84/39

# FIRTA PROJECT 84/39-THE LIFE HISTORY OF THE BONY BREAM

## FINAL REPORT

J. T. PUCKRIDGE

DR. K. F. WALKER

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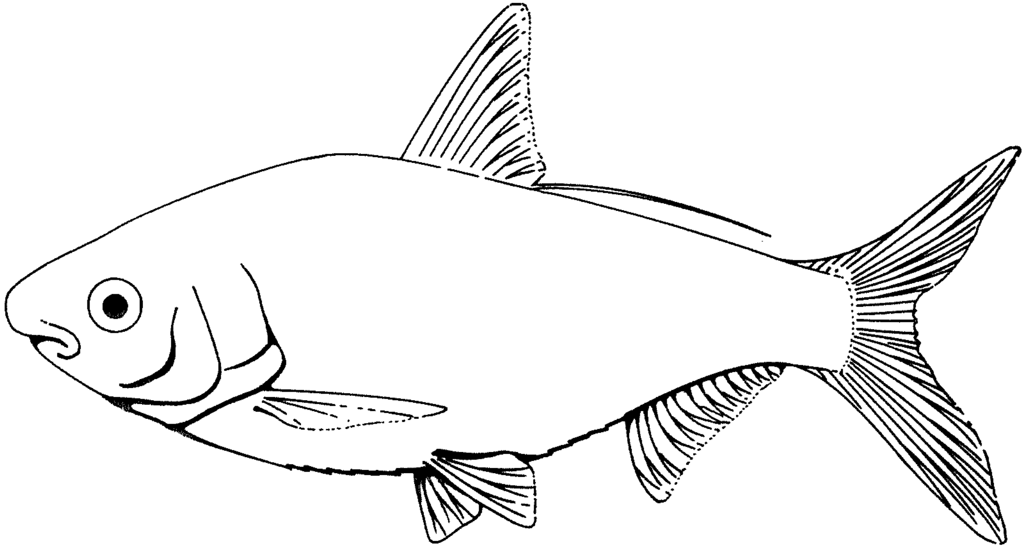
Fig.1



THE BONY BREAM, *Nematalosa erebi*

## 1. INTRODUCTION

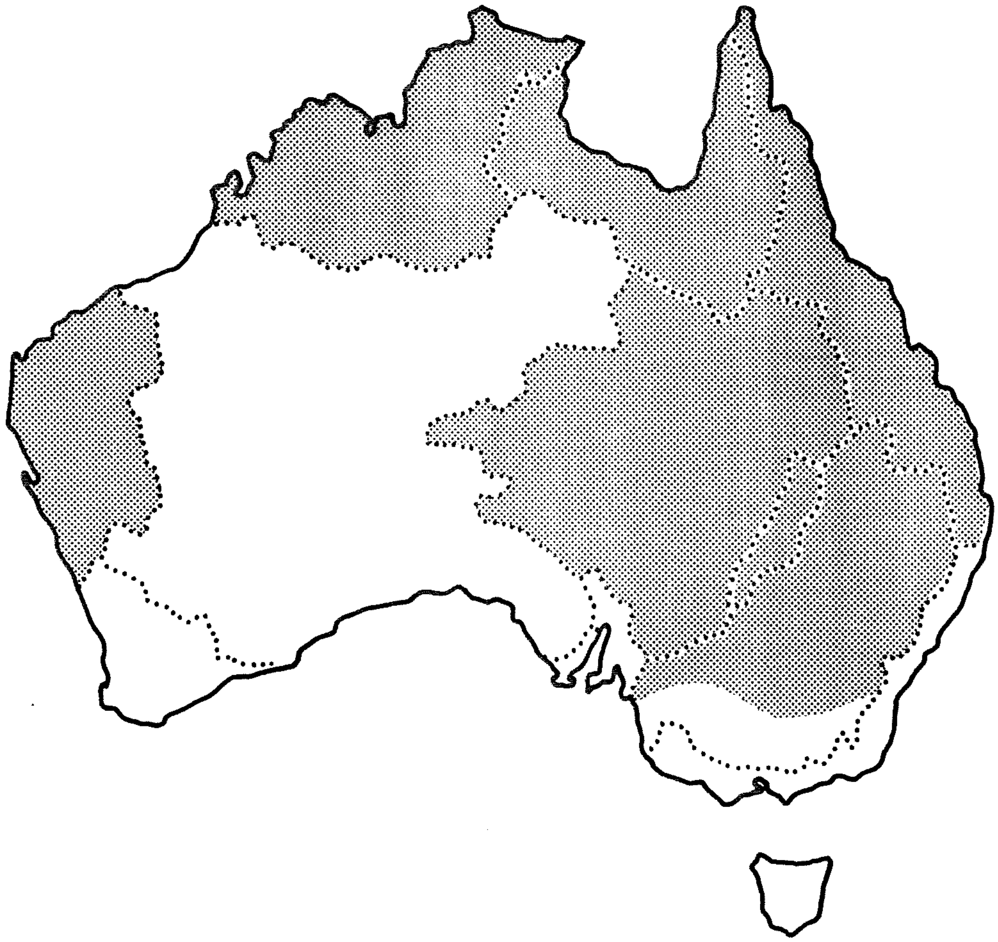
The bony bream, Nematalosa erebi (Fig.1) is a member of the family Clupeidae (herrings), sub-family Dorosomatinae (gizzard shads). The gizzard shads are a group of primarily filter-feeding medium-sized schooling fishes common in sub-tropical coastal shallows and estuaries (Miller 1960, Nelson & Rothman 1973). They are characteristically early maturing and produce many small eggs (Babu Rao 1965, Kilambi & Baglin 1969a, 1969b). Some members of the group have successfully invaded freshwater, and the North American gizzard shads Dorosoma cepedianum and Dorosoma petenense dominate slow-flowing and still waters over much of that continent (Miller 1960, Noble 1981). In a similar manner, the bony bream dominates slow - flowing rivers and lakes in all the warm-water catchments of Australia, and is probably the most widespread native freshwater fish in this country (Fig. 2, Merrick & Schmida 1984).

Freshwater gizzard shads are of major ecological importance in their role as converters of detritus and phytoplankton to food for piscivorous fish and birds. Dorosoma species are widely considered in North America to be important forage for game fishes (Jenkins & Morais 1978, Noble 1981) and bony bream are a major component in the diets of, for example, callop Macquaria ambiqua, Murray cod Macullochella peeli, barrumundi Lates calcarifer, redfin Perca fluviatilis and ariid catfishes (Milward 1965, Weatherley 1977, Mackinnon 1984, Merrick & Midgley 1985, Morrissy 1986).

In South-East Asia, several gizzard shads are utilized for human consumption (Jacob 1948, Jhingran & Gopalakrishnan 1973) but in Australia the flesh of bony bream, although tasty, is considered too bony for this purpose. There is probably untapped potential for marketing of this species as pickled herring. Both the bony bream and

Fig.2

# DISTRIBUTION OF BONY BREAM IN AUSTRALIAN CATCHMENTS



Adapted from Merrick & Schmida, 1984

the estuarine Perth herring Nematalosa vlaminghi are caught for crayfish bait, and the bony bream catch in the lower Murray in 1985/6 was 700,000 kg (S.A. Dept. Fisheries 1987). Interest has been expressed in the use of bony bream as forage for barrumundi in Queensland reservoirs (Mackinnon 1984, McKay 1984), and several successful stockings have already taken place (Cadwallader 1983). For reasons both ecological and economic therefore, knowledge of the life-history of the bony bream is needed.

A study of the life - history of an estuarine cogener of the bony bream, the Perth herring (Nematalosa vlaminghi) provides useful comparative material (Chubb & Potter 1984, 1986). However, previous findings about the bony bream itself have been incidental to studies of other species or of whole fish communities. Cadwallader's (1977) publication of J.O. Langtry's River Murray Investigations gives estimates of bony bream growth rates based on length-frequencies, and Bishop, Allen, Pollard & Cook (in prep.) sketch the principal life-history features (diet, age at first maturity, reproductive cycle, fecundity, growth, habitat preferences and migration patterns) of the species in the Magela Creek as part of a community study. The latter work, although of great interest - particularly in comparison with temperate studies - was not intended as an intensive life-history study of any single species, and does not provide the data necessary to management of a bony bream fishery or stocking program.

The present study was intended to provide a detailed account of the life-history of bony bream in the lower Murray, and to use this as a basis for recommendations on the management of the bony bream fishery, and the use of bony bream as a forage species for game fishes.

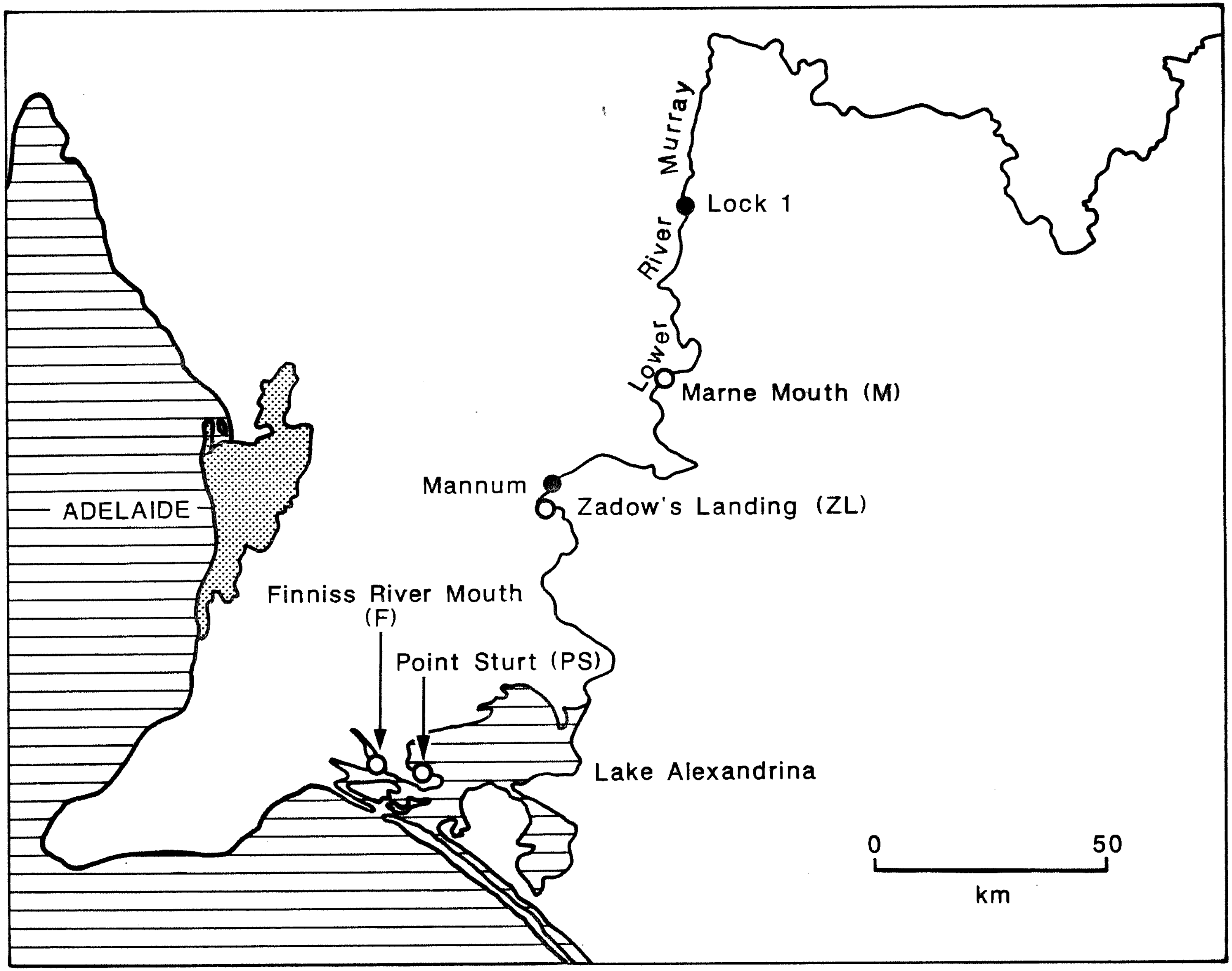
## 2. METHODS

### 2.1. General

Fish were sampled principally at Zadow's Landing (ZL) (Lat. 34, 58 Long. 138, 59) on the lower Murray, and Point Sturt (PS) (Lat.34, 58 Long. 139, 18) in Lake Alexandrina, but ichthyoplankton trawls were also conducted south of the mouth of the River Marne (M), and at the mouth of the Finnis River (F) South Australia (Fig. 3). ZL is a shallow permanent backwater with a mud-clay substrate, bordered with *Juncus* sp., *Typha orientalis* and *Phragmites australis*, and densely vegetated with *Vallisneria spiralis*. Gillnetting was conducted along the edge of the main channel between islands of *Salix* sp., seining on both the river channel and floodplain borders of the backwater. PS, on the northern side of Point Sturt, is a bay protected from the prevailing winds, but still subject to occasional strong wave action. It has a sand on clay substrate, and only very sparse fringing vegetation - principally *Phragmites australis*. Gillnetting was conducted at PS 200m offshore, seining both parallel to and 50m offshore, or from offshore onto the beach. Site F is a broad shallow inlet, bordered with dense *Phragmites australis* stands, and densely vegetated with *Myriophyllum* sp. Site M is a 2-km reach of the main channel of the Murray immediately south of the Marne mouth, bordered with *Salix* sp. and *Eucalyptus camaldulensis*.

Sampling was conducted monthly at ZL and PS from September 1983 to December 1984, but from then to December 1986 took place only during the fungus disease and breeding seasons (June to December). A set of seven 50m gill nets (mesh sizes 20-110mm), three seines (lengths 2, 18, 130m; mesh sizes 2, 12, 30/50 mm), and a 0.5m diameter 500u mesh ichthyoplankton trawl were used. However, only two of the seven gillnets (mesh sizes 90, 110) were used at PS, and the 130m seine was

Fig.3


Lower River Murray
Lock 1
Marne Mouth (M)
Mannum
Zadow's Landing (ZL)
ADELAIDE
Finniss River Mouth
(F)
Point Sturt (PS)
Lake Alexandrina
0
50
km

not used at ZL. The distances hauled per seine were 5m, 20m, and 50m respectively. The ichthyoplankton trawl was hauled at the surface for 3 minutes at 3-4 km/hr. A Smith-RooT (GPP 7.5 h) boat-mounted electrofisher was trialled at ZL. Gill-netting took place over a 24 to 72 hour period, with nets emptied at a frequency of 0.5 to 8 hours, depending on catch rates. Seines and trawls were conducted in mid-afternoon. Data recorded at capture in gillnets included depth of specimens in the net. Depending on catch size, the whole catch or stratified random samples (size-class interval 50 mm total length (TL)) were retained and processed at the PS and ZL field stations. All fish were measured (TL, LCF, and body depth to 1 mm), weighed (to 0.1 gm), dissected, gonads photographed in situ, left and right gonads weighed (to 0.01 gm) and measured (width, to 0.1 mm), then preserved in either Gilson's fluid or 10% buffered formalin. About ten scales were removed immediately posterior to the tip of the left pectoral fin, and in 1986, the left pectoral fin was removed for fin spine sectioning.

Data was analysed on Osborne and Sanyo 555 microcomputers, using both programs written by one of the authors (Walker, unpub.) and NWA Statpak Version 3.1 (Northwest Analytical, Portland Oregon 1984). Gonadosomatic index [10 (Gonad weight)/Body weight)], condition factor [10 (Body weight-Gonad weight)/(Total length)], gillnet catch/mesh size/hour, mean seine and trawl catch/haul, species composition of catches, and length - frequencies of bony bream catches were routinely calculated.

Wind strength and direction, water level, monthly water temperature, Ph, conductivity, secchi depth, dissolved oxygen and river levels were routinely recorded, and data on day length (Bureau of Meteorology), weekly river temperatures, daily discharge and water chemistry were obtained (E&WS Dept., S.A., unpub. data).

## 2.2 Reproduction

### 2.2.1 Gonad morphology

Linear regressions were computed for right gonad weight on left gonad weight for both sexes, and for log 10 (left gonad width) on log 10 (total gonad weight) for females, and the slopes tested for significance by t-test. The difference between the slopes of male and female right vs left gonad regressions was also tested (d-statistic, Bailey 1959).

### 2.2.2 Seasonal cycle

GSI was defined as 100 (total gonad weight)/body weight, means +/- SE calculated per sex and size-class per month, and plotted against mean monthly water temperature, mean daily discharge and mean monthly daylength. Log 10 (Mean GSI per month for females > 300mm) was compared for PS and ZL by paired-samples t-test. Gonads were staged into the categories of virgin, maturing virgin, recovering spent/developing, mature, ripe and spent on the basis of colour, size, texture and shape, and these stages checked against the GSI and ovum diameter frequency (ODF) cycles. Ovum diameters were determined from ovaries preserved in Gilson's fluid for at least six months. Ova were freed by shaking, the suspension diluted to one litre (giving a density which could be reliably counted in a counting maze) and a 10 ml subsample taken while the suspension was agitated with a perforated plunger. Ova were viewed using a Leitz Diavert compound microscope fitted with a Panasonic colour video camera connected to a TVC model 7808 ME colour screen. Ova were measured (larger diameter) from the screen with electronic calipers recording to an Arlec microprocessor model MPF-1 recording 16 channels. Units conversion, calculation of means and derivation of histograms were performed on an Osborne microcomputer running MBASIC programs. Two channels (maximum 120 measurements/channel) were allocated per fish, and 8 fish were measured per month. Measurements had to be taken at two magnifications (40X, 200X) which were separately calibrated (at 0.5 um and 0.1 um), because the equipment could not accomodate the full range of diameters simultaneously.

### 2.2.3 Spawning

In December 1984 and 1985, running ripe fish were retained from gillnet catches and stripped into a dry petri dish. Milt was dry - mixed with ova, and the fertilized eggs washed gently into lightly aerated glass 500ml jars.

At monthly intervals from November 1985 to February 1986 (with a final sampling in April) ten 3-minute hauls of the 500 um ichthyoplankton trawl were made in mid-afternoon on consecutive days at the four sites. Samples were fixed in 10% buffered formalin, preserved in 70% alcohol, examined under a dissecting microscope, fish larvae identified and catch/effort calculated.

### 2.2.4 Sex ratio

Linear regressions of log 10 body depth against log 10 total length were calculated for males and females, and the difference in slopes tested by t-test. Sex ratios were determined for size-classes and seasons, and the differences tested by Chi-square.

### 2.2.5 Larval development

Eggs from stripped fish and from the 500 um trawls, were examined under dissecting microscope at 40X, and under compound microscope at 100X. Larvae from the 500 um trawls were immersed in glycerine and viewed under polarised light at similar magnifications. Ova and larvae were measured and drawn, and larval series were developed from identifiable juveniles back to embryos.

### 2.2.6 Fecundity

The ovaries of twenty-seven fish captured in the period late October-early December (when ovaries are mature but not likely to have spawned), and covering the whole range of sizes of adult fish, were preserved in Gilson's fluid and agitated to break down connective tissue. The suspension was diluted (to between 1 and 4 litres total volume) and while it was agitated with a perforated plunger, a subsample was pipetted off, and counted under a dissecting microscope at 40X. Both dilution ratio and subsample size (2.5 - 9.0 ml) were adjusted to give a maze count between 50 and 500 ova. From ODF analysis, it was determined that only ova of diameter >250 um were likely to be spawned in the current season, so only ova of diameter greater than this size were counted. Subsamples were repeated on each fish until confidence intervals were less than 10% of the mean. Fecundity (+/- 95% CIs) was calculated by multiplying mean subsample count by the ratio of total volume to subsample volume. Regressions of fecundity on total length, fecundity on body weight - gonad weight, fecundity on total body weight, fecundity on gonad weight fecundity/(body weight - gonad weight) on total length, GSI on total length and all these variables log - transformed were calculated, and the significance of the regressions tested by F-test.

### 2.2.7 Age and length - maturity relations

Sexual maturity of fish was determined from a combination of gonad appearance, GSI, and ODF analysis. Fish used to determine the age and length - maturity relations were chosen from the October - December catches at ZL and PS, when the distinction between maturity and immaturity is unambiguous. Although fish were captured by both gillnetting and seining, the frequency distribution of size-classes of fish used was adjusted to match that of the 130m seine catches of this period, because they came closest to a random sampling of the population. The age - % maturity and class midlength - % maturity relations were plotted for each sex, and after the procedure of Leslie, Perry & Watson (1945) the % mature were transformed to weighted probits, and plotted against both log 10 (age + 1) and log 10 (midlength). Intercepts and slopes of the curves were tested for differences between the sexes, and median length and age at maturity (with 95% confidence intervals), were derived.

## 2.3 Feeding and condition

### 2.3.1 Feeding

Although this project did not attempt to describe diet, the sampling program supplied specimens to a concurrent study of this subject (Atkins in prep.). Further, in October 1986, 9 adult bony bream were transported successfully from ZL in aerated plastic bins at 7ppt salinity. They were maintained in a 5m diam. x 1m deep circular aerated pool, offered a variety of artificial diets, and their feeding, schooling and other behaviours observed.

### 2.3.2 Condition

Mean condition per month through 1983-84 was plotted for different size-classes and for males and females at PS and ZL. Differences between overall means and variances for males and females and for ZL and PS were tested (paired - samples t-test and F-test) for untransformed and log-transformed data.

## 2.4 Age and Growth

### 2.4.1 Weight - length relation

Untransformed and log - transformed weight-length relations were derived for males and females over all seasons from 1983-85 at ZL, and the slopes tested for difference (d-statistic).

### 2.4.2 Age

Scales were stored in paper envelopes on collection. They were later examined (without knowledge of the corresponding fish size) under a dissecting microscope at 40X, and unless blown were taped between microscope slides. (Blown scales have a large area around the focus either transparent and smooth or with a cross-hatched effect.) Approximately 5 - 15 unblown scales were examined per fish, the number of annual growth checks (annuli) counted, and the distance of each check measured from the focus to the posterior margin of the annulus in micrometer units. Annuli were distinguished by the following criteria:

a. Annulus continuous in both fields.

b. Circuli closer spaced anterior to annulus than posterior.

c. Circuli irregular at annulus and/or circuli cutting over at annulus.

e. More than 50 % of scales in the sample show the annulus clearly.

f. All annuli of comparable distinctness.

False (sub-annual) annuli were distinguished by failure to fulfil one or more of these criteria. A regression of scale length (SL: focus - posterior edge) against total length (TL) was fitted for each sex, and the difference in slope tested (d-statistic). The SL-TL regressions were used to correct TL at each annulus for each fish, the mean TL at the last annulus calculated and compared to back-calculated weighted means, the age-length curves plotted and a range of polynomial and exponential curves fitted. The slopes of log-transformed male and female regressions were compared (d-statistic). Finally, Von Bertalanffy curves were fitted (method of Rafail 1973) to the data for each sex.

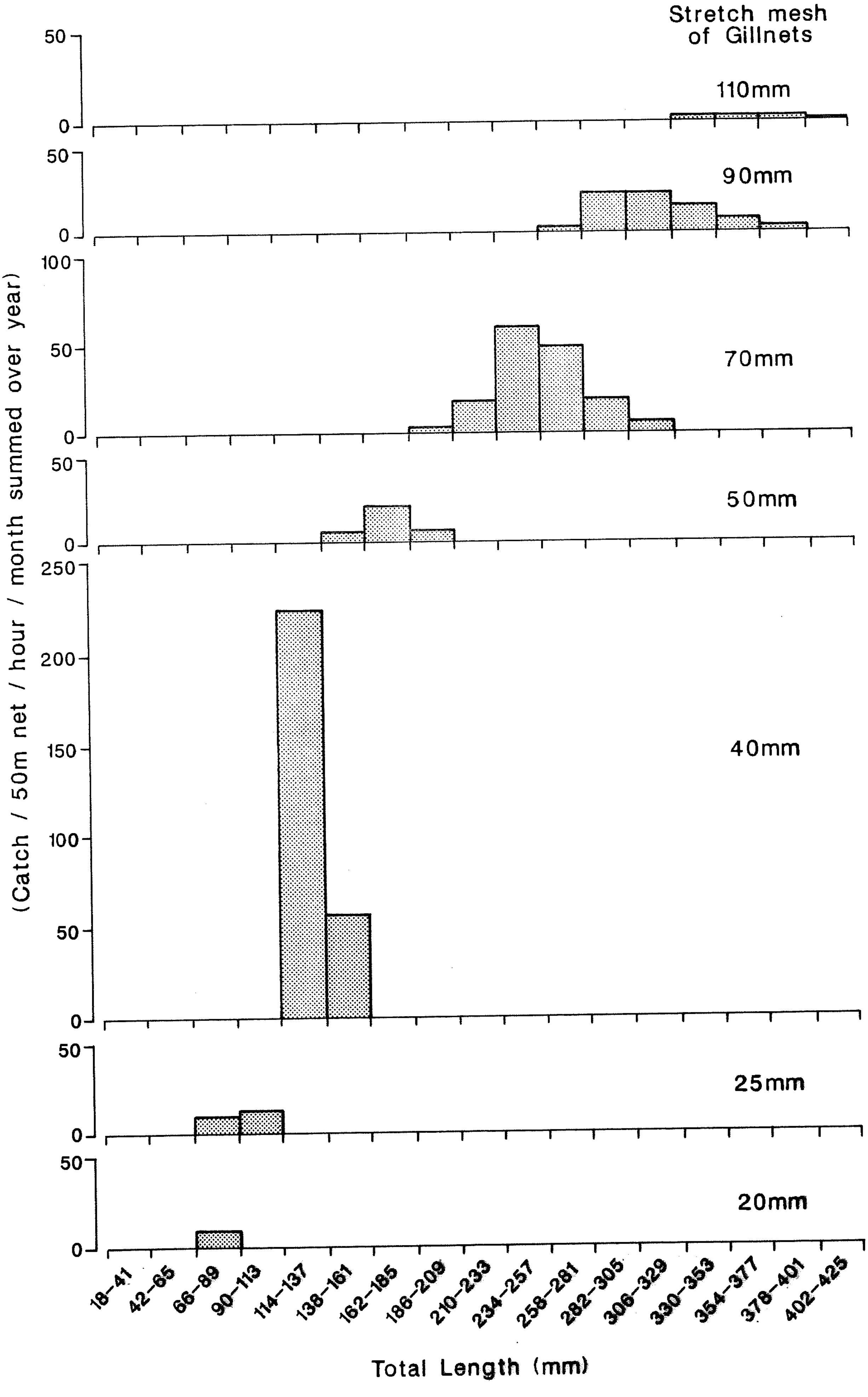
## 3. RESULTS AND DISCUSSION

### 3.1 Gear selectivity and efficiency

All length measurements are in total length (TL), but the conversion equation to length at caudal fork (LCF) for the lower Murray population is LCF = -1.406 + 0.84(TL) ($r2 = 0.997$, $P(F\text{-test})<0.001$). Gillnets are well-known for a tendency to selectivity. For a species without spines or other nettable projections, like the bony bream, catch depends largely on body cross-section (although occasional small specimens will bridle in large-mesh nets), and the gear is precisely selective. Such selectivity is obvious in frequency histograms of gillnet catch/hour/mesh size (Fig. 4). The larger mesh-sizes show ample overlap in the range of size-classes caught, but there is less overlap between the smaller mesh catches. A closer spacing of mesh sizes would have improved overlap and provided a more efficient tracking of year-classes, but this was not feasible because of financial constraints.

SELECTIVITY OF GILLNETS FOR BONY BREAM AT ZADOW'S LANDING, 1983 - 1984

Fig.4



The 2m and 18m seine nets provided adequate sampling of the young-of-year fish (Figs. 5, 6, 7) although no bony bream were caught in the 2m seine at ZL. The 130m seine could only be used at PS, where there was suitable ground, but it caught nearly all size-classes, and gave the best data for the tracking of age-classes (Fig. 8). Further, as an active method of capture, seining provided a check on the activity component in the passive gillnet captures. However, it was also labour-intensive, and during winter, catches were low.

Electro-fishing normally provides low-selectivity catches, but tests in winter gave negligible returns, and it was not considered the method could efficiently provide the size of catches necessary for the purposes of the project.

## 3.2 DISTRIBUTION AND DENSITY

Juvenile bony bream are present in all aquatic habitats of the lower Murray (Lloyd & Walker 1986), but they are not found in the cooler waters below Hume and Burrinjuck dams (Lake 1971) In the lower Murray, catch/effort of 18m seines (i.e. of juveniles) was not significantly different at the Lake Alexandrina (PS) and the river backwater (ZL) sites (paired sample t-test of log - transformed data, Fig. 9). However, catch/effort of large mesh gillnets (i.e. of adults) was significantly higher at PS (paired sample t-test of log - transformed data, $P<0.01$, Fig. 10), as was 2m seine (i.e. fry & larval) catch/effort (Fig. 11). Freshwater gizzard shads have been found to flourish particularly in warm turbid shallow lakes (Jester & Jensen 1972), and it appears bony bream may also (see also Hutchins 1977, Bishop et al. in prep., Llewellyn 1983, Puckridge 1988).

