The biology of the Dhufish, *Glaucosoma hebraicum*, in offshore waters on the lower west coast of Australia

By

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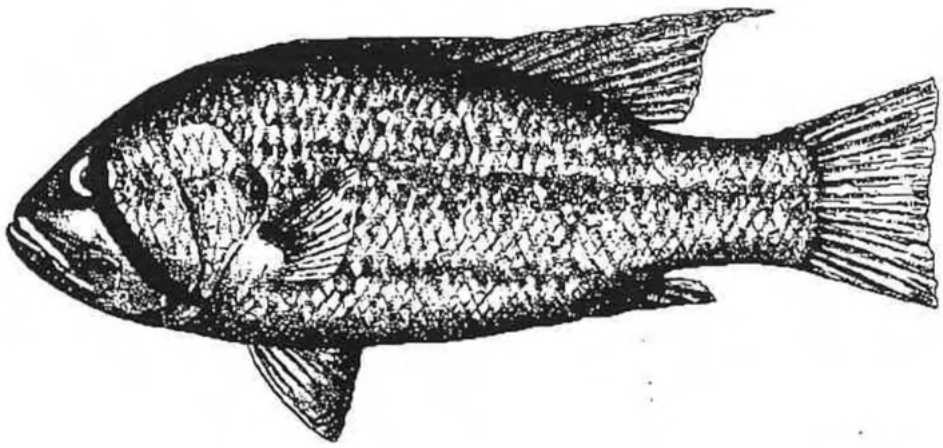

Submitted for the Honours Degree of
Murdoch University

August 1997

DECLARATION

I declare that the information contained in this thesis is the result of my own research unless otherwise cited.

14 August 1997

Abstract

Samples of Dhufish, *Glaucosoma hebraicum*, were collected in each month between May 1996 and May 1997 from the catches of commercial and recreational wetline fishers and commercial trawlers. These catches were taken in the offshore waters of Western Australia near Geraldton (*ca* 28°S) and Perth (*ca* 33°S). Comparisons were made between the number of circuli on scales and the number of translucent zones on sectioned otoliths, and between the number of translucent zones on sectioned and whole otoliths. The number of circuli on scales was often either greater or less than the number of translucent zones on sectioned otoliths of the same fish. The number of translucent zones observed on whole otoliths were the same as on sectioned otoliths for fish with otoliths that have up to six translucent zones. However, the prevalence of underestimates, when using whole as opposed to sectioned otoliths, subsequently increased progressively as the number of translucent zones increased. The mean monthly marginal increments for sectioned otoliths showed a pronounced decline in spring and then a progressive rise during summer and mid-autumn, before levelling off in winter. These trends provide strong evidence that the translucent zones on the otoliths of *G. hebraicum* are formed annually and that their numbers in sectioned otoliths can be used to age this species.

The von Bertalanffy growth parameters, $L\infty$, K and t_0, derived for the growth curves of *G. hebraicum* from length-at-age data were 1038, 0.108 and -0.172, respectively, for females and 1087, 0.109 and -0.219, respectively, for males. Males grew slightly faster than females, attaining total lengths of 234, 448, 688, 832 and 921mm after 2, 5, 10, 15 and 20 years, compared with 212, 405, 626, 792 and 865mm for females at the same corresponding ages. Females and males reached the legal minimum (total) length (LML) for capture of 500mm at *ca* seven and six years, respectively. The maximum ages recorded for females and males were 29 and 35 years, respectively, and the maximum lengths for females and males were 976 and 1120mm, respectively. Although the growth curves of both females and males of *G. hebraicum*

caught in waters near Geraldton were shown by a maximum likelihood ratio test to differ from those of fish caught in waters near Perth, the differences in the von Bertalanffy growth parameters for fish in these two regions were not pronounced.

Macroscopic and microscopic examination of gonads showed that female and male *G. hebraicum* first reach sexual maturity at total lengths of between 250 to 300mm and 350 to 400mm, respectively. Sexual maturity was first attained by females and males at the end of their fifth and eighth years of life, respectively. Histological sections showed that some mature ovaries contained post-ovulatory follicles as well as granular and hydrated oocytes during the spawning period. This provides strong evidence that this species is a multiple spawner. On the basis of the monthly trends exhibited by gonadosomatic indices, gonad maturity stages and different stages in oocyte development, *G. hebraicum* is considered to breed between December and April, with spawning reaching a peak in late January/early February. For this reason, *G. hebraicum* was accorded a birth date of the first of February.

The nematode parasite *Philometra* sp. was found to infect the gonads of *G. hebraicum*. Preliminary studies have shown that the prevalence of infection is far higher in females than males, and that it increases with fish size and age. At the completion of spawning, this parasite can occupy 50% of the volume of the ovary. Thus, since philometrid worms are known to feed on blood, it is possible that the parasite has a deleterious effect on the reproduction of *G. hebraicum*. However, histological sections of ovaries failed to reveal visible signs of egg destruction by the parasite, and nor were there any signs of disruption of normal gonadal development of *G. hebraicum*. Observations of the life cycle stages of *Philometra* sp. throughout the year indicate that the life cycle of the parasite is closely synchronised with the pattern of reproductive development of its host. No fish were infected under the size at which sexual maturity is first reached and there was evidence that infection by the parasite occurs when *G. hebraicum* aggregates during the spawning period, when older, infected fish meet younger, uninfected fish.

Since female and male *G. hebraicum* reach first sexual maturity at total lengths of between 250 to 300mm and 350 to 400mm, respectively, this means that the majority of both female and male *G. hebraicum* have had the opportunity to spawn at least once before they reach the LMLof 500mm. However because almost all Dhufish caught in waters >30m die upon release after capture, this species is subject to fishing mortality before they reach the LML. Therefore, in terms of fisheries management, there would be little value in maintaining a legal size limit for this species. Future management strategies for maintaining stocks of this recreationally and commercially important and heavily-fished species could include reducing fishing pressure in heavily-fished areas and closing from fishing certain areas of known high population density of *G. hebraicum*. However, for conservation purposes, further research is needed to determine locations of high population densities of Dhufish that could be restricted from fishing, and the migratory patterns of this species.

Future studies involve the collection of a greater number of small *G. hebraicum* (*i.e.* <300mm), to provide more points for the commencement of the growth curve, more data for determining marginal increment trends in fish with otoliths containing one or two translucent zones, a more precise estimate of the size and age at which females and males reach sexual maturity, and the habitats of these small fish. An histological study of spermatogenesis would improve and consolidate the reproductive data already obtained for males and provide additional information for aiding the aquaculture studies presently being carried out on this species. Further investigations of *Philometra* sp. infection in *G. hebraicum*, including a comparison of the fecundity of parasitised fish and unparasitised fish, may provide information on the effects of this parasite on the reproduction of Dhufish.

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ACKNOWLEDGMENTS

I would like to express my gratitude to Prof. Ian Potter for giving me the opportunity to undertake this study and for his encouragement, guidance and editing of the manuscript. Special thanks to all the members of the Murdoch Fish Group for their encouragement, support and friendship. In particular, Dr Glenn Hyndes, for general assistance and help in the collection of samples, Gavin Sarre for his assistance in reproductive staging and statistical analysis, Margaret Platell and Fiona Valesini for their invaluable advice and critical reading of the manuscript, Glen Young for assistance in preparing the plates, and Simon DeLestang for assisting, at times, with "computer problems!" I would like to further thank Dr Glenn Hyndes and Professor Ian Potter and Dr Howard Gill for giving me the opportunity and assistance to complete three ISCs prior to the commencement of this study.

I thank the Fisheries Research and Development Corporation (FRDC), the Fisheries Department of Western Australian and the Recreational Fishing Advisory Committee for the funding of this project which made it possible.

Sincere thanks to the many people in the fishing industry who made the collection of samples possible. These include the staff and workers at Sealanes Fish Market and Festival Fish Market, in particular Paul, Toby and Daryl at Sealanes, and the members and organisers of the Marmion Angling and Aquatic Club and the Mandurah Offshore Fishing Club. In addition, many thanks to commercial fishers for their assistance in the collection of small (under legal size) Dhufish and also for many valuable conversations regarding the project, namely, Warren Aitchison, Barry Stone, Franz VanderPoll, Mark Jurinovich, Glenn Dunstan, Dean Jenson, Ron Lopresti, Ian Riggs and Frank Mazzeo. Further thanks to Barry Stone and Bob Stone for taking me fishing and hence improving my knowledge of the industry. Further, I thank Ron Lopresti, in particular, for his friendship and for his interest and assistance in this project, which included many trips spent fishing in search of juvenile Dhufish, and all the fish trap trials.

I thank Dr. Brian Jones at the W. A. Department of Agriculture and Dr. Russel Hobbs at the Veterinary Science School of Murdoch University for their expertise in identification of the nematode parasite, *Philometra*.

Sincere thanks to Gordon Thomson for preparing all of the histological sections of the gonads (and many photography lessons!).

Finally, I would like to thank my family, and most of all, my father, for his interest, help in collecting samples and editing of this manuscript, and for his financial and loving support throughout all of my studies.

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1: Introduction

1.1. The Leeuwin Current

The Leeuwin Current exerts a major influence on the coastal and offshore marine environments of Western Australia. This current also exerts a major influence on the distribution of coral reefs along the coast of Western Australia (Hatcher, 1991; Hutchins, 1991). It consists of a narrow (<200km), shallow (<200m), relatively warm, low salinity and low nutrient current of oceanic water of tropical origin, which flows down the outer continental shelf of the Western Australian coast (Hatcher, 1991). Many of the requirements for coral reef accretion are the factors which are strongly influenced by the Leeuwin Current. These include (a) a consistent supply of, mostly planktonic, larvae of reef-binding and infilling plants and invertebrates, (b) non-lethal sea temperatures and salinities, (c) adequate irradiance for positive net daily photosynthesis by symbiotic and free-living algae, (d) adequate supplies of inorganic nutrients to meet the demands of autotrophic organisms for growth and calcification and, (e) low concentrations of inorganic and organic particulates in the water column which otherwise inhibit coral growth by shading, smothering, and promoting bacterial infection (Hatcher, 1991). The tropical water delivered by the Leeuwin Current interacts with southern Indian Ocean water delivered by the West Wind Drift. The outcome of this interaction determines whether or not the conditions for coral reef development are favourable. Conditions for the development of coral reefs are good where the mixing of the water bodies is weak and the Leeuwin flow dominates. Conditions for coral reef development are poor where mixing is rapid and the Leeuwin flow is diluted and dissipated in its interaction with other water masses (Hatcher, 1991). Four major and two minor coral reef systems on the west Australian coast are influenced by the Leeuwin current, namely, the Rowley Shoals, the Dampier Archipelago and adjacent reefs of the Pilbara coast, the Ningaloo Reef tract and

adjacent reefs, the Houtman Abrolhos reefs and adjacent banks and the Pocillopora reefs at Rottnest Island (Hatcher, 1991).

The effects of the Leeuwin Current differ markedly from those of other current systems in the southern hemisphere. For example, the Humbolt and Benguela currents, the two major eastern boundary currents recognised in the southern hemisphere, result in the upwelling of cool nutrient-rich water. This leads to high rates of primary production, *i.e.* high phytoplankton biomass, which accounts for the presence of substantial populations of pelagic planktivorous fishes in these upwelling systems (Lenanton *et al.*, 1991). In contrast, the warm, low nutrient water flowing into continental shelf waters, due to the Leeuwin Current, results in lower primary production. Although similar planktivorous fishes occur in the Leeuwin Current to the Benguela Current, the commercial catches of these are far smaller in the former current. Indeed, demersal crustacean species that are dependent on benthic production, such as the rock lobster, *Panulirus cygnus*, and prawns, *Penaeus* spp., dominate the commercial fishery in the Leeuwin current system (Lenanton *et al.*, 1991). Demersal fish species such as the Dhufish, *Glaucosoma hebraicum*, and pink snapper, *Pagrus auratus*, are an important component of the offshore fishery (Pink, 1995) and are probably the two most important offshore recreational species in Western Australia.

1.2. *Glaucosoma hebraicum*

Glaucosoma hebraicum (Richardson, 1845) is one of only four verified species of the small monogeneric family Glaucosomatidae (Allen & Swainston, 1988). All four of these species occur in Australian waters. The following account of these species is taken from Sudmeyer *et al.* (draft document, 1992).

(1) *Glaucosoma hebraicum* (West Australian jewfish or Dhufish), is characterised by a silvery grey body with a black line through its eye, that is often indistinct in large fish. Juveniles of *G. hebraicum* also have dark body stripes, which usually disappear in

the adult (Plates 1a,b). *Glaucosoma hebraicum* is a large species, which grows to a maximum total length of 1200mm and a maximum weight of 26Kg. The distribution of *G. hebraicum* in Australian waters is confined to south-western Australia, ranging from the Recherche Archipelago off the southern coastline to Shark Bay in the north. Dhufish occur in inshore waters to the inner edge of the continental shelf (10-200m depth) (see also, Cusack & Roennfeldt, 1987; Starling, 1992).

(2) *Glaucosoma burgeri* (deep sea jewfish) is caught northwards from Onslow (just to the north and east of Exmouth Gulf), on the North West Shelf of Western Australia. The deep sea jewfish is closely related to *G. hebraicum*, but is distinguished from that species by the presence of a single dorsal fin, a large eye and narrow stripes which may disappear in larger fish.

(3) *Glaucosoma magnificum* (threadfin pearl-perch), is distributed northwards from Exmouth Gulf, through northern Australia and in New Guinea. It is of similar morphology to *G. burgeri*, but has elongate dorsal fin filaments and brown bars on the head.

(4) *Glaucosoma scapulare* (pearl perch), differs from *G. hebraicum* by not possessing a dark line through the eye. A dark blotch is usually present at the top of the gill opening. This species is restricted to the deep waters (>50m) along the southern coast of Queensland to northern New South Wales.

Two species of *Glaucosoma* have been recorded as occurring in Japan and Taiwan, namely *G. hebraicum* and *G. fauvelii*, although it has been suggested that the smaller-striped *G. fauvelii* may be the juvenile stage of *G. hebraicum*.. Furthermore, the presence of G. hebraicum in these waters has not yet been verified.

In Australia, *G. hebraicum* is sometimes confused with the mulloway, *Argyrosomus japonicus* (Griffiths and Heemstra, 1995), an unrelated species frequenting the same waters and known in the eastern states as jewfish (Allen & Swainston, 1988; Starling, 1992).

Glaucosoma scapulare is the only species of Glaucosomatidae other than *G. hebraicum* for which there is any biological information. This species grows to a maximum fork length of 650mm and reaches a maximum age of at least 14 years. Female *G. scapulare* reach sexual maturity at a fork length of 250 to 300mm, and have a spawning period that extends between October and May (W. Sumpton, - Southern Fisheries Centre, Queensland, pers comm).

Glaucosoma hebraicum supports a lucrative commercial fishery and a recreational fishery which is similar to or greater in size than the commercial catch (Sudmeyer *et al.*, 1992). In the 12 months up to July 1987, it was estimated that 300,000 people went fishing recreationally in Western Australia, of which 60,900 fishers targeted Dhufish. Furthermore, *G. hebraicum*, in conjunction with the snapper *Pagrus auratus*, was the fourth most sought after finfish in Western Australia in 1987 (Pink, 1990). Most of the commercial fishery is located on the lower west coast, between Jurien Bay and Geographe Bay. *Glaucosoma hebraicum* is the most valuable of Western Australia's finfish, with a current retail value of $15.50 per Kg of whole fish and $29.95 per Kg of boneless fillets, which correspond to wholesale values of $11.50 and $26.50 per Kg, respectively (price on 22 July, 1997, at Sealanes Fish Market, W. A.). *Glaucosoma hebraicum* had a total commercial value of $1.5m in the 1994/95 season.

The catches of *G. hebraicum* have declined in the past few years. For example, the total seasonal commercial catches of *G. hebraicum* in the 1986/87 to 1988/89 seasons were between 206-216 tonnes, whereas in the 1992/93 to 1994/95 seasons they were between 167-173 tonnes (Pink, 1990, 1995). Commercial fishers report that they now have to move much further offshore to catch *G. hebraicum*, and that the increased travelling time, together with presumably a decreased abundance of the species, means that the time taken catching a given weight of this species has increased by 4-6 times over the last 20-30 years. Furthermore, the decline in catches of *G. hebraicum* has forced some commercial fishers to diversify their activities, such as chartering their boats. Recreational fishers have also expressed concern over the apparent decline in *G. hebraicum*. Members

of angling clubs consider that the abundance and maximum length of Dhufish they catch have declined in recent years, and many feel it necessary to fish further offshore to catch this species. In an effort to conserve *G. hebraicum*, one major angling club in Perth, the Mandurah Offshore Fishing Club, has now removed this species of fish from the list considered for prizes for its annual "fishing classic" competition.

Despite its high value, both as a commercial and recreational species, little is known about the biology of *G. hebraicum*. Despite this, studies are currently being conducted by researchers at the Fremantle Maritime Centre in an attempt to aquaculture this species, which they have already managed to breed successfully in captivity (G. Jenkins - pers comm). In the last few years, a series of small-scale studies on the biology of this species were conducted by third-year undergraduate students at Curtin University.

Analysis of translucent zones in whole otoliths in Curtin University studies indicate that this species attains a length of *ca* 300mm at the end of the first year of life (at 1+ years of age), 400-450mm at 2+, 520mm at 3+, 590mm at 4+, 650mm at 5+ and 710mm at 6+, and that it may live for at least 20 years (Sudmeyer *et al.*, unpublished document, 1992). However, no attempt was made to either section the otoliths to determine whether all of the translucent zones could be detected in whole otoliths or to validate that each of the translucent zones were formed annually. Furthermore, no growth parameters, such as those derived using the von Bertalanffy growth equation, were calculated from the data. Reproductive data suggest that *G. hebraicum* has a protracted spawning period, extending from December to March. However, since no detailed histological studies were carried out on the gonads, it is not clear whether this estimate of the breeding period was accurate and/or precise. There are also no data on whether *G. hebraicum* spawns more than once in a spawning season. The limited available evidence suggests that female and male *G. hebraicum* reach sexual maturity at approximately 520 and 580mm, respectively (Sudmeyer *et al.*, unpublished document, 1992). Dietary studies suggest that *G. hebraicum* are piscivorous, with a diet consisting mainly of reef-dwelling fish,

particularly wrasses, and, to a lesser degree, various species of crustaceans and molluscs (Sudmeyer *et al.*, 1992).

1.3. Ageing of fish

The age of a fish is usually determined by counting the number of annually-formed growth zones in hard tissues, such as scales, otoliths and other cartilaginous or bony structures (Bagenal & Tesch, 1978, Campana & Neilson, 1985; Fenton & Short, 1992). The occurrence of annual rings in hard structures is associated with differences in the proportions of protein and calcium deposited during alternating slow and fast phases of growth, *i.e.* in the autumn/winter and spring/summer periods, respectively (Campana & Neilson, 1985). In general, the opaque zones, which consist of a large amount of protein, are formed during the fast growth phase, whilst hyaline zones, which consist largely of calcium, form during the slow growth phase (Casselman, 1974). If only one opaque and one hyaline zone forms in each year, each zone corresponds to an annual zone (Beamish & McFarlane, 1983).

The main advantage of using scales for determining the age of fish is that these hard structures can be collected and examined more easily than other hard structures (Bagenal & Tesch, 1978). However, age assessments using scales, are often extremely variable and evidence is accumulating that this method of ageing is unreliable (Casselman, 1983; Beamish & McFarlane, 1983, Booth *et al.*, 1995). Furthermore, many species have regenerated scales, which thereby produce inaccurate estimates of age (Simkiss, 1974).

Three types of otoliths are present in the heads of fish. The sagittal otoliths are the most commonly used for ageing because they are usually relatively larger (Bagenal & Tesch, 1978). Otoliths can be examined whole, or after they have been sectioned, cracked, burnt or stained (Pannela, 1974). The age of the older fish of some species can be underestimated, when using whole otoliths, because of the difficulties in reading the outer growth rings caused by allometric growth of the otolith (Pannella, 1974). As sectioning is time consuming, many workers make preliminary comparisons between the results

obtained through counting growth zones on both whole and sectioned otoliths of a wide size range of fish. If there are discrepancies between the number of zones on whole and sectioned otoliths, such comparisons enable determination of the length of fish at which such discrepancies between age assessments begin to occur. Thus, the age of fish smaller than this length can be accurately determined using whole otoliths, whereas the age of larger fish has to be determined using sectioned otoliths (Campana, 1984; Hyndes *et al.*, 1992a).

A major requirement for all ageing studies is that the growth zones used for ageing are validated as having been formed annually (Beamish & McFarlane, 1983; Casselman, 1987; Faragher, 1992; Fenton & Short, 1992; Francis *et al.*, 1992; Hyndes *et al.*, 1992b). The failure to do so by many researchers in the past has sometimes lead to a gross misunderstanding of the biology of some species (Beamish & McFarlane, 1983). Several methods are used to validate age estimates. One method is the analysis of poly-modal length-frequency progressions. However, in the case of long-lived species, this method is of limited value, and is only appropriate for juveniles (and possibly young adults), as the modes of the different cohorts tend to merge as the fish increase in size and age, due to the typical allometric growth pattern observed for teleost fish (Gooley, 1992; Stewart *et al.*, 1992; Gordon & Swan, 1996). Another method commonly used to validate the annual formation of growth rings in hard structures is the 'labelling' of calcified tissue, which involves the capture, tagging and then injecting of a label (for example, tetracycline) and subsequent recapture of the fish such that the period between capture and recapture is known (partly known age). The labelling compound leaves a temporal mark in all calcareous structures, and thus, if the number of growth zones corresponds to the partly known age, the ageing technique is assessed as valid (Casselman, 1983; Casselman, 1987). This method is not, however, applicable for species living in deep water, since fish from these depths die when they are brought to the surface or upon release, due to the large difference in pressure between the bottom and surface of the water column (Stewart *et al.*, 1995; Gordon & Swan, 1996). Another common method used for validating that the

growth zones on calcified tissue are formed annually is marginal increment analysis (Maceina & Betsill, 1987). The marginal increment is the distance outside the outer translucent zone. If the outer opaque and translucent zones are formed annually, the marginal increment should undergo a decline and then a progressive increase only once during each year (Hyndes *et al.*, 1996).

The ageing of fish is crucial for providing the type of data that can be used for determining the pattern of growth. It is also important from the point of view of managing fisheries since it enables the age (as well as length) at first maturity to be determined. Such data can then enable fisheries managers to put in place legislation to prevent a species from being fished until it has reached a certain length and thus age. Alternatively, it can be used to select the approach size and age at which a species may not be fished. In addition, determining the age and growth correctly can ensure reliable stock assessments, thereby assisting in conservation and allowing sustainable utilisation (Hyndes *et al.*, 1992b; Booth *et al.*, 1995).

1.4. Methods of assessing the reproductive cycles of fish

Determination of the age and size at first sexual maturity, the duration of the spawning season and fecundity, require knowledge of the stage of gonadal development of individual fish at different ages and lengths and at different times of the year (West, 1990). Many methods are used for assessing the gonad stages of fish. These include the use of gonadosomatic indices (GSIs), which is the direct comparison of gonad weight to whole body weight, the macroscopic staging of gonads, which can be used to assign a specific stage for the gonad of each fish based on visual appearance of the gonad, and the measurements and histological appearance of oocytes, which demonstrate precisely whether or not the fish is in spawning condition (microscopic staging).

In general, the size of the gonad of a fish increases with the stage of gonadal development, and with the fish size and/or age (West, 1990). The trends shown by the

mean monthly values for the gonadosomatic index provide a useful indication of seasonal trends in gonad maturation, and may also provide an indication of the spawning strategy of the species. However it is an unreliable indicator of the later stages of maturation and is not independent of fish size (West, 1990). The main criteria for the macroscopic staging of ovaries is the overall size of the gonad, and whether the oocytes are visible through the ovarian wall and are opaque (yolked) or translucent (ripe). Macroscopic staging relies heavily on the experience of the observer. Therefore, this technique should be backed up with additional measures of ovarian development. Oocyte measurements (commonly the size of the largest oocyte or group of oocytes), together with the stage of those oocytes, are a proven technique for the assessment of ovarian maturation. Furthermore, oocyte size-frequency distributions provide an insight into the dynamics of oocyte maturation but have limited predictive value for estimating spawning duration or frequency (West, 1990). Histology is the most detailed and accurate method for assessment of gonad stage, but it is also the most time consuming. Ideally, several techniques should be used together, to improve the reliability of results (West, 1990). These methods, when used in combination, can provide sound data on the spawning period and also the size and age at which sexual maturity is first reached by each sex (Bagenal & Braun, 1978; Pitcher & Hart, 1982).

1.5. *Philometra*

Parasitic nematode worms of the genus *Philometra* (Family Dracunculoidea) commonly occur in the gonads and other visceral organs and serosa of marine fishes (Snieszko & Axelrod, 1970). Philometrid worms feed on blood and sometimes have marked pathological effects. For example, *Philometra* sp. can virtually destroy the gonads of sexually-mature *Pomatomus saltatrix*, thereby reducing reproductive potential (Williams & Jones, 1994). *Mugil cephalis* infected with philometrid worms with heavily-infected ovaries were strongly swollen, with most developing ova atrophy. Ovarian tissue showed fibrosis, increased numbers of granulocytes, haemorrhages and a progressive

deposition of black pigment (Snieszko & Axelrod, 1970). The ovaries of skipjack tuna, *Katsuwonus pelamis*, were greatly damaged by the infection of philometrid worms, with one ovary containing *ca* 68,000 larvae, resulting in the destruction of most of the eggs (Snieszko & Axelrod, 1970).

Oliva *et al.* (1992) found that only the sexually mature representatives of *Paralabrax humeralis* (Serranidae) were infected by a *Philometra* spp. They thus concluded that this is evidence for a relationship between first maturity and the infectious process, and also provided a description of the mechanism for infection. Infection can occur when fishes arrive at spawning aggregations. Fishes that arrive for the first time in a spawning aggregation (at first sexual maturity) join older fishes, that have already spawned several times. Viviparous larvae can be expelled in conjunction with sexual products of infected, mature fish and these larvae then actively penetrate another host (Oliva *et al.*, 1992).

Philometrid species infect the gonads of some fish species, which co-occur with *G. hebraicum*, including coral trout *Plectropomus sp.* (Glazebrook *et al.*, 1988), and pink snapper *Pagrus auratus* (Sharples & Evans, 1995): Preliminary inspection of the male and female gonads of *G. hebraicum* showed that a high proportion of these were infected with parasitic worms that were later identified as *Philometra* sp.

1.6. Objectives of the study

The aforegoing review demonstrates that the data available on the biology of *G. hebraicum* is fragmentary and, in the case of the ageing studies, was based on growth zones that had not been validated as being formed annually. The overall aim of the present study was therefore to provide reliable qualitative data on aspects of the biology of this species, and particularly those that are crucial to the development of future management plans for this important commercial and recreational fish species. In the context of

management, particular emphasis is placed on determining the length and age at first maturity and the duration of the spawning period.

