Determination of the biological parameters required for managing the fishery of West Australian dhufish

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Table of Contents

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Objectives

1. Determine the age and size compositions and growth of *G. hebraicum.*
2. Determine the location and period of spawning of *G. hebraicum.*
3. Determine the size and age at which sexual maturity is attained by *G. hebraicum.*
4. Determine the habitats occupied by *G. hebraicum* and whether these change with size of fish and maturity.
5. Determine the fecundity of *G. hebraicum* and whether this species spawns more than once in a breeding season.
6. Provide Fisheries W. A. with the above biological data in a format that will enable that agency (i) to review whether the current minimum legal length for capture (500mm) is appropriate and (ii) facilitate the construction of stock assessment models. This in turn will enable the fishery for this valuable species to be managed for the benefit of both commercial and recreational fishers.
7. Identify the nematode parasite which infects the gonads of *G. hebraicum* and determine the prevalence of infection and any possible deleterious effects of this parasite on the reproduction of its host.

(I) Non-technical Summary

The aim of this project was to determine the biological parameters required to enable Fisheries Western Australia to establish appropriate management plans for conserving dhufish. Dhufish were obtained from the catches of commercial and recreational wetline fishers, commercial trawl fishers and divers in waters ranging from 10 to 150m in depth at latitudes between $31^0$55'S and $28^0$45'S on the lower west coast of Australia. Small fish, *i.e.* < 300mm TL, were mainly caught by trawling and spearfishing over flat, hard substrata and low-lying limestone reefs, whereas larger fish were caught by wetline fishing in rocky gullies and over limestone and coral reefs. Comparisons between the number of opaque growth zones (= annuli) on sagittal otoliths prior to and after sectioning demonstrate that the otoliths of larger fish often need to be sectioned to reveal all of their annuli. The trends exhibited throughout the year by the marginal increments on otoliths show that a single growth zone is formed on the otoliths of dhufish each year and that the number of such zones can thus be used for ageing this species. Since the annuli on scales were often not well defined and their number frequently differed from the number of annually-formed opaque zones on sectioned otoliths, they were thus not suitable for ageing dhufish.

Female dhufish grow slightly slower than male dhufish. Thus, at the end of the second, third, fourth and fifth years of life, females attained lengths of *ca* 195, 271, 340 and 401mm, respectively, whereas males attained lengths of *ca* 224, 309, 384 and 452mm, respectively. By the time dhufish had reached 10, 15 and 20 years, females were *ca* 626, 757 and 834mm, respectively, and the males were *ca* 697, 837 and 917mm, respectively. The maximum total lengths, weights and ages recorded for females and males were 981mm, 15.3kg and 39 years, and 1120mm, 23.2kg and 42 years, respectively. Fish of 250, 500 and 1000mm were estimated to weigh approximately 300, 2160 and 15580g, respectively. Fifty percent of females and males reached the minimum legal size for capture (500mm) towards the end of their seventh and sixth years of life, respectively.

The trends exhibited throughout the year by gonadosomatic indices, gonadal maturity stages and oocyte stages demonstrate that, while dhufish spawn between November and April, the majority of spawning activity occurs between December and March. Fifty percent of females and males reached sexual maturity at lengths of about 300 and 320mm, respectively, and over 50% of both sexes attain maturity by the end of their third year of life. Dhufish, which apparently spawn in a wide range of water depths, are multiple spawners, *i.e.* produce eggs at intervals during a spawning season. The mean number of maturing and mature oocytes in ovaries removed from females at the early part of the spawning period collectively was *ca* 1.78×10^3. However, since some earlier-stage oocytes would almost certainly have also eventually become mature during the spawning season, this value represents an underestimate of the fecundity.

A large nematode parasite, identified as *Philometra lateolabracis*, was often found in the gonads and particularly the ovaries of dhufish. This parasite, which increases in prevalence as the size of its host increases, develops from larva to adult during the spawning period of dhufish. Since this parasite can reach up to 470mm in length and several individuals are sometimes present in an ovary, it may reduce the supply of nutrients to the gonads and thus lead to a reduction in the number of eggs produced by infected fish.

Since the minimum legal length (MLL) for capture of dhufish (500mm) is greater than the length at which the females and males of this species first become sexually mature, fish have usually spawned at least once before they reach this size limit. However, since the vast majority of undersize dhufish that are caught, and particularly those taken from waters deeper than 30m, die after release, the imposition of a MLL is of limited value. Thus, since dhufish are being increasingly targeted by commercial and recreational fishers, management plans will have to focus on other methods for protecting the stock of this species. Such measures could include one or more of the following: closing areas to commercial and recreational fishing, introducing quotas for commercial fish catches, making adjustments to the number of commercial licenses, restricting further the bag limit for recreational fishers and limiting the number of recreational fishers that can fish in a given area. Since the Fremantle Maritime Centre has had success in their preliminary attempts to culture dhufish, there is also now the possibility, in the future, to restock areas which have become severely depleted of this species.

KEYWORDS: ***Glaucosoma hebraicum*, age, growth, reproduction, spawning period, sexual maturity, parasite, *Philometra*.**

(II) Background

The West Australian dhufish, *Glaucosoma hebraicum* (Richardson, 1845), which is a member of the small monogeneric family Glaucosomatidae, is one of the most valuable of Western Australia's finfish. *Glaucosoma hebraicum* is confined to south-western Australia, where its distribution ranges from the Recherche Archipelago on the southern coast, eastwards and then northwards to Shark Bay. It grows to a maximum total length and wet weight of *ca* 1200mm and 26kg, respectively (Allen & Swainston, 1988) and lives in waters extending outwards from depths of 10m to about 200m at the inner edge of the continental shelf (Cusack & Roennfeldt, 1987; Starling, 1988).

Glaucosoma hebraicum supports a lucrative commercial fishery and a strong recreational fishery (Sudmeyer *et al.*, 1992). Dhufish has a current retail value of $16.90 per kg of whole fish and $34.90 per kg of boneless fillets, which correspond to wholesale values of $12.00 and $27.90 per kg, respectively (price on 14 July, 1999, at Sealanes Fish Market, W. A.).

Dhufish are invariably caught from boats. A creel survey was carried out by Sumner and Williamson (1999) on the recreational boat catch between Kalbarri and Augusta in the twelve months up to August 1997. This survey included the area where most of the recreational and commercial catch of this species occurs (R. C. J. Lenanton, Fisheries W. A., pers. comm.). The estimated number of dhufish caught from trailered boats during the 12 month study was *ca* 43,000. Of these fish, approximately 29,000 were kept (67%) and 14,000 released (33%) (Sumner and Williamson, 1999). The total weight of the catch retained by recreational fishers was 132 tonnes, which is similar in magnitude to the estimated commercial wetline catch of 160 tonnes for Western Australia during 1996/97 (Crowe *et al.*, 1999).

Many recreational fishers have expressed concern over the decline that has apparently occurred in the abundance of *G. hebraicum* in recent years and consider that it is now necessary to move further offshore to catch this species. In an effort to conserve *G. hebraicum*, one major angling club near Perth, the Mandurah Offshore Fishing Club, has removed dhufish from the list considered for prizes at its annual "Fishing Classic" competition. Records kept by

the Victoria Park Angling Club from 1982 to 1995 confirm that the number of dhufish caught has declined in recent years.

Information from the commercial fishery is recorded via mandatory monthly returns completed by each licensed fisher and entered into the Catch and Effort Statistics system (CAES) maintained by the Research Division at Fisheries W. A. (N. Hall, Fisheries W. A., pers. comm.). There are no discernible long term trends in total catch or catch per unit effort (CPUE). However, the usefulness of the CPUE for commercial wetline fishing as an indicator of trends in the relative abundance of dhufish is very limited because of great variation in the type of vessels and amount and type of gear used by commercial fishers, the duration over which fishing takes place and the time taken travelling to fishing locations (N. Hall, pers. comm.). The data also do not take into account increases in effectiveness of fishing effort, and the introduction of Global Positioning Satellite systems (GPS) and depth sounders. Catch per unit effort data are available, however, for *G. hebraicum* from the Southern Demersal Gillnet and Longline Fishery (SDGDL Fishery), which, while targeting sharks, also take a considerable number of dhufish. Since demersal gillnets sample spatially and are not affected by feeding behaviour, this fishery provides the best CPUE data that are available for dhufish. The data indicate that the relative abundance of dhufish is lower now than in the 1970s.

In conversations with a number of commercial fishers during the three years of the present study, it became clear that, like recreational fishers, these fishers consider that the abundance of dhufish has declined in recent years. 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 this species, means that they consider the time taken to catch a given weight of this species has increased by four to six times over the last 20 to 30 years. Furthermore, the decline in catches of *G. hebraicum* has forced some commercial fishers to diversify into other activities, such as chartering their boats. The above information, some of which is circumstantial, points to a decline in the abundance of *G. hebraicum* in certain areas, particularly where there is heavy fishing pressure from both commercial and recreational fishers.

Despite the high value of *G. hebraicum*, as both a commercial and recreational species, the biological data for this species was restricted, until the present study, to a series of small-scale investigations conducted by third-year undergraduate students. One such study involved the use of whole otoliths to age *G. hebraicum*. However, no attempt was made in that study to validate that the growth zones on this hard structure are formed annually.

(III) Need

From the above, it is clearly evident that there are insufficient data from commercial fishery sources to calculate the levels of exploitation of dhufish and to assess whether that exploitation can be sustained. Indeed, such calculations require a long time series data set, with far more contrast than is currently available. An alternative approach for obtaining data on levels of exploitation and sustainability is to combine information drawn from biological sources on growth, mortality, fecundity, *etc.*, with data obtained from the size and age structure of the fishery.

It is now considered imperative that any growth zones on hard structures that are to be used for ageing a species should be validated as being formed at known intervals, usually annually (Beamish & McFarlane, 1983; Casselman, 1987; Faragher, 1992; Fenton & Short, 1992; Hyndes *et al.*, 1992). The two hard structures most commonly used to age fish are scales and otoliths. However, the use of scales for ageing many species often produces unreliable results (Casselman, 1983; Beamish & McFarlane, 1983; Booth *et al.*, 1995), especially since many fish have regenerated scales (Simkiss, 1974). Otoliths are now the main hard structure used for ageing fish. However, the number of growth zones that can be detected on the otoliths of the larger representatives of species is often increased when the otoliths have been sectioned. Therefore, the use of whole otoliths for ageing can lead to gross underestimates of the age attained by a species (Panella, 1974).

Fish biologists now recognise that some species of fish spawn more than once during a breeding period (*e.g.* Burt *et al.*, 1988; Weddle & Burr, 1991; Hyndes & Potter, 1996). Since estimates of fecundity play a vital role in stock assessment models, it is necessary to determine

whether a species is a multiple spawner, *i.e.* spawns more than once in a breeding season, and, if this is the case, to take this into account when determining fecundity. Such information can be gained by examining histological sections of ovaries immediately prior to and throughout the spawning period. The sections also enable the pattern of maturation to be determined which, in turn, enables the precise duration of the spawning period to be elucidated.

Sound data on the biology of dhufish would not only be of value to Fisheries W. A. for developing management plans, but also of considerable benefit to the TAFE Aquaculture Development Unit at Fremantle in their aquaculture program for this species (See FRDC Proposal by that unit).

During the course of this study, the gonads of *G. hebraicum* were often found to be infected with a large nematode parasite, later identified as *Philometra lateolabracis*. The presence of philometrids has detrimental effects on the reproduction of several other species, *e.g. Pagrus auratus* (Sharples & Evans, 1995), *Pomatomus saltatrix* (Williams & Jones, 1994), *Plectropomus* spp. (Glazebrook *et al.*, 1988) and *Mugil cephalus* (Snieszko & Axelrod, 1970). Since one of the aims of this project was to determine the reproductive biology of *G. hebraicum*, a study was made of the prevalence and biomass of this parasite in the gonads of dhufish and an attempt made to determine its potential impact. This information would be of benefit to research workers at the Fremantle Maritime Centre, who are culturing this species.

(IV) Objectives

1. Determine the age and size composition and growth of *G. hebraicum*.
2. Determine the location and period of spawning of *G. hebraicum*.
3. Determine the size and age at which sexual maturity is attained by *G. hebraicum*.
4. Determine the habitats occupied by *G. hebraicum* and whether these change with size of fish and maturity.
5. Determine the fecundity of *G. hebraicum* and whether this species spawns more than once in a breeding season.

6. Provide Fisheries W. A. with the above biological data in a format that will enable that agency (i) to review whether the current minimum legal length for capture (500mm) is appropriate and (ii) to facilitate the construction of stock assessment models. This in turn will enable the fishery for this valuable species to be managed for the benefit of both commercial and recreational fishers.

7. Identify the nematode parasite which infects the gonads of *G. hebraicum* and determine the prevalence of infection and any possible deleterious effects of this parasite on the reproduction of its host.

(V) Methods

Glaucosoma hebraicum < 500mm total length (TL), the minimum legal length (MLL) for capture, were collected between May 1996 and June 1999 by commercial trawl and wetline fishers and spearfishers, under a special research collection permit issued by Fisheries W. A. Filleted carcasses of *G. hebraicum*, > 500mm TL, together with their gonads, were obtained from commercial fish processing plants and weigh-ins at local recreational fishing club competitions in each month between May 1996 and April 1998. These fish had been caught by commercial or recreational wetline fishers along the lower west coast of Australia between Perth (31^0 55'S) and Geraldton (28^0 45'S), and in water depths ranging from 10 to 150m.

The total lengths of all fish were measured to the nearest 1mm and the weights of all fish < 500mm were weighed to the nearest 1g. The weights of 334 of the females and 442 of the males > 500mm TL were weighed to the nearest 10g, prior to filleting. The relationships between the wet weights and lengths of female and male *G. hebraicum* were determined and later used to estimate the weights of those large fish which had been filleted but had not been weighed.

On several occasions, a video camera, attached by cable to a television monitor and video recorder, was lowered over the substrata whilst wetline fishing with a commercial fisher

for dhufish. Video footage was taken of the substrate over which dhufish were observed, and often later caught.

In an attempt to catch greater numbers of the juveniles of *G. hebraicum*, trials using baited fish traps over reef areas, constructed with 1cm wire mesh to dimensions of *ca* 1m^2, were conducted. Divers were also employed to catch small dhufish, including commercial operators who catch ornamental fish for aquaria.

Determination of age

The two sagittal otoliths were removed from each fish and cleaned, dried and stored in paper envelopes. They were later placed in methyl salicylate and examined microscopically under reflected light against a black background. Every attempt was made to determine the number of growth zones on each whole otolith. However, the opaque zones in the whole otoliths of large fish were so numerous and closely spaced that they were often difficult to distinguish from one another. Thus, otoliths were sectioned to determine whether this improved the resolution of the growth zones and thus resulted in more growth zones becoming discernable.