Fig.5

LENGTH-FREQUENCIES OF 2m SEINE CATCHES OF BONY BREAM AT POINT STURT, 1983 - 1984

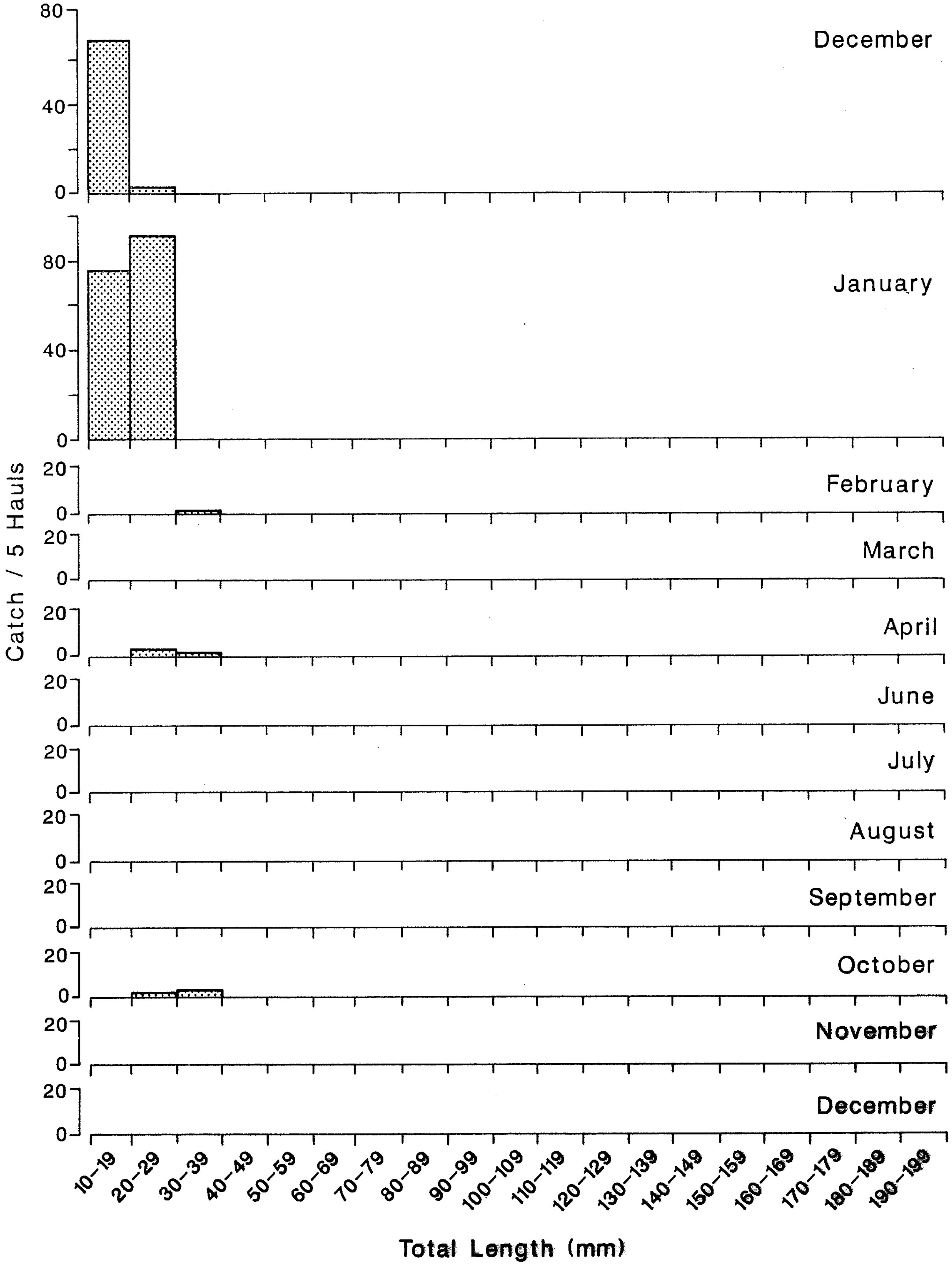


Fig.6

# LENGTH-FREQUENCIES OF 18m SEINE CATCHES OF BONY BREAM AT POINT STURT, 1983 - 1984

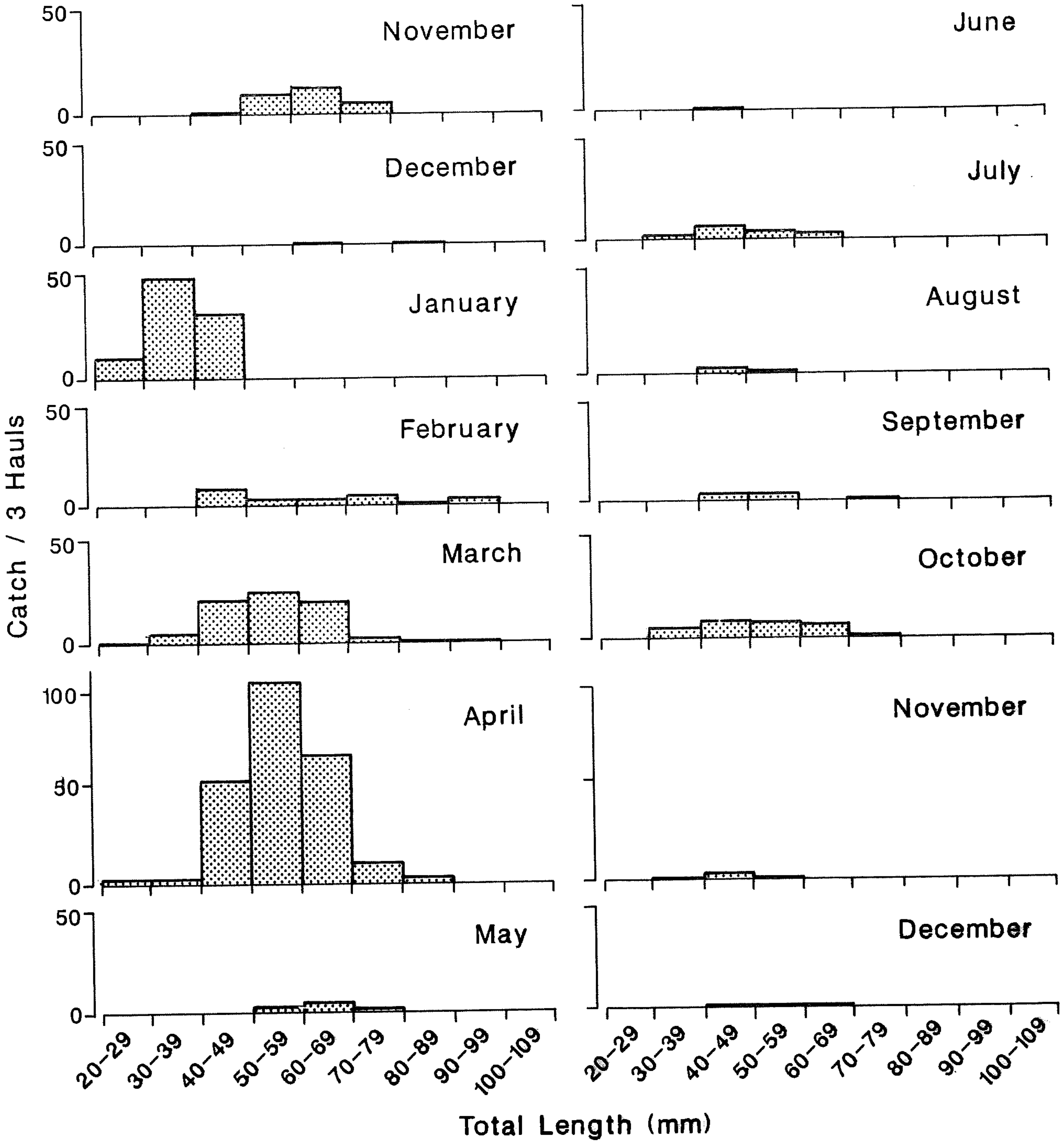


Fig.7

LENGTH-FREQUENCIES OF 18m SEINE CATCHES OF BONY BREAM
AT ZADOW'S LANDING, 1984 - 1985

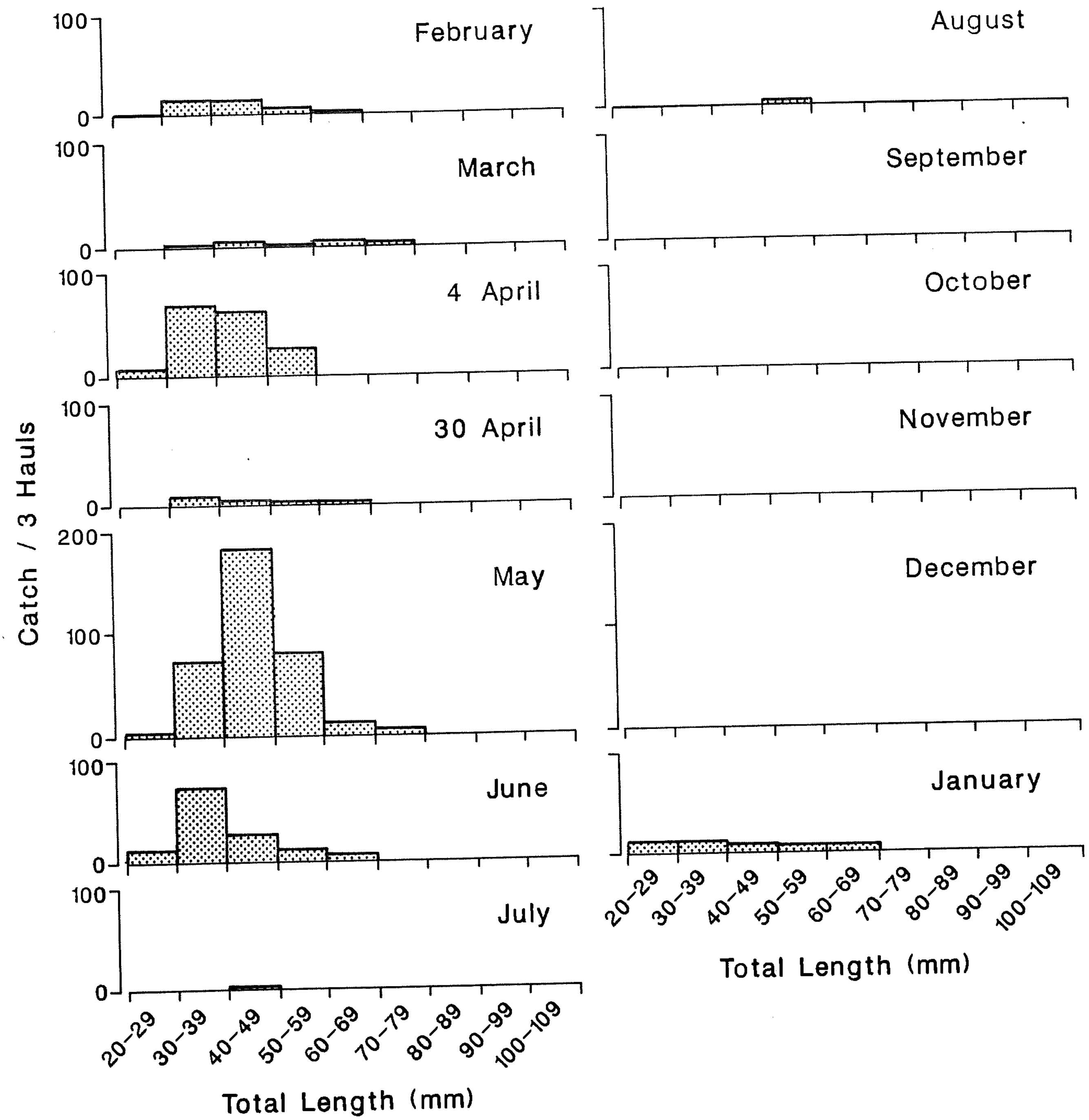
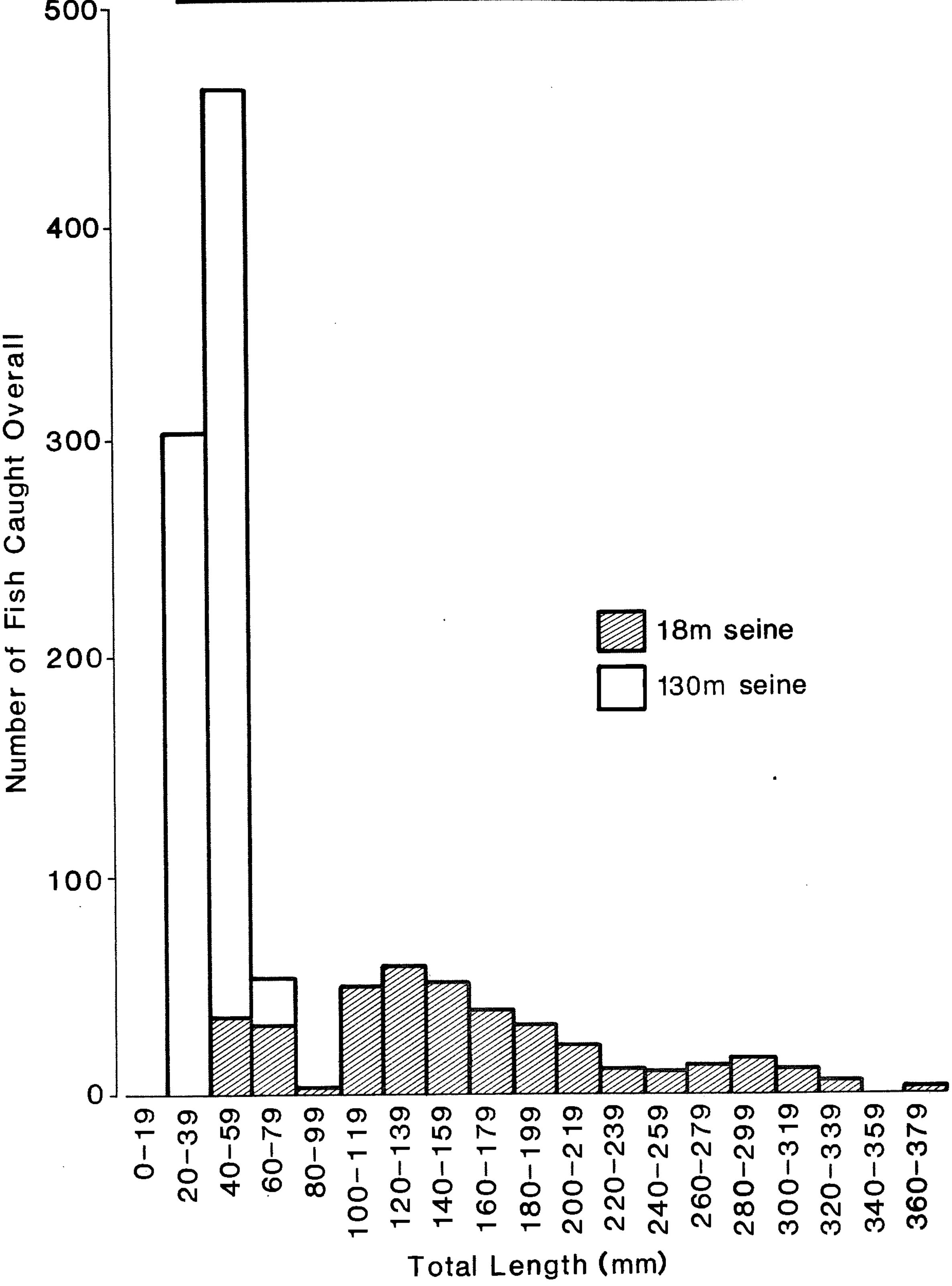


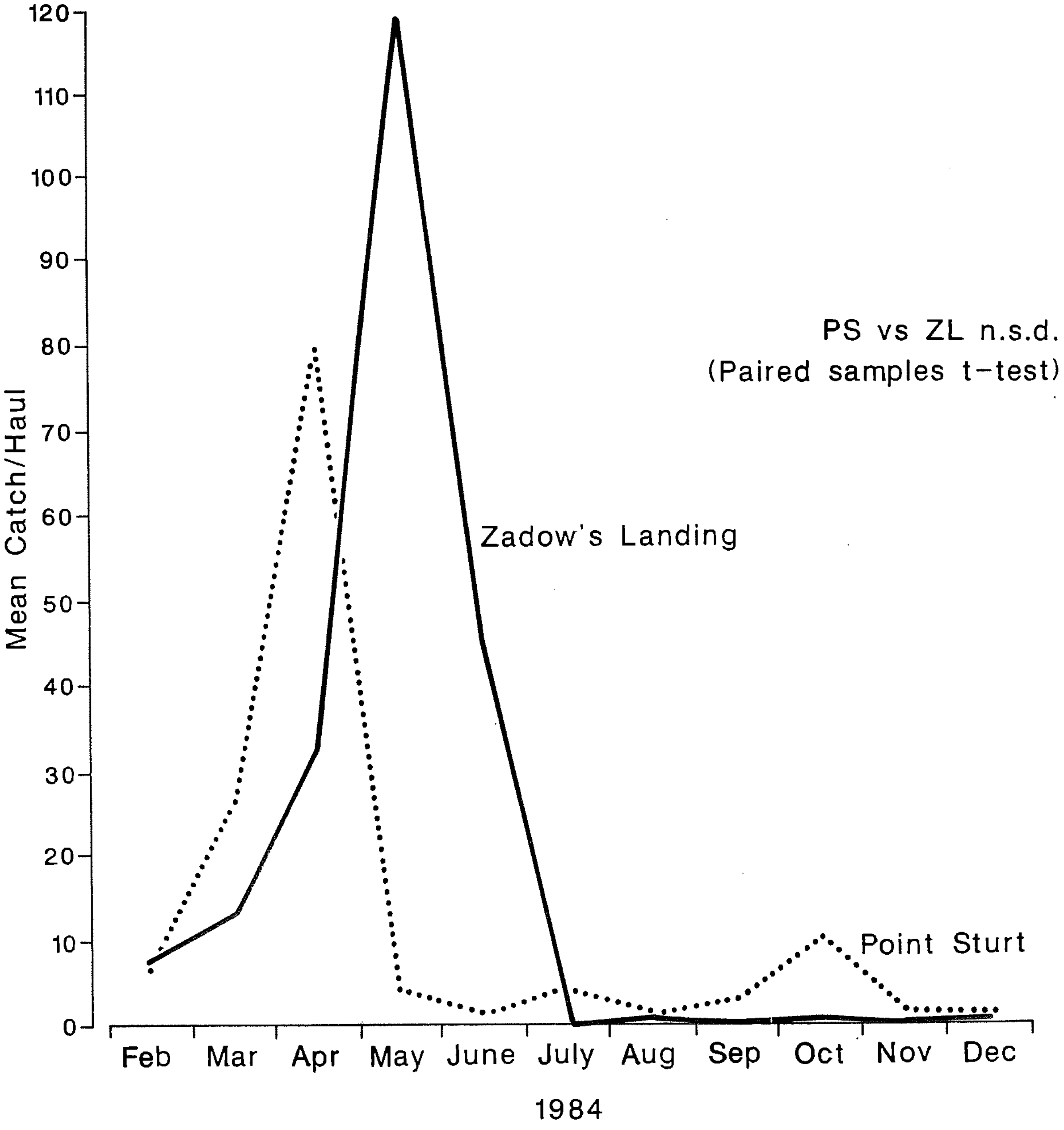
Fig.8



BONY BREAM IN THE LOWER MURRAY:
LENGTH-FREQUENCIES FOR SEINE CATCHES
- SUM OF 1984-1985

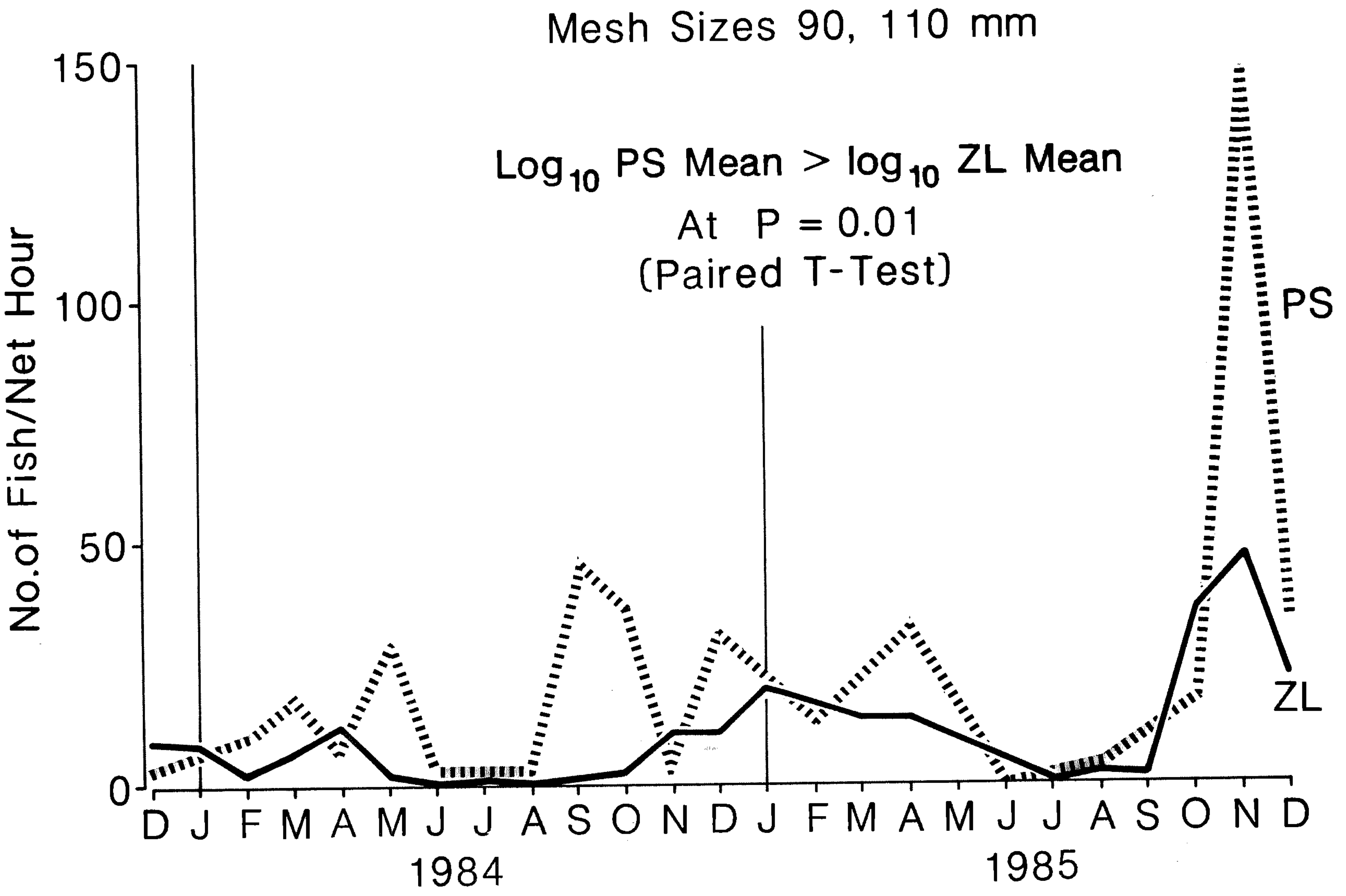
Fig.9

18m SEINE CATCH/EFFORT OF BONY BREAM AT POINT STURT AND ZADOW'S LANDING, 1984



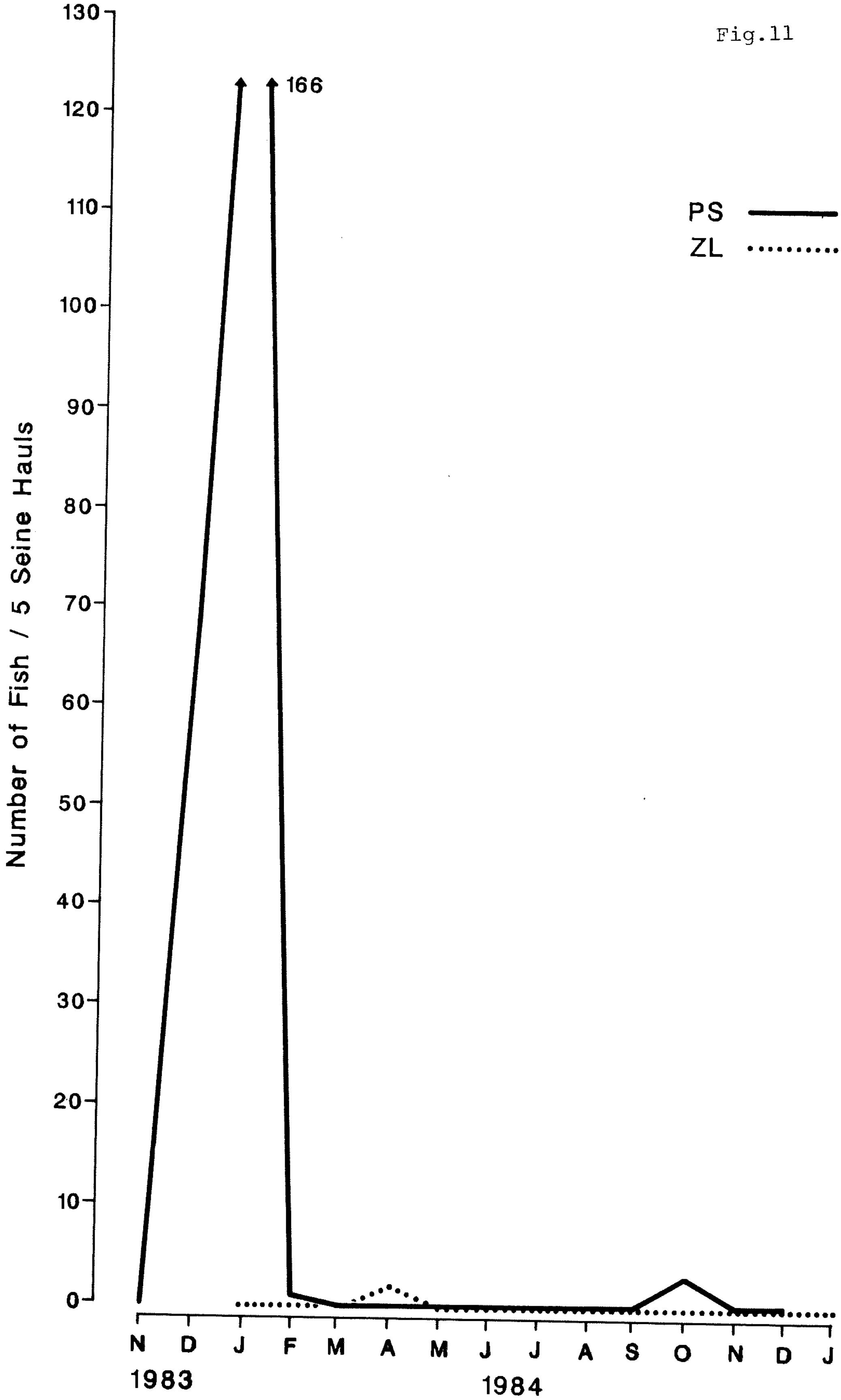
# GILLNET CATCH/EFFORT OF BONY BREAM - ZL vs PS

Fig.10



2m SEINE BONY BREAM CATCH/EFFORT - ZL vs PS
1983 - 1984

Fig.11



A strong decline in catch/effort for both gill and seine nets during winter was noticed at the margins of both the river and the lake (Fig. 12). A decrease in temperature - dependent activity during winter could be expected to reduce passive gear catch rates, but this does not explain the effects on seine catches. A similar phenomenon has been observed with American Dorosoma species in Florida (Moody 1957), and the same species are known to over-winter offshore in cool temperate habitats (Jester & Jensen 1972, Madden 1951, Pahl & Willfahrt 1962). Such behaviour in bony bream would account for the seasonality of catches. The commercial catch data gives little information on this matter, since effort is not accurately calculable per species in this multi-species fishery, and depends anyway on seasonal demand. A seasonal program of comparative offshore and onshore sampling, using trawls and echosounding, would provide relevant data.

Bony bream dominate gillnet catches in both the lower Murray and Lake Alexandrina (Table 1, Figs. 13, 14), with carp second. This is also apparent in the commercial gillnet catches, despite the fact that carp fetch a higher price than bony bream (Fig. 15). In the 1985 130m seine catches, bony bream were again dominant, but juvenile redfin Perca fluviatilis were second most abundant, principally because of a particularly strong 1984 year - class (Fig. 13). In the 18m seine catches, bony bream and smelt (Retropinna semoni) dominate both habitats, although smelt are more abundant in the lake environment (Figs. 13, 14). In the 2m seine, larval and small juvenile bony bream are dominant in the PS samples (Fig. 13), reflecting the importance of the lake as a spawning ground. The catch of larval bony bream at ZL was negligible, indicating that little breeding occurs in this river backwater habitat (Fig. 14).