The first individual aim was to determine the best hard structures to use for ageing *G. hebraicum* and to validate that the growth zones in those structures were formed annually. This part of the study will include a preliminary comparison between the number of growth zones in scales with those in sectioned otoliths, and between those in whole and sectioned otoliths. Those growth zones, that have subsequently been demonstrated as being formed annually, will then be used to age individual fish, and to describe the age structure of the population of *G. hebraicum*. The von Bertalanffy growth parameters will then be determined for both female and male fish to describe the pattern of growth. Comparisons will be made between the age structures and growth rates of *G. hebraicum* in two areas at different latitudes along the lower west coast of Western Australia to determine whether differences in temperatures or other variables in those regions are reflected by differences in growth.

Both macroscopic and histological techniques will be used to examine the gonads of *G. hebraicum*. The data obtained will be used to determine the time and duration of spawning, the size and age at which *G. hebraicum* become sexually mature and the proportion of females to males, *i.e.* the sex ratio.

The prevalence of *Philometra* infection, and the life cycle stages of this parasite present in the gonads of *G. hebraicum* will be investigated focusing on comparisons between sexes and at different lengths of fish and different stages of maturity. Macroscopic and histological investigations of the gonads will be used to determine whether the parasites are likely to have a detrimental effect on the reproduction of *G. hebraicum*, and to obtain preliminary information on the life cycle of this parasite.

Catch data from a recreational boat survey conducted by the Fisheries Department of Western Australia, covering over 70 boat ramp sites along the coast of Western

Australia, will be incorporated with data in this study to determine whether the size attained by fish differs with latitude.

2: Materials and Methods

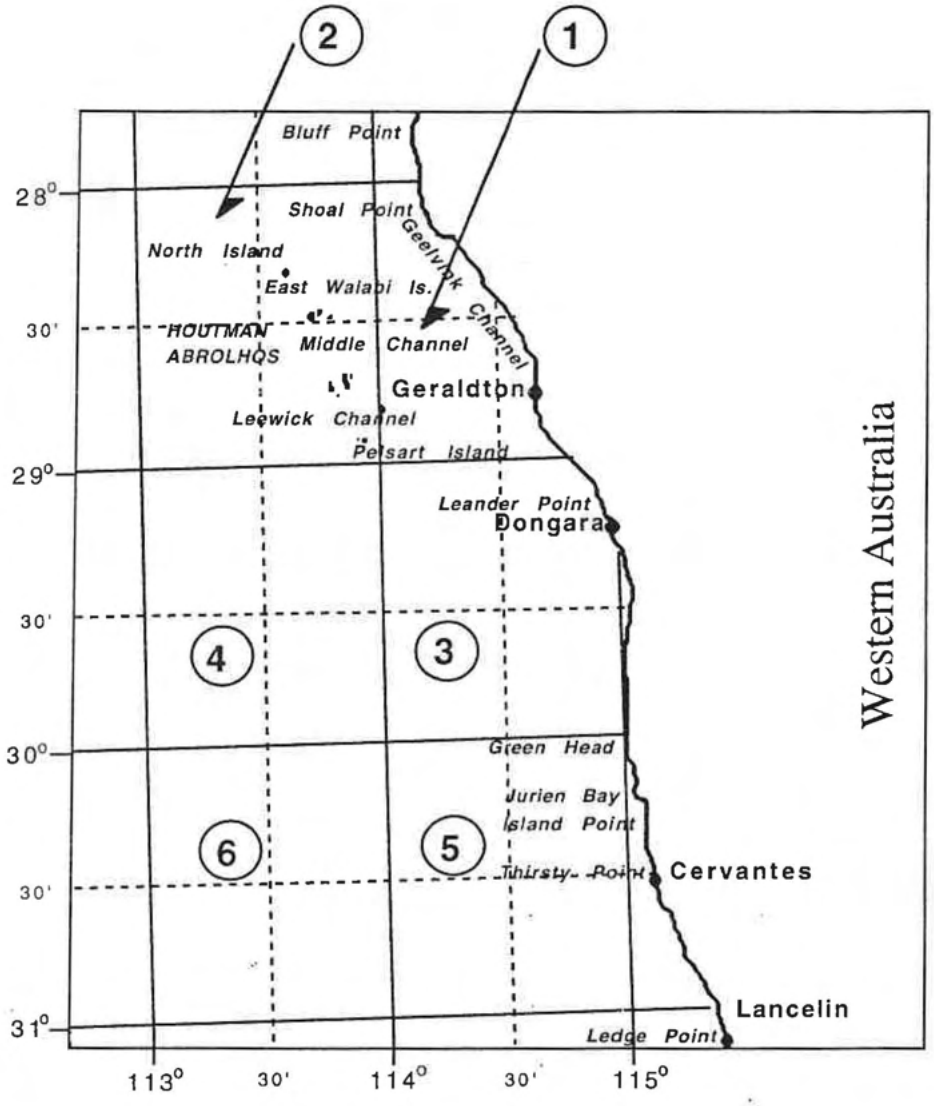
2.1. Sampling

Representatives of *Glaucosoma hebraicum* were obtained in thirteen consecutive months (May 1996 to May 1997) from the catches obtained through commercial trawling and commercial and recreational line fishing in deep water (>20m) off the coast of Western Australia between Perth (*ca* latitude 31°55'S) and Geraldton (*ca* latitude 28°45'S) (see Fig.1a,b). The fish were retrieved from fish processing plants and from "weigh-ins" at local recreational fishing club competitions. The date and region of capture of all fish were recorded. Undersized fish, *i.e.* those below the legal minimum length for capture (LML) of 500mm, were collected from commercial wetline and trawl fishers under a special research collection permit issued by the Western Australian Department of Fisheries.

The numbers and lengths of each sex of *G. hebraicum* were recorded during a large scale boat survey of recreational fishing conducted by the Fisheries Department at the same time as the current study. That study covered over 70 boat ramp sites between latitudes 26°S and 34°S on the West Australian coast. The data from that study are incorporated with those obtained during the present study in an attempt to determine the numbers and sizes of Dhufish that are caught in different regions along the West Australian coast.

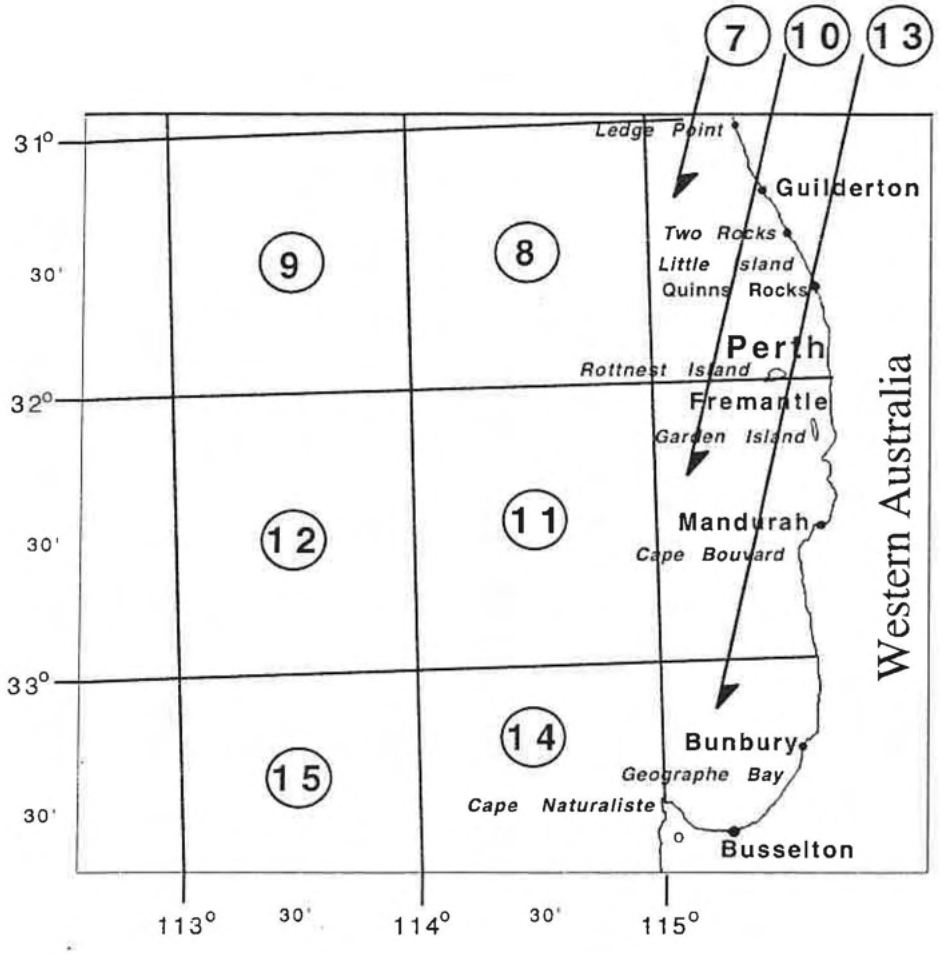
2.2. Laboratory Procedures

The total length and weight of *G. hebraicum* were measured to the nearest 1mm and 1g, respectively. Large fish (>500mm) were weighed on site to the nearest 10g. The weights of those large fish which could not be weighed on site were estimated from the regression equation relating the weight of this species to its length (see results).



Black shading represents area of Australian coastline in map. Numbers denote assigned area codes. N.B. most samples were collected from areas 2 and 3.

Figure 2.1a. Bluff Point (Nth. of Geraldton) to Ledge Point (Sth. of Lancelin). Assigned area codes for samples of Glaucosoma hebraicum from the lower west coast of Australia.



Shading represents area of Australian coastline in map. Numbers denote assigned area codes. N.B. most samples were collected from areas 7,8,10, and 11.

Figure 2.1b. Ledge Point (Guilderton) to Cape Naturaliste (Bunbury). Assigned area codes for samples of *Glaucosoma hebraiucm* taken from the west coast of Australia.

2.3. Age and Growth

A minimum of three scales per individual were removed from underneath the pectoral fins of over 200 *G. hebraicum* caught in the first five months of the study, *i.e.* between May and September, 1996. All scales were then mounted between two glass slides and examined under a light microscope. The growth zones (circuli) on the scales of *G. hebraicum* were often highly irregular or completely undetectable and many scales showed signs of regeneration. Counts of circuli were thus taken from the scales of only 100 of these fish, which showed relatively clearer zoning patterns and had no visible signs of regeneration. Counts of the number of circuli on scales and the number of translucent zones on whole otoliths (see below) removed from the same fish were compared.

Sagittal otoliths were removed by a horizontal incision in the head, just above the level of the eye. They were then cleaned, dried and stored in paper envelopes. Preliminary examination of otoliths showed that the growth zones in the otoliths of large fish were so numerous and closely spaced that they were difficult to distinguish from one another. An examination of whole and sectioned otoliths, from a wide size range of fish, was therefore carried out to determine whether the resolution of the growth zones was improved by sectioning. Whole otoliths were placed in methyl salicylate and examined microscopically under reflected light (see Hyndes *et al.*, 1992a; Hyndes *et al.*, 1996). In contrast, the otoliths used for sectioning were mounted in (clear) epoxy resin and then cut into 0.4 mm sections using a low speed diamond saw (Bueler). These sections were then ground using fine carborundum paper and mounted on glass slides using DePX mounting medium. The otolith sections were examined under reflected light using a dissecting microscope linked to a video camera (Panasonic WV-CD20). The image was analysed employing the computer imaging package Optimus 5.1a. Since more translucent zones could be detected in the otoliths of larger fish after sectioning, the otoliths of all large fish were sectioned. To maintain consistency in the method used to measure the marginal increment (for definition see below) of all otoliths, it was decided also to section the otoliths of small fish.

The number of translucent zones on each sectioned otolith was recorded. The distance between the outer edge of the outermost translucent zone and the periphery of each otolith known as the marginal increment, was then measured. Measurements were always made perpendicular to the translucent zones and were recorded to the nearest 0.01mm. Furthermore, whenever possible, marginal increments were measured along the same axis, in the same region of each otolith (Fig.3). The computer imaging package Optimus 5.1a was used for measuring marginal increments, thereby enabling measurements to be made more accurately than could be achieved by eye using a microscope. Indeed, the marginal increments in the otoliths of even old fish (20+ years) could be determined with confidence. The marginal increment is expressed either as a percentage of the distance between the focus and the outer edge of the translucent zone, when only one translucent zone is present, or as a percentage of the distance between the outer edges of the two outermost translucent zones, when two or more translucent zones are present (see Hyndes *et al.*, 1992a; Hyndes *et al.*, 1996). The monthly trends exhibited by the mean marginal increments were examined to ascertain whether they underwent only one pronounced decline in each year, which would demonstrate that each translucent zone was formed annually and could thus be used for ageing. This validation technique is widely employed by fish biologists in ageing studies (Campana, 1984; Barbieri *et al.* 1994). Furthermore, preliminary comparisons were made between the counts of the number of translucent zones that could be detected on sectioned otoliths taken from a large size range of fish, between an experienced age reader of otoliths (Gavin Sarre - Murdoch University Fish Research Group) and those of the author.

The mid-point of the peak-spawning period, which was estimated from the trends shown by the gonadosomatic indices and by gonadal and oocyte development, was used to assign a birth date to Dhufish (see Hyndes *et al.* 1996). von Bertalanffy growth curves were then fitted to the individual lengths of females and males at the estimated age at capture by a non-linear technique (Gallucci & Quinn, 1979), using a non linear sub-

routine in SPSS (SPSS Inc, 1988). The von Bertalanffy equation is $L_t=L_\infty [1-e^{-kt(t-t_0)}]$, where L_t is the length at age t (years), L_∞ is the mean of the asymptote predicted by the equation, K is the growth coefficient and t_0 is the hypothetical age at which fish would have zero length, if their growth had followed that predicted by the equation. The growth of females was compared to that of males, using a likelihood ratio test (see Kimura, 1980).

2.4. Reproduction

Those gonads, which could be identified as either testes or ovaries, were removed and weighed to the nearest 0.01g. Each gonad was then assigned to one of the following stages, using the criteria of Laevastu (1965) : I = virgin; II = maturing virgin; III = developing; IV = maturing; V = mature; VI = spawning; VII = spent. Gonadosomatic indices (GSI) were then determined from the equation W1/W2 x 100, where W1 = wet weight of gonad and W2 = total weight of fish. Ovaries of up to 10 large females and males collected in each month were placed in Bouin's fixture for 24h, and then dehydrated in 70% ethanol and embedded in paraffin wax. Transverse sections (6μm) of the mid-region of each ovary were then triple stained in Mallory's trichrome. The circumferences of 30 oocytes, that had been sectioned through the nucleus, were measured to the nearest 5μm using Optimus 5.1a. This measurement was used to calculate the mean diameter of each oocyte. The terminology for the oocyte stages follows that given by Khoo (1979).

During the course of this study, it was observed that parasites were often present in the gonads of *G. hebraicum*. These parasites were identified, and their prevalence recorded separately for females and males. Histological sections of the gonads of both parasitised and unparasitised fish were examined to determine whether there were any indications that the presence of these parasites has a deleterious effect on gonadal development and hence, in the case of females, the potential fecundity of Dhufish.

N.B. Since histological slides were required to examine the gonads of parasitised fish, it was not possible to dissect out and weigh the gonads and parasites separately, as

dissection would have caused such damage to the parasites and gonads that they would have been rendered useless for histology, and thus for the histological examination of the possible effects of parasites on adjacent oocytes.

3: Results - Age and Growth

3.1. Comparisons between the number of growth zones in scales and whole and sectioned otoliths.

The number of translucent zones observed in sectioned otoliths with up to six such zones were the same as those on the corresponding otoliths prior to sectioning (Fig 3.1). However, the prevalence of differences between the number of translucent zones detected prior to and after sectioning subsequently increased as the number of translucent zones increased. In all cases where there were discrepancies, the number of translucent zones observed were greater after sectioning than prior to sectioning. In such cases of disparity, the underestimates using whole otoliths rose from one in those otoliths with seven to nine translucent zones after sectioning to between one and seven in those otoliths with 10-21 translucent zones after sectioning, and, in some cases, exceeded eight in those otoliths with $\geq$ 22 translucent zones after sectioning.

The circuli in scales were far more difficult to detect than was the case with translucent zones in either whole or sectioned otoliths. Furthermore, there was a very poor correspondence between the number of circuli observed in scales and the number of translucent zones recorded in sectioned otoliths (Fig. 3.2). Thus, in some cases, scales yielded overestimates and in other cases underestimates, compared with the number of translucent zones revealed by sectioned otoliths. Furthermore, the discrepancies in counts between scales and sectioned otoliths were sometimes as great as five to seven.

3.2. Marginal Increments

The mean monthly values for the marginal increment on those otoliths with 2-5 translucent zones rose from *ca* 0.5 in May 1996, to a maximum value of *ca* 0.7 in September, 1996, before falling sharply to *ca* 0.2 in October (Fig. 3.3). Subsequently, the mean marginal increment rose progressively to *ca* 0.5 in the following May. The trends

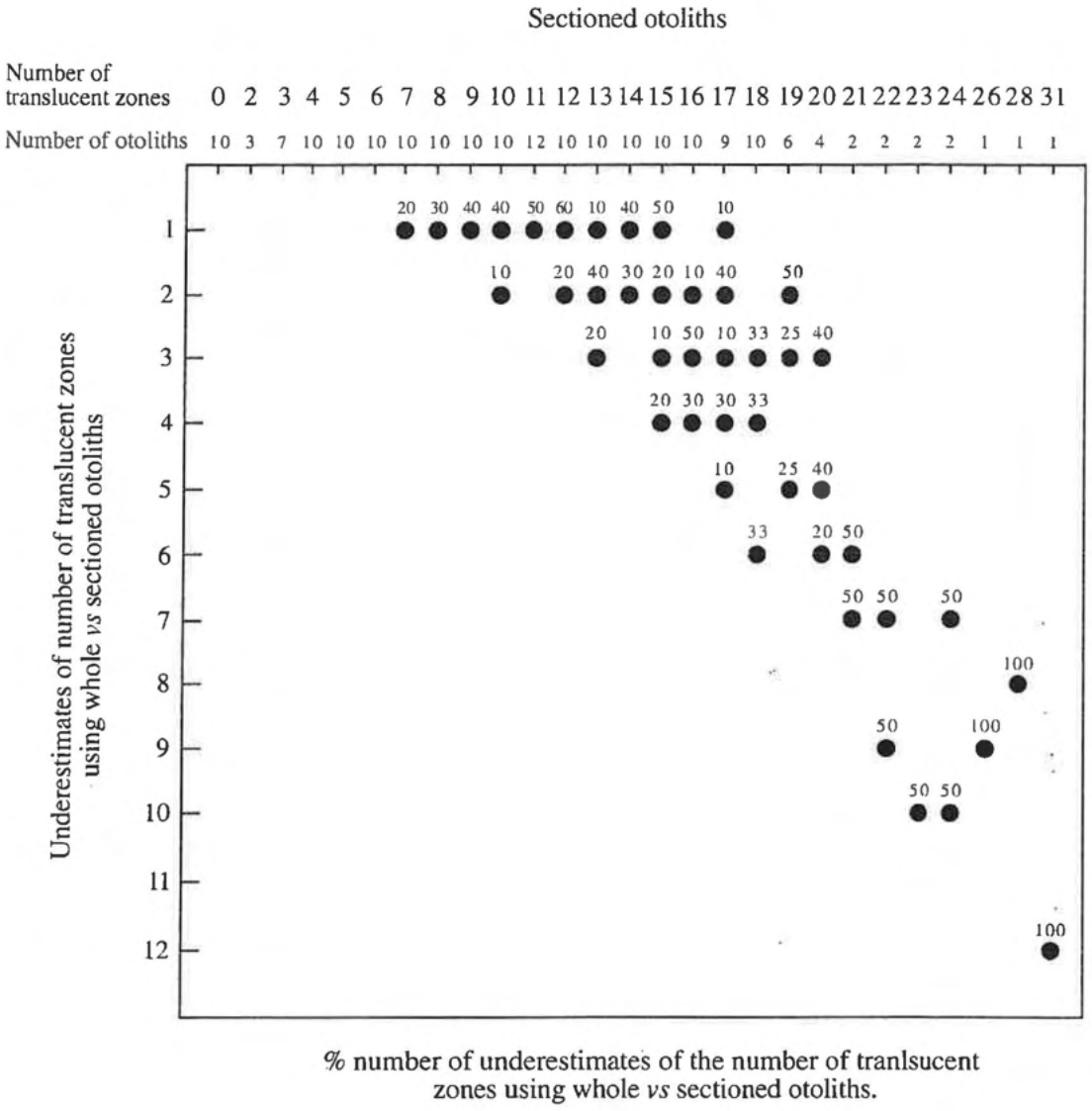


Figure 3.1. Comparison of the number of translucent zones observed on the otoliths of *Glaucosoma hebraicum*, prior to and after sectioning.

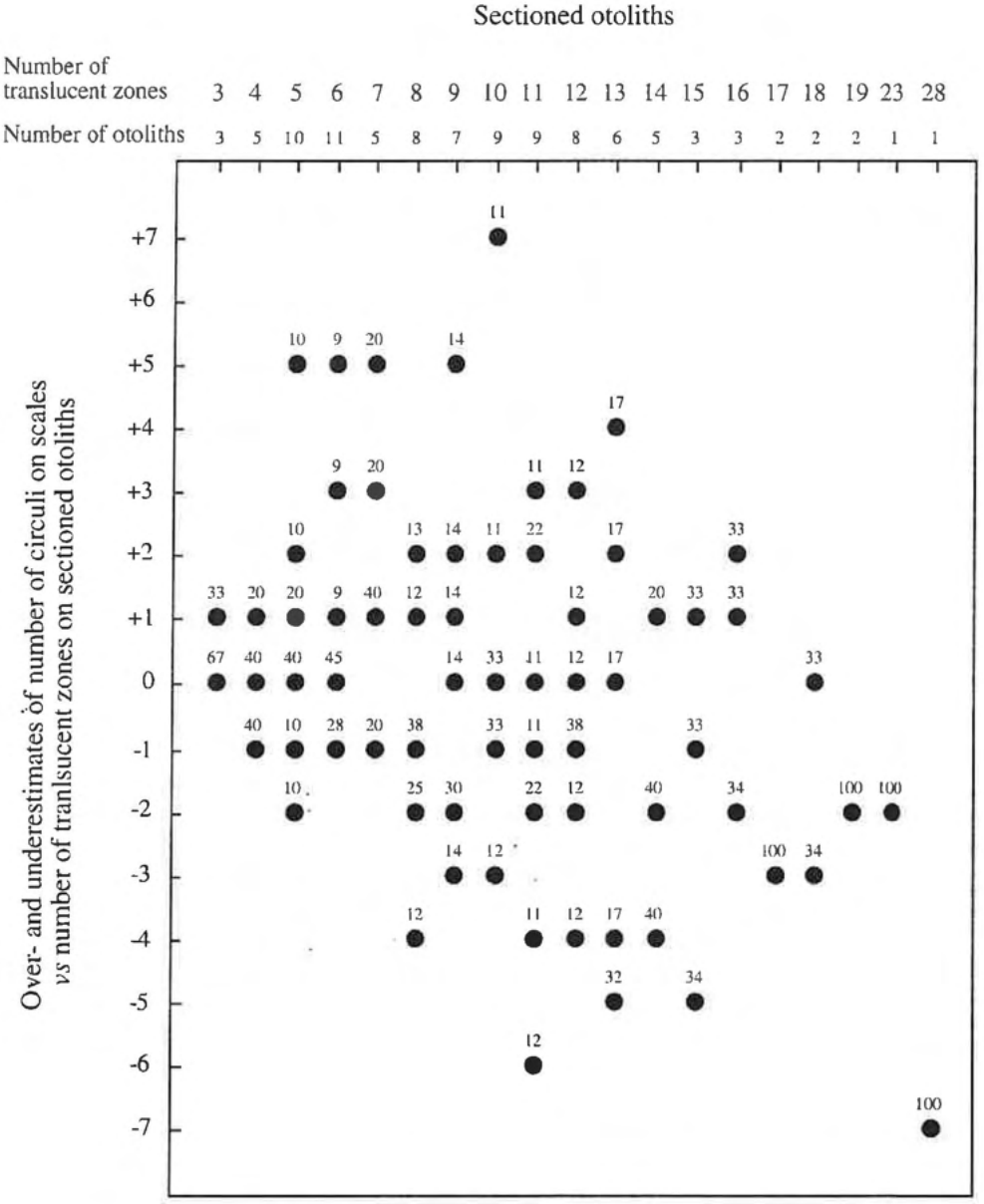


Figure 3.2. Comparison of the number of circuli on scales and the number of translucent zones on sectioned otoliths of *Glaucosoma hebraicum.*

N.B. These data are based on scales and otoliths from the same suite of fish.

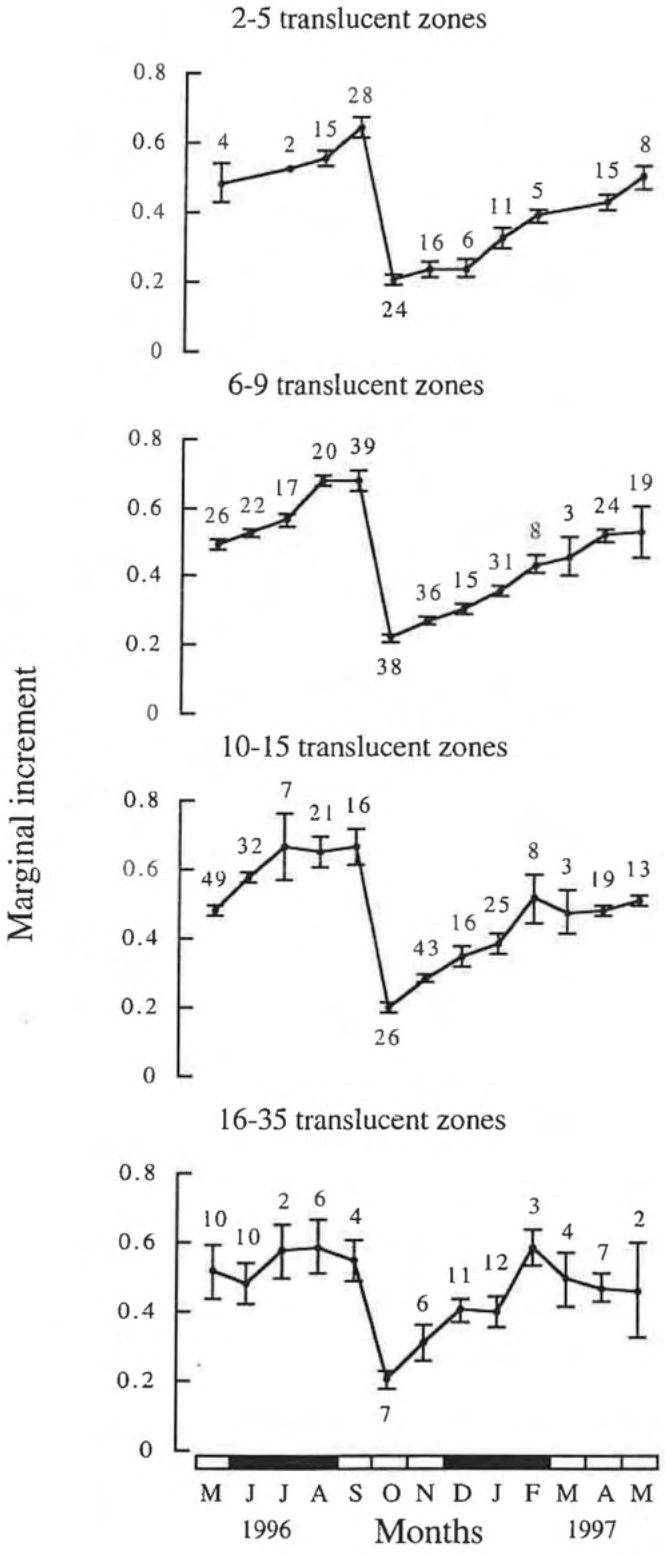


Figure 3.3. Mean monthly marginal increments ±1SE for sagittal otoliths of *Glaucosoma hebraicum.* Sample size is given for each month.