For sectioning, the otoliths were mounted in clear epoxy resin and cut into 400µm sections using a low speed diamond saw (Buehler). The sections were cleaned and mounted on slides using DePX mounting medium and examined under reflected light employing a dissecting microscope attached to a video camera (Panasonic WV-CD20). The image was analysed using the computer imaging package Optimas®. The number of opaque rings or zones (= annuli) on each sectioned otolith was compared with those recorded prior to sectioning.

Since the opaque zones became far more easily detectable after the otoliths had been sectioned, validation that these zones are formed annually was carried out using sectioned otoliths. For this purpose, the distance between the outer edge of the single or outermost opaque zone and the periphery of each otolith, *i.e.* the marginal increment, was measured. Measurements, which were always made perpendicular to the opaque zones, were recorded to the nearest 0.01mm using the computer imaging package Optimas®. The marginal increment is

expressed either as a proportion of the distance between the core and the outer edge of the opaque zone, when only one opaque zone is present, or as a proportion of the distance between the outer edges of the two outermost opaque zones, when two or more opaque zones are present. The marginal increments recorded in each corresponding month of the year between May 1996 and April 1998 were pooled. These values were then separated into groups according to the number of opaque zones on the otoliths, *i.e.* 1, 2-5, 6-8, 9-11 opaque zones *etc*..

To assess the level of reproducibility of the counts of opaque zones on sectioned otoliths, a comparison was made between the number of opaque zones recorded in sectioned otoliths of 100 fish covering a wide size range with those recorded independently by another member of the research group.

von Bertalanffy growth equations

The approximate time of peak spawning, which was estimated from the trends shown throughout the year by the gonadosomatic indices, gonadal maturity stages and the pattern of oocyte development, was used to determine the middle of the spawning period which was then considered to correspond to the birth date of *G. hebraicum*. This birth date was then used to help determine the length at age of individual fish on their date of capture. von Bertalanffy growth curves were fitted to the length at age data for females and males by a non-linear technique (Gallucci & Quinn, 1979), using a non linear sub-routine in SPSS (SPSS Inc., 1988). The von Bertalanffy equation is $L_t = L_\infty\left[1 - e^{-k(t-t_o)}\right]$, 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. Since fish < 150mm could not be sexed, the lengths at age of these small fish were allocated to the data sets for female and male fish that were to be used for constructing monthly length-frequency histograms and the von Bertalanffy growth

curves. The growth of females and males was compared using a likelihood ratio test (Kimura, 1980).

Reproductive biology

The gonads of each fish that could be sexed macroscopically were removed and weighed to the nearest 0.01g. Gonadosomatic indices (GSIs) were then determined from the equation W1/W2 x 100, where W1 = wet weight of the gonad and W2 = wet weight of the whole fish. The macroscopic stages which were assigned to different states of gonadal maturation were adapted from those described by Laevastu (1965) *i.e.* : I = virgin; II = immature (= maturing virgin and recovering spent of Laevastu); III = developing; IV = maturing (= developed of Laevastu); V = prespawning (= gravid of Laevastu); VI = spawning; VII = spent and VIII = resting. Since female dhufish release eggs at intervals throughout the spawning season (see later), it was not possible to differentiate macroscopically between stage V and VI ovaries and thus the data for these two stages have been pooled.

The percentage contributions made by the different gonadal stages to sequential 50mm length intervals were calculated for both female and male *G. hebraicum.* The lengths at which 50% of female and male *G. hebraicum* reach sexual maturity (L_{50}) were determined by fitting the logistic curve to the percentage of fish which, during the spawning period, possessed gonads that were at stages III-VIII (see results for rationale for using these stages). The logistic curve was fitted by employing a non-linear technique (Saila *et al.*, 1988), using a non-linear sub-routine in SPSS (SPSS Inc., 1988). The logistic equation is $P_L = 1/\left[1+e^{(a+bL)}\right]$ where P_L is the proportion of fish with mature gonads at length interval L, and a and b are constants. The L_{50}s for females and males are derived from the equation L_{50} = -a/b. The ages at which 50% of females and males reached maturity, *i.e.* the A_{50}, were estimated from the inverse von Bertalanffy growth equations for the two sexes (see Stergiou, 1999):

$$A_{50} = t_0 - \left(\frac{1}{k}\right)\ln\left(1 - \frac{L_{50}}{L_\infty}\right)$$

using the t_0, k and L_∞ of *G. hebraicum* and the L_{50}s determined for female and male fish.

The mid-region of the ovaries of up to 20 large females from each month between June 1996 and May 1997 were placed in Bouin's fixative for 48h, dehydrated in a series of ethanols, embedded in paraffin wax, cut into 6μm transverse sections and stained with Mallory's trichrome. The circumferences of 30 oocytes, that had been sectioned through the nucleus, were measured to the nearest 5μm employing the computer imaging package Optimas® and then used to calculate the oocyte diameters. Thirty hydrated oocytes were removed from the ovaries of five large females, fixed and dehydrated as described above. Since hydrated oocytes collapse on sectioning (Wallace & Selman, 1981; West, 1990), the diameters of whole unsectioned eggs were measured to the nearest 5μm under a dissecting microscope. The terminology for the oocyte stages follows that given by Khoo (1979).

Whole ovaries, which were either at stage V (prespawning) or early stage VI (spawning), were removed from 25 females, that were caught early in the spawning season and ranged in length from 320 to 981mm. The ovaries were stored in Gilson's fluid for at least nine months to facilitate the breakdown of connective tissue. The effectiveness of Gilson's fluid in dissolving the connective tissue was enhanced by making incisions in the ovaries and, every few days, shaking the containers in which the ovaries were stored. The yolk vesicle and yolk granule oocytes, and also the hydrated oocytes if present, were removed from the remaining connective tissue by filtering the ovarian material through firstly a 2000μm and then a 200μm filter. The total wet weight of these vitellogenic oocytes was recorded. Three random subsamples of known weight (*ca* 0.1g) were weighed, placed in a sorting tray and examined under a dissecting microscope. The yolk vesicle, yolk granule and hydrated oocytes, which were easily distinguishable from each other, were then each counted. The number of each of these oocyte types in each sample and also of all of these oocytes collectively, were then used, in conjunction with the total weight of the oocytes, to estimate the numbers of the corresponding oocytes that would have been present in the whole ovary.

Philometra lateolobracis infection in the gonads of *Glaucosoma hebraicum*

Between September 1996 and May 1998, the gonads of *G. hebraicum* were cut open to determine whether they contained either live or dead *Philometra lateolabracis*. Individuals of *P. lateolabracis* were dissected from the ovaries of *G. hebraicum* and fixed in either 10% formalin or 70% ethanol. The prevalences of this parasite in the ovaries and testes of each sequential 100mm size interval of dhufish in the corresponding months of the three years were recorded. Since it became apparent that live *P. lateolabracis* were almost invariably found only during the spawning season, the studies aimed at determining which life cycle stages were present in the gonads of *G. hebraicum* and the pattern of growth of this nematode were carried out on samples dissected out of the gonads of *G. hebraicum* during the last spawning period of this study, *i.e.* late spring to early autumn of 1998/99. These samples were preserved in 70% ethanol. The wet weight of all *P. lateolabracis* in each gonad was subsequently recorded to the nearest 0.01g. Since the larger of these nematodes were often tightly coiled within the gonads, usually in groups of two or three, and tended to break during attempts to disentangle them from each other, it was often not possible to record accurately the individual lengths or total number of these large nematodes.

Histological sections were used to compare the gonads of parasitised and unparasitised fish in an attempt to elucidate whether the presence of this nematode has a deleterious effect on the gonads.

(VI) Results

Habitats of *Glaucosoma hebraicum*

Glaucosoma hebraicum that were < 150mm TL and < 14 months old were caught regularly by employing the services of a commercial trawl fisher to fish offshore in water depths of 27 to 33m. The depth sounder indicated that these small *G. hebraicum* were most consistently caught over hard substrate, which lay adjacent to reefs, a view later confirmed by video footage.

Dhufish > 300mm in length were obtained in considerable numbers from wetline fishers, who operate in waters that were shown by video camera and commercial echo sounders to be located over limestone and coral reef formations and, in particular, where the "drop-offs" (reef edges) are two or more metres high.

Great effort was invested in capturing *G. hebraicum* with lengths of 150 to 300mm, through employing a variety of methods. Very occasionally, fish of this size were obtained, together with larger individuals of *G. hebraicum*, by line fishing over reefs (as described above). In an attempt to catch greater numbers of *G. hebraicum* of this size, fishing rigs were made with small hooks. Although a variety of other species of fish were caught, often including large numbers of juveniles of large species such as pink snapper, *Pagrus auratus,* few dhufish of this size range were caught. Since *G. hebraicum* has a relatively larger mouth gape than *P. auratus*, it is likely that, if small dhufish were abundant in this habitat type, they would have been caught.

In addition to line fishing, baited fish traps were lowered over reefs and, whilst a number of other fish species were caught, including the juveniles of *P. auratus* and *Epinephelides armatus* (breaksea cod), juvenile dhufish were not caught. Recently, fish traps constructed using larger dimensions have been used by the Fremantle Maritime Centre to catch adult dhufish over reefs, for their aquaculture program. However, relatively few dhufish were caught employing this method (Cleary *et al.*, 1999).

Samples of *G. hebraicum* of the 150-300mm size group were occasionally caught by trawling over hard and relatively flat substrata (see above). One reason why only a few dhufish were caught by trawling may be due to the boat speed, though operating at the maximum speed possible for trawling, having not been sufficiently fast to prevent the larger fish from escaping. Alternatively, since trawling had to be restricted to areas which fringed reefs, as indicated by an eco-sounder and shown by video camera, sampling may not have been undertaken in the areas where the 150-300mm size group are found. Samples were

occasionally obtained by an experienced spearfisher who dived over low-lying reef habitat with rock ledges < 30cm high, in which he had observed this size group to be present.

Validation that opaque zones are formed annually

The mean monthly marginal increment on sectioned otoliths with 2-5 opaque zones rose from 0.33 in January to a maximum of 0.67 in September, before declining markedly to 0.22 in October and then rising slightly to 0.24 in December (Fig. 1). The mean monthly marginal increment on otoliths with 6-8, 9-11, 12-15 and ≥ 16 opaque zones each followed the same trend as that just described for otoliths with 2-5 opaque zones. They thus reached high levels in early spring, before declining markedly in mid-spring, as the outermost opaque zone became delineated through the formation of a new translucent zone, and then increased progressively in the ensuing months as the translucent region increased in width (Fig. 1). Although fish possessing otoliths with one opaque zone were not caught in all months, the trends exhibited by the mean monthly marginal increments for those months when such fish were caught were consistent with those exhibited by otoliths with a larger number of opaque zones.

Since the mean monthly marginal increment rose and declined only once during the year, irrespective of the number of opaque zones in the otolith, a single opaque zone is laid down in the otoliths of *G. hebraicum* each year. The number of opaque zones in sectioned otoliths can thus be used to age *G. hebraicum*.

Comparisons between the number of opaque zones visible on sectioned and whole otoliths

Although the number of opaque zones observed in each sectioned otolith, in which up to six such zones could be seen, was the same as those visible on the same otolith prior to sectioning, this frequently did not apply when a greater number of opaque zones were present (Fig. 2). Furthermore, where such discrepancies occurred, the extent of the maximum

differences between the number of opaque zones detected prior to and after sectioning increased as the number of opaque zones increased. In all cases where there were discrepancies, the number of opaque zones detected after sectioning were greater than prior to sectioning. Underestimates of the number of growth zones using whole otoliths, based on comparisons with those detected in sectioned otoliths, rose from one in whole otoliths with seven to nine opaque zones to between one and seven in those with 10-21 opaque zones and the difference sometimes exceeded eight in those with ≥ 22 opaque zones (Fig. 2).

Comparisons between the number of opaque zones visible on sectioned otoliths and number of annuli on scales

The annuli in scales were far less well delineated than were the opaque zones in either whole or sectioned otoliths. Furthermore, there was a very poor correspondence between the number of annuli observed in scales and the number of opaque zones recorded in sectioned otoliths (Fig. 3). Thus, in some cases, the number of annuli on scales were greater than the number of opaque zones in sectioned otoliths, while in some other cases, the reverse was true. Furthermore, the discrepancies in counts between scales and sectioned otoliths were sometimes as great as seven.

Growth of juvenile *Glaucosoma hebraicum*

Since the trends exhibited by the GSIs, gonadal maturity stages and size and composition of oocytes demonstrated that the middle of the spawning period was late January/early February (see later), *G. hebraicum* was assigned a birth date of 1 February. The members of the 0+ cohort were thus, on average, about eight to nine months old in October, when the first opaque zone becomes delineated on their otoliths.

Small *G. hebraicum*, in which no opaque zones were visible in their otoliths, were caught by trawling over hard substrates that were located in waters of 27 to 33m in depth, and at distances of 6-7 km offshore. These small 0+ fish were first caught in April and May, when their lengths ranged from 57-81mm (Fig. 4). The mean lengths of the 0+ age class had reached

95mm by October and 108mm by January, when fish were approaching the end of their first year of life. The mean length of 1+ fish had reached 127mm in March, after which month the number of fish caught in trawl samples declined markedly (Fig. 4).

Ages of *Glaucosoma hebraicum*

The points for the length at age of females and males of *G. hebraicum* are well described by the von Bertalanffy growth curve, with the age at length zero (t_o), derived from the von Bertalanffy equation, being close to zero (Table 1, Fig. 5). The likelihood ratio test showed that the growth curves of females and males were significantly different ($P \leq 0.001$). The von Bertalanffy growth curves demonstrate that females grow slightly slower than males. Thus, at ages 2 to 5, females had reached lengths of 195, 271, 340 and 401mm, compared with 224, 309, 384 and 452mm for males. By the time *G. hebraicum* had attained 10, 15 and 20 years, the females had reached *ca* 626, 757 and 834mm, respectively, while the males had reached *ca* 697, 837 and 917mm, respectively (Fig. 5). The maximum ages recorded for females and males were 39 and 41 years, respectively, and the maximum total lengths of females and males were 981mm (= *ca* 15.3kg), and 1120mm (= *ca* 23.2kg), respectively. The ages at which female and male *G. hebraicum* reach the minimum legal length for capture (500mm TL) is 6.9 and 5.8 years, respectively.

Table 1. von Bertalanffy growth parameters derived from length at age data for *Glaucosoma hebraicum*, including upper and lower 95% confidence limits.

		von Bertalanffy parameters				
		L_∞	k	t_0	r^2	n
Females	Estimate	940.4	0.108	-0.153	0.967	812
	Upper	966.3	0.115	-0.072		
	Lower	914.5	0.102	-0.236		
Males	Estimate	1023.4	0.112	-0.020	0.976	940
	Upper	1040.9	0.116	-0.040		
	Lower	1005.8	0.108	-0.081		

Length-weight relationship

The relationships between the total length (TL) and total wet weight (W) of female and male *G. hebraicum* (Fig. 6) are described by the following equations.