# CATCH / EFFORT OF BONY BREAM AT POINT STURT AND ZADOW'S LANDING, 1983 - 1985

90 + 110mm Mesh Gillnets : Catch / 100m Net / Hour
130m Seine : Mean Catch / Haul

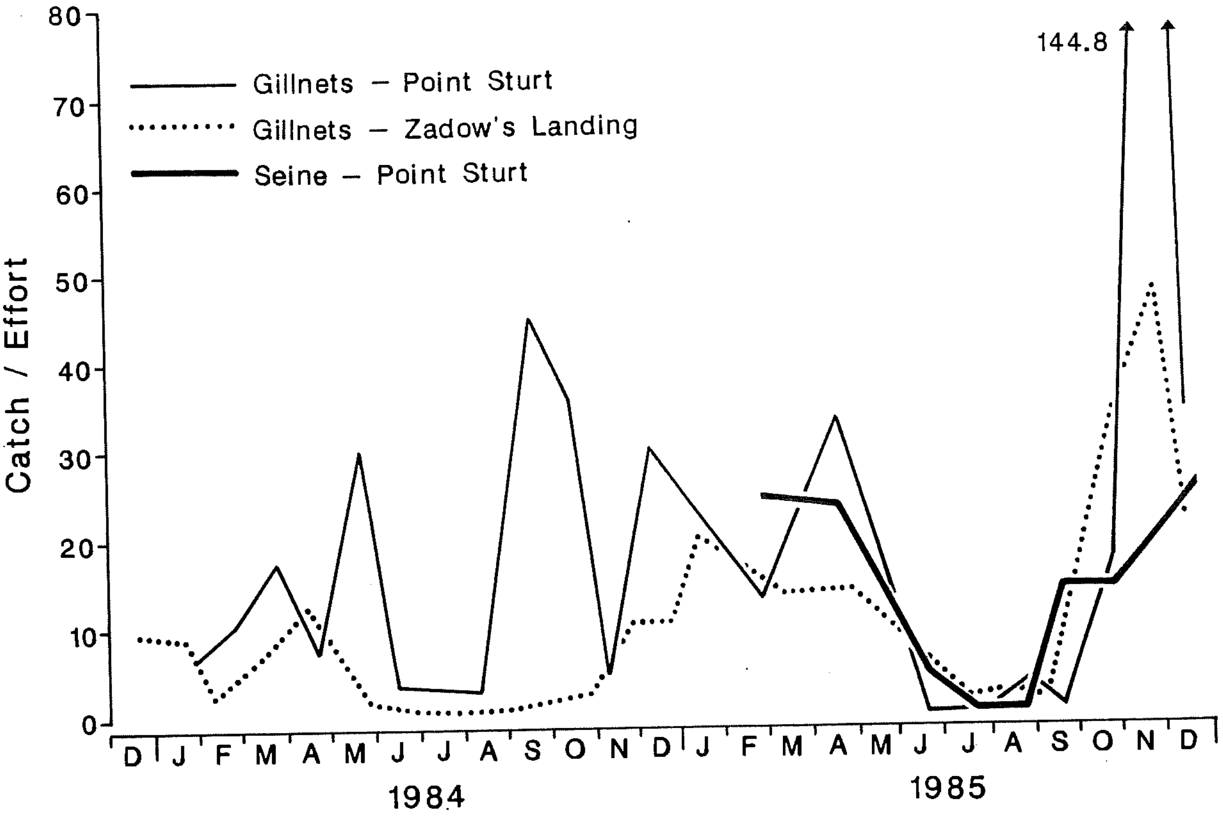


Table 1

## KEY TO SPECIES

| | | |
|---|---|---|
| BB | bony bream | *Nematalosa erebi* |
| SM | smelt | *Retropinna semoni* |
| HH | hardyheads | *Craterocephalus* spp. (*C. eyresii* & *C. stercusmuscarum*) |
| BHG | big-headed gudgeon | *Philypnodon* spp. (*P. grandiceps* & *P.* sp.) |
| CG | common galaxias | *Galaxias maculatus* |
| BG | blue - spot goby | *Pseudogobius olorum* |
| PF | redfin | *Perca fluviatilis* |
| SS | sandy sprat | *Hyperlophus vittatus* |
| CON | congolli | *Pseudaphritis urvillii* |
| MF | top minnow | *Gambusia affinis holbrooki* |
| WCG | western carp gudgeon | *Hypseleotris klunzingeri* |
| RF | crimson-spotted rainbowfish | *Melanotaenia splendida fluviatilis* |
| CAR | common carp | *Cyprinus carpio* |
| C | callop | *Macquaria ambigua* |
| GF | goldfish | *Carassius auratus* |
| SIP | silver perch | *Bidyanus bidyanus* |
| CF | catfish | *Tandanus tandanus* |
| BT | brown trout | *Salmo trutta* |

Fig.13

# SPECIES COMPOSITION OF CATCH FOR DIFFERENT GEARS AT POINT STURT, 1983 - 1985

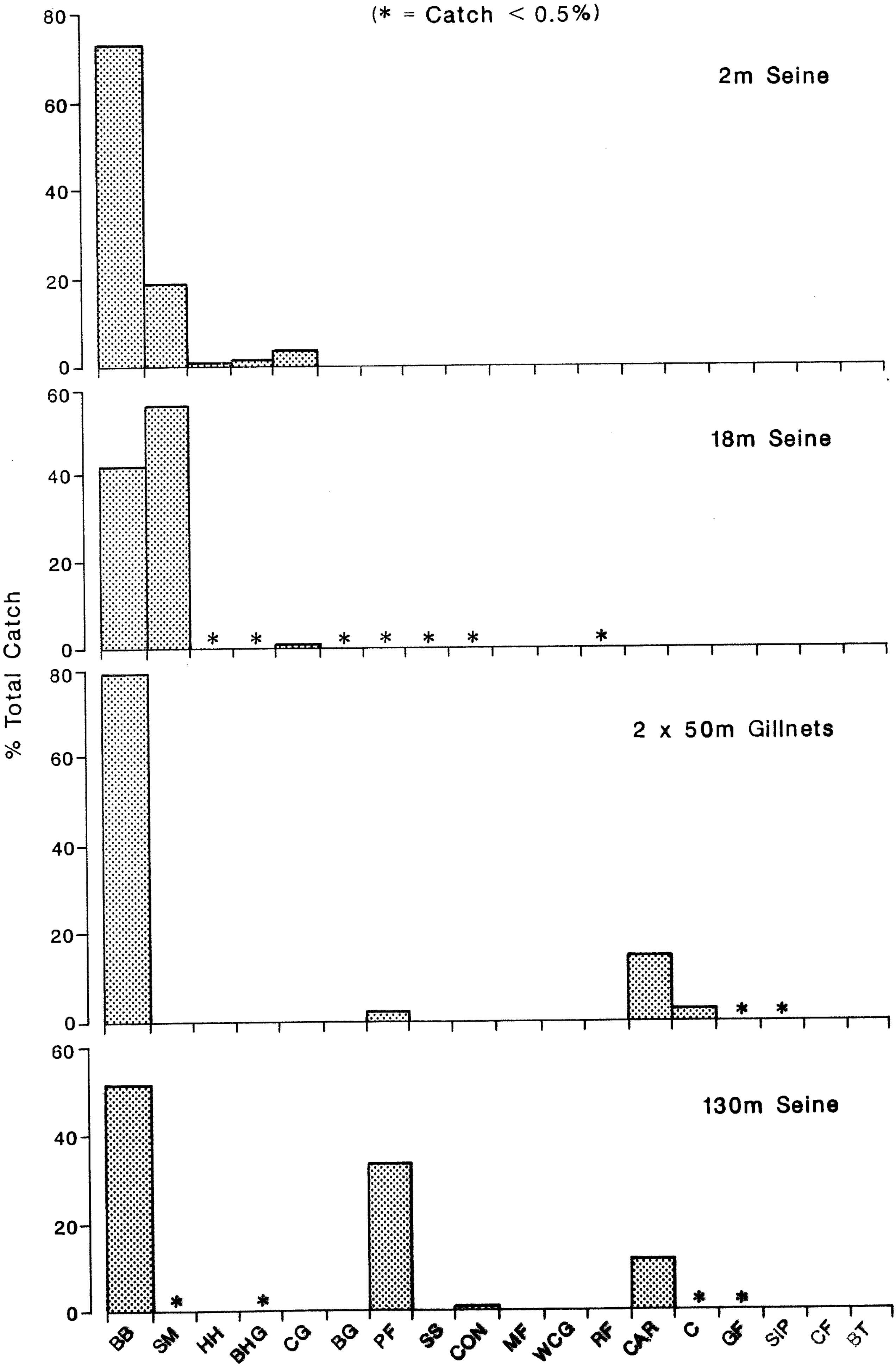
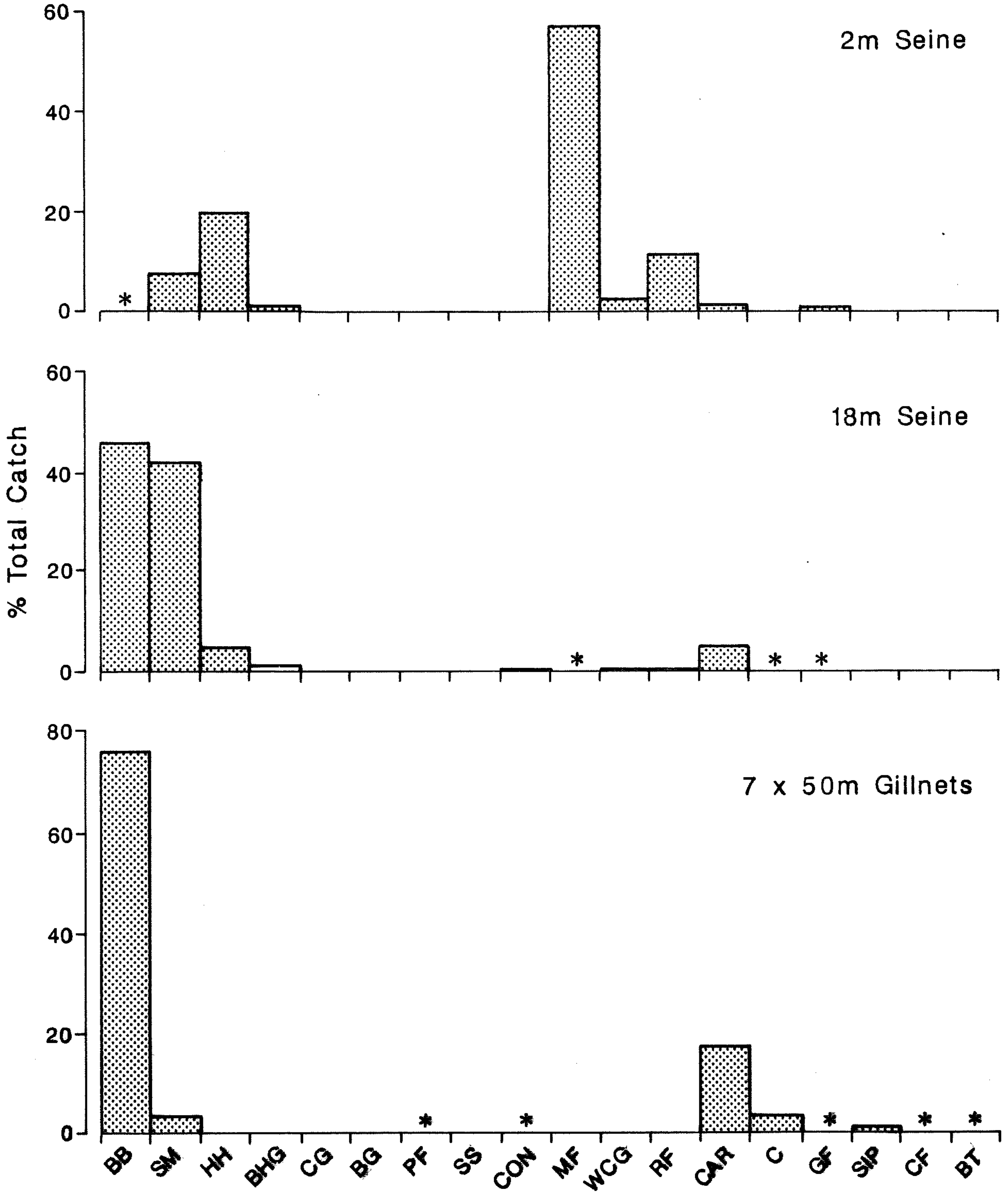


Fig.14

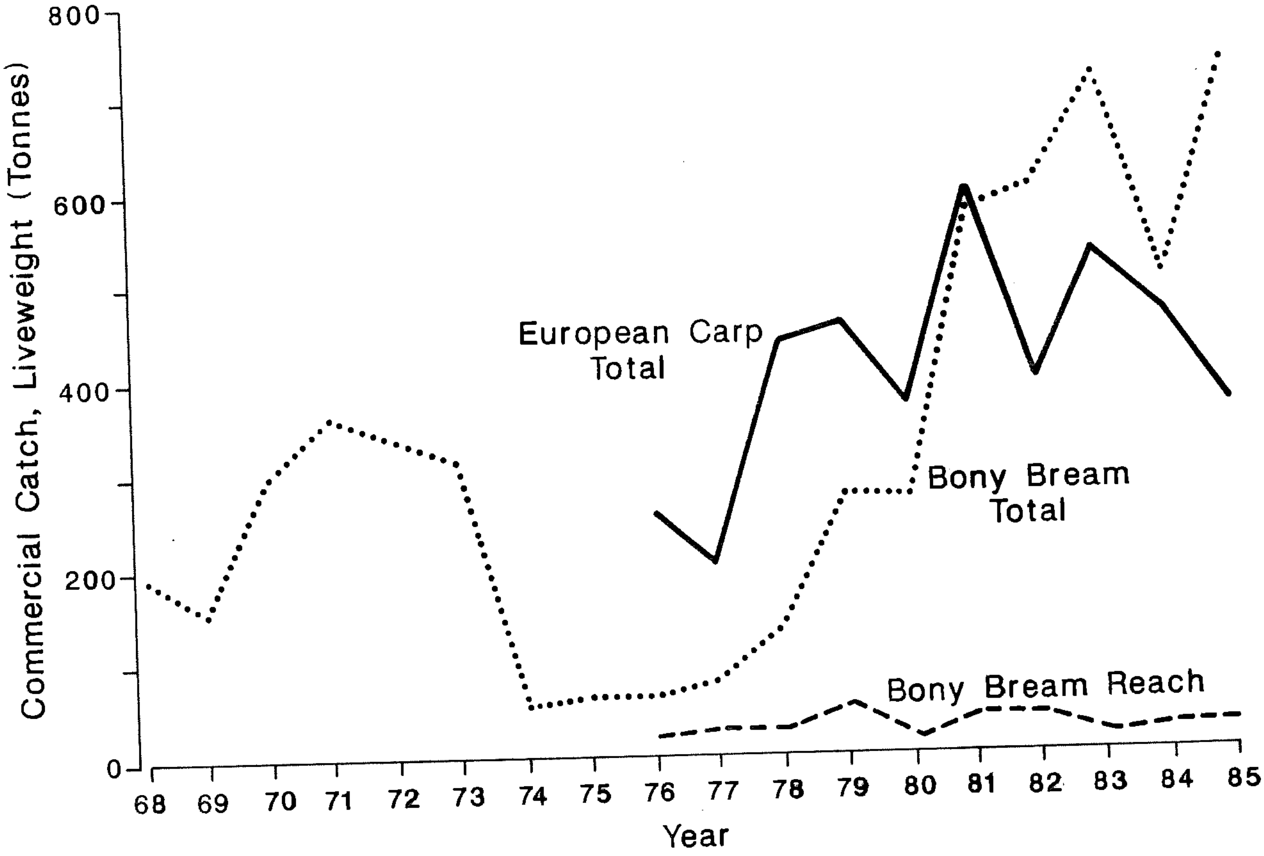
SPECIES COMPOSITION OF CATCH FOR DIFFERENT GEARS
AT ZADOW'S LANDING, 1983 - 1984

(* = CATCH < 0.5%)



# BONY BREAM (REACH AND TOTAL CATCHES) AND EUROPEAN CARP (TOTAL CATCHES)

(S.A. Department of Fisheries)



## 3.3 Reproduction

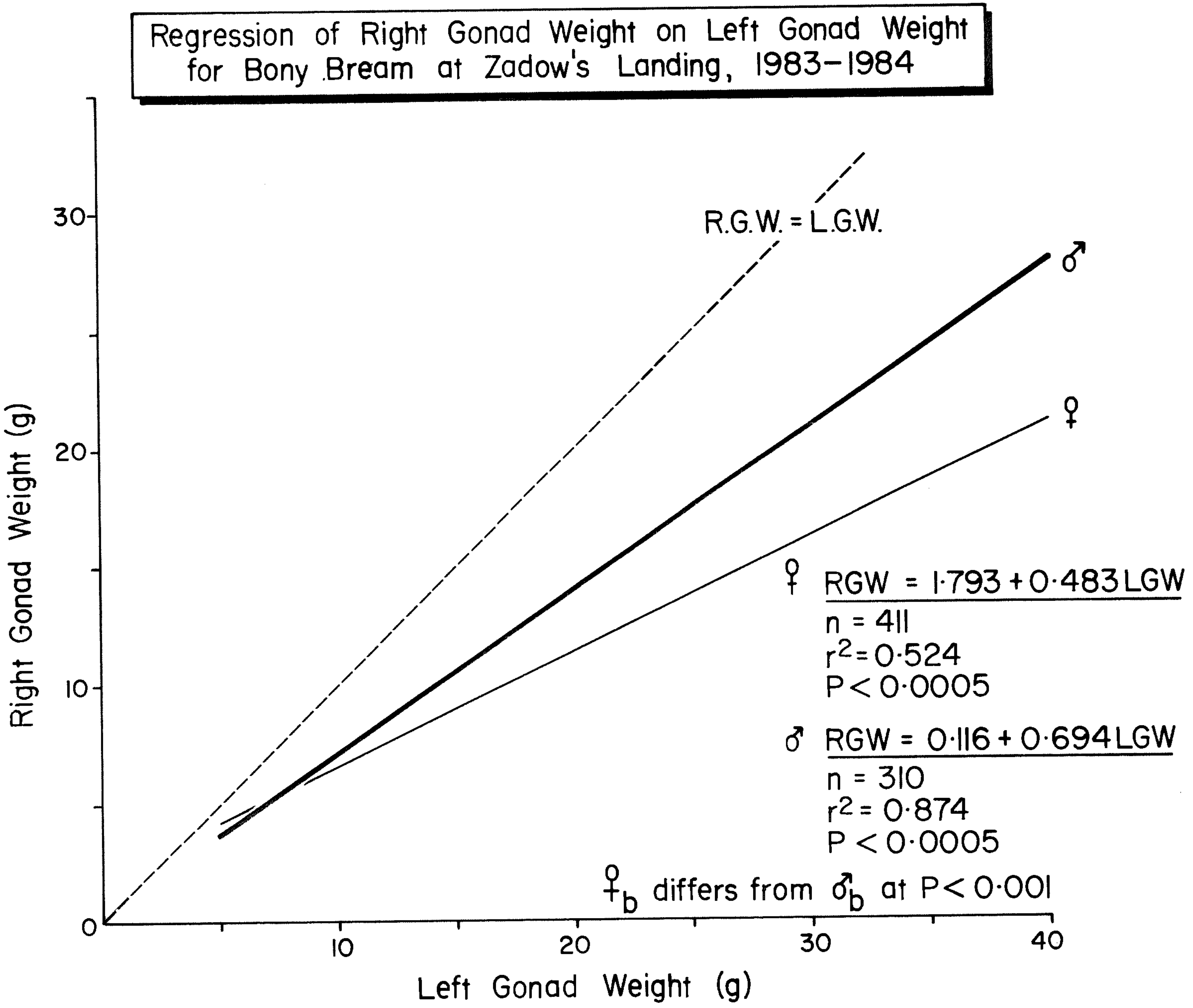
### 3.3.1 Gonad morphology

Gonads of both sexes are elongate (2/3 the length of the body cavity even in immature individuals), enclosed in the peritoneum (and sometimes encased in fat deposits) and opening externally through short paired gonadal ducts. The left lobe is commonly larger in both sexes but is more markedly so for females. Figure 16 indicates the extent of departure from gonad symmetry in regressions of right against left gonad weights. Such assymetry is not uncommon in fishes, and has been recorded for other gizzard shads (Jacob 1948). Since gonad width is linearly related to gonad weight at a high level of significance (Fig. 17), a more convenient alternative to GSI for depiction of seasonal cycles could be provided by an index based on gonad width, which would do away with dissecting and weighing.

### 3.3.2 Seasonal cycle

In 1983-85, GSI at ZL showed a clear seasonal cycle, with a peak in November at water temperatures of 19-20 C (Fig. 18), at a day-length of 14 hrs (Fig. 19) and 0-2 months after the flood peak (Fig. 20). The pattern was identical in its timing (at a monthly resolution) for males and females and for different size-classes (Figs. 21, 22). The ZL pattern was repeated at PS (Figs. 23, 24). However, the peak log 10 female GSI was significantly higher than at ZL (paired samples t-test, P<0.01), which may indicate that the lake is a nutritionally superior environment (Fig. 25). There is some indication of a direct temperature effect on spawning, with a delay in the decline of GSI evident at PS in 1985, when water temperature rise was also delayed (Fig. 23). Flooding is not an essential cue to spawning, as the species is known to spawn in isolated

Fig.16



Regression of Right Gonad Weight on Left Gonad Weight for Bony Bream at Zadow's Landing, 1983–1984

Fig.17

Regression of $\text{Log}_{10}$ Gonad Width (G.W.) on $\text{Log}_{10}$ Gonad Weight (TGWT) for Bony Bream at Zadow's Landing, 1983–1984

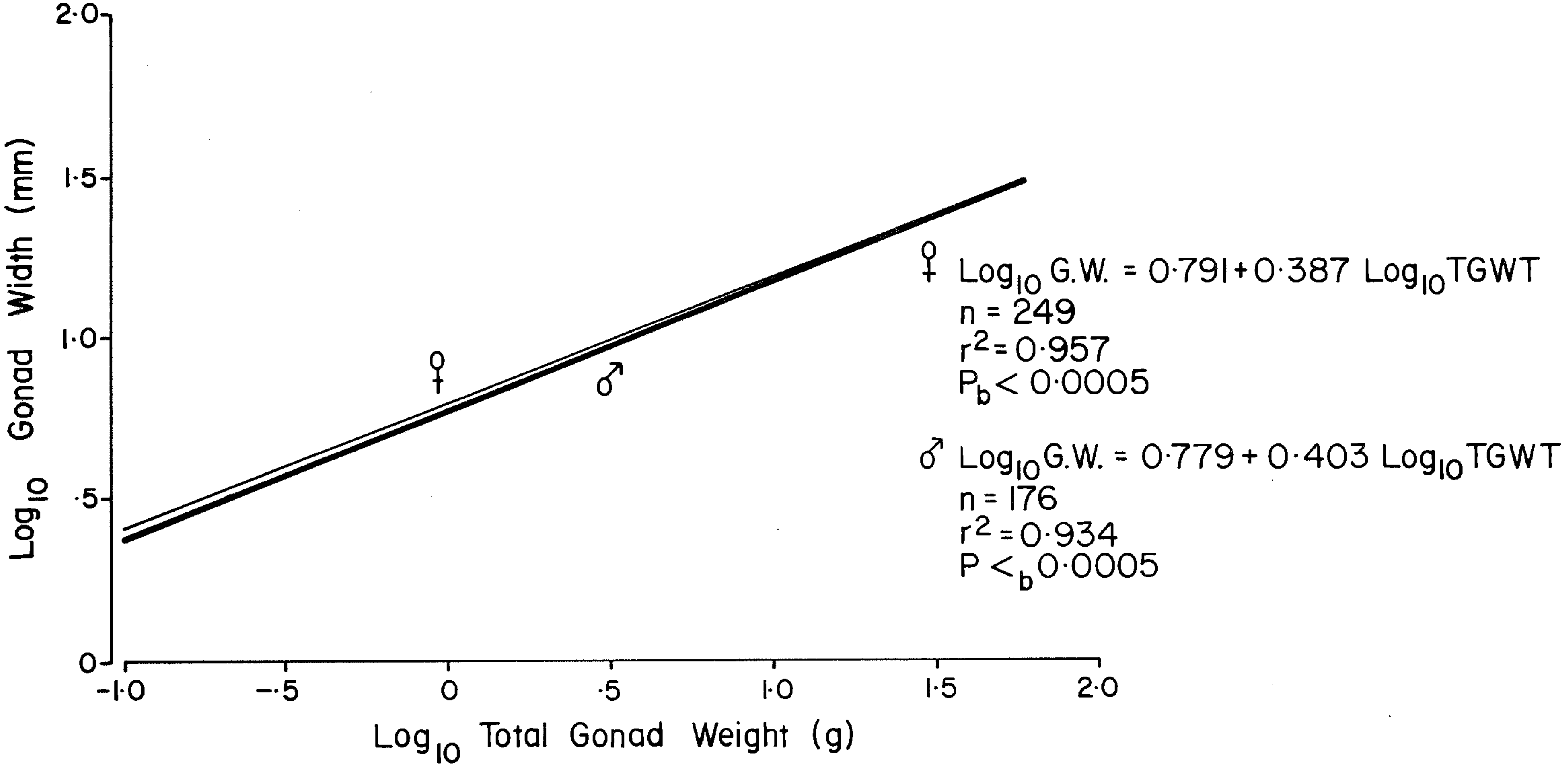


Fig.18

BONY BREAM GSI (ZL) vs WATER TEMPERATURE (MANNUM)

