particularly during winter and spring, the prime invasion period of the shortfin glass eel in south-eastern Australia. This then suggests that glass eels must change from a largely passive, flow-carried migration behaviour to an active swimming pattern during the latter stages of the post-metamorphic oceanic phase of their migration. It would be expected that this would commence somewhere near the southern fringe of the East Australian Current, or its eddies, enabling glass eels to continue their journey westwards into Bass Strait, and southwards down the east coast of Tasmania. Such a requirement for this behavioural change may account partly for the observed lower incidences of shortfin glass eel invasion and abundance in areas close to the southern and western limits of the known distribution of this species, such as in western Victorian and eastern Tasmanian waters.

7.4.2 MIGRATION AND INVASION CUES

The data obtained from the Snowy River are the most useful for the evaluation of glass eel migrational "cues" although very little consistency in the results of the analyses was observed, particularly between years and between gear types. In the first year of the project, when only glass eel nets were used, CPUE was significantly greater during full moon periods, and when salinity was over 20000 µS/cm and temperature was between 11 and 16°C. In 1995 in glass eel nets however, CPUE was significantly greater only during the first and last quarters of the moon, with temperature and salinity having no effect. In stow nets for the same year, CPUE was greater at the lower salinity range of 8000-20000 µS/cm and at 9-11°C, but moon phase had no effect. In 1996, CPUE in stow nets was greatest at 7-9°C, during the new moon phase and at low stream discharge, whereas salinity had no significant effect.

It appears that, in any given year, the variables of temperature, salinity, moon phase, and as occurred in 1996, stream discharge, can affect CPUE of glass eels, but these effects are not easily explained. The complexity of the relationship between glass eel abundance and environmental factors is highlighted by the appearance of significant interactive effects between these variables on CPUE. Earlier analysis of data from the Snowy, Tarwin and Tamar Rivers (McKinnon and Gooley 1998) indicated that the invasion of glass eels of *A. australis*, and subsequent passive migration via tidal bore, was most common at low salinity and within a specific temperature band in estuarine waters in

south-eastern Australia. The correlation of these variables with CPUE of glass eels was found to be stronger than that with either lunar phase or height of high tide, suggesting that such movements may occur during most flood tides, irrespective of lunar phase, provided the water temperature is between 10 and 14°C. This indicates that time of year, or season, may dictate the presence or absence of glass eels. More specifically, temperature reflects other seasonal changes, of which some may have a more direct influence on glass eel invasion.

Observations for *A. anguilla* glass eels have shown that a preference for fresh water is affected by temperature (Tosi *et al.* 1990). The initial arrival of incompletely pigmented glass eels of *A. rostrata* at the fresh water interface has been seen to coincide with a large increase in water temperature (Sorensen and Bianchini 1986), and temperature has been shown to be more important than time of year in determining the invasion of *A. anguilla* glass eels into estuaries (Moriarty 1987). However, other studies have failed to find any correlation between temperature and capture of glass eels of *A. rostrata* (Sorensen and Bianchini 1986), *A. anguilla* (Moriarty 1987) and *A. australis* in New Zealand (Jellyman 1979) during the active migration phase. Thus it is suggested that temperature may play a more important part in predicting the initial invasion and passive migration phase of glass eels into estuaries, than in the subsequent active freshwater migration phase within estuaries.

The apparent effect of salinity on CPUE may suggest that *A. australis* glass eels are also attracted to fresh water, as concluded by Tosi *et al.* (1990) and Chen *et al.* (1994). This is, however, contradicted in the present study by significantly higher CPUE of glass eels with low stream discharge in 1996. This relationship may be attributed to the fact that low stream discharge allows further upstream tidal bore, and therefore greater penetration of glass eels into an estuary. Conversely, high stream discharge, while possibly attracting glass eels toward an estuary, may reduce tidal flow, and consequently glass eel invasion, into the estuary. It is therefore suggested that significant invasions of glass eels may occur in estuaries which have recently experienced high flow events.

Although lunar phase has been shown to be important in glass eel migration, with upstream migration of *A. australis* commencing on the new and full moon and reaching a peak several days later (Jellyman 1979), no consistent effect of lunar cycle on the invasion of glass eels in south-eastern Australian estuaries could be concluded from the data. However, significant interactions between moon phase and temperature and moon phase and salinity were found on occasions.

Observed effects of environmental variables on glass eel abundance may really only be incidental rather than causal, with the strongest influences on glass eel presence in south-eastern Australian estuaries due to more extrinsic factors such as spawning success of adult eels and associated recruitment pulses, and intensity and direction of the ocean currents which transport glass eels from the spawning grounds to the estuaries. Such factors may primarily dictate the quantities of glass eels, with the timing of their arrival at a given estuary varying from year to year. Once glass eels are in the region of the estuaries, then localised environmental variables such as stream discharge, temperature and salinity may affect their movement into and within estuaries with an overriding effect of moon phase. The peak period of *A. australis* glass eel invasion in south-eastern Australia has previously been suggested as late winter and spring (Beumer and Harrington 1980). In the present study, the greatest concentrations of glass eels occurred during the period from mid July to late September in the Snowy River, but were present in all three years throughout the study period from June to November. Recruitment variability appeared to increase over a spatial gradient, particularly at sites west of Gippsland, Victoria. Glass eel abundance, as measured by CPUE, was greater overall in Gippsland than in Western Victoria, nearer the western extreme of the range of *A. australis*.

Although many factors appear to affect glass eel invasion and migration in estuaries, from the results of this study, the most productive conditions for shortfin glass eel harvesting in south-eastern Australia are immediately following the new and full moons from mid July to late September. During this period, high stream flows often occur, and the associated low water temperature and salinity, as well as other possible chemoattractants, may act solely or in combination to orient glass eels towards estuaries and triggering the commencement of inland migration.

7.4.3 LENGTH-WEIGHT ANALYSIS

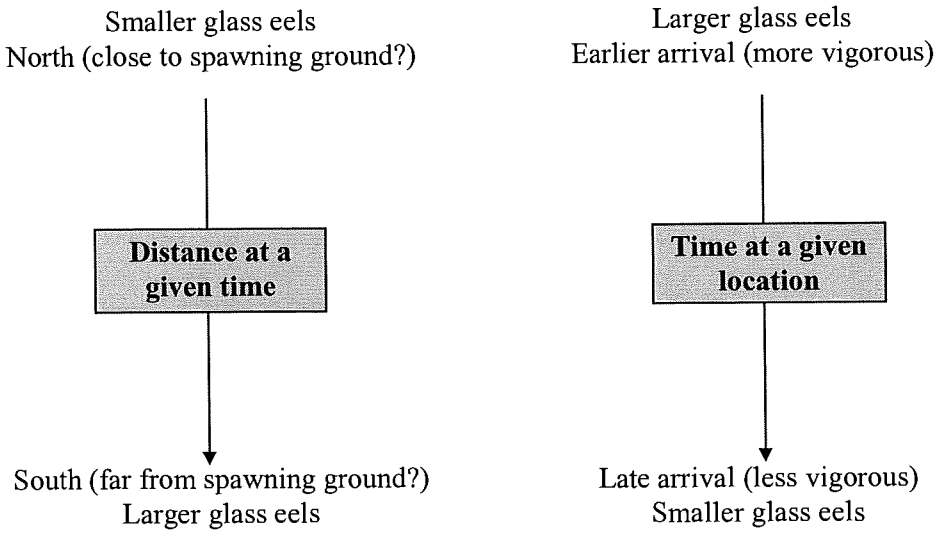
Worldwide, a reduction in both length and weight occurs in Anguillid glass eels throughout the progress of any one season, along with advancing pigmentation stage (Deelder 1970; Jellyman 1977; Tesch 1977; Sloane 1984a, Guérault *et al.* 1992). *A. australis* glass eels arriving at the north-east of Tasmania, the area considered to first receive glass eels for Tasmania in any one year, have been found to have higher condition factors than in other parts of the state, and were heavier than glass eels at other pigmentation stages (Sloane 1984a). Sloane (1984a) also suggests that glass eels arrive earlier and are in best condition in waters nearest the region of the onset of metamorphosis from the leptocephalus to the glass eel. With respect to south-eastern Australia, glass eels in the more easterly waters may be expected therefore, to be greater in both length and weight and arrive earlier in the season, than those in more westerly waters.

In each year of the study, both length and weight of glass eels differed significantly between rivers sampled in each year. Only in 1996 were differences found in length and weight over time in the same river. In the Snowy River a significant reduction in both length and weight occurred in glass eels over approximately six weeks. In the Tamar River however, a significant reduction in weight only was observed in glass eels sampled over approximately the same length of time. This supports observations in the literature for Anguillid glass eels, that mean weight decreases at any one location as the season progresses (Deelder 1970; Jellyman 1977; Tesch 1977; Sloane 1984a, Guérault *et al.* 1992).. Evidence of a concomitant reduction in mean length of glass eels is less conclusive as, although a significant reduction in mean length of glass eels was observed in the Snowy River in 1996, such a reduction was not observed in the Tamar River for the same period. It is clear however, that an overall reduction in size and condition occurs in glass eels with time in any given season. That is, glass eels are heavier and are in better condition earlier in the season at any given location. This may have important implications for aquaculture as better conditioned glass eels collected earlier in the season may perform better as aquaculture seedstock. Thus glass eels caught earlier in the season, for example during July and August, may be preferable for aquaculture than those caught in September in the Snowy River.

It is believed that Anguillid eels feed and grow as leptocephali at sea and metamorphose into the glass eel stage when ontogenetically ready, possibly upon reaching the general vicinity of the continental shelf (Tesch 1977). After this event feeding ceases (Deelder 1970) and, as has been seen during this study and in the literature, glass eels subsequently lose condition until feeding recommences in the estuary (Deelder 1970; Jellyman 1977; Tesch 1977; Sloane 1984a, Guérault *et al.* 1992). It would appear therefore, that the longer the leptocephalus stage, the larger their size at metamorphosis and consequently the larger their size upon entering the estuary. Thus if leptocephali metamorphose into glass eels near the estuaries into which they invade, then waters distant from the spawning grounds should receive glass eels of greater size and condition than waters closer to the spawning grounds. Preliminary observations of differences in mean weight of *A. australis* glass eels from spatially separated estuaries in Victoria and Queensland have been recently observed (A. Collins, QDPI, *pers. comm.*), with glass eels caught in Victoria being heavier than glass eels from Queensland waters caught at the same time. These observations were made as part of a second FRDC funded glass eel assessment program and will be discussed in further detail at the conclusion of that particular project.

Once metamorphosis has occurred however, glass eels entering estuaries further from the site of metamorphosis may be expected to be smaller and of poorer condition than those entering estuaries nearer the site of metamorphosis. Glass eels metamorphosing in the region of south-eastern Australia and migrating in a westerly direction through Bass Strait and down the east and west coasts of Tasmania would therefore be expected to decrease in condition as the distance of migration prior to invasion of estuaries increases. Additionally, glass eels, which have metamorphosed but due to prevailing oceanographic and/or general ambient environmental conditions, are not positioned or cued to invade fresh waters, may ultimately be smaller at final invasion due to reduced energy reserves.

It is hypothesised therefore that the spatial and temporal effects on *A. australis* glass eels are as described in the following schematic:



Note, this relationship assumes that at any one time, glass eels are migrating over a wide spatial scale, and that at any one location, glass eels may migrate over protracted periods of time. Note also that this relationship assumes that feeding and growth of glass eels ceases from point of metamorphosis from the leptocephalus to the glass eel.

Thus, the greater the length of time spent as leptocephali, the larger the resultant glass eels and the greater the distance from the supposed spawning ground they occur. These observations are also pertinent for *A. anguilla* (Guérault *et al.* 1992).

7.4.4 PIGMENTATION

The progression of pigmentation of *A. australis* glass eels over time within sites and between sites during the present study was consistent with that seen for other species and for *A. australis* in both New Zealand and Australian waters (Jellyman 1977, 1979; Sloane 1984a). The development of pigment over time in invading glass eels sampled from the same location within any one river supports the observation by Jellyman (1977) that pigmentation of glass eels proceeds irrespective of salinity and that the rate of pigmentation is a function of the length of post-metamorphic sea life.

The most commonly observed pigmentation stage at all sites was VB. Interestingly, few stage VA glass eels were found in Victorian waters and none were observed from Tasmanian waters, while relatively high numbers of stage VA were recorded from the Crookhaven, Clyde and Bega Rivers in NSW. This may however be due to the fact that these more northerly waters were sampled earlier in the season than the Victorian and Tasmanian rivers. Stage VB was the earliest stage observed for *A. australis* glass eels by Sloane (1984a) in Tasmanian waters and in New Zealand waters by Jellyman (1977). It appears therefore that early stages of pigmentation of glass eels may occurring during oceanic migration to the more distant parts of the species' distribution.

Although increasing pigmentation stage appears to correspond with decreasing length and weight of anguillid eels (Deelder 1970; Jellyman 1977; Tesch 1977; Sloane 1984a; Guérault *et al.* 1992) until Stage VIAIII2 (Tesch 1977), no strong correlation between these factors was observed for the data collected from this study. Length and weight reduction and a reduction in condition were seen in

samples of glass eels from a number of locations in the final year of the study, however little correlation with increasing pigmentation in glass eels was observed.

7.4.5 BYCATCH

The composition of fish assemblages in the estuaries of south-eastern Australia is both diverse and unique with over 70 species recorded in the estuaries of East Gippsland, Victoria, alone (McCarraher 1986). Included in these are 19 species of native freshwater fish, including three of which are listed as threatened species under the Victorian *Flora and Fauna Guarantee Act 1988* (Raadik 1992). A further 7 freshwater species are considered threatened in Victoria (Raadik 1992). Of the ten species considered threatened in Victoria, up to four have been recorded on more than one occasion in the bycatch during glass eel surveys in the present study. These are pouched lamprey (*Geotria australis*),striped gudgeon (*Gobiomorphus australis*), climbing galaxias (*Galaxias brevipinnis*) and mountain galaxias (*Galaxias olidus*).

The reduction of non-target organisms, or bycatch, is considered desirable, if not essential, for the operation of a commercial glass eel fishery in south-eastern Australia, particularly where threatened species may be at risk. Given the peculiar morphology of the glass eels, it should be possible to develop bycatch reduction devices (BRDs) that can separate the target glass eels from non-target organisms. BRDs such as a modified Nordmøre grid as trialed in the Clarence River prawn-trawl fishery (Broadhurst and Kennelly 1996) may be effective in reducing quantities of the bycatch of small fish and crustaceans, provided the bars of the grid were set at appropriate spacings to allow the passage of glass eels, while diverting other organisms out of the net. Reducing bycatch quantities will also have benefits by reducing damage to glass eels. Often large quantities of bycatch accumulating in the codend of a net over as little as one hour can cause physical damage to all animals in the net, including any glass eels. Likewise, more rapid sorting methods will decrease damage to glass eels and to bycatch, thus improving the chances of recovery and survival of the latter.

In the absence of effective and efficient BRDs, much of the non-threatened bycatch species could be utilised rather than discarded. The large quantities of sandy sprat caught as bycatch from the Snowy River for example, could be on-sold as a by-product of glass eel fishing. In fact this species is presently sold as "whitebait" in both the retail bait market and, indeed, in restaurants. Other species, such as juvenile galaxiids, which are true whitebait, and anchovies could also be destined for human consumption. Some fish species such as tupong and the various glassfishes may have value as aquarium fish. The commonly caught opossum shrimp may make a useful, high protein ingredient in commercial fish feed production, and other fish species such as juvenile mullet, Australian salmon, black bream and estuary perch may be utilised for on-growing and value adding as aquaculture species in their own right.

8 CULTURE COMPONENT

8.1 INTRODUCTION

8.1.1 BACKGROUND

The reproductive cycle of *Anguilla* has not been closed. Mature eels of several species have been induced to spawn, and eggs have hatched, but larvae do not survive beyond one month of age (Prokhorchik *et al.* 1987, Wang *et al.* 1980, Ohta *et al.* 1996). There are no reported attempts to spawn *A. Australis* in captivity. As a result, all aquaculture operations rearing *Anguilla* spp. Relies solely on the capture of seedstock (both glass eels and elvers) from the wild. A description of the glass eel fishery in Victoria, and other parts of south eastern Australia, is provided in Section VII of this report.

The initial rearing period of *A. anguilla* and *A. japonica*, in which glass eels have to adapt to artificial food is generally regarded as the most difficult stage of the rearing process (Kamstra and Heinsbroek 1991). Continuation of the migration activity, non-acceptance of food, cannibalism and disease can cause mortalities ranging from 15% to 90% in the first few months (Heinsbroek 1989; Applebaum 1980; Degani and Levanon 1986). Most eel farms work with so little profit that a slight variation in the price of inputs, productivity or excessive losses of stock can lead to financial losses. Glass eels make up 23-38% of production costs of eel farms (Gousset 1992), emphasising the importance of the weaning process on the viability of future farms. This procedure of weaning glass eels, and separating weaned eels from those that have not yet adapted to artificial food occurs during the first month or two (Degani and Gallagher 1995).

There is expanding interest in eel culture in Australia (Zeller and Beumer 1996), however there is a clear lack of fundamental information necessary for further development of the industry. A recent search for information regarding aquaculture of eels prior to this study identified only five publications directly related to the culture of Australian eel species (Sumner and Hopkirk 1978; Johnson 1980; Copland 1981; Beumer 1983a; Jones *et al.* 1983). With such a small amount of literature available, little is known of the weaning and rearing of the glass eel phase of the Australian eel *A. australis*. The effects of temperature (Seymour 1989), feeding and growth (Usui 1991; Seymour 1989; Heinsbroek and Kreuger 1992), density (Degani *et al.* 1988), disease and water quality (Usui 1991), are well documented for *A. anguilla* and *A. japonica*. The same parameters need to be investigated to establish a foundation to foster the culture of *A. australis* eels. Differences in husbandry, growth, and feed utilisation may be found to exist between *A australis* and *A. anguilla*, and *A australis* and *A japonica*, as they do between *A. anguilla* and *A japonica* (Heinsbroek 1989). The established techniques and environmental parameters for glass eels of *A. anguilla* and *A japonica* provided general guides for commencement of investigations on *A. australis* glass eels. In the present study, these have been used in some facets of experimental design and in comparison of the results.

It is noted, however, that fundamental differences exist between initial culture techniques for *A. anguilla* glass eels in the European industry and *A. japonica* glass eels in the Asian industry, not all of which was well documented at the time of the present study. Indeed, much of the reported best practices were only validated anecdotally during the course of the study. Accordingly, although cognisant of such reported practices, an empirical approach based on incorporating and testing largely standard finfish larviculture techniques, and use of locally available feeds, was adapted initially in the present study.

8.1.2 FEEDING AND DIET FORMULATION

As stated earlier, one of the major problems in eel culture (of *A. anguilla* and *A. japonica*) occurs in the weaning of glass eels to artificial feed(s). For the purpose of the present study "natural" foods are

considered to be substances occurring naturally, primarily of raw and/or refined foodstuffs of animal origin, that have no processing other than blending or pureeing to a size the glass eels are capable of accepting. "Artificial" foods are manufactured, usually processed in a variety of ways (including heating and pressure) to produce a dry pellet or semi-moist paste with texture different to the natural foodstuffs, and with a taste typically unfamiliar to recently captured glass eels.

The first feeding of glass eels is traditionally done with "natural" feeds. Artificial feeds are reported to result in low growth, decreased survival and large growth variation, the latter leading to size variation or depensation (Applebaum 1980; Kastelein 1983; Heinsbroek 1989; Heinsbroek and Kreuger 1992). Artificial feeds (still with a very high proportion of natural, fresh ingredients) are replacing an increasing part of the *Tubifex* spp. traditionally used for the first feeding of *A. japonica* glass eels. These feeds are reported to give a survival of 70-90% and a growth comparable to a *Tubifex* diet, both a necessity in view of glass eel prices of 2000-4000 US$/kg (Heinsbroek 1991; Heinsbroek and Kreuger 1992)[1]. The first feeding of *A. anguilla* glass eels mainly consists of fish roes, in particular cod roe from *Gadus morhua* L, which is well accepted, resulting in uniform growth and high survival, initially. First feeding to artificial feeds subsequently results in a lower survival and a large variation in growth, attributed to non-acceptance of the feed by a large proportion of glass eels. Relatively little is known about the utilisation of artificial feeds by glass eels (Heinsbroek and Kreuger 1992), although such practice is widespread in the industry both in Asia and Europe.. The present study aims to target the problem of first feeding with regard to *A. australis*. Following successful weaning on to artificial diets the effects of different feeding regimes, diet types, weaning times and water temperature on the growth and survival of glass eels and elvers were determined under intensive conditions.

Body composition studies are useful in determining nutrient utilisation in both wild and cultured fish, and in the determination of appropriate artificial diet formulations. Also, composition studies can be used in setting marketability standards for cultured fish (Degani and Gallagher 1995). When trying to formulate a commercial feed for cultured carnivorous fish, dietary protein component has a special significance both quantitatively and qualitatively. Therefore, establishing the dietary protein requirements (minimum protein level that produces maximum growth) is an obligatory first step in diet formulation. While it is not in the scope of this study to determine such requirements, or to ascertain optimum levels of any other facets of diet composition, limited analysis of food and eels have been conducted to establish the levels of fats, protein, ash and moisture. These levels are then used for comparison with *A. anguilla, A. japonica*, and *A. rostrata*.

8.1.3 WATER QUALITY

Water quality includes all the physical, chemical, and biological variables that affect growth. Routine monitoring of water quality and management procedures in aquaculture aim at providing acceptable chemical and biological conditions for fish to live in. Generally, it is agreed that if the quality of the water is optimal, cultured eels will be healthy and grow relatively fast. If water quality is poor, eels will be unhealthy and grow poorly (Usui 1991). Among the major constraints in intensive aquaculture are the depletion of oxygen (DO) and the accumulation of ammonia and other toxic products of metabolism (Boyd 1990). Dissolved oxygen is the most critical and limiting factor in intensive aquaculture, and was monitored constantly in these trials, and never allowed to fall below 5 mg/l. Levels as low as 4 mg/L did not affect the growth of *A. anguilla* glass eels, so it is unlikely it never became a limiting factor for *A. australis* glass eels studied here.

The negative effect of a constantly high ammonia concentration on the growth of eels (Degani and Gallagher 1995; Degani *et al.* 1988; Knights 1989) is well documented. It is the major waste product of protein or nitrogenous metabolism in fish and other aquatic organisms. TAN (Total Ammonia - as Nitrogen) in aquaculture is positively correlated to the feeding rate (Boyd 1990) and

[1] Industry sources recently reported *A. Japonica* as > AUS $12,000/kg.

stocking density (Degani *et al.* 1988). Consequently when high protein diets are fed to fish stocked at high densities, very high levels of TAN can be expected.