N.B. In this and subsequent figures, the open rectangles on the horizontal axis refer to the autumn and spring months, and the closed rectangles to the winter and summer months.

exhibited by the mean marginal increment on otoliths with 6-9, 10-15 and 16-35 translucent zones followed essentially the same trend as that just described for otoliths with 2-5 translucent zones, with the marginal increment likewise undergoing a very marked decline between September and October (Fig. 3.3).

As the trends exhibited by GSIs, gonad maturity stages and size-frequency distribution of oocyte diameters, indicated that spawning peaked in February (Chapter 4), the 0+ cohort were thus on average about nine months old when the first translucent zone was formed in October.

3.3. Ageing of sectioned otoliths of *Glaucosoma hebraicum*

3.3.1. *von Bertalanffy Growth Curves*

Since fish <150mm could not be sexed (Chapter 4), the points for the length at age of these small fish were repeated on the growth curves of female and male fish, so that the trends shown by fish <150mm were placed in perspective. The points for the length at age of females and males of *G. hebraicum* were well described by the von Bertalanffy growth model and the derived age at length zero (t_o) from the von Bertalanffy equation is close to zero (Table 3.1, Fig. 3.4). The likelihood ratio test showed that the growth curves of females and males were significantly different ($P \leq 0.001$). From the von Bertalanffy growth curves, it is evident that male *G. hebraicum* grow slightly faster than females, attaining total lengths of 234, 313 384 and 448mm, respectively, at ages 2-5, compared with total lengths of 212, 283, 347 and 405mm, respectively, at the same ages with females. Male *G. hebraicum* grow to 688, 832 and 920mm after 10, 15 and 20 years, and female *G. hebraicum* grow to 626, 792 and 865mm, at those same respective ages (Fig. 3.4). The maximum total lengths of females and males were 976 and 1120mm, respectively, and the maximum ages recorded for females and males were 29 and 35 years, respectively.

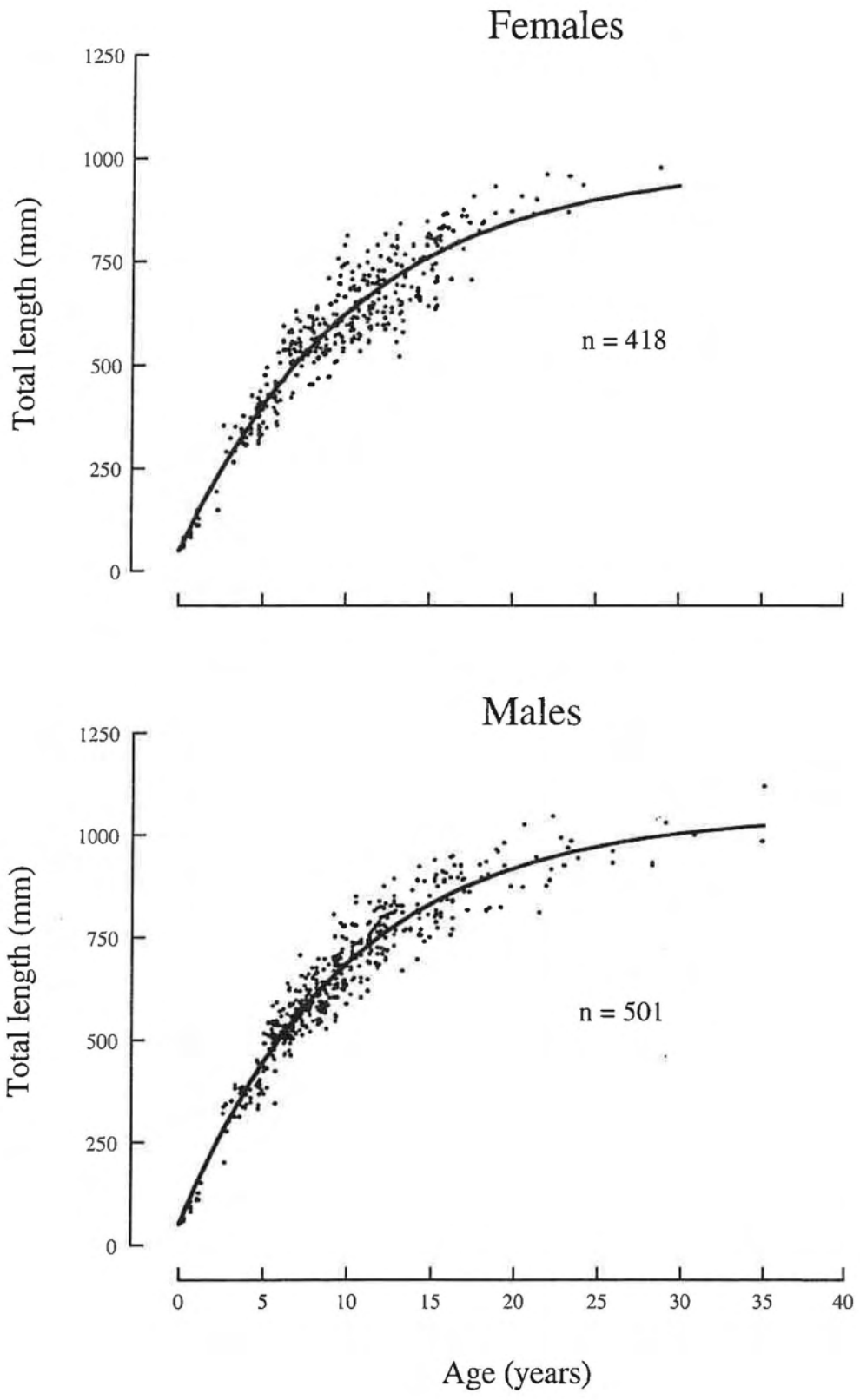


Figure 3.4.von Bertalanffy growth curves fitted to age-at-length data derived from sagittal otoliths of females and males of *Glaucosoma hebraicum* caught between Geraldton and Perth on the lower west coast of Australia. n refers to number of fish.

Table 3.1. von Bertalanffy growth parameters derived from length-at-age data for *Glaucosoma hebraicum* caught along the lower west coast of Australia between Geraldton and Perth, including upper and lower 95% confidence limits.

		von Bertalanffy parameters				
		L_∞	K	t_0	R^2	N
Females	Estimate	983.8	0.096	-0.526	0.891	418
	Upper	1038.0	0.108	-0.172		
	Lower	929.7	0.083	-0.880		
Males	Estimate	1052.4	0.101	-0.491	0.915	501
	Upper	1086.6	0.109	-0.219		
	Lower	1018.3	0.093	-0.763		

3.3.2. *Age at which Glaucosoma hebraicum reach legal size*

The age at which female and male *G. hebraicum* reach the minimum legal size for capture (500mm) is *ca* seven and six years, respectively. These lengths correspond to approximately one fourth and one sixth of the maximum ages recorded for females and males, *i.e.* 29 and 35 years, respectively.

3.3.3. *Comparison of growth rates of Glaucosoma hebraicum caught in waters near Geraldton and Perth*

The growth curves of female and male *G. hebraicum* caught in waters near Geraldton were similar to the corresponding growth curves for females and males caught near Perth (Fig. 3.5). For female *G. hebraicum*, the fish caught at Perth were, in all cases, slightly greater in length than those at the same age at Geraldton. The growth curves for males were very similar in appearance, with the lines crossing when fish were aged *ca* 9 years of age (Fig. 3.5). The likelihood ratio test showed, however, that the growth curves for both females and males from the two regions

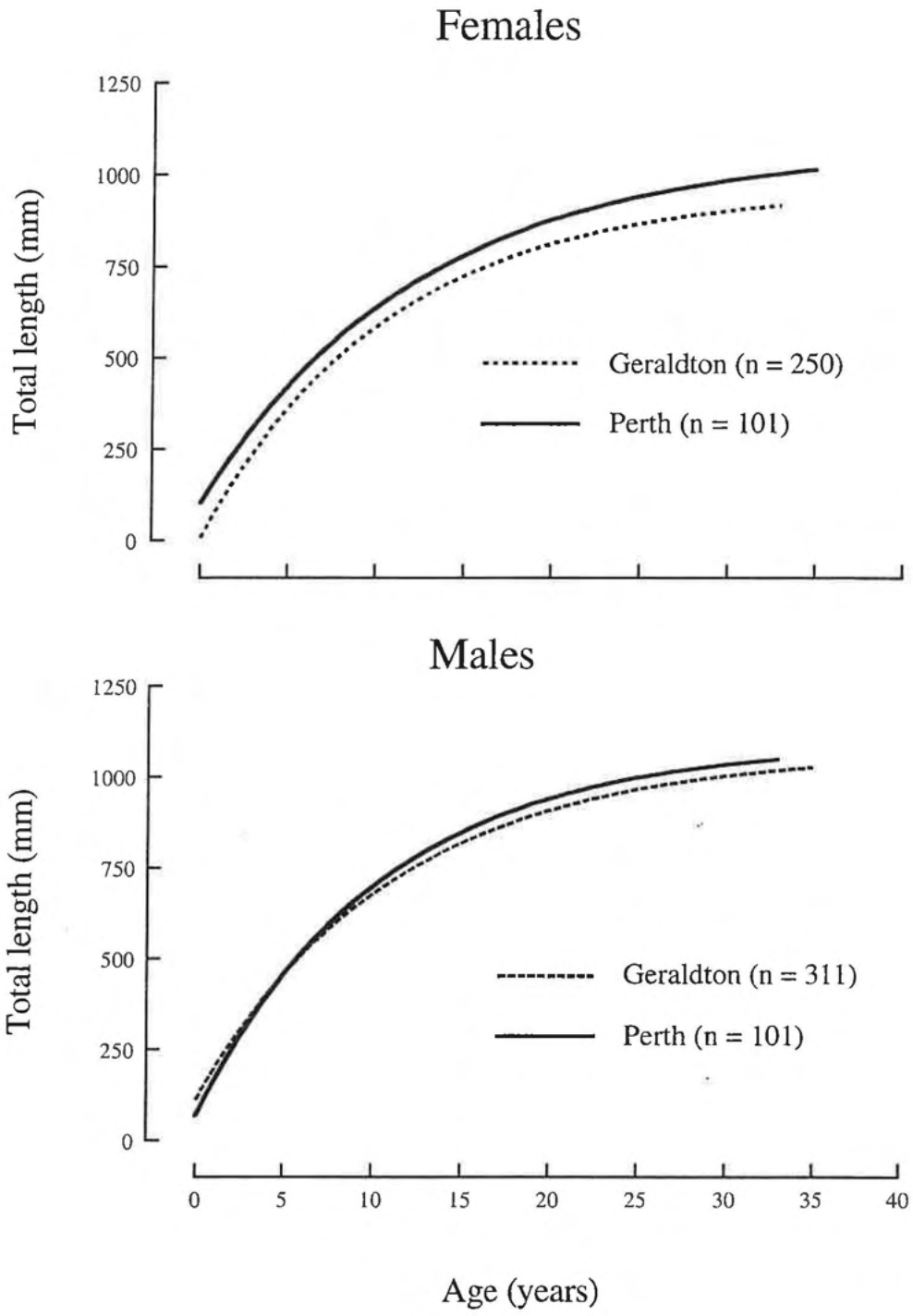


Figure 3.5. Comparison of von Bertalanffy growth curves of females and males of *Glaucosoma hebraicum* caught in waters near Geraldton and Perth, on the lower west coast of Australia, fitted to age-at-length data derived from sagittal otoliths. n refers to number of fish.

were highly significantly different ($P \leq 0.001$). The t_0 estimates for these growth curves were further from zero than the composite growth curve derived for fish from both regions (Table 3.2). (N.B. for the comparative growth curves, fish <250mm were not included in either of the curves, as fish of this size interval were only caught at Perth)

Table 3.2. Comparison of von Bertalanffy growth parameters derived from length-at age data for *Glaucosoma hebraicum* caught in waters near Geraldton and near Perth, including upper and lower 95% confidence limits.

		von Bertalanffy parameters				
		L_∞	K	t_0	R^2	(N)
Geraldton						
	Estimate	944.7	0.096	-0.802		
Females	Upper	1066.4	0.130	0.364	0.802	250
	Lower	823.0	0.063	-1.977		
	Estimate	1003.3	0.112	-1.883		
Males	Upper	1050.9	0.129	-0.736	0.895	311
	Lower	955.8	0.096	-0.359		
Perth						
	Estimate	1072.5	0.08	-1.274		
Females	Upper	1214.8	0.107	-0.098	0.895	101
	Lower	930.1	0.054	-2.538		
	Estimate	1093.9	0.093	-0.666		
Males	Upper	1146.0	0.107	-0.004	0.945	101
	Lower	1041.7	0.080	-1.329		

3.4. Length frequencies of different age classes

Since there were low numbers of many age classes in each month, the length data for each season were pooled. In addition, as fish <150mm in length could not be sexed,

the lengths for these small fish were repeated on the length-frequency histograms for female and male fish so that the trends shown by the fish <150mm were placed in perspective (Figs. 3.6, 3.7).

Low numbers of the smallest cohort (*i.e.* <150mm) were caught in all seasons. The otoliths from fish of this cohort, that were caught between February and September did not possess a translucent zone, while those of the same cohort between October and January possessed a single translucent zone. Since spawning of *G. hebraicum* peaked in late January/early February (Chapter 4), these small fish represent the 0+ recruits from the spawning period that took place predominantly early in 1996 (except those small fish caught in autumn - see below). The lengths of the 0+ cohort increased from a size range of between 75 and 99mm in winter, to between 50 and 124mm in spring, and between 100-150 in summer as they approached the end of their first year of life. All fish <150mm in the autumn samples were caught in 1997. Therefore, the small fish between 50-74mm caught in this season represent a new cohort of 0+ recruits, which were spawned early in 1997.

The 1+ and 2+ fish were poorly represented in the length-frequency data (see discussion for explanation). The length-frequency data showed that all age classes up to 10+ were represented in the samples and that the lengths of successive age classes, in the different seasons, started to overlap after completion of the second year of life (Figs 3.6, 3.7).

3.5. Comparison of length frequencies of *Glaucosoma hebraicum* from commercial and recreational catches at different latitudes along the coast of Western Australia.

The lengths of *G. hebraicum* retained in recreational catches between 35-33°S latitude were relatively evenly distributed, ranging from 500-1050mm total length (Fig. 3.8). In commercial catches for the similar latitudes, total lengths of *G. hebraicum* ranged

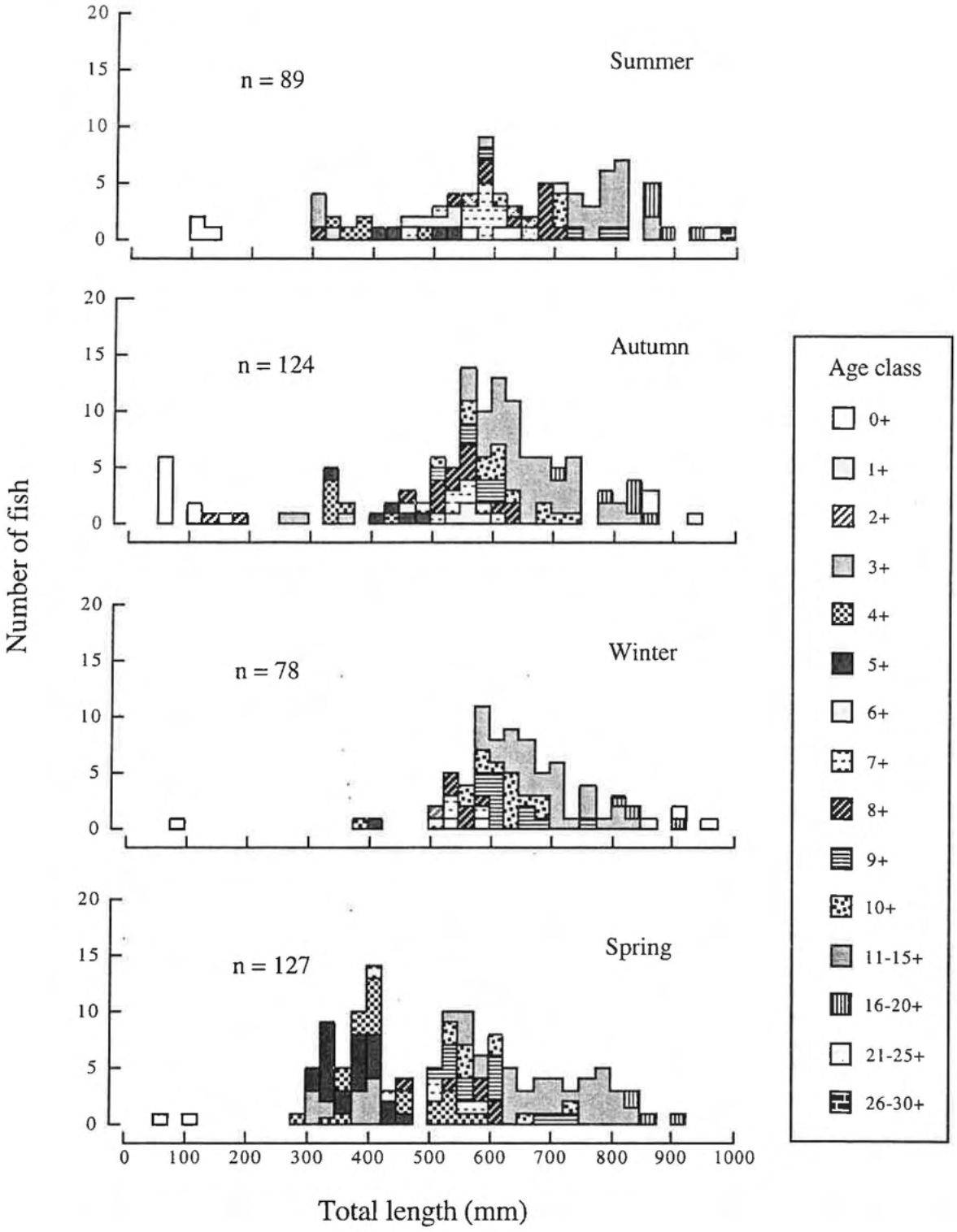


Figure 3.6. Seasonal length-frequency histograms for different age classes of female *Glaucosoma hebraicum*. n refers to number of fish.

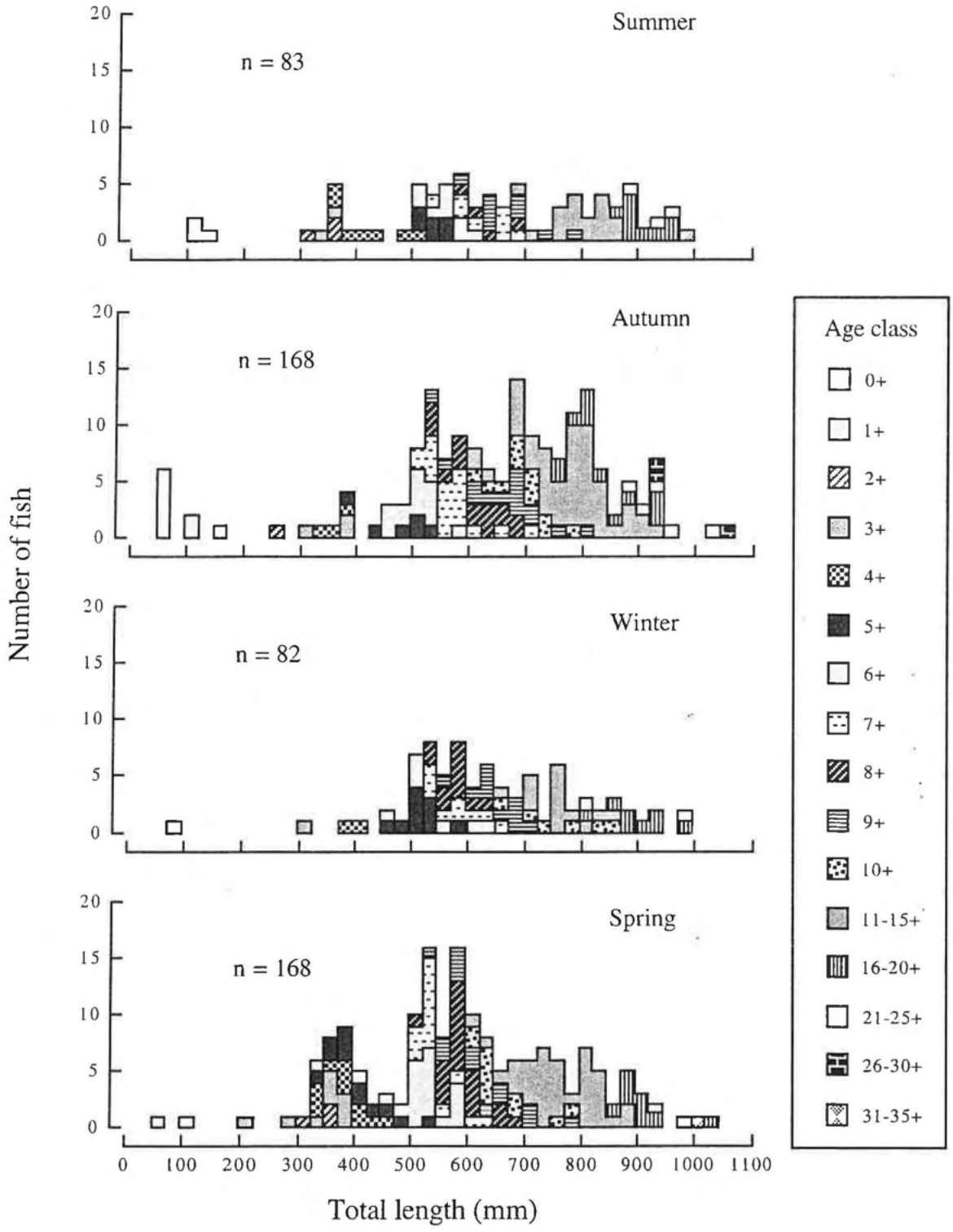


Figure 3.7. Seasonal length-frequency histograms for different age classes of male *Glaucosoma hebraicum*. n refers to number of fish.

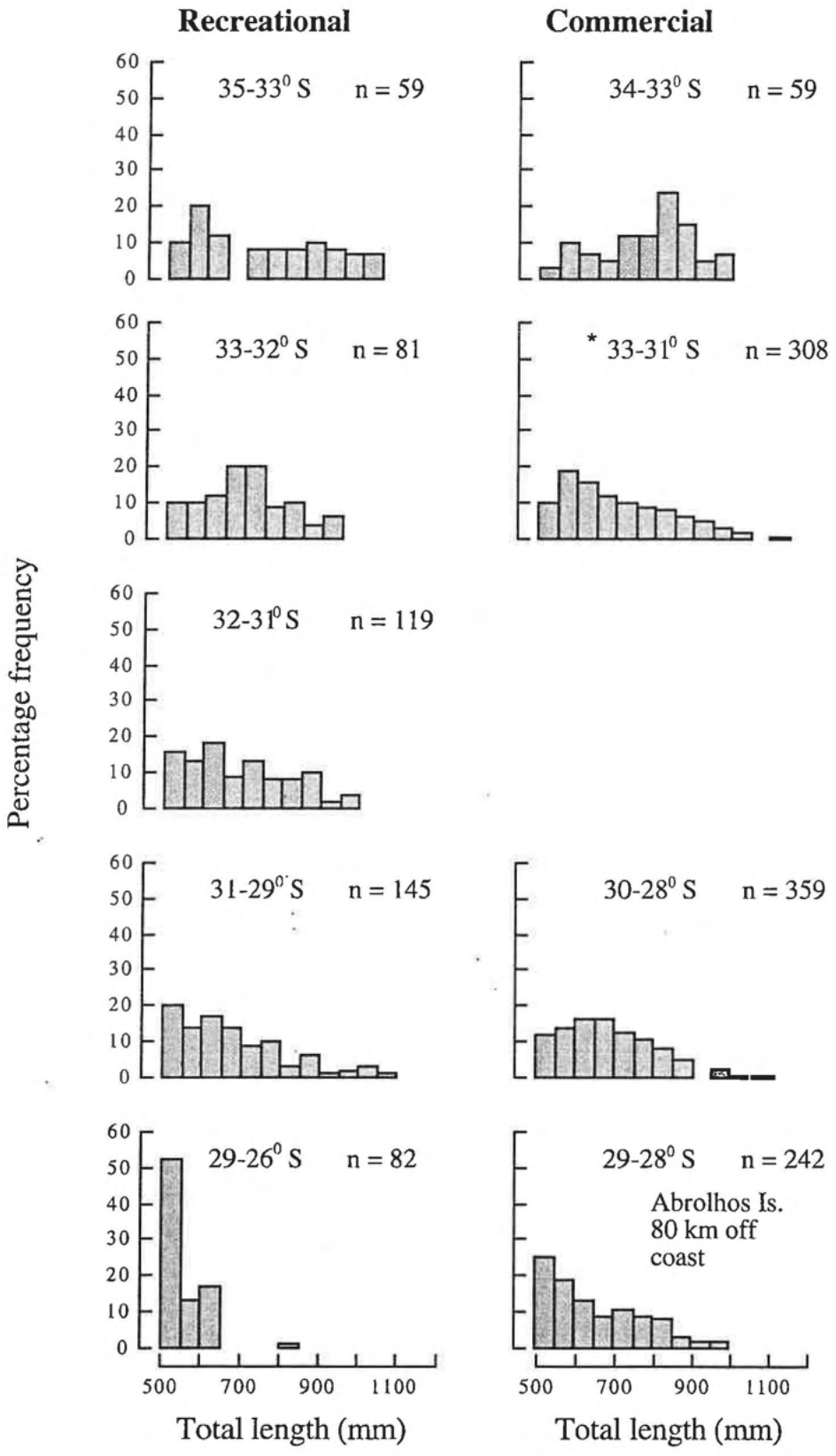


Figure 3.8. Length-frequency distributions of both recreational and commercial catches of *Glaucosoma hebraicum* at different latitudes along the west coast of Australia. n refers to number of fish.