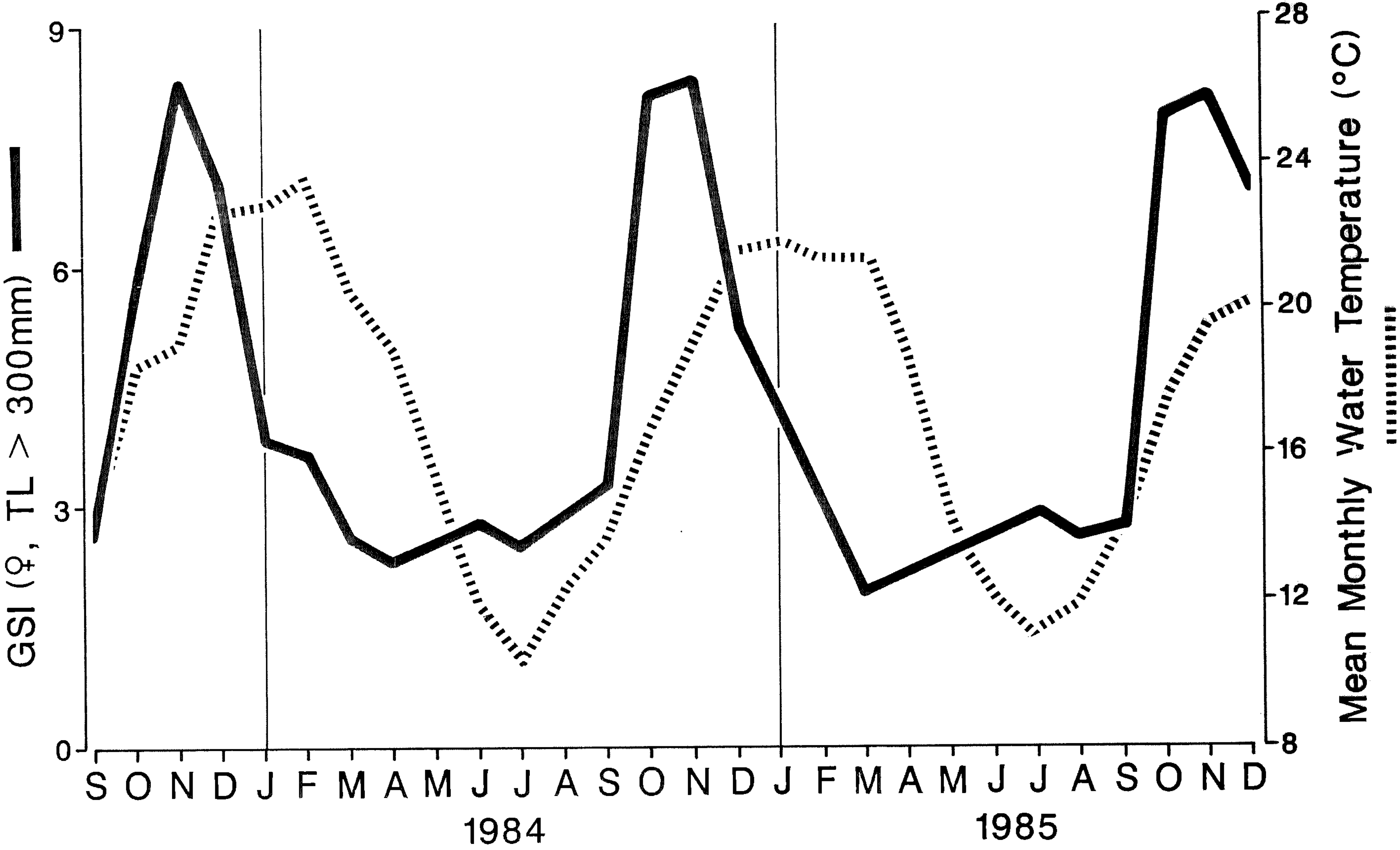


Fig.19

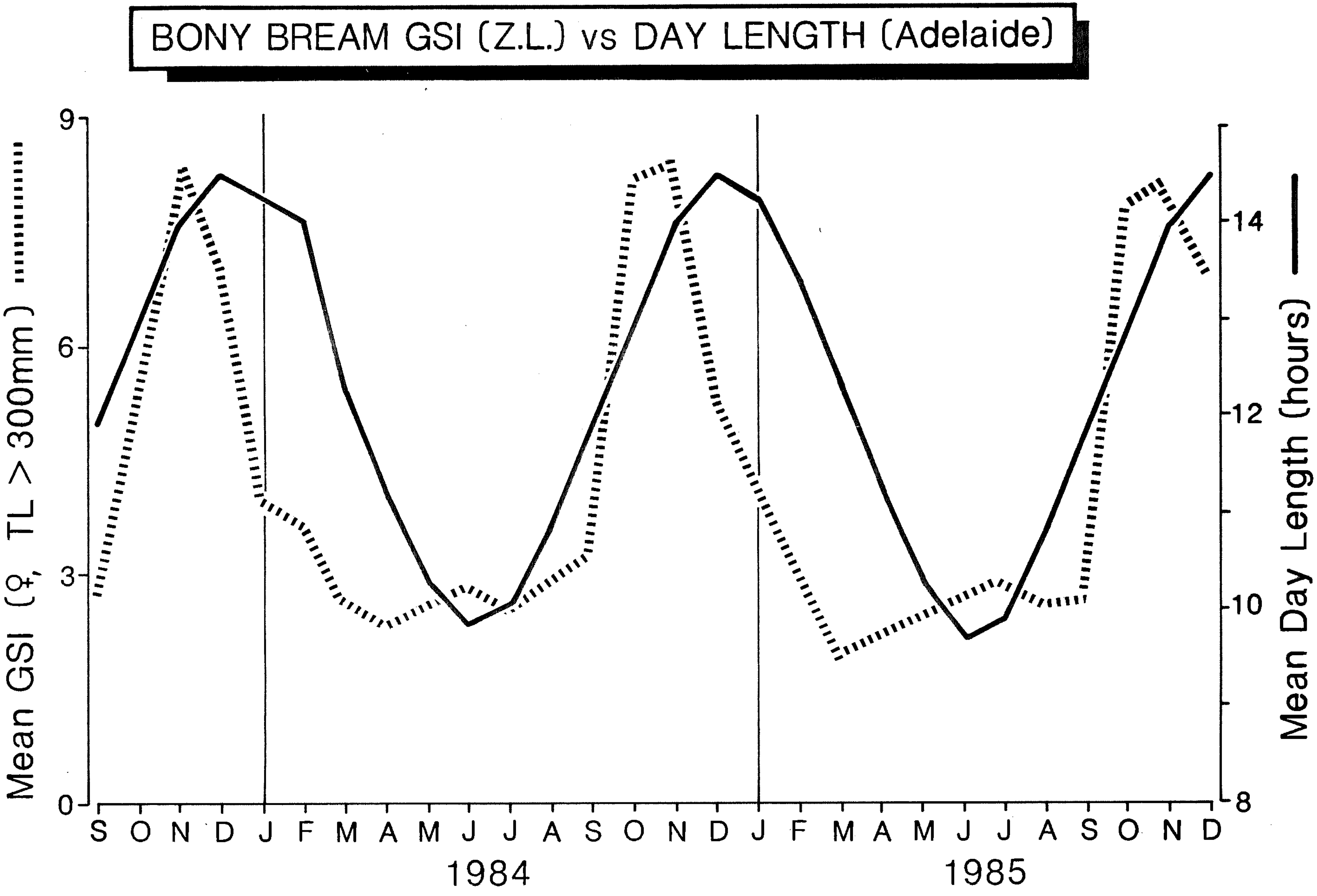

BONY BREAM GSI (Z.L.) vs DAY LENGTH (Adelaide)
Mean GSI (♀, TL > 300mm)
Mean Day Length (hours)
0
3
6
9
8
10
12
14
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1984
1985

Fig.20

BONY BREAM GSI (ZL) vs MURRAY DISCHARGE (LOCK 1)

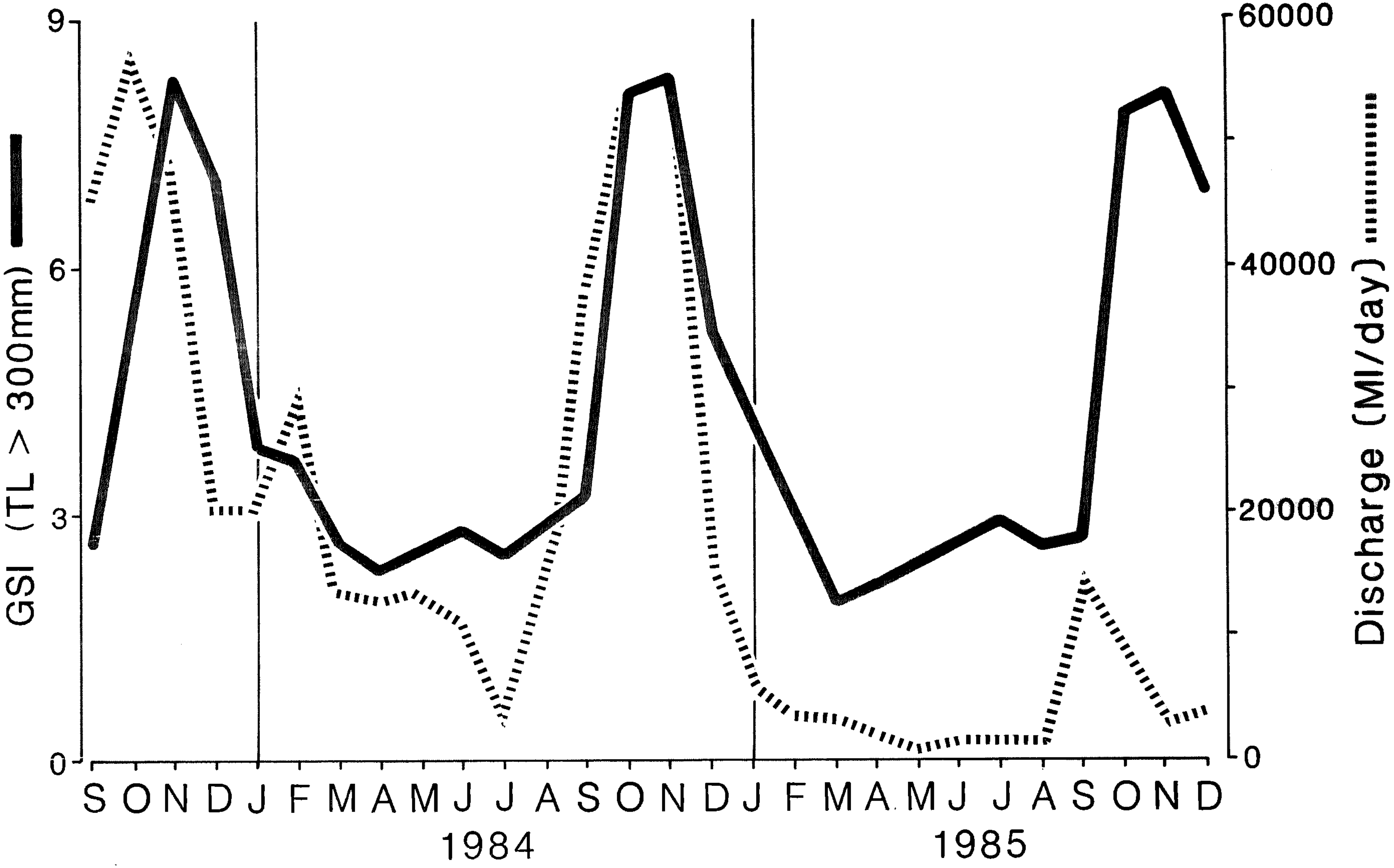


Fig.21

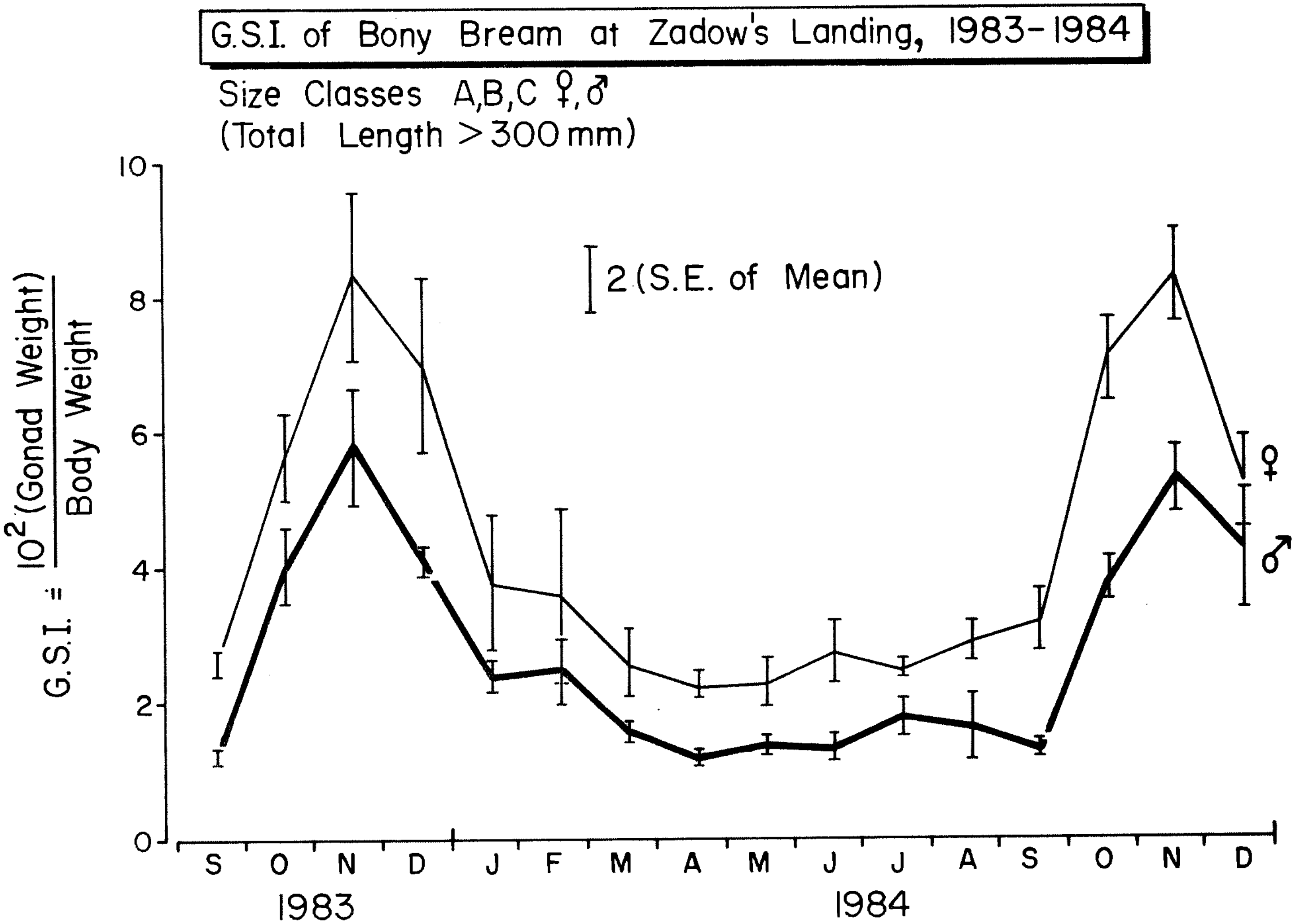

G.S.I. of Bony Bream at Zadow's Landing, 1983-1984
Size Classes A,B,C ♀,♂
(Total Length > 300 mm)
2 (S.E. of Mean)
G.S.I. = 10² (Gonad Weight) / Body Weight
0
2
4
6
8
10
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1983
1984
♀
♂

Fig.22

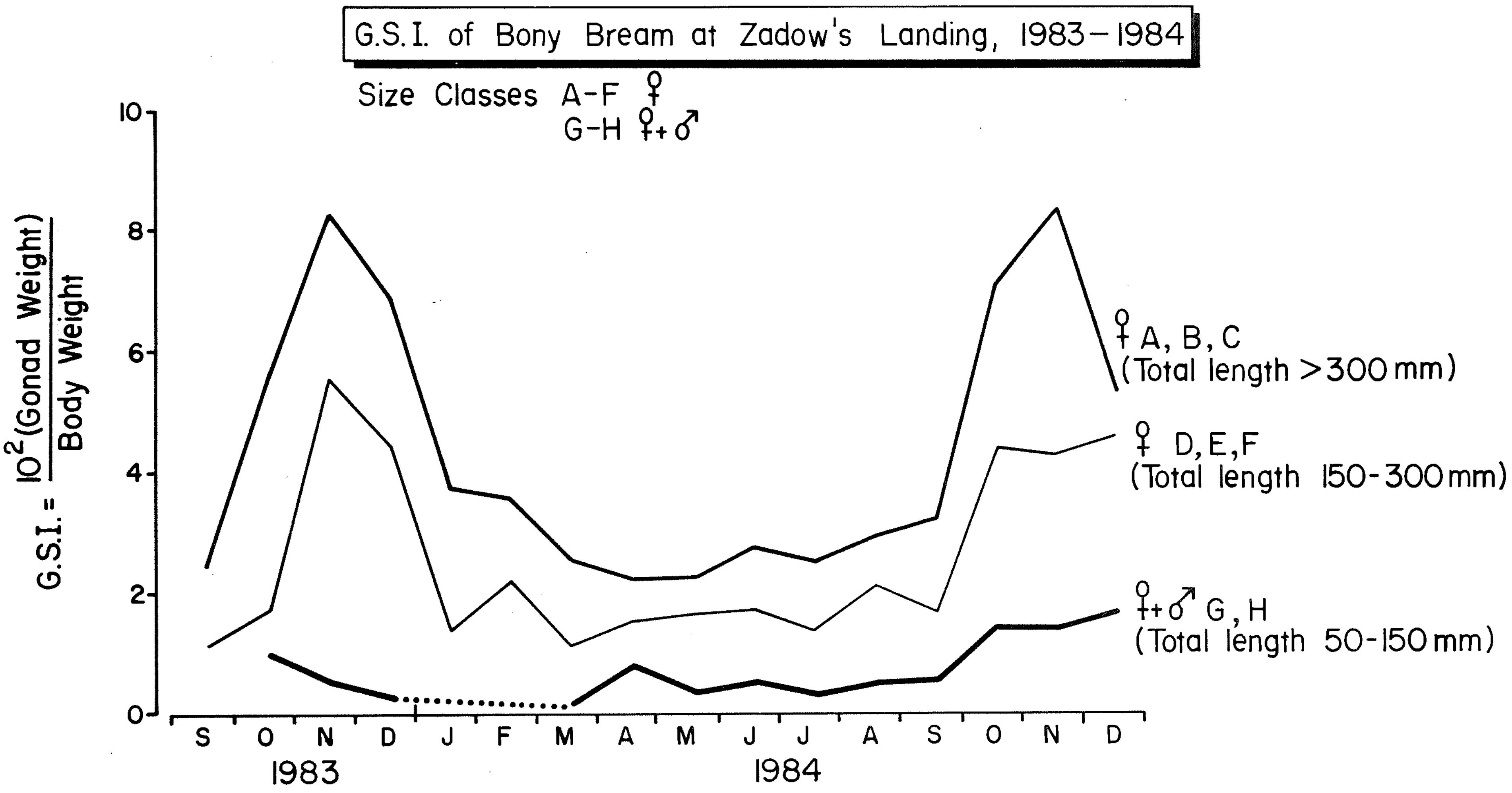

G.S.I. of Bony Bream at Zadow's Landing, 1983–1984
Size Classes A–F ♀
G–H ♀+♂
G.S.I. = 10²(Gonad Weight) / Body Weight
10
8
6
4
2
0
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1983
1984
♀ A, B, C
(Total length >300 mm)
♀ D, E, F
(Total length 150-300 mm)
♀+♂ G, H
(Total length 50-150 mm)

Fig.23

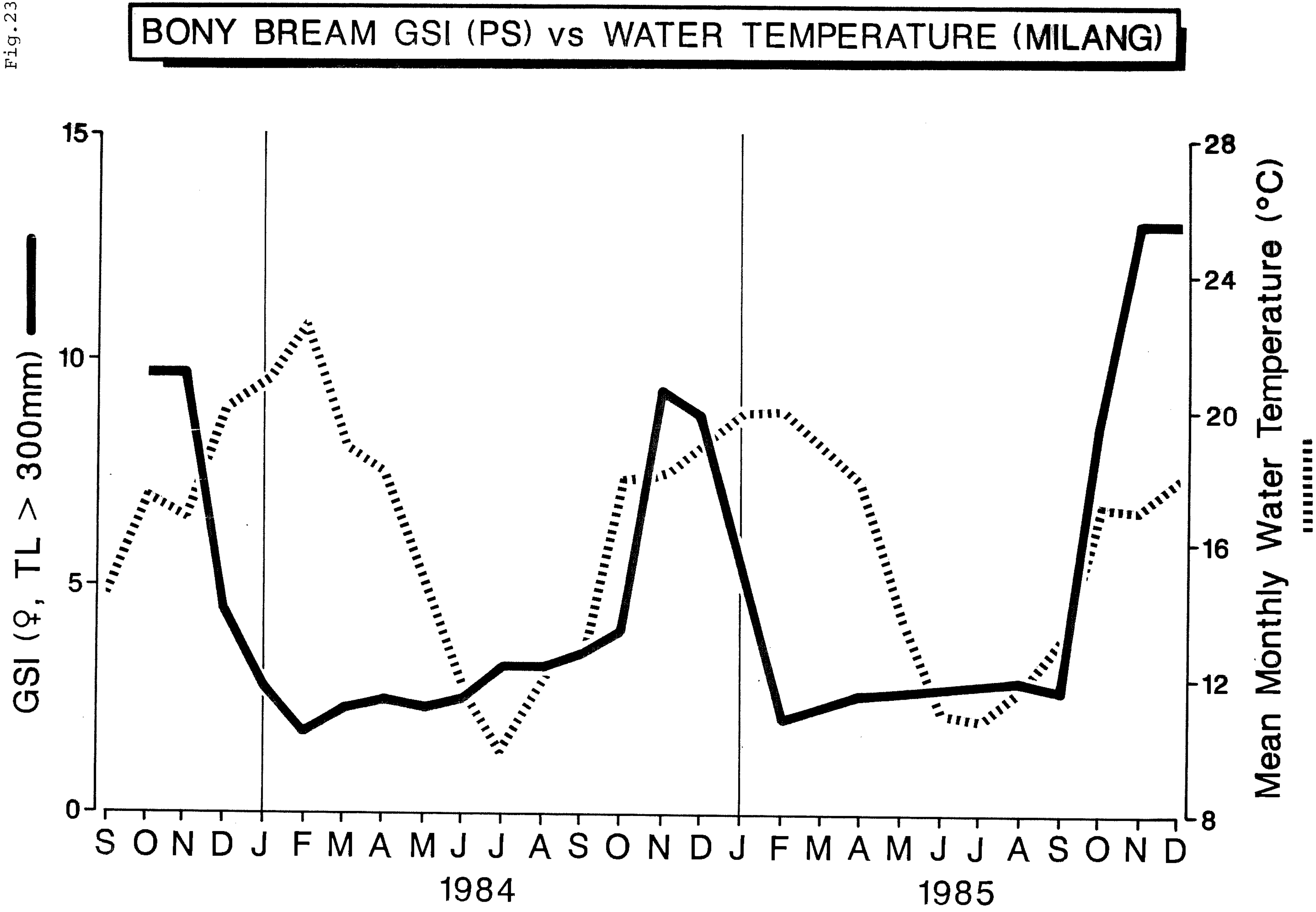

BONY BREAM GSI (PS) vs WATER TEMPERATURE (MILANG)
GSI (♀, TL > 300mm)
Mean Monthly Water Temperature (°C)
15
10
5
0
28
24
20
16
12
8
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1984
1985

Fig.24

G.S.I. of Bony Bream at Point Sturt, 1983–1984

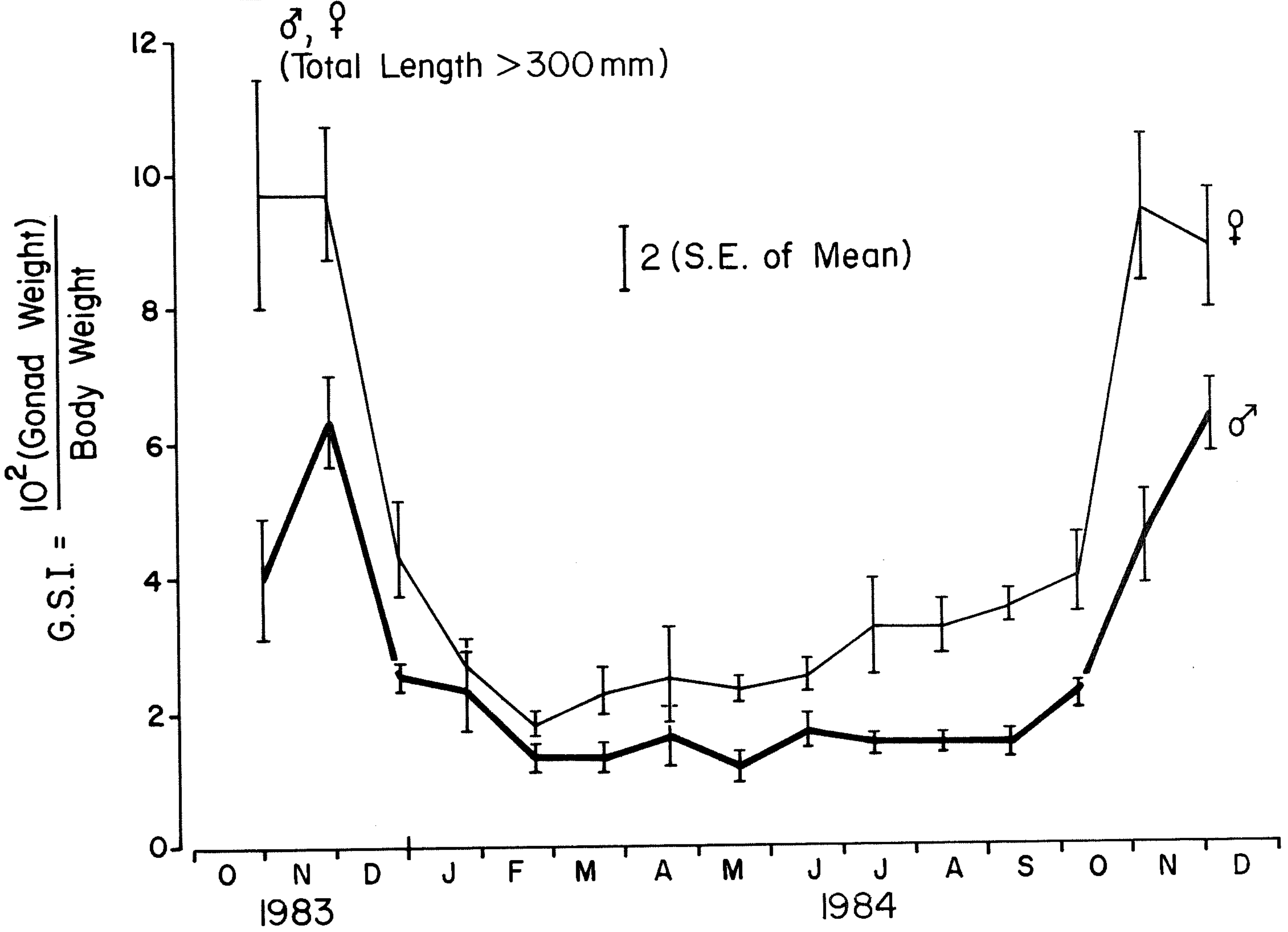
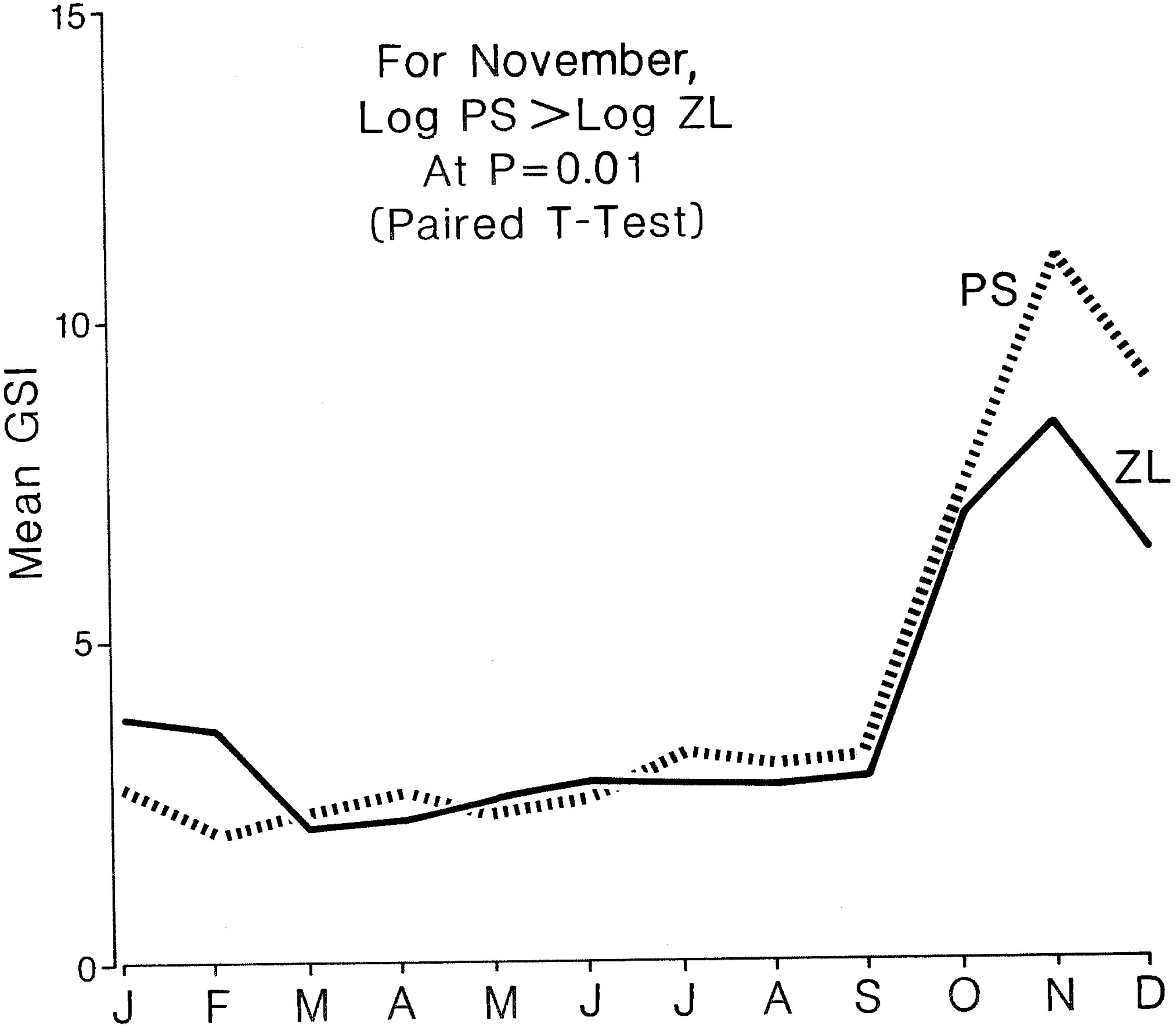


Fig.25

BONY BREAM GSI - ZL vs PS

Means of 1983-1985
(♀, TL<300mm)



water-bodies (Lake 1971), and there is no obvious adjustment of the GSI cycle to flood timing (Fig. 20), but flooding may greatly enhance recruitment through its effects on food supply (Puckridge 1988).

The appearance of the gonads at different stages in this cycle is described in Table 2. The major stages show those features widely recognized as diagnostic for stages of fish gonad development (Pollard 1972), and closely match the staging based on gonad histology described for a bony bream cogener, the perth herring, Nematalosa vlaminghi (Chubb & Potter 1984). The cycle suggests that vitellogenesis begins in mid-Spring (September-October), maturity is attained in November - December, and spawning occurs in December-February.