The pH is a measure of the hydrogen ion concentration, and indicates whether the water is acidic or basic in reaction. The desirable range for most aquatic organisms is 6.5 to 9.0, and the preferred range for *Anguilla* is 7.2 - 9.0 (Table 24). The pH is greatly influenced by concentration of carbon dioxide (produced through respiration of organisms), which has an acidic reaction in water, thereby altering pH. Small changes in pH can produce dramatic changes in the proportion of NH_3. In the present study, water quality was maintained at optimum levels in all trials, except where the influence of specific parameters on growth and survival was being studied.

8.1.4 POND CULTURE

The pond culture of freshwater eels under ambient and/or semi-controlled environmental conditions using both glass eels and/or elvers as seedstock is well established in various Asian and European countries (Heinsbroek 1991; Usui 1991; Gousset 1992), albeit under varying degrees of intensity and system design. Production is species and region specific and varies from up to 40,000 tonnes per annum in Japan for *A. japonica* (mostly in greenhouse-covered ponds) to a maximum of 3,000 tonnes per annum in Italy for *A. anguilla* (Heinsbroek 1991).

Commercial pond production of *A. australis* to date, has been limited to stock enhanced wild fisheries in Victoria and Tasmania in which extensive grow-out of translocated elvers and sub-adult eels is practiced in natural wetlands, lakes and farm storages (eg. Sloane 1984b, 1984c, 1984d; Hall *et al* 1990; Skehan and de Silva 1998).

In the latter situation yields have been reported as ranging from < 3kg/Ha to 40 kg/Ha and are broadly consistent with yields reported for other such wild fisheries around the world (Skehan and de Silva 1998). Furthermore, the latter study shows that fish yields are related to stocking rates, particularly with "restock" eels. Specifically Skehan and de Silva (1998) established that fish yields increased linearly with the stocking rate of restock eels and that small lakes can be stocked at relatively high densities (compared with natural levels) to achieve high yields.

The use of semi-intensive pond culture techniques for *A. australis* in managed, purpose built systems has been trialed experimentally in New Zealand (Jones *et al* 1983), and although such a practice was concluded to be technically feasible, it was not economically feasible when considering production costs and market imperatives of the day. It is assumed therefore that the lack of commercial eel aquaculture development in New Zealand is partly as a result of these findings. Nonetheless, the New Zealand trials showed that semi-intensive pond cultured shortfin eels using glass eel seedstock could be grown in commercial quantities to a harvestable size of 150-200g in 12-18 months (Jones *et al* 1983).

The experiments presented here deal specifically with the pond rearing aspect of weaned glass eels and/or elvers over three growing periods, commencing in the southern summer of 1995 until the winter of 1997. The objectives of these experiments were to describe the growth and survival of eels reared in fertilised earthen ponds, with and without supplementary feeding. Diets during these experiments were provided by naturally occurring organisms in all ponds, and supplementary feed in the form of an artificial eel diet in some ponds only.

A schematic summary of the conceptual approach adopted as part of the experimental culture component of the project is presented in Figure 25. The actual trials undertaken in the present study focused on the nursery phase, predominantly glass eel culture and to a lesser extent elver culture.

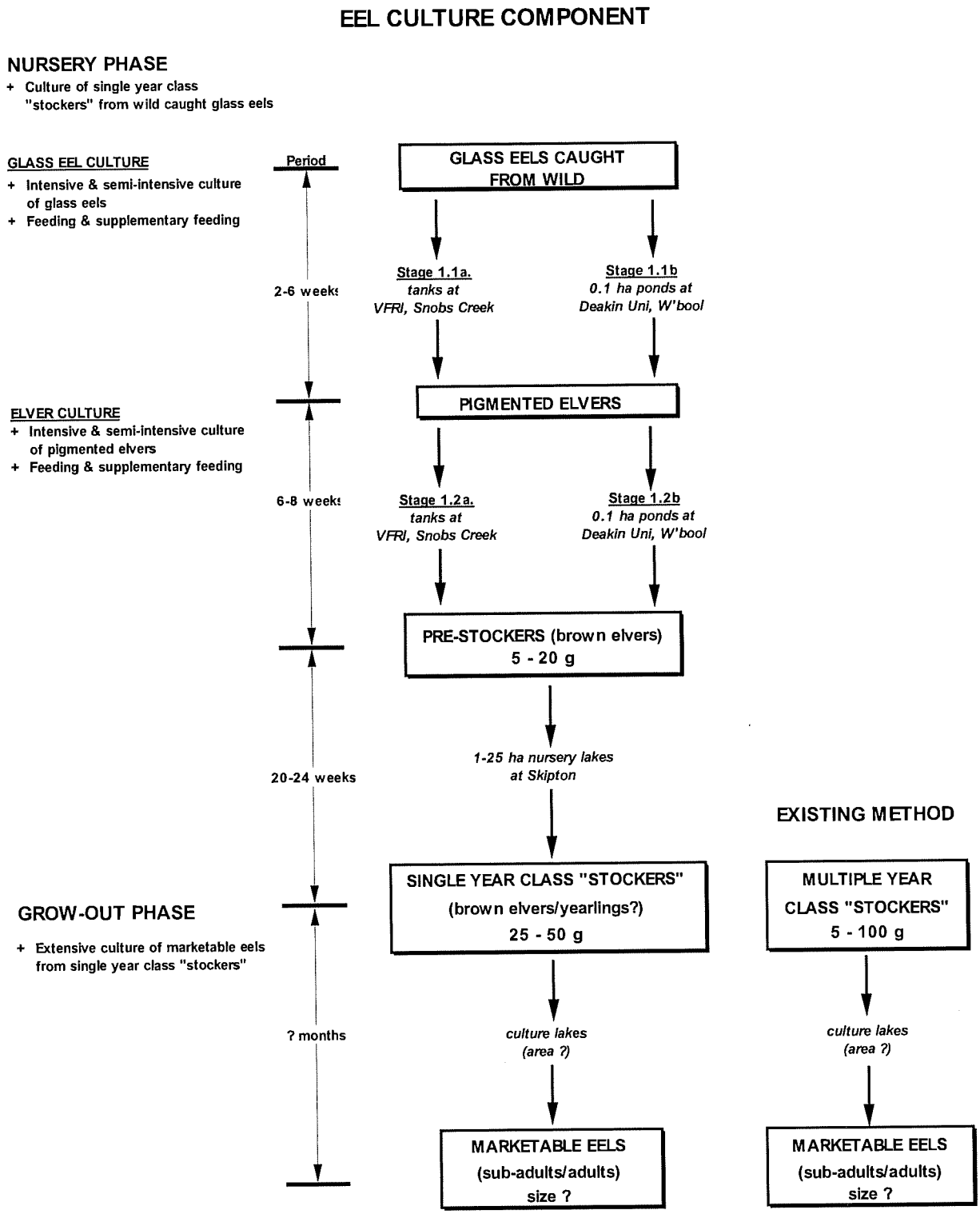


Figure 25 Schematic summary of the conceptual approach adopted as part of the experimental culture component of the project

8.2 MATERIALS AND METHODS

8.2.1 TANK CULTURE TRIALS

Collection and transport of glass eels

All glass eels used in experiments were obtained from surveys conducted as part of this study. See Section VI of this report for a description of collection and handling methods employed in the field. A summary of sites from which glass eels were collected for culture trials is presented in Table 8. In addition a small number of elvers were supplied by the Inland Fisheries Commission, Tasmania, collected from the Tamar River at Trevallyn Power Station in Launceston. Eels were transferred to MAFRI, Snobs Creek in sealed plastic bags containing a small amount of water collected from the point of capture, and inflated with Oxygen. These bags were placed into an insulated box containing a freezer block to maintain low temperatures (<10^{o}C) during transport.

On arrival at MAFRI, Snobs Creek, glass eels were generally placed in a quarantine system and allowed to acclimate to the hatchery conditions. During acclimation, a period of up to 5 days, the temperature in which the eels were being held was gradually increased to 20-25°C and the salinity was reduced from 5 - 10 g/l to freshwater. In addition, the tanks were covered with black plastic to reduce light intensity. This was gradually remove to increase light intensity to normal hatchery conditions.

Table 8 Summary of sites from which glass eels were collected for culture at MAFRI Snobs Creek

Locations captured	Date	Trial utilised in
Barwon R. (Vic.)	Oct. 1994	Trials 1 and 2
Tamar R. (Tas.)	Oct. 1994	Trials 1 and 2
Snowy R. (Vic.)	Aug. 1995	Trial 3
Tarwin R. (Vic)	Aug 1995	Trial 6
Snowy R. (Vic.)	Aug-Sep 96	Trials 4, 5 and 7
Tamar R. (Vic)	Nov 96	Trial 8 and 9

Facilities

All tank-based experiments were conducted indoors under controlled environmental conditions at MAFRI, Snobs Creek. Initial observations undertaken during the first two months of the project were undertaken with small numbers of glass eels held in 20 l static glass aquaria. All subsequent experiments were conducted in 160 l circular fibreglass tanks (Figure 26), which were maintained at a volume of 100 l, supplied with a continuous flow of water at a constant temperature (20-25°C) (depending on experimental requirements), at a rate of approximately 1-5 litres/minute, and with supplementary aeration. Water supply was from either a continuous flushing system or a recirculation system. In both cases the water was filtered (mechanical and biofiltration), heated to the desired temperature (20-25°C) and sterilised (UV light) before being used. Drainage was via a centrally located outlet covered with mesh to prevent escapement. To help prevent the screening mesh from blocking, the surface area of the screen mesh was increased by placing a 'standpipe' (a 900 mm length of 50 mm stormwater grade PVC with 20 mm by 60 mm vertical slots) covered in 350µm or 800µm mesh in each tank, depend on size of eels. These standpipes were sealed at the base and protruded approximately 100 mm from the water surface. They performed well as an outlet, preventing blockages, provided they were cleaned twice daily. The sleeve of mesh placed over the standpipe was replaced with larger aperture mesh as the eels grew.

The glass eels of *A. anguilla* and *A. japonica* are reported to be able to escape by climbing moist vertical surfaces (aquaria and tanks) (Heinsbroek and Kreuger 1992; Kuhlmann and Koops 1980).

To prevent escape, each tank and culture unit was either fitted with a horizontal lip, or the distance between the top of each tank and the water level was maintained at a minimum of 250 mm. In addition, to prevent escape of eels from the hatchery, screens were placed on all outlets leading from the building in which the trials were being conducted.

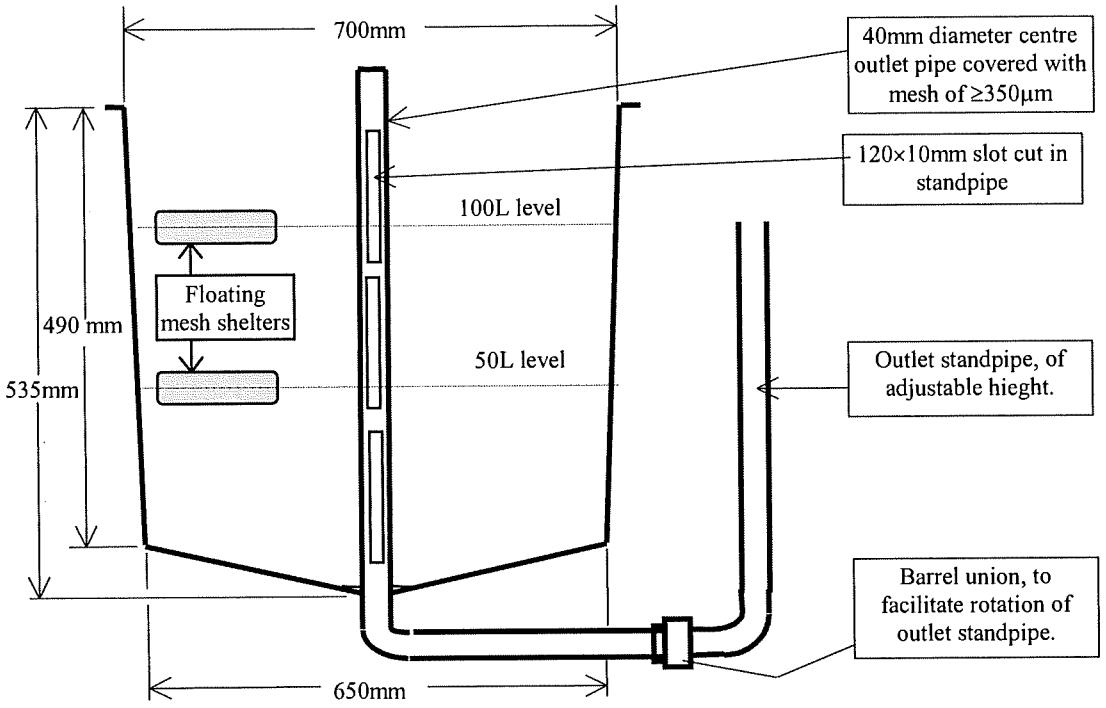


Figure 26 Cross section of 160 l fibreglass tanks used in eel culture experiments at MAFRI Snobs Creek.

Experimental design

For each treatment being tested, three tanks (replicates) were used in all experiments. Allocation of a treatment to each tank was randomised to avoid any inherent bias associated with tank position. Each tank was provided with a floating resting platform for the eels (5 mm or 10 mm aperture black polypropylene mesh attached to a rectangular PVC float), which tended to accumulate out of the water on the platforms when not actively feeding. Moist feeds (pastes etc) were placed directly onto the resting station for feeding. All fish were fed by hand, according to set feed rates, 2-4 times daily (or according to experimental requirements). Feeding rates ranged from 5% to 12% (dry feed weight) of body weight per day (unless a variable being tested), and were adjusted after calculation of the increase of weight after each set of measurements. All tanks were cleaned daily; excess food and faecal material was removed, the sides and floor were wiped clean.

Apart from specific experimentation to test optimal stocking densities, the biomass of eels used in tank during each trial largely depended on the number of eels available at the time. To prevent crowding affects, however, initial stocking densities were generally kept below 10 kg/m^3.

Sampling and measurement of eels

Total biomass of each tank was determined by wet weighing as a group, all eels allocated to that tank. Eels were removed from the tank, excess water was drained from the eels which were then were placed in a beaker on a balance and the weight recorded to the nearest 0.1 g. After allocation of eels to tanks, random samples of 10-30 individual fish from each tank were anaesthetised and measured.

Sedation of glass eels was achieved using 15-25 mg/l Marinal (Syndel, Canada). In the initial experiments the total length (most anterior part of the nose to the most posterior point of the tail) was measured to the nearest 0.1 mm using vernier callipers, the body depth immediately anterior of the dorsal fin was measured to the nearest 0.01 mm using a dissecting microscope fitted with a calibrated eyepiece micrometer, and weight (Wt) was measured to the nearest 0.1 to 0.001 gram (g) for each eel. Every 1-2 weeks during each trial a random sample of 20-30 individual eels were weighed from each tank. Throughout the trial fish mortalities were recorded daily. At the termination of each trial, the total fish biomass in each tank, and individual weights of 20-30 eels from each tank, were measured.

Although measurement of body depth was initially undertaken to give an indication of whether or not eels were feeding, this measurement was not subsequently undertaken in later experiments because it was difficult and time consuming to obtain (eels had to be anaesthetised and examined under a dissecting microscope). Measurement of total length was also discontinued in later experiments for similar reasons. For general comparison between treatments, growth in weight was primarily used as the growth parameter of choice for estimates of overall production in the present study.

Pigmentation stages of glass eels and elvers, which were based on those described by Strubberg (1913) and summarised in Table 3 of Section VI. Assessment Component, were routinely recorded for 20-30 eels sub-sampled from each new batch of eels which arrived at MAFRI, Snobs creek and at various times during the study sub-samples of eels.

Feed rates

Throughout this report, feed rates are presented as percentage of wet weight of eels. All feeds rates were calculated for dry weight of feed using the following formula:

$$Feedrate\ (\%) = \frac{Dry\ weight\ of\ feed\ (g)}{Wet\ weight\ of\ eels\ (g)} \times 100$$

Food conversion ratios (FCR)

Food conversion ratios (FCR's) were determined by dividing the total amount of feed delivered to each tank by the increase in weight of fish (wet weight) in that tank for the duration of the trial, as indicated in the following formula:

$$FCR = \frac{\text{Weight of food fed (g)}}{\text{Weight gained by fish (g)}}$$

Specific growth rates (SGR)

Specific growth rates (SGR's), which were expressed as the percentage increase in body weight per day (%/day) or per week (%/week), were determined by using the following formula:

$$SGR = \frac{\ln Wt - \ln Wo}{t} \times 100$$

where: t = Final time in days (for %/day) or final time in weeks (for %/week)
$lnWo$ = natural logarithm of the average weight at time zero
$lnWt$ = natural logarithm of the average weight at time t.

Water quality analysis
Water temperature was measured using a Datataker 100 data logger (single probe positioned in one tank) which measured temperature every 15 minutes and logged the maximum and average of these measurements every 24 hours.

Dissolved oxygen (as mg/1) in each tank was measured with a YSI meter, 1-3 times each week. Total Ammonia Nitrogen (TAN) (Nessler Method), total Phosphorus (total P) (Acid Persulphate Digestion Method) and pH were measured 1-3 times per week by collecting a 200 ml sample of water from the discharge drain of each tank and then pooling samples (one from each replicate) for each treatment within the trial. From the pooled samples triplicate readings of TAN, total P, and pH were measured with a Hach DR 2000 or Hach DR 4000 spectrophotometer. In addition, triplicate readings of these parameters were taken of inlet water. Net TAN and net total P were calculated by subtracting the concentration of TAN and total P in the inlet water from concentrations of TAN and total P in the discharge water, respectively.

Data analysis
Analysis of fish growth, SGR, FCR, feeding rates, survival rates and water quality data for each trial were analysed using the SAS General Linear Models Procedure and Tukey's Multiple Range Test (SAS Institute Inc. 1990), following testing for homogeneity using Cochran's Test and log transformation of data wherever necessary. Standard error bars for all graphs were generated from SAS and were equal to two standard deviations of the mean.

8.2.2 POND CULTURE TRIALS

Pond rearing experiments, conducted on weaned glass eels and/or elvers, were carried out at Deakin University, Warrnambool, in southwestern Victoria over three consecutive seasons commencing in the summer of 1995. These eels were initially captured and weaned onto artificial diets under hatchery conditions using techniques described earlier in this report. Experiments were conducted in four, earthen, 0.1 Ha ponds (50m x 20m; average water depth 1.2m; of approximate volume 170m^3). The ponds were netted with 8 cm square mesh net to check bird predation, but had no drainage or aeration.

Pond preparation and monitoring
Prior to stocking, the ponds were emptied by pumping and allowed to dry for a period of three-eight weeks, depending on prevailing weather conditions, for each trial. Two weeks before filling, pond substrates were rotary hoed to a depth of 100-120 mm and subsequently raked smooth with a set of vehicle-pulled, driven-tyne harrows.

All ponds were filled with bore water and were fertilised with both inorganic (ammonium sulphate and mono ammonium phosphate - M.A.P. - at a rate of 20 kg/ha) and organic fertiliser (2 bales of lucerne hay/ha). After the development of an initial algal bloom, at water temperatures between 18°C and 24°C, two weeks was normally sufficient to gain a minimum total zooplankton density of 500 individuals/l. Zooplankton density was maintained at or above this level throughout the trials by monitoring nutrients and plankton levels weekly and adding fertiliser accordingly. The above protocol was similar to that used for Australian native fry rearing ponds at MAFRI, Snobs Creek (Ingram *et al.* 1997).

Water quality parameters were monitored weekly, including surface temperature, Secchi depth (20 cm disc) and pH, ammonia, nitrite, nitrate and total phosphate using the recommended Aquamerck 8027, 1.08024, 1.11118, 11170 and 14661 kits, respectively. Weekly, plankton density of each pond was estimated using a plunger sampler (2 m x 50 mm) and was treated as previously described by Ingram *et al.* (1997). The concentrated plankton samples were identified to the major taxonomic groups (e.g. copepods, cladocerans, rotifers etc.) and counted under a Nikon dissecting microscope (x40).

Culture trials and experimental protocols

Three pond trials were conducted over three consecutive years, from 1995 to 1997. All trials compared growth and survival of eels initially stocked as pigmented glass eels (of differing sizes and density each year) and fed either naturally on zooplankton only, or with a supplementary artificial feed also. A summary of each trial including commencement dates, initial size and number of eels is presented in Table 9. During each trial a random sub-sample of eels from each pond was collected using tea-tree refuges placed into the ponds for this purposes. The sub-sampled fish were anaesthetised in benzocaine (1:10,000) and the body weight and length of a minimum of 30 randomly selected individuals from each pond were determined to the nearest 0.1 g and 1 mm, respectively. In addition, the same data were obtained for the 20 biggest individuals at the final harvest of each pond (note that the larger, faster growing eels tended to be more difficult to sample during the trials).

Supplementary feeds, consisted of a powdered formulation (Taiwanese origin; crude protein 49.5%, lipid 8.9%, ash 12.6%, NFE 29.0% by dry weight), which was made into a paste by adding small quantities of lukewarm water at a time until the correct consistency of a smooth, doughy paste was achieved. A weighed amount of this paste (approximating 5% of the biomass of stocked eels) was presented daily in a floating prawn crate, and the young eels were able to access the food through the meshes of the crate or by moving physically into the crate through the mesh. At each weighing, the amount of food to be presented for the ensuing two week period was adjusted according to the mean weight of the sampled eels (and assuming nil mortality).

At the end of each trial the ponds were drained and the eels harvested. In the laboratory the number of eels from each pond and the total surviving biomass were determined. A sub sample of eels from each pond was anaesthetised and individual lengths and weights were determined as previously; the same being done on the biggest 30 eels from each pond.

Data analysis

Analysis of fish growth in weight, SGR and survival rates were analysed using the SAS General Linear Models Procedure and Tukey's Multiple Range Test (SAS Institute Inc. 1990), following testing for homogeneity using Cochran's Test and log transformation of data wherever necessary. Standard error bars for all graphs were generated from SAS and were equal to two standard deviations of the mean.

Table 9 Summary of pond rearing experiments conducted in 0.1 ha ponds at Deakin University, Warrnambool from 1995 to 1997.

	Diet supplemented with artificial feed		**Natural diet only**	
Trial 1				
Date stocked	20 February 1995		20 February 1995	
Duration (weeks)	10		10	
Pond No. stocked	2	3	1	4
Number eels stocked per pond	1,500	1,500	1,500	1,500
Initial mean size (g)	0.69	0.69	0.69	0.69
Trial 2				
Date stocked	21 November 1995		21 November 1995	
Duration (weeks)	21		21	
Pond No. stocked	2	3	1	4
Number eels stocked per pond	4,820	4,840	4,830	4,840
Initial mean size (g)	0.42	0.44	0.38	0.39
Trial 3				
Date stocked	25 November 1996		25 November 1996	
Duration (weeks)	24		24	
Pond No. stocked	3	4	1	2
Number eels stocked per pond	4,920	6,920	5,120	5,687
Initial mean size (g)	0.22	0.19	0.23	0.17

8.3 RESULTS

8.3.1 TANK CULTURE TRIALS

8.3.1.1 ESTABLISHMENT OF BASIC HUSBANDRY TECHNIQUES AND INITIAL PRE-WEANING FEEDING OBSERVATIONS

At the time of commencement of the present study there was no information available on the basic handling and husbandry techniques for *A. australis* glass eels. Therefore during the early part of the first season, efforts concentrated on development of basic husbandry techniques.