Females Log W = Log 0.000043 + 2.853 Log TL (n = 756, r^2 = 0.99)

Males Log W = Log 0.000043 + 2.854 Log TL (n = 840, r^2 = 0.99)

Trends exhibited by gonadosomatic indices and gonadal maturity stages

Between May 1996 and April 1997, the mean monthly GSIs of the large females of *G. hebraicum*, that were greater than the L_{50} of 301mm at first maturity (see later), were always low in winter and early spring, *i.e.* < 1.0, but then rose sharply to reach a peak of *ca* 2.8 in mid-summer, before declining markedly in early to mid-autumn (Fig. 7). The seasonal trends displayed by the mean monthly GSIs of the males of *G. hebraicum*, that were greater than the L_{50} of 320mm at first maturity, paralleled those just described for females. Since the trends exhibited by the mean monthly GSIs of females and males were the same in each 12 month period, the data on the percentage contributions of the different gonadal stages of

female and male *G. hebraicum* in each of the corresponding months in those two periods have both been pooled.

The vast majority of the ovaries of large female *G. hebraicum* caught between July and October were at stages I-II, *i.e.* immature (Fig. 8). Ovaries at stage III were first found in August, albeit in only a few fish, and those at stage IV and stages V-VIII were first found in September and October, respectively. Stage V and VI ovaries, *i.e.* prespawning and spawning, became the most prevalent stage in females in November and was the most dominant stage by far in December to March. The samples in February and March contained a few female fish with stage I-II ovaries and none with either stages III or IV (Fig. 8). These trends provide strong circumstantial evidence that any female whose ovaries develop to stage III will progress through to maturity. Thus, the L_{50}s for females were calculated using the percentage of ovaries with stages III and IV, as well as stages V-VIII, as indicators of fish that would be likely to become mature during a spawning season. Stages VII and VIII, *i.e.* spent and resting ovaries, were found between January and May. However, by the latter month, the majority of ovaries were at stage I-II and all were at this stage in June. The trends exhibited by the pattern of gonadal development in males were essentially the same as that just described for females (Fig. 8).

Trends exhibited by oocyte diameters and stages

In each month, the oocyte diameters of *G. hebraicum* produced a well defined mode at *ca* 65μm (Fig. 9), which was attributable predominantly to the presence of numerous perinucleolar oocytes. The oocytes in July and August, which comprised almost exclusively perinucleolar oocytes, ranged from 15 to 130μm in diameter. Ovaries with yolk vesicles first appeared in September, in which month their diameters ranged from 160-260μm, while those with yolk granules were first found in October, at which time their diameters ranged from 261-520μm. Yolk granule oocytes became increasingly prevalent in November and dominated the complement of larger oocytes between December and March. Some of the residual yolk granule oocytes in April and all of those in May were undergoing atresia. No yolk vesicle or

yolk granule oocytes were found in June. Hydrated oocytes, which ranged from 700 to 1180μm, were first found in November and were present in the majority of ovaries between December and March and in a few ovaries in April, but were found neither in May nor in the immediately ensuing months (Fig. 9). Small numbers of post-ovulatory follicles were present in sections of about a third of the ovaries of large females caught between December and March.

The oocyte diameters of randomly-selected individual large *G. hebraicum* caught in each month of the spawning period produced a series of modes (Fig. 10). The perinucleolar oocytes produced a discrete mode at 65μm, while yolk vesicle oocytes produced modes between 130 and 230μm and yolk granule oocytes at 300 to 500μm.

Length and age at maturity

Glaucosoma hebraicum was not able to be sexed by macroscopic examination of the gonads until it had reached a length of *ca* 150mm. During the main part of the spawning period, *i.e.* December to March, the gonads of all female and male *G. hebraicum* < 250mm were at the earliest stages of development, *i.e.* stages I or II (Fig. 11). Gonads at stages III-VIII were first found in the 250-299mm length class of females and the 300-349mm length class of males, to which they contributed *ca* 25 and 78%, respectively, to the total number of gonads. The presence of such stages in development of the gonads demonstrates that the gonads are maturing or that spawning is occurring or has already occurred (see earlier). The prevalence of ovaries at stages III-VIII increased to > 75% in the 300-349mm length class and to 100% in all females > 450mm. The gonads of all males > 450mm were at stages III-VIII (Fig. 11). The L_{50}s for the lengths of female and male *G. hebraicum* at first maturity, derived from the logistic curve fitted to the percentage contributions of fish with gonads at stages III-VIII in sequential 50mm length classes, were 301 and 320mm, respectively (Fig. 11).

One female and no males at two years of age possessed gonads at stage III or greater (Fig. 12). However, 50% of three year old female and male fish, and all five year old females

and all six year old males possessed such gonads and were thus regarded as mature. The A_{50}s for the age of females and males at first maturity were 2.5 and 2.6 years, respectively.

Fecundity

The numbers of yolk vesicle, yolk granule and hydrated oocytes in the ovaries of 25 females caught at the beginning of the spawning season have been plotted against the total lengths of fish (Figs 13a, b). The regression equations for the relationships between the number of yolk vesicle (V) and yolk granule oocytes (G) and the total length (TL), respectively, were:

$$V = 14280x10^{0.002(TL)}$$

$$G = 8929x10^{0.003(TL)}$$

The regression equation relating the number of yolk vesicle, yolk granule and hydrated oocytes collectively (F) and the total length was:

$$F = 24005x10^{0.002(TL)}$$

Extrapolations from the above equations show that, when fish have reached lengths of 300, 500 and 981mm (the largest female), the ovaries of dhufish would contain approximately 59,000, 208,000 and 4,213,000 yolk granule oocytes, respectively, and 71,000, 245,000 and 4,839,000 yolk vesicle and yolk granule oocytes combined, respectively. The mean number of yolk vesicle, yolk granule and hydrated oocytes in ovaries was approximately 1,780,000 (±1SE = 1,450,000).

Prevalence and timing of infection of *Philometra lateolabracis* in the gonads of *Glaucosoma hebraicum*

Philometra lateolabracis was present in the ovaries and testes of some fish in every month of the year. However, live parasites were observed only in the gonads of fish examined between December and early April (Fig. 14), *i.e.* during the spawning period of *G. hebraicum*. Furthermore, live parasites were found only in ovaries at stages V-VII and in testes at stages IV-VI (Fig. 15). While live parasites were represented by larvae, juveniles and adults, all dead

parasites were adults. In infected gonads of recently-killed fish, the juveniles and adults of live *P. lateolabracis* were free and moving, whereas dead parasites were tightly coiled, rigid and usually encapsulated by host tissue. Even when the fish had been dead for up to a week, the maximum period before the gonads were examined for nematode infection, the morphological appearance of adult *P. lateolabracis* made it possible to distinguish clearly between parasites that had been alive and those which were dead at the time of the capture of the host. The prevalence of infection, reflected by the presence of either live or dead *P. lateolabracis*, was greater in the ovaries than testes of *G. hebraicum* (Fig. 15). Thus, the prevalence of infection in the different months ranged from 30 to 72% in female fish and from 12 to 30% in male fish. Furthermore, the monthly prevalences of live parasites in December to March ranged from 18 to 54% in female fish compared with 0 to 6% in male fish (Fig. 14).

No live or dead *P. lateolabracis* were found in either the ovaries or testes of any *G. hebraicum* that was < 200mm in length during the spawning period (Fig. 16). The overall prevalence of infection in females, as reflected by the presence of live and/or dead parasites in ovaries, rose progressively from 14% in the 300-399mm length class to 61% in the 600-699mm length class and 63% in the 700-799mm length class, before declining slightly in fish > 800mm. In the case of only live parasites, the prevalence in ovaries increased progressively from 7% in the 300-399mm length class to 15% in the 600-699mm length class and then to a maximum of 33% in fish ≥ 900mm (Fig. 16). Although the prevalence of infection was far lower in the testes of *G. hebraicum*, it was still greater in larger than smaller fish.

Large *P. lateolabracis* were often entwined in small groups and were thus difficult to disentangle (see Methods). However, one large individual nematode that was found on its own, was found to measure 470mm in length. The mean weight of live larval, juvenile and adult *P. lateolabracis*, collectively, in the ovaries of *G. hebraicum* increased from *ca* 0.01g in December, at the beginning of the spawning period, to *ca* 0.5g at the end of the spawning period (Fig. 17). The number of live juvenile and adult *P. lateolabracis* in each ovary of infected fish ranged between 1 and 4 in over 90% of such fish and never exceeded 10.

(VII) Discussion

Ageing

The trends exhibited by the marginal increments on sectioned otoliths of *G. hebraicum* show that an opaque zone is formed annually in the otoliths of this species. The difficulty in reading the number of annuli on scales and the differences often found between the counts of annuli on scales and the number of opaque zones revealed by sectioning the otoliths of the same fish, and which are known to be formed annually, show that scales are not suitable for ageing *G. hebraicum*. Comparisons between the number of opaque zones on otoliths prior to and after sectioning demonstrate that, in otoliths of fish more than six years old, some of these zones often do not become visible unless the otolith has been sectioned. In the current study, all estimates of the age of fish, except in the case of 0+ and 1+ fish, were derived from the number of opaque zones in sectioned otoliths.

An inability to detect all of the opaque zones in the whole otoliths of older fish can largely be attributed to the fact that as the width of the otolith increases, it becomes increasingly difficult to distinguish between the more peripheral of these zones. This parallels the situation recorded for several 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.*, 1992). The use of the computer imaging package Optimas® proved invaluable for distinguishing the annuli on the sectioned otoliths of large fish, since it greatly magnified the image on a computer monitor and thus made the zones far easier to detect. Furthermore, the opaque zones on the otolith image could be marked whilst counting, thereby reducing the chance of either missing opaque zones or of reading opaque zones twice in the counting process.

In a previous study, which used whole otoliths in an attempt to age *G. hebraicum*, the maximum age was estimated as 19 years, which was recorded for a fish measuring 1070mm total length (see Sudmeyer *et al.*, 1992). In contrast, the maximum age determined for *G. hebraicum* during the present study using sectioned otoliths was 42 years, this being

recorded for a fish 1023mm in length (TL). Since the number of opaque zones that can be detected on whole otoliths is often far less than those visible on sectioned otoliths, the estimates of age in that earlier study almost certainly represent a gross underestimate, as a result of the difficulties in detecting all of the opaque zones on the whole otoliths of older fish. However, the estimates of the age of small fish in that study were also at variance with those determined for fish of comparable size during the present investigation. For example, in that previous study, dhufish were estimated to reach the (total) minimum legal length for capture (MLL) of 500mm at three years of age (Sudmeyer *et al.*, 1992), whereas our results show that the females and males of *G. hebraicum* do not reach this MLL until they are seven and six years of age, respectively. The above discrepancies in age estimates, even when using the number of opaque zones in whole otoliths of smaller fish, highlights the fact that such counts can vary according to the interpretation of the "reader". Thus, it is important that the level of reproducibility of the counts of the number of opaque zones on otoliths should be determined by, for example, making comparisons with the counts of those made by an independent reader. In the case of the present study, the counts of the number of opaque zones in sectioned otoliths made by an independent reader closely paralleled those of the senior author, a result shown for otoliths removed from a subsample of fish that varied widely in length.

Spawning location, period and mode

Since *G. hebraicum* with gonads at stages V-VI were caught in waters ranging from 10 to 150m in depth and 5 to 90km from the shore and between the latitudes of 28 and 32^{0}S, the spawning of dhufish is not apparently restricted to any particular water depth or region within its range of distribution. However, as dhufish that were greater than the size of first sexual maturity were invariably caught around limestone or coral reef formations, they apparently spawn in the vicinity of reefs.

Since hydrated eggs and post-ovulatory follicles were found in at least some of the ovaries of large females in each month between November and April, this species spawns

between the end of spring and middle of autumn. Although some fish commenced spawning in November, the mean GSI of female fish in that month was still well below their maxima. This indication that only a small amount of spawning occurs in November is borne out by the fact that many of the ovaries of large fish were still at stages III and IV. Although most of the ovaries of large females caught in May 1997 contained some vitellogenic oocytes, these oocytes could usually be seen to be undergoing atresia and the ovaries of the other large fish in that month were either spent or resting. Furthermore, none of the ovaries of large *G. hebraicum* caught in May contained hydrated oocytes. This provides strong evidence that the spawning period does not extend into May. There is also strong evidence that spawning peaks in January and February. For example, by January, the ovaries and testes of large fish had progressed through to stages V-VI, *i.e.* prespawning and spawning, and for the first time, some were even fully spent (stage VII). Although the GSIs still remained at their maxima in January and February, this can be attributed to the fact that, as *G. hebraicum* is a multiple spawner, new batches of hydrated oocytes are continually being developed in the ovary during these two months. However, the GSIs of females and males both underwent a pronounced decline in March, which indicates that, in the case of ovaries, there was a decline in the production of large eggs and thus presumably in spawning activity. Since 1 February is the approximate mid-point of this period, it was considered appropriate to use it as the birth date of *G. hebraicum* when assigning an age to each fish.

The combination of a protracted spawning period and occupation of deep water by *G. hebraicum* parallels that recorded for certain other species in south-western Australia, such as *Sillago robusta* (Hyndes & Potter, 1996) and *Pagrus auratus* (Scott & Pankhurst, 1992). The protracted spawning period of these species may be related to the less variable environmental conditions in deep than shallow water (Hyndes & Potter, 1996).

During the spawning period, the mature ovaries of *G. hebraicum* often contained yolk vesicle, yolk granule and hydrated oocytes and, in some cases, also post-ovulatory follicles. This species is thus presumably a multiple spawner *sensu* de Vlaming (1983), *i.e.* individual females release eggs on more than one occasion in a spawning season. The oocytes of

individual female *G. hebraicum* during the spawning period ranged widely in size and, in many cases, their diameters formed relatively discrete modes in oocyte diameter-frequency distributions. The ovaries of *G. hebraicum* thus contain clutches of oocytes, which are presumably released at different times. Multiple spawning over a protracted period enables a greater number of eggs to be produced and released during a spawning period and for these eggs to be discharged at different times (McEvoy & McEvoy, 1992), which would increase the overall chance of recruitment success.

Do oocyte counts in *Glaucosoma hebraicum* correspond to fecundity?

Estimates of the number of hydrated (fully mature) oocytes on one particular occasion, will not provide a good estimate of the total fecundity of a species such as *G. hebraicum*, which is a multiple spawner, *i.e.* spawns more than once in a breeding season (Weddle & Burr, 1991). A number of workers have attempted to overcome this problem by counting the number of vitellogenic oocytes in ovaries. Such an approach is valid for those species in which it can be shown that previtellogenic oocytes are not recruited into vitellogenesis during the spawning period, *i.e.* they are determinant spawners (Hunter *et al.*, 1992). In the present study, estimates were made of the number of vitellogenic oocytes in the ovaries of female *G. hebraicum* caught just prior to or at the commencement of the spawning period.