(* catches of metropolitan angling clubs)

from 500-1000mm. In these commercial catches, the majority of *G. hebraicum* ranged between 700-900mm in total length, with *ca* 24% being between 800-850mm. Recreational catches from the Fisheries 'boat ramp' survey of *G. hebraicum* carried out by the Fisheries Department of Western Australia between 33-32°S ranged from 500-950mm in total length, with a relatively high proportion (*ca* 40%) of fish between 650-750mm. The length distribution of recreational catches from the metropolitan angling clubs ranged between 500-1150mm, with a relatively high proportion of fish between 550 and 650mm (*ca* 34%) (Fig. 3.8.). The catches of *G. hebraicum* caught by recreational anglers between 32-31°S ranged between 500 and 1000mm in length. In these catches, slightly higher proportions of fish occurred for the smaller length classes (*i.e.* between 500 and 650mm) compared to the larger length classes (Fig. 3.8). The length-frequency distributions for *G. hebraicum* caught between 31-28°S were similar for recreational and commercial catches, with lengths ranging between 500-1100mm in both figures, and the proportions of fish greater than 750mm being far lower than those of smaller fish (Fig. 3.8). The lengths of commercial catches of *G. hebraicum* caught at the Abrohlos Islands, *i.e.* 29-28°S which are *ca* 80km off the coast of Western Australia, differed to those closer to the coast (< 40km) at a similar latitude, with far higher proportions of small fish (*ca* 45% of fish below 600mm) recorded in the former area. For *G. hebraicum* caught between 29-26°S, most fish were below 550mm in length, and there were very few large fish (*i.e.* the largest fish was only 850mm in length) (Fig. 3.8).

Therefore, the average sizes of commercially caught *G. hebraicum*, and to some extent, the maximum sizes caught, tended to decrease with decreasing latitude. Furthermore, the sizes of *G. hebraicum* caught at the Abrohlos Islands were markedly smaller than those caught closer to the coast at a similar latitude. There were no clear trends relating differences in the sizes of catches between recreational and commercial fishers.

3.6. Length-Weight relationship

The relationship between the length and weight of female and male *G. hebraicum* are plotted on a linear scale (Fig. 3.9) and a log scale (Fig 3.10). The equations relating the lengths and weights are shown on the figures. The data for unsexed juveniles (<150mm) were used for both curves.

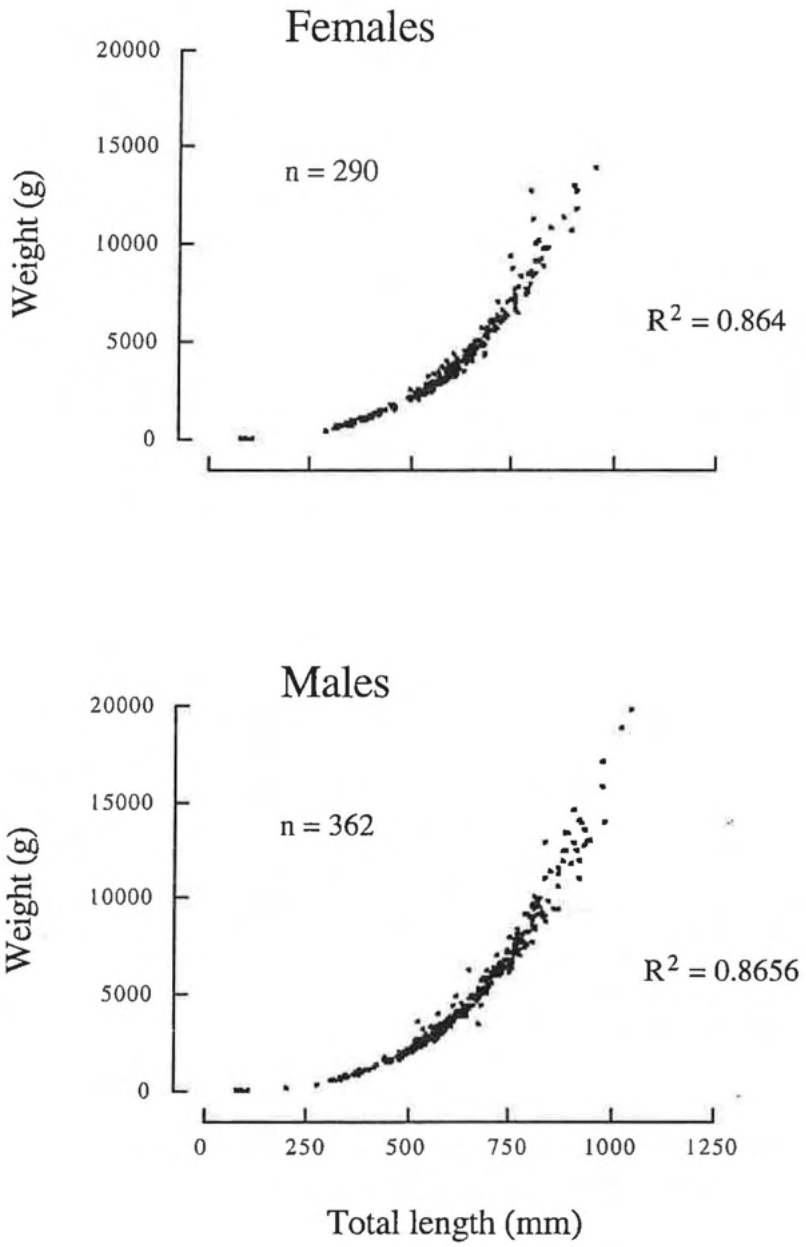


Figure 3.9. Relationship between length and weight for females and males of *Glaucosoma hebraicum*. (n refers to the number of fish measured).

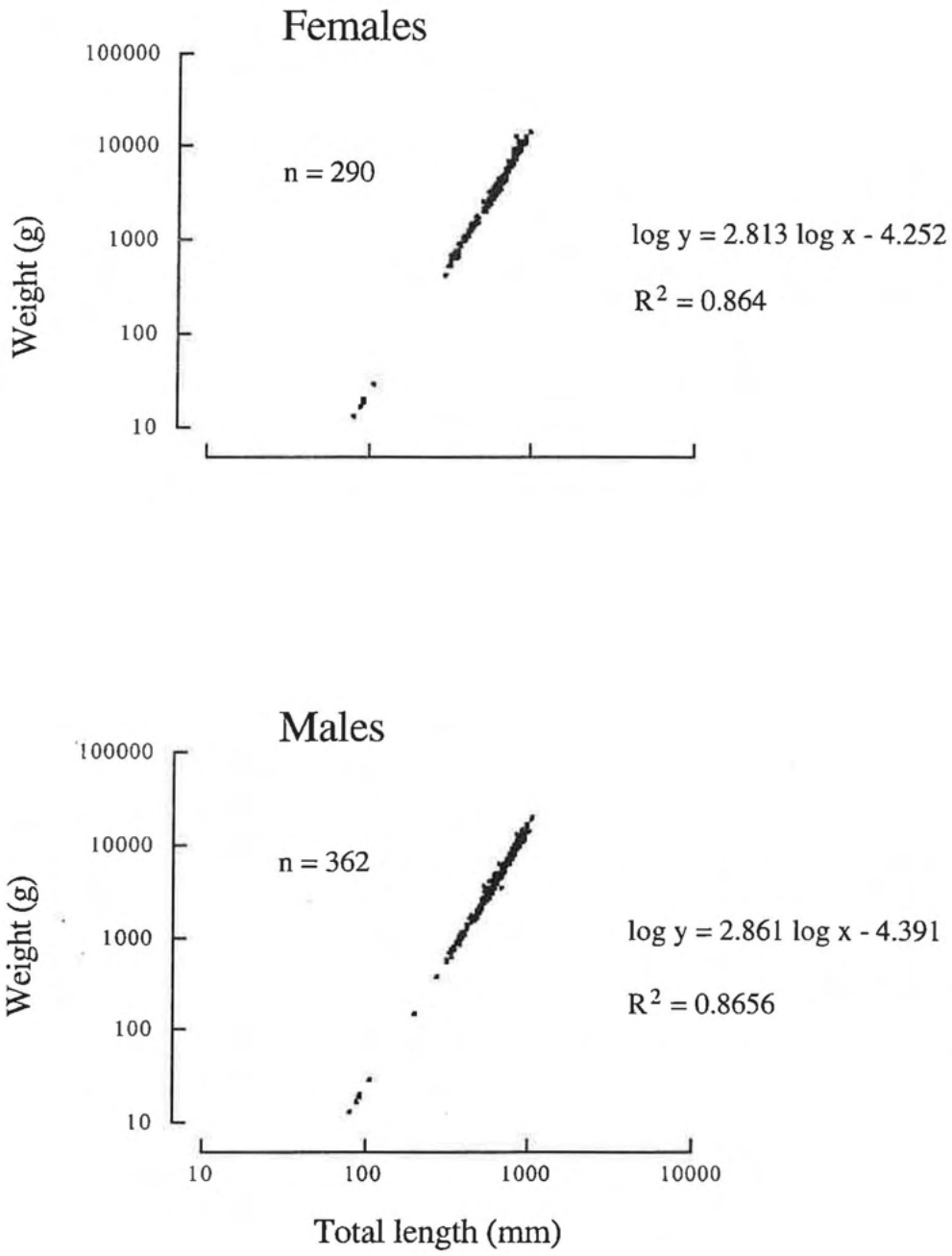


Figure 3.10. Relationship between length and weight for females and males of *Glaucosoma hebraicum*, plotted on a logarithmic scale (n refers to the number of fish measured).

4: Results - Reproduction

4.1. Sex ratio

The overall ratio of the numbers of females to males of *Glaucosoma hebraicum* throughout the whole sampling region was 46 : 54. This ratio remained relatively constant throughout all months of the sampling regime.

4.2. Size and age at maturity

The gonads of *G. hebraicum* ≤150mm in length and < *ca* 2yrs of age could not be used to sex these fish, and thus the data for these gonads are represented for females and males and are recorded as stage I, *i.e.* virgin (Figs 4.1a,b). The smallest size category (50mm interval) of *G. hebraicum* for which there were samples that could be sexed was 200-249mm in the case of females and 250-299mm for males. The gonads of all female *G. hebraicum* in the 200-249mm size range were at stage II (Fig. 4.1a). During the spawning period, the ovaries of fish between 250 and 299mm were predominantly at stage V-VIII (86%), with the remaining being at stage II. All of the ovaries taken from fish between 300 and 349mm in length were at stages V-VIII, *i.e.* mature, and those of larger females were also predominantly mature (Fig. 4.1a).

The testes of males between 250-349mm were predominantly at stages II or IV, but with a small number being at either stage III or stages V-VIII. Between 350-449mm, the testes were predominantly at stages V-VIII (67%), with the remaining gonads being at stages III or IV. The testes of larger males were also predominantly at stages V-VIII, with a small percentage of testes between stages II to IV, stage IV being the most common of these "non-mature" gonads (Fig. 4.1a).

During the spawning period, no females in their first four years of life possessed mature gonads. However, all females did possess mature gonads by the end of their fifth year of life (Fig. 4.1b). The vast majority of female *G. hebraicum* older than five years

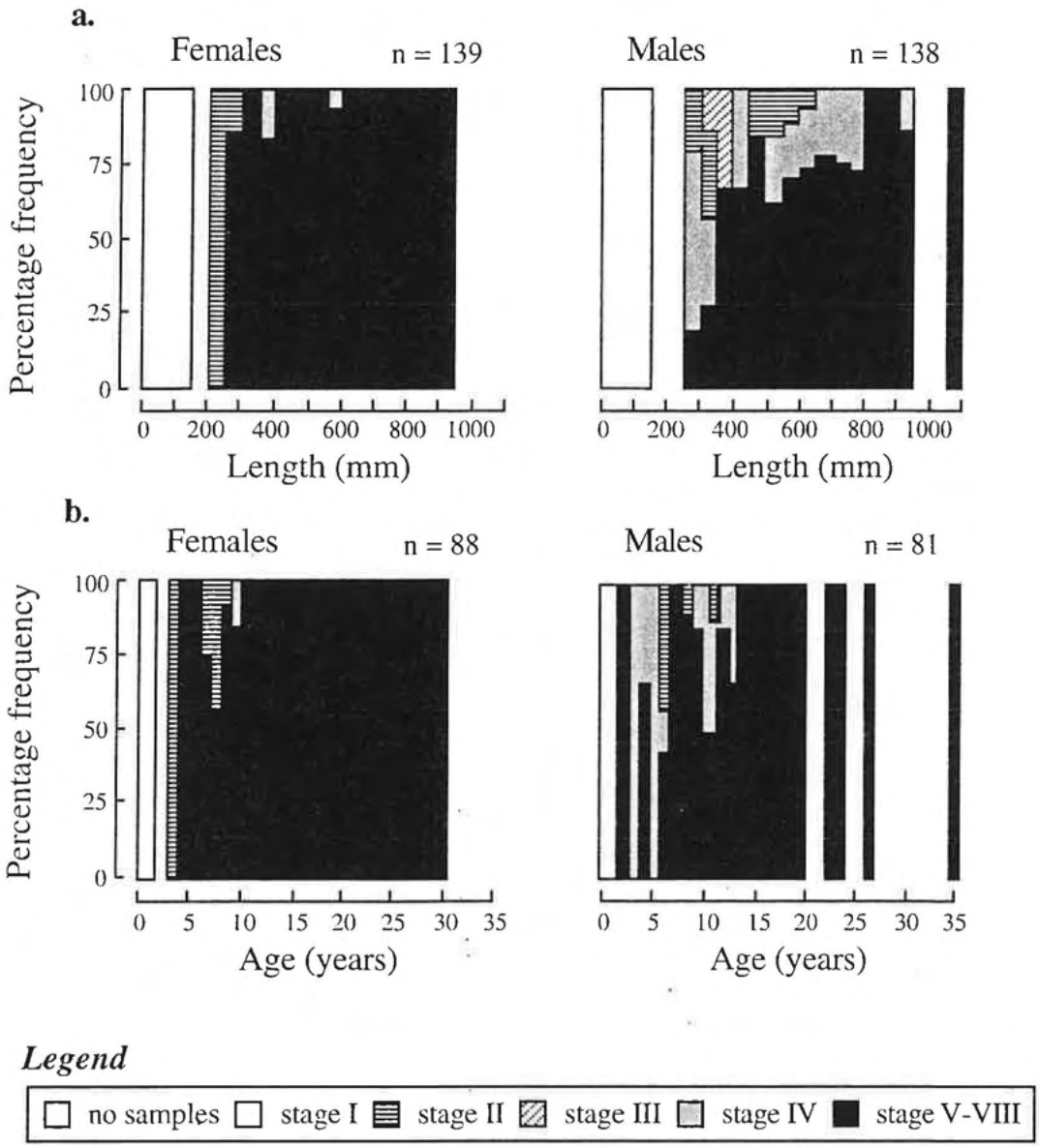


Figure 4.1a. Percentage frequency of occurrence of sequential stages in gonadal development in each sequential 50mm category of females and males of *Glaucosoma hebraicum* caught between December 1996 and February 1997.

Figure 4.1b. Percentage frequency of occurrence of sequential stages in gonadal development in each sequential age class of females and males of *Glaucosoma hebraicum* based on data obtained for fish caught between December 1996 and February 1997.

n refers to number of fish examined.

N.B. Stages V-VIII are referred to as mature gonads, *i.e.* on the basis of histological characters, they were expected to reach maturity in the current spawning period or possessed hyaline oocytes and were about to spawn or had spawned.

had mature ovaries. The trends exhibited by the testes of male *G. hebraicum* were less clear. Although the testes of males between two and six years of age were often immature (*i.e.* less than stage V) a considerable number of the testes of fish of this age were also mature (*i.e.* at stages V-VIII). The majority of four to five year-old *G. hebraicum* were mature, whereas, all five and six year-old males were immature. The majority of male *G. hebraicum* seven years (*i.e.* in their eighth year of life) and older contained mature gonads (Fig. 4.1b).

As the majority of female and male *G. hebraicum* did not reach sexual maturity until they were 300 and 400mm total length, respectively, the following trends shown by gonadosomatic indices, gonadal maturity stages and oocyte diameters have used data derived from those fish greater in length than those mentioned above for the respective sexes. In the case of female *G. hebraicum*, relatively few fish were collected between 250 and 300mm, and therefore, data in the following trends were derived only from fish ≥350mm, to be absolutely sure that the representative fish were above the size and age of first sexual maturity for females.

4.3. Gonadosomatic Index

4.3.1. *GSIs of female and male* Glaucosoma hebraicum *in different areas*

The mean GSIs (gonadosomatic indices) of females of *G. hebraicum* (>300mm) caught near Geraldton increased progressively from *ca* 0.6-0.9 between May and September 1996 to a peak of *ca* 2.8 in January 1997 and then fell sequentially to *ca* 0.7 in May 1997 (Fig. 4.2). The mean GSIs of female *G. hebraicum* caught near Perth followed a similar trend, rising from *ca* 0.3-0.7 between May and October to *ca* 3.0 in December to reach a peak of *ca* 3.7 in February, and then declining sharply to *ca* 0.9 in May 1997. Although the rise in the mean GSIs of female *G. hebraicum* caught near Perth and Geraldton thus occur during the same period of the year, the mean GSIs of females caught

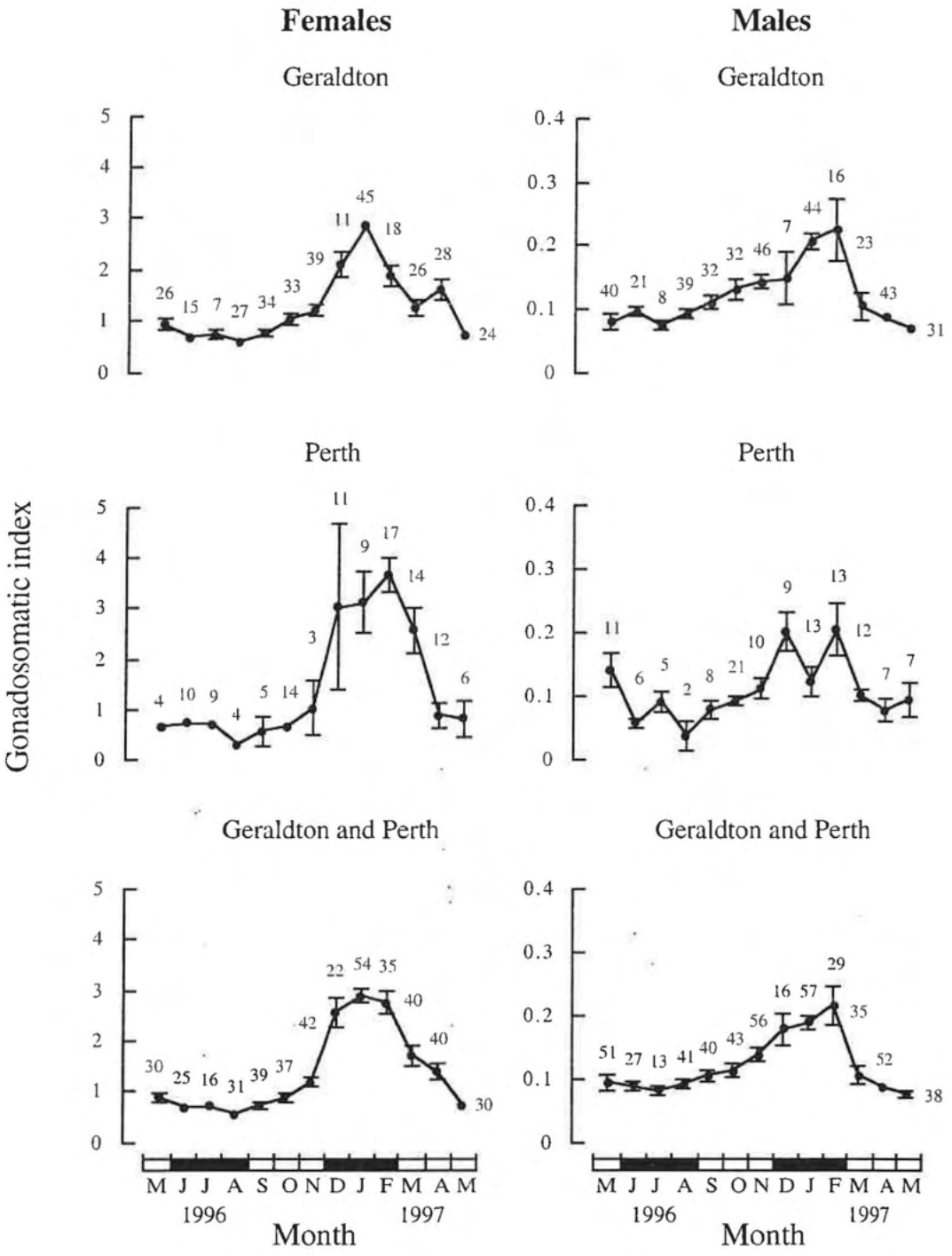


Figure 4.2. Mean monthly gonadosomatic indices ±1SE for females (>350mm) and males (>400mm) of *Glaucosoma hebraicum* caught between May 1996 and May 1997, shown for Geraldton, Perth and the two regions combined. Numbers of fish in each sample are shown next to each mean.

N.B. In this and subsequent figures, the open rectangles on the horizontal axis refer to the autumn and spring months, and the closed rectangles to the winter and summer months.

near Perth were considerably higher during the spawning period. In pooled data for both regions, the mean GSIs rose from *ca* 0.6-0.8 between May and October 1996 to a peak of *ca* 2.9 in December, and then fell sequentially to *ca* 0.7 in May 1997 (Fig. 4.2). The mean GSIs of female *G. hebraicum,* based on pooled data, were highest between December and February.

For males caught at Geraldton, the mean GSIs remained at *ca* 0.08 to 0.09 between May and August 1996, and then rose progressively to *ca* 0.22 in February 1997, before declining precipitously to a minimum of *ca* 0.07 in May. The mean GSIs of male *G. hebraicum* caught near Perth, remained low from June to October 1996 (*ca* 0.04-0.09), increased to *ca* 0.2 in December, and then declined substantially in January to *ca* 0.13 before increasing again to *ca* 0.21 in February. Values fell precipitously thereafter to *ca* 0.09 in May 1997 (Fig. 4.2.). The mean GSIs for the pooled data from Geraldton and Perth rose progressively from *ca* 0.08-0.11 between May and October 1996 to *ca* 0.22 February, after which it declined precipitously to a minimum of 0.08 in May 1997 (Fig. 4.2). Based on pooled data for the two regions, the mean GSIs of male *G. hebraicum* were also highest between December and February, but were approximately an order of magnitude lower in males than in females.

4.3.2. *Comparison of GSIs of females and males of different size classes*

The mean GSIs of small female *G. hebraicum*, with total lengths of 350-550mm, fell slightly from *ca* 0.8 in May 1996 to a minimum of *ca* 0.4 in August, before subsequently rising to a peak of *ca* 2.8 in January 1997 and then falling to *ca* 0.7 in May (Fig. 4.3). For medium-sized female *G. hebraicum* (551-700mm), the mean GSIs increased from *ca* 0.6-0.9 between May and November 1996 to a maximum of *ca* 2.7 in February 1997, and then fell to *ca* 0.7 in May. The mean GSIs of large *G. hebraicum* (≥701mm) decreased from *ca* 1.7 in May 1996 to *ca* 0.6 in June, remained low (*ca* 0.6-0.8) until September, increased to *ca* 1.4 in October and November, and then rose sharply

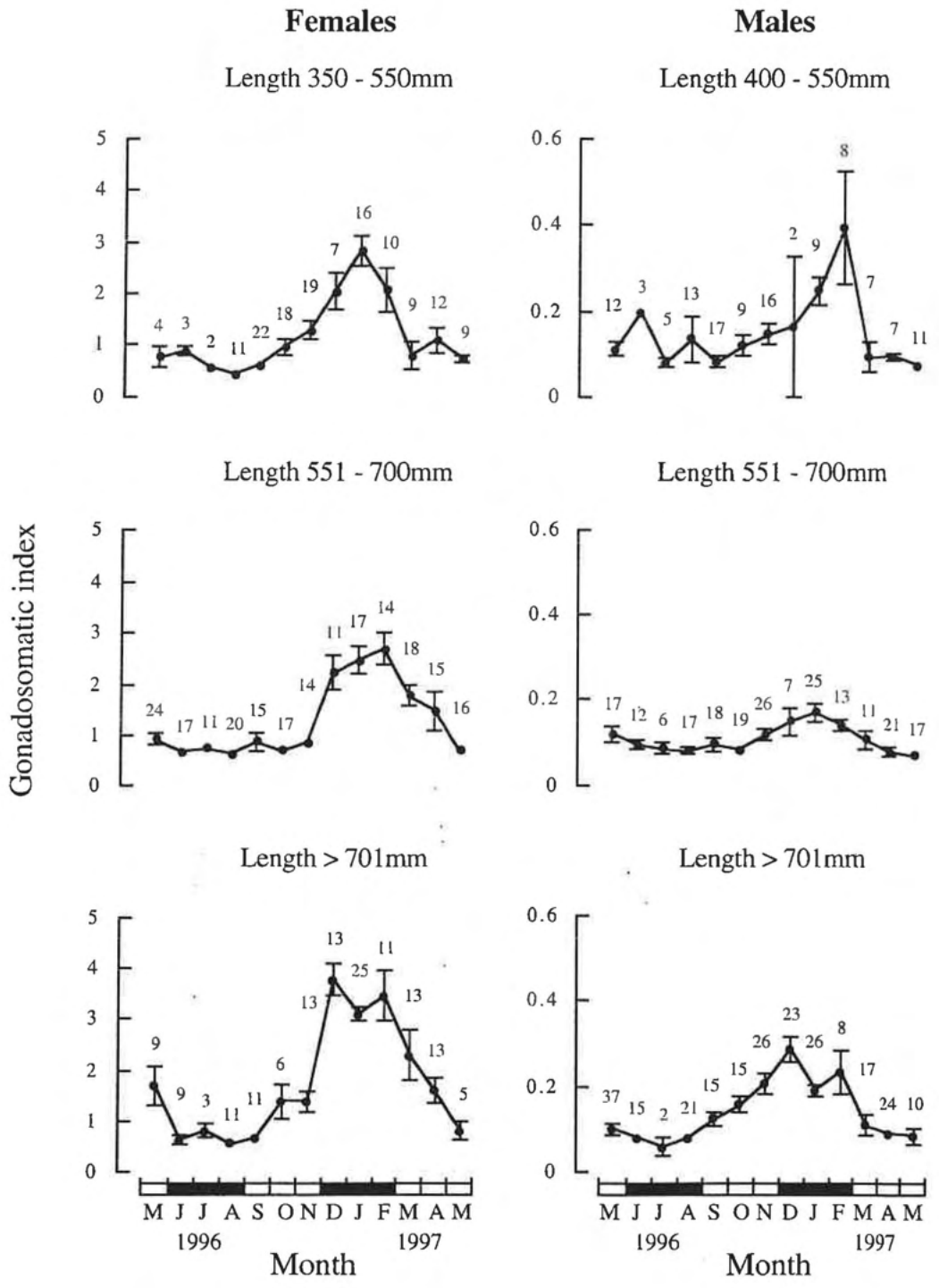


Figure 4.3. Mean monthly gonadosomatic indices ±1SE for different length classes of females and males of *Glaucosoma hebraicum* caught between May 1996 and May 1997. Numbers of fish in each sample are shown next to each mean.

to a peak of *ca* 3.8 in December, before falling progressively from *ca* 3.4 in February 1997 to *ca* 0.8 in May (Fig. 4.3). The overall trends for mean monthly GSIs exhibited by different-sized (*i.e.* total length) female *G. hebraicum* thus show that the mean GSIs of large fish reach a higher peak, and remain relatively high for a longer period than those of small fish.