The first consignment of approximately 200 glass eels (Stage 0 - VIAIII) arrived at MAFRI, Snobs creek on 6 September 1994. These eels were transferred directly into static glass aquaria containing freshwater. No mortalities or abnormal behaviour were observed during this process which suggested that glass eels do not need a prolonged acclamation period.

As a precaution against the introduction of diseases to MAFRI, Snobs Creek, all glass eels upon arrival were given a prophylactic treatment of 10g/l salt (NaCl) and/or 0.2 ppm malachite green for 60 minutes.

Most literature on *A. anguilla*, *A. japonica* and *A. rostrata* glass eels indicates the need to break the "fast" of non-feeding glass eels soon after capture by establishing them on a natural diet before, before subsequently weaning to a pre-manufactured artificial diet. These natural diets have included *Tubifex*, minced fish flesh, minced earthworms, cod roe, and ox liver (Heinsbroek 1991; Heinsbroek and Kreuger 1992; Kamstra and Heinsbroek 1991; Rickards *et al.* 1978). Preliminary observations made on *A. australis* in the present study indicated that newly caught glass eels needed to break the "fast" by undergoing a weaning phase on natural feed before they commenced feeding on an artificial diet.

In order to investigate initial feeding, groups of 100 glass eels were stocked into three separate 20 l glass aquaria filled with 10 l of static, aerated water with a 50% exchange in water daily. The water was held at 20^{0}C and folded plastic mesh with an aperture diameter of 1.0 cm was floated in each aquaria to serve as a resting and feeding platform. A different diet was fed to each tank. These were live, newly hatched *Artemia* (brine shrimp), paste (trout fines plus 50% water by weight) and a ox liver/paste mix (50% trout fines/50% Ox liver by weight). Newly hatched *Artemia* nauplii (Aquafauna, Bio-marine) , were 350-400μm in length at the time of feeding to glass eels. After two weeks the group being fed on *Artemia* was split into two groups. One group remained on *Artemia* while the other was fed freshly minced fish (trout) flesh. No statistical analysis was carried out on the data collected.

Results and discussion

Weekly total length and body depth measurements (Figure 27; Table 10) and survival rates (Figure 28; Table 10) indicated that glass eels fed on *Artemia* and minced fish flesh grew more rapidly and mortalities were less than for eels fed on the other two diets after 47 days. Observations of gut contents indicated the majority (>60%) of those glass eels being provided paste or ox liver/paste mix were not eating. This was also reflected in survival rates of the glass eels fed on paste or liver/paste mix, as after approximately 20 days the rates of mortalities of these two groups increased (Figure 28). These results indicated that *Artemia* or minced fish flesh may be suitable diets for the initial feeding of *A. australis* glass eels in captivity, before attempting to wean to an artificial diet.

During this trial, the glass eels effectively utilised the floating mesh as a habitat which was also used as a feeding station. The plastic mesh was subsequently used in all future experiments. The vertical sides of the aquaria were sufficient to prevent eels from escaping, provided that the water level was

kept low and the sides of the aquaria kept clean and dry. The eels were unable to climb further than approximately one body length from the water surface.

In the initial 2-3 days of the trial the glass eels hid in the floating mesh away from light and movement. However, in subsequent days eels became more mobile, swimming away from the mesh for greater periods. The aquaria in which eels were fed with the paste and liver/paste mix became cloudy with suspended food particles approximately 10 minutes after the placement of food on the mesh. In these aquaria it then became necessary to replenish 50% of the water within an hour of feeding to partially clear the water, and decrease the risk of disease (Kastelein 1983).

Most literature on *A. anguilla* and *A. japonica* glass eels indicates the need for glass eels to be first adapted to a "natural" food, and be feeding readily on it (Usui 1991; Heinsbroek 1989; Heinsbroek and Kreuger 1992). From about 20 days onwards, the mortalities in *A. australis* glass eels fed either paste or liver/paste mix increased, while few fed on either *Artemia* or minced fish flesh died (Figure 27). This is consistent with reports in literature that glass eels should not be fed an artificial diet without first undergoing a weaning period to a natural diet.

Table 10 Initial and final (day 47) mean length, body depth, and survival rates of glass eels fed four different diets.

PARAMETER	**DIET**			
	Artemia	Ox liver/ trout fines	Trout fines	Fish mince
Total length (mm)				
Initial (mean ± s.e.*)	58.9 ± 0.4	58.9 ± 0.4	58.9 ± 0.4	58.9 ± 0.4
Final (mean ± s.e.)	61.6 ± 0.79	58.2 ± 0.49	58.0 ± 0.66	60.9 ± 0.69
Body depth (mm)**				
Initial (mean ± s.e.*)	3.03± 0.10	1.66 ± 0.04	1.75 ± 0.03	2.17 ± 0.05
Final (mean ± s.e.)	2.93 ± 0.06	1.61 ± 0.09	1.99 ± 0.10	2.76 ± 0.07
Survival (%± s.e.)	93.1 ± 3.14	52.8 ± 2.2	38.9 ± 3.2	98.4 ± 0.05

* s.e. = standard error.

** measured from day 19

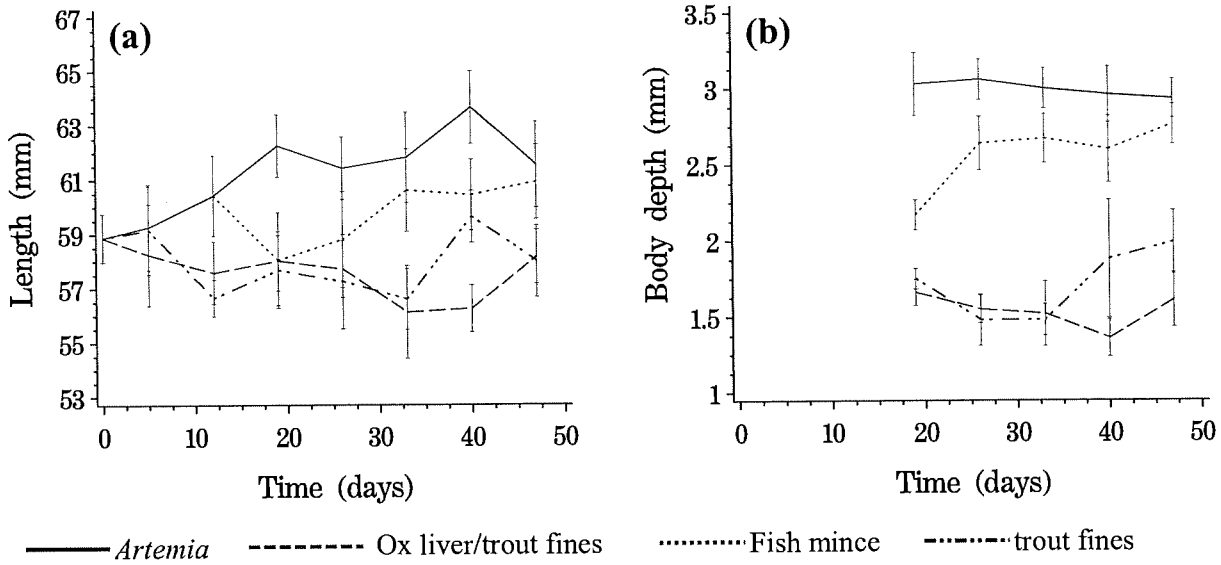


Figure 27 Changes in (a) total length and (b) body depth of glass eels fed four different diets during a preliminary trial conducted in glass aquaria (mean ± standard error).

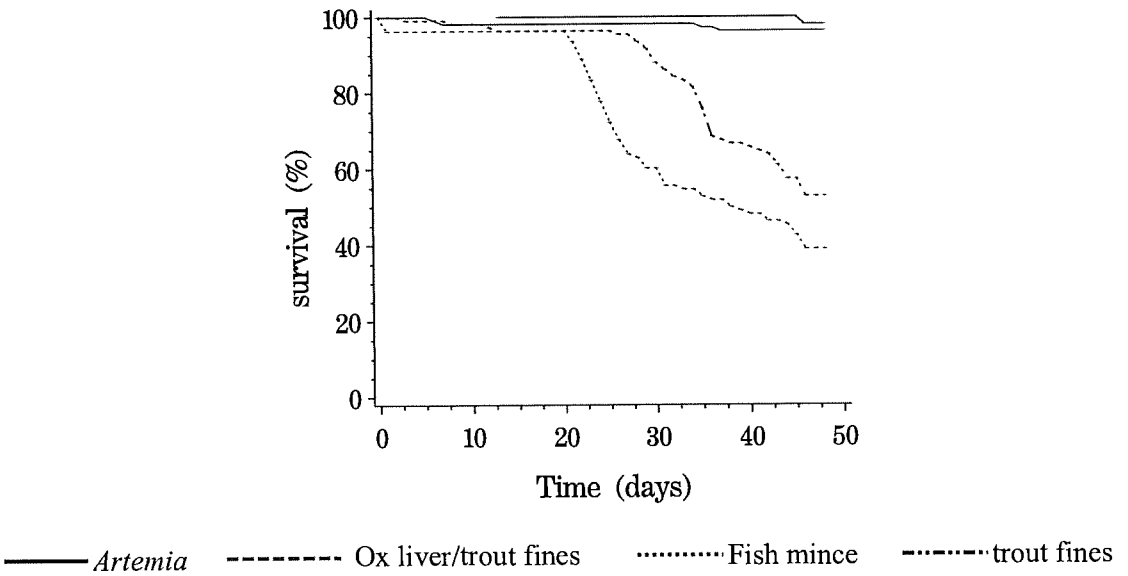


Figure 28 Survival rates of glass eels fed four different diets during a preliminary trial conducted in glass aquaria.

8.3.1.2 TRIAL 1: FIRST/PRE-WEANING FEEDING

Introduction

Initial feeding of artificial feeds is reported to result in low growth, large growth variation and, associated with the resulting size variation, a decreased survival (Applebaum 1980; Kastelein 1983; Heinsbroek 1989; Heinsbroek and Kreuger 1992) The first feeding of *A. anguilla* and *A. japonica* glass eels is traditionally done therefore with natural feeds such as, cod roe, fish flesh, *Tubifex* and minced earth worms (Heinsbroek and Kreuger 1992; Usui 1991; Rickards, *et al.* 1978). Following preliminary observations made with initial feeding trials (Section 8.3.1.1), it appeared that *A. australis* glass eels also require a natural diet for first feeding. In order to find the best food for initial feeding of *A. australis* glass eels, Trial 1 set out to determine if *Artemia*, minced fish flesh, or a blend of the two, was the most suitable for feeding, prior to commencement of weaning to an artificial diet.

Material and methods

Glass eels, which were collected from the Tamar River (Stage VB - VIAIII) and fed three diets were selected, live *Artemia* nauplii (350-400μm TL), minced fish flesh (trout) and a 1:1 mix (by weight) of *Artemia* and minced fish flesh. Three replicates were used for each diet. Eels were placed into 160 l experimental tanks as described in Section 8.2, which were maintained at a temperature of 20°C and provided with a constant flow (2-5 l/min.) and aerated. Eels were fed to satiation six times per day, at approximately 0730, 0930, 1130, 1330 1530 and 1800 hrs.

Results and discussion

At termination of the trial (15 days post commencement) eels fed either fish mince or a mixture of *Artemia* and fish mince were significantly greater in weight (day*diet interaction: $F_{2,6}$ = 5.44; P=0.045) and body depth (day*diet interaction: $F_{2,6}$ = 11.39; P = 0.0091), but there was no significant difference in total length (day*diet interaction: $F_{2,6}$ = 3.52; P= 0.0973) for diet (Figure 29). Specific growth rates (SGR) ranged from 0.6 to 2.2 %/day (Table 11), however no significant difference between SGR's was detected ($F_{2,6}$ = 2.17; P = 0.1953).

Survival rates were significantly different for each diet ($F_{2,6}$ = 6.40; P=0.0325). Mean survival was 93% or greater for eels fed either fish mince or a mixture of fish mince and *Artemia*, but survival of those fed *Artemia* dropped rapidly after the first week to 52% by the end of the trial (Figure 30; Table 11). Infestations of the protozoan parasites *Ichthyobodo* and *Trichodina* on eels being fed *Artemia* only may have contributed to the poor survival rate and reduced growth (total length, weight, body depth) of this group of eels. Few parasites were observed on moribund eels from tanks receiving other diets. These parasites were subsequently eradicated by standard chemical treatments applied at the MAFRI, Snobs Creek (see Section 8.3.1.11).

In Europe and Japan artificial feeds are reported to result in low growth, growth variation, associated with the resulting size variation, a decrease in survival in *A. anguilla* and *A. japonica* glass eels (Appelbaum 1980; Heinsbroek 1989; Heinsbroek and Kreuger 1992). Of the three natural diets used in this trial the mixture of *Artemia*/minced fish flesh (SGR: 2.2%/day), and minced fish flesh (SGR: 1.2%/day), produced the best growth, which were comparable to, or better than those recorded previously for *A. anguilla* and *A. japonica* (Appelbaum 1980; Heinsbroek 1989; Heinsbroek and Kreuger; 1992).

The amount of uneaten food was difficult to monitor, and may have had an effect on growth rates as the amount of food available varied between diets. The lower growth rate for *Artemia* fed glass eels may have resulted from lower feed availability; a consequence of the mobile nature of the nauplii enabling escape through the screens. Consequently, the *Artemia*/minced fish flesh and minced fish flesh diets used in the trial, disintegrated at different rates, producing variable amounts of available food, and may have resulted in inconsistent, or lower than optimal growth rates for the diet disintegrating most rapidly.

Observed gut contents indicated the percentage of glass eels feeding throughout the trial was 95% for all three groups. This indicated that *Artemia*, *Artemia*/minced fish flesh mix and the minced fish flesh

were all palatable to *A. australis* glass eels. A more thorough investigation including monitoring the amount of uneaten food, the rates of disintegration of the different diets in water, the time taken to consume the portion of food per feed, and the weight and composition of faecal waste, is required. This would help indicate whether the glass eels eating the *Artemia*/minced fish flesh mix were receiving a more nutritionally beneficial diet per unit weight of food, whether they were eating greater amounts before the food became unavailable as a result of removal after routine cleaning while cleaning, whether the food was lost through the outlet screens, or became unpalatable after a set period of time.

SGR's are influenced by mortalities, as non-feeding fish begin to die. Sixty to ninety percent of mortalities during the weaning of *A. anguilla* and *A. japonica* occur between the second and third month after stocking and are caused by non-acceptance of feed and subsequent starvation (Degani and Levanon 1983; Kastelein 1983; Degani *et al.* 1986; Heinsbroek 1989). The average weight of the remaining stock increases as a result of the removal of these individuals, artificially increasing the SGR of the remaining stock. This effect was not observed in this trial due to it lasting for only 15 days. Deaths were recorded during the trial but these were attributed to infestation by protozoan parasites *Ichthyobodo* and *Trichodina* rather than starvation, though loss of weight by non-feeing eels would have reduced the overall SGR of the remaining stock.

As a result of this trial, minced fish flesh was chosen as the initial diet for glass eel upon arrival at MAFRI, Snobs Creek., prior to weaning onto artificial diets. Maintenance and growth has been achieved for *A. anguilla*, *A. japonica*, *A. rostrata*, and *A. bicolor pacifica* on a fish flesh diet (Cremer 1976; Heinsbroek 1991; Rickards *et al.* 1978; Usui 1991), and was also observed in this trial. Minced fish flesh is easier and cheaper to obtain than *Artemia*. Although *Artemia* are routinely used to feed a wide range of larval and juvenile fish, the cost associated with purchasing *Artemia* cysts made the extensive use of these as a first feeding diet was attractive, and aquaculture enterprises would not have to install special equipment to hatch *Artemia*.

Artificial feeds, still with a very high proportion of natural, fresh ingredients such as fresh fish, squid and/or krill fed either frozen or thawed, are reported to be replacing natural diets, such as *Tubifex* spp. (Oligochaeta), traditionally used for the first feeding of *A. japonica* glass eels (Heinsbroek 1991). These feeds are reported to give a survival of 70-90% and a growth comparable to *Tubifex* spp. when used in the first feeding of *A. japonica* (Heinsbroek and Kreuger 1992). No experiments on the weaning of *A. australis* glass eels directly to commercially manufactured first feeding diets, have yet been reported. These would be required to assess the acceptance of these feeds.

In Europe the preferred diet for the initial feeding of newly caught glass eels of *A. anguilla* is cod roe (Heinsbroek 1991). Unfortunately, this diet is not available in Australia, however, future experiments should determine if there are readily available, alternative, sources of fish roe which may provide a suitable natural starter feed for the glass eels of *A. australis*.

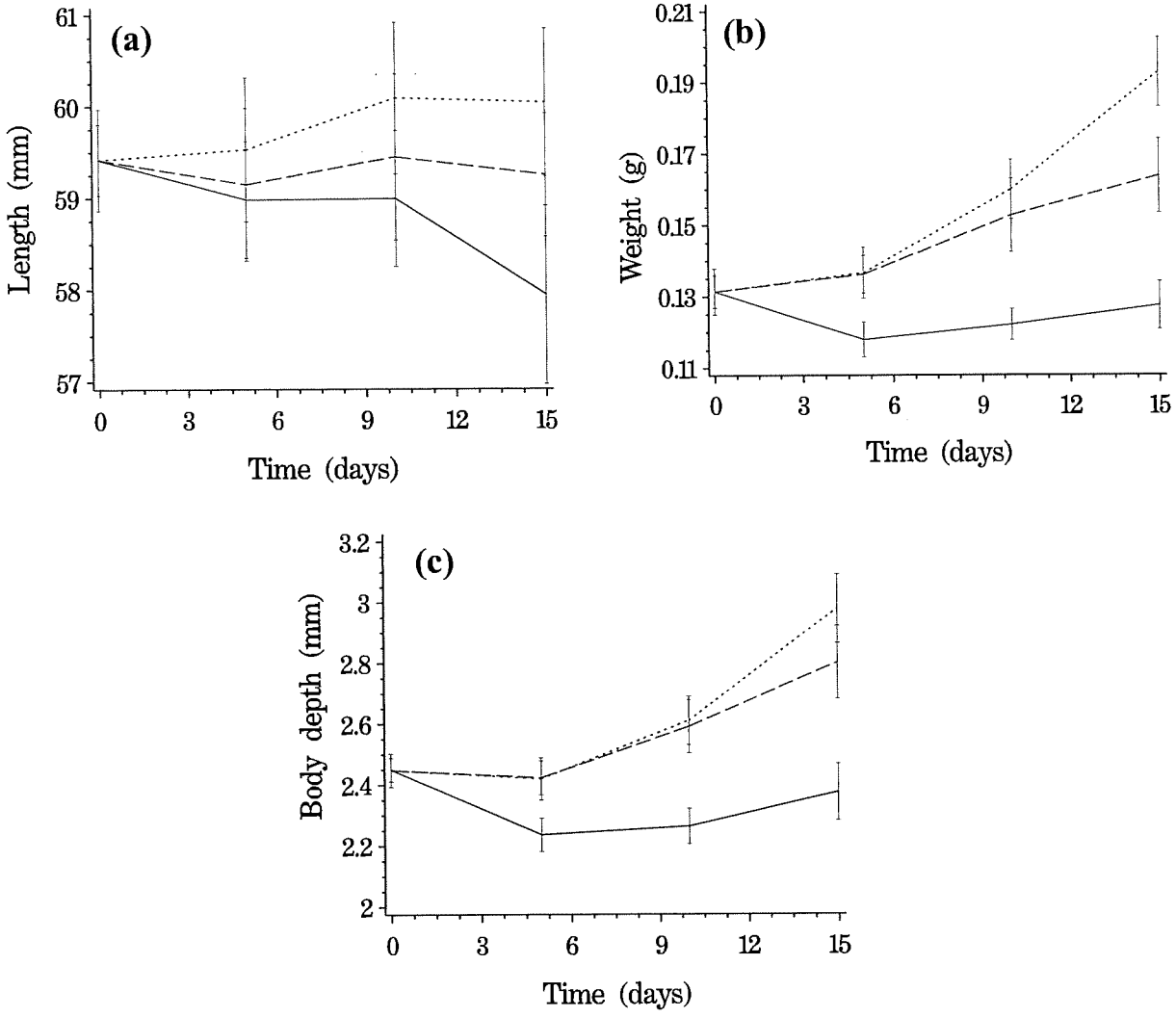


Figure 29. Changes in (a) total length, (b) weight and (c) body depth of glass eels fed three different diets during Trial 1 (mean ± standard error bars).

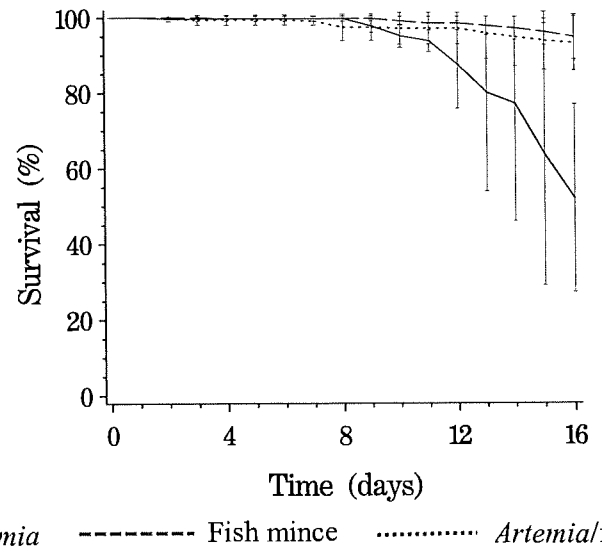


Figure 30 Survival rates (mean % ± standard error) of glass eels fed three different diets during Trial 1.

Table 11 Initial and final mean weight, total length and body depth, survival rates and SGR of glass eels fed three different diets during Trial 1.