Ovum diameter frequency analysis confirms the above pattern (Fig. 26). From the background of primary oocytes (mean diam. = 104 um), vitellogenic ova (diam. >250 um) appear first in substantial numbers in September, and reach a pre-spawning size (mean diam. = 507 um) in November. In December, spawning begins depletion of this batch of mature eggs, and this depletion is substantially completed in January. Since only one batch of ova separates from the reservoir of primary oocytes during the cycle, it may be assumed that serial spawning is not important in the species. Nematalosa nasus, N. vlaminghi and Dorosoma cepedianum also appear to normally spawn only one batch of oocytes per season (Annigeri 1967, Baglin & Kilambi 1968, Chubb & Potter 1984), although Anodontostoma chacunda and D. cepedianum may undergo a second minor spawning in bony bream, the presence of mature - size oocytes in some individuals much later in the year (March, July and August) suggests either incomplete atresia or a capability for opportunistic spawning. Bony bream in tropical habitats certainly show more pronounced spawning aseasonality, with a peak in the early-wet

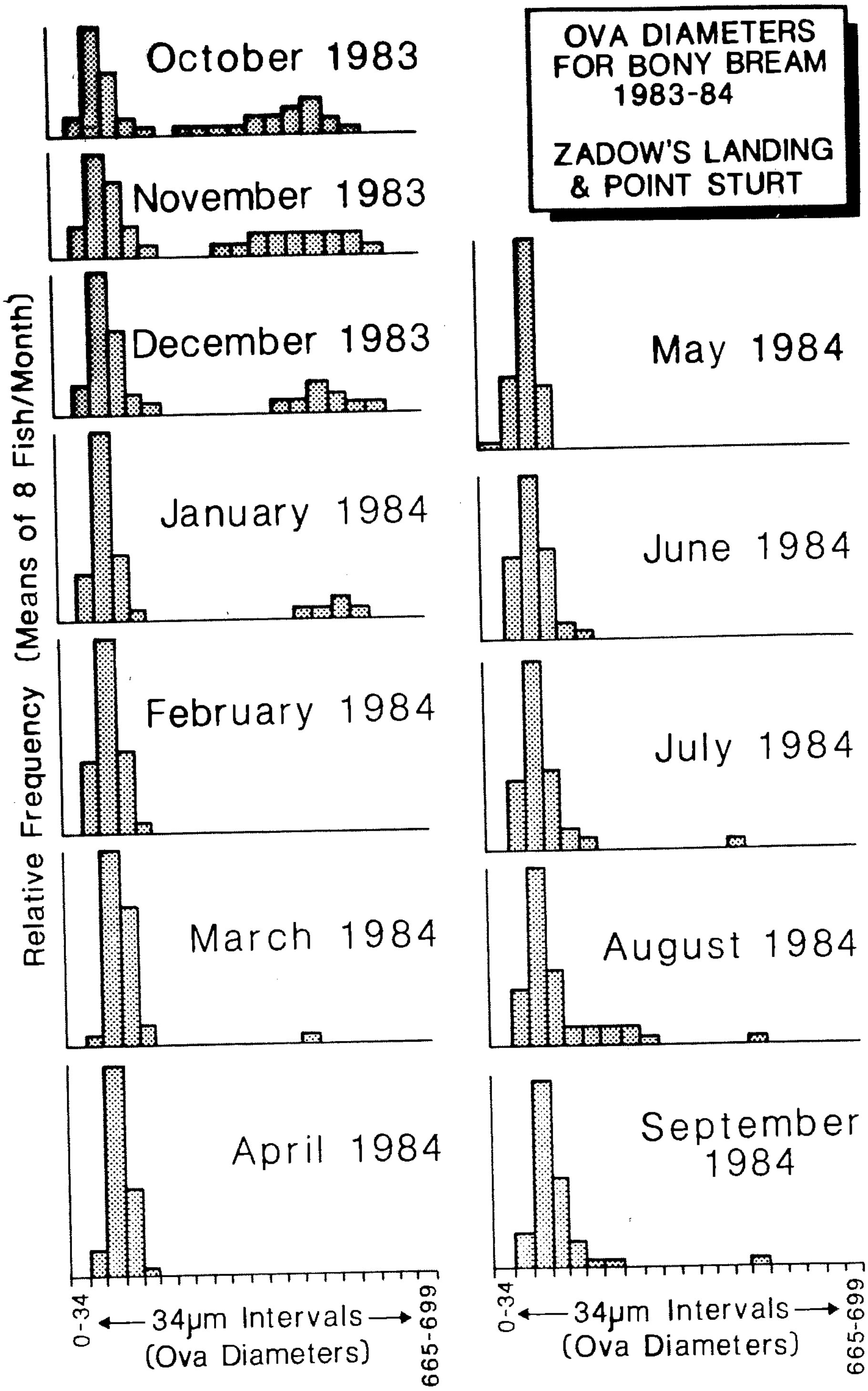
Table 2

## GONAD STATES OF *NEMATALOSA EREBI*, THE BONY BREAM, IN THE LOWER MURRAY 1983-84

| STAGE | SEX | INTERVAL | APPEARANCE | LENGTH /BODY CAVITY |
|---|---|---|---|---|
| virgin | F | | grey, translucent thin strips | 2/3 |
| | M | | colourless to grey-white thin strips | " |
| maturing virgin | F | Apr. - Aug. | pink-grey, translucent, firm | 3/4 |
| | M | " | creamy-pink, opaque firm | " |
| Recovering spent/ Developing | F | Apr. - Sep. | orange-pink, translucent, firm, quilted | 4/5-1.0 |
| | M | " | creamy-pink, firm, smooth, opaque | " |
| Mature | F | Oct. - Dec. | yellow-orange, bloodshot, granular, opaque, quilted, distended | 1.0 |
| | M | " | creamy-white, turgid, blocky | " |
| Ripe (gonad products exuded on pressure) | F | Dec. - Jan. | translucent in patches, light yellow, quilted, distended, ova distinct | 1.0 |
| | M | " | creamy-white, turgid, blocky | " |
| Spent | F | Dec. - Mar. | grey-pink, watery,semi-translucent, flaccid | 1.0 |
| | M | " | pink to dark pink, bruised, flaccid | " |

NOTE: Appearance is in situ; colours differ when gonads are dissected free of the peritoneum.

Fig.26



OVA DIAMETERS FOR BONY BREAM 1983-84

ZADOW'S LANDING & POINT STURT

(Bishop et al. in prep.). Bony bream in the present study were occasionally found with hardened egg-masses, suggestive of incomplete atresia.

### 3.3.3 Spawning

No spawning event was observed in the wild or in stocked ponds. Spawning may occur at night, as for D. cepedianum (Shelton 1972). Attempts to strip and artificially fertilize ova from running ripe fish were unsuccessful, partly because fertilized ova are very fragile, but principally because female fish were very rarely encountered in running ripe condition. Most males however were in this condition throughout the breeding season, as are male D. cepedianum (Johnson 1971). Ichthyoplankton trawling at two river (W, ZL) and two lake sites (PS, F) through the breeding season, collected substantial numbers of ova only off a sandy shore west of PS in early February (Fig. 27). This timing was slightly later than one would expect from the 1983-84 ODF and GSI cycles, but as shown above (Fig. 23), the temperature rise at PS in late 1985 was delayed, and GSI remained high through December, suggesting a late (January) spawning. Catch/effort of bony bream larvae was higher at this site than at either of the river sites (Fig. 28), or at the other lake site, which had dense submergent macrophyte growth. No other sites yielded catches of ova. This suggests that open sandy lake shallows may be preferred spawning habitat; there is no evidence of association of spawning with macrophyte beds, as in D. petenense (Gerdes & McConnell 1963). The result also reinforces the above evidence indicating a preference of bony bream for lake environments. However, in the N.S.W. Murray-Darling, spawning occurs in schools in shallow backwaters (Llewellyn 1983), and in the Magela Creek, N.T., spawning

Fig.27

# BONY BREAM - EGGS AND LARVAE IN PLANKTON HAULS

Point Sturt, 1985-1986

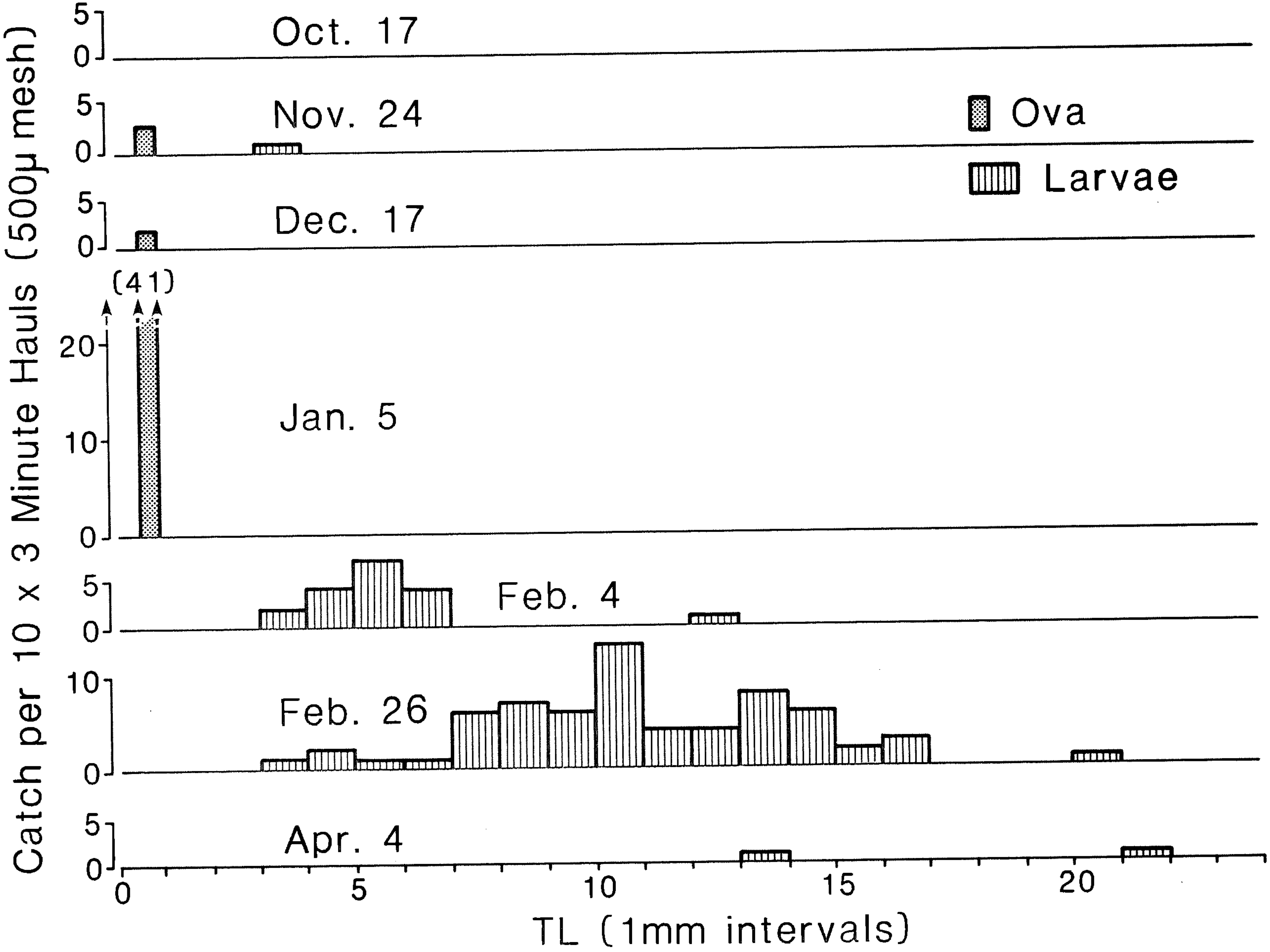
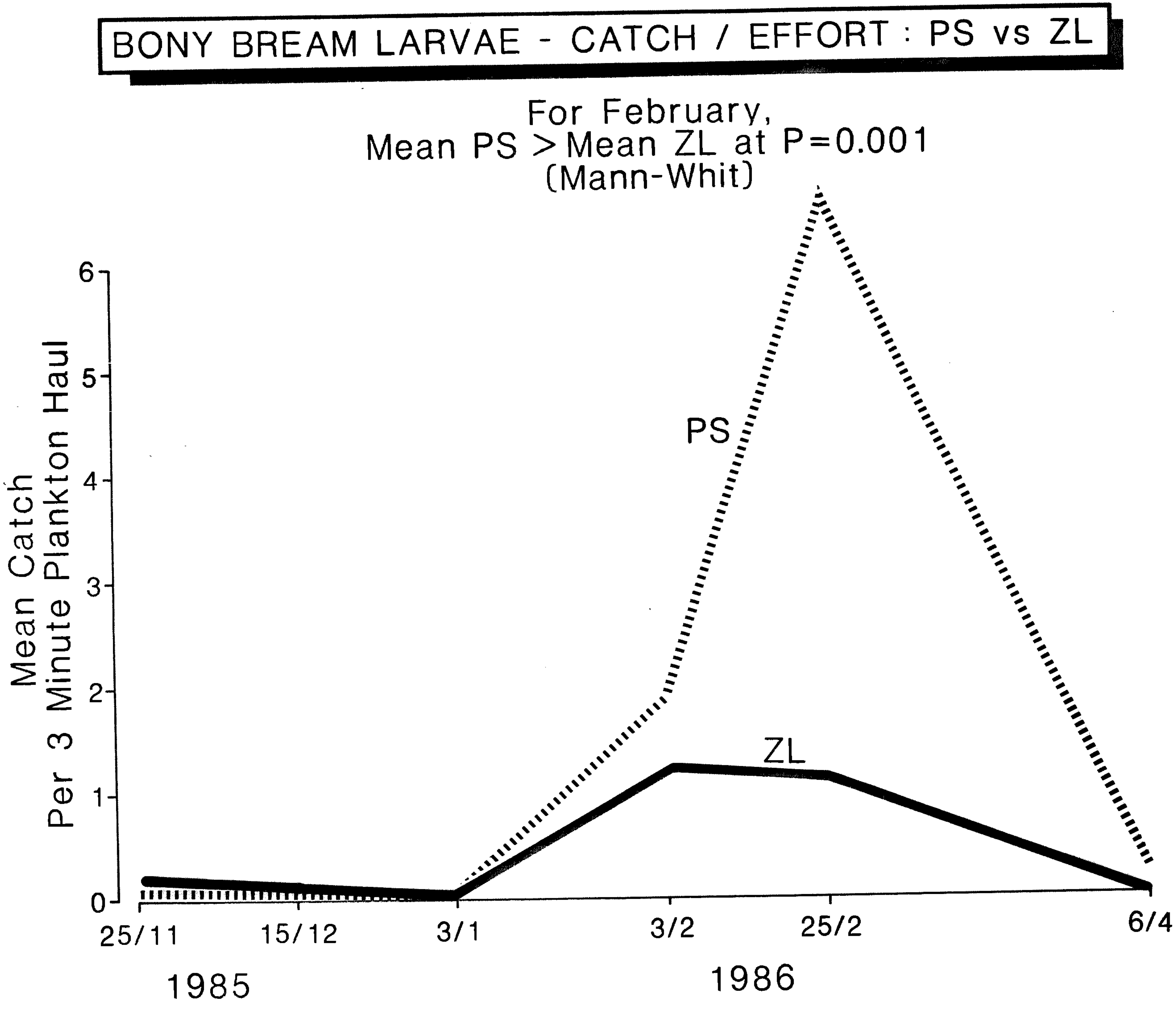


Fig.28


BONY BREAM LARVAE - CATCH / EFFORT : PS vs ZL
For February,
Mean PS > Mean ZL at P=0.001
(Mann-Whit)
Mean Catch
Per 3 Minute Plankton Haul
0
1
2
3
4
5
6
PS
ZL
25/11
15/12
3/1
3/2
25/2
6/4
1985
1986

appears to be concentrated in the muddy lowland lagoons (Bishop *et al*. 1980). *D. cepedianum* and *D. petenense* may spawn in either shallow backwaters or lake coves (Jester & Jensen 1972, Shelton 1972, Littlejohn, Holland, Jackson, Huston & Horning 1985).

### 3.3.4 Sex ratio

The sexes in bony bream, as in most gizzard shads (Miller 1960), are not readily distinguishable from external morphology, even in breeding adults. There is no significant difference (d-statistic) in the slopes of the log body length - log body depth curves for the two sexes (Fig. 29), although older females of *D. cepedianum* are said to be more deep-bodied than males (Bodola 1966). Sex ratios were determined from gillnet catches through 1983-84 at ZL, because these catches provided the largest and temporally most complete sample of the population. In the 1105 fish sexed, the overall ratio of males to females was 0.86, which was significantly different from 1.0 at $P<0.25$ (Chi-square, Fig. 30). Females were significantly more abundant in the largest size-range (TL>350 mm) than overall ($P<0.001$ on Chi-square) at both PS and ZL, which agrees with findings for *D. cepedianum* (Jester & Jensen 1972). However, they were significantly less abundant in the middle size-range (250<TL<350mm, $P<0.01$ on Chi-square) and not significantly different in abundance than males in the lower size-range (100<TL<250mm). The overall ratio is in contrast to the 1:1 found for this species in the Alligator Rivers Region (Bishop *et al*. in prep.) but agrees with findings for *D. cepedianum* (Jester & Jensen 1972). It suggests either that gillnets are differentially selective for the sexes, or the sexes have different growth or mortality rates. If the body depth - total length ratio was an important factor in catch rates,

Fig.29

Regression $Log_{10}$ Body Depth on $Log_{10}$ Total Length for Bony Bream at Zadow's Landing, 1983-1984

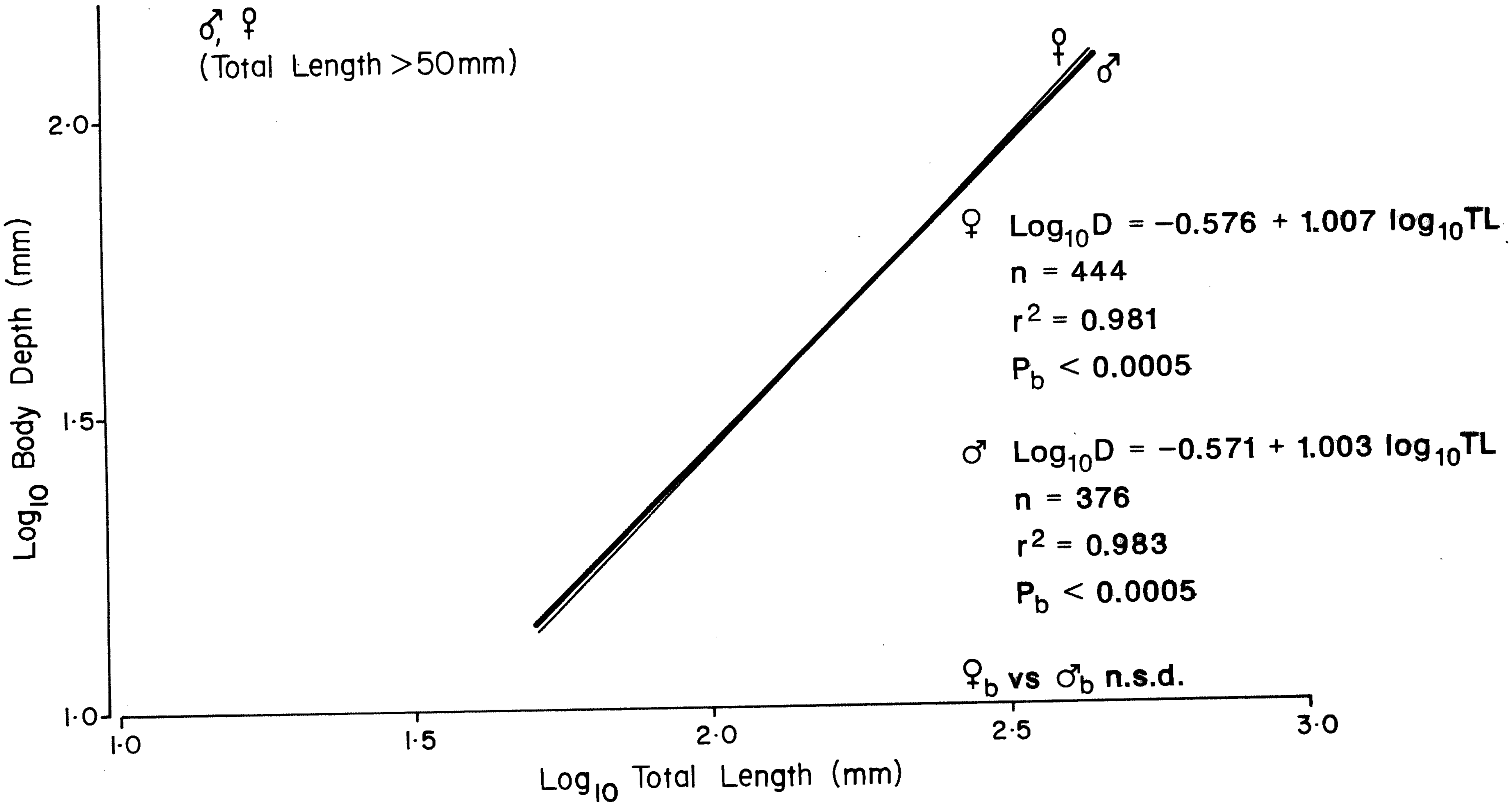
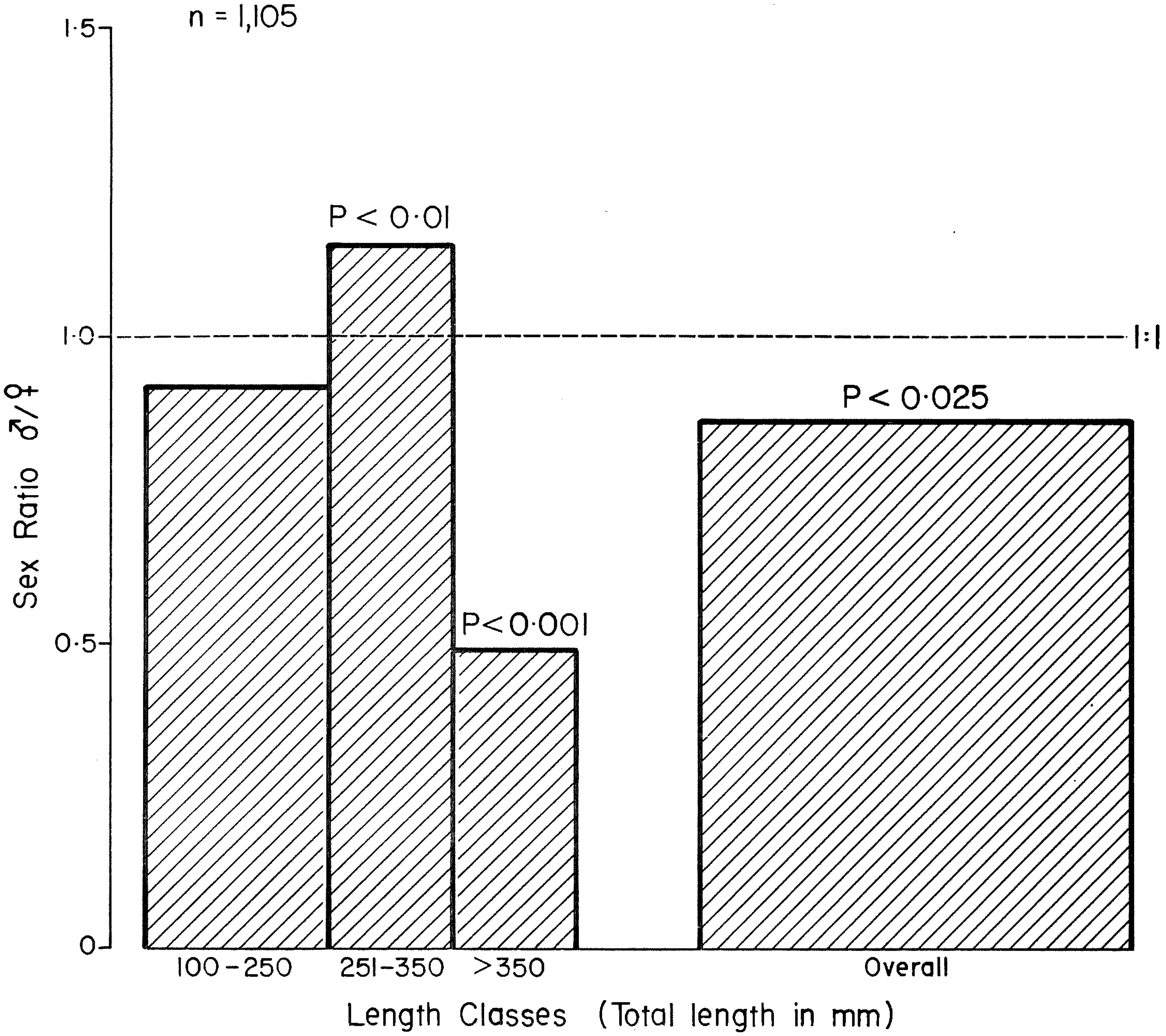


Fig.30

Sex Ratios of Bony Bream at Zadow's Landing, 1983-1984



one would expect a dominance of males in the smallest sizes, which does not occur. Some indication that there may be seasonal behavioral differences between the sexes which could temporarily affect catch rates is given by a comparison of the sex ratios for the pre-spawning period and the remainder of the year (Fig. 31). The ratios for these two periods are significantly different (Chi-square, $P<0.001$) with elevated catches of females in the pre-spawning period, and elevated catches of males in the remainder of the year. This could arise if males greatly outnumbered females on the spawning grounds, as has been recorded for <u>Dorosoma</u> sp. (Warner 1941, Jester & Jensen 1972, Bodola 1966). The fact that males are running ripe throughout the breeding season suggests multiple matings by males are the rule. This would deplete the male population of non-spawning areas like ZL. Unfortunately, a comparable size-distribution of specimens (and so a test of the ratio) is not available for PS, which is close to a known spawning ground.