As stated above, this approach for estimating the fecundity of a species depends on the assumption that smaller oocytes do not undergo vitellogenesis during the spawning season (Hunter & Leong, 1981; Weddle & Burr, 1991). However, since the distributions of the oocyte diameter frequencies for individual mature females of *G. hebraicum* caught during the spawning season were essentially continuous, this strongly suggests that some of the previtellogenic oocytes at the beginning of the spawning period could become vitellogenic and eventually fully mature later in the spawning season (Gotting, 1961 and Oven, 1976, *In* Lisovenko & Andrianov, 1992). If this is the case, counts of vitellogenic oocytes early in the spawning season of *G. hebraicum* would be likely to result in an underestimate of total fecundity. As mentioned earlier, the oocyte diameter frequency curves for individual ovaries

are characterised by the presence of a series of modes, which strongly suggest that eggs are matured and released in batches over a protracted period. An accurate determination of the total fecundity of dhufish requires further data, including the timing and frequency of spawning, which would be very difficult to obtain.

Ontogenetic changes in habitat of *Glaucosoma hebraicum*

From the extensive sampling carried out for *G. hebraicum* during the present study, it is apparent that this species changes habitat as it increases in size. Thus *G. hebraicum* $< L_{50}$ at first sexual maturity occupy areas of hard substrate near reefs and low-lying reef, whilst the adults, *i.e.* individuals $> L_{50}$ occupy the waters over large reefs. The reduction in numbers of 1+ dhufish caught by trawling in late autumn, may have been due to fish of this cohort moving away from a habitat which could be trawled, *i.e.* to reef. From the sampling carried out in this study, there is evidence that these 1+ juveniles do not immediately move to the same habitat which is occupied by the adults of this species, but rather, move to a "transitional habitat" *i.e.* low-lying reefs that contain rock ledges no more than 30cm high. It would thus appear relevant that, as adult *G. hebraicum* live in habitats where large predatory fish are abundant, the occupation by juvenile *G. hebraicum* of areas away from the habitats used by adults may reduce their susceptibility to predation.

The life cycle of *Philometra lateolabracis* and the infection of the gonads of *Glaucosoma hebraicum* by this nematode

The parasite found to infect the gonads of *G. hebraicum* was identified as:

Order Spirurida

Superfamily Dracunculoidea *sensu* Chabaud, 1975

Family Philometridae Baylis and Daubney, 1926

Philometra lateolabracis (Yamaguti, 1935) Yamaguti, 1941

Philometra lateolabracis has previously been reported from the gonads of several species of teleosts in mainly tropical regions of the Indian, Pacific and Atlantic Oceans. Only one male specimen of this species has been recorded (Crisp & Klein, 1973), whereas all other records are based solely on female specimens. It is well known that females of closely-related species of *Philometra* are almost identical morphologically, leading Moravec *et al.* (1998) to consider *P. lateolabracis* to be a composite species.

Philometrids typically have a one year life cycle and develop rapidly at one time of the year (Molnar & Fernando, 1975; Moravec & Dykova, 1978; Molnar *et al.*, 1982). Our study provides strong evidence that the individuals of *P. lateolabracis* found in *G. hebraicum* also have a one-year life cycle. However, live parasites were only found in gonads between December and April, *i.e.* during the spawning period of *G. hebraicum,* and only in ovaries at stages V-VII and in testes at stages IV-VI. The fact that *P. lateolabracis* develops in gonads during the spawning period enables this parasite to derive nutrition from gonads when they are at their largest size. The far lower prevalence of *P. lateolabracis* in the testes is presumably related to the fact that the weight of the testes is approximately an order of magnitude less than that of the ovaries in size. Since philometrid worms feed on blood (Sniezko & Axelrod, 1970), there would also presumably be a greater food supply in ovaries than testes. In contrast to the situation with our study, Sharples & Evans (1995) found that, in the case of the pink snapper *Pagrus auratus*, a species which often co-occurs with *G. hebraicum*, the prevalence of *P. lateolabracis* is far higher in male than female fish. However, the testes of *P. auratus* are relatively larger than those of *G. hebraicum.*

Most philometrids in temperate zone waters achieve gravidity, *i.e.* their uteri become full of larvae, and release those larvae into the water column during spring (*e.g.* Molnar *et al.*, 1982). In the case of *P. lateolabracis* in *G. hebraicum*, gravidity occurs in early autumn at the end of the dhufish spawning period, and thus the larvae are presumably released in late autumn. However, it should be recognised that the majority of ecological studies on philometrids have been conducted on species which infect freshwater fishes, and this makes comparisons difficult.

In freshwater, the larvae of most philometrids enter an intermediate host, usually a cyclopoid copepod, for 2 to 3 weeks, and infect or re-infect the main host through consumption of prey in summer (Molnar *et al.,* 1982). In some cases, such as with *Philometra obturans* which infects the pike *Esox lucius*, it infects a *Cyclops* species, the intermediate host, as well as paratenic hosts (small fish prey) during its development (Molnar *et al.,* 1982).

Since *G. hebraicum* has a piscivorous diet at lengths at which it becomes susceptible to infection by *P. lateolabracis*, *i.e.* > 250mm (Sudmeyer *et al.*, 1992), the infection of dhufish by this parasite presumably occurs via a teleost host. As with the *P. lateolabracis* in *G. hebraicum*, Hine & Anderson (1981) found that, in New Zealand, the snapper *P. auratus,* that were infected by *Philometra* sp. [presumably *P. lateolabracis,* as Sharples & Evans (1995) identified *P. lateolabracis* in *P. auratus* from New Zealand] likewise contained a low prevalence in small fish (151-200mm) and much higher prevalence (up to 58%) in snapper 351 to 400mm in length.

The existence of large numbers of parasite larvae in the uteri of adult *P. lateolabracis* and the large size attained by the adult nematodes, suggests that this parasite would place a substantial drain on the supply of nutrients to the ovary. It has also been suggested that *P. lateolabracis* can block the oviducts of *G. hebraicum*, thereby preventing the release of eggs during spawning (G. Jenkins, Fremantle Maritime Centre, pers. comm.). However, there was no evidence that this nematode destroyed oocytes, and the gonadal development of the ovaries did not seem to be affected by the presence of this parasite, *i.e.* the developing ovaries and testes still appeared to mature normally even when infected by *P. lateolabracis*.

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

Since 50% of female and male *G. hebraicum* first reach sexual maturity, *i.e.* spawn for the first time, at total lengths of *ca* 300 and 320mm respectively, the vast majority of dhufish will have spawned at least once before they reach the MLL of 500mm TL. However, since at least some of those dhufish, that are caught in water depths > 30m, die upon release

(S. A. Hesp, pers. observations, Greg Jenkins, Fremantle Maritime Centre, pers. comm., several commercial and recreational fishermen, pers. comm.), the current MLL may be of limited use for conserving this species. Measures that could be used to help conserve this species include: closing areas to commercial and recreational fishing, introducing quotas for commercial fish catches, making adjustments to the number of commercial licenses, restricting further the bag limit for recreational fishers and limiting the number of recreational fishers that can fish in a given area. For such measures to be fully effective, more comprehensive information is required on the locations that are most frequently inhabited by *G. hebraicum* and on any migratory movements which this species undertakes. It is also worth recognising, since the Fremantle Maritime Centre have had preliminary success in culturing dhufish (see FRDC interim report, project 96/308), there is now also the possibility to restock areas which have become severely depleted of this species.

(VIII) Benefits

The biological parameters determined in this project provide crucial information that will be used by Fisheries W. A. to develop effective management strategies for this species, particularly as the type of long-term commercial catch data that could be used for the purpose of stock assessments are limited. The dissemination of information on the biology of dhufish amongst commercial and recreational fishers will enable those fishers to understand the rationale for any measures that are adopted to help conserve this species. The biological data are of value to the Fremantle Aquaculture Centre in their attempts to culture *G. hebraicum.* The data on the incidence of the large nematode *Philometra lateolabracis* in the gonads of *G. hebraicum* will also be of value to the Fremantle Aquaculture Centre, as this species could cause detrimental effects in the tanks in which they are culturing dhufish and in which the densities of this fish species are high.

(IX) Further Development

During the first year of this study, it proved virtually impossible to obtain dhufish < 300mm. The provision of additional funds by FRDC enabled a commercial trawl fisher to be employed to trawl over the hard substrata where it was believed the small dhufish live. This trawling was very useful in that it yielded appreciable numbers of 0+ and early 1+ fish, which ranged in length from 30 to 160mm. However, dhufish with lengths of 150 to 300mm were caught far less frequently by this method. The paucity of fish at these lengths in the trawl catches could be due to a reduction in the catching efficiency of the trawl as dhufish increase in size and/or the movement of dhufish to a different habitat. The possibility that such a habitat movement does take place is supported by the capture, by a licensed spear fisher, of dhufish of the above size in areas of low-lying reef, which could not be trawled.

Further studies are desirable to determine more precisely the impact of the nematode parasite *P. lateolabracis* on the reproductive potential and health of *G. hebraicum*. Such data will be of particular importance for any research or commercial organisation that aims to culture this species.

The detailed biological data collected for dhufish during the present study can now be used by Fisheries W. A. to refine the approaches it uses to conserve this important recreational and commercial species.

(X) Conclusions

- Scales are unsuitable for ageing *G. hebraicum*.
- The opaque zones in the sagittal otoliths of *G. hebraicum* are formed annually and can thus be used to age this species.
- Whole otoliths with up to six opaque zones can be used to age this species, but thereafter the otoliths have to be sectioned to be certain that all of the opaque zones are visible.

- The von Bertalanffy growth parameters L_∞, k and t_o, for the growth curves of *G. hebraicum* derived from length at age data were 940.4mm, 0.108 and -0.153, respectively, for females, and 1023mm, 0.112 and -0.020, respectively, for males.
- The maximum ages recorded for females and males were 39 and 42 years, respectively, and the maximum lengths for females and males were 981 and 1120mm, respectively.
- Males grow slightly faster and attain a greater maximum length than females. Fifty percent of females and males of *G. hebraicum* reach first sexual maturity at total lengths of 301 and 320mm, respectively, and at 2.5 and 2.6 years of age, respectively.
- *Glaucosoma hebraicum* spawns between November and April, with the majority of spawning activity occurring between December and March.
- *Glaucosoma hebraicum* is a multiple spawner, *i.e.* produces eggs at intervals during the spawning period.
- The nematode parasite *Philometra lateolabracis* 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 lateolabracis* develops from larvae to mature adult during the spawning season of *G. hebraicum*.
- *Philometra lateolabracis* may have a deleterious effect on the reproductive potential of *G. hebraicum*.
- Since dhufish often die at capture, particularly when they are brought to the surface from water depths > 30m, there is little value in maintaining a minimum legal length (MLL) for this species.
- Conservation measures for *G. hebraicum* could include one or more of the following: closing areas to commercial and recreational fishing, introducing quotas on commercial fish catches, making adjustments to the number of commercial licenses, imposing further restrictions to the bag limit of recreational fishers and restricting the number of recreational fishers allowed to fish a particular area at any given time.

- Since the Fremantle Maritime Centre has now been successful in culturing dhufish, there is also now the opportunity to consider restocking areas which have become severely depleted of this species.

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(XII) Appendix 1: Intellectual Property

N/A

(XIII) Appendix 2: Staff

The following researchers at the Centre for Fish and Fisheries Research Group, Murdoch University contributed to this report:

Principal investigator: Prof. Ian C. Potter

Honours student & subsequently graduate research assistant: Sybrand A. Hesp

Technologist: Russell P. Hobbs (* Veterinary Department at Murdoch University)

Professional Officer: Glenn A. Hyndes

Professional Officer: Margaret E. Platell

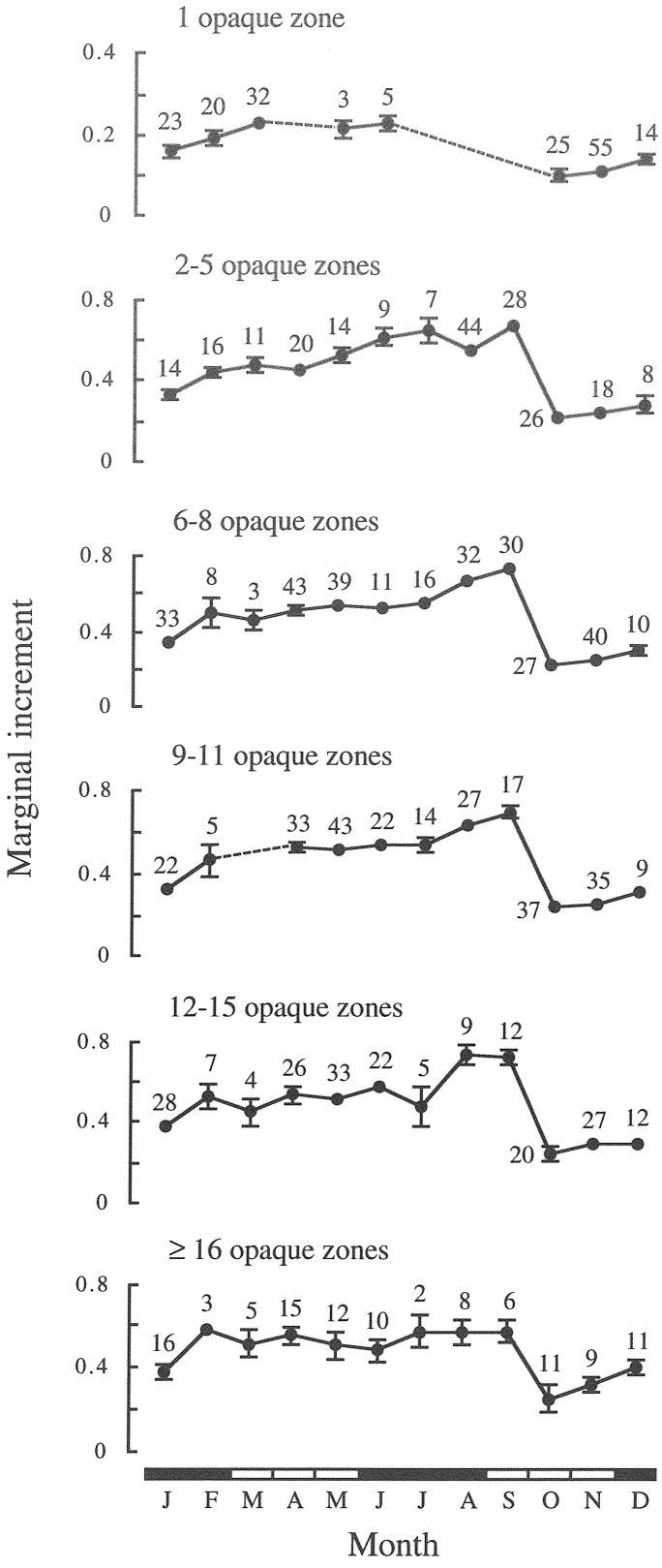

Figure 1. Mean monthly marginal increments ±1SE for sagittal otoliths of *Glaucosoma hebraicum*. Sample size is given for each month. In this and Fig. 7, the closed rectangles on the horizontal axis refer to summer and winter months, and the open rectangles to autumn and spring months.