The mean GSIs of small (400-500mm) male *G. hebraicum* rose from *ca* 0.08-0.2 between May and November 1996, to reach a maximum of *ca* 0.40 in February 1997 and then fell markedly to a minimum of *ca* 0.7 in May. In contrast, the overall mean GSIs of medium-sized male *G. hebraicum* (551-700mm) were considerably lower and varied less than those of small males, with the mean GSIs remaining between 0.08-0.12 from May to October, 1996, then rising to a peak of *ca* 0.17 in January 1997, before subsequently falling to *ca* 0.07 in May. For large males of *G. hebraicum* (>701mm), the mean GSIs fell from *ca* 0.10 in May 1996 to *ca* 0.06 in July, then increased to a maximum of *ca* 0.29 in December, after which they decreased to *ca* 0.08 in the following May (Figure 4.3). Thus, the mean GSIs of large males were higher than those of medium-sized males, but not higher than those of small males (Fig. 4.3).

4.4. Gonad Development

Table 4.1. Description of characters used to distinguish gonad maturity stages for females and males of *Glaucosoma hebraicum* using macroscopic staging, and of the females of this species using histological staging criteria. Adapted from Laevastu (1965). (Oocyte stages I-VI described later in this chapter - section 4.5.1).

Stage	Macroscopic stage (male and female)	Histological stage (female)
I	Gonads very small, just under vertebral column. Eggs invisible to naked eye. Testes and ovary transparent, colourless to grey.	Virgin - stages I-III oocytes abundant
II	Ovaries small, yellowish in colour, slightly transparent. Eggs not visible to naked eye. Testes still very small and strand-like. Whitish with blood capillary running length of each lobe.	Maturing virgin - stage I-III oocytes, ovigerous lamellae very organised, some stage IV oocytes present
III	Ovaries larger, grey-red with blood capillaries. Length close to half of body cavity. Testes slightly larger. Capillaries not as obvious.	Developing - stage IV oocytes abundant
IV	Ovary larger, occupying about a half of body cavity. Orange, reddish in colour. Eggs clearly discernible to naked eye. Testes larger, white. No milt drops appear under pressure.	Maturing - Abundant stage IV oocytes, also, densely packed, stage V oocytes
V	Ovaries larger, filling body cavity, orange in colour. No hydrated oocytes visible through ovary wall. Testes larger and more lobular, white in colour. Milt drops appear under pressure. Testes still only occupy small portion of body cavity at this mature stage.	Mature - stage V oocytes dominate, some stage VI oocytes evident
VI	Ovaries similar to stage IV. Hydrated oocytes easily visible through ovary wall. In testes, milt runs under slight pressure.	Spawning - stage VI oocytes abundant
VII	Not yet fully empty. No opaque eggs left in ovary. Testes pinkish in colour, smaller than stage 5 or 6. Testes sometimes has a large blood capillary running length of lobe.	Spent - post ovulatory follicles (POFs) abundant, some stage V oocytes present, ovigerous lamellae disrupted, some reabsorption
VIII	Ovaries and testes dark red, small. Testes often full of blood.	Spent/Recovering - reorganisation of lamellae, resorption of stage V oocytes, POFs present.

4.4.1. *Comparisons of gonad development of female and male* Glaucosoma hebraicum *of different sizes*

All of the ovaries of those female *G. hebraicum* 350-550mm in length, caught in the months between May and August 1996, were at stage II (Figure 4.4). Ovaries at stage III first appeared in September and were also present in October and November, and stage IV ovaries were present in the latter two months and December. Ovaries at stages V-VI were first found in November, when they contributed *ca* 50% to all ovaries examined (Fig. 4.4). The proportion of these ovaries were high in the next three months, but then declined in prevalence in March to May 1997. Stage VII, *i.e.* spent ovaries, were first detected in this size class in January 1997, and were also found in each month between February and May. Stage VIII, *i.e.* recovering spent ovaries, were found in March to May (Fig. 4.4). The above trends exhibited by the different ovarian stages in female fish of 350-550mm were paralleled by those shown by fish of 551-700mm and >701mm (Fig. 4.4). However, in the largest size category, stage V-VI ovaries were detected earlier, *i.e.* October vs November, and yet stage VII ovaries and stage VIII ovaries were first found later, *i.e.* March vs January and May vs March, respectively, than in the small and medium size classes (Fig. 4.4).

The testes of those small (400-550mm) male *G. hebraicum,* that were caught between May and August 1996 were at stage II, with a relatively small percentage being at stages III and VIII. Testes of stages IV and V first appeared in September and October 1996, respectively, and were still present in January and March 1997, respectively. The proportion of stage V testes remained relatively high between November and February. Recovering and spent testes, *i.e.* stages VII and VIII, first appeared in February 1997 and were still present in the following May. Larger males followed similar trends, except that in the largest size category (≥701mm total length), the overall proportion of stage V testes was higher than in smaller males. Furthermore, for males larger than 550mm, stage V

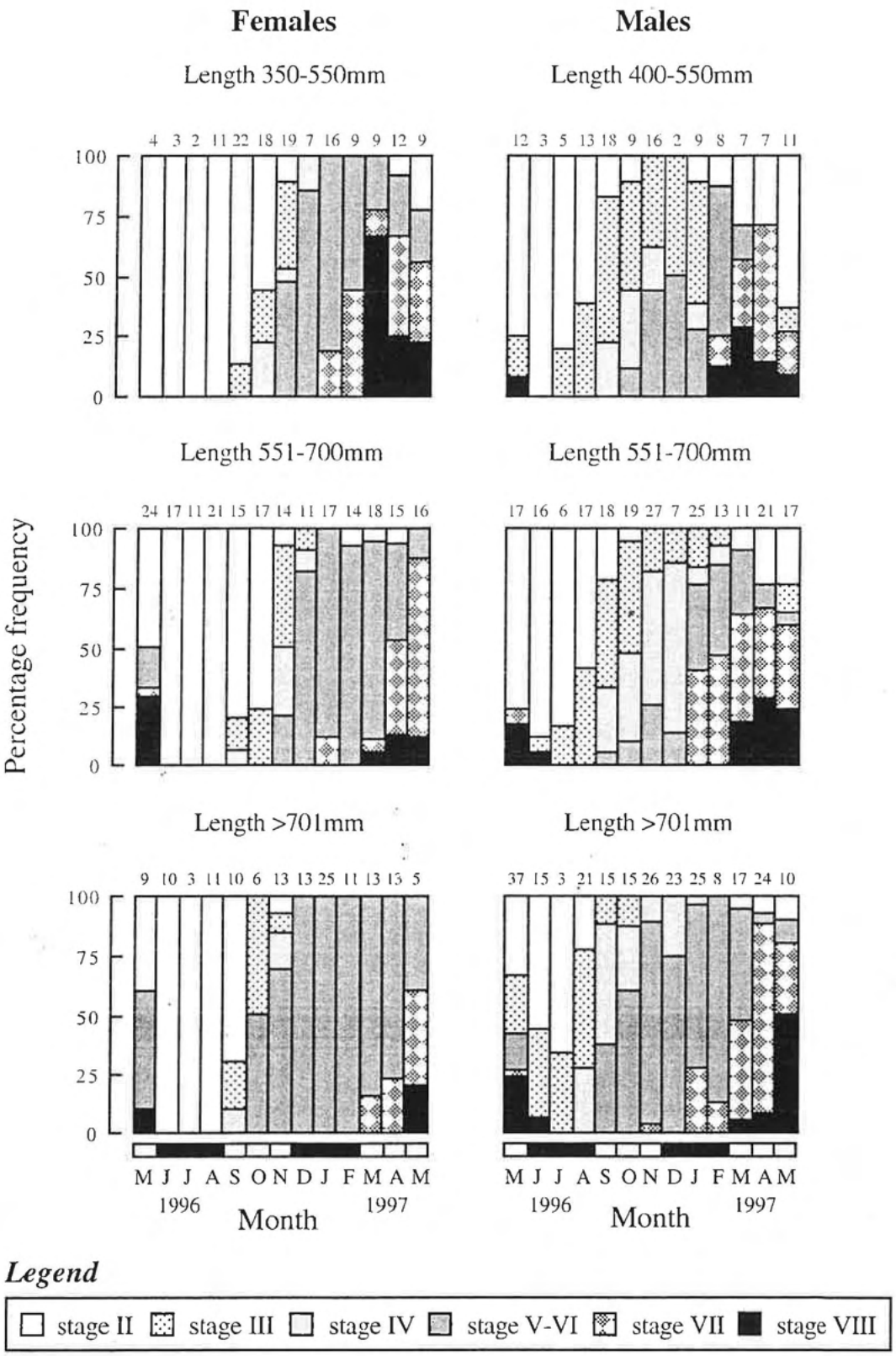


Figure 4.4. Percentage frequency histograms of gonadal maturity stages of females (>350mm) and males (>400mm) of different length classes of *Glaucosoma hebraicum*, in sequential months between May 1996 and May 1997. Sample sizes are given above each month.

testes were detected earlier, (*i.e.* September vs October), and persisted later (*i.e.* May vs March) than in smaller males (Fig. 4.4).

4.4.2. *Comparison of gonad development of female and male* Glaucosoma hebraicum *from different areas*

The monthly trends exhibited by the gonad stages of both female and male fish in the Geraldton and Perth regions were very similar (Fig. 4.5). Thus, for example, in both regions, stage V-VI ovaries started to become prevalent in female fish in October and remained in high proportion (*i.e.* > 60%) between the months of December to March. Stage II ovaries were highly predominant (*i.e.* 80%) between May and September 1996, and increased in prevalence between January and May 1997 in female *G. hebraicum* caught in both areas. The pooled data for female *G. hebraicum* shows that gonadal recrudescence occurs rapidly, with stage III ovaries first appearing in September and stage V-VI ovaries first appearing in October. Furthermore, the pooled data for females suggest that the majority of spawning of female *G. hebraicum* occurs between the months of December and March with some fish spawning in April, and presumably also in May (Fig. 4.5). The data also show overall, that, although gonadal development followed similar trends in females to males, there were much higher proportions of stages III, IV, VII and VIII, and thus also lower proportions of stage II and V ovaries present in females than males (Fig. 4.5).

4.5. Oocyte Development

4.5.1. *Histological description of oocyte development*

I - *Oogonia*

Oogonia are small, rounded cells, possessing a large nucleus surrounded by a conspicuous nuclear membrane and a small area of basophilic cytoplasm. Although the

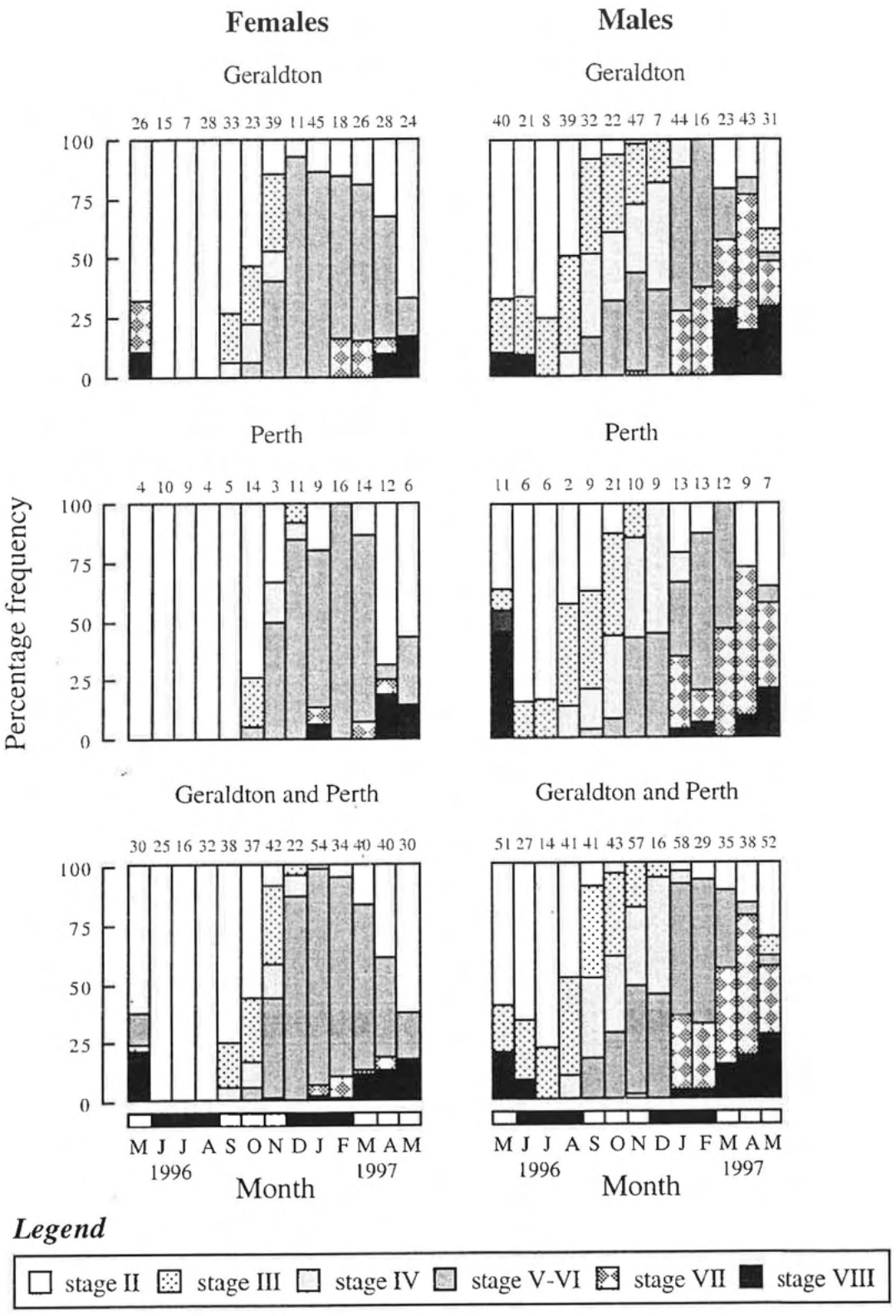


Figure 4.5. Histograms showing the percentage frequency of the different gonadal maturity stages of females (>350mm) and males (>400mm) of *Glaucosoma hebraicum*, in sequential months between May 1996 and May 1997, shown for Geraldton, Perth and the two regions combined. Sample sizes are given above each month.

oogonia occur singly, they tend to be present in nests in the stroma of ovigerous folds. The peak period of proliferation of the oogonia by mitotic divisions occurs during the immediate post-spawning period. No nucleoli could be detected.

Diameter: *ca* ≤ 5μm

First Growth Phase

Following the development of the oogonia, oocytes enter the first growth phase, which can be subdivided into the chromatin nucleolar stage and the perinucleolar stage.

II - *Chromatin nucleolar stage (or early perinucleolar stage)*

Oocytes of the chromatin nucleolar stage are slightly larger than oogonia and have a single conspicuous nucleolus. Furthermore, the cytoplasm occupies a larger volume of the oocyte and has become basophilic. The early perinucleolar oocyte stage has been separated into two broad categories. The oocytes in the first of these stages, the primary or non-vitellogenic growth phase, enter meiotic prophase. The later perinucleolar stage is the vitellogenic growth phase (*e.g.* Khoo, 1979; De Vlamming, 1983) (Plate 3a).

Diameter: *ca* 5-100μm

III - *Perinucleolar stage*

Perinucleolar oocytes have a larger nucleus than that of previous stages, with numerous small nucleoli aligned at their periphery. Early in this stage, the cytoplasm is less basophilic. During this stage, the cytoplasm becomes granulated with increasing oocyte development. A thin layer of connective tissue, the theca, surrounds the periphery of the majority of oocytes (Plates 3a, 3b).

Diameter: *ca* 100-160μm

Second growth phase

The appearance of yolk vesicles in the inner cytoplasm marks the beginning of this growth phase. Two types of yolk vesicles are formed sequentially, with yolk vesicles being formed before yolk granules.

IV - *Yolk vesicle stage*

In this stage, yolk vesicles, which stain light blue with Mallory's trichrome, form initially in a ring at the periphery of the cytoplasm, but are later deposited randomly throughout the cytoplasm. The follicular layers become well-developed with distinct thecal and granulosa cells. The zona radiata develops in this stage (Plate 3b).
Diameter: *ca* 160-260μm

V - *Yolk granule oocyte*

The formation of yolk granules in oocytes with fully-developed vesicles marks the beginning of the yolk granule stage and the final stage of vitellogenesis. At the beginning of this stage, yolk granules form near the zona radiata and are easily distinguished due to the orange to deep red colour that they exhibit after staining with Mallory's trichrome. Later, yolk granules form throughout the cytoplasm between the yolk vesicles (Plate 3b, 3c).
Diameter: *ca* 260-530μm

VI - *Hyaline (hydrated) oocyte stage*

During the early stages of hydration, the yolk granules lose their granular appearance and the vacuoles start to coalesce. The nucleus begins to migrate towards the periphery of the cytoplasm. These oocytes are stained blue by Mallory's trichrome. As these cells mature, they tend to collapse during histological preparation (Plates 3b, 3d, 3f).
Diameter: 530-800μm (before they collapse)

VII - *Atretic stage*

Pre-ovulatory atretic eggs can be recognised by their irregular shape (in the later stages), the breakdown of the granulosa, heterotrophy of the cuboidal cells (theca) around the periphery, and degradation of the interior inclusions (Plate 3e). Atretic eggs were found only in mature gonads, mostly at the end of the breeding season (*i.e.* in April and May). Atresia may occur by phagocytosis (Marshall *et al.*, 1993).

4.5.2. *Size-frequency distribution of the diameters of oocytes throughout gonad development*

Since the trends shown by the size-frequency distribution of the oocyte diameters of *Glaucosoma hebraicum* were similar in the samples caught at Perth and Geraldton (*c.f.* Figs. 4.6 and 4.7), the oocyte data for these two regions were pooled (Fig. 4.8). Virtually all of the oocytes in histological slides prepared from ovaries in May 1996 were previtellogenic and had a diameter less than 180μm. However there were a few larger oocytes, which were either granular or becoming hydrated and had diameters that ranged from 360 to 600μm. Between June and August 1996, all oocytes were either oogonia or in the first growth phase, with the largest having a maximum diameter of less than 130μm (Fig. 4.8).

Although the vast majority of the oocytes in September had a diameter of less than 200μm, there were a few larger oocytes in maturing ovaries (oocytes in the yolk vesicle stage, or early yolk granule stage) with a diameter of up to 260μm (Fig. 4.8). In October, there were several granular oocytes, which had a maximum diameter of 300μm.

Hydrated oocytes were formed between November 1996 and March 1997, the maximum oocyte diameter of to 800μm being recorded in the latter month. In April and May 1997, the maximum diameter of oocytes declined to 530μm in April and 420 μm in May (Fig. 4.8). The few larger oocytes recorded in May were granular oocytes that were

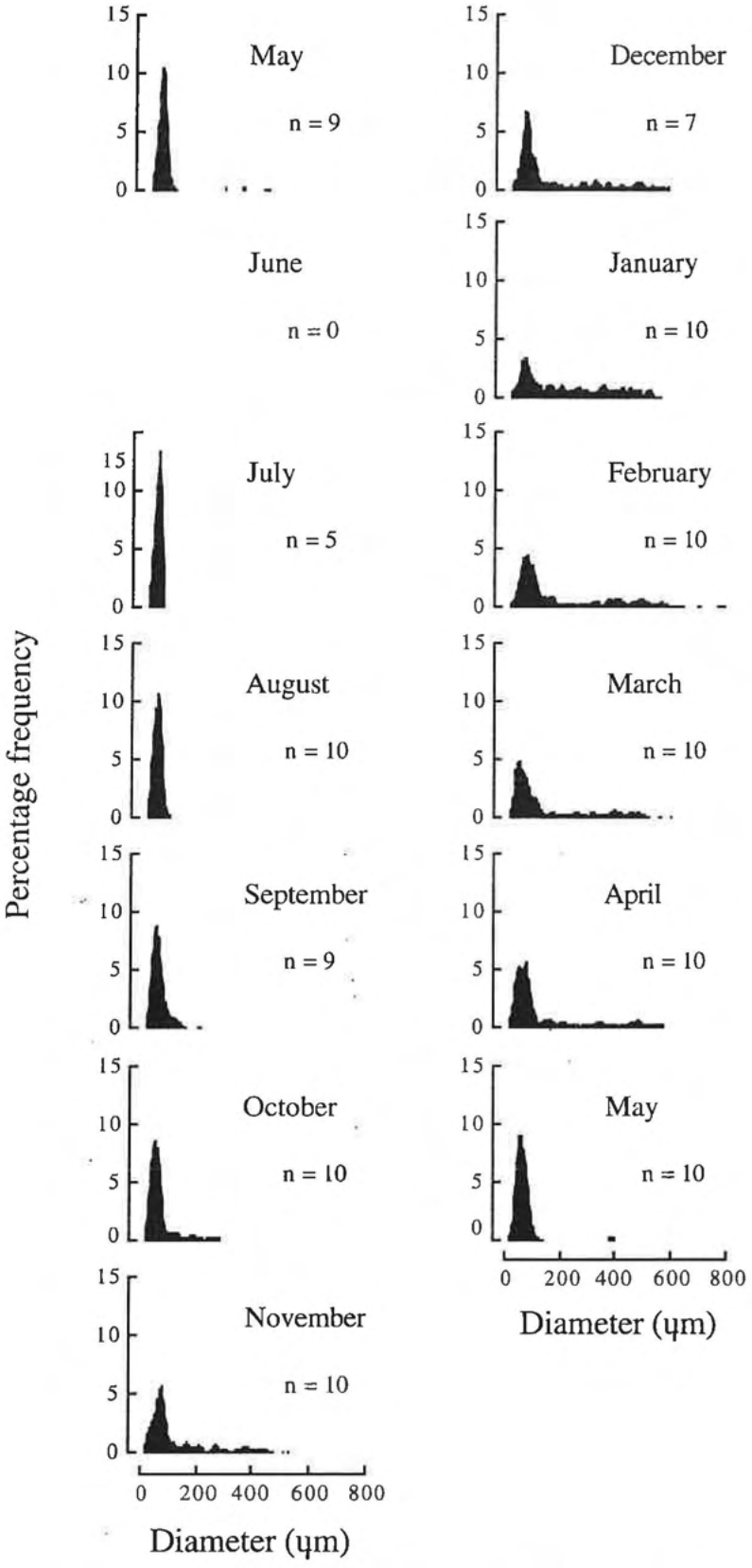


Figure 4.6. Monthly percentage frequencies for the oocyte diameters from the ovaries of *Glaucosoma hebraicum* >350mm total length caught in waters near Geraldton along the west coast of Australia. In this and Figs 4.7 and 4.8, the data were smoothed by an average of five. n = number of fish from which ovaries were examined.

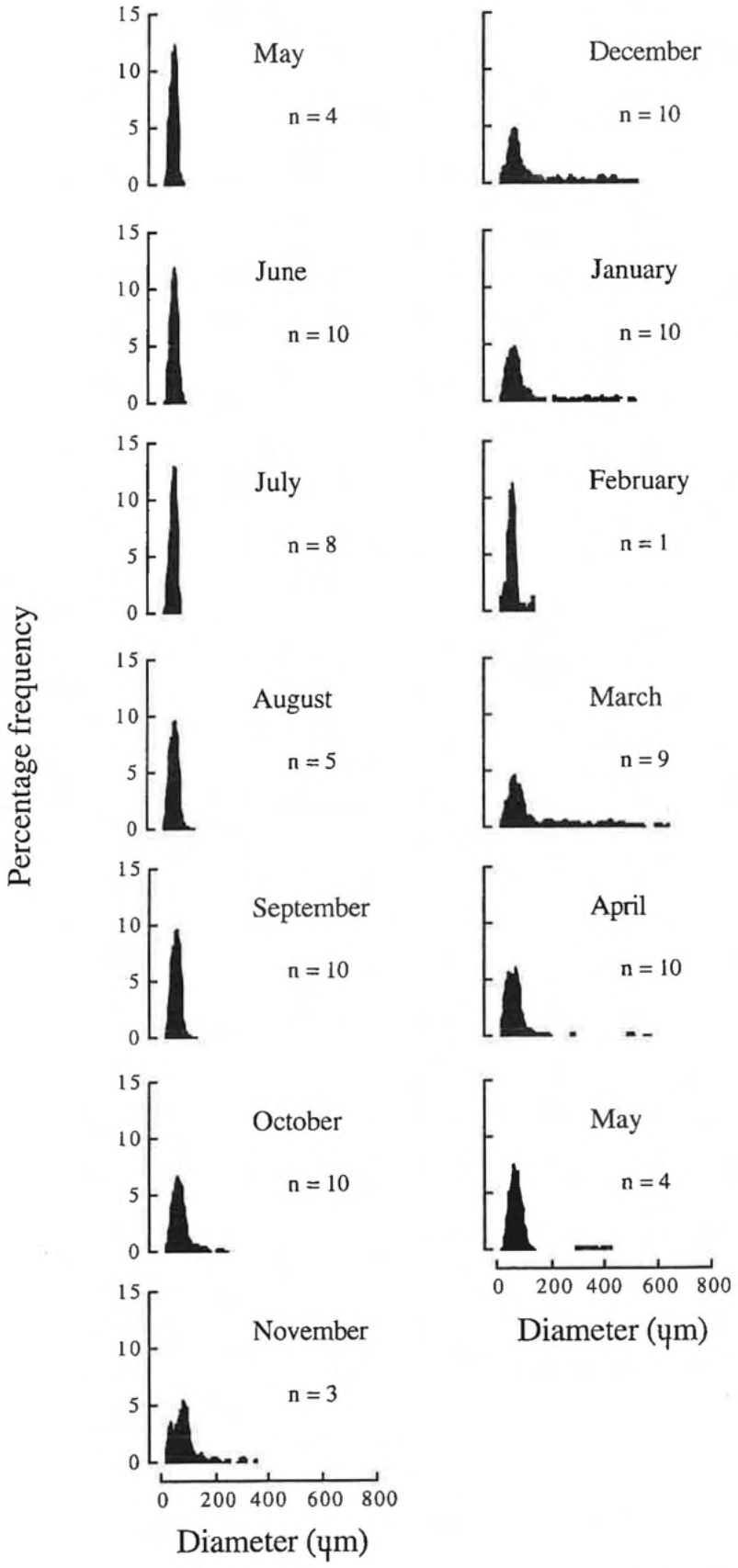


Figure 4.7. Monthly percentage frequencies for the oocyte diameters from the ovaries of *Glaucosoma hebraicum* >350mm total length caught in waters near Perth along the west coast of Australia. n = number of fish from which ovaries were examined.