PARAMETER	DIET		
	Artemia	*Artemia*/fish mince	Fish mince
Weight (g)			
Initial (mean ± s.e.*)	0.13 ± 0.002	0.13 ± 0.003	0.13 ± 0.003
Final (mean ± s.e.)	0.13 ± 0.003	0.19 ± 0.005	0.16 ± 0.005
Total length (mm)			
Initial (mean ± s.e.*)	59.4 ± 0.19	59.4 ± 0.28	59.4 ± 0.28
Final (mean ± s.e.)	57.9 ± 0.49	60.0 ± 0.40	59.3 ± 0.34
Body depth (mm)			
Initial (mean ± s.e.*)	2.45 ± 0.02	2.45 ± 0.03	2.45 ± 0.03
Final (mean ± s.e.)	2.38 ± 0.05	2.98 ± 0.06	2.80 ± 0.06
Survival rate (%± s.e.)[1]	52.0 ± 12.4[a]	93.0 ± 3.6[ab]	94.7 ± 3.0[b]
Specific growth rate (%/day ± s.e.)[1]	0.6 ± 0.7[a]	2.2 ± 0.5[a]	1.2 ± 0.4[a]
Specific growth rate (%/week ± s.e.)	4.3 ± 5.1	15.3 ± 3.2	7.5 ± 2.4

* s.e. standard error

8.3.1.3 TRIAL 2: INITIAL WEANING

Introduction

Artificial diets have several advantages over natural diets in the growth of eels including:

a) More convenient to use as cold storage not required and needs less space is needed (Usui 1991).
b) Readily available from commercial suppliers.
c) Relatively easy to incorporate additives such as antibiotics and appetite stimulants.
d) Low incidence of thew bacterial disease edwardselliosis when used (note that there is a poorly understood relationship reported between *Tubifex* weaning diets and the incidence of edwardselliosis) (Gousset 1992).
e) Attractiveness is equal, if not higher than natural diets once accepted (Gousset 1992).

Commercially formulated eel feed mixes are usually produced in powder form and mixed with water and 5-10% oil (by weight) to make a moist paste (Usui 1991). Relatively little is known about the utilisation of artificial feeds by *A. anguilla* and *A. japonica* glass eels (Heinsbroek and Kreuger 1992). As there is no literature on the acceptance and utilisation of artificial foods by *A. australis* glass eels the aim of this trial was to develop a method of weaning glass eels onto an artificial diet.

Materials and methods

Groups of 100 glass eels (0.21 g initial mean wt) were each placed into each of six 160 l fibreglass tanks (See Section 8.2). Eels in three tanks were gradually weaned from 100% minced fish flesh to 100% paste, composed of trout fines (48%), cornflour as a binder (2%), and water (50%). This was achieved by increasing the proportion of paste in the minced fish flesh diet by 20% every three days until complete transition to paste. Eels in the other three tanks were fed with minced fish flesh throughout the trial, which served as a control. During the trial, which lasted for 23 days, water temperature was maintained at 20^0C, a constant flow of water was provided and all tanks were aerated. Eels were fed to satiation six times per day, at approximately 0730, 0930, 1130, 1330 1530 and 1800 hrs.

Results and discussion

By the end of the trial (22 days after commencement) eels fed minced fish flesh only were significantly greater in weight (day*diet interaction: $F_{1,4} = 163$; $P = 0.0002$), total length (day*diet interaction: $F_{1,4} = 33.23$; $P = 0.0045$) and body depth (day*diet interaction: $F_{1,4} = 65.73$; $P = 0.0013$) (Figure 31). Glass eels fed minced fish flesh only had a SGR of 3.6%/day which was significantly greater than the SGR recorded for eels weaned onto paste (1.0%/day) ($F_{1,4} = 182.58$; $P = 0.0002$) (Table 12).

Survival rates were low (77-88%) after 22 days, but were not significantly different for diet ($F_{1,4} = 3.38$; $P = 0.1396$) (Figure 32; Table 12).

Natural diets have consistently produced better average growth rates than artificial diets for *A. anguilla* glass eels (Heinsbroek and Kreuger 1992). The natural diet of minced fish flesh produced a significantly greater SGR than for weaning to a paste composed of trout fry (Table 12). This may be the result of differences in feed utilisation by the glass eels (that is, trout fry crumbles are of less nutritional value to the glass eels than fish flesh), or differences in feed intake (that is, there are fewer glass eels eating, or food intake by the glass eels is lower on the trout fry crumbles than the minced fish flesh diet). More evidence of growth differences resulting in bimodal weight and body depth distributions among the group weaned to paste when compared with the control, or minced fish flesh, would require the duration of the trial to be increased.

Small eels rely largely on olfactory means to locate their food (Knights 1983). Several authors have shown the incorporation of attractants (such as *Tubifex*, chicken blood, minced earthworms, bovine spleen extract and mixtures of synthetic L-amino acids) to artificial food can increase acceptance of the food by *A. anguilla*, *A. japonica* and *A. rostrata* glass eels (Heinsbroek 1991; Heinsbroek and Kreuger 1992; Kamstra and Heinsbroek 1991; Rickards *et al.* 1978). More work is required to

establish if *A. australis* glass eels will grow better on trout fry crumbles with the addition of attractants.

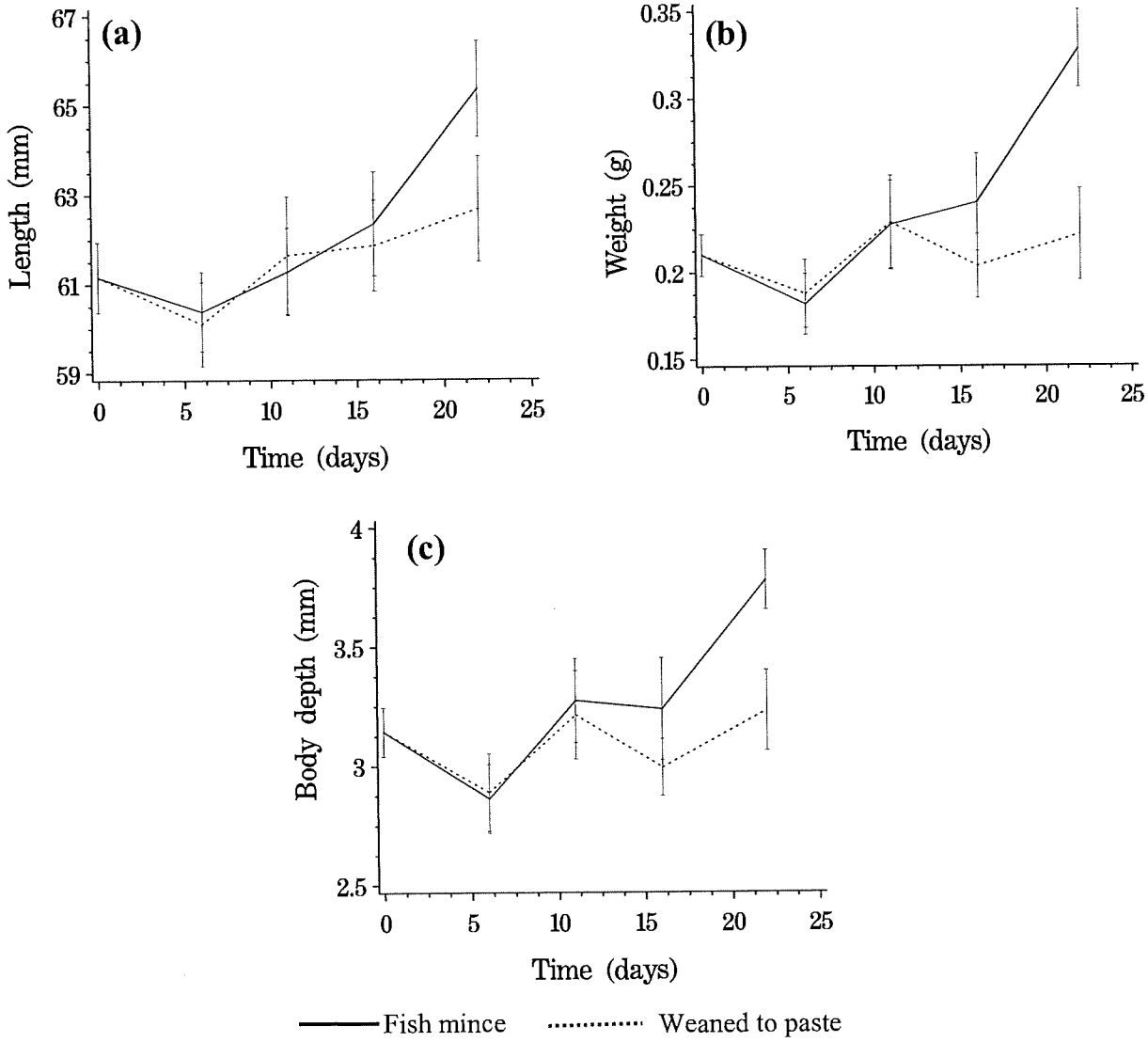


Figure 31 Changes in (a) total length, (b) weight and (c) body depth of glass eels fed two different diets during Trial 2 (mean ± standard error bars).

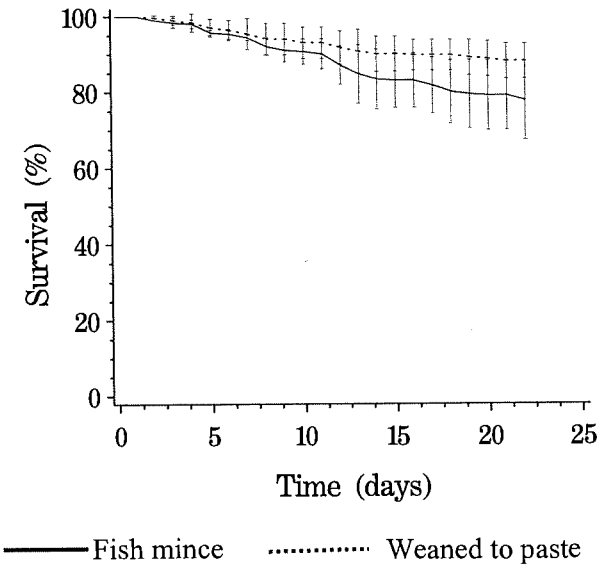


Figure 32 Survival rates (mean % ± standard error bars) of glass eels fed two different diets during Trial 2.

Table 12 Initial and final mean weight, total length, and body depth, survival rates and SGR of glass eels fed two different diets during Trial 2.

PARAMETER	DIET	
	Fish mince	Weaned to paste
Weight (g)		
Initial (mean ± s.e.*)	0.21 ± 0.01	0.21 ± 0.01
Final (mean ± s.e.)	0.33 ± 0.01	0.22 ± 0.01
Total length (mm)		
Initial (mean ± s.e.*)	61.2 ± 0.39	61.2 ± 0.40
Final (mean ± s.e.)	65.4 ± 0.54	62.7 ± 0.59
Body depth (mm)		
Initial (mean ± s.e.*)	3.14 ± 0.05	3.14 ± 0.05
Final (mean ± s.e.)	3.78 ± 0.06	3.23 ± 0.08
Survival rate (%± s.e.)[1]	77.7 ± 5.2[a]	88.0 ± 2.3[a]
Specific growth rate (%/day ± s.e.)[1]	3.6 ± 0.2[a]	1.0 ± 0.1[b]
Specific growth rate (%/week ± s.e.)	25.3 ± 1.3	7.0 ± 0.5

* s.e. standard error

1. Treatments with the same letter (superscript) are not significantly different from each other (Tukey's multiple range test)

8.3.1.4 TRIAL 3: WEANING DIET AND RATE OF WEANING

Introduction

Eel farmers and researchers have traditionally weaned glass eels from natural to artificial diets under different weaning regimes to accustom them to the new taste, texture, and freshness of the new food (Rickards *et al.* 1978; Heinsbroek 1989; Heinsbroek 1991; Gousset 1992; Usui 1991). In commercial fish-farming operations survival from glass eel to the fingerling stage is estimated to be only about 30 to 50% (Kamstra and Heinsbroek 1991), although recent industry advice suggests this rate is improving. A small increase in glass eel survival and/or growth are a necessity to increase profitability of eel farms, as a major cost is the purchase of glass eels (Heinsbroek 1991).

Heterogeneous growth, cannibalism and starvation, are the results from poor weaning to artificial diets. Trial 3 aimed to determine the optimum time period required for weaning glass eels to an artificial diet, and to trial a commercially available grower paste against trout fines (prepared as a paste) and fish flesh as a weaning diet.

Materials and Methods

Two diets were selected, eel grower paste (a commercially formulated eel grower paste supplied by the feed Manufacturer Primo), and fines (48% trout fines, 2% binder and 50% water by weight, pureed in a blender), against a control group fed on fish mince. The proportions of water and binder in the pureed trout fines made the consistency similar to that of the grower paste to attempt to reduce differences in palatability. A fast weaning period over five days (ie. a daily 20% increase in proportion by weight of fines or paste) and a slow weaning period over fifteen days (ie. a 20% increase in proportion by weight every three days of fines or paste), from a diet of fish mince to either fines or grower paste, were tested. Three replicate 160 l fibreglass tanks, each stocked with 400 glass eels, were employed for each treatment. During the trial, 10 eels were randomly selected from each tank and measured weekly for weight and length, and mortalities recorded daily. Feeding was reduced to three times daily, as observations from previous experiments indicated food wastage, due to a lack of time between feeds.

During the trial, A suite of water quality parameters were recorded from inlet water and discharge waters for each of the feed types. The trial ran for 35 days, during which water temperature was held at 20^0C provide with a constant flow of water and aerated. Tanks were cleaned and purged daily. Growth, survival and water quality data were analysed according to methods described in Section 8.2.

Results and discussion

Both diet type and weaning period significantly effected growth of glass eels for both length (day*treatment interaction: $F_{4,10} = 24.11$; $P = 0.0001$) and weight (day*treatment interaction: $F_{4,10} = 38.26$; $P = 0.0001$) (Figure 33). Stress of the initial acclimation period of weaning may have effected on the growth of all glass eels, as the length and weight decreased in the first 7 days (Figure 33) for al diets.

SGR (%/day) for eels weaned onto trout fines for both the short and long weaning periods were significantly lower than rates for eel fed either fish mince or weaned onto eel paste ($F_{4,10} = 31.5$; $P = 0.0001$) (Table 13). The highest growth rate was found in the control group (1.9 %/day) whereas fish fed trout fines had negative SGR (-1.2 to -2.1 %/day). Observations on the feeding behaviour of the eels indicated the control group were the most vigorous in their approach to feeding, followed by the grower paste groups, while the fines groups were disinterested in feeding.

There was a significant difference in survival rates ($F_{4,10} = 13.6$; $P = 0.0005$) of eels treated with the five different weaning regimes after 35 days (Figure 34; Table 13). Both groups of eels (slow and fast weaned) fed trout fines were in poor condition and mortalities began to increase after the third week of the trial (Figure 34). Tukey's Multiple Range test indicated that the survival rates for eels weaned on to trout fines using a short weaning period were significantly lower than for all other treatments (Table 13).

No significant differences ($P<0.05$) between inlet and discharge waters, and between discharge waters for each feed rate were observed in most water quality parameters measured during the trial. Net TAN concentration was significantly different for treatment ($F_{2,15} = 5.29$; $P = 0.0182$) (Table 14).

Of the artificial foods *A. australis* glass eels grew better and accepted the commercially available grower paste more readily over 35 days (personal observation), than trout fines made into a paste. The weaning period also had an effect on the acceptance of trout fines, as measured by growth and survival. The acceptance of trout fines by *A. anguilla* glass eels was improved by the addition of attractants, such as cod roe extract, bovine spleen extract, chickens blood and some synthetic amino acids (Brusle 1990; Degani and Levanon 1986; Kamstra and Heinsbroek 1991). The addition of attractants has also been found to significantly improve the conversion efficiency of artificial diets (Kamstra and Heinsbroek 1991; Seymour 1989; Takii *et al.* 1984). As there has been no analysis, as yet, carried out on the grower paste used here it is unknown if it had any of these feeding stimulants, or if some other property made it more attractive to the glass eels than the trout fines. The time taken to wean the glass eels to the grower paste did not make any significant difference to growth (although the average growth of the slow weaned group was consistently higher than the fast weaned group), indicating a daily 20% increase from 0% to 100% in the proportion of grower paste in the diet during weaning is suitable for *A. australis* glass eels.

The control diet of minced fish flesh produced faster growth than either of the artificial diets on both fast and slow wean rates. This is consistent with the results of Trial 2 and with other research on *A. anguilla* and *A. japonica* glass eels Heinsbroek and Kreuger 1992; Gousset 1992). For fish farms the cost of artificial foods is often high, partly justifying the use of low cost, raw fish which have a high nutritional value. Fish such as mackerel, atka fish, saury pike, miscellaneous types of ground fish, tuna, bonito head and fish offal's (Usui 1991) have been used. These come from fish processing and from abattoir waste, and may be used either as a whole or part of the diet to provide a significant decrease in the rearing costs (Brusle 1990). There are a number of disadvantages in the raw fish as food, these include:

-bones are indigestible and fall to the bottom of the pond to accumulate as undesirable waste matter (Usui 1991).

-supplies of fish cannot be guaranteed throughout the year, and cold storage for out-of -season use is very expensive (Degani and Gallagher 1995).

Artificial fish meal-based paste diets are becoming increasingly common (Matsui 1980; Usui 1991; Degani and Gallagher 1995), and have a number of advantages: good storage, handling and dispensing properties (Hasting and Dickie 1972), and fewer undigested organic residues remain on the bottom of the pond (Degani and Gallagher 1995). Health requirements concerning the feeding of untreated animal by-products, and pollution concerns with the use of raw unprocessed materials, would also have to be addressed.

Dry particulate foods are also more stable in water than wet pastes and soft pellets (Knights 1983). No research comparing these three main forms of eel foods necessary to assess their effectiveness on *A. australis* has been published.

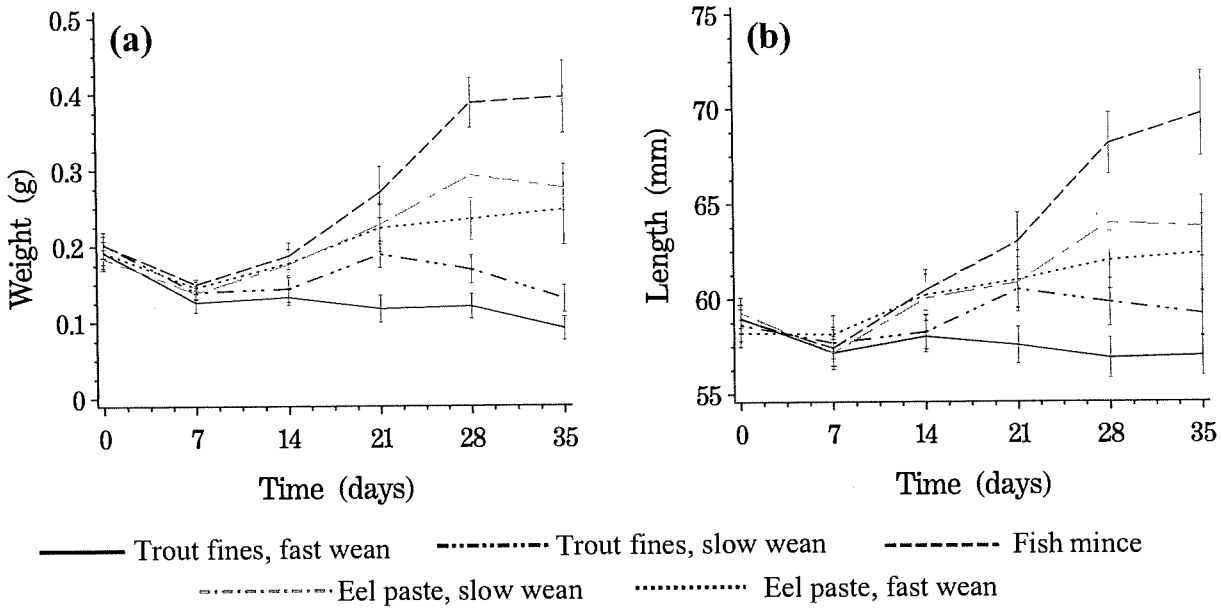


Figure 33 Changes in (a) weight and (b) total length of glass eels fed three different diets and weaned over two periods (mean ± standard error bars) during Trial 3.

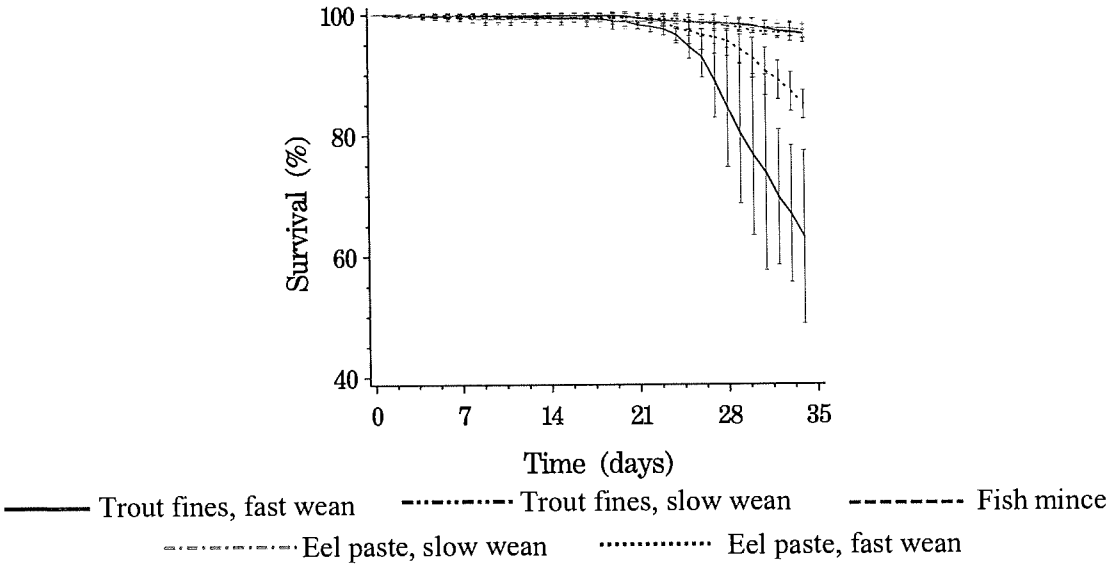


Figure 34 Survival rates (mean % ± standard error bars) of glass eels fed three different diets and weaned over two periods during Trial 3.

Table 13 Initial and final mean weight, total length, survival rates and SGR of glass eels fed three different diets and weaned over two periods during Trial 3.