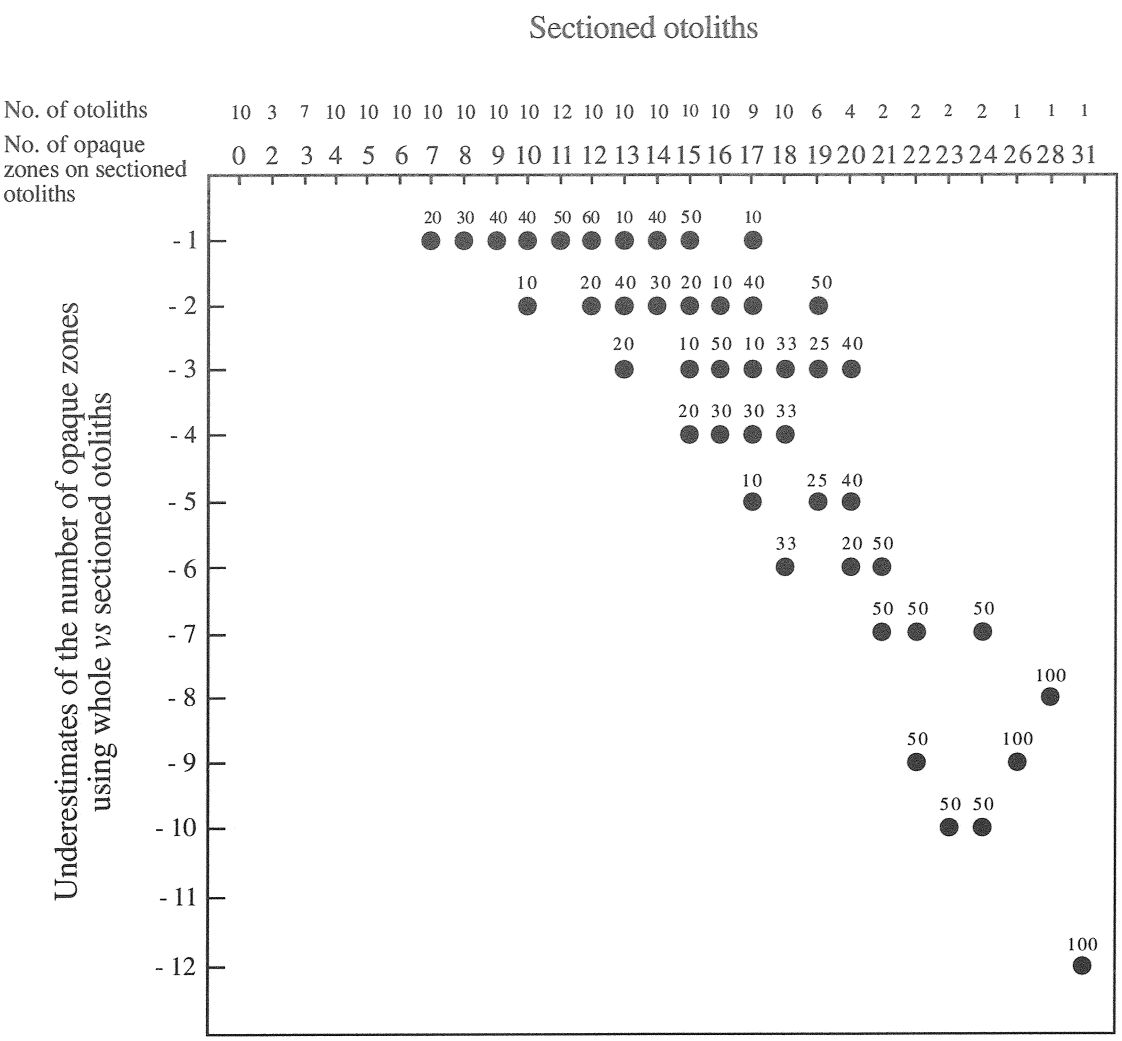

Figure 2. Comparisons between the number of opaque zones observed on the otoliths of *Glaucosoma hebraicum* prior to and after sectioning those otoliths. The numbers above enclosed circles represent the percentage number of underestimates of the number of opaque zones observed on whole *vs* sectioned otoliths.

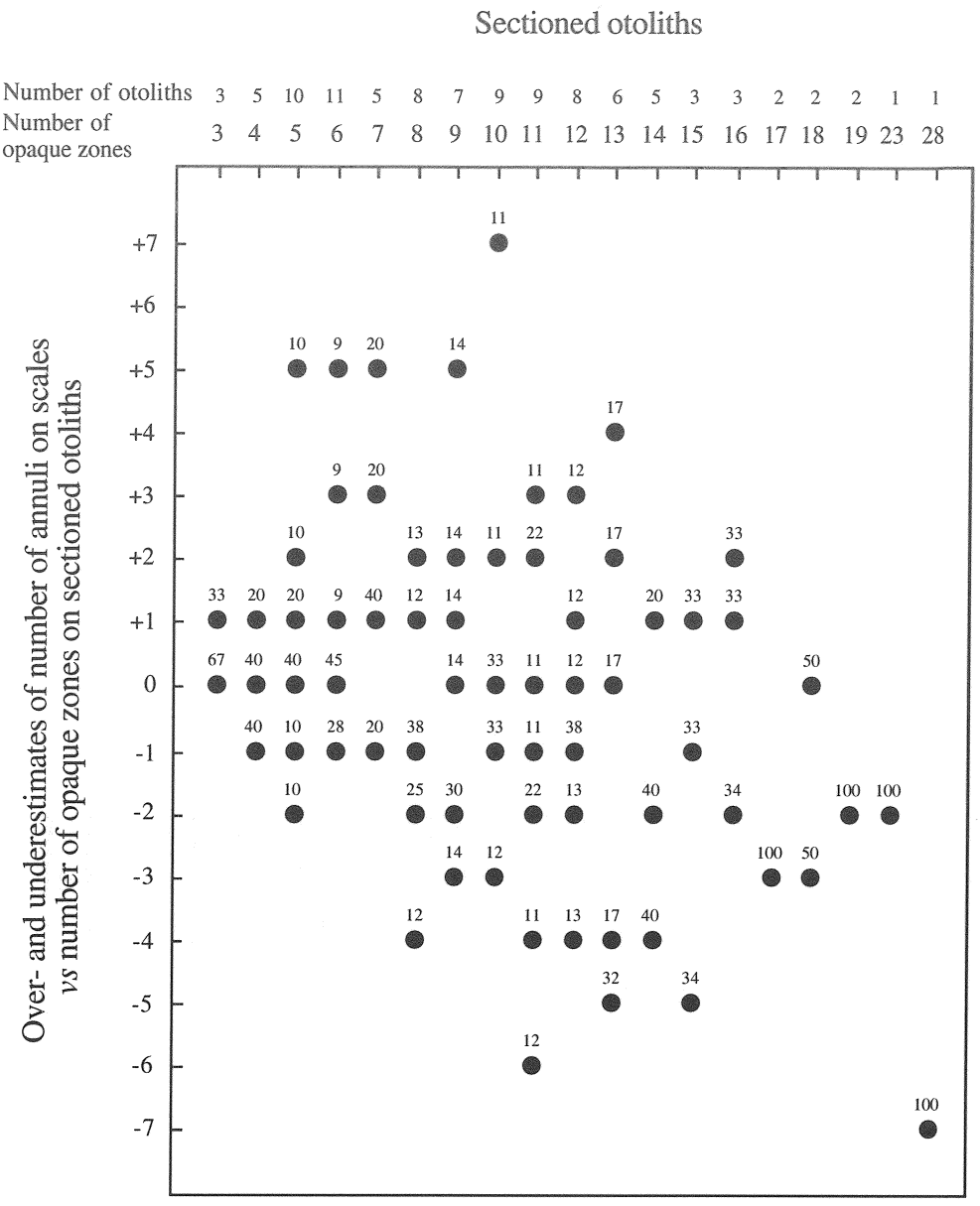

Figure 3. Comparisons between the number of annuli on scales and the number of opaque zones on sectioned otoliths of *Glaucosoma hebraicum*. The numbers above enclosed circles represent the percentage of over- and underestimates of the number of annuli on scales *vs* the number of opaque zones on sectioned otoliths.

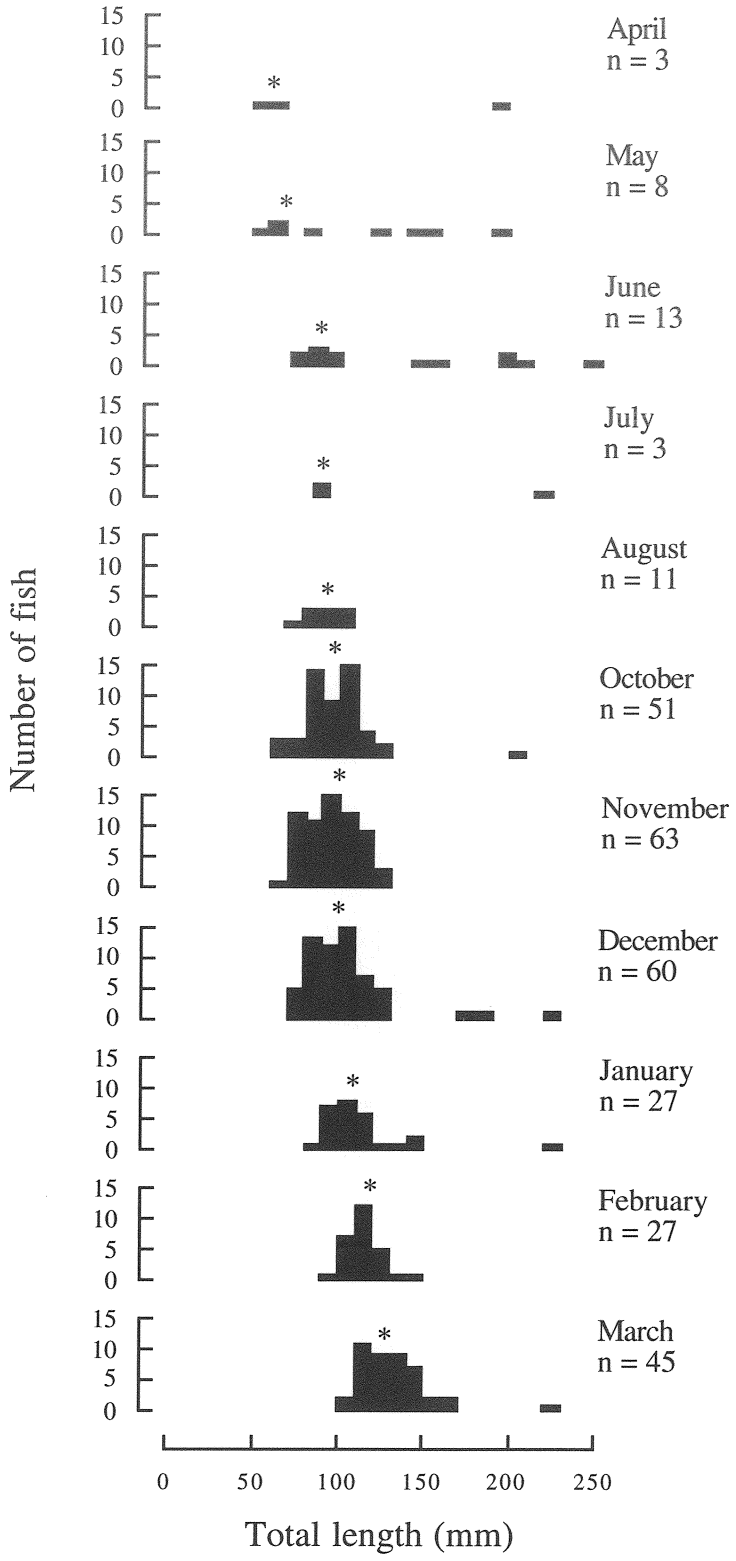

Figure 4. Length-frequency distributions of *Glaucosoma hebraicum* caught by trawling along the south west coast of Australia, utilising data for corresponding months in the period between May 1996 and June 1999. * denotes mean lengths of 0+ and early 1+ fish. n refers to the number of fish measured.

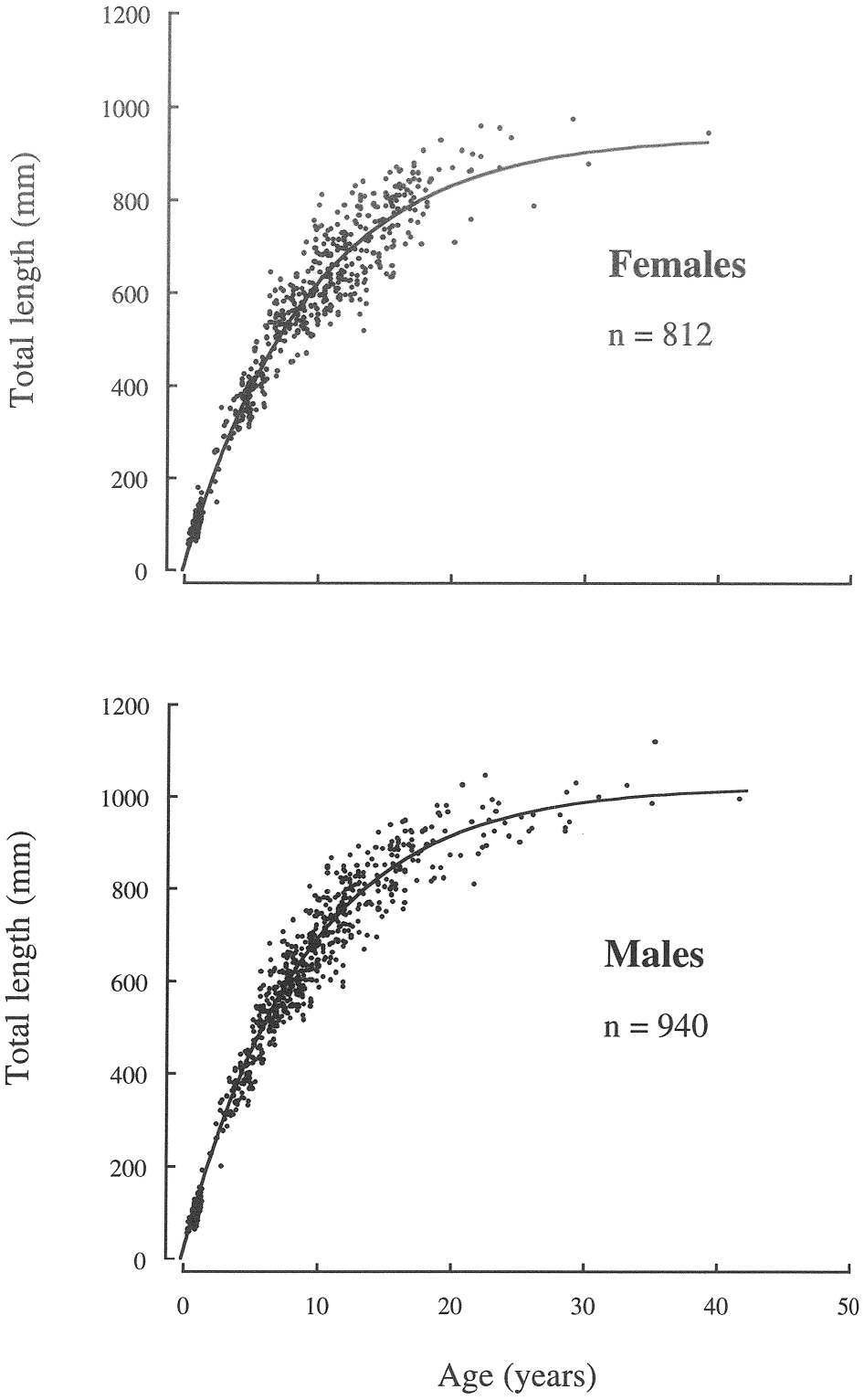

Figure 5. von Bertalanffy growth curves fitted to length at age data for females and males of *Glaucosoma hebraicum* caught on the lower west coast of Australia. n = number of fish.