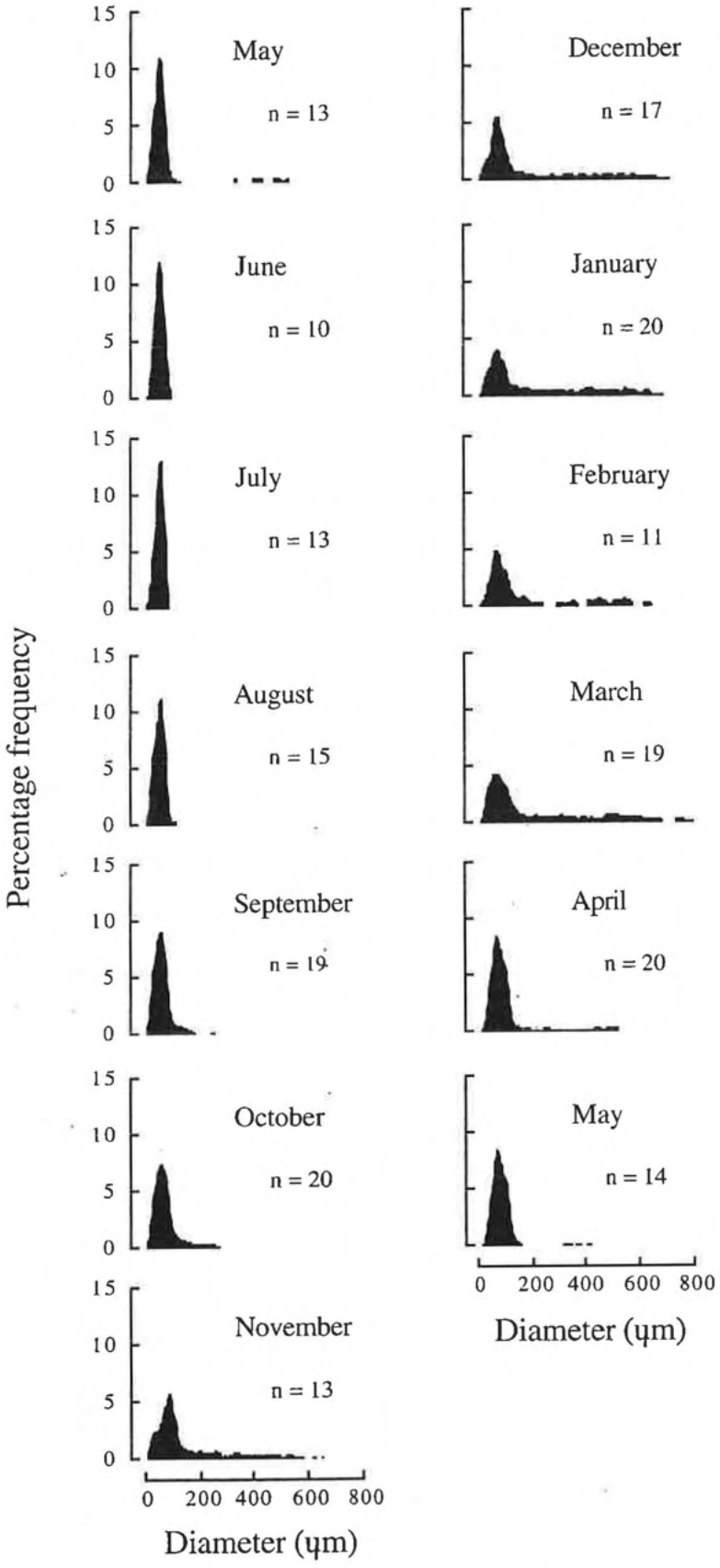


Figure 4.8. Monthly percentage frequencies for the oocyte diameters from the ovaries of *Glaucosoma hebraicum* >350mm total length, caught in waters between Geraldton and Perth along the west coast of Australia. n = number of fish from which ovaries were examined.

beginning to become atretic. Many other oocytes in the ovaries of fish in May had become almost completely resorbed, and were therefore not measured (see Plate 3e). In April 1997, a high proportion of the ovaries from *G. hebraicum* caught at Geraldton were at stages V-VI (Fig. 4.5), with many large hydrated oocytes and large granular oocytes being present in this month (Fig. 4.6). The fact that the ovaries of fish caught at Perth during this month were mostly immature or spent (Fig 4.4) accounts for the fact that few large oocytes were present (Fig 4.7).

The proportion of mature to immature oocytes, based on oocyte diameter trends, may not be indicative of the true proportions of these oocytes in the ovary, since oocyte measurements were recorded only for the oocytes that had been sectioned through the nucleus, which would cause a bias towards the measurement of small oocytes. However, even so, the frequency curves for oocytes suggest that the ovaries of female fish caught in January had the highest proportion of large oocytes (Figs. 4.6, 4.8). This finding is consistent with monthly gonad stage data, which showed that the majority of ovaries in this month were mature.

4.6. Preliminary data on the parasitic nematode (*Philometra* sp.) in the gonads of *Glaucosoma hebraicum*.

The large parasite found in the gonads of *G. hebraicum* was identified as belonging to the genus *Philometra* (Dr. R. Hobbs, School of Veterinary Science, Murdoch University, W. A. and Dr B. Jones, Department of Agriculture of Western Australia, pers comm), and to one its three subgenera, which is also named *Philometra*. No parasites were recorded in ovaries or testes from fish <200mm in length. After fish had reached *ca* 500mm, the prevalence of this *Philometra* sp. during the spawning period reached *ca* 75% of ovaries and *ca* 25% of testes and then remained at about this level. (Fig. 4.9).

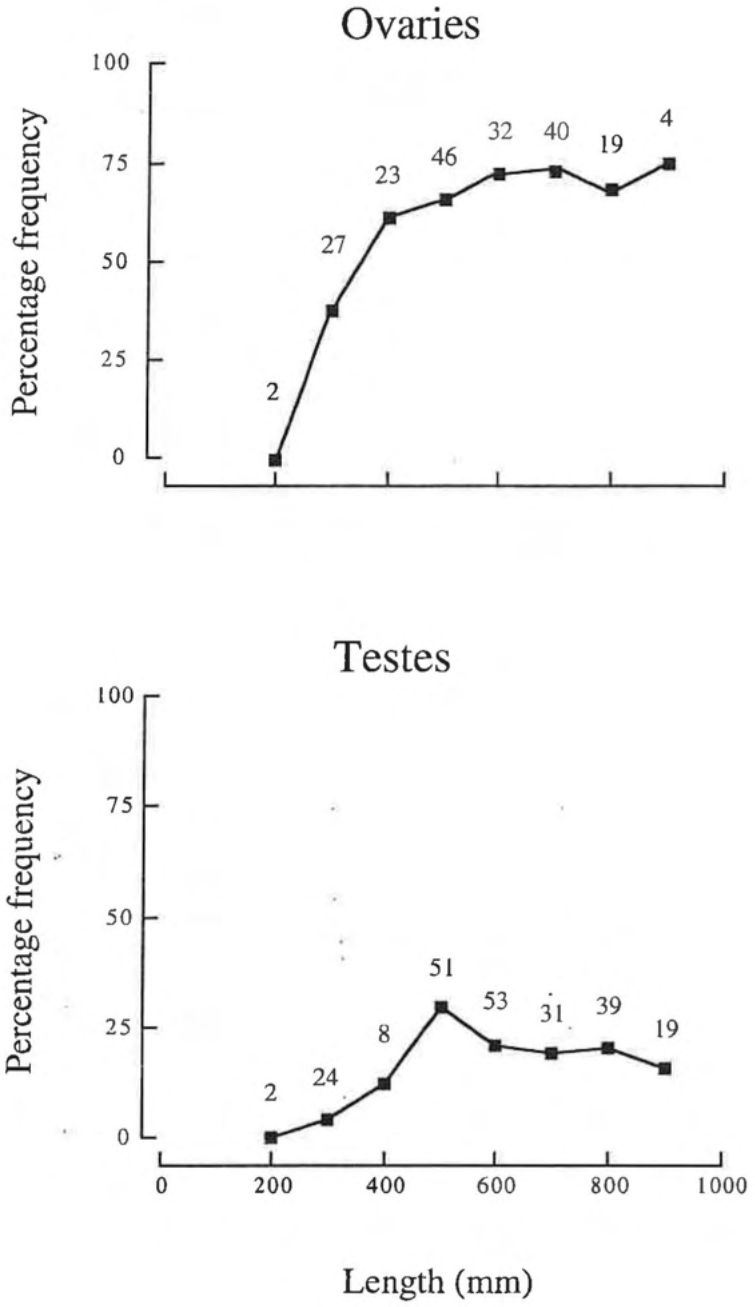


Figure 4.9. Prevalence of nematode parasites (*Philometra* sp.) in the gonads of females and males of *Glaucosoma hebraicum* between September 1996 and March 1997. n refers to total number of fish examined.

Macroscopic examination of dissected gonads, and of histological sections of the ovaries and testes, showed that, towards the end of the reproductive season and particularly in stage VII and VIII gonads, *Philometra* can occupy up to 50% of the gonads. Most or all stages of the life history of this parasite have been observed in the gonads of *G. hebraicum.*

Towards the end of the reproductive season of *G. hebraicum* (*i.e.* April to May), parasites formed a single mass within the gonads. At this stage, the proportion of space taken up in the gonad by the parasite is large, reflecting, in part, the small size of the gonad after spawning as well as the relatively large size of the parasite mass. Histological sections show that this parasitic mass often consists of cyst-like structures full of eggs and small larval worms (Plate 4a), presumably developing within the body of the dead adult worm. The numbers of eggs and larvae of this parasite (Plate 4a) indicate that this nematode has a very high fecundity. Furthermore, some histological sections showed that there were "free-living" (*i.e.* not contained within the parasitic mass) larvae in spawning ovaries of *G. hebraicum* (Plate 4b). When the gonads of *G. hebraicum* were beginning to mature (*i.e.* stages III and IV), few parasites were observed macroscopically or histologically, presumably because the parasitic larvae were absent or of microscopic size, and because the dead parasite mass present at the end of the previous spawning season had either been expelled or absorbed by the fish. However, early stage V (mature) gonads of *G. hebraicum* often contained numerous macroscopically visible parasite larvae. During the breeding season of *G. hebraicum*, the larvae increased in size and transformed into large adults, which were sometimes over 15cm in length (Plate 4c). Subsequently, towards the end of the breeding season, the large adult worms were coiled together to form, as previously mentioned, a single parasitic "mass" (Figure 4d).

On some occasions, live parasites were observed in "fresh" gonads of *G. hebraicum*, and these were sometimes moving.

5: Discussion

5.1. Marginal Increments

Validation that the translucent zones on otoliths are formed annually depends on demonstrating that the trends shown by the marginal increments on otoliths with different numbers of translucent zones each follow a consistent annual trend (Potter *et al.*, 1988; Beckman *et al.*, 1989; Hyndes *et al.*, 1992a). Although the marginal increment trends shown in the present study were based on values for groups of sectioned otoliths, that had a range of different numbers of translucent zones, the highly consistent annual trends followed by the mean monthly marginal increments by each of these groups provide strong evidence that the translucent zones are formed annually in the otoliths of *G. hebraicum*. These results thus demonstrate that it is valid to use the translucent zones on sectioned otoliths to age *G. hebraicum*. It should be recognised that the grouping of marginal increment data for otoliths with different numbers of translucent zones was necessary in order to obtain sample sizes that were sufficiently large to be able to demonstrate whether or not the mean marginal increments exhibited clear trends.

5.2. Accuracy of ageing

The difficulty in reading the number of circuli on scales and the differences in their number, compared with the situation with the translucent zones revealed in sectioned otoliths of the same fish, show that scales are unsuitable for ageing *G. hebraicum*. Furthermore, the results demonstrated that, while the number of translucent zones on whole otoliths corresponded to those on sectioned otoliths with up to six translucent zones, discrepancies between the number of translucent zones subsequently appeared as the number of these zones increased. Furthermore, the prevalence of underestimates of age readings taken from whole otoliths increased as the number of translucent zones increased, with discrepancies between the number of translucent zones observed on whole

and sectioned otoliths exceeding eight years in some otoliths with more than 22 translucent zones. The inability to detect all of the translucent zones in the whole otoliths of larger fish could be attributed, in part, to the allometric pattern of growth of the otolith. Whereas the first several translucent zones could easily be detected in whole otoliths, the disproportionate increase in otolith thickness relative to its width resulted in the translucent zones becoming more closely opposed as the otolith increased in size, thereby making the outer zones more difficult to distinguish from one another (see Plates 2a,b,c,d). This situation parallels that found in other marine species, *e.g.* Pacific hake *Merluccius productus* (Beamish 1979a,b), the starry flounder *Platychthys stellatus* (Campana, 1984), and the blue-spotted flathead *Platycephalus speculator* (Hyndes *et al.*, 1992a). For ageing *G. hebraicum*, it was therefore necessary to section otoliths when more than six translucent zones were observed in whole otoliths. In addition, due to the high number of translucent zones which occur on sectioned otoliths in old *G. hebraicum*, the use of a computer imaging package such as Optimus 5.1a was found to be invaluable, as it highly magnified the image on a computer monitor and thus made the zones easier to observe. Furthermore, translucent zones on the otolith image can be marked whilst counting, thus reducing the chance of missing translucent zones, or reading translucent zones twice in the counting process.

The age estimates of female and male *G. hebraicum* differed greatly from those recorded in a previous study, which was presented in Sudmeyer *et al.* (1992), a report, including a review of unpublished work by third year students at Curtin University. In this previous ageing study, using whole otoliths, the maximum age recorded for *G. hebraicum* was 19 years for a fish measuring 1070mm total length (Sudmeyer *et al.*, 1992). In contrast, the maximum age recorded for *G. hebraicum* using sectioned otoliths was 35 years, for a fish measuring 1023mm total length. From the results of the present study, it seems highly likely that the results obtained in that previous study represent gross underestimates of age, due to the difficulties in detecting all of the translucent zones on the whole otoliths of older fish. The marked discrepancy in age estimates for fish of similarly

large lengths using sectioned and whole otoliths further highlights the necessity for sectioning of otoliths of large fish. However, large differences in age estimates also occurred between the age estimated for small fish in that study and those determined during the present investigation. For example, it was previously suggested that Dhufish reach the (total) legal minimum length for capture (LML) of 500mm at three years of age (Sudmeyer *et al.*, 1992), whereas the results of the present study indicate that females and males of *G. hebraicum* do not reach this LML until they are seven and six years of age, respectively. Discrepancies in age estimates, even when using whole otoliths in small fish, highlights the fact that age estimates can vary depending on the interpretation of the reader. Thus, it is advantageous for readings of the same otoliths to be undertaken initially by two independent readers to determine the precision of the ageing technique. In this study, preliminary comparisons were made between the counts of translucent zones on sectioned otoliths taken from fish of a large range of lengths, as determined by an experienced age reader (Gavin Sarre - Murdoch University Fish Research Group) and the author. Counts made of translucent zones on sectioned otoliths with up to 13 translucent zones were almost always equal, and for otoliths with greater than 13 and up to 26 translucent zones, counts were always to within three years.

5.3. Growth

In the previous ageing study of *G. hebraicum*, no attempt was made to compare the growth rates of females and males, such as by the use of a likelihood ratio test, or by comparing scatterplot data for the length-at-age data or the von Bertalanffy parameters for each sex (Sudmeyer *et al.*, 1992). Comparisons of these types should be used to determine whether or not there are any conspicuous differences between the growth rates of females and males, and therefore whether the age data should be treated separately for each sex. The present study showed that the growth of female and male *G. hebraicum* differed, with the lengths reached by males at a given age always being greater than those

of females at the corresponding age (Chapter 3). Furthermore, the L_∞ for males was greater than females, *i.e.* 1052 vs 984mm, whereas the growth coefficient (K) was essentially the same, *i.e.* 0.11. This differs from the situation typically found in other marine species, where the growth rate and/or maximum length attained by females is either equal to or greater than males, *e.g.* King George whiting *S. punctata* (Hyndes *et al.*, in press), bonefish *Albula vulpes* (Crabtree *et al.*, 1996), tarpon *Megalops atlanticus* (Crabtree *et al.*, 1995), Atlantic croaker *Micropogonias undulatus* (Barbieri *et al.*, 1994) and winter flounder *Pleuronectes americanus* (Witherell & Burnett, 1993). Although the mechanisms which have resulted in the rather atypical growth patterns exhibited by females and males of *G. hebraicum* remain unclear, they may be of biological significance.

5.4. Lengths of *Glaucosoma hebraicum* at different latitudes

The fact that the number of large fish caught in commercial catches at the Abrohlos Islands (*ca* 80km offshore) was less than that in waters near Geraldton, which is situated at the same latitude, may be due, in part, to sampling bias. Samples of *G. hebraicum* were only obtained from one commercial fisher in each area. Therefore, any variation in fishing technique between these two fishers, such as the use of different hook sizes, could have affected the size of fish caught (see Ralston, 1982; Ralston, 1990; Otway & Craig, 1993). Indeed, it may well be relevant that the commercial fisher who obtains his catches from the Abrohlos Islands uses a relatively small hook size, compared to those employed by some other commercial and recreational fishers from whom samples were obtained in different areas.

Although the differences in the lengths of fish caught between the Abrohlos Islands and waters near Geraldton may be due to sample bias, there does appear to be, in the catches of both commercial and recreational fishers, an overall decline in the modal length of Dhufish from Busselton northwards. Moreover, fish were only caught at

Busselton during the three months of the spawning season. At present, there are insufficient data to make a sound assessment of whether the above differences in size between the different regions are due to migratory patterns or to differences in the duration of life in different regions.

5.5. Sampling bias of age classes in samples

Almost all of the fish collected for the present study were obtained from wetline fishers, except in the case of small juvenile *G. hebraicum* (<150mm total length), which were caught as by-catch by trawl fishers. The *G. hebraicum* collected by wetline fishing were almost always >300mm, with only a few fish being caught between 250-300mm. Since first sexual maturity was reached by female *G. hebraicum* at 250-350mm, there were thus insufficient numbers of fish caught in this size range to obtain a precise estimate of the size and age at which the females (and also the males) of *G. hebraicum* attain sexual maturity. In a previous study by third-year students at Curtin University, the length at first maturity of female and male *G. hebraicum* was estimated to be 585 and 520mm total length, respectively, results which are far higher than those of the present study (Sudmeyer *et al.*, 1992). These estimates are presumably erroneous since it was said that females and males were not able to be sexed in that study until they had reached total lengths of 365 and 300mm, respectively. These lengths are far higher than the lengths at which fish were able to be sexed in the present study and are close to the size at which fish were found to first reach sexual maturity by the studies carried out in this thesis.

Much effort was made to obtain undersize *G. hebraicum*, *i.e.* less than the LML of 500mm. *Glaucosoma hebraicum* were regularly caught between 300 and 500mm total length by wetline fishing. From personal observations, it was noticed that line fishing for *G. hebraicum* resulted in the capture of many other species of fish between 150 and 300mm, including skipjack trevally *Pseudocaranx dentex*, breaksea cod *Epinephelides armatus*, several wrasse species (Family Labridae) and large numbers of pink snapper

Pagrus auratus. In comparison with many of these species, the juveniles of *G. hebraicum* have a much larger mouth gape, which suggests that they would have been caught by line fishing if they were present. In an attempt to collect members of this missing size class of *G. hebraicum*, *i.e.* 150-300mm, fish traps were used in the same areas as line fishing was being employed. However, while these traps have proved to be very efficient in catching a variety of the reef-dwelling species mentioned above, they did not catch *G. hebraicum*.

From the above account, it is tentatively suggested that *G. hebraicum* between 150-300mm were not caught by line due to a difference between the habitat of these small juveniles and that of the larger representatives of this species. Evidence to support this theory is provided by several commercial fishers, who report that they have occasionally caught considerable numbers of juvenile *G. hebraicum* in trawls over "weed bank" areas, and by the fact that the majority of *G. hebraicum* under 150mm obtained in this study were caught in trawls over areas where some "weed" had accumulated. It is noteworthy that the juveniles and adults of some co-occuring species, such as *Sillaginodes punctata* (Hyndes *et al.*, 1998) and *P. auratus* (Dr Rod Lenanton, Fisheries Department of Western Australia, pers. comm.) occur in different habitats. Since adult Dhufish occur in habitats where there is a high concentration of predatory fish, it would certainly appear advantageous for the juveniles of *G. hebraicum* to occupy different areas as nursery habitats.

5.6. Timing of spawning period and its relation to recruitment success

The elevated GSIs and high proportions of mature gonads (stages V-VI) between December and February and, to a lesser extent, in March and April, suggest that *G. hebraicum* spawns during these months. This conclusion is consistent with the presence of fully-hydrated eggs and post-ovulatory follicles in ovaries examined between December and March. Furthermore, the majority of ovaries of fish caught in May 1997

contained a high proportion of yolked-oocytes that were atretic (see Plate 3e), and the remaining ovaries examined in that month were spent or immature. This finding provides strong evidence that the spawning period does not extend beyond May. The slight decline in mean GSIs in February and the appearance of several spent females in that month, suggest that spawning peaks in late January and early February and, for this reason, it was justifiable to assign a birth date of the first of February for this species.

The deep water habit of *G. hebraicum* (generally over 20m and up to well in excess of 100m) and the protracted spawning period of this species, that extends throughout summer and into early autumn, parallels the situation with certain species in south-western Australia. For example, *Sillago robusta* (Hyndes & Potter, 1996) and *P. auratus* (Scott & Pankhurst, 1992) occur in deeper waters in south-western Australia, and have protracted spawning periods occurring at some stage between late spring and early autumn. The limited fluctuation of environmental variables in the deep water may favour a longer spawning period amongst species that inhabit this type of environment (Hyndes & Potter, 1996).

It is now widely accepted that much of the variation in recruitment in fish is related to events that occur during the larval stages. This view is based on the fact that the numbers of a cohort are greatest initially, and that the mortality of a cohort is also greatest at the larval stage when individuals are most susceptible to starvation and predation (*e.g.* Kane, 1984; Houde, 1987; Miller *et al.*, 1988; Simpson, 1987; Cury & Roy, 1989; Wootton, 1990). The vulnerability of fish larvae to these factors decreases with increasing body size. Small larvae will be more susceptible to starvation because of the limited reserves of energy in their yolk sac (Blaxter & Hunter, 1982), short reaction distances in terms of food detection (*i.e.* can only detect and thus react by swimming towards food particles which occur within a very close vicinity) and limited swimming abilities which reduces their efficiency in searching for food. Futhermore, the size of food particles that larvae can ingest depends on their mouth gape and the ability to capture the particle, which increases with body size (Miller *et al.*, 1988). In temperate environments, there are

predictable periods of high temperature and food abundance and low temperature and food scarcity (Shuter & Post, 1990). Thus, the timing of spawning in teleost fishes is crucial for maximising the probability of larval survival, and it is widely viewed among researchers that spawning is restricted to periods of the year when physical factors favour the survival of offspring (Cushing, 1990). The spawning period of *G. hebraicum* is similar to that of most marine temperate fish species, *i.e.* it occurs some time between late spring and early autumn (Conover, 1992). This coincides with the period of highest temperature and food abundance, which would be advantageous for larval survival.

Furthermore, in temperate fishes at middle to high latitudes, there is a second period of size-dependent vulnerability to starvation during the first winter of life. Smaller fish spawned late in the spawning season die of starvation over winter because they exhaust their fat reserves before winter ends (Conover, 1992). There is therefore selection in temperate fishes for spawning to occur early in the season as this will enable larval fish to have a substantial growing season prior to the onset of winter. As peak spawning of *G. hebraicum* occurs in early February, the majority of larvae would have the opportunity to grow over some of the summer period and all of the relatively warm autumn period before experiencing their first winter.

Sillaginodes punctata is apparently the only species in south-western Australia that occurs at comparable depths to *G. hebraicum* and for which there are published data. However, this species has a winter spawning period (Hyndes *et al.*, 1998). Unlike *G. hebraicum*, this sillaginid uses nearshore embayments and estuaries as nursery areas. Since some estuaries along the coast of Western Australia do not open until winter, when the sand bars at their mouths are breached by freshwater discharge, it was suggested that a winter spawning period would enable the juveniles of this species to recruit into these estuarine nursery areas (Hyndes *et al.*, 1998).

5.7. Is *Glaucosoma hebraicum* a multiple spawner?

During the spawning period, the mature ovaries of *G. hebraicum* often contained yolk vesicle, yolk granule and hydrated oocytes, which ranged widely in size. This feature, and the fact that some of these ovaries also contained post-ovulatory follicles provide strong circumstantial evidence that this species is a multiple spawner (de Vlaming, 1983; Hyndes *et al.*, 1992b; Hyndes *et al.*, 1996). Furthermore, observations of a large number of histological sections of ovaries throughout the spawning period indicated that the oocytes of *G. hebraicum* may constitute an essentially continuous size distribution, a pattern typically exhibited by indeterminant multiple spawners. That is, species in which pre-vitellogenic oocytes are recruited via *de novo* vitellogenesis throughout the spawning period, as opposed to the situation found in determinate multiple spawners, where the size distribution of these oocytes is separated from the pre-vitellogenic oocytes prior to spawning (McEvoy & McEvoy, 1992). However, the oocyte distributions of several individual fish captured throughout the spawning period must be examined to confirm this observation.

The multiple spawning strategy of *G. hebraicum* has important implications regarding the recruitment success of this species because it enables a greater number of eggs to be produced during a spawning period. Just prior to ovulation, oocytes hydrate and increase greatly in size. If all oocytes hydrate at the same time, the space within the body cavity will limit the level of fecundity. However, the spawning of eggs in batches over time enables a greater number of eggs to be produced by the ovary during a spawning season than would be the case if all of the eggs were matured and discharged at one time (McEvoy & McEvoy, 1992). In addition, the slow release of eggs into the environment over time would reduce the risk of the new cohort being subjected to high larval mortality, due to adverse environmental conditions, such as low food availability and high predation pressure (Lambert & Ware, 1984; Hyndes *et al.*, 1996).

It is evident from the data present in this thesis that *G. hebraicum* first reaches maturity at a far lower size and earlier age than the maximum length and age attained by this species. Moreover, the trends shown be the gonadal stages of fish of different size and age, suggest that, once it has first spawned, *G. hebraicum* breeds in each subsequent year. This means of course that an individual female can potentially produce a large number of eggs in her life time.

5.8. Implications of the biology of *Glaucosoma hebraicum* for fisheries management

The fact that the females and males of *G. hebraicum* become reproductively mature at 350 and 400mm, respectively, means that, in general, fish have spawned at least once before they reach 500mm total length, the LML for capture . However, the vast majority of undersize Dhufish caught, particularly in waters deeper than 30m, die after release (G. Jenkins - Fremantle Maritime Centre, pers. comm.). Therefore, the majority of these undersize *G. hebraicum* caught by line fishing are being "killed" either before they reach the size and age of first sexual maturity, or in the first of their many potential spawning seasons.

The GSIs for *G. hebraicum* were not proportional to body size, but were in fact disproportionately higher in large fish (*e.g.* >700mm). Furthermore, as was found with *Sillago bassensis* by Hyndes and Potter (1996), the data on the prevalence of mature gonads indicate that the spawning period becomes more protracted with increasing body size (Figs. 4.3, 4.5). These features result in the large individuals of the population being, to a high degree, the most fecund, and hence very important in terms of population recruitment success. In some large marine West Australian species (*e.g.* pink snapper *P. auratus*, and mulloway *Argyrosomus japonicus*), there are upper-size limits to protect the large individuals which are most important to the spawning stock.

Since most *G. hebraicum* die when they are brought to the surface, it would seem of little value to impose a size limit. From both personal experience and conversations with many commercial and recreational fishers, it is apparent that large and small fish (down to a total length of 300mm) are often caught together. On this basis, the most effective measures that could be undertaken to conserve this species would be to reduce fishing pressure, either by reducing the daily bag limit for recreational anglers, suspending certain commercial licences (see below) or by introducing quotas on commercial fish catches. In addition, the restriction of fishing in certain areas of known high population density may be an effective means for preserving important breeding stocks. However, such a measure would require reliable information both on the areas where the abundance is high and on the migratory habits of this species.

Commercial fishermen, who make a living solely by wetline fishing, have expressed the view that crayfishers who line fish for *G. hebraicum* during the off-season for crayfish have a large impact on the numbers of this species, and that the licences of these part-time line fishermen should be reviewed.