PARAMETER	DIET				
	Fish mince	Trout fines, fast wean	Trout fines, slow wean	Eel paste, fast wean	Eel paste, slow wean
Weight (g)					
Initial (mean ± s.e.*)	0.20 ± 0.01	0.19 ± 0.01	0.20 ± 0.01	0.19 ± 0.01	0.18 ± 0.01
Final (mean ± s.e.)	0.40 ± 0.02	0.09 ± 0.01	0.13 ± 0.01	0.25 ± 0.01	0.28 ± 0.01
Total length (mm)					
Initial (mean ± s.e.*)	59.0 ± 0.38	59.0 ± 0.38	58.6 ± 0.43	58.2 ± 0.36	59.3 ± 0.40
Final (mean ± s.e.)	69.7 ± 1.12	57.0 ± 0.52	59.2 ± 0.60	62.4 ± 1.01	63.8 ± 0.80
Survival rate (%± s.e.)[1]	96.7 ± 0.7[b]	63.1 ± 7.1[a]	85.0 ± 1.2[b]	96.6 ± 0.3[b]	97.3 ± 0.7[b]
SGR (%/day ± s.e.)[1]	1.9 ± 0.2[b]	-2.1 ± 0.2[a]	-1.2 ± 0.5[a]	0.7 ± 0.3[b]	1.1 ± 0.1[b]
SGR (%/week ± s.e.)	13.2 ± 1.6	-14.5 ± 1.5	-8.7 ± 3.4	5.0 ± 2.3	8.0 ± 0.4

* s.e. = standard error

1. Treatments with the same letter (superscript) are not significantly different from each other (Tukey's multiple range test)

Table 14 Water quality measured during trial (Treatments with the same letter (superscript) are not significantly different from each other) (Tukey's multiple range test) during Trial 3

Parameter			Diet type		
		Inlet	Eel paste	Fish mince	Trout fines
pH	Mean	6.72	6.68	6.66	6.64
	s.e.*	0.03	0.05	0.05	0.03
TAN[1] (mg/l)	Mean	0.09	0.11	0.17	0.13
	s.e.	0.02	0.02	0.03	0.03
UIA[2] (mg/l)	Mean	<0.001	<0.001	<0.001	<0.001
Net[3] TAN (mg/l)	Mean		0.03[a]	0.09[b]	0.05[ab]
	s.e.		0.01	0.01	0.02
Total P (mg/l)	Mean	0.02	0.02	0.02	0.02
	s.e.	0.01	0.01	0.01	0.01
Net[3] Total P (mg/l)	Mean		0.01	<0.01	<0.01
	s.e.		0.01		

* s.e. = standard error

1. TAN = total ammonia as Nitrogen
2. UIA = unionised ammonia
3. Net = discharge concentration less inlet concentration

8.3.1.5 TRIAL 4: FEEDING RATES

Introduction
The aim of this trial was to investigate the growth and survival rates of glass eels (initial mean weight 0.14-0.16 g) fed at three different feeding rates (% body weight/day), and determine the impact of feed rate on the quality of discharge water.

Materials and methods
Eels were fed with a commercial eel paste (Primo) at three different rates, 6%, 9% and 12% dry weight of feed to eel weight/day, which were administered over four feeds each day. Three replicate 160 l fibreglass tanks, each stocked with approximately 1,100 glass eels, were employed for each treatment. During the trial, a random sample of 30 eels from each tank was measured every week for five weeks, and feed rates were adjusted according to change in weights of eels weekly. Mortalities were recorded daily for each tank. In addition, a suite of water quality parameters were recorded from inlet water and discharge waters for each of the three feed rates. Tanks were cleaned and purged daily. During the trial, water temperature was held at approximately 23^{0}C. Growth, survival and water quality data were analysed according to methods described in Section 8.2.

Results and discussions
Rate of change in weight of glass eels during the trial was significantly different for feed rate (day*treatment interaction: $F_{4,10} = 52.22$; $P = 0.0002$) (Figure 35). SGR, which ranged from 1.1%/day (6%/day feed rate) to 2.8%/day (12%/day feed rate), were significantly different for feed rate ($F_{2,6} = 41.62$; $P = 0.0003$). Tukey's Studentized Range (HSD) Test indicated that there was no significant difference in SGR's of glass eels fed at rates of 12%/week and 9%/week, and that glass eels fed at a rate of 6%/week had significantly lower growth rates than for eels fed at higher rates (Table 15).

Survival rates ranged from 88.5% (9% feed rate) to 92.3%(6% feed rate) over the duration of the trial. Survival rates of glass eels were not significantly different for feed rate ($F_{2,6} = 1.46$; $P = 0.3043$) (Table 15). Food Conversion Ratios (FCR) ranged from 4.5 (9% feed rate) to 6.6 (6% feed rate) over the duration of the trial, but were not significantly different for feed rate ($F_{2,6} = 3.52$; $P = 0.0974$) (Table 15).

A summary of water quality variables measured during this trial is presented in Table 16. No significant differences ($P<0.05$) between inlet and discharge waters, and between discharge waters for each feed rate were observed in most water quality parameters measured during the trial. However, a significant different was detected between treatments for unionised ammonia concentrations (UIA) ($F_{3,43} = 3.99$; $P = 0.0136$), though concentrations were extremely low overall (<0.0002 mg/l).

Increasing feed rates significantly increases the rate at which glass eels grow. However, this trial did not identify a maximum feeding rate. The relatively high FCR's observed during this trial were attributed to the nature of the feed used. The paste, once in the water, quickly dissipated and much was lost from the tank through the overflow before it could be eaten. High FCR's such as observed here have been reported for the juveniles of other eel species. For example in feeding trials Kamstra and Heinsbroek (1991) recorded FCR of 1.1 - 16.0, and in a review of eel aquaculture in Japan and Europe Heinsbroek (1991) reported FCR's of 1.5 - 1.9 and 1.5 - 4.0 for juvenile eels reared in Japan and Europe, respectively. It is suggested that less food would be wasted if dry feeds were used, which would also improve FCR's.

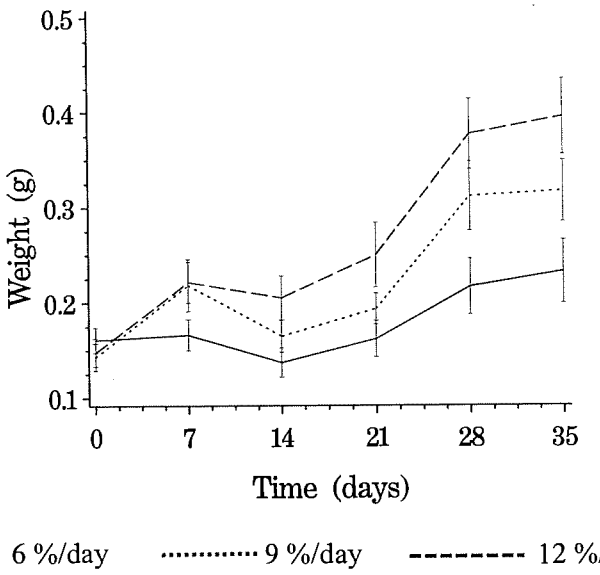


Figure 35 Changes in weight of glass eels fed at three different rates in Trial 4 (mean ± standard error bars).

Table 15 Initial and final mean weight, survival rates and SGR of glass fed at three different rates during Trial 4

PARAMETER	Feed rate (% body weight/day)		
	6.0	9.0	12.0
Weight (g)			
Initial (mean ± s.e.*)	0.16 ± 0.007	0.14 ± 0.007	0.15 ± 0.007
Final (mean ± s.e.)	0.23 ± 0.017	0.32 ± 0.016	0.40 ± 0.020
Survival rate (% ± s.e.)[1]	92.3 ± 1.0[a]	88.5 ± 2.5[a]	88.7 ± 1.4[a]
Specific growth rate (%/day ± s.e.)[1]	1.1 ± 0.1[a]	2.3 ± 0.1[b]	2.8 ± 0.2[b]
Specific growth rate (%/week ± s.e.)	7.5 ± 0.8	16.0 ± 0.9	19.8 ± 1.2
FCR[1]	6.60 ± 1.00[a]	4.46 ± 0.40[a]	4.58 ± 0.27[a]

* s.e. standard error

1. Treatments with the same letter (superscript) are not significantly different from each other (Tukey's multiple range test)

Table 16 Water quality variables measured during Trial 4.

Parameter		Inlet	Feed rate 6%/day	Feed rate 9%/day	Feed rate 12%/day
pH	Mean	6.12	6.11	6.15	6.14
	s.e.*	0.06	0.04	0.04	0.04
TAN[1] (mg/l)	Mean	0.10	0.11	0.10	0.11
	s.e.	0.02	0.02	0.02	0.02
UIA[2] (mg/l)	Mean	<0.001	<0.001	<0.001	<0.001
Net[3] TAN (mg/l)	Mean		0.01	0.01	0.01
	s.e.		0.01	0.01	0.01
Total P (mg/l)	Mean		0.32	0.31	0.32
	s.e.		0.08	0.07	0.08
Net[3] Total P (mg/l)	Mean		0.01	0.00	0.02
	s.e.		0.01	0.01	0.01
Dissolved Oxygen (mg/l)	Mean		6.40	6.58	6.72
	s.e.		0.08	0.07	0.08

* s.e. = standard error

1. TAN = total ammonia as Nitrogen
2. UIA = unionised ammonia
3. Net = discharge concentration less inlet concentration

8.3.1.6 TRIAL 5: STOCKING DENSITY

Introduction

The initial stocking densities of farmed glass eels in Japan varies between 2.0 kg/m^3 and 25 kg/m^3 whereas on farms in Europe the stocking densities are reported to be higher, between 25 kg/m^3 and 75 kg/m^3 (Heinsbroek 1989; Usui 1991). Both species, *A. japonica* and *A. anguilla*, produce highly variable growth and mortality rates in the critical early weaning period, as has been true also of *A. australis* glass eels during preliminary trials in the present study.

The purpose of this trial was to examine the influence of stocking densities on growth and survival of juvenile, pigmented eels (initial mean weight 1.9 - 2.2 g). The effect of stocking densities on water quality is also investigated.

Material and methods

Three densities were selected for this trial; 2.5 kg/m^3, 5.0 kg/m^3, and 10 kg/m^3. The trial was conducted in 160 l tanks filled to 100 l, with water heated and held at 25 ± 3^{0}C. "Primo" eel grower paste was fed at 8% (dry feed weight) of body weight per day to previously weaned eels, at approximately 0800 hrs, 1300 hrs, and 1700 hrs daily. Three replicates were employed for each treatment. During the trial, a random sample of 40 eels from each tank was measured every fortnight for 16 weeks, and feed rates were adjusted according to change in weights of eels every fortnight. Mortalities were recorded daily for each tank. In addition, a suite of water quality parameters were recorded from inlet water and discharge waters for each of the three densities and the inlet water. Tanks were cleaned and purged daily. During the trial, water temperature was held at approximately 24^{0}C. Growth, survival and water quality data were analysed according to methods described in Section 8.2.

Results and discussion

The rate of change in weight during 110 days of the trial was not significantly different for stocking density (day*treatment interaction: $F_{2,6} = 0.99$; $P = 0.4242$) (Figure 36; Table 17).

SGR's ranged from 0.1%/day for 5 kg/m^3 to 0.3%/day for 2.5 kg/m^3 and 10 kg/m^3, but these were not significantly different from each other ($F_{2,6} = 0.68$; $P = 0.5434$) (Table 17).

Survival rates ranged from 99.7% (5 kg/m^3 and 10 kg/m^3) to 100%(2.5 kg/m^3) over the duration of the trial, but these were not significantly different for stocking density ($F_{2,6} = 1.97$; $P = 0.2194$) (Table 17).

A summary of water quality variables measured during this trial are presented in Table 18. Significant differences ($P<0.05$) between inlet and discharge waters, and between discharge waters for each stocking density were observed in all water quality parameters measured during the trial (Table 18). The pH readings in the discharge for the high stocking density treatment were significantly lower than those for all other treatments ($F_{3,332} = 23.28$; $P = 0.0001$). TAN concentrations in inlet water were significantly lower than concentrations in the discharge waters from all treatments, while concentrations in the discharge water from the high density treatment were significantly greater than for other treatments ($F_{3,332} = 25.34$; $P = 0.0001$) (Figure 37). Total phosphorus concentrations in the discharge water from the high density treatment were significantly greater than for other treatments ($F_{3,332} = 23.28$; $P = 0.0001$) (Figure 37).

In an adaptive response to intensive culture conditions, considered less than ideal in both space and nutritional requirements, glass eels and elvers produce highly variable growth rates and exhibit some sexual differentiation (Roncarati *et al.* 1997). In this trial, differences in growth and survival of pigmented eels were not observed when grown in tanks stocked at densities of between 2.5 and 10 kg/m^3. However, stocking density did influence discharge water; at higher stocking densities pH readings were lower, while TAN and total Phosphorus concentrations were significantly higher ($p>0.05$) at high densities than at lower densities.

The negative effect of a constantly high ammonia concentration on the growth of eels (Degani and Gallagher 1995; Degani *et al.* 1988; Knights 1989) is well documented.

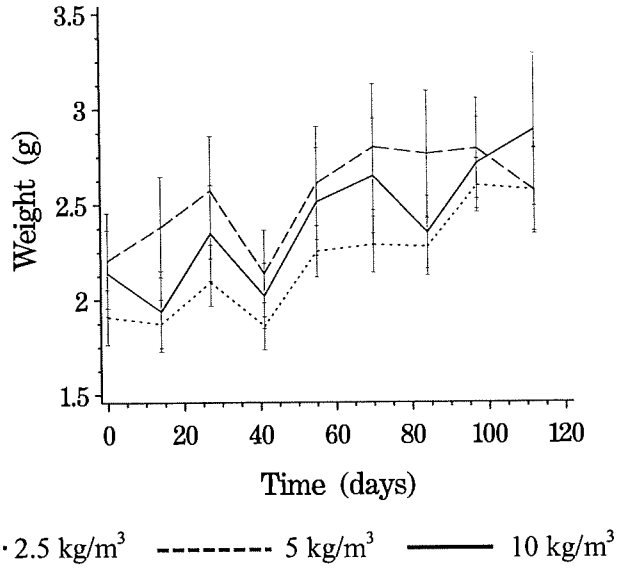


Figure 36 Changes in weight of pigmented eels stocked at three different densities during Trial 5 (mean ± standard error bars).

Table 17 Initial and final mean weight, survival rates and SGR of eels reared at three different stocking densities during Trial 5

PARAMETER	Stocking density (kg/m^3)		
	2.5	5.0	10.0
Weight (g)			
Initial (mean ± s.e.*)	1.91 ± 0.07	2.21 ± 0.13	2.14 ± 0.11
Final (mean ± s.e.)	2.57 ± 0.11	2.57 ± 0.11	2.89 ± 0.20
Survival rate[1] (%± s.e.)	100[a]	99.7 ± 0.1[a]	99.7 ± 0.1[a]
Specific growth rate[1] (%/day ± s.e.)	0.3 ± 0.1[a]	0.1 ± 0.1[a]	0.3 ± 0.0[a]
Specific growth rate (%/week ± s.e.)	1.8 ± 0.4	0.9 ± 0.9	1.8 ± 0.3

* s.e. standard error

1. Treatments with the same letter (superscript) are not significantly different from each other (Tukey's multiple range test)

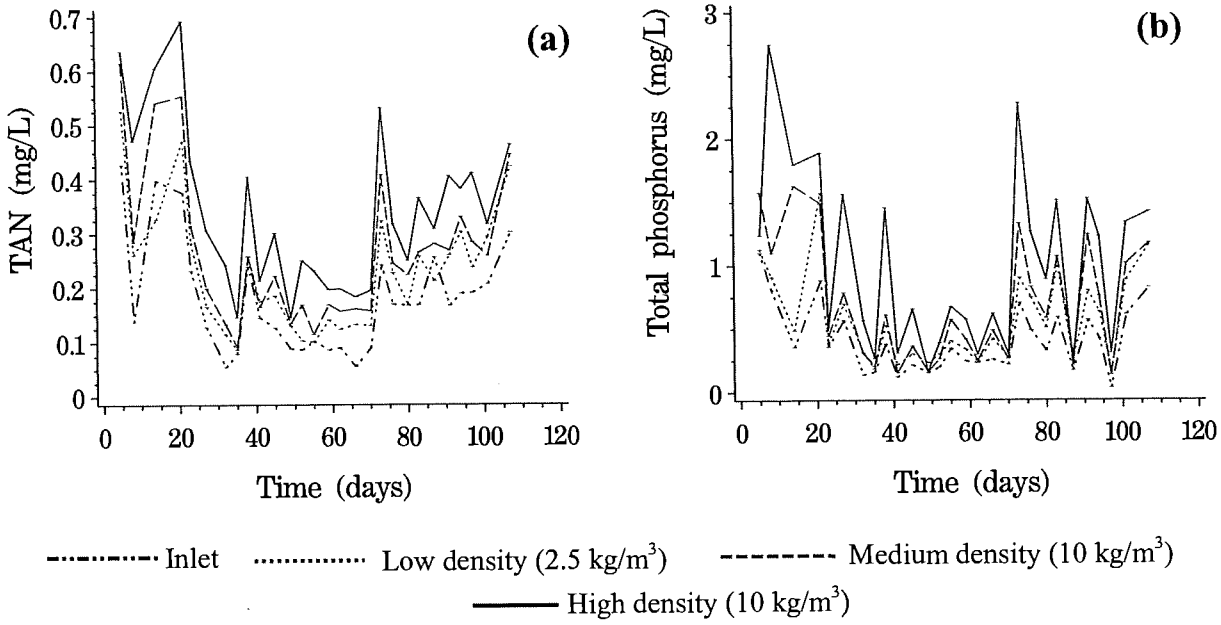


Figure 37 Concentrations of (a) TAN and (b) total Phosphorus recorded from inlet water and discharge water from tanks stocked at three different densities during Trial 5

Table 18 Water quality variables measured during Trial 5

Parameter		Stocking density (kg/m^3)			
		Inlet	2.5	5.0	10.0
pH	Mean	6.71^a	6.69^a	6.67^a	6.60^b
	s.e.*	0.01	0.01	0.01	0.01
TAN[1] (mg/l)	Mean	0.18^a	0.23^b	0.27^b	0.34^c
	s.e.	0.01	0.01	0.01	0.02
UIA[2] (mg/l)	Mean	<0.001	<0.001	<0.001	<0.001
Net[3] TAN (mg/l)	Mean		0.05^a	0.09^b	0.16^c
	s.e.		0.01	0.01	0.01
Total P (mg/l)	Mean	0.41^a	0.57^{ab}	0.70^b	1.00^c
	s.e.	0.03	0.04	0.05	0.07
Net[3] Total P (mg/l)	Mean		0.16^a	0.29^a	0.59^b
	s.e.		0.02	0.03	0.05
Dissolved Oxygen (mg/l)	Mean	8.13^a	7.79^{ab}	7.57^{bc}	7.37^c
	s.e.	0.04	0.06	0.07	0.08

* s.e. = standard error

1. TAN = total ammonia as Nitrogen
2. UIA = unionised ammonia
3. Net = discharge concentration less inlet concentration

8.3.1.7 TRIAL 6: WATER TEMPERATURE

Introduction

The two Atlantic species of *Anguilla*, (*A. anguilla* and *A. rostrata*) spawn in tropical oceanic waters (Moriarty 1987). The origin of the Japanese eel *A. japonica* is in the northeast Pacific, in tropical oceanic waters near Okinawa (Usui 1991). The Australian eels *A. australis* and *A. reinhardtii* are believed to spawn to the east of New Caledonia, again in tropical oceanic waters (Schmidt 1925; Jespersen 1942; Jellyman 1987). Water temperature is seen as critical for the commencement of migration Martin 1995; Sorenson 1951; Sloane 1984a, 1984c), accelerates or retards the progress of pigmentation of elvers (Strubberg 1913), and is seen as important in the growth of glass eels and elvers (Halls 1995; Heinsbroek 1991; Kastelein 1983; Seymour 1989). For commercial success *A. japonica* eels must reach a marketable size of 150-200 g in two years or less (Heinsbroek 1989; Usui 1991), while *A. anguilla* eels reach 180-200 g in three years or less (Gousset 1989). Enhanced growth is required to achieve such rates and previous studies suggest temperatures of 23-30^{0}C are required to achieve such performances (Usui 1991). It is notable that fishery statistics indicate that more than half the catches of anguillid eels (family Anguillidae) are made in temperate waters (FAO 1984).

The most suitable temperatures for the weaning and growth of glass eels varies between species, from 19.5^{0}C for *A. rostrata* (Rickards *et al.* 1978) to 26.5^{0}C for *A. anguilla* (Seymour 1989), and 25-28^{0}C for *A. japonica* (Heinsbroek 1991). There are some conflicting reports but the above figures are representative of the consensus on latest figures. This trial set out to determine the most suitable temperature for the weaning and growing of *A. australis* glass eels.

Materials and methods

The trial was conducted in 160l fibreglass tanks filled to a volume of 100 l, with water heated and to three different temperature ranges (Table 19; Figure 38), nominally;

Low temperature (15°C):	Snobs Creek ambient (flow through)
Medium temperature (20°C):	Recirculation system
High temperature (25°C):	Recirculation system

Each tank was provided with a constant flow of water (2-4l/min) and aerated.

"Primo" eel grower paste was fed at 10% of body weight per day, over three separate occasions. Three tanks, each stocked with 100 glass eels, were employed for each treatment. During the trial, a random sample of 20 eels from each tank was measured every 7-10 days for seven weeks. Mortalities were recorded daily for each tank. Temperature was monitored manually using a maximum/minimum thermometer, and by a data logger (Data Taker 100) recording the maximum, minimum and mean temperature every minute. Growth, survival and water quality data were analysed according to methods described in Section 8.2.

Results and discussion

Temperatures recorded for the three treatments were all significantly different from each other ($F_{2,6}$ = 1026.37; P= 0.0001) (Figure 38, Table 19). The water recirculation systems (20°C and 25°C) both provided fairly stable temperatures throughout the trial, however, because the low temperature water treatment was provided by Snobs Creek at ambient conditions, it afforded less control and as a result the mean temperature in tanks receiving this water was 17.4°C (Figure 38). Although water provided for the other two temperature treatments (20°C and 25°C) was supplied from two separate recirculation systems, make-up water (approx 10% of total system volume/day) added to these two systems came from Snobs Creek.

Water temperature significantly effected the growth of glass eels for both weight (day*treatment interaction: $F_{2,6}$ = 33.11; P = 0.0006) and length (day*treatment interaction: $F_{2,6}$ = 59.22; P = 0.0001) (Figure 39). Observations indicated the warmer water produced more vigorous swimming

and feeding activity in the glass eels, than in cooler water. SGR's, which ranged from -0.2%/day (low temperature) to 2.0%/day (high temperature), were significantly different from each other ($F_{2,6}$ = 29.38; P= 0.0008) (Table 20). Because growth rates were negative for the low temperature treatment, these eels were removed from the trial after 33 days while the remaining eels in the 20°C and 25°C waters were reared for another week. There was no significant difference in survival after 33 days for temperature ($F_{2,6}$=0.09; P = 0.9148) (Table 20).