### 3.3.5 Egg and larval development

The water - hardened ova collected by ichthyoplankton trawl (Fig. 32) had a mean diameter of 0.829mm (95% CIs = +/- 0.016), slightly larger than for <u>D. cepedianum</u> ova (0.75mm - Warner 1941) and identical to that for <u>A. chacunda</u> (0.82mm - Devanesan & Chidambaram 1941). Ova were at least semi-buoyant since they were collected in a surface trawl. Newly stripped water hardened ova were not significantly different in diameter (0.834 mm +/- 0.036), but the fact that they were demersal and adhesive suggests that bony bream ova may have both an early demersal and a later pelagic phase, making them, like <u>D. cepedianum</u>, litho - pelagophils in the scheme of Balon (1975). Llewellyn (1983) estimated diameter of bony bream ova at 0.8mm, and

Fig.31

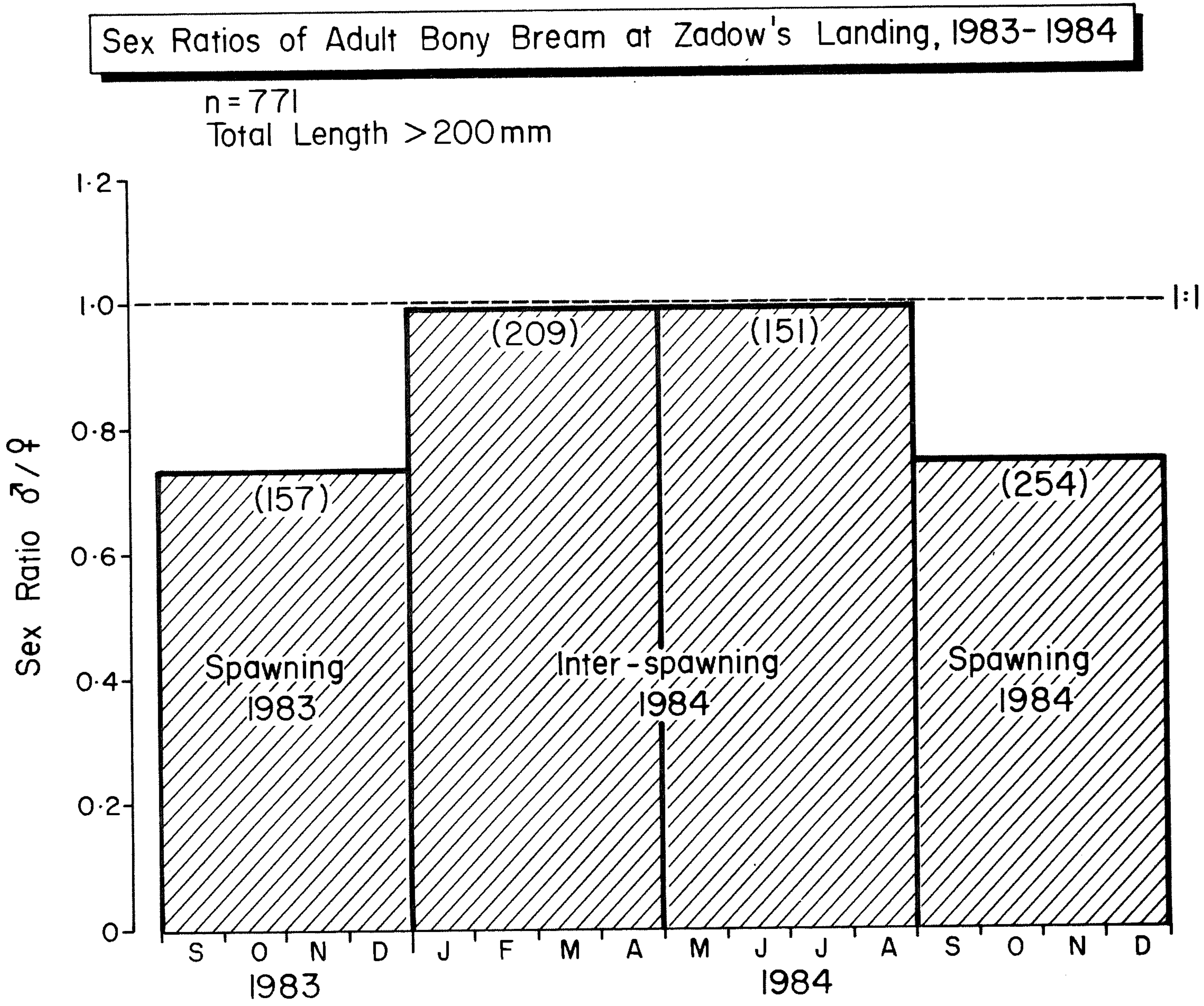
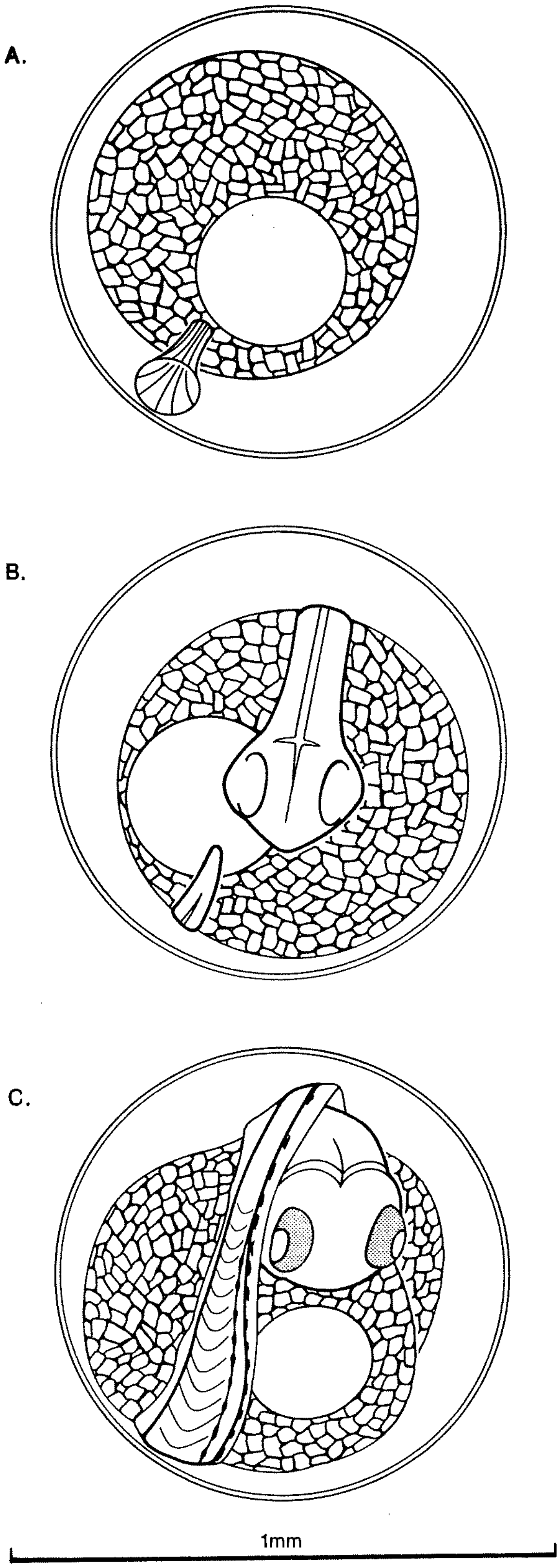

Sex Ratios of Adult Bony Bream at Zadow's Landing, 1983-1984
n = 771
Total Length > 200 mm
Sex Ratio ♂/♀
1·2
1·0
0·8
0·6
0·4
0·2
0
1:1
(157)
(209)
(151)
(254)
Spawning 1983
Inter-spawning 1984
Spawning 1984
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1983
1984

Fig.32

BONY BREAM OVA AND EMBRYOS FROM 500μ TRAWL
AT POINT STURT, 5.1.86

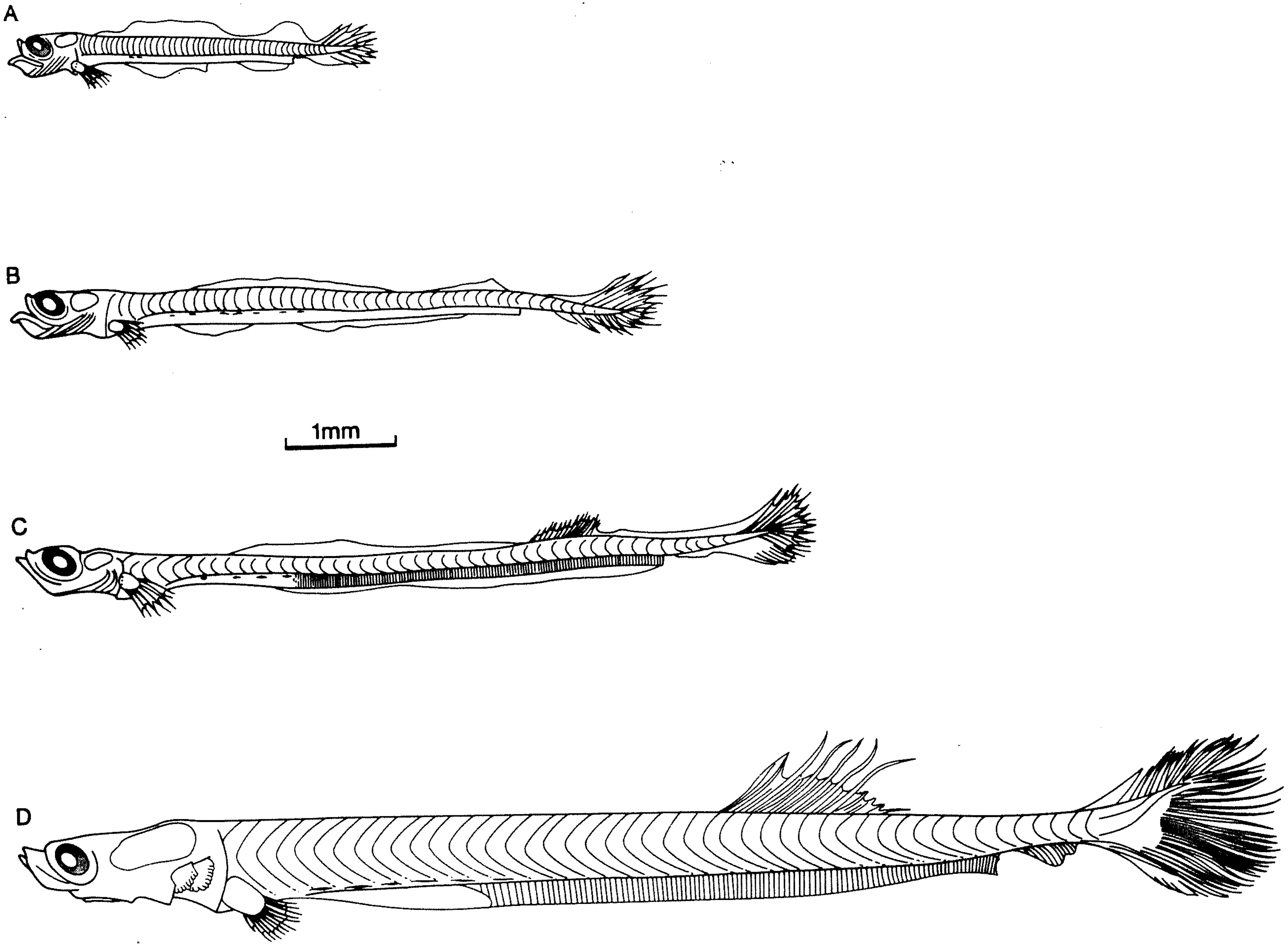


suggested they were semi-buoyant. Some gizzard shads have pelagic ova (Delsman 1926, Venkataramanujam & Ramamoorth 1974), some are demersal and adhesive (Shelton & Stephens 1980). In the trawled ova, yolk diameter was 0.54 mm and chorion thickness approximately 0.010 mm, leaving a perivitelline space of 0.14 mm. There was normally a single large oil-droplet (diam. 0.26 mm) (although this was occasionally divided into as many as four) and the micropyle was clearly visible adjacent to it. Sand grains were commonly adhering to a gelatinous extra-chorionic adhesive layer. The yolk was finely segmented. 20% of the ova trawled had clearly recognizable embryos, and the more developed showed eye pigmentation and a line of ventro-lateral melanophores (Fig. 32D). Embryonic eye pigmentation occurs also in *D. petenense* but not in *D. cepedianum* (Shelton & Stephens 1980). The largest embryo found had a TL = 2.5 mm, and since the smallest free larva trawled was 3.3 mm TL, size at hatch must lie between these figures. This puts the likely length at hatch below the 3.25mm recorded for *D. cepedianum* (Warner 1941), and probably above the 2.7mm recorded for *A. chacunda* (Devanesan & Chidambaram 1941).

Bony bream, smelt (*Retropinna semoni*) and western carp gudgeon (*Hypseleotris klunzingeri*) comprised almost all the larval trawl catch. Western carp gudgeon larvae were readily distinguishable from body shape, body length, and retention of yolk sac, although a mean myomere count of 31 (+/- 0.97) was also distinctive. But bony bream and smelt have very similar eel-like larval form (Fig. 33) and both absorb the yolk sac early, so distinction of early larvae was based on mean myomere counts (44.7 +/- 0.53 for bony bream (pre-anal count 38.5 +/- 0.83) and 53.6 +/- 0.95 for smelt). As soon as dorsal fin development begins, the two larvae are readily distinguished by the more anterior placement of

Fig.33

BONY BREAM LARVAE FROM 500μ TRAWL AT POINT STURT, FEBRUARY 1986



this fin in relation to the anal in bony bream - there is no overlap in the position of the two fins along the anterior-posterior axis; in smelt, the dorsal overlaps with the anal. Fine details of bony bream larval development could not be determined from monthly catches, but the sequence of major changes is as follows (see also Fig. 33):

(1) The yolk-sac is absorbed early, as 3.3mm TL larvae showed no sign of it. This is surprising, since D. cepedianum and D. petenense retain yolk sacs for 2-3 days after hatch, to a TL of at least 5 mm (Shelton & Stephens 1980). Laboratory rearing of bony bream larvae from ova will be necessary to clarify this matter.

(2) The caudal and pectoral fins appear to develop rays first, at approximately 3mm TL. (Early development of the pectoral fin is evidently unusual in clupeids - McGowan & Berry 1984.) The dorsal fin follows at 7 mm , the anal at 11 mm , and the ventral at 16 mm. This sequence of fin development differs markedly from that for D. cepedianum, where the order is dorsal, caudal, pectoral, pelvic and anal (Warner 1941).

(3) Melanophores are present throughout larval development in a line along the dorsal border of the gut, but they appear to be more numerous in pre-hatch embryos (Fig. 32D) and in larvae of TL>6 mm. After TL 6 mm, a single melanophore becomes obvious ventrally and immediately anterior to the cleithrum, and a pair appears ventrally immediately posterior. A fine mid-ventral line of melanophores also appears along the posterior 2/3 of the gut at this time.

(4) Caudal flexion of the notochord begins at TL = 10 mm. Larval growth rates cannot be inferred in any detail from the timing of peak ova catch and length - frequency plots of subsequent catches of larvae at PS (Fig. 27), because hauls were too infrequent, but there

appears to be a doubling of modal total length from 5.5 to 10.5 mm in the three weeks from Feb. 4 to Feb. 26.

(5) Anterior migration of the anus, dorsal and anal fins becomes noticeable at 17 mm.

(6) First scalation appears along the lateral line at 26 mm, and is complete by 35-40 mm.

Since eggs and larvae are small, and the yolk-sac stage brief, larval survival must depend even more acutely than usual on zooplankton density at first feeding.

### 3.3.5 Fecundity

Fecundity is high in bony bream, rising exponentially with TL according to the equation log(10) fecundity = -3.923 + 3.725 log(10) TL ($r2=0.88$, $P(slope)<0.001$, Figs. 34, 35). The range recorded of the 27 gonads counted was from 33,000 for a fish of TL = 199 mm (body wt. - gonad wt. = 84 gm) to 880,000 for a fish of TL = 403 mm (body wt. - gonad wt. = 532 gm). The three gonad counts given by Bishop _et_ _al_. (in prep.) for bony bream in the Magela Creek fall within this range. The relation between non-reproductive body mass and fecundity is more accurately expressed as fecundity vs (body weight - gonad weight) than as fecundity vs total body weight. The fecundity - body weight less gonad weight relation is best fitted by a log - log relation, of the form log(10) fecundity = 2.221 + 1.297 log(10) (body weight - gonad weight) ($r2=0.9$, $P(slope)<0.001$, Figs. 36, 37). The equations for fecundity vs total body weight are: $F = -87931.7 + 1198.1\ BW$ ($r2=0.85$, $P(F\text{-test})<0.001$) and $LOG\ F = 2.188 + 1.290\ LOG\ BW$ ($r2=0.91$, $P(F\text{-test})<0.001$). There is a significant relation between fecundity/(body weight-gonad weight) and total length (F/(BW-GW) =

Fig.34

## FECUNDITY - TOTAL LENGTH RELATION IN BONY BREAM AT ZADOW'S LANDING, 1983 - 1985

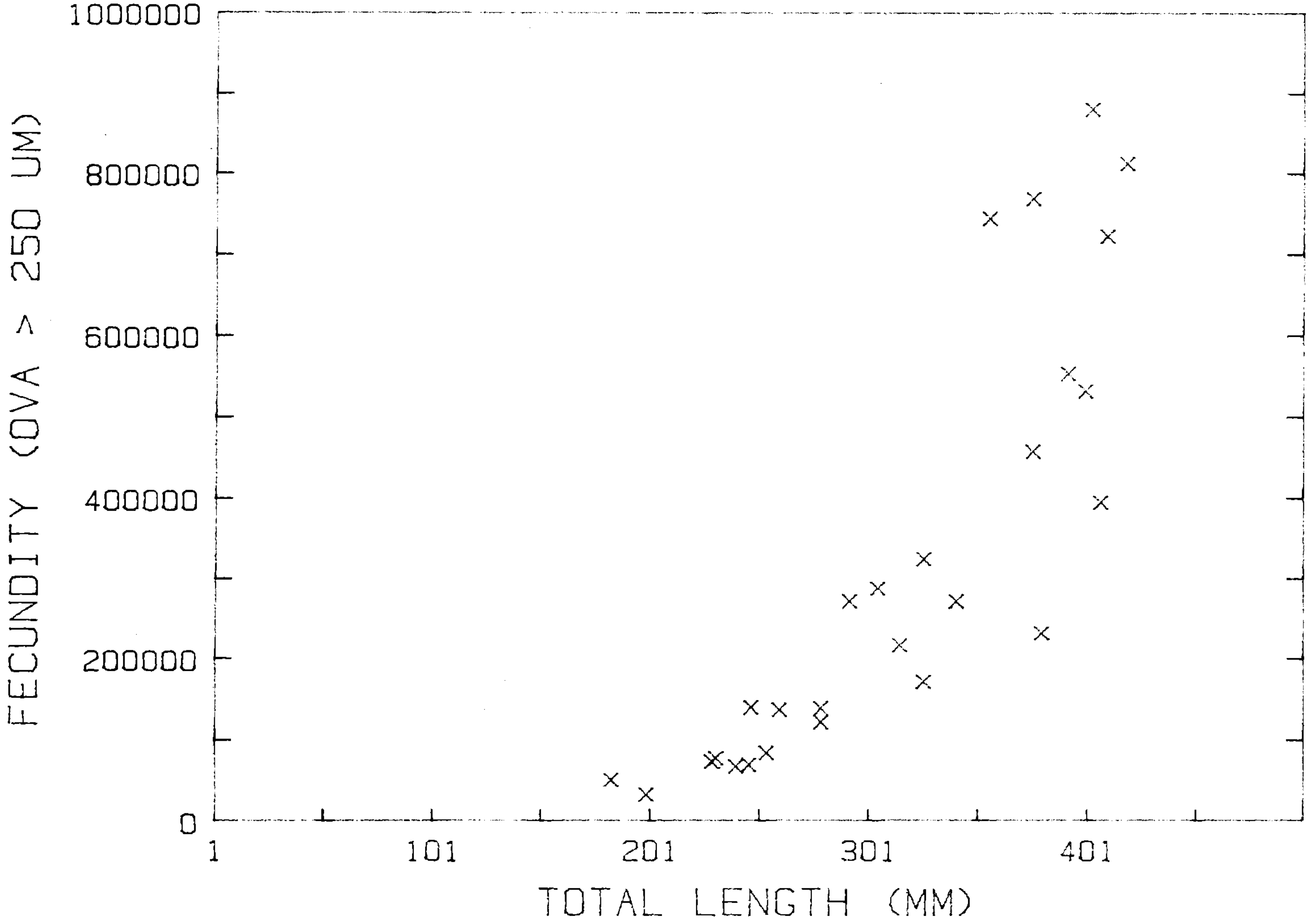


Fig.35

# $LOG_{10}$(FECUNDITY) – $LOG_{10}$(TOTAL LENGTH) RELATION IN BONY BREAM AT ZADOW'S LANDING, 1983 – 1985

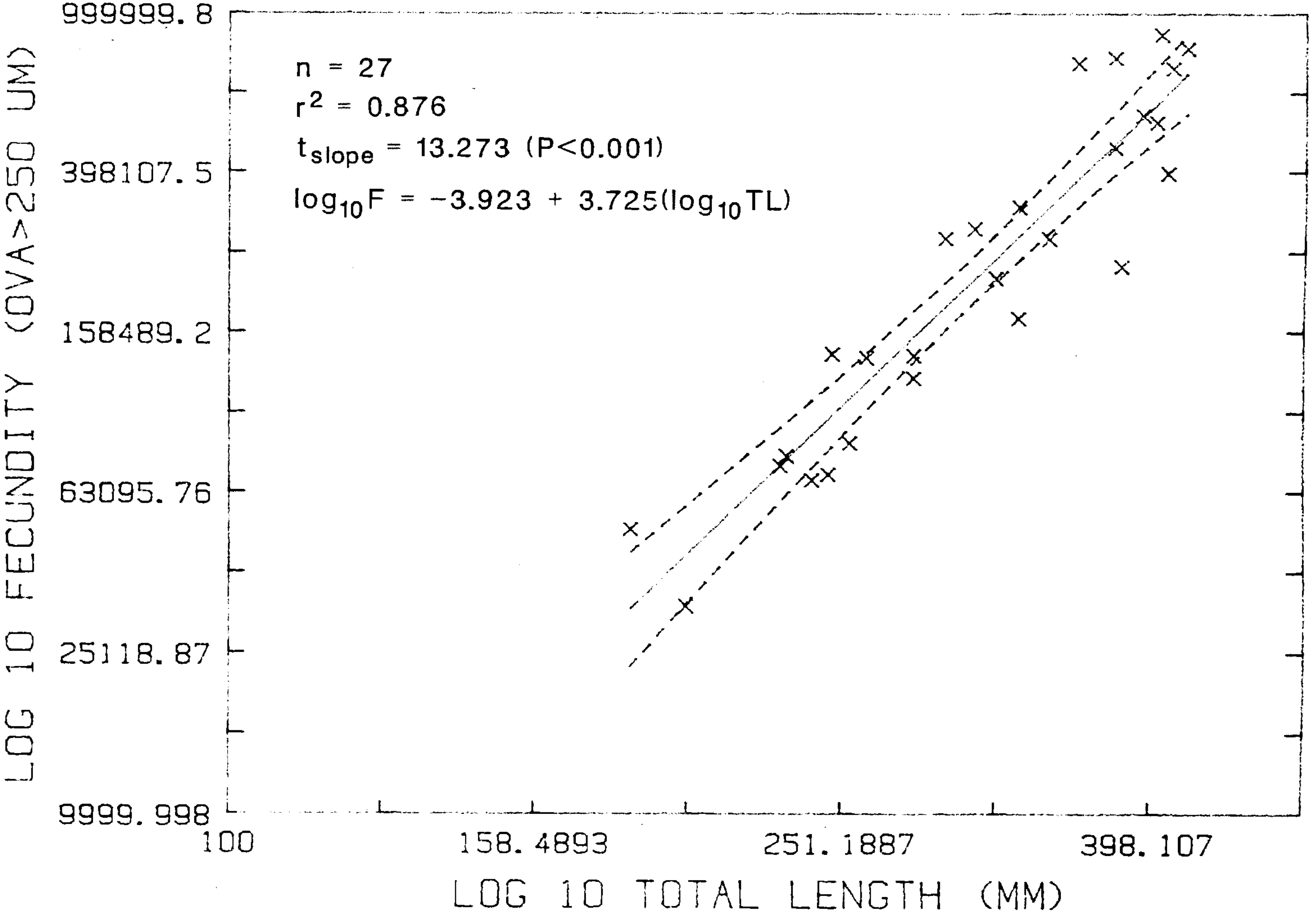


Fig.36

FECUNDITY – (BODY WEIGHT – GONAD WEIGHT) RELATION IN BONY BREAM
AT ZADOW'S LANDING, 1983 – 1985

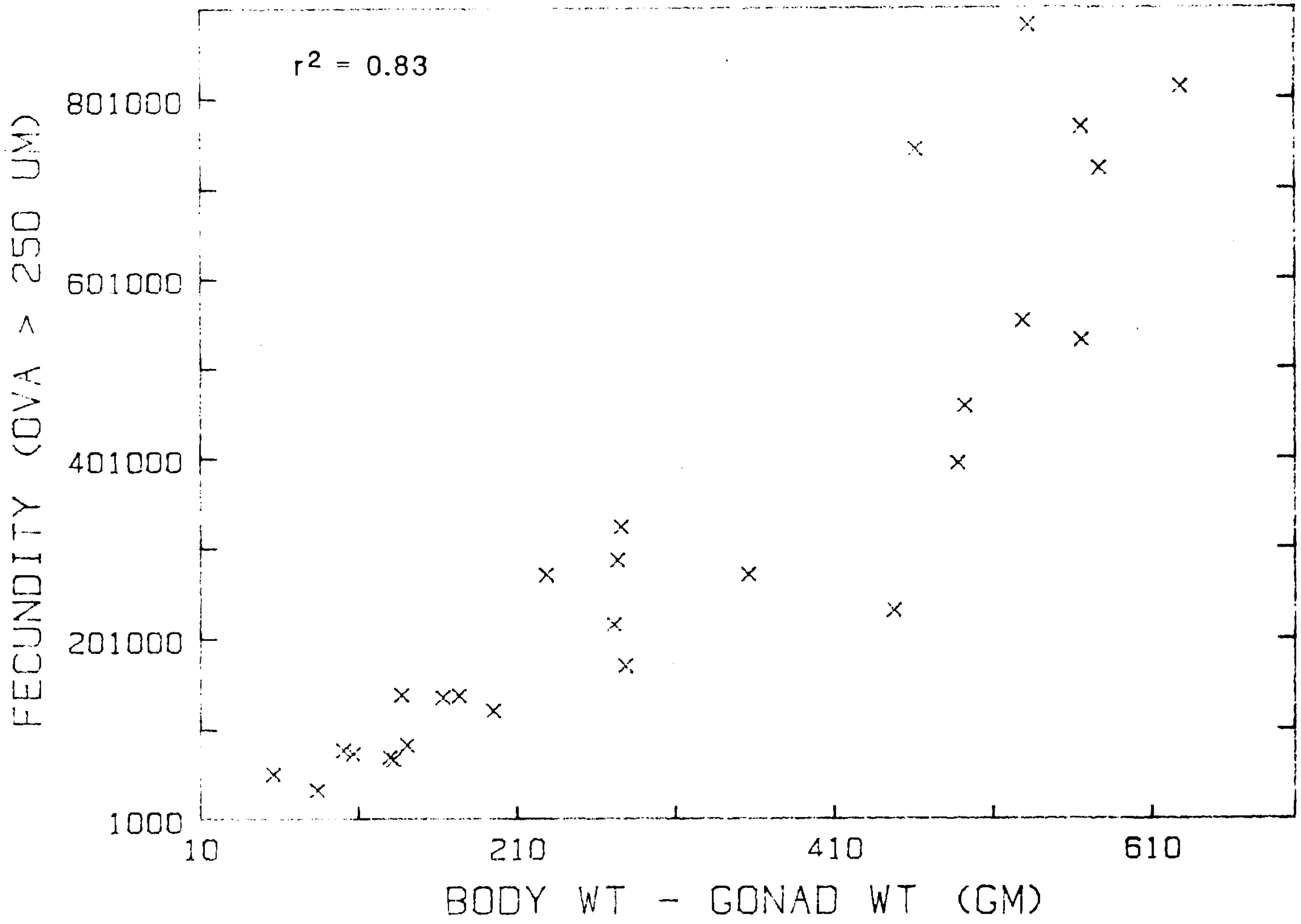
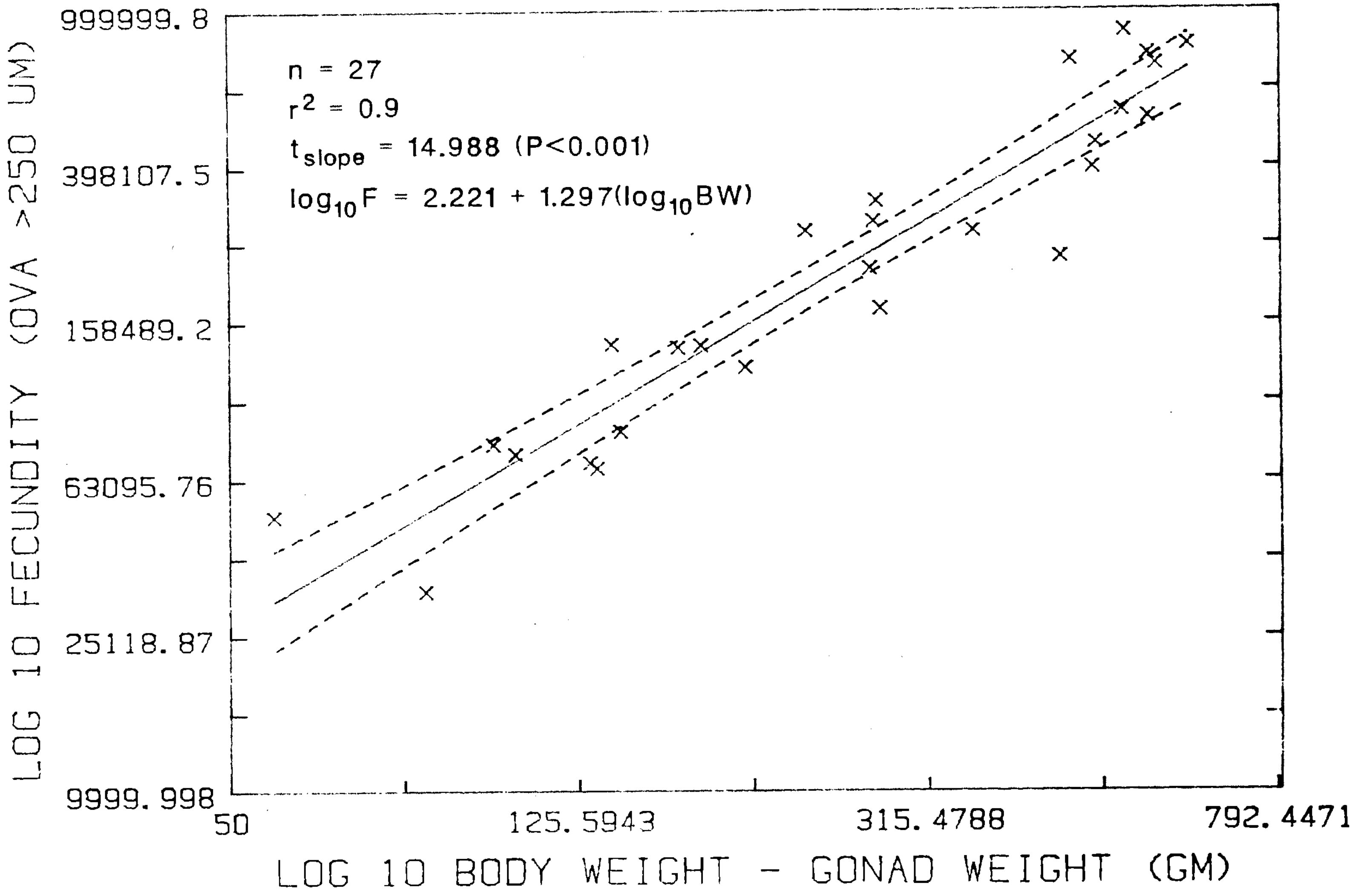


Fig.37

LOG$_{10}$(FECUNDITY) - LOG$_{10}$(BODY WEIGHT - GONAD WEIGHT) RELATION IN BONY BREAM AT ZADOW'S LANDING, 1983 - 1985



117.58 + 2.54 TL, r2=0.28, P(F-test)<0.01, Fig. 38), which indicates increasing reproductive effort with size, and therefore with age. Fecundity relations for other gizzard shads, viz. N. vlaminghi - logF = 1.704 + 1.346logBW (Chubb & Potter 1984), A. chacunda - F = -18.17 + 0.817BW (Babu Rao 1965), and D. cepedianum - F = 11,223 + 332.9BW (Kilambi & Baglin 1969), demonstrate the variety of such relations, partly arising from differences in the criteria used to distinguish potentially spawnable ova, partly from a real diversity in the sub-family. Bony bream appear to have a higher overall fecundity than the Perth herring and A. chacunda, and lower than D. cepedianum but with a higher rate of growth of fecundity with body size. A log - log equation gives the best fit for the relation between fecundity and gonad weight (Fig. 39, r2 = 0.95), but it is little improvement on the equation for untransformed data (r2 = 0.92). This indicates that egg size does not vary greatly with fish size, as is the case for some fish (Mann & Mills 1985). A plot of log GSI vs log TL gives significant regressions for both males and females (r2=0.32, P(F-test)<0.001, r2=0.68, P(F-test)<0.001 Fig. 40), confirming the above finding of an increasing reproductive effort with size. Female reproductive effort increases with size more rapidly than male (F-test, P<0.001). The rate of change of reproductive effort with size evidently depends on local conditions, since some populations of D. cepedianum show an increasing reproductive effort with size (Fagan & Fitzpatrick 1978), and some show a decline (Jester & Jensen 1972, Bodola 1966, Shelton 1972).