Recreational fishers have suggested that areas which are heavily fished by recreational fishers, such as those near the Metropolitan area, should be closed to commercial fishing. The introduction of such a measure may be of long-term economic benefit, as the amount of time and money spent by recreational fishermen to catch a certain weight of fish would far exceed that of commercial fishermen. Furthermore, measures to preserve local fish stocks would also be of considerable social benefit.

As the recreational catches of *G. hebraicum* is as large or maybe larger than the commercial catches of this species (Sudmeyer *et al.*, 1992), the introduction of any conservation measures would need equally to take into account both the recreational and commercial fisheries. One option that has been raised, is the introduction of recreational licenses to catch this (and possibly other deep sea) species. These licenses would enable some regulation of the recreational fishery, and the revenue raised from these licenses

could be used to set up a trust fund, such that, if any commercial licenses were to be suspended, they could be bought back from the fishers using this fund.

4.9. The life cycle of *Philometra* sp. and its infection of the gonads of *Glaucosoma hebraicum*

At maturity, the ovaries of *G. hebraicum* were approximately an order of magnitude larger than testes. The higher prevalence of *Philometra* sp. in the ovaries than testes of *G. hebraicum* may thus be related, in part, to these differences in the relative sizes of the female and male gonads. Since philometrid worms feed on blood (Sniezko & Axelrod, 1970), there would presumably be a greater food supply in the ovaries than in the testes.

Most philometrids in temperate areas have a one-year life cycle (Molnar, 1982). This study provides strong evidence that *Philometra* sp. in *G. hebraicum* also has a one-year life cycle. The eggs and first stage larvae developed in what appeared to be cysts. However, histological sections showed that these cysts were the uteri of gravid adult worms, in which the eggs and larvae of philometrid parasites develop (Molnar, 1982). Several presumably dead adult worms are, at this stage, coiled together in a single mass. These parasitic masses occurred in spawning and spent ovaries between March and April. Larger larvae (*ca* 3-7cm length) were formed in stage IV and early stage V gonads in September and November, and live adult worms (*ca* 10-17cm length) were present in late stage V and spawning gonads in December to March. No *Philometra* sp. were observed in developing and maturing (*i.e.* stages III and IV) ovaries. This situation parallels that observed with *Philometra* sp. infection in Chilean sea *bass Paralabrax humeralis*, in Skipjack tuna *Katsumonus pelamis* (Molnar, 1982) and in *Paralabrax humeralis* (Oliva *et al.*, 1992).

Most philometrids in the temperate zone are reported to achieve gravidity (*i.e.* uteri full of larvae) and to release their larvae into the water column in spring. In contrast,

gravidity in the *Philometra* sp. infection in *G. hebraicum* occurred in early autumn at the end of the Dhufish spawning period, and thus the larvae were probably released in late autumn. In many cases, the larvae of philometrids enter an intermediate host, usually a cyclopoid copepod, for 2-3 weeks, and infection or reinfection of the main host occurs through consumption of prey in summer (Molnar, 1982). In some cases, such as *Philometra obturans* infection of the pike *Esox lucius*, the philometrid parasite infects *Cyclops*, the intermediate host, as well as carrier hosts (small fish prey) during its development (Molnar, 1982). *Philometra obturans*, however, unlike most philometrids, do not show any seasonality in its development.

As was the case with *G. hebraicum* in this study, the infection of *Philometra* sp. in *P. humeralis* occurred only in fish that had reached the size at which they first become sexually mature (Oliva *et al.*, 1992). The latter authors suggested that there was no infection of an intermediate host in the case of *P. humeralis*, and that infection occurred when fish arrived at spawning areas. Larvae of the nematode can be expelled in conjunction with sexual products, and *Philometra* sp. in *P. humeralis* can actively penetrate the host. Fish arriving for the first time at a spawning area meet with older and already infected fish (Oliva *et al.*, 1992). The fact that the chance of infection would increase with the number of spawnings, would account for the higher rate of infection amongst larger fish (Oliva *et al.*, 1992). This parallels the situation observed with *G. hebraicum.*

This latter explanation seems a likely route of infection in *G. hebraicum.* The presence of "free" larvae in spawning ovaries of *G. hebraicum* (Plate 4b) indicate that these larvae would probably be expelled from the gonad into the water column at some stage towards the end of the spawning period. However, *G. hebraicum* are piscivorous, and therefore infection could also occur by consumption of carrier hosts (prey fish).

The high numbers of parasite larvae and the large size of adult worms suggest that the parasites would have a substantial demand for food and, as a consequence, may have a drain on the supply of nutrients to the ovary. However, there were no cases where parasite

infection was observed to cause destruction of oocytes. Furthermore, the normal gonadal development of the ovaries did not seem to be affected by the presence of the parasite. The effect of parasite infection on the testes was not investigated in detail. However, adult male worms were observed in the testes and, in one case a histological section of the testes also revealed parasite eggs and larvae.

4.10. Further directions for future research

The collection of a greater number of small *G. hebraicum* would provide more points for the commencement of the growth curve, more data for determining marginal increment trends in fish with otoliths containing one and two translucent zones, and a more precise estimate of the size and age at which females and males reach sexual maturity. The collection of samples over the next reproductive season would also allow comparisons of the reproductive biology of *G. hebraicum* in two different years.

Sampling for this study showed that small fish (250-500mm) occur together with very large fish. However, there is some evidence to suggest that fish <200-250mm occur in a different habitat to the adults. It is therefore important that further trials are carried out using fish traps and experimental trawls over the weed bank areas in an attempt to obtain the length and age classes of *G. hebraicum* that are poorly represented in this study. Such trials would also hopefully provide information on the habitats used by the juveniles of this species.

A wide range of testes of *G. hebraicum* has already been collected for histological examination in the future. Since the GSIs of males are approximately an order of magnitude less than those of females, the different maturity stages of testes were far more difficult to delineate than was the case with ovaries. A detailed histological examination of spermatogenesis would improve and consolidate the reproductive data already obtained for males and may provide additional information of value in the aquaculture studies being carried out on this species by the Fremantle Maritime Centre.

Future investigations into the infection of the gonads of *G. hebraicum* by *Philometra* sp. could include records of infection rates of all months of the year. Detailed records of the prevalence of the different parasite life cycle stages in each month, including length-frequency data for maturing worms, should reveal precise information on the timing of infection or reinfection of fish, and the life cycle of this parasite in *G. hebraicum*. Microscopic examination of gonadal material between June and October may reveal the presence of very small larvae. Furthermore, prey items of *G. hebraicum* could be dissected to determine if these act as carriers for infection. Also, the number of eggs in infected verses uninfected fish could be studied to determine if parasite infection leads to a lowered fecundity.

Conclusions

- Scales are unsuitable for ageing *G. hebraicum*.
- The translucent zones in the sagittal otoliths of *G. hebraicum* are formed annually and can be used to age this species.
- Whole otoliths with up to six translucent zones can be used to age this species, but thereafter, the otoliths have to be sectioned to be certain that all of the translucent zones are revealed.
- The von Bertalanffy growth parameters L_∞, K and t_0, for the growth curves of *G. hebraicum* derived from length-at-age data were 984mm, 0.096 and -0.526, respectively, for females, and 1052mm, 0.101 and -0.491, respectively, for males.
- The maximum ages recorded for females and males were 29 and 35 years, respectively, and the maximum lengths for females and males were 976 and 1120mm, respectively.
- Males grow slightly faster and attain a greater maximum length than females. Although the von Bertalanffy parameters of both female and male *G. hebraicum* caught in waters near Geraldton differ from those of Perth, the differences in these parameters were not marked.
- Females and males of *G. hebraicum* reach first sexual maturity at total lengths of 250 to 300mm and 350 to 400mm, respectively, and at the end of their fifth and eighth years of life, respectively.
- *Glaucosoma hebraicum* breeds between December and April, with spawning reaching a peak in late January/early February. *Glaucosoma hebraicum* was thus accorded a birth data of the first of February.
- *Glaucosoma hebraicum* is a multiple spawner.
- The nematode parasite *Philometra* sp. infects the gonads of *G. hebraicum*. The prevalence of infection is far higher in females than males, and increases with the size and age of the fish.

- *Philometra* sp. may have a deleterious effect on the reproduction of *G. hebraicum*.
- The life cycle of this parasite is closely synchronised with the pattern of reproductive development of its host.
- There is no value in imposing a legal size limit on this species.
- Conservation measures for *G. hebraicum* could involve restricting the numbers of fish caught, particularly in heavily-fished areas, and the closure from fishing of certain areas of known high population density.
- Further research is needed to determine the precise locations of high population densities of *G. hebraicum* and the migratory habits of this species to determine the most effective conservation measures.

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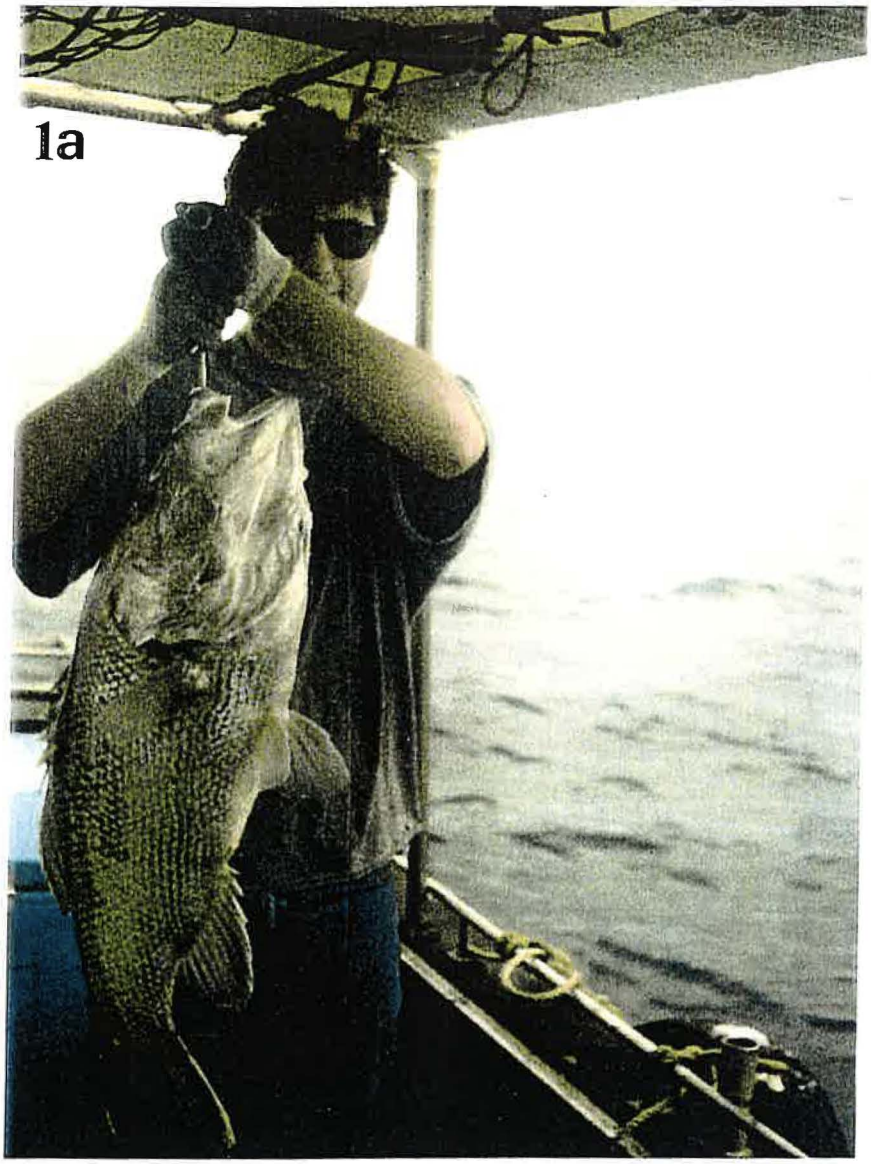

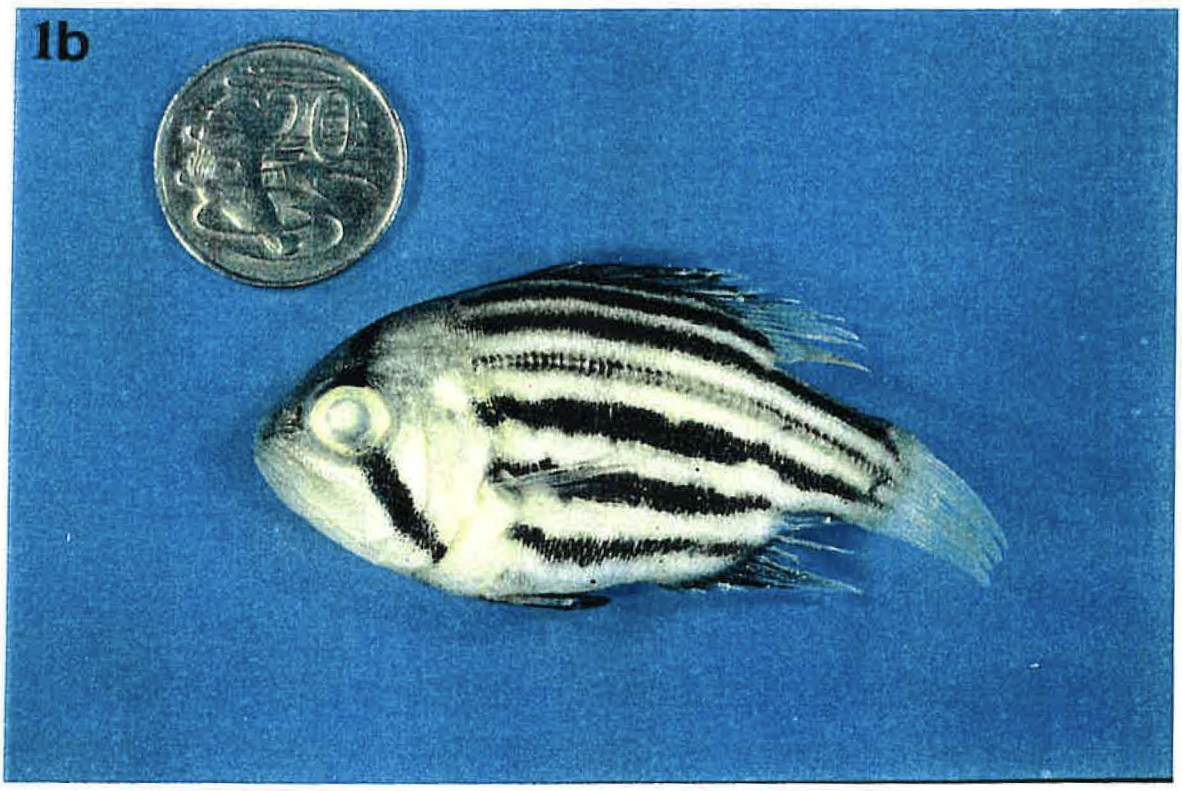

Plate 1a. Adult *Glaucosoma hebraicum* caught by wetline fishing.
Plate 1b. Juvenile *Glaucosoma hebraicum* caught by trawl fishing.

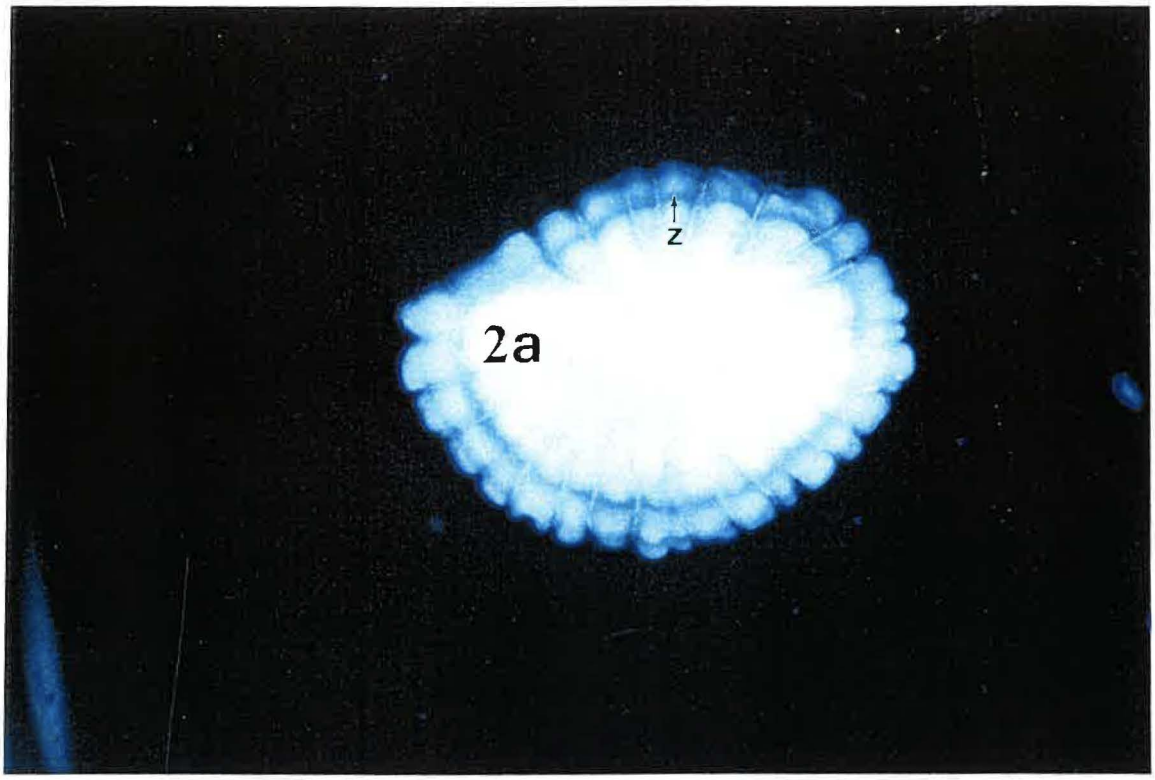

Plate 2a. Whole otolith of *Glaucosoma hebraicum* with one translucent zone (z).

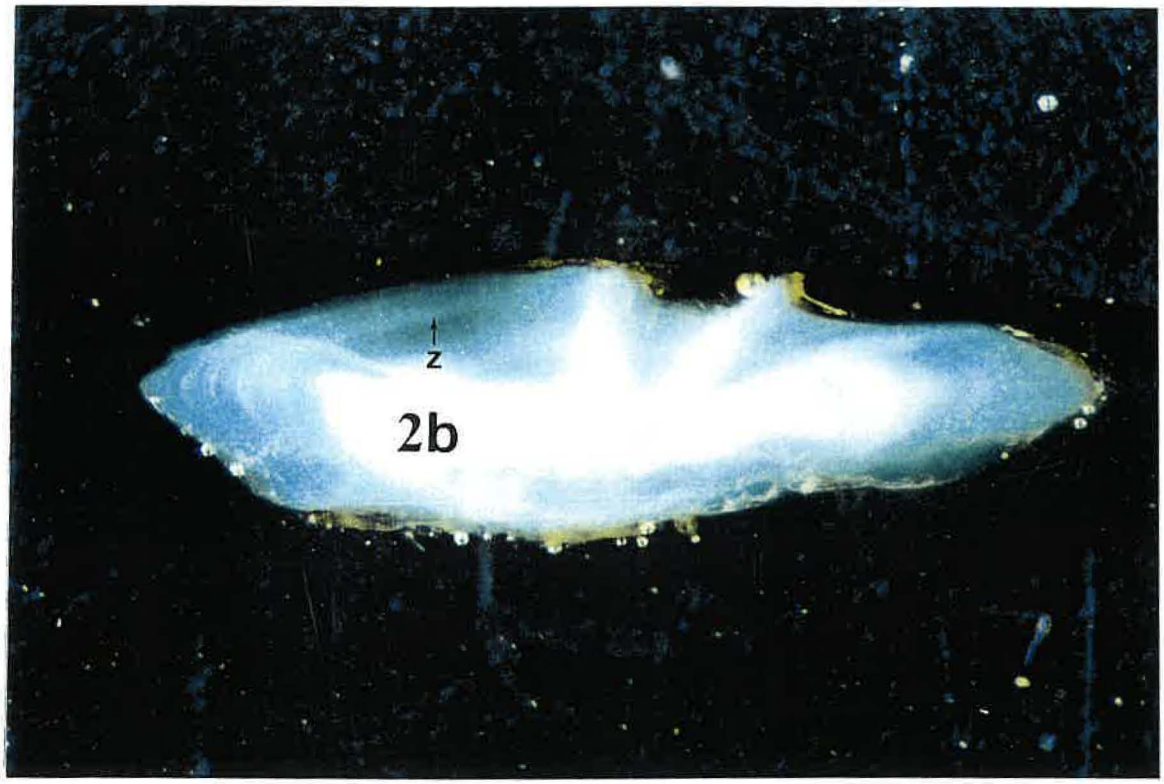

Plate 2b. Sectioned otolith of *Glaucosoma hebraicum* with one translucent zone (z).

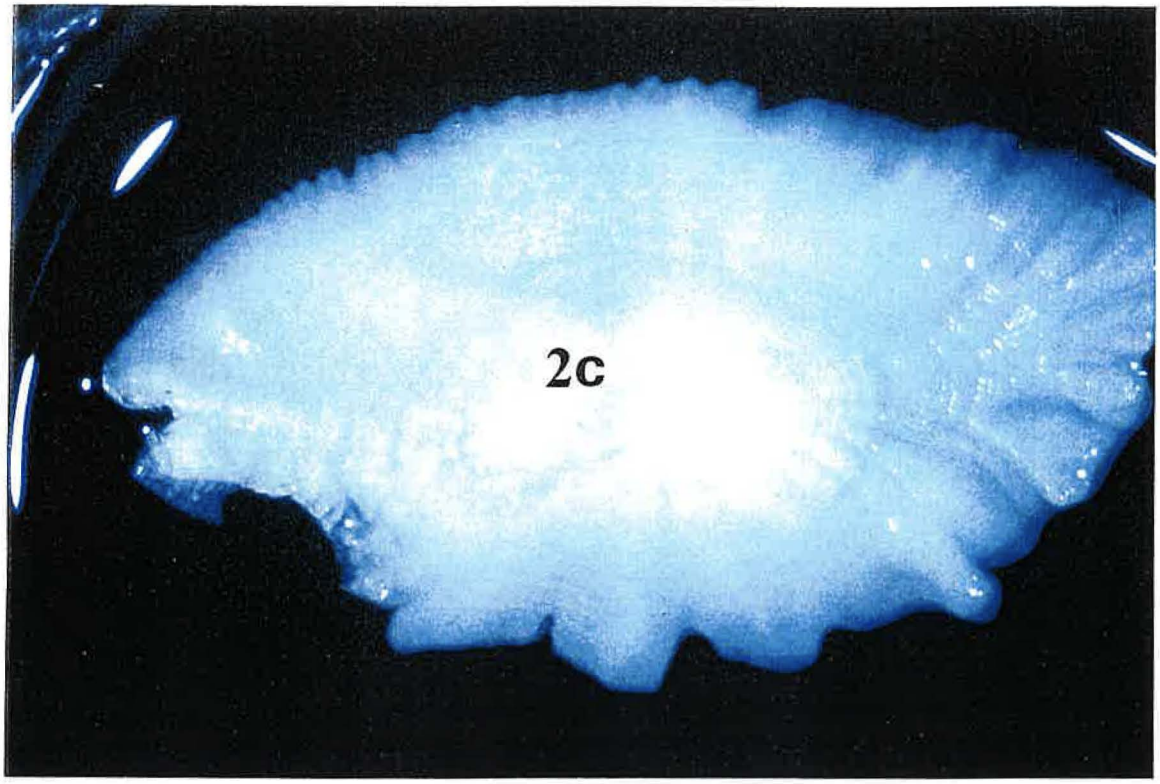

Plate 2c. Whole otolith from a large *Glaucosoma hebraicum* (963mm total length). Translucent zones are difficult to distinguish.

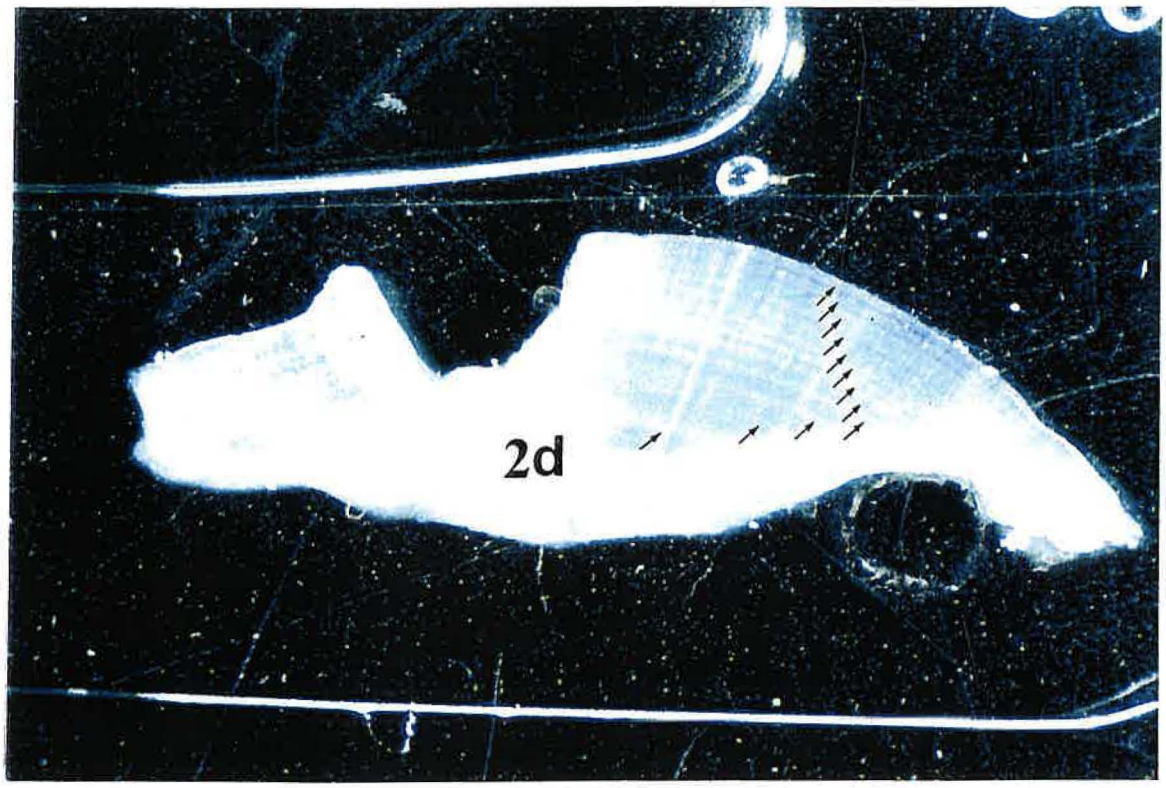

Plate 2d Sectioned otolith of a medium-sized *Glaucosoma hebraicum* (751mm total length). Translucent zones are clearly visible (see arrows).