In cool water, anguillid eels in the wild are less effective than cold water fish in obtaining food; the frequency of empty stomachs in eel samples is unusually high, and growth rates lower, when compared with sympatric species (Moriarty 1972). However in warm inshore waters where food is plentiful, anguillid eels are exposed to predators and competition, in particular from the conger eel. The Anguillid eels therefore move to cool waters and ultimately to freshwater where competition is less and their nocturnal habits give them a measure of protection from predators (Moriarty 1987), and growth may be slower but survival more likely.

There was a clear indication of the significant effect of water temperature on the growth of *A. australis* glass eels during this trial. These observations show close parallels with similar observations for *A. anguilla* and *A. japonica* (Heinsbroek 1991; Heinsbroek and Kreuger 1992; Seymour 1989; Usui 1991). The 25°C water, the warmest water temperature tested, produced the greatest SGR. More tests are required to determine if temperatures higher than 25°C will produce higher SGR's.

Seymour (1989) found the optimum conditions for growth of *A. anguilla* eels was in 26.5°C water, with maximum consumption at a feeding frequency of three or four feeds a day. Temperature was also found to dictate the capacity and emptying of the stomach; at 16°C highest daily consumption's occurred with frequent feeding, but gut passage slowed and limited consumption at this temperature. Seymour (1989) also observed at higher temperatures feed consumption and conversion was increased by feeding meals at a defined optimum frequency, which was observed to rise with temperature. Furthermore, optimum feed intake was reduced in response to lower temperatures, however growth rate was also reduced. If *A. australis* glass eels are affected in a similar way, trials with water temperatures between 23°C and 35°C may indicate the optimum weaning and growth temperatures.

Table 19 Summary of water temperatures recorded in tanks during a trial testing the effects of temperature on growth of glass eels during Trial 6

Treatment	Temperature (°C)		
	Mean[1]	Range	standard error
Low temperature	17.4[a]	13.6 - 20.7	0.05
Medium temperature	20.3[b]	17.9 - 22.3	0.02
high temperature	25.3[c]	21.9 - 28.9	0.04

1. Treatments with the same letter (superscript) are not significantly different from each other (Tukey's multiple range test)

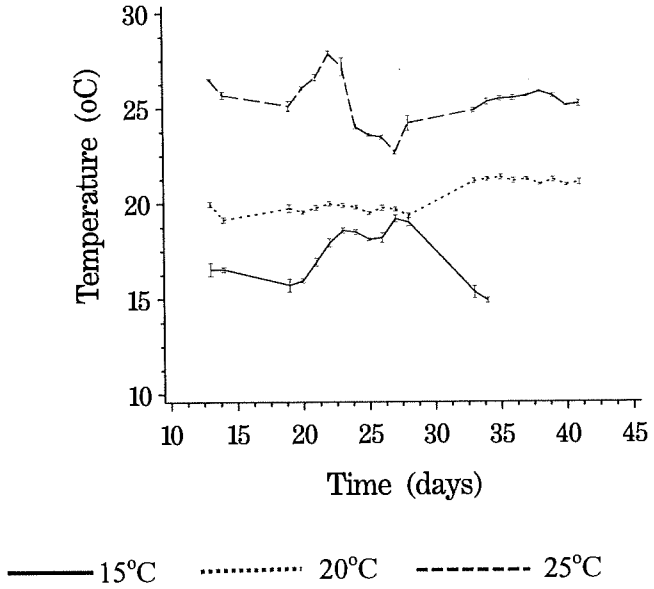


Figure 38 Water temperatures recorded in tanks (mean ± s.e.) during Trial 6, testing the effects of temperature on growth of glass eels

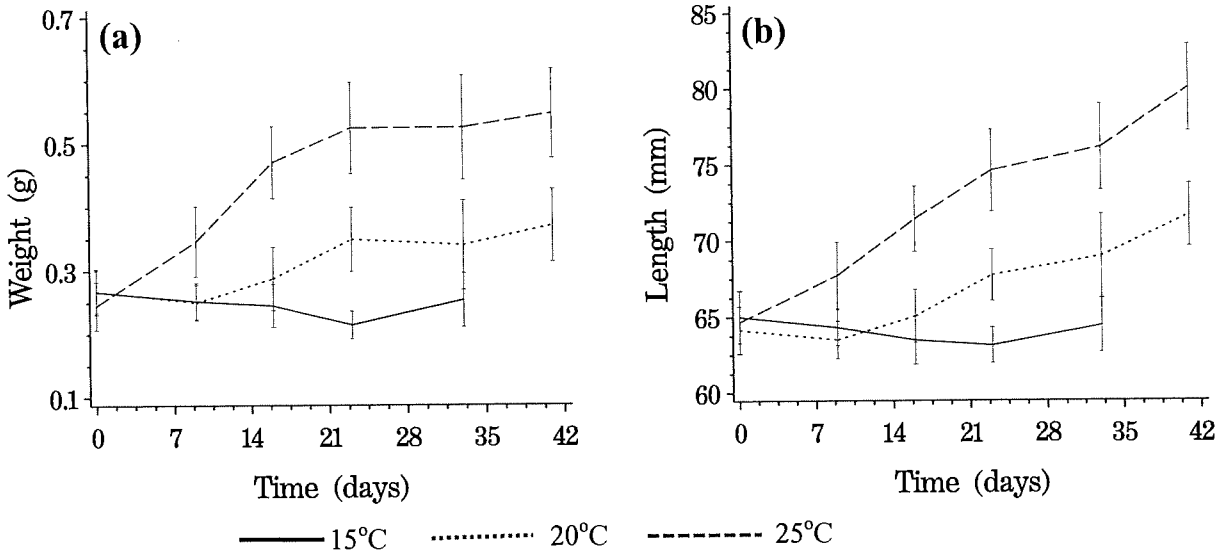


Figure 39 Changes in (a) weight and (b) total length of glass eels reared at three different water temperatures during Trial 6 (mean ± standard error bars).

Table 20 Initial and final mean weight, total length, survival rates and SGR of glass eels reared at three different water temperatures during Trial 6. (15°C reared for 33 days while 20°C and 25°C reared for 41 days)

PARAMETER	Mean water temperature (°C)		
	15[2]	20	25
Weight (g)			
Initial (mean ± s.e.*)	0.27 ± 0.02	0.27 ± 0.02	0.25 ± 0.02
Final (mean ± s.e.)	0.25 ± 0.02	0.37 ± 0.03	0.55 ± 0.04
Total length (mm)			
Initial (mean ± s.e.*)	65.0 ± 0.85	64.2 ± 0.77	64.7 ± 1.04
Final (mean ± s.e.)	64.4 ± 0.88	71.7 ± 1.04	80.0 ± 1.42
Survival rate after 33 days (%± s.e.)[1]	91.0 ± 2.3[a]	91.8 ± 1.8[a]	90.3 ± 2.7[a]
Specific growth rate (%/day ± s.e.)[1]	-0.2 ± 0.2[a]	0.8 ± 0.2[b]	2.0 ± 0.2[c]
Specific growth rate (%/week ± s.e.)	-1.1 ± 1.4	5.5 ± 1.4	13.7 ± 1.4

* s.e. standard error

1. Treatments with the same letter (superscript) are not significantly different from each other (Tukey's multiple range test)
2. Eels reared at 15°C terminated after day 33 when final measurements taken.

8.3.1.8 TRIAL 7: LIGHT INTENSITY

Introduction

Experiences in New Zealand indicate cover and shade are important for the growth and well being of eels (Jones *et al.* 1983). All the trials carried out at Snobs Creek have been carried out under ambient light conditions. Due to the nature of recirculating systems a high level of water quality is maintained and clarity is high. While every endeavour was made to protect experimental tanks from disturbances, any traffic or movement near the site may have had an influence on the growth and mortalities of glass eels. This trial set out to determine the effects of light reduction, and shelter on the growth and survival of juvenile, pigmented eels (initial mean weight 1.9 g).

Materials and methods

The trial was conducted in 160 l filled to 100 l, with water heated and held at 25±3^{0}C. "Primo" eel grower paste was fed at 8% of body weight per day to previously weaned eels, at approximately 0800 hrs, 1300 hrs, and 1700 hrs. Tanks covered with an impermeable plastic membrane, which was only moved to facilitate the cleaning, feeding and measuring of eels, were compared with non-covered tanks under ambient light regime. Three replicates were employed for each treatment, from each replicate the weight of 20 randomly selected eels was measured every two weeks for 16 weeks, and feed rates were adjusted according to change in weights of eels every fortnight. Density was held at 2.5 kg/m^3, in both the control and covered tanks. Growth, survival and water quality data were analysed according to methods described in Section 8.2.

Results and discussion

The rate of change in weight of elvers during the trial was not significantly different for the two lighting conditions (day*treatment interaction: $F_{1,4} = 0.61$; $P = 0.4771$) (Figure 40). The SGR's, which ranged from 0.2%/day for dark to 0.3%/day were not significantly different for lighting conditions ($F_{1,4} = 2.25$; $P = 0.2078$) (Table 21).

Survival rates, which ranged from 99.7% for elvers grown under dark conditions to 100% for elvers grown under light conditions, were not significantly different for lighting conditions ($F_{1,4} = 1.0$; $P = 0.3739$) (Table 21).

These results indicated that, under the conditions of the trial, neither growth or survival of weaned, captive eels, where effected by light intensity. This suggests that in an intensive eel farming operation light intensive may not be an important factor in eel production.

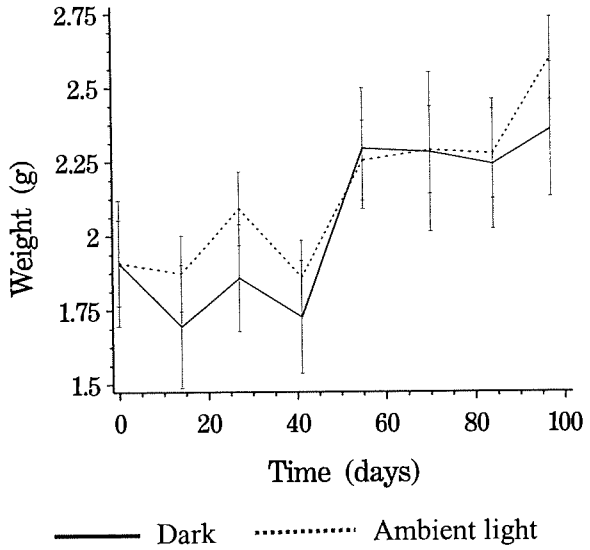


Figure 40 Changes in weight of eels reared in subdued light (dark) and ambient light during Trial 7 (mean ± standard error bars).

Table 21 Initial and final mean weight, survival rates and SGR of eels reared in subdued light (dark) and ambient light in Trial 7.

PARAMETER	Light conditions	
	Dark	Ambient
Weight (g)		
Initial (mean ± s.e.*)	1.91 ± 0.11	1.91 ± 0.07
Final (mean ± s.e.)	2.26 ± 0.10	2.57 ± 0.11
Survival rate (%± s.e.)[1]	99.7 ± 0.3[a]	100[a]
Specific growth rate (%/day ± s.e.)[1]	0.2 ± 0.0[a]	0.3 ± 0.1[a]
Specific growth rate (%/week ± s.e.)	1.0 ± 0.3	1.8 ± 0.4

* s.e. standard error

1. Treatments with the same letter (superscript) are not significantly different from each other (Tukey's multiple range test)

8.3.1.9 TRIAL 8: GRADING AND GROWTH DEPENSATION

Eels, more than any other cultured species, are characterised by significant growth differences (depensation) between individuals (Brusle 1990). In the wild, the occurrence of a single spawning ground for *A. australis* means that there is an infinite capacity for cross fertilisation (Helfman *et al.* 1987), and therefore no control on the genotypes used in culture. Females grow faster than males and 25% of the individuals in a population may account for 50% of the biomass (Brusle 1990). Large and small, slow and fast growing individuals, are all contained in the same group of glass eels. Natural variation in growth rates is substantial, both between and within groups and/or experiments on *A. anguilla* and *A. japonica* (Applebaum 1980; Degani and Levanon 1983; Degani *et al.* 1986; Kastelein 1983; Kuhlmann and Koops 1981; Rand 1986). The same heterogeneity of size and growth has existed for *A. australis* glass eels described in previous trials in the present study (note the large coefficients of variation associated with the weight, length and body depth Vs time).

In intensive culture of the Japanese and European eels *A. japonica* and *A. anguilla* size grading is employed at least every 6-8 weeks (Kamstra 1992; Usui 1991). Grading is generally believed to improve the growth rate of smaller individuals by removing the suppressing, or intimidating effect of larger individuals. This trial aimed to determine the effect of grading on the growth of *A. australis* glass eels.

Materials and methods

Three replicates of large, medium and small sized eels were graded and placed, along with an ungraded control group, in separate tanks of equal biomass (initial stocking density = 1.0 g/m^3). The trial was conducted in 160 l filled to a volume of 100 l, with water heated and held at approximately 20^{0}C. Diet and feeding protocols were as for pervious trials. Eels were individually graded by hand and sorted into small, medium and large sizes. The weights of 10 eels from each graded tank, and 30 from the control groups were measured every two weeks. At the beginning of the trial then every six weeks the eels were graded, tank biomass's were equalised, and the weights taken before and after the grade as in the two weekly measurements. Growth and survival data were analysed according to methods described in Section 8.2.

Results and discussion

The effect of grading on the growth of glass eels, measured against a control group, is presented in Figure 41. Large variations in size, and the problems associated with grading eels by hand produced large variations in weight within the groups, resulting in large error bars around estimates of mean weight. Nonetheless, the rate of change in weight of eels over time was not significantly different for each group (day*treatment interaction: $F_{3,8} = 2.60$; $P = 0.1247$). Similarly, SGR recorded fro each group of eels were not significantly different from each other ($F_{3,8} = 1.30$; $P = 0.3399$) (Table 22)

Although survival in all treatments was greater than 98.3%, a slightly significant difference was detected between treatments ($F_{3,8} = 4.14$; $P = 0.0480$) (Table 22).

Frequent size sorting through grading is required in eel farming, but the anguilliform body shape and morphometric changes during growth make accurate size-sorting difficult (Knights 1983). Sorting by hand is extremely time consuming and stresses the fish, which may reduce food conversion, and cause outbreaks of disease shortly afterward (Koops and Kuhlmann 1982). In modern eel farms, however, the process of grading eels, which may happen at least every 2 months (Kamstra 1993) has been mechanised and is now routine.

In mixed populations the feeding and growth of smaller eels is generally believed to be suppressed by the dominance of larger eels (Wickins 1987). This may lead to increased stress, loss of weight and an increased susceptibility to disease in the smaller eels. Consequently the hierarchical effects on mortality, weight losses, disease risk and feed conversion should improve if eels are graded into size classes (Koops and Kuhlmann 1982). However, This was not found to be the case for eels in this trial as mortalities for the graded group and ungraded groups were both low, and there were no significant

differences between the groups. Size separation through grading also produced no significant differences in growth between treatments. Similarly, Kamstra (1993) found that size grading in *A. anguilla* did not effect either individual growth rates of eels or total biomass output. Other factors, besides dominance by larger eels, may affect growth rates in eels. For example, the slower growth rates of the smaller individuals may be governed by physiological responses and not necessarily by social interactions (Jobling and Reinsnes 1986; Wickins 1987).

In the present study, hierarchical effects were not operative, or there was insufficient time for such effects to develop to a significant level in this trial. If the time was sufficient for the hierarchical effects to establish, the apparent slow growth rates of small eels may be affected by social interactions, or by physiological changes, that may be to some extent, dependent on size or sex. A longer experimental period is required to test if time was insufficient for any hierarchical effects to be seen.

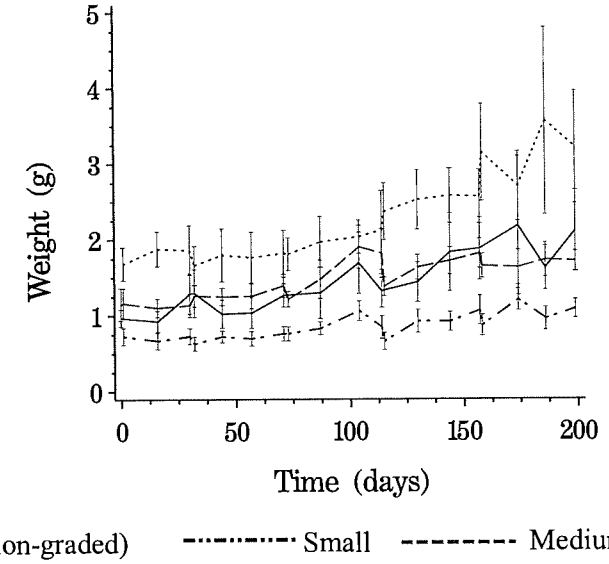


Figure 41 Changes in weight of eels during regular grading into three size classes (small, medium and large) and eels that were not graded during Trial 8 (mean ± standard error bars).

Table 22 Initial and final mean weight, total length, survival rates and SGR of eels graded into three size classes, and non-graded (control) eels in Trial 8.

PARAMETER	Graded eel size class			
	Control	Small	Medium	Large
Weight (g)				
Initial (mean ± s.e.*)	0.97 ± 0.06	0.73 ± 0.10	1.16 ± 0.07	1.68 ± 0.11
Final (mean ± s.e.)	2.11 ± 0.27	1.08 ± 0.06	1.71 ± 0.07	3.22 ± 0.37
Survival rate (% ± s.e.)[1]	98.5 ± 0.4	99.2 ± 0.5	98.3 ± 0.4	100
Specific growth rate (%/day ± s.e.)[1]	0.4 ± 0.1[a]	0.2 ± 0.1[a]	0.2 ± 0.1[a]	0.3 ± 0.1[a]
Specific growth rate (%/week ± s.e.)	2.7 ± 0.7[a]	1.3 ± 0.5[a]	1.3 ± 0.4[a]	2.2 ± 0.7[a]

* s.e. standard error

1. Treatments with the same letter (superscript) are not significantly different from each other (Tukey's multiple range test)

8.3.1.10 TRIAL 9: WEANING AND GROWTH OF ELVERS

Introduction

It has been suggested that the practice of feeding non-living foods to glass eels is based on the assumption that the eels begin to eat substrate material (detritus) at first feeding and later learn to feed on living organisms (Jones *et al.* 1983). For both *A. australis* and *A. reinhardtii* caught in the wild the most important dietary items ingested were dependent on eel size (Sloane 1984d). A change in the diet with size of eels has also been recognised as necessary for other *Anguilla* spp. (e.g. Cairns 1942; Jubb 1961; Ogden 1970). Granulated, crumbled or pelleted food of the correct size and texture, with no weaning period, has been used successfully for rearing elvers (Kastelein 1983) resulting in growth rates comparable to those of the more traditionally used pastes (Jones *et al.* 1983; Usui 1991; Gousset 1992). The fact that elvers will adapt to granulated or crumbled food without any weaning period indicates elvers may adapt to artificial food more readily than glass eels, however a weaning period is still included when weaning elvers to paste (Knights 1983; Usui 1991). The aim of Trial 9 was to determine the effect of weaning from minced fish flesh to paste on elvers.

Material and methods

One group of elvers was gradually weaned from 100% minced fish flesh to 100% paste ("Primo", a commercially formulated eel grower mix). This was achieved by increasing the proportion of paste in the diet by 20% every three days (as in the protocol established for the slow wean group in Section 8.3.1.4). A second group of elvers fed with minced fish flesh served as a control. Three replicates for each treatment were stocked into 160 l filled to a volume of 100 l, (initial stocking density = 6.5 g/m^3). Eels were fed three times daily at a rate of 10% of body weight per day, and water temperature held at 20^{0}C. The same sampling and feeding and protocols as for previous trials were employed. Growth and survival data were analysed according to methods described in Section 8.2.

Results and discussion

There was a significant difference in change of weight of pigmented eels due to diet during the trial (day x treatment interaction: $F_{1,4} = 23.48$; $P = 0.0084$) (Figure 42). Observations indicated greater than 95% of each group were eating within the first 2 minutes of food being placed in the tank. At termination of the trial (77 days after commencement) eels weaned onto the grower paste were significantly smaller than those fed minced fish flesh only (Figure 42). However, no significant difference was recorded for SGR ($F_{1,4} = 1.09$; $P = 0.3553$) (Table 23).

Survival rates for both treatments were greater than 99%, and were not significantly different from each other ($F_{1,4} = 0.27$; $P = 0.6284$).

The overall growth rate of 0.8 - 1.0 %/day were low when compared with those found by other researchers using around the same sized *A. anguilla* eels but being fed crumbles or granulated food; 0.53% (Kastelein 1983), 1.65% (Heinsbroek 1989), 1.69% and 0.48% (Applebaum 1980), and 0.87% (Seymour 1989). These growth rates were comparable with those of elvers fed on paste (Kastelein 1983). No real explanation is forthcoming for this; the husbandry techniques, water temperature, and experimental protocols were all similar to those producing the aforementioned growth rates, such that they should not produce significant differences in growth rates.

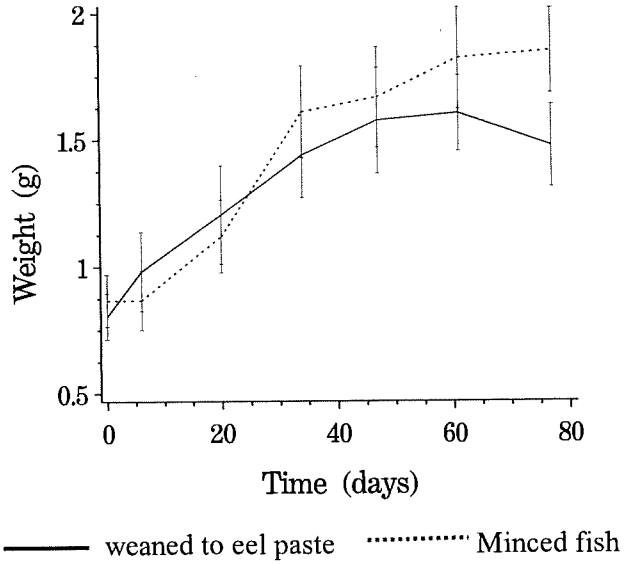


Figure 42 Changes in weight of eels fed two different diets during Trial 9 (mean ± standard error bars).

Table 23 Initial and final mean weight, survival rates and SGR of eels reared during Trial 9.

PARAMETER	Diet	
	Minced fish	Eel paste
Weight (g)		
Initial (mean ± s.e.*)	0.87 ± 0.05	0.81 ± 0.05
Final (mean ± s.e.)	1.85 ± 0.08	1.48 ± 0.08
Survival rate (%± s.e.)[1]	99.9 ± 0.1[a]	99.8 ± 0.1[a]
Specific growth rate (%/day ± s.e.)[1]	1.0 ± 0.1[a]	0.8 ± 0.1[a]
Specific growth rate (%/week ± s.e.)	6.7 ± 0.7	5.4 ± 1.0

* s.e. standard error

1. Treatments with the same letter (superscript) are not significantly different from each other (Tukey's multiple range test)

8.3.1.11 ADDITIONAL OBSERVATIONS ON HUSBANDRY (INCLUDING NOTES ON FEEDING, GROWTH, DISEASES ETC.)

Water quality

Water quality parameters measured throughout the experiments, were found to fall within ranges preferred for the culture of *A. anguilla* and *A. japonica* (see Table 24).