Fig.38

# REPRODUCTIVE EFFORT IN BONY BREAM ♀+♂
# FECUNDITY / (BODY-WEIGHT - GONAD WEIGHT) vs TOTAL LENGTH
# AT ZADOW'S LANDING, 1983 - 1984

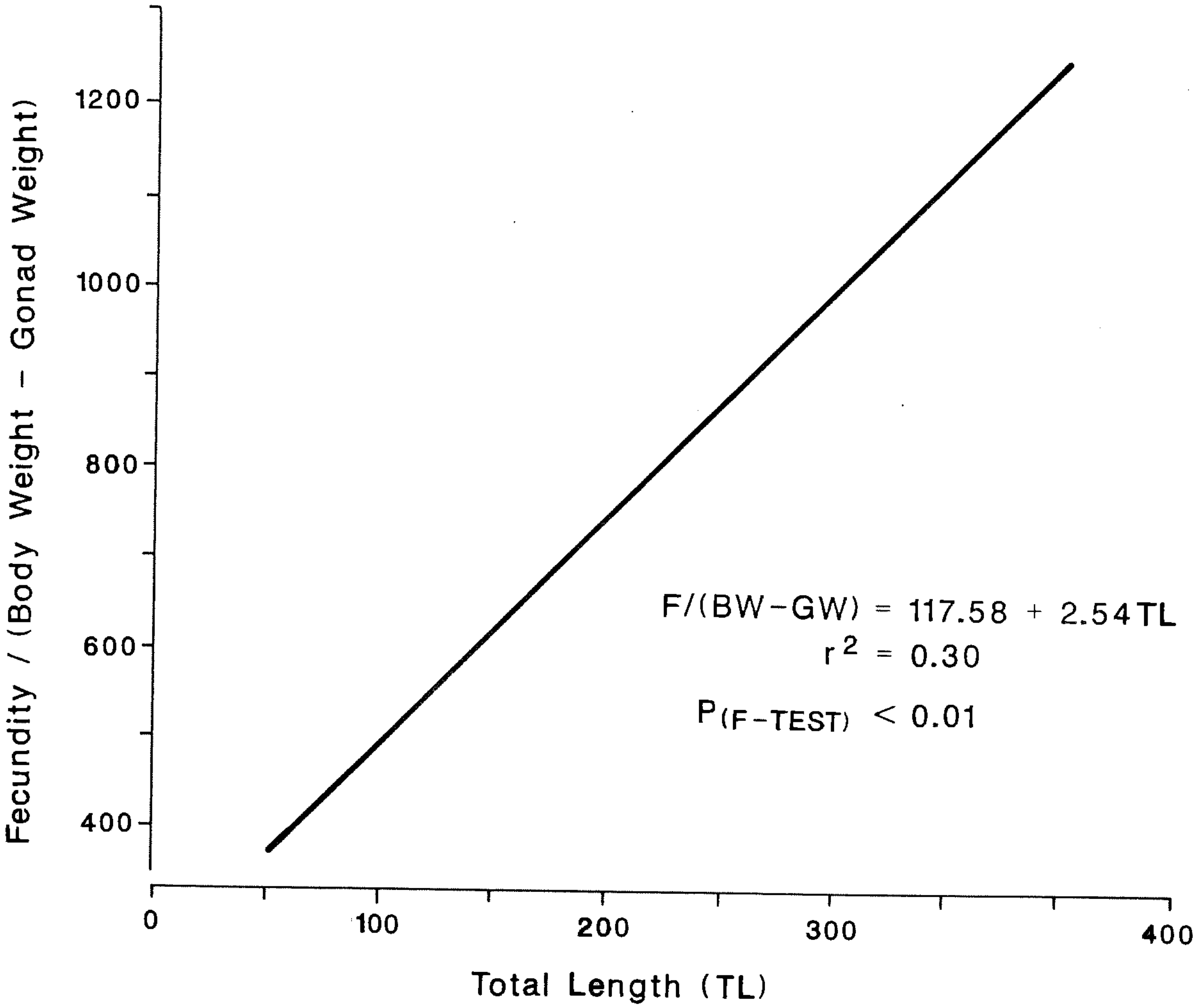


Fig.39

LOG$_{10}$(FECUNDITY) - LOG$_{10}$(GONAD WEIGHT) RELATION IN BONY BREAM AT ZADOW'S LANDING, 1983 - 1985

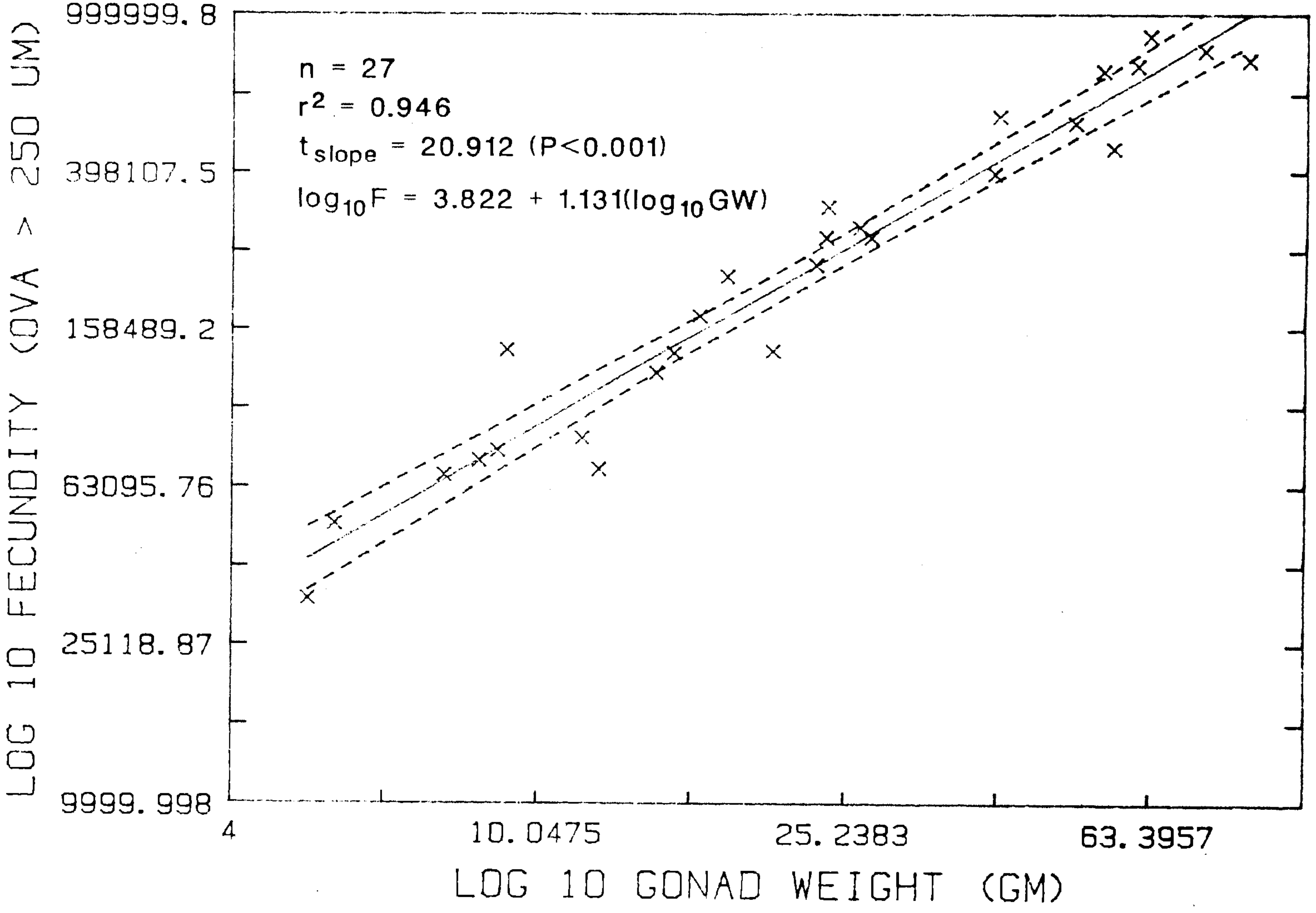
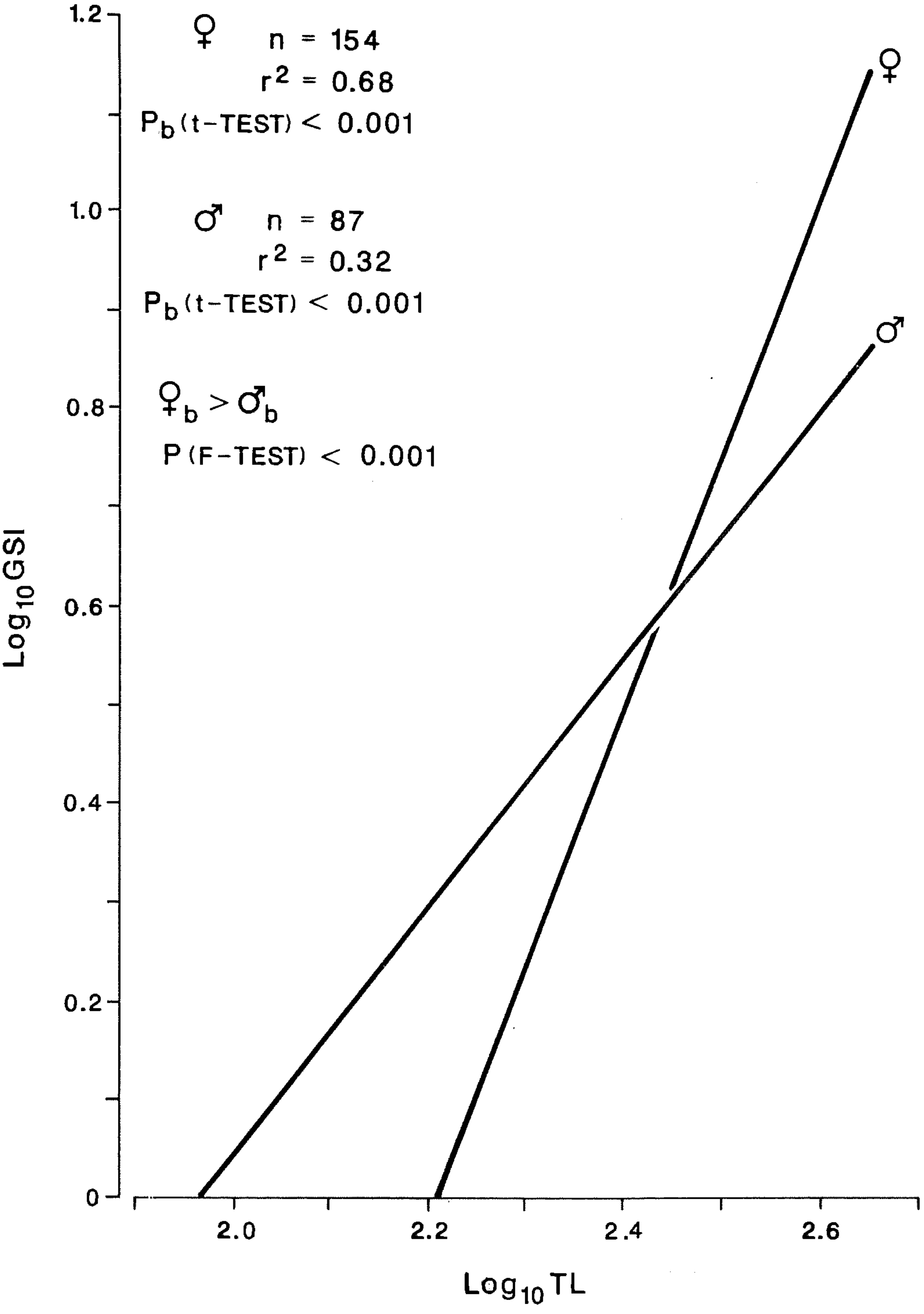


Fig.40

REPRODUCTIVE EFFORT IN BONY BREAM ♀, ♂
LOG$_{10}$GSI vs LOG$_{10}$TOTAL LENGTH AT ZADOW'S LANDING,
NOVEMBER + DECEMBER, 1983 - 1985



♀ $n = 154$
$r^2 = 0.68$
$P_b$ (t-TEST) $< 0.001$

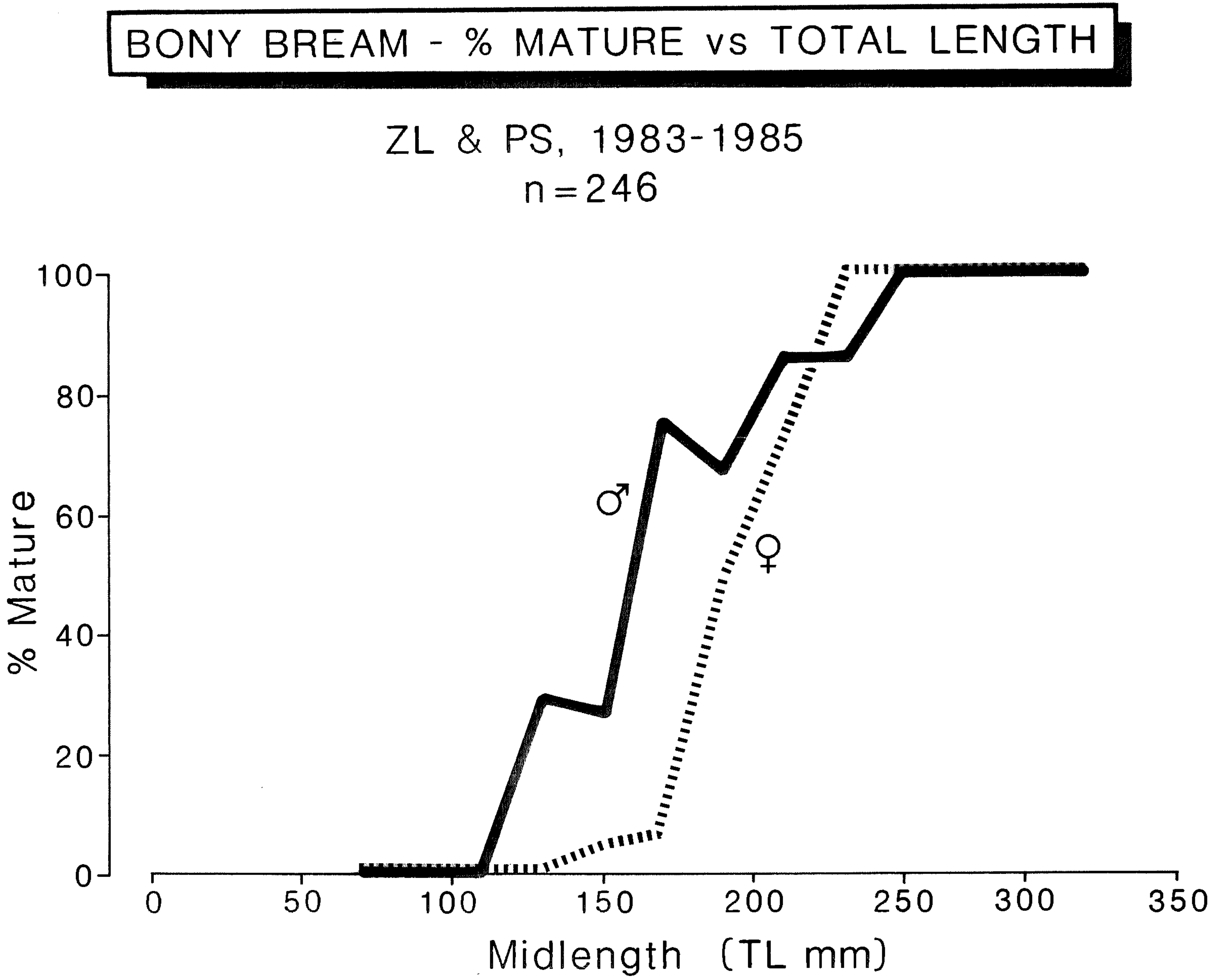
♂ $n = 87$
$r^2 = 0.32$
$P_b$ (t-TEST) $< 0.001$

$♀_b > ♂_b$
P (F-TEST) $< 0.001$

### 3.3.6 Length and age at maturity

Although it has been common practice in fish biology to use a simple "age at first maturity " number to describe the age (or length) - maturity relation, such a practice gives very little information about what is a complex, and from a management point of view, critical process, and the figure is very sensitive to sample size. A plot of % mature fish in a length - group against the midlength of that group (Fig. 41) gives a sigmoid curve with many males maturing at an earlier age than females - a common finding in fish populations (Beacham 1983). However males also appear to mature over a greater range of total length than females. The same pattern is evident in a plot of % mature fish against age (Fig. 42). Probit analysis of these two sets of curves allows a statistical comparison of the curves, and derives a median length or age at maturity from the whole curves. The analysis shows that for the % mature - length relation, there is a significant difference between the intercepts of the curves for the two sexes, but not between the slopes (Fig. 43). In other words, males begin maturing at a smaller size than females, but the rate of maturation per total length is the same for both sexes. The median lengths at maturity for males and females are 159 (CIs +16,-15)mm TL and 199 (CIs +35,-19)mm TL respectively (Fig. 44). For the % mature - age relation however, the curves for the sexes differ in both intercept and slope (Fig. 45). So males begin maturing younger, but the female population matures more rapidly, and overtakes the males in percentage mature at a given age. It is difficult to explain how this could occur without a significant sexual difference in the rate of maturation with length, unless immature females have a significantly lower growth rate than males. Male and female median ages at maturity are 2.4 (CIs +1.0,-0.8) years and

Fig.41



BONY BREAM - % MATURE vs TOTAL LENGTH

ZL & PS, 1983-1985
n=246

Fig.42

BONY BREAM - % MATURE vs AGE

October-December, 1983-1985
n=242

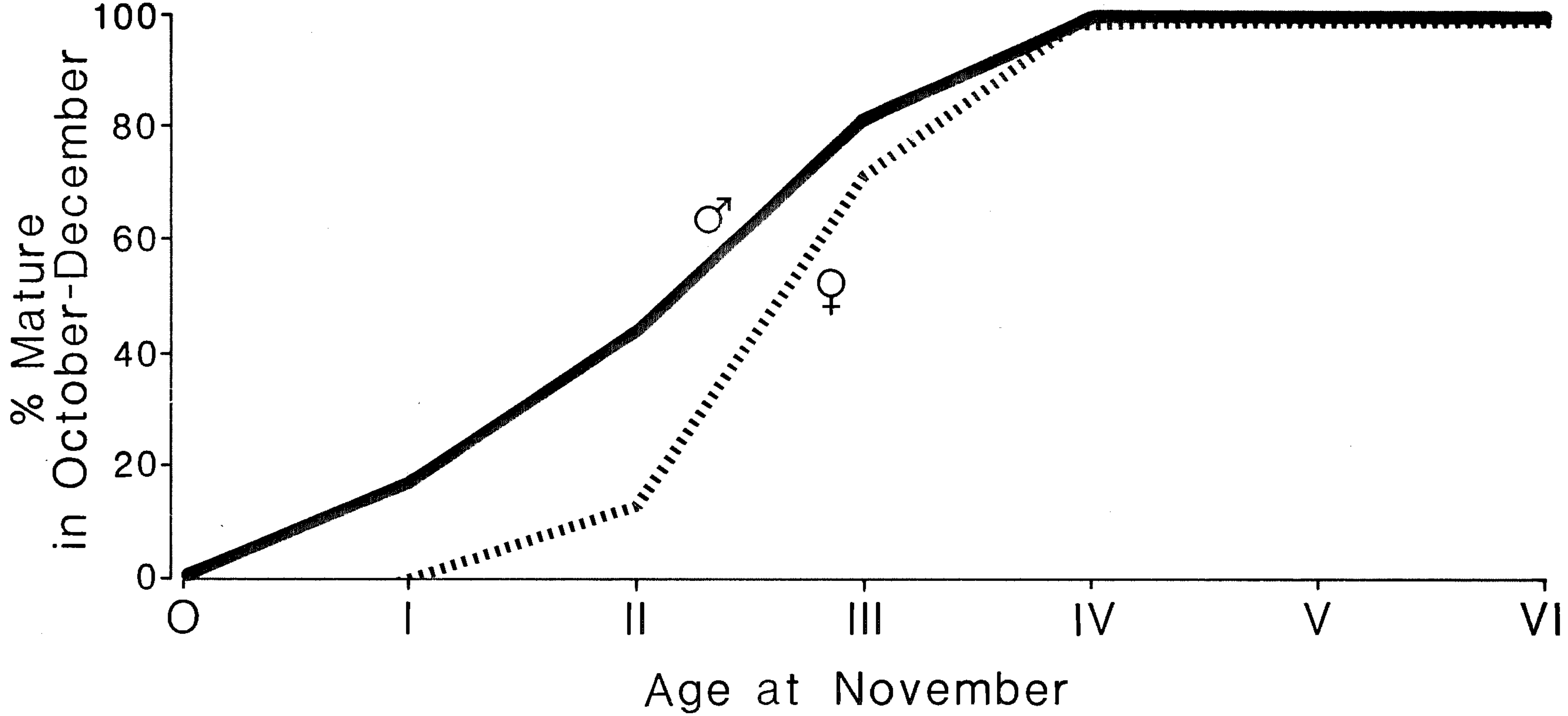


Fig.43

## BONY BREAM - % MATURE vs LENGTH PROBIT / LOG FITTED CURVES

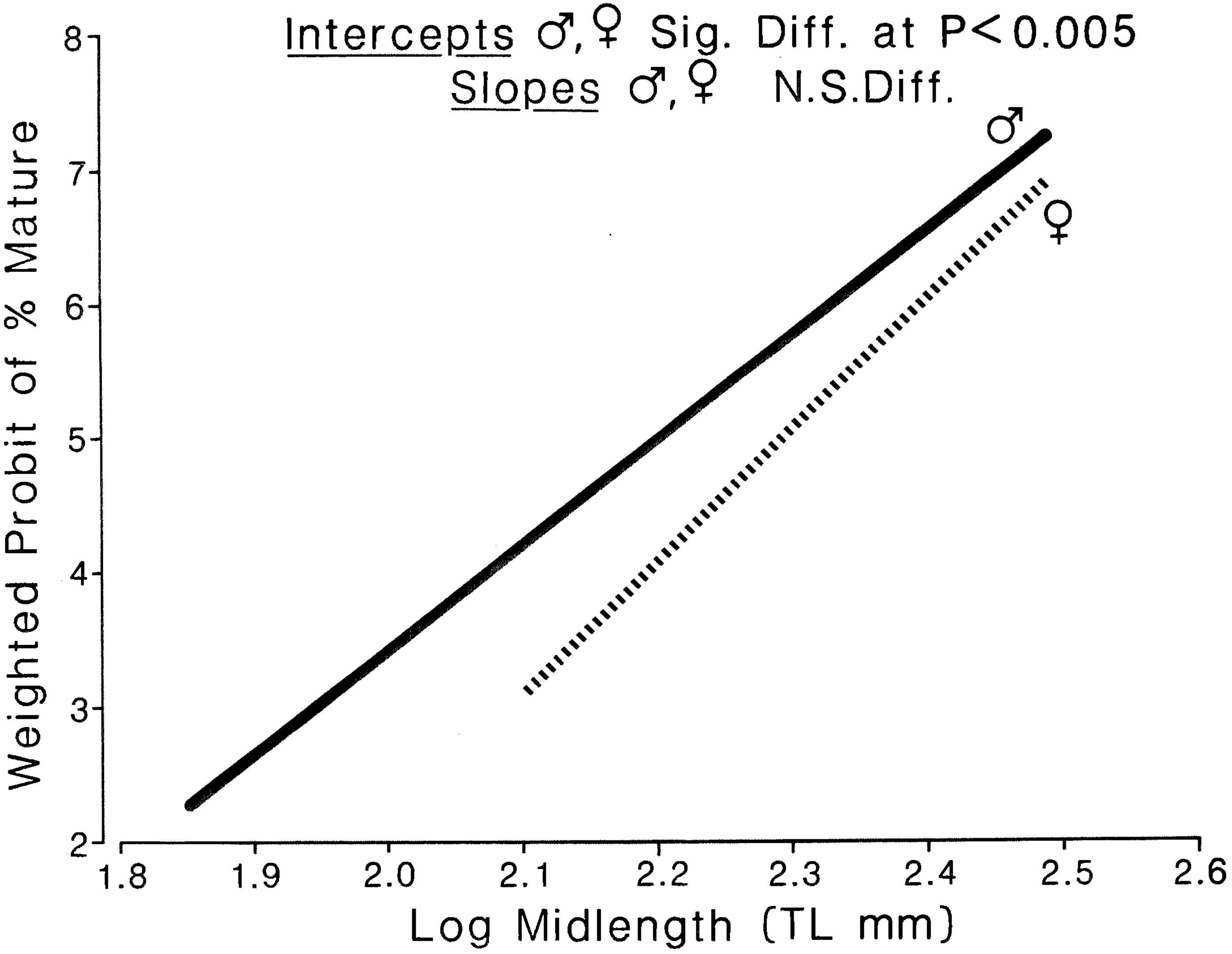
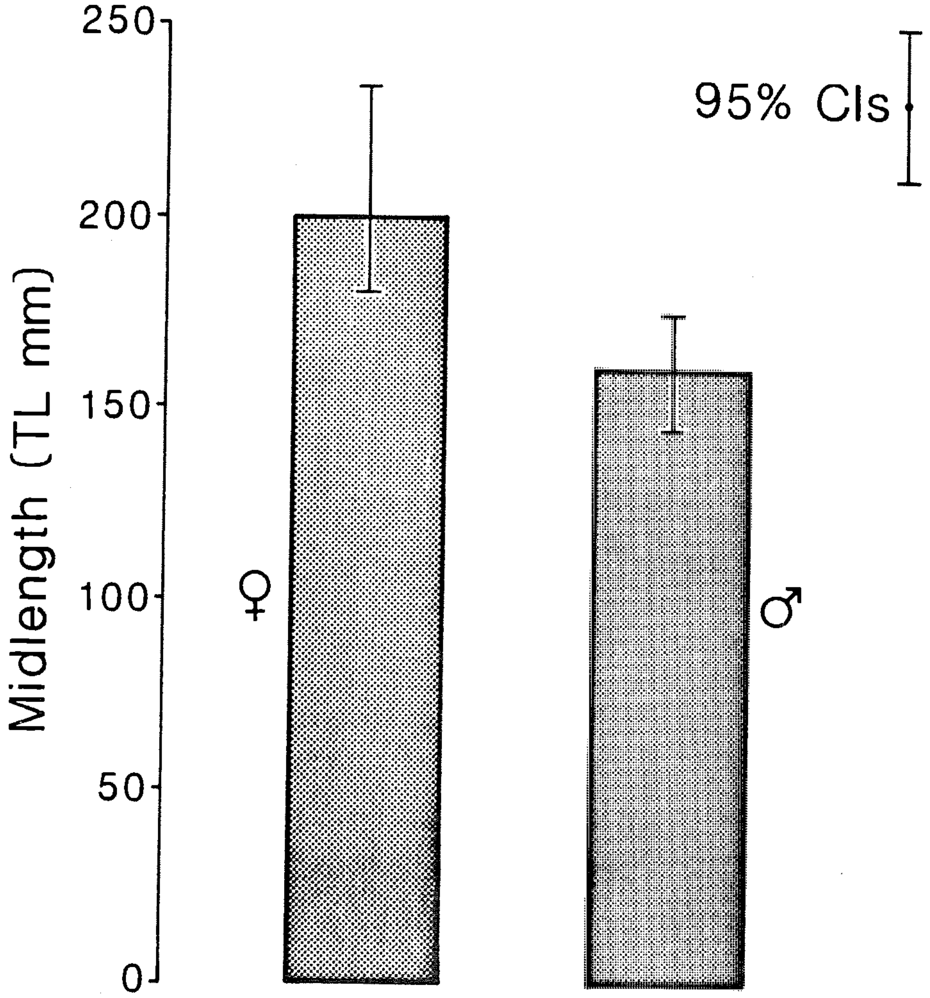
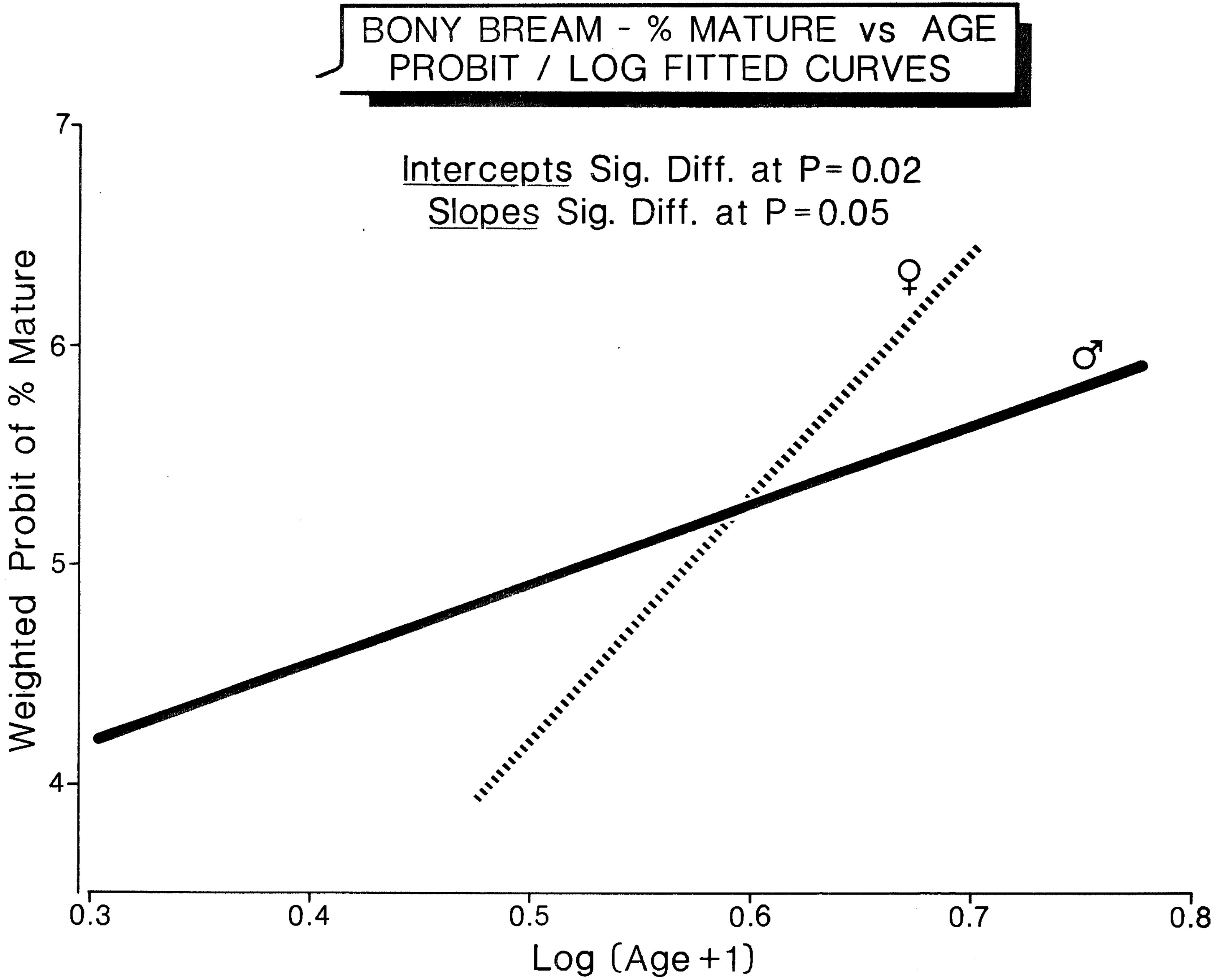