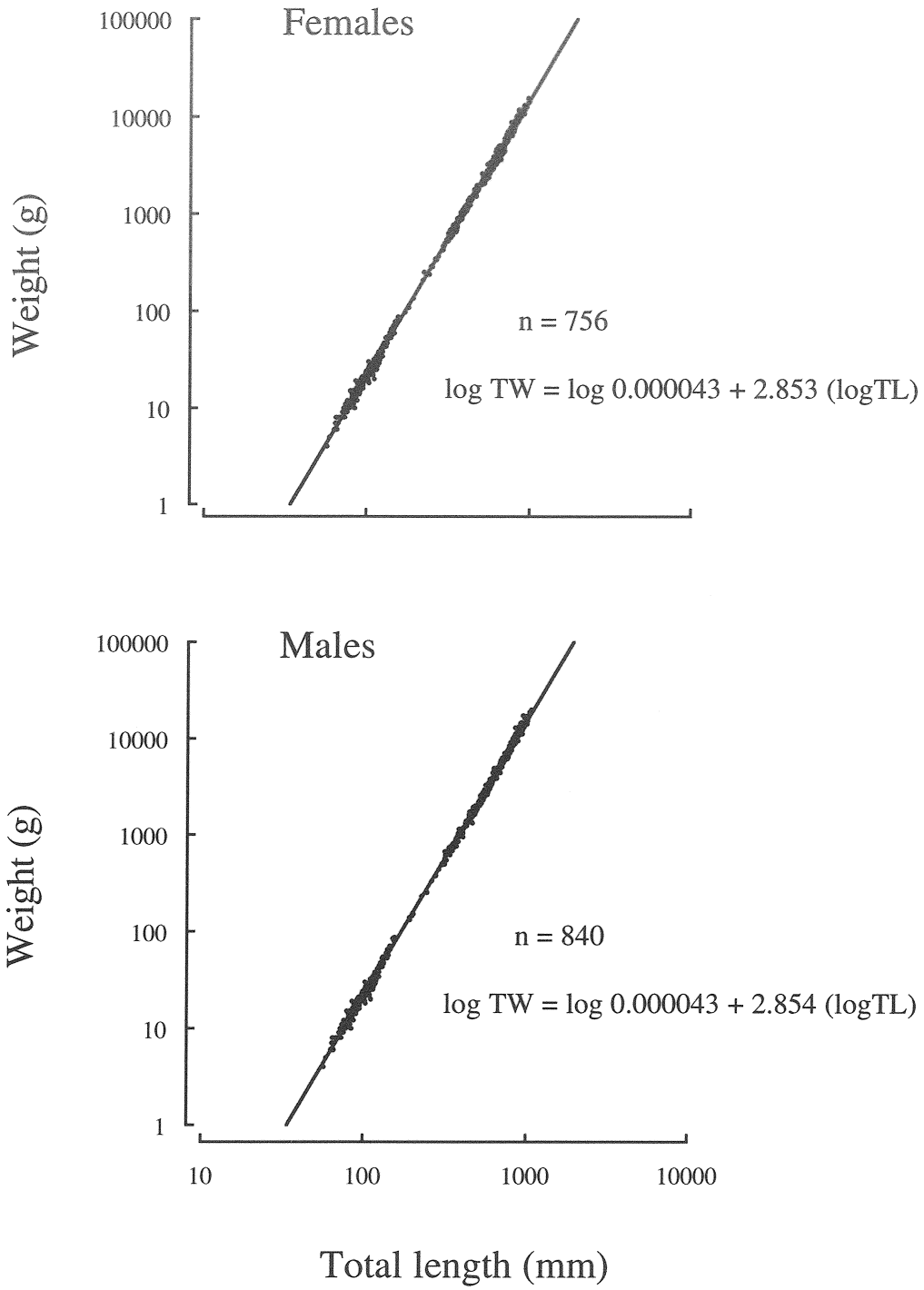

Figure 6. Relationship between total length (TL) and total wet weight (TW) for females and males of *Glaucosoma hebraicum* n refers to the number of fish measured.

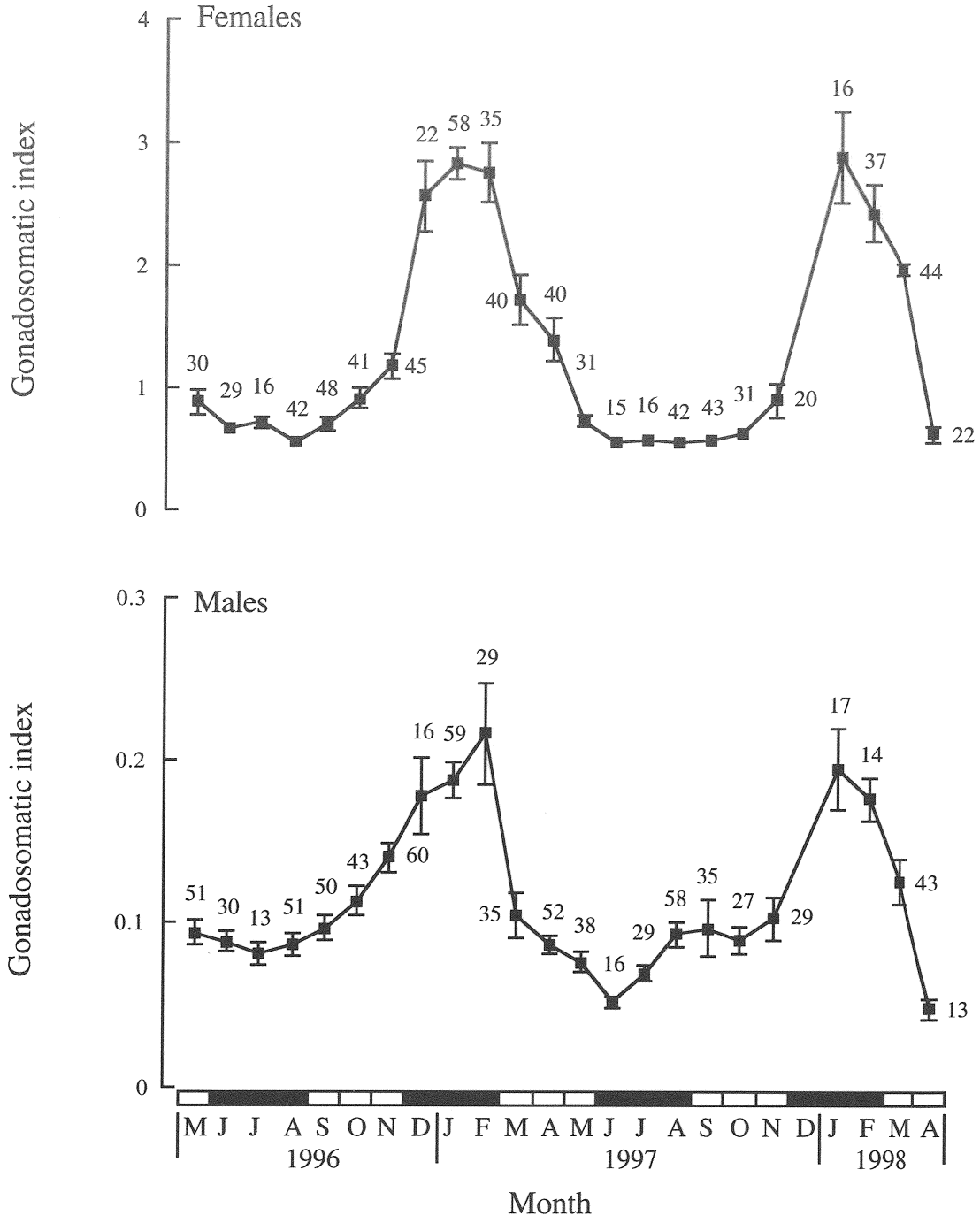

Figure 7. Mean monthly gonadosomatic indices ±1SE for females and males of *Glaucosoma hebraicum* caught in offshore waters between Geraldton and Perth between May 1996 and April 1998. Data in this Fig. and Fig. 8 are restricted to females and males ≥ L_{50} at first maturity. Numbers of fish in each month are shown above each mean.

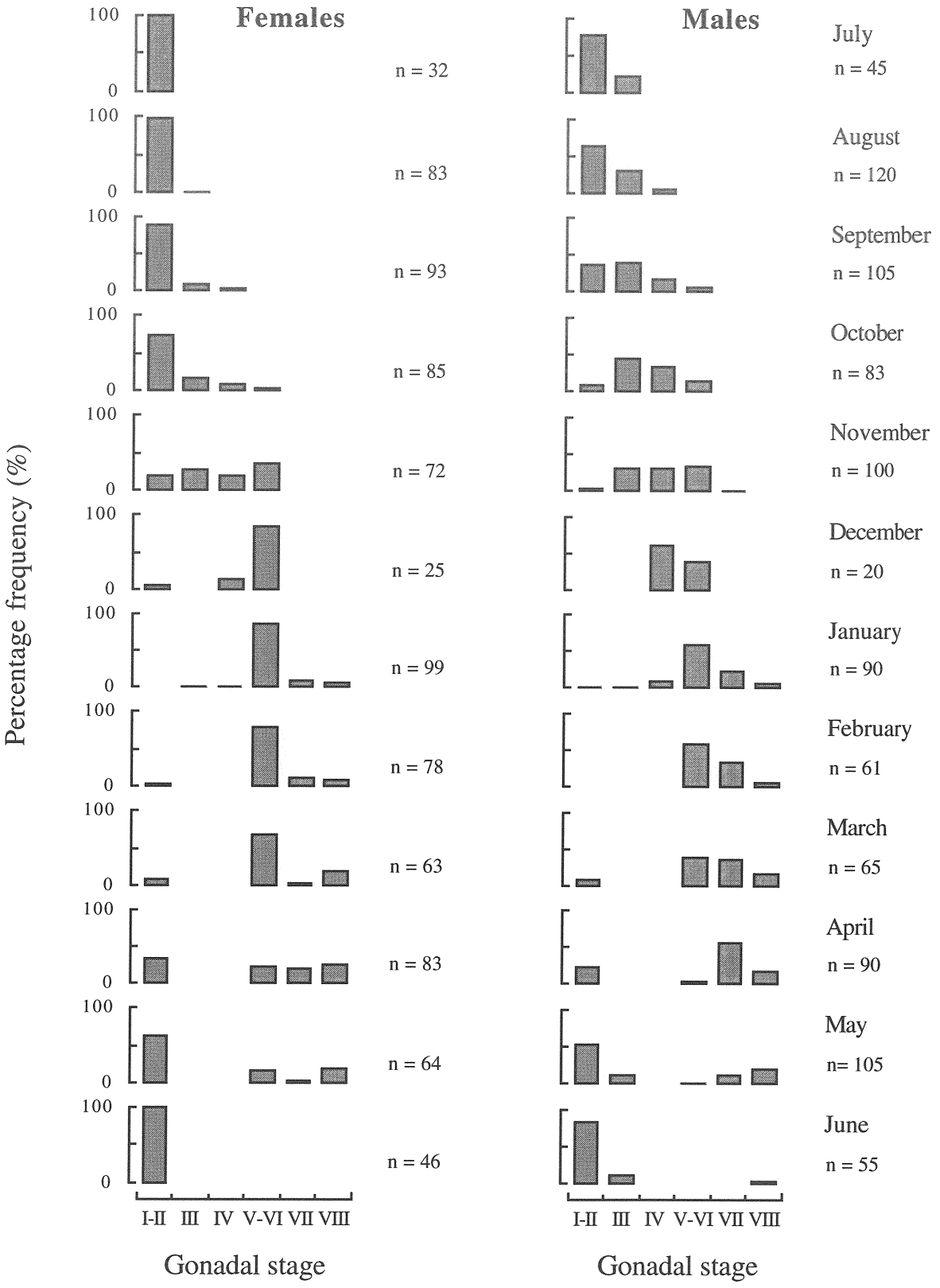

Figure 8. Percentage-frequency histograms for the gonadal maturity stages of females and males of *Glaucosoma hebraicum*. Data have been pooled for the corresponding months of the year in the period between May 1996 and May 1998. Sample sizes (n) are given for each month.