Table 24 Preferred range of selected water quality parameters for eel culture (after Brusle 1990; Usui 1991; Gousset 1992), and ranges of water quality parameters recorded during the present study

Parameter	Acceptable Range	Comments	Measurements recorded during the present study
Temperature (°C)	22-28	Growth will be optimised within this range	16-27
Dissolved oxygen (mg/l)	>5	Eels can tolerate short periods of lower concentrations	5.2-9.6
pH	7.0-9.2	Waters should be well buffered	6.1-6.9
Salinity (ppt)	0-10	Eels can be cultured in slightly saline waters	0-5
Light	Intense light to be avoided	Eels prefer shaded conditions	
Total hardness (mg/l as $CaCO_3$)	>50 - <500		
Total Nitrogen (mg/l)	<0.5	Ammonia toxicity increases with rising pH and temperature	
TAN (mg/l)			0.02-0.6
Suspended Solids (mg/l)	<40	Eels are adaptable to a wide turbidity range	
Iron (mg/l)	<0.1		
Hydrogen sulfide (mg/l)	<0.002		

Fish health

Historically, diseases such as branchio-nephritis, bacterial and fungal infections have caused serious problems in eel culture overseas (Heinsbroek 1991; Gosper 1996). The only diseases and parasites encountered during these experiments were protozoan infestations of *Ichthyobodo* and *Trichodina*. The poor survival rates observed in glass eels fed *Artemia* during an early weaning trial (Section 8.3.1.2) was attributed to an outbreak of *Ichthyobodo* and *Trichodina*. These parasites were subsequently eradicated by standard therapeutic methods applied at MAFRI, Snobs Creek Namely, 5-10 g/l salt for up to 1hr and/or 0.2 ppm malachite green for up to 1.5 hours.

8.3.2 POND CULTURE TRIALS

Trial 1 (1994/95 season)

The rate of change in both weight and length of elvers during the trial were not significantly different for feeding regime (day*treatment interaction: Weight, $F_{1,2} = 0.01$; $P = 0.9223$; Length, $F_{1,2} = 0.00$; $P = 0.9544$) (Table 25) (Figure 43a). The SGRs for eels reared in ponds receiving supplementary feed (1.65%/day) were higher than for eels reared in ponds with natural food only (1.36%/day), however, this trend was not significant ($F_{1,2} = 1.29$; $P = 0.3733$) (Table 25). Survival rates, which ranged from 73 - 77%, were not significantly different for feeding regime ($F_{1,2} = 0.04$; $P = 0.8596$) (Table 25). A summary of water quality variables measured during this trial are presented in Table 28.

Trial 2 (1995/96 season)

The rate of change in growth of glass eels during the second pond rearing trial was not significantly different for feeding regime for weight (day*treatment interaction: $F_{1,2} = 2.83$; $P = 0.2348$), but was significantly different for length (day*treatment interaction $F_{1,2} = 33.64$; $P = 0.0285$) (Table 26) (Figure 43b). However, the SGRs which ranged from 1.51 -1.55%/day were not significantly different for feeding regime ($F_{1,2} = 0.04$; $P = 0.8655$) (Table 26). Survival rates, which ranged from 49-53%, were not significantly different for feeding regime ($F_{1,2} = 2.90$; $P = 0.2305$) (Table 26). A summary of water quality variables measured during this trial are presented in Table 28.

Trial 3 (1996/97 season)

The rate of change in both weight and length of glass eels during the trial were not significantly different for feeding regime (day*treatment interaction: Weight $F_{1,2} = 0.50$; $P = 0.5513$; Length, $F_{1,2} = 0.95$; $P = 0.4316$) (Table 27) (Figure 43c). SGRs, which ranged from 1.37-1.49%/day, were not significantly different for feeding regime ($F_{1,2} = 0.25$; $P = 0.6687$) (Table 27). The survival rate for eels reared in ponds receiving supplementary feed (50%) was lower than for eels reared in ponds with natural food only (66%), however, this trend was not significant ($F_{1,2} = 7.85$; $P = 0.1073$) (Table 27). A summary of water quality variables measured during this trial are presented in Table 28.

Table 25 1994/95 pond rearing Trial. Initial and final mean weights, lengths, survival rates and SGR of eels reared in earthen ponds at Deakin University, Warrnambool

PARAMETER	Diet	
	Suppl. feeding	**No feeding**
Weight (g)		
Initial (mean ± s.e.*)	0.69 ± 0.06	0.69 ± 0.06
Final (mean ± s.e.)	2.02 ± 0.11	1.98 ± 0.08
Total length (mm)		
Initial (mean ± s.e.*)	98.5 ± 1.6	98.5 ± 1.6
Final (mean ± s.e.)	112.0 ± 1.4	112.3 ± 1.7
Survival rate (%± s.e.)	77.2 ± 16.0	73.4 ± 9.6
Specific growth rate (%/day ± s.e.)	1.65 ± 0.19	1.36 ± 0.17
Specific growth rate (%/week ± s.e.)	11.6 ± 1.4	9.6 ± 1.2

* s.e. standard error

Table 26 1995/96 pond rearing Trial. Initial and final mean weights, lengths, survival rates and SGR of eels reared in earthen ponds at Deakin University, Warrnambool

PARAMETER	Diet	
	Suppl. feeding	**No feeding**
Weight (g)		
Initial (mean ± s.e.*)	0.43 ± 0.04	0.39 ± 0.03
Final (mean ± s.e.)	4.50 ± 0.42	4.40 ± 0.328
Total length (mm)		
Initial (mean ± s.e.*)	72.8 ± 1.6	71.0 ± 1.6
Final (mean ± s.e.)	136.8 ± 2.5	138.2 ± 2.6
Survival rate (%± s.e.)	52.9 ± 1.9	38.9 ± 7.9
Specific growth rate (%/day ± s.e.)[1]	1.55 ± 0.13	1.51 ± 0.19
Specific growth rate (%/week ± s.e.)	10.9 ± 1.0	10.6 ± 1.4

* s.e. standard error

Table 27 1996/97 pond rearing Trial. Initial and final mean weights, lengths, survival rates and SGR of eels reared in earthen ponds at Deakin University, Warrnambool

PARAMETER	Diet	
	Suppl. feeding	No feeding
Weight (g)		
Initial (mean ± s.e.*)	0.20 ± 0.02	0.20 ± 0.03
Final (mean ± s.e.)	2.26 ± 0.08	2.62 ± 0.11
Total length (mm)		
Initial (mean ± s.e.*)	62.9 ± 0.9	62.3 ± 1.1
Final (mean ± s.e.)	117.3 ± 1.3	122.7 ± 1.7
Survival rate (%± s.e.)	49.5 ± 1.9	66.1 ± 5.6
Specific growth rate (%/day ⇧ s.e.)[1]	1.37 ± 0.10	1.49 ± 0.22
Specific growth rate (%/week ⇧ s.e.)	9.6 ± 0.7	10.5 ± 1.6

* s.e. standard error

Table 28 Summary of water quality variables measured in fertilised earthen rearing ponds at Deakin University during eel rearing experiments.

Parameter		Trial No.		
		1	2	3
Temperature (°C)	Mean	19.0	18.2	14.3
	Range	9.2-26.8	11.0-28.5	3-26.0
pH	Mean	8.0	8.0	8.1
	Range	7.0-9.0	7.3-9.0	7.2-9.0
TAN[1] (mg/l)	Mean	0.49	0.12	0.06
	Range	0-3.0	0-1.0	0-0.05
UIA[2] (mg/l)	Mean	0.03	0	0
Nitrite (mg/l)	Mean	0.12	0.07	0.18
	Range	0-0.80	0-0.70	0-1.0
Nitrate (mg/l)	Mean	12.1	10.03	20.3
	Range	0-88.0	0-25.0	0-30.0
Phosphate (mg/l)	Mean	0.87	0.06	
	Range	0-0.36	0-0.25	
Secchi depth (cm)	Mean	51	35	65
	Range	20-118	11-115	11-100
Dissolved Oxygen (mg/l)	Mean	9.2	9.0	9.3
	Range	3.1-17.8	3.2-16.4	3.1-17.3

1. TAN = total ammonia as Nitrogen
2. UIA = unionised ammonia

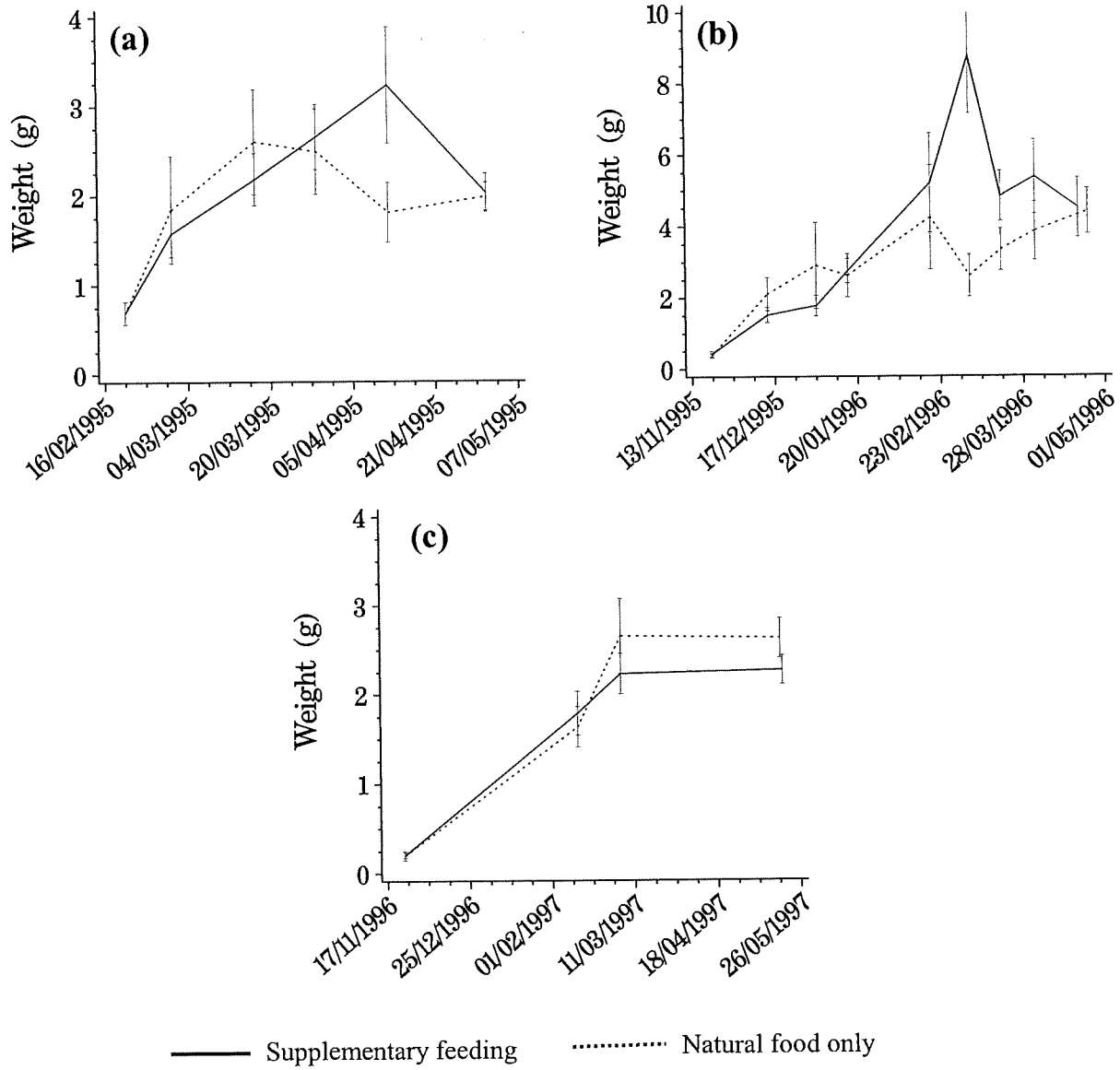


Figure 43 Changes in weight (mean ± standard error bars) of eels reared in earthen ponds (Deakin University, Warrnambool), with or without supplementary feeding, during the (a) 1994/95 season (Trial 1), (b) 1995/96 season (Trial 2) and (c) 1996/97 season (Trial 3).

8.4 DISCUSSION

8.4.1 TANK CULTURE

8.4.1.1 ACCLIMATION TO AQUACULTURE CONDITIONS

This study has shown that the glass eels collected from the wild can be successfully domesticated to aquaculture conditions. Despite these eels being transferred directly from estuarine conditions of varying salinities (freshwater to seawater; mean 15 ppt) to freshwater without an acclimation period, observations indicated that this had minimal effects on glass eels. Studies have shown that glass eel have a strong preference for freshwater flows (Tosi *et al* 1989). Yahyaoui (1986) found that feeding and growth of glass eels (*A. anguilla*) was favoured by low salinity. Current practice in the Dutch intensive eel farming industry do not include an acclimation period to freshwater for newly caught glass eels, however, emphasis is placed on obtaining glass eels of a high quality. Japan eel farmers originally included an acclimation period during which salinity was slowly decreased, but now prefer to transfer glass eels directly into freshwater, then allow then to rest for up to one week before feeding (Gousset 1992).

The glass eels of *A. australis* were captured in the wild during the period from June to October when ambient temperatures were 10-17°C (mean 12°C). Since weaning and rearing of eels was generally conducted at temperatures between 20°C and 25°C, MAFRI Snobs Creek has adopted a protocol for the acclimation of newly caught glass eels to aquaculture conditions. This includes a period of up to 5 days during which the holding water is slowly increased, and the salinity is slowly decreased.

Although this study did not assess the performance of different batches of glass eels captured from either different estuaries or from the same estuary at different times, it is indeed possible that these factors may influence growth and survival in captivity. Weber and Antunes (1990) indicated that differences in mortalities between glass eels collected over several months from the one location, seemed to more associated with parasite build-up rather than time of capture. The quality of the glass eels of *A. australis* caught in at different time of the year and from different river systems requires further investigation.

8.4.1.2 FIRST/PRE-WEANING FEEDING

In general newly captured glass eels need to be first fed on a "natural" diet prior to weaning onto manufactured, "artificial" formulations (Usui 1991; Heinsbroek 1989; Heinsbroek and Kreuger 1992). Diets initially fed to glass eels following capture vary from country to country. In Japan, the initial diet traditionally was live aquatic oligochaetes (eg. *Tubifex*) (Gousset 1988), however, in recent years use of artificial starter feeds containing fresh fish, squid and/or krill (presented as a paste) is becoming more common (Heinsbroek 1990). In Europe, glass eels are usually fed on cod roe (Heinsbroek 1990).

This study has shown that the glass eels of *A. australis* will commence feeding on diets of either live, newly hatched brine shrimp (*Artemia*) and/or freshly minced fish flesh (*Oncorhynchus mykiss*) within days of being in captivity. Commencement of feeding was facilitated by providing a floating mesh habitat in each tank which acted both as a resting station for eels as well as a feeding platform on which was placed freshly minced fish. Glass eels could not, however, be placed directly onto an artificial diet without first breaking the "fast" using a "natural" diet.

8.4.1.3 WEANING

During the present study, the weaning phase (weaning to artificial diets) was found to be critical for the successful adaptation of eels to aquaculture conditions. A number of variables were found to be important during this phase. In Trial 3, glass eels weaned at a slow rate (ie. 20% change from "natural" diet to artificial diet every 3 days) had higher SGR's than those weaned at a faster rate (ie. 20% change from "natural" diet to "artificial" diet every day). Similarly, Melotti and Perrucci (1989) found that gradual weaning of the elvers of *A. anguilla* gave greater survival rates and final weights than accelerated weaning. In the same Trial, survival rates were significantly higher for eels weaned

onto an eel diet than for eels weaned onto a salmonid starter diet. Weaning onto artificial diets is an important an difficult stage in the production of eels and further development of weaning protocols, combined with improved diets specifically formulated for the glass eels of *A. australis*, may improve both growth and survival during this stage.

8.4.1.4 GROWTH AND SURVIVAL

During this study SGR's were highly variable, and ranged from -2.1%/day to 3.6 %/day (see tables in text and Figure 44a). The wide range in SGR's is a reflection of growth conditions the eels were exposed to during the trials (eg. water temperature, feed rate etc.). SGR's of glass eels (< 0.5 g weight) was generally higher and more variable than for larger eels (>0.5 g weight). Growth rates have been reported to be highly variable for eels (eg. Heinsbroek 1989), and various rates for juvenile eels under culture conditions have been reported: 0.55-2.81%/day for *A. anguilla* glass eels (Kamstra and Heinsbroek 1991); 0.5-2%/day for *A. anguilla* elvers in nursery tanks (Heinsbroek 1991); and 0.6-4%/day for *A. japonica* glass eels and elvers in nursery ponds (Heinsbroek 1991; Gousset 1992). SGR's for glass eels in the present study compared favourably with figures reported for glass eels of other species, but less favourable results were obtained for larger eels.

The low SGR's of elvers observed during this study may be a attributed to several factors including inappropriate husbandry practices (light intensity, water flow rates, grading frequency etc.), poor water quality and inappropriate diet formulation/presentation. In the present study water quality variables measured were within what was considered to be acceptable for *A. australis*. Unfortunately, little is known about the dietary requirements for *A. australis*. During the present study the main diet used was an *A. japonica* diet imported from Taiwan, which may not have been suitable for optimising growth in *A. australis*. Throughout the present study husbandry practices were continually being developed and refined with the view to improving growth and survival.

During this study survival rates were highly variable, and ranged from less than 40% to 100% (see tables in text and Figure 44b). The wide range in survival rates, like SGR's, reflected conditions the eels were exposed to during the trials (eg. diet type etc.). Survival rates of glass eels (< 0.5 g weight) was generally lower and more variable than for larger eels (>0.5 g weight). Various rates of survival for juvenile eels under culture conditions have been reported in the literature: 74-99% for *A. anguilla* glass eels being weaned (Kamstra and Heinsbroek 1991); 20-95% for *A. japonica* elvers in nursery ponds and 40-60% for *A. anguilla* elvers in nursery tanks (Heinsbroek 1991). Survival rates of *A. australis* during the present study compared favourably with these survival rates.

These results indicate the importance of having good quality glass eels for weaning, and the efficient use of these eels through maximising survival during weaning and adaptation to captivity, Indeed, this has been identified as a critical phase of eel culture for other species of eel (Degani and Levanon 1983, 1986; Kamstra and Heinsbroek 1991).

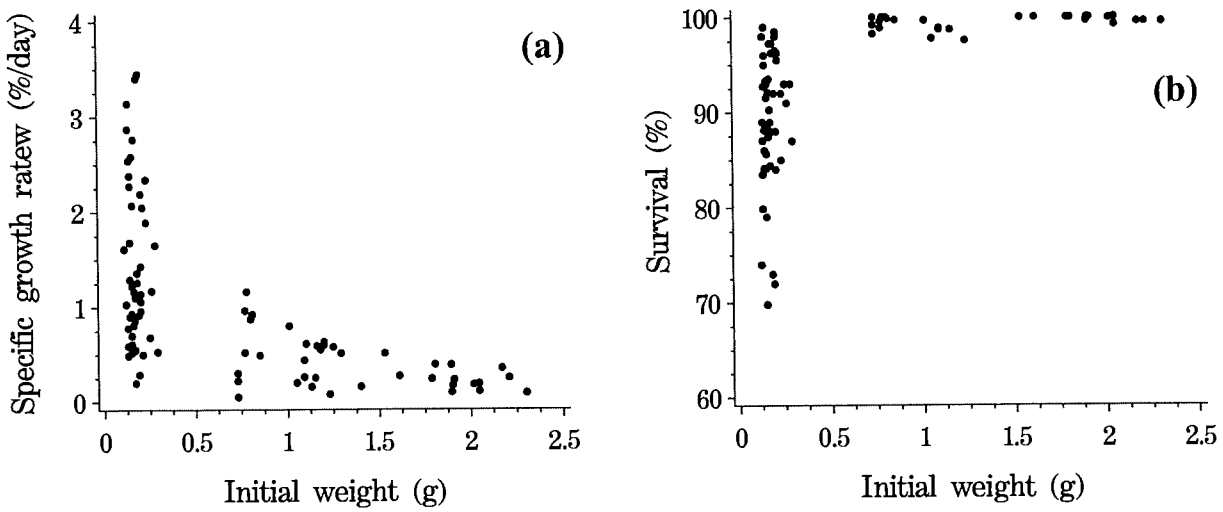


Figure 44 Examples of, (a) Specific growth rates (SGR) and, (b) survival rates of glass eels and elvers observed in each tank during trials conducted in current study. (Negative SGR's not shown).

8.4.1.5 FEEDING RATES

This study showed that the SGRs of glass eels of *A. australis* grew were significantly effected by feed rate (Trial 4). Feed rates of cultured eels varies for both species and developmental; stage (size). For example, *A. japonica* are fed at rates of 0.5 %/day (0.5 g eels) to 1.9%/day (100-200 g eels) (Kondô 1986 in Gousset 1992), 3-8%/day for *A. japonica* elvers in nursery ponds and 2-5%/day for *A. anguilla* elvers in tanks (Heinsbroek 1991).

8.4.1.6 STOCKING DENSITY

During this study initial stocking densities were generally kept below 10 kg/m^3. In trial 5, initial stocking density (2.5, 5.0 and 10.0 kg/m^3) did not significantly effect either the growth or survival of *A. australis* elvers. *A. anguilla* has been stocked in intensive systems at densities of 30-60 kg/m^2 (Heinsbroek 1991) while *A. Japonica* has been stocked at densities up to 21 kg/m^2 in intensive recirculation systems (Gousset 1992) and 6-30 kg/m^2 in greenhouses (Heinsbroek 1991). In addition, increasing the oxygen content of culture water may increase the densities at eels can be cultured (Wienbeck 1980). However, One major drawback of stocking at high densities is constant, elevated concentrations of ammonia which may inhibit growth (Degani *et al.* 1988). These studies suggest that, under appropriate conditions such as high oxygen injection and low ammonia concentrations, that *A. australis* may be cultured at densities far in excess to those densities used during the present study.