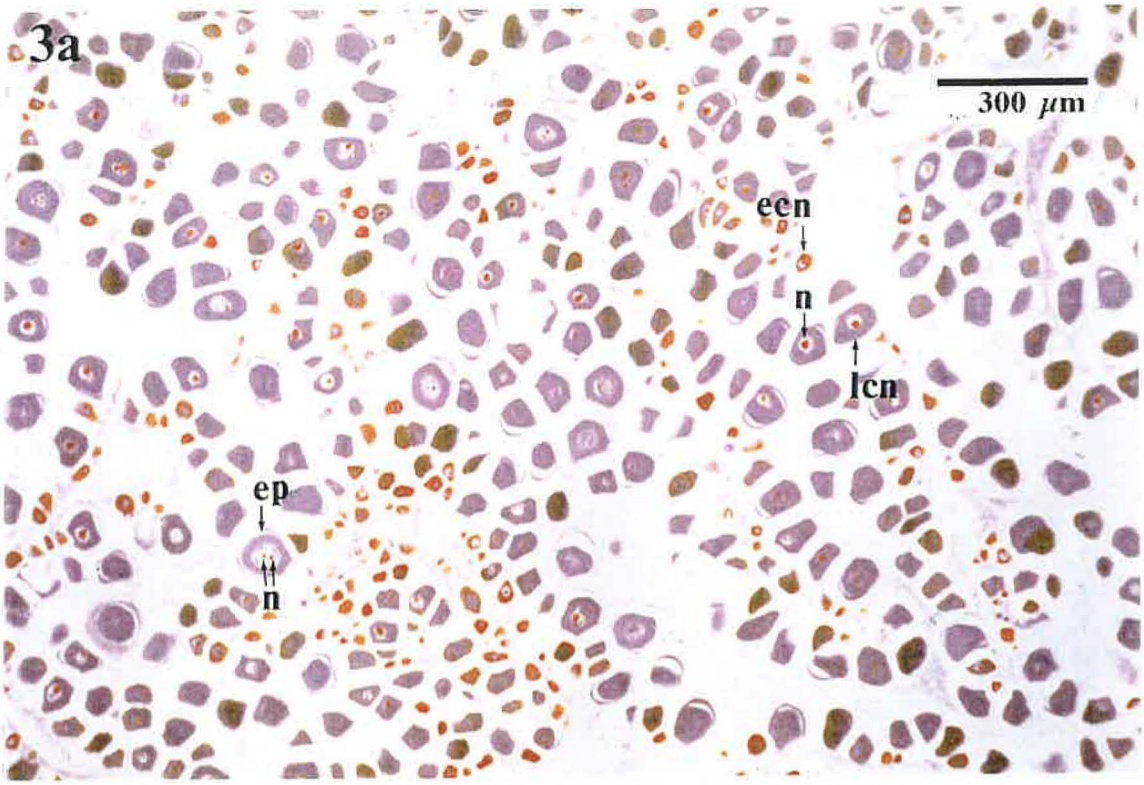

Plate 3a. Histological section of a stage II ovary with early (ecn) and late chromatin nucleolar stage oocytes (lcn) and early perinucleolar oocytes (ep) with two nucleoli (n) in nucleus.

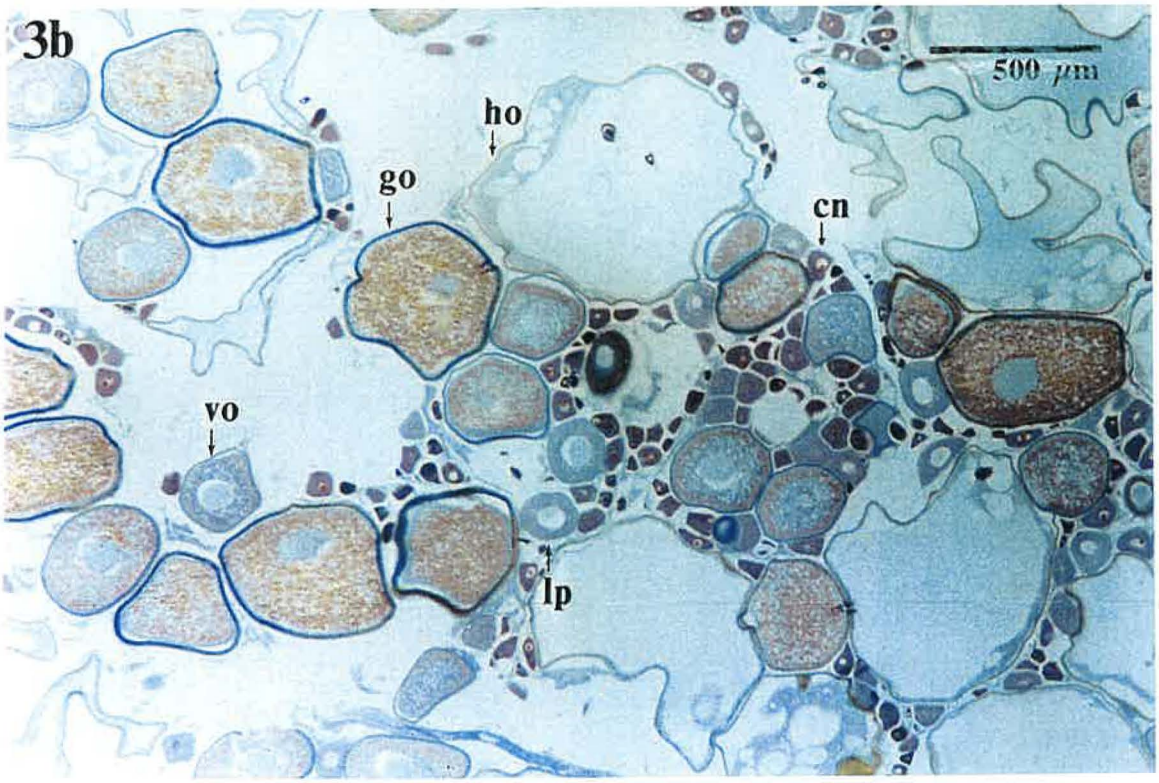

Plate 3b. Histological section of a stage VI ovary with oocytes at various developmental stages, including chromatin nucleolar stage oocytes (cn), late perinucleolar stage oocytes (lp), yolk vesicle stage oocytes (vo), yolk granule stage oocytes (go) and hydrated oocytes (ho).

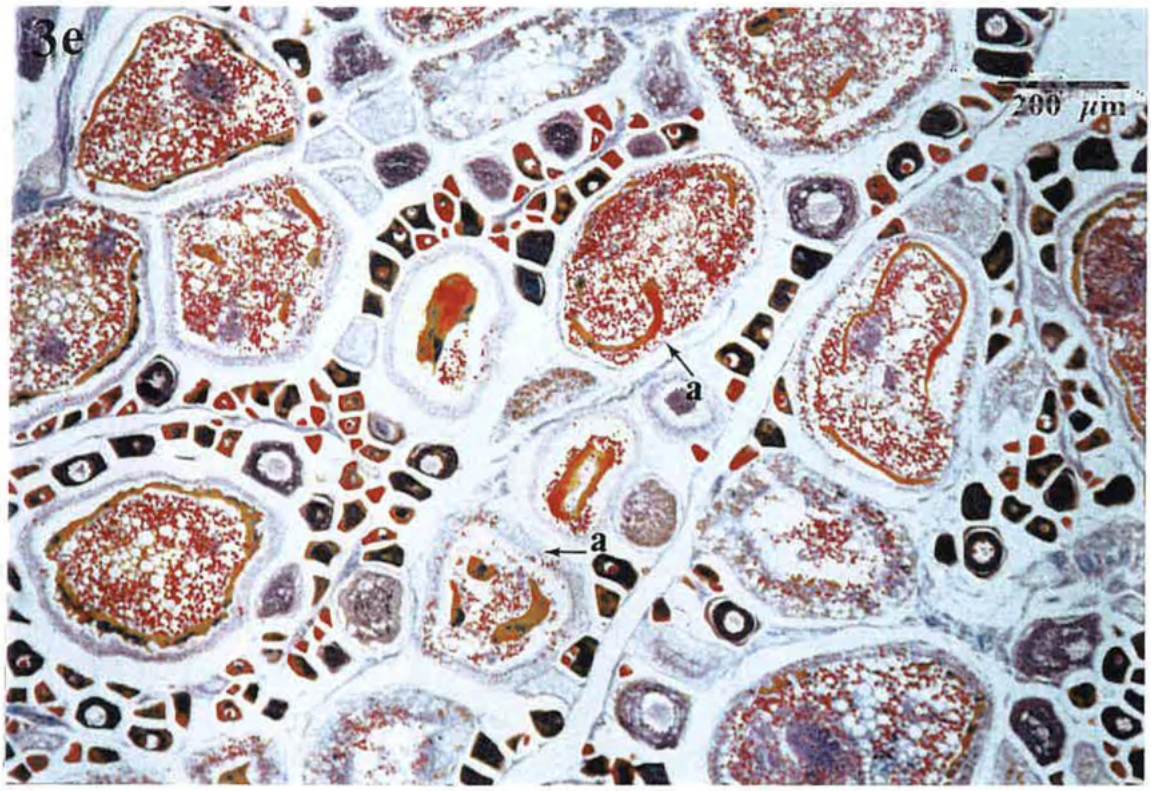

Plate 3e. Histological section through an ovary of *Glaucosoma hebraicum* with oocytes in different stages of atresia (a). All yolk granule oocytes are becoming atretic.

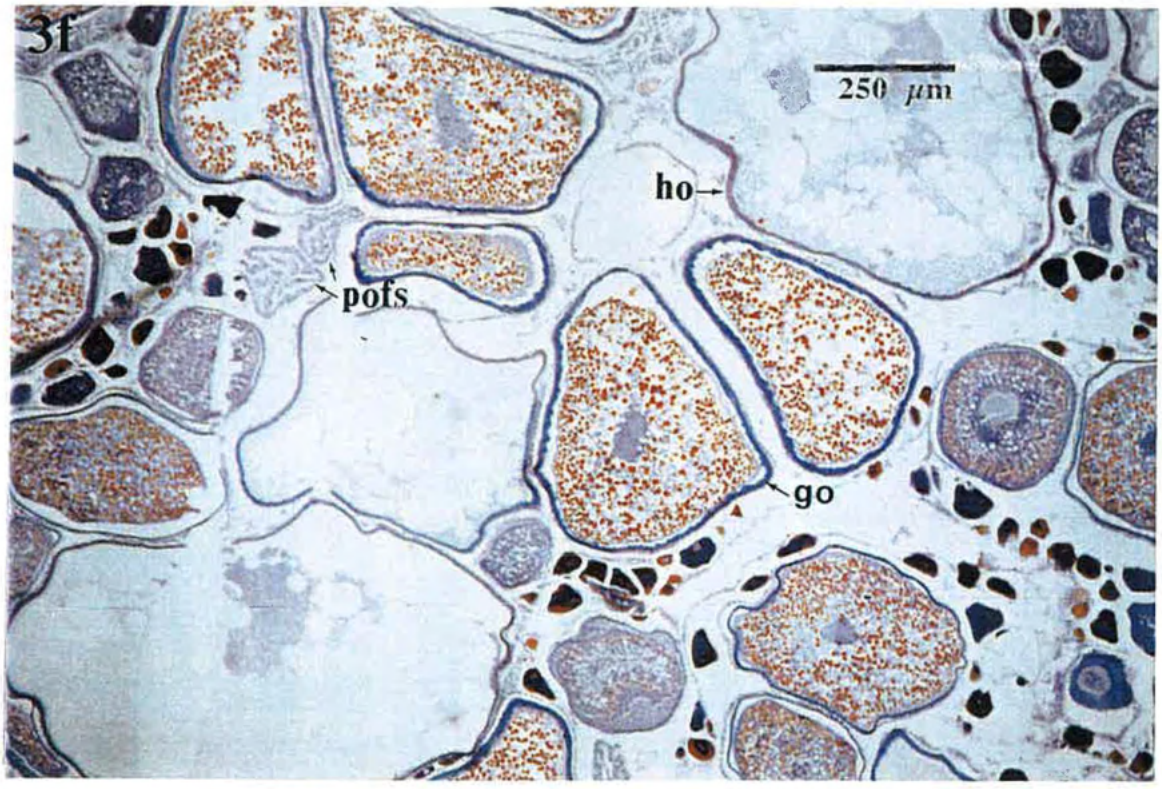

Plate 3f. Histological section of a stage VI ovary of *Glaucosoma hebraicum* with post ovulatory follices (pof), hydrated oocytes (ho) and yolk granule oocytes (go).

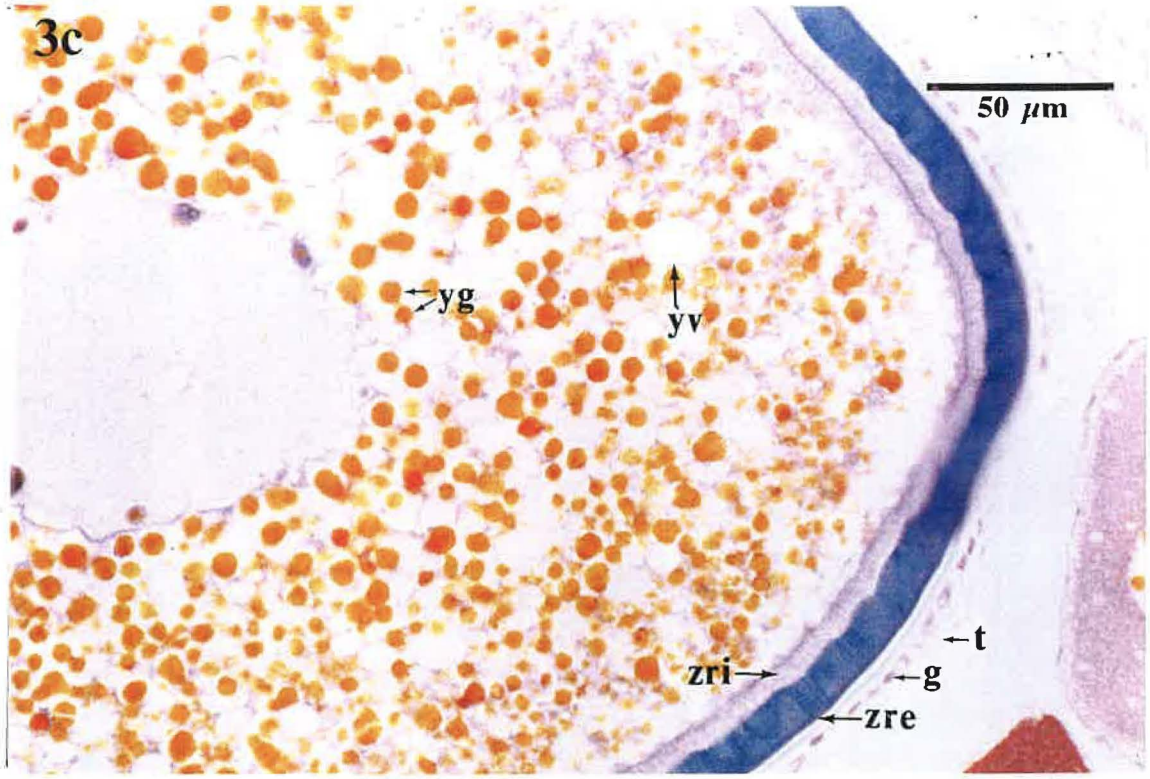

Plate 3c. Histological section through a yolk granule stage oocyte with a thecal layer (t), and a granulosa layer (g), surrounding the zona radiata externa (zre) and zona radiata interna (zri). Yolk granules (yg) and yolk vesicles (yv) are found throughout the cytoplasm.

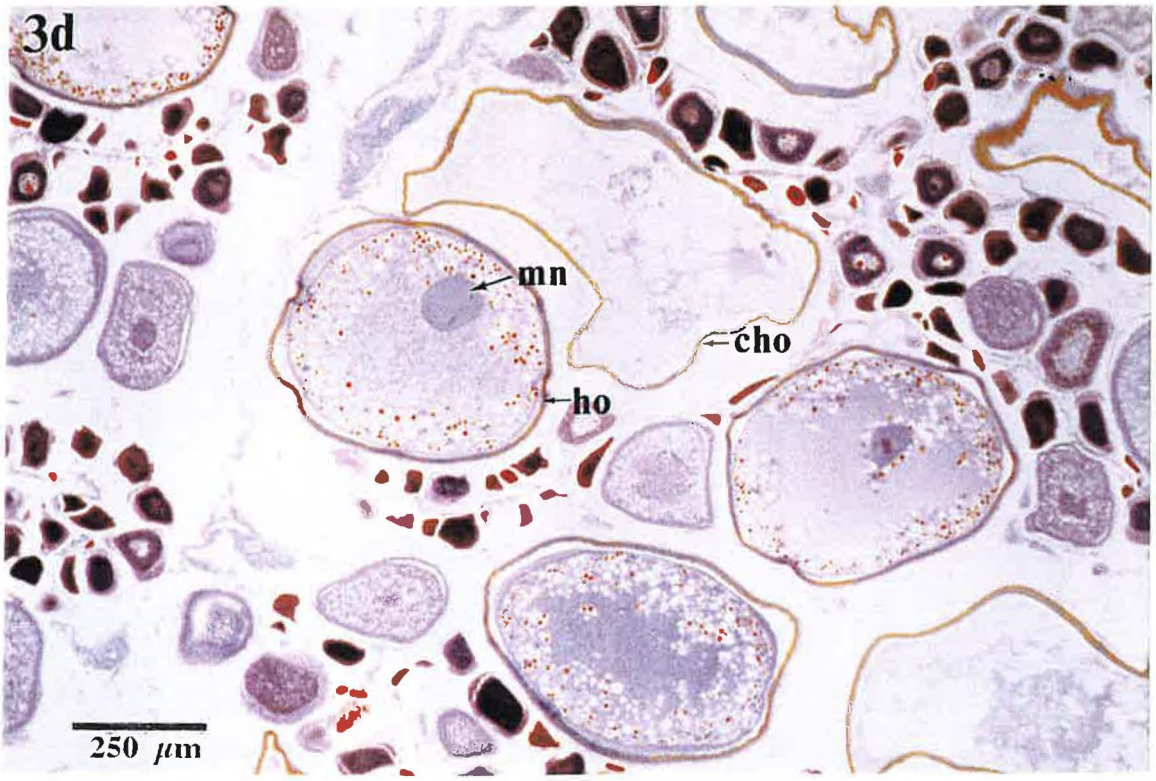

Plate 3d. Histological section through a stage VI ovary of *Glaucosoma hebraicum* with hydrating oocytes (ho) with migrating nuclei (mn) and collapsing hydrated oocytes (cho).

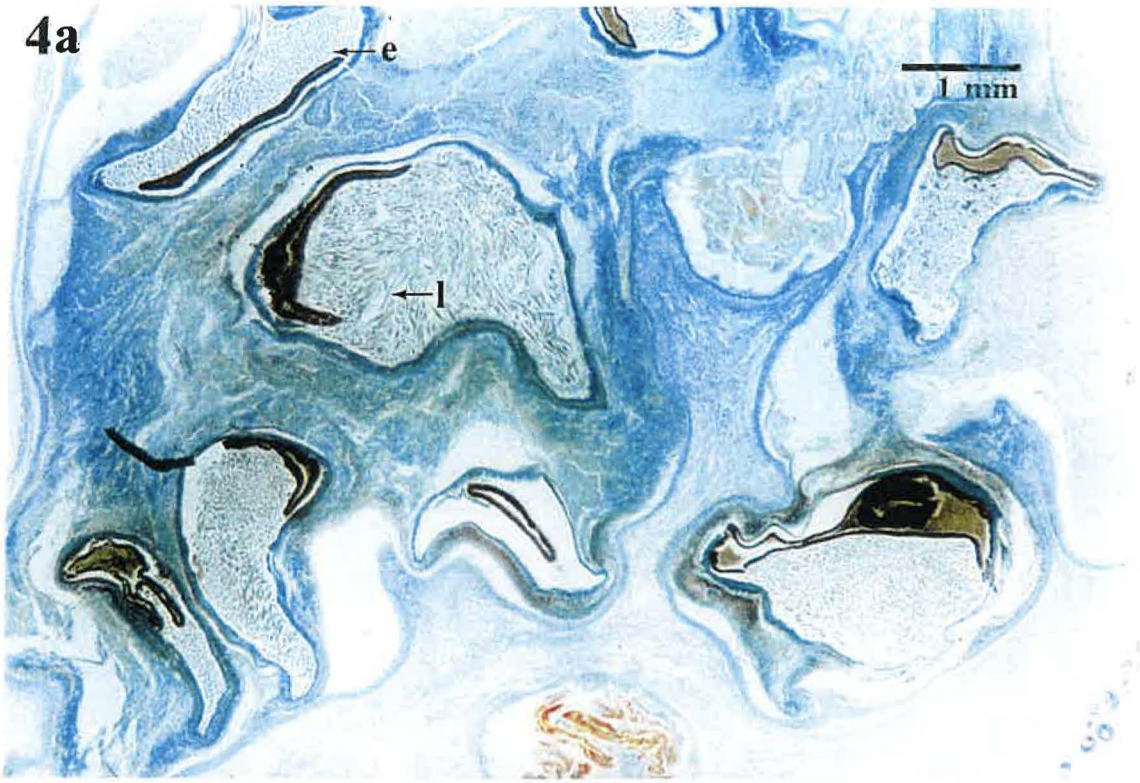

Plate 4a. Histological section through an ovary of *Glaucosoma hebraicum* infected with *Philometra* sp., whose uteri contain eggs (e) and developing larvae (l).

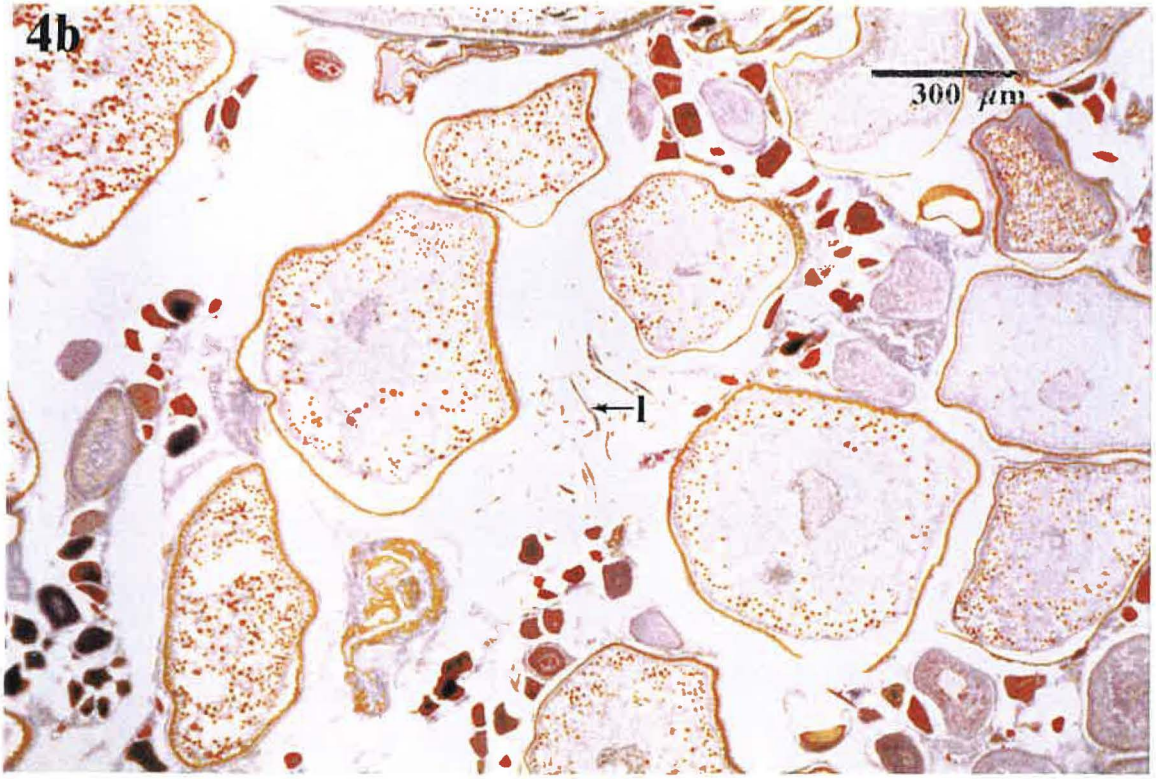

Plate 4b. Histological section through an ovary of *Glaucosoma hebraicum* infected with *Philometra* sp. containing "free-living" larvae (l).

4c

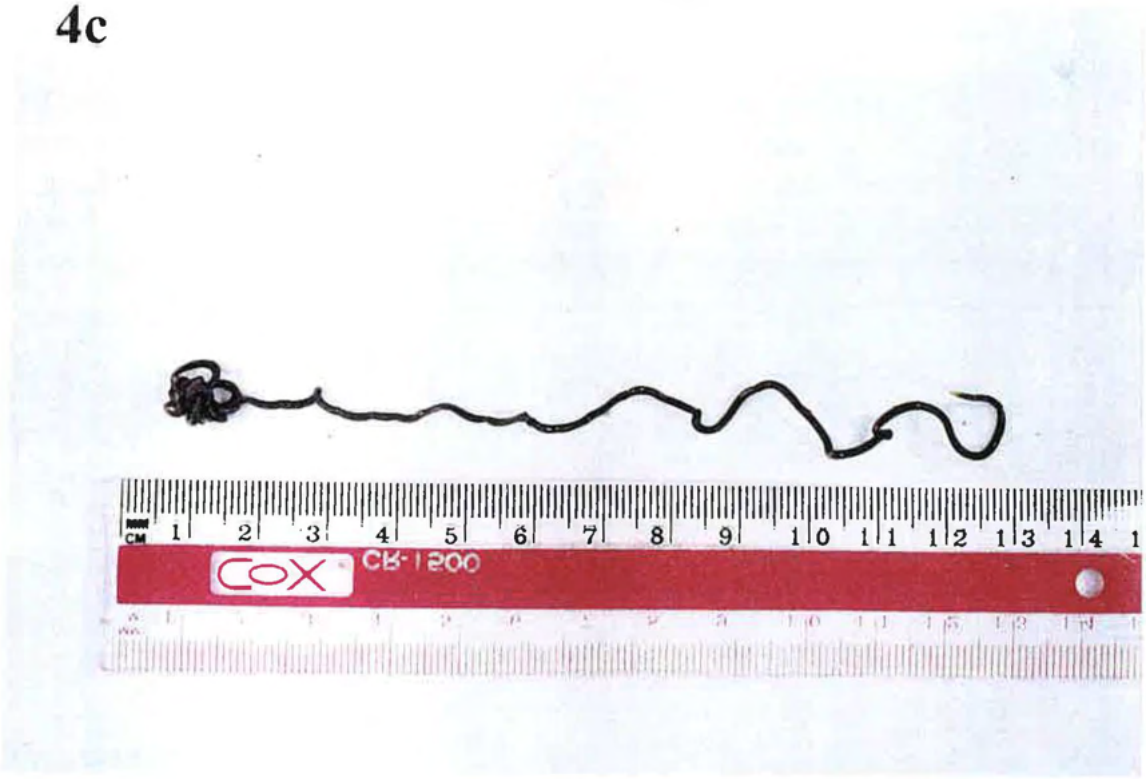

Plate 4c. Adult *Philometra* sp. from a stage VI ovary of *Glaucosoma hebraicum*.

4d

Plate 4d. Parasitic mass of *Philometra* sp. from a stage VII ovary of *Glaucosoma hebraicum*.