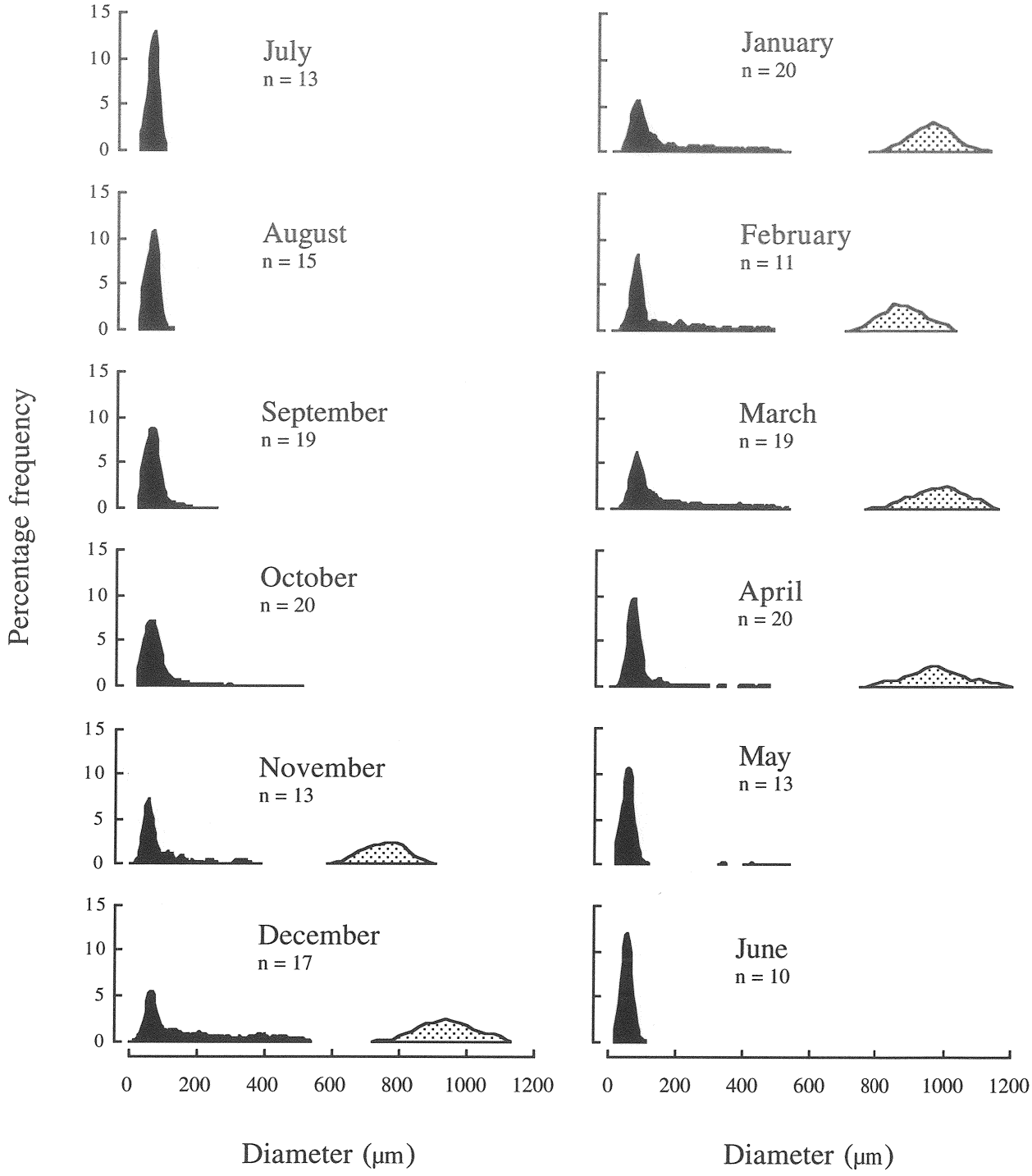

Figure 9. Monthly percentage frequencies for oocyte diameters (μm) in the ovaries of large *Glaucosoma hebraicum* in each month of the spawning period. Diameters were smoothed using a moving average of 5. n refers to the number of ovaries examined, darkly shaded areas to oocytes on histological slides meaured using computer imaging and lightly shaded areas to hydrated oocytes which were taken from ovaries and measured directly under the microscope.

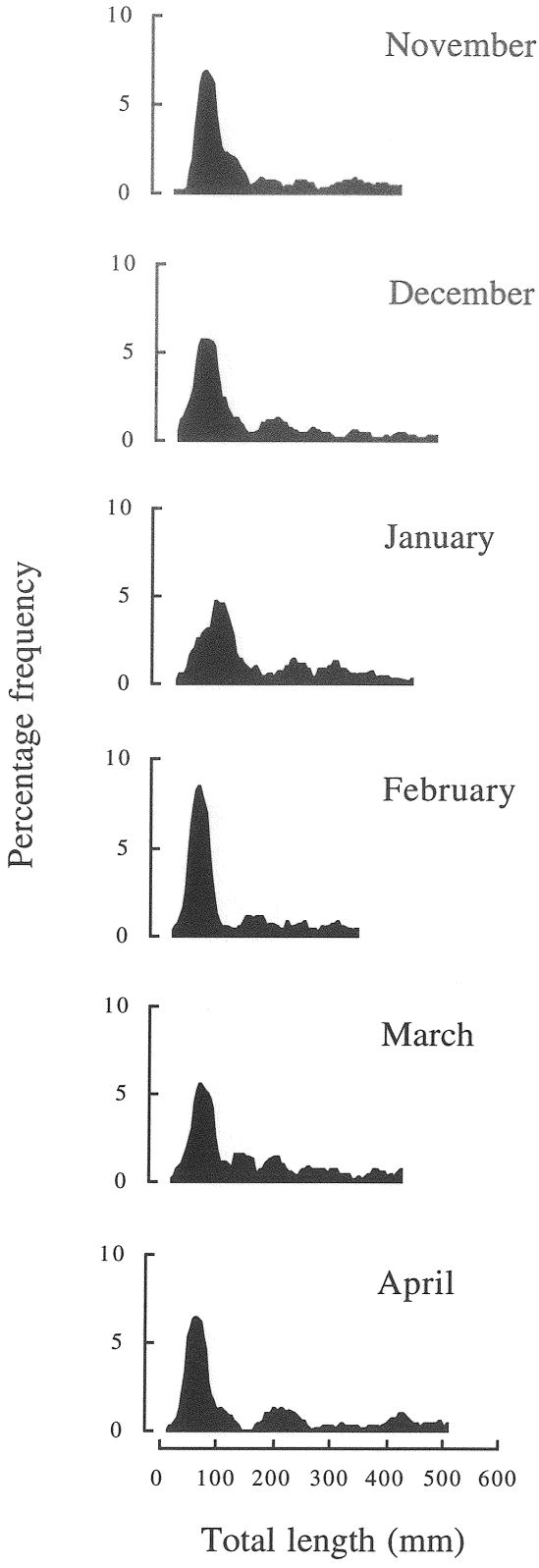

Figure 10. Percentage frequencies for oocyte diameters in the ovaries of single mature females of *Glaucosom hebraicum* in each month of the spawning period. Diameters were smoothed using a moving average of 7.

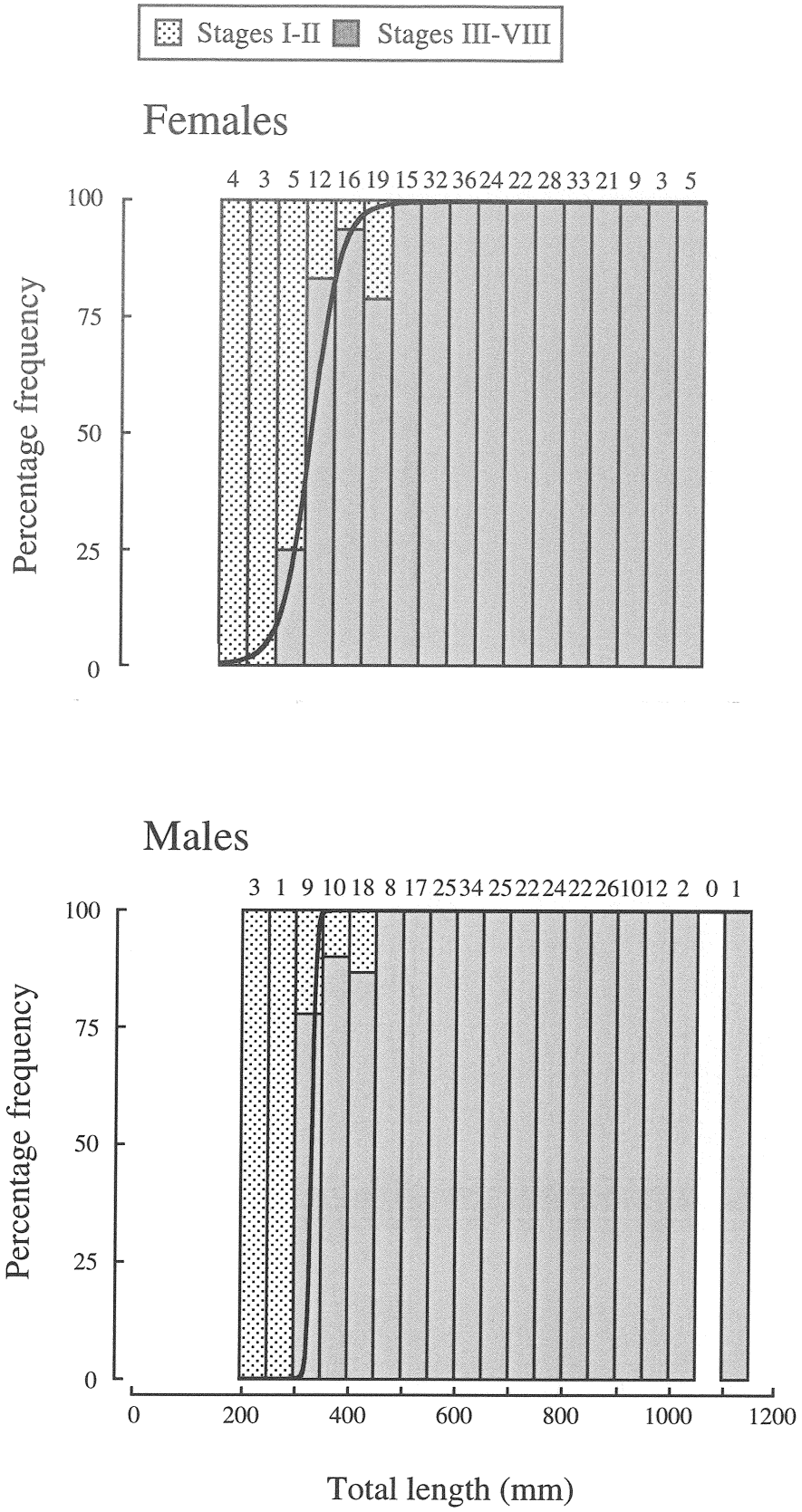

Figure 11. Percentage frequency of occurrence of sequential stages in gonadal development in each sequential 50mm category of females and males of *Glaucosoma hebraicum* between December and March. The sample size is given for each length class.

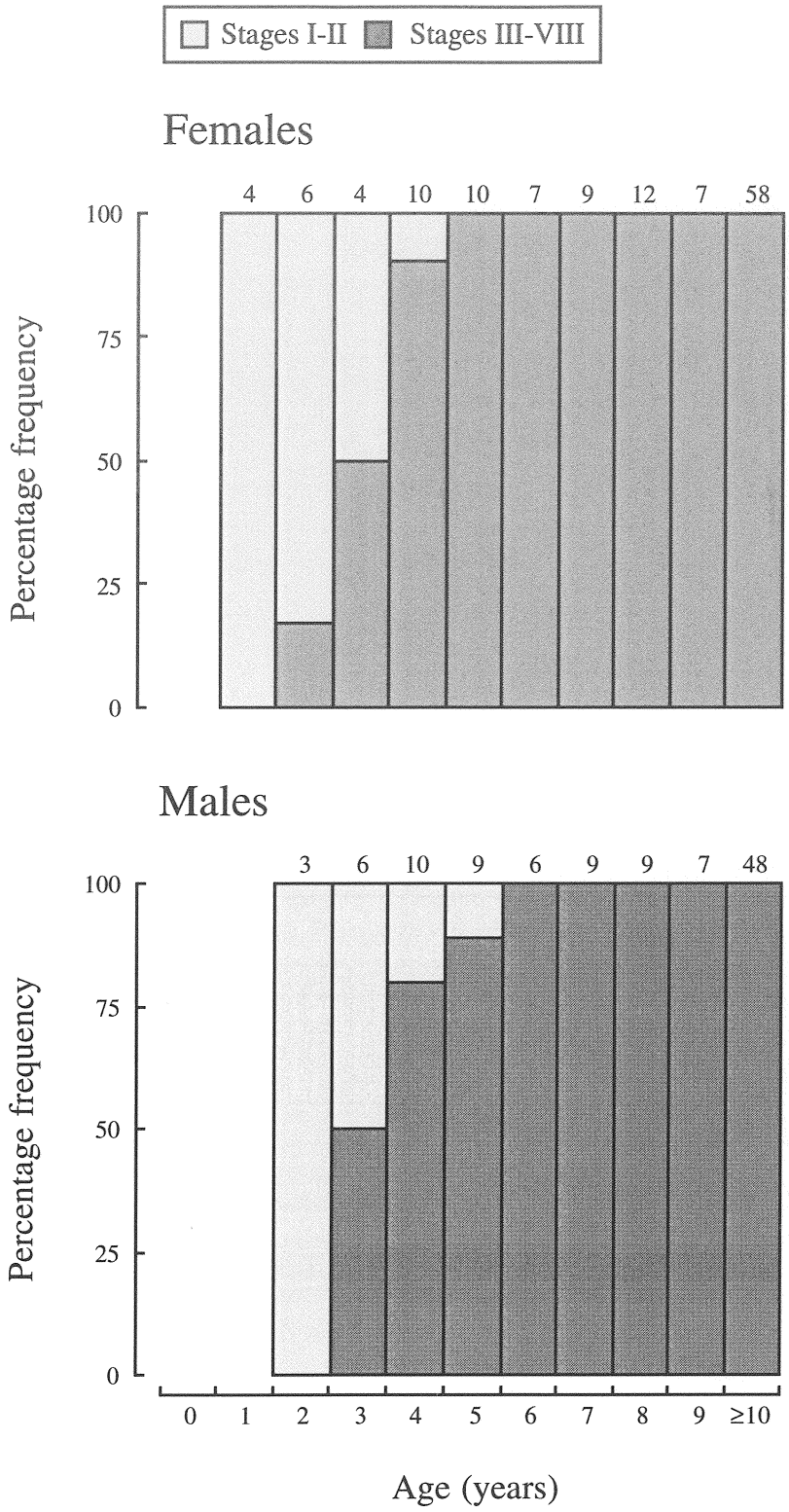

Figure 12. Percentage frequency of occurrence of gonads at stages I-II and stages III-VIII in sequential age classes of females and males of *Glaucosoma hebraicum* caught between December and March. Sample sizes are given above each column.