8.4.1.7 WATER TEMPERATURE

This study showed that the glass eels of *A. australis* grew significantly faster at 25°C than at lower temperatures (Trial 6). Water temperatures in culture systems for other species of eel have been reported to be in the range of 25-28°C for *A. japonica* and 23-25°C for *A. anguilla* (Heinsbroek 1991). Studies have shown that optimal growth temperatures may different at various stages in their growth and development (Degani *et al.* 1988). The effects of temperatures higher than 25°C on the growth and survival, and the effects of various temperature on the different developmental stages, are not known for *A. australis* and were not determined during this study.

8.4.1.8 HEALTH

A wide number of diseases and parasites are know from eels (Gosper 1996), and have been periodically caused serious problems in aquaculture systems in other parts of the world where eels are cultured (Gousset 1988; Heinsbroek 1991). During this study, infestations of two species of ectoparasitic protozoans (*Ichthyobodo* and *Trichodina*) were observed on eels, but these were successfully eradicated by standard therapeutic treatment used at MAFRI, Snobs Creek.

8.4.2 POND CULTURE

Very little comparable work has been done previously with *A. australis* in ponds. Comparisons from the literature in most cases are based in the northern hemisphere under very different environmental conditions and using different species.

8.4.2.1 STOCKING DENSITY AND SURVIVAL

Stocking densities in these trials varied from 1.5 glass eels /m^2 to 6.9 /m^2, with survival rates varying form 77% to 39% and initial weights varied from 0.6 g to 0.2 g.

There is little information to gauge whether this range or some of these results are acceptable, over the time of each trial period. Trials conducted by Jones *et al.* (1983) in a New Zealand study using *A. australis* indicated that at stocking densities of 1 kg of 0.22 g glass eels / m^2 or 4,500 / m^2 they expected 5% survival through to market size of 150 g. While in Japan *A. japonica* is recorded as being stocked in ponds at 2,500 glass eels /m^2 (Usui 1991), with survival to 150 g of 10%. In Taiwan stocking densities may be up to ten times that in Japanese farms while densities in European ponds are much lower at 4 - 10 elvers (not glass eels) /m^2 (Pillay 1993). Survival figures were not indicated for the last two references.

As would be expected, with populations selected from the wild, survival to different stages of production, and 20% - 30% survival post nursery ponds ready for growout has been accepted as viable under Japanese culture conditions (Brusle 1990). It is obvious from the figures presented from overseas experience in commercial operations that stocking densities vary greatly. It is also obvious that the densities used in the Deakin trial were very much lower than accepted commercial densities.

From the survival data collected during these trials (Table 25, Table 26 and Table 27), there is a trend towards higher survival with shorter trial period. Trial 1 ran for three months with a survival of 73% and 77% for supplementary fed (sf) and natural (n) feed, respectively, whereas Trials 2 and 3 ran for six months with considerably lower survival rates. Trial 2, 53% (sf), 39% (n), Trial 3, 50% (sf), 66% (n). This is most likely due to longer exposure to varying water quality problems mainly caused by the development of filamentous algae in trial ponds. Filamentous algae developed in all trial ponds to some extent, however was worst in the ponds with the lowest survival rates. Filamentous algae has many unwanted features in pond culture situations. It reduces the natural agitation of water by wind impairing effective transfer of oxygen to surface and lower depths. Once established it becomes a massive nutrient sink, preventing nutrients added to ponds to stimulate single cell algal production reaching the target algal species and therefore progressing through the food chain to produce zooplankton. Its physical presence has a shading effect again interfering with the natural growth of other algal species. Filamentous algae eventually dies and sinks to the bottom of ponds where it decomposes causing oxygen depletion. During harvest however it exhibits it's worst feature where it blankets the bottom of the pond trapping many eels in the mud. This algae has also been credited with causing problems with the feeding of elvers in ponds in Japan (Pillay 1993).

8.4.2.2 SPECIFIC GROWTH RATES (SGR)

By way of some comparison with the results achieved in the Deakin trials, Pillay (1993) records *A. japonica* are achieving 7 g weight in four months under pond conditions with artificial diets, while Shepherd and Bromage (1988) have reported SGR's for *A. japonica* elvers of 3.1% under what were considered ideal conditions in intensive systems. Survival has not been mentioned with these references. Results from the present study gave SGR's ranging from 1.4% to 1.6%. These results indicate that the Deakin results are probably in the ballpark with results from overseas, keeping in mind the environmental and species differences.

Specific Growth Rates within the three trials show no significant differences between (sp) and (n) regimes over the period of each trial. It appears from Figure 43 that there is generally no difference in growth over the first two to two and a half months of each trial, to where in all cases eels have reached a weight of 2.0 - 2.5 g. From the graphs of a) and b) in Figure 43 from this point there is a trend towards (sf) having a greater influence on growth than (n). The high point in b) of Figure 43 was due to an unusually high proportion of comparatively large eels in the sample taken on that day. With c) from Figure 43 even though the curve for (n) appears to be trending higher than (sf) in the latter part of the trial there is no real difference here.

Trial 3 or c) in Figure 43 was the highest stocking density at 6.9 glass eels /m2. From the growth curves for this experiment it is evident that this stocking density did not have a dramatic impact on (n) feeding regime. Given the very large differences in commercial stocking densities, discussed above compared to those in the Deakin trial the outcome is not a surprise.

SGR's between trials, however, does appear to have some relationship with average temperature for each experiment. From Table 25, (sf), SGR 1.65%, (n), SGR 1.36% mean temp 19^{0}C, Table 26, (sf), SGR 1.55%, (n) SGR 1.51%, mean temp 18^{0}C, Table 27, (sf), SGR 1.37, (n) SGR 1.41, mean temp 14^{0}C. This observation helps explain why, although both Trials 2 and 3 ran for approximately the same time, eels in Trial 2 reached a mean weight almost twice that of Trial 3, 4.0 g and 2.2 g respectively. Another reason for this may have been that the eels in Trial 3 started the trial at a lower start point than those in Trial 2, 0.22 g and 0.69 g respectively.

It is noted that in Figure 43 both a) and b) growth trends downwards towards the end of the trials . This is particularly true of the last sample point in both experiments. The last point is a mean figure of the total harvest from a pond and along with the mean stocking weight figure is the only accurately known mean weight for an trial. Truly random sampling is extremely difficult to achieve on sampling days because of the influence of the weather on residency in refuges and also the effect of dominance hierarchies that establish close to feeders and within refuges.

8.4.2.3 CONCLUSIONS

It was difficult to conclude whether the results of the pond trials in the present study were good or poor because of the pioneering nature of this study in Australia. However, given the vagaries of nature on natural swamps and lakes and the cost of glass eels it is difficult to conceive that there is a case for wild nurseries as apposed to the semi controlled environment of purpose built nursery ponds. The results of the pond trials indicate that there are a lot of management areas that could be improved to effect higher survival and possibly faster growth. Further, investigation could be conducted into such areas as. pond design, refuge structure and number, feeder design and number, harvesting strategies, behavioural studies, grading, stimulation of plankton and diet.

The pond trials indicate that under the conditions of the trials with respect to the given facilities, it could be expected that a similar nursery would be able to grow out supplementary fed pigmented glass eels of an approximate initial weight of 0.3 g to a mean weight of approximately 4 g and with a survival of approximately 50%, over a six month period (given a mean water temperature around 18^{0}C). Such a system would be consistent with conclusions of Skehan and de Silva (1998) in relation to the proposed use of "....intensive and/or semi-intensive rearing of elvers and glass eel in culture

ponds to a larger size which may then be grown-out extensively....". Furthermore, it can be concluded that given the seasonal limitations on semi-intensive production under ambient climatic conditions at these latitudes, the pond culture of glass eels to market size is unlikely to be commercially viable. It is suggested that a cost-benefit analysis comparing production in such a system with tank-based intensive culture under controlled environment conditions is likely to reveal the latter to be more economically feasible for temperate climates as in southeastern Australia.

9 BENEFITS

The principal industry benefits and associated beneficiaries of the key research outcomes from the present study are summarised as follows:

9.1 ASSESSMENT COMPONENT BENEFITS

Identification of significant shortfin glass eel resources, collection locations and key glass eel invasion cues, together with evaluation of the various glass eel fishing equipment and associated techniques, will benefit both existing eel fishers wishing to diversify into commercial glass eel fishing in the future, and potential new entrants to the industry. Although Australian eel fishers are experienced and largely successful at collecting adult, sub-adult and, to a lesser extent, elvers on a fairly routine, cost-effective basis, the same cannot be said for glass eel fishing. Specifically, glass eel fishing expertise is limited to one or two individuals with limited recent experience and with little in the way of reliable, commercially relevant information and/or advice to assist. The research outcomes effectively provide preliminary advice on where, when and how to fish for commercial quantities of shortfin glass eels. Having said this, it should be noted that at the point of completion of this study, harvesting of glass eels for aquaculture seedstock purposes in Australia was limited to exploratory fishing only under scientific research and/or commercial permit conditions, the latter of which vary from State to State. Opportunities to actually undertake such activities as a commercial enterprise therefore are still limited in Australia and are likely to be considered by the relevant State fisheries agencies only on a case by case basis in practice.

Despite such constraints, with eel fishers having the capability to harvest shortfin glass eels, eel farmers and eel fishers with grow-out capability in "culture" waters, potentially have access to a new, additional source of seedstock for commercial production purposes, and therefore will be ultimate beneficiaries. The industry as a whole will have the ability to substantially increase production in terms of both value and quantity, through utilisation of a previous inaccessible resource.

The establishment of standardised CPUE data over an appropriate temporal scale in the Snowy River, and to a lesser extent other SE Australian glass eel collection sites, will provide the industry and state government fisheries resource managers with a useful index to be used as a relative measure of annual recruitment and associated eel standing crop. Such an index will however be most reliable when considered to be part of a suite of production parameters to be measured over an appropriate time frame (>10 years) at a number of sites within the natural range of the species.

9.2 CULTURE COMPONENT OUTCOMES

Development of reliable transport, acclimation, and early rearing techniques (environmental, husbandry, diet, system requirements, health protocols etc) specifically for shortfin glass eels has enabled fish farmers, both existing and new entrants to the industry, to reliably utilise glass eels as a source of commercial eel aquaculture seedstock for intensive production purposes. Moreover, the ability to "value-add" to glass eels through application of initial intensive culture techniques has provided wild fishers with an alternative supply of juveniles for re-stock purposes for enhanced capture fisheries in natural and/or unmanaged grow-out waters.

It is expected that with the implementation of intensive glass eel culture techniques and associated industry investment, the specialist role of weaning and early rearing of glass eels will be accommodated by specific "nursery" operations servicing the weaned glass eel seedstock needs of other industry proponents specialising primarily in growing. The resultant vertical integration of glass eel fishers, nurseries and growout operations would be an appropriate structure upon a viable and productive industry could be based.

The development of intensive glass eel aquaculture in Australia is also likely to have a flow on effect with support industries such as feed companies and system manufacturers benefiting. Many such fundamental requirements will need to be met by imported goods and services in the first instance, but inevitably such imports will encourage competition and therefore production and associated industry at a local level, adding further to the value of the eel aquaculture sector.

9.3 SUMMARY

Benefits and beneficiaries described above are predominantly those described in the original project application. In summary, it is estimated that for every 100 kg of shortfin glass eels harvested annually in Australian waters, an additional value of up to AUD$100,000 or more could be added to the wild fishery and total aquaculture productivity likewise could increase by 50-100 tonnes worth approximately AUD$0.75-1.5 million (farm gate price).

10 FURTHER DEVELOPMENT

Much of the research outcomes from the present study described in this report are deemed to be of a preliminary nature. During the project the spatial and temporal dimensions of glass eel invasions along the east coast of Australia have been better elucidated and shown to be of a broader scale than previously thought. Together with the inherent variability in eel recruitment patterns evident from the present study and from the literature, it is now apparent that a larger scale, more comprehensive and detailed stock assessment is warranted on a broader geographic basis and over a longer timeframe. Such a study would provide managers and industry with a more reliable basis upon which to allocate what is otherwise a limited and increasingly valuable natural resource.

Furthermore, to date there has been no systematic assessment of the related Australian longfin glass eel (*A. reinhardtii*) resource and there is little understanding of the dynamics of shortfin/longfin interactions, particularly in relation to the respective mechanisms of the invasion and migration phase.

The culture component of this project has likewise been of a preliminary nature, with most of the trials necessarily conducted over relatively short-term periods, over limited developmental stages and under predominantly experimental scale conditions. Additionally, there has been no evaluation of the feasibility of longfin glass eel culture and there has been little effort directed at species specific diet development. These issues need to be addressed as priorities in the context of future research and development.

These issues are presently being addressed as part of FRDC Project No. 97/312 entitled:

"Assessment of eastern Australian glass eel stocks and associated eel aquaculture"

This is a three year project, commencing in 1997/98, and is being managed by the Marine and Freshwater Resources Institute (Fisheries Victoria, Department of Natural Resources and Environment). The Project involves collaboration with the Deakin University School of Ecology and Environment, NSW Fisheries, Queensland Department of Primary Industries, and the Inland Fisheries Commission of Tasmania. The objectives for this Project are:

1. To characterise migrations and assess stocks of glass eels in coastal catchments of southern Queensland, NSW, Victoria and Tasmania to enable evaluation of the potential of seedstock supply for Australian aquaculture.
2. To develop pond and tank culture technology for commercial Australian eel production, with an emphasis on the use of eastern drainage Australian glass eel seedstock.
3. To contribute to the development of eel aquaculture industry development plans and fisheries management plans through the provision of relevant information in the form of reports, publications, seminars, newsletters and workshops.

11 CONCLUSIONS

11.1 ASSESSMENT COMPONENT– COMMERCIAL &/OR MANAGEMENT IMPLICATIONS

Based on the results in the present study, probable sustainable commercial harvest levels of Australian shortfin glass eels are difficult to determine. More specifically, insufficient information is available at this stage on the value and associated costs of a commercial glass eel harvest operation in south-eastern Australia in order to determine the economic viability of such an initiative. In many respects it depends on the market value of Australian glass eels, which has also yet to be determined. However, if certain assumptions are made about the potential market value of glass eels, "break even" quantities in Australia, in terms of covering collection costs for commercial fishers, are likely to be in the order of 1.0 kg/net/night (4,500-6,000 pieces, depending on mean weight of glass eels). Such catches were achieved in the Snowy River in the final year of the Project over the main invasion period (mid July-mid September), where glass eel CPUE was in the order of 1000-4000 pieces/net/hour (max. up to 3 kg in one night), and in the Tarwin River in 1995 (1-2 kg/night).

Actual quantities of glass eels collected during the study were relatively small in commercial terms (<20 kgs over three years), most of which were caught in the final year of the project (approximately 17kg). The fact that most glass eels were caught in the final year has as much to do with the increased fishing expertise of the research team and the improved fishing gear and techniques, all resulting from the preceeding efforts as part of the project, as it may have with any inherent biological variability and/or environmental perturbation. It should also be noted that more recent investigations in the Snowy River (FRDC Project No. 97/312; see Chapter 11, Further Development), indicate that much greater quantities of glass eels (>10 kg/night) can be caught at specific times and sites. Furthermore, in other parts of the world, "commercial quantities" of glass eels may be as low as 2 kg/licence holder/year (average return for *A. japonica* harvest in Japan in 1996, as an example).

Due to insufficient data and relatively low numbers of glass eels taken in the surveys within NSW and Tasmanian waters, it is not possible to draw any valid conclusions or even speculate about the nature of stocks in sampled waters in these States. The exception perhaps is that a significant Australian shortfin elver resource exists in the Tamar River, as evidenced by the reliable annual harvest of around 1-2 tonnes at the Trevalyn Power Station (Inland Fisheries Commission, Tasmania), which in turn clearly indicates that an equally significant glass eel resource must also be present periodically. The sheer size of the Tamar estuary however in comparison to the smaller mainland streams suggests that alternative, perhaps larger scale fishing techniques may be required for an effective glass eel harvest in this water.

An estimate of the absolute stock size of Australian shortfin glass eels was not attempted in the present study and is clearly not possible at the present time. Such an estimate, to be reliable, would require more detailed analysis over many years as there is likely to be very large inherent variability in glass eel invasion and migration with any one year and/or at any one location. In general however, it is reasonable to speculate that in Victoria at least, there is a greater chance of more frequent (perhaps annual) glass eel invasions occurring into estuaries within the eastern Gippsland region of the State than elsewhere. This is probably due to the apparent dominance of prevailing "west to east" sea surface currents in Bass Strait at the time of year when most shortfin glass eels appear to invade the estuaries. In other words, assuming that glass eels are transported down the east coast of Australia with the assistance of the East Australian current before attempting to move through Bass Strait in an "east to west" direction, the prevailing currents in Bass Strait might be expected to hinder the natural dispersal of glass eels through to more westerly catchments in Victoria and Tasmania. Furthermore, the degree to which this may occur would be expected to vary between years, subject to a suite of large-scale climatic and oceanic perturbations eg. El Niño phenomena and associated annual sea surface temperature changes.

In the absence of an absolute estimate of glass eel stocks, the establishment of standardised CPUE data over an appropriate temporal scale in the Snowy River, and to a lesser extent other SE Australian glass eel collection sites, should provide the industry and state government fisheries resource managers with a useful index to be used on an interim basis as a relative measure of annual recruitment variability; albeit on a site specific, year by year basis. Such an index will however be most reliable when considered to be part of a suite of production parameters to be measured over an appropriate time frame (>10 years) at a number of sites within the natural range of the species. Indeed the complicated life cycle of the shortfin eel, involving marine and freshwater stages, long maturation period to sexual maturity (>15 years), likely remote spawning grounds (Coral Sea), long larval stage (>150 days), and broad natural distribution (south-eastern Australia), precludes any effective or reliable, quantitative estimates of absolute stock size due to the inherent variability of key population parameters. In short, this means that there is typically very large variability in glass eel invasion and migration events (size, timing etc), in any one year and at any one location. This scenario is consistent with the dynamics of other glass eel fisheries around the world for much the same reasons. Additional assessment measures in Australia should therefore include CPUE data for commercial fishing returns on adult stocks, as well as any other fishery independent stock assessment parameters for as many developmental stages as possible. Given the likelihood of a high degree of genetic heterogeneity of shortfin glass eel stocks throughout what is a broad geographic range distributed over several Australian states, it will also be necessary for a consistent resource management approach to be adopted by the relevant fisheries agencies. This approach likewise will need to be based on conservative risk management principles in the early stages, in the absence of any reliable estimates of absolute stock size, to ensure sufficient escapement of spawning fish in the wild.

11.2 CULTURE COMPONENT - COMMERCIAL &/OR MANAGEMENT IMPLICATIONS

Australian shortfin glass eels are suitable seedstock for commercial production purposes, although the economic viability of specific production systems is not yet determined. System options include extensive (low density) stock enhancement in surface waters (under varying degrees of active management), semi-intensive (medium density) pond production under ambient conditions, and intensive tank production under controlled environment conditions.

Preliminary transport, acclimation, weaning, water quality, environmental, health management and general husbandry protocols are sufficiently established to enable pilot-scale commercial operations. It can be expected that relatively high survival can be achieved (>80-90%) during the initial production stages, although growth under such production protocols is likely to be variable (up to 3.6% body weight/day). At such rates, commercially viable production of marketable eels (eg. 150-200g live weight) from glass eels within 12-24 months is conceivable.

It is apparent that existing technologies developed for commercially established species, such as *A. japonica* and *A. anguilla*, are generally adaptable for *A. australis*, albeit in many cases with some degree of refinement and/or other modification. However, specific improvements in weaning and early rearing diet development for Australian shortfin glass eels, particularly in the use of artificial feeds in the pigmented glass eel stages, are necessary for more efficient production. Although fish mince was used successfully to wean glass eels in the present study, future investigations should focus on the use of locally available fish roe.

Species-specific formulation of diets for Australian shortfin glass eels is likely to significantly improve critical food conversion ratios and to enhance water quality management of culture systems. In the absence of such diets, the use of readily available salmonid-type, extruded pelleted feeds is considered more appropriate than the use of moist "pastes", including those that may presently be imported from Asia. In the present study better results were actually achieved using a combination of natural and paste-type feeds, however the differences were relative to each other, were not

benchmarked against industry "Best Practice" feeds, and were considered to reflect the limitations of the alternative test feeds rather than the inherent advantages of the more successful feeds used in the trials. Also, the wet feeds tended to result in very high FCR's and poor water quality within the culture tanks. Other recommended production parameters include water temperatures (>25^{0}C), and feeding and stocking rates during weaning (9-12% body weight/day and >10kg/m^3 respectively).

In the present study, the use of intensive, tank-based, early rearing techniques has increased the overall survival of glass eels held in captivity to provide the potential for significantly increased numbers of juveniles to be made available to industry for commercial production purposes on an annual basis. With much the same survival in captivity, but with a higher Specific Growth Rate, intensively reared glass eels have the potential to yield a substantially higher total biomass of marketable product over the same time period and under the same conditions, compared with later juvenile and sub-adult eel stages. Further development of more efficient grading protocols, culture tank, water filtration and sterilisation design is necessary however. Based on growth and survival projections from the present study it is conceivable that for every 100 kg of shortfin glass eels harvested annually in Australian waters, total aquaculture productivity likewise could increase by 50-100 tonnes worth approximately AUD$0.75-1.5 million (farm gate price).

Pond production under ambient environmental conditions in south-eastern Australia is likley to be restricted only to relatively short-term, seasonal production, perhaps as a preliminary "nursery" phase for subsequent stock enhancement purposes into public and private surface waters (eg. wetlands, swamps, lakes etc, as deemed appropriate by State-based fishery management plans).

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13 APPENDICES

13.1 INTELLECTUAL PROPERTY

Intellectual property generated from this Project is primarily in the form of research information, including:

- Techniques for locating and harvesting shortfin glass eels in southeastern Australia
- Environmental criteria for targeting glass eel invasions into estuaries
- Preliminary size, condition and catch-effort indices as relative measures of glass eel productivity in different locations
- Techniques for handling and translocating and acclimating shortfin glass eels to freshwater
- Techniques for weaning to and rearing on artificial diets, and husbandry and system requirements for intensive tank and semi-intensive pond production

13.2 STAFF EMPLOYED ON THE PROJECT

Name	%Time
From Marine and Freshwater Resources Institute (formerly Victorian Fisheries Research Institute), Snobs Creek:	
Geoff Gooley	20
Lachlan McKinnon	80
Brett Ingram	35
Richard Gasior	50
Peter Ryder	15
Paul Petraitis	15
Russell Strongman	5
Andrew Pickworth	5
Nathan O'Mahoney	5
Peter Grant	5
Additional technical support (FTE)	25 (casual staff, work experience students etc)
From Deakin University, School of Ecology and Environment, Warrnambool:	
Bob Collins/Dave Wearne	15
Sena de Silva	10
Brendan Larkin	20
Additional technical support (FTE)	20 (students)
From Inland Fisheries Commission, Tasmania:	
Wayne Fulton	5
Frances Ruwald	25
Phil Boxall/Brett Mawby/John Diggle	15