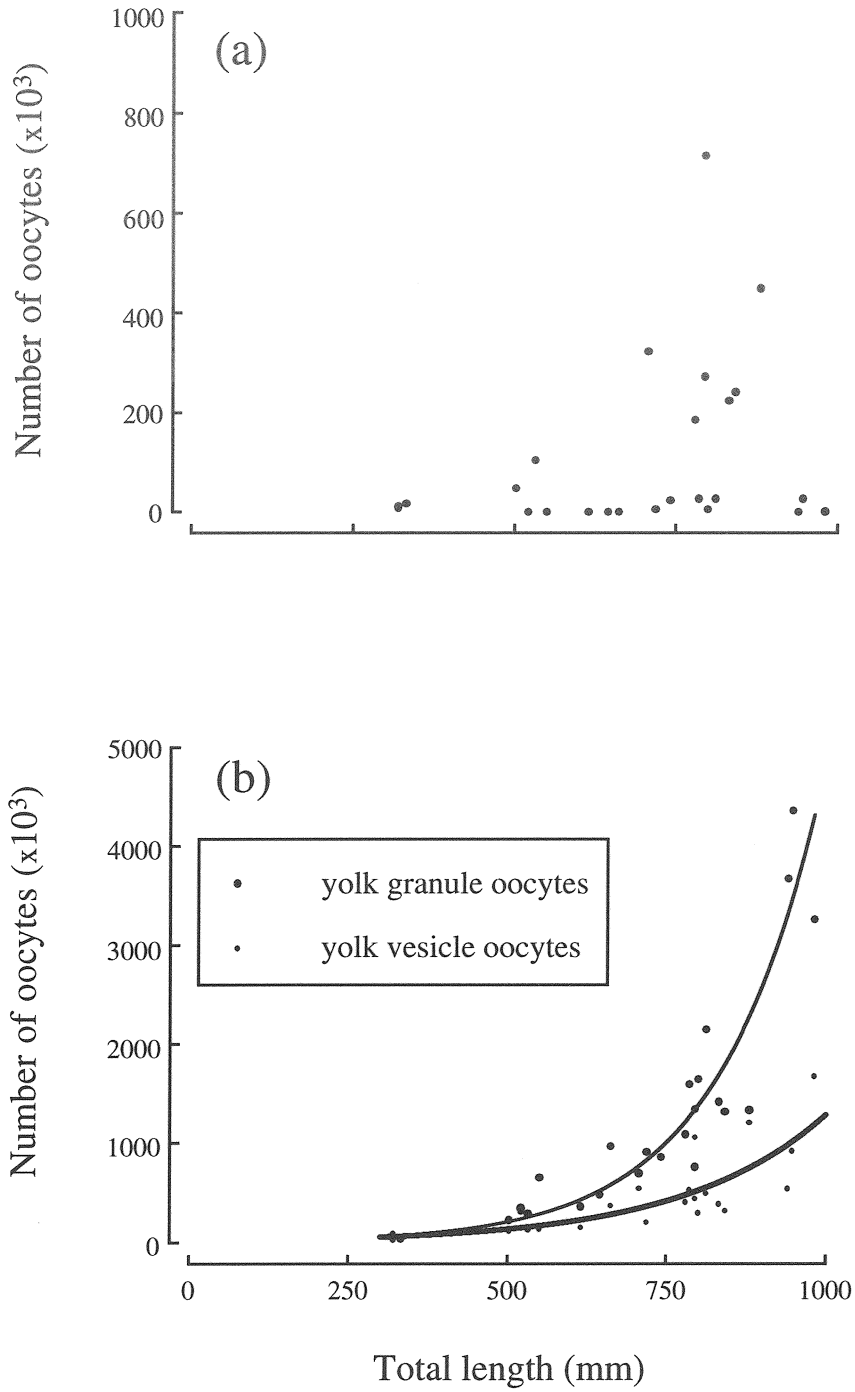

Figure 13 Relationship between total length of female *Glaucosoma hebraicum* and the number of (a) hydrated oocytes and (b) yolk vesicle and yolk granule oocytes in mature and spawning ovaries *i.e.* between December and March.

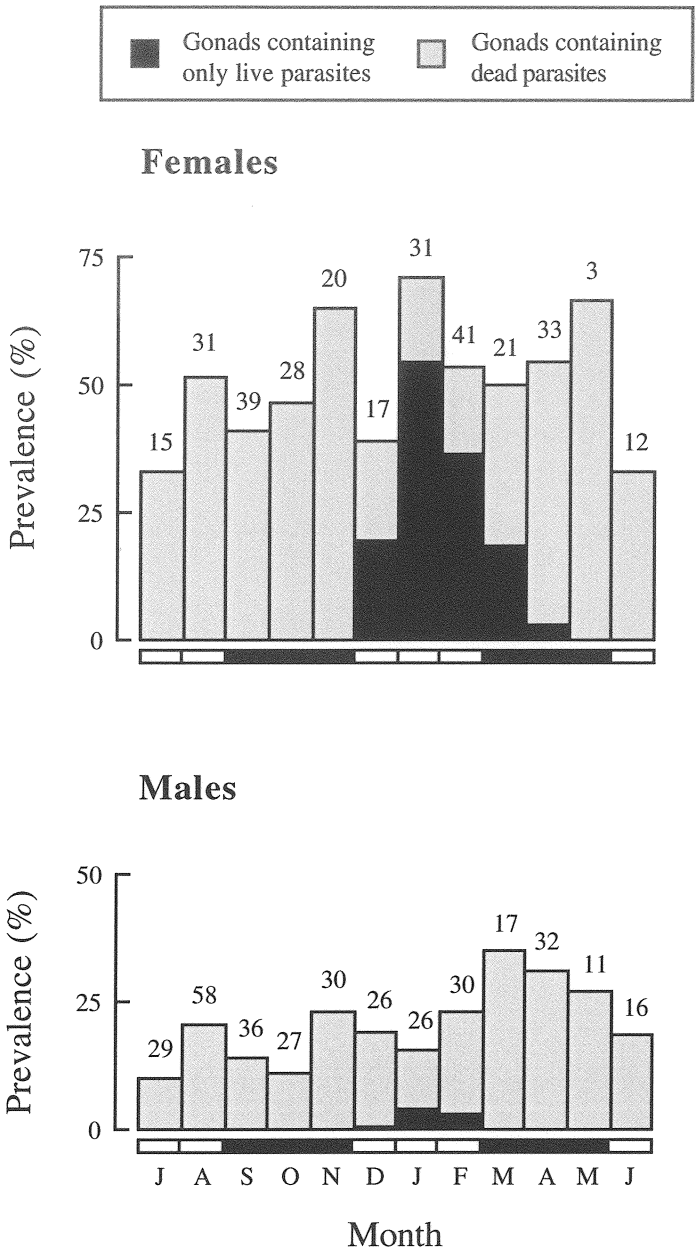

Figure 14. Mean monthly prevalence of live and dead *Philometra lateolabracis* in gonads of female and male *Glaucosoma hebraicum*. Sample sizes are shown above each month.

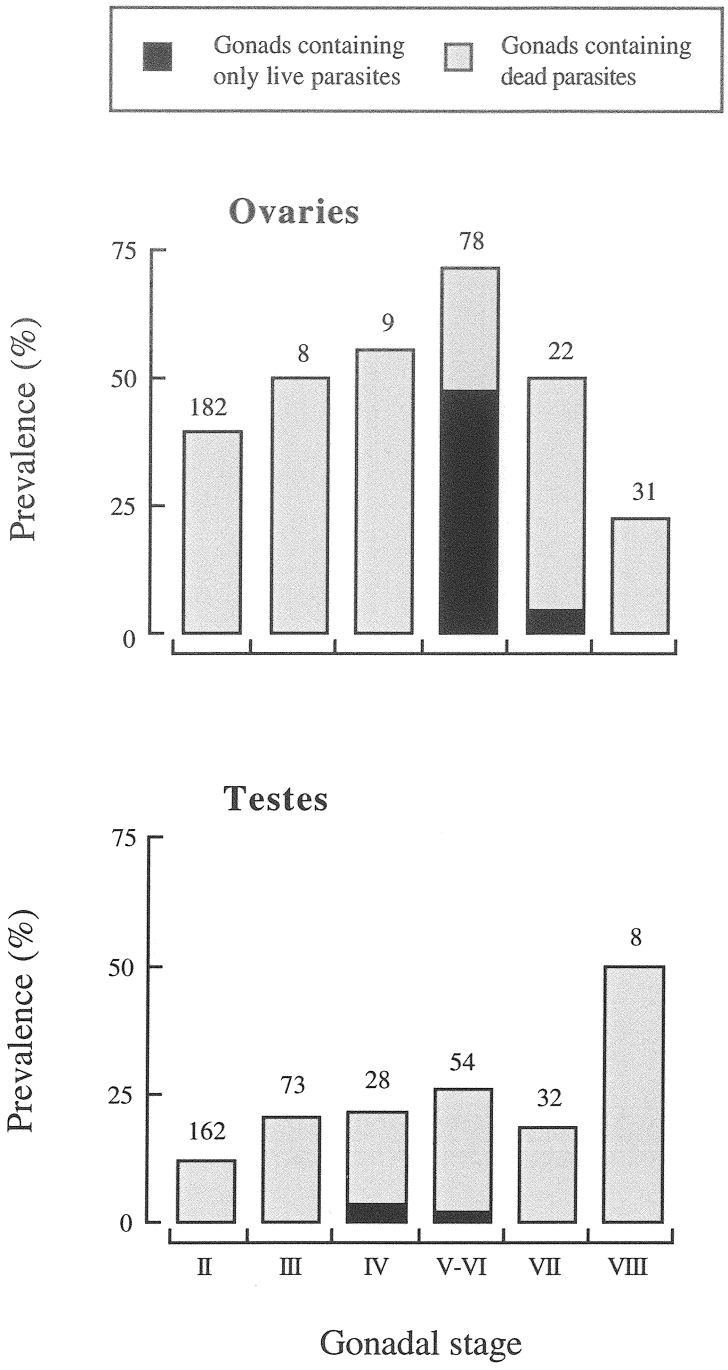

Figure 15. Prevalence of live and dead *Philometra lateolabracis* in each developmental stage of the ovaries and testes of *Glaucosoma hebraicum*. Sample sizes are given for each category of gonadal stages.

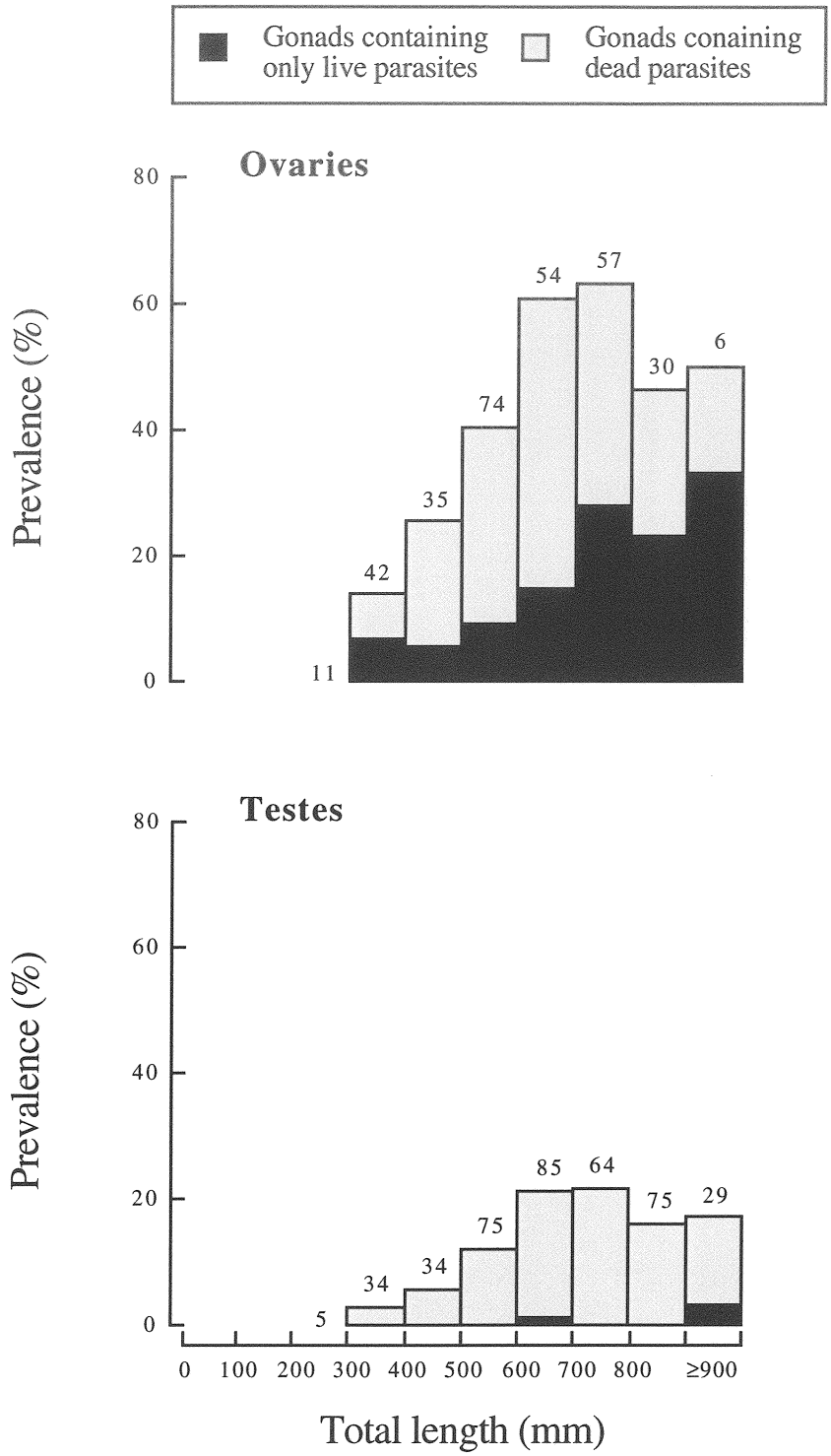

Figure 16. Prevalence of live and dead *Philometra lateolabracis* in the gonads of sequential 100mm length classes of female and male *Glaucosoma hebraicum* captured between November and March. Sample sizes are given for each length category.

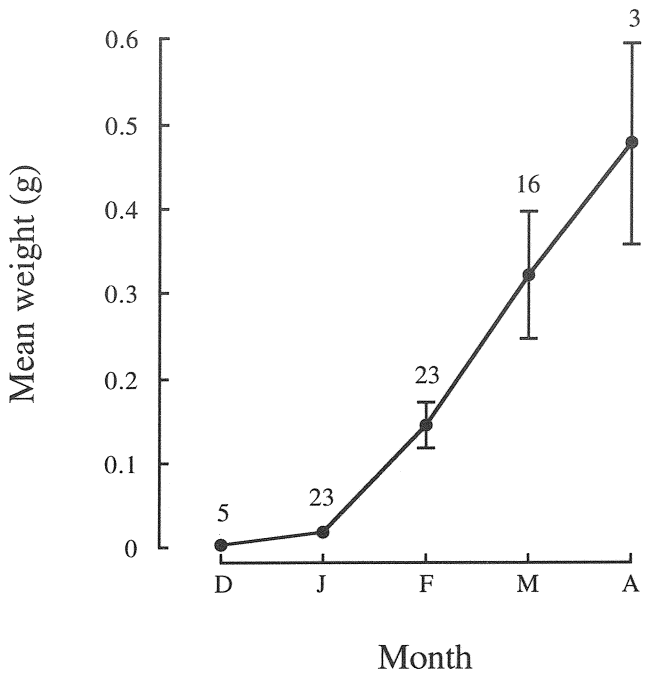

Figure 17. Mean weights ±1SE of live *Philometra lateolabracis* removed from the ovaries of *Glaucosoma hebraicum* caught between December 1997 and April 1998. Sample sizes are shown above each month.