Fig.44



BONY BREAM - MEDIAN LENGTHS AT MATURITY FROM LOG-PROBIT ANALYSIS

Fig.45


BONY BREAM - % MATURE vs AGE
PROBIT / LOG FITTED CURVES
Intercepts Sig. Diff. at P=0.02
Slopes Sig. Diff. at P=0.05
♀
♂
Weighted Probit of % Mature
7
6
5
4
0.3
0.4
0.5
0.6
0.7
0.8
Log (Age+1)

2.7 (CIs +0.9,-0.3) years respectively (Fig. 46). One male matured, however, in the first year, at a total length (i.e. LFM) of 126 mm, and one female in the second year, at a total length of 155 mm. Although no other age or length - maturity relations have been derived for bony bream, the above result may be compared with estimated LFMs of 168 mm for females, 156 mm for males in the first year's growth in the Magela Creek, Northern Territory (Bishop *et al*. in prep.) and 50-100 mm TL in the first or second years in the middle Murray (Cadwallader 1977). Thomson (1957) gives an LFM of 189mm for *N. come*, and a surprisingly high LFM of 225mm at age I+ for *N. vlaminghi*. *A. chacunda* has an LFM of 125mm (Jacob 1948), and *D. cepedianum* typically matures in the second or third year, at TL varying from 113 to 300mm, depending on the population sampled (Bodola 1966, Jester & Jensen 1972). This early maturity in bony bream, combined with high fecundity, must allow rapid recovery of bony bream populations from years of poor recruitment.

## 3.4 Feeding and Condition

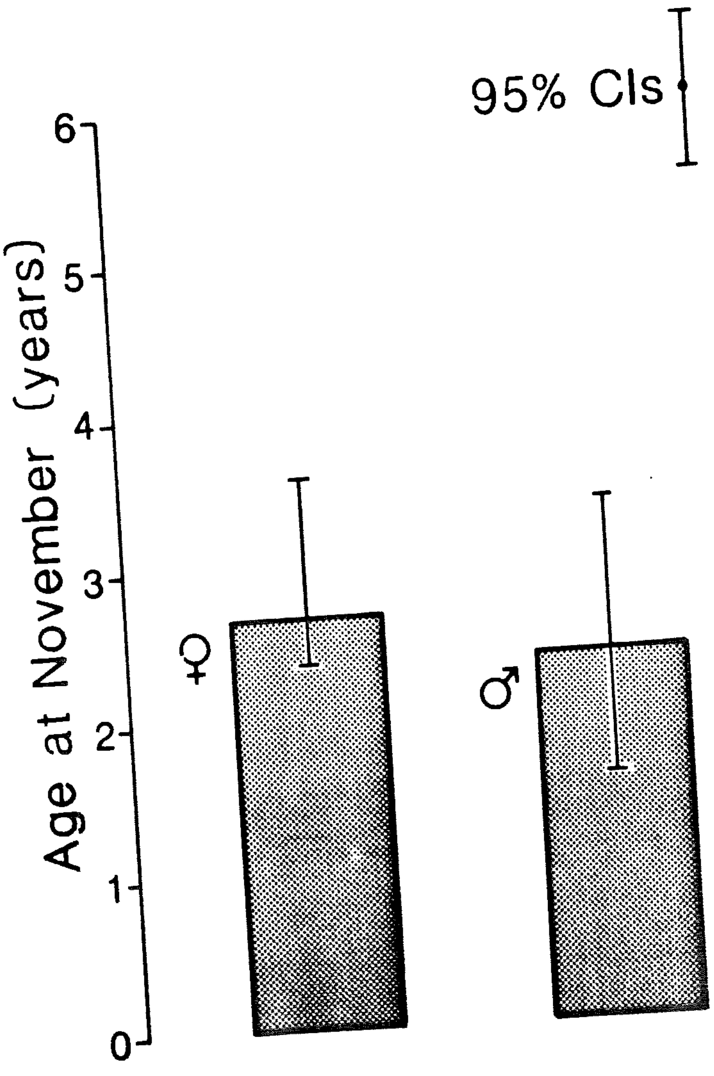
### 3.4.1 Feeding

Bony bream, like other gizzard shads, are morphologically adapted to filter-feeding and to foods needing elaborate digestive processing. They have no teeth, very fine gill-rakers, oesophageal pouches (probably for fine particle consolidation), a muscular gizzard, an extensive system of fine caecae, and a complexly folded, long intestine.

A study of the diet of bony bream in the lower Murray was done on specimens collected for this project (Atkins in prep.). That study found 0+ juveniles are primarily zooplanktivorous until TL = 60-80 mm. Larger juveniles are omnivorous, with an increasing proportion of fine detritus included in the diet. Adults are largely detritivorous. In parallel with this change of diet, gut length and the number of caecae increase, and mouth position progresses ventrally.

Fig.46

BONY BREAM - MEDIAN AGES AT MATURITY FROM LOG-PROBIT ANALYSIS

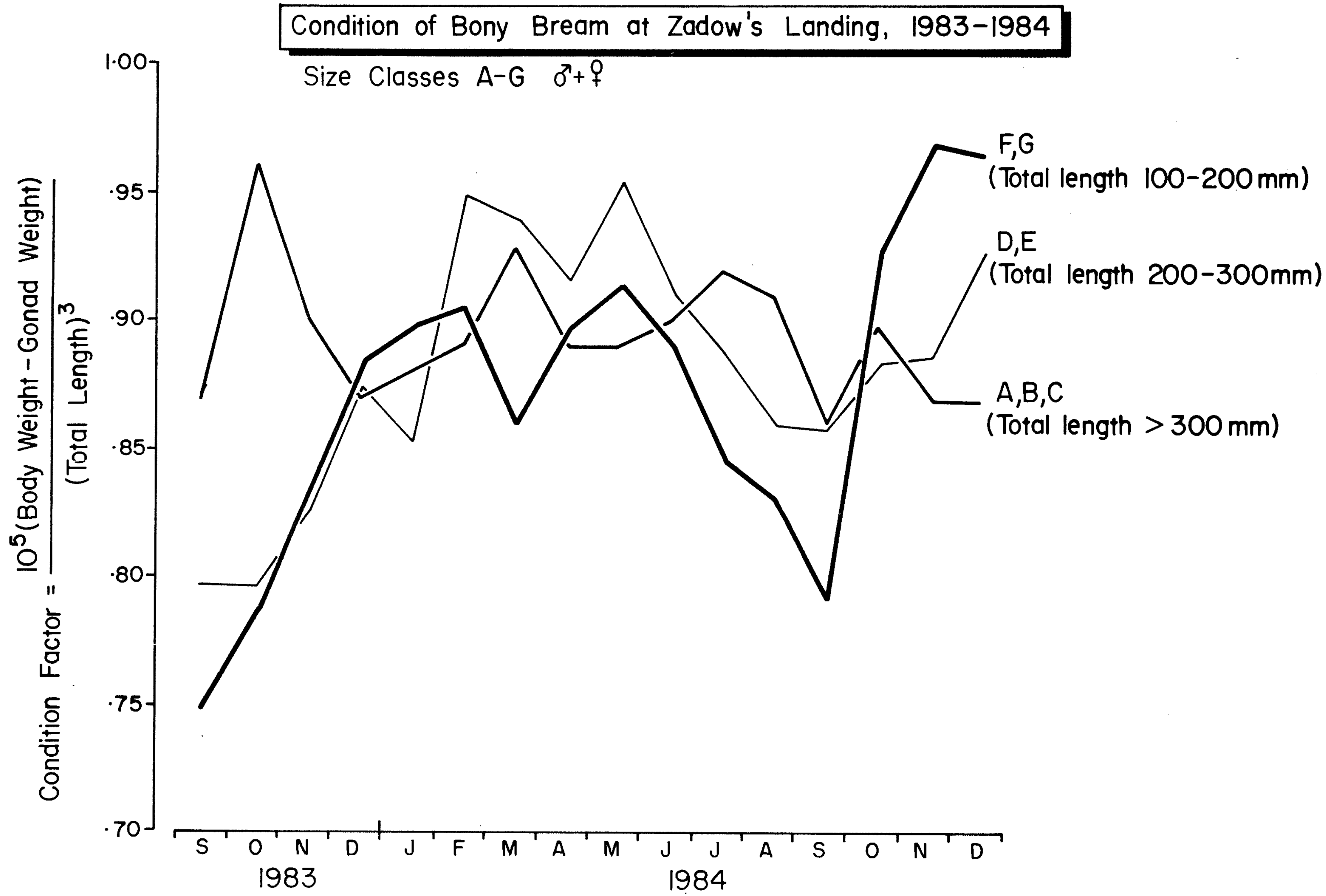


Adult bony bream maintained in outdoor ponds showed no interest in artificial foods, either pelleted, flaked or powdered, but either filter-fed in midwater while cruising in a school, or else browsed individually on the pool walls - presumably for filamentous algae. The above-mentioned study did not deal with diurnal or seasonal changes in feeding behaviour, and is unlikely to have covered the full dietary range of the species. In fact, other authors have found dietary items such as chironomids (Ruello 1976), phytoplankton or microcrustaceans depending on season (Bishop et al. in prep.) and benthic algae (Allen 1982) to comprise a major portion of the diet under different conditions, so the species is to some extent a dietary opportunist. Seasonality in feeding intensity is evident in the tropical waters, with a low in the early-wet season - the period of greatest breeding activity (Bishop et al. in prep.). Evidence on juvenile bony bream diurnal and long-term migration (Puckridge 1988) indicates that the species is highly mobile, capable of seeking out widely dispersed food concentrations. All gizzard shads are microphagous, but feed on a variety of items, such as foraminiferans and diatoms (Beumer 1978), phytoplankton (Kutkuhn 1957), detritus (Pierce, Wissing & Megrey 1977) and zooplankton (Saiki & Tash 1977).

### 3.4.2 Condition

Since gonad weight is deducted from body weight in the calculation of condition factor, this factor acts as an index of fatness exclusive of reproductive output. At ZL, smaller fish (100<TL<200 mm) show a distinct seasonal cycle, with a low in late winter - early spring and maximum in summer - autumn (Fig. 47). In fish of TL between 200 mm and 300 mm, a similar cycle occurs, but is less marked. In the majority

Fig.47


Condition of Bony Bream at Zadow's Landing, 1983-1984
Size Classes A-G ♂+♀
Condition Factor = $\frac{10^5(\text{Body Weight} - \text{Gonad Weight})}{(\text{Total Length})^3}$
1·00
·95
·90
·85
·80
·75
·70
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1983
1984
F,G
(Total length 100-200 mm)
D,E
(Total length 200-300mm)
A,B,C
(Total length >300 mm)

of fish, then, there is probably a winter fast. In the Magela Creek, condition peaks in late wet-early dry after the period of maximum feeding which follows flooding, and falls in the late dry (Bishop _et al_. in prep.). I+ Perth herring and O+-III+ _D_. _cepedianum_ show a pattern similar to that of young bony bream in the lower Murray (Pierce, Wissing, Jakorski, Givens & Megrey 1980, Chubb & Potter 1986). However, lower Murray bony bream of TL>300mm show a different pattern, with a short peak in early spring - perhaps associated with a pre-vitellogenic lipid accumulation - a steep fall during spawning in November-December, and a rise over late summer - autumn. Overall, fluctuations in condition are less than for smaller fish. The absence of a pronounced late winter low in condition may be due to the greater metabolic efficiency of larger fish (see Pierce, Wissing & Megrey 1981); the presence of a low during spawning may be due to the greater demands reproductive output makes upon this size-class. At ZL, there is no significant difference in log10 mean monthly condition (paired samples t-test) between the sexes for all size-classes together (Fig. 48), but males do have a significantly higher variability in untransformed mean condition than females on a monthly basis (F-test, $P<0.05$). Such extreme changes of condition may be some indication of greater stresses on males, which is also suggested by the reduced incidence of males in the larger size-classes, and by some evidence of higher mortality in older males than in older females. Prolonged spawning by males, as in _D_. _petenense_ (Johnson 1971) may account for higher male stress levels. The log-transformed mean condition of larger fish (TL>300mm) at PS and ZL is identical (Fig. 49), despite the significant difference in GSI between these sites. There is however a significant difference in the variance of untransformed means (F-test, $P<0.001$), suggesting that PS is a more stable environment for bony bream than ZL.

Fig.48

# CONDITION OF ♀, ♂ BONY BREAM AT ZADOW'S LANDING (ALL SIZE-CLASSES)

♂ Variance > ♀ Variance
$P < 0.05$ (F-TEST)

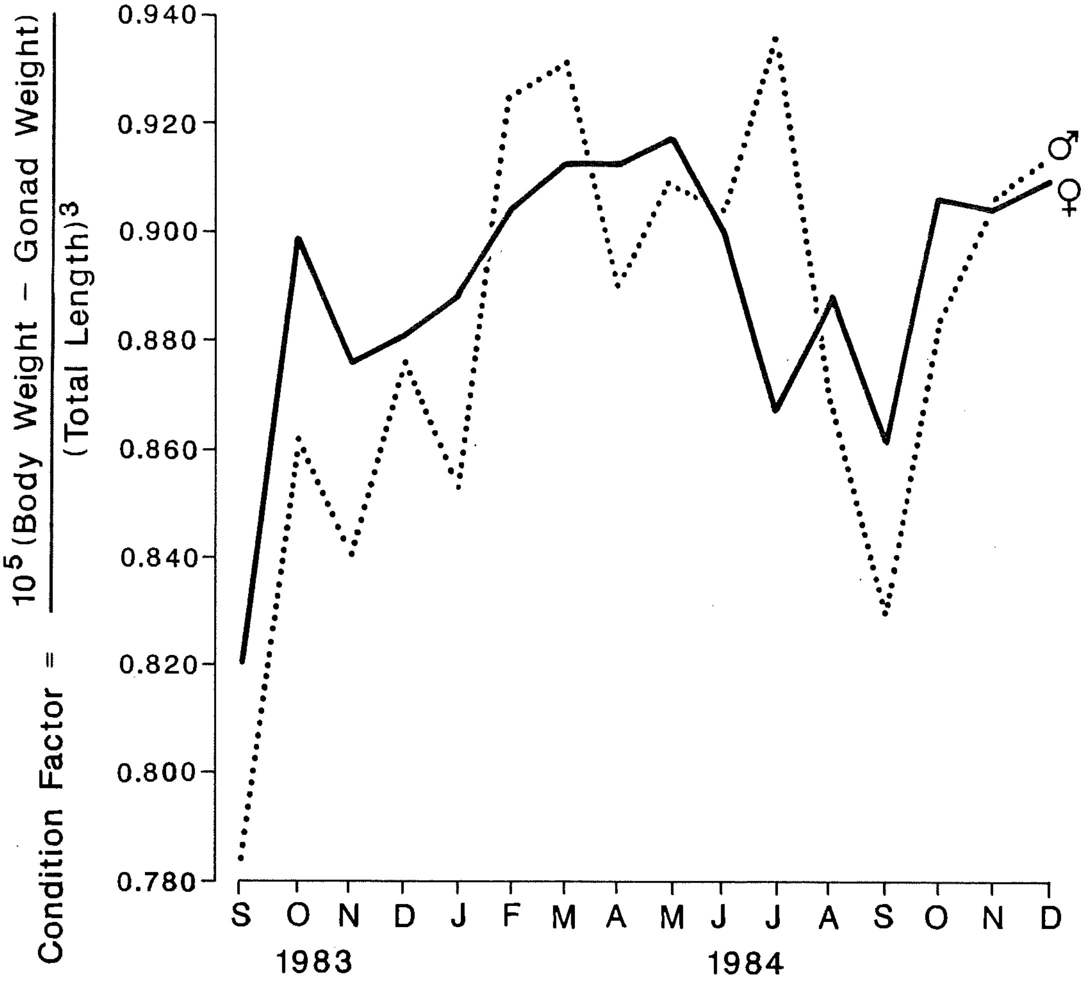
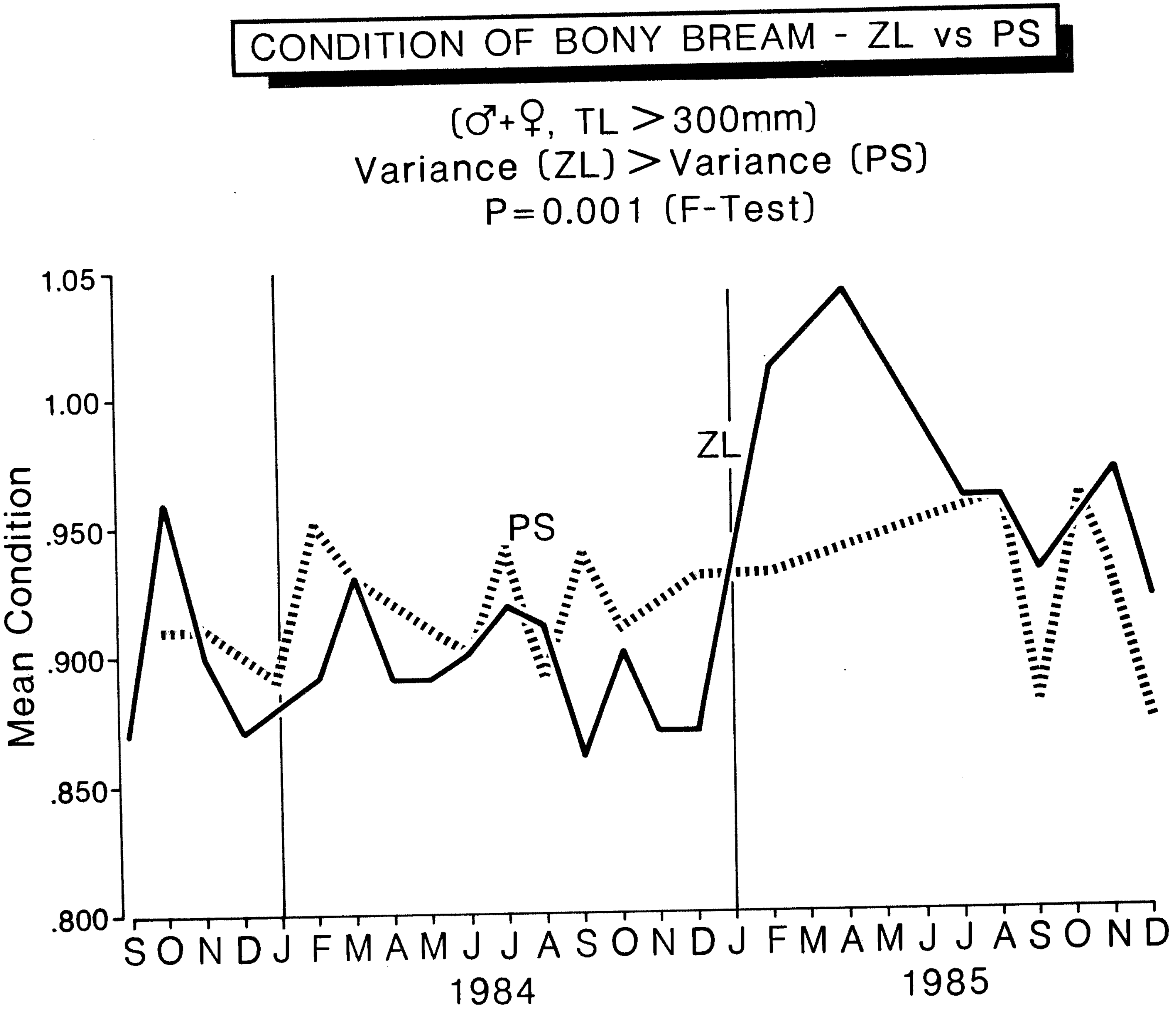


Fig.49


CONDITION OF BONY BREAM - ZL vs PS
(♂+♀, TL > 300mm)
Variance (ZL) > Variance (PS)
P=0.001 (F-Test)
Mean Condition
1.05
1.00
.950
.900
.850
.800
ZL
PS
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1984
1985

## 3.5 Age and growth

### 3.5.1 Weight - length relation

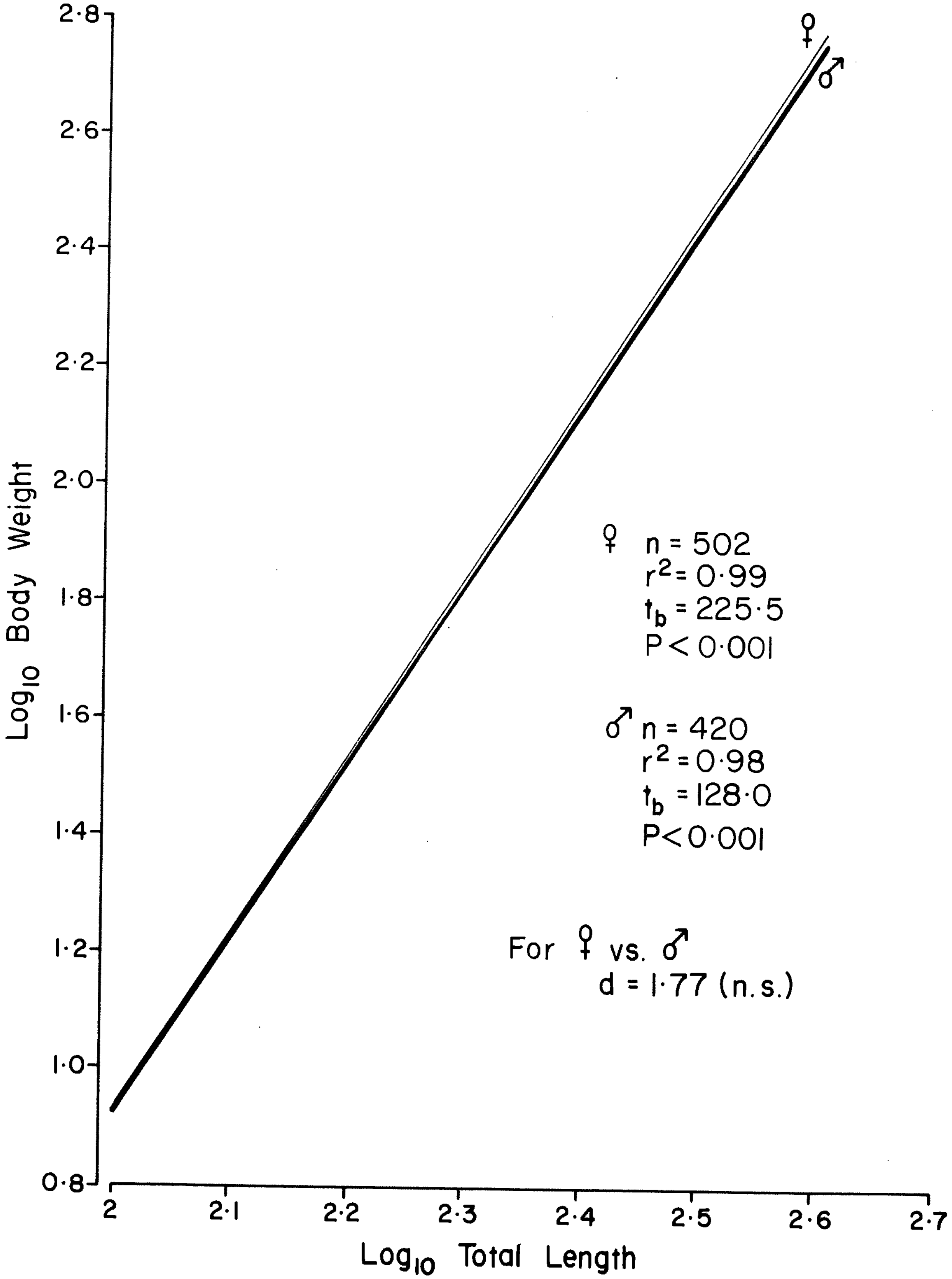
The slopes of the log 10 weight-log 10 total length relations for males and females over all seasons for 1983-85 (Fig. 50) are not significantly different (d statistic ) - a surprising result considering the significant difference in the TL - Body depth relations and the preponderance of females in the larger size-classes (shown above). Data for both sexes were combined to give an overall relation of the form log10 body weight (W) = -5.290 + 3.104 log10 TL. This may be compared with the equation log10 W = -1.92 + 3.12 log10 LCF for bony bream in the Magela Creek (Bishop et al. in prep.), which gives a very similar slope but a different intercept because LCF is used instead of TL. The equation log10 W = -5.1 + 3.04log10 TL for D. cepedianum (Jester & Jensen 1972) is very close in both intercept and slope, and demonstrates the uniformity of gizzard shad body shape.

### 3.5.2 Population structure

In summer, the population is dominated by young-of-the-year juveniles, as is illustrated by the plot of 2m, 18m, & 130m seine catches at PS corrected for area hauled (Fig. 51), and by the plot of gillnet catches for ZL (Fig. 52). Mortality of juveniles is evidently high, as catch declines exponentially with TL, but the rate stabilizes in older fish (at a TL of approximately 150 mm, age II+), and there is a relatively long-lived brood-stock which should give resilience to the population. A mortality curve cannot confidently be derived from these data, since the catches in the different seines, even when corrected for area hauled, are not strictly comparable. However the pattern is similar to that for D. cepedianum, where mortality of YOY may exceed 99% (Bodola 1966, Houser & Bryant 1967, Jenkins 1974).

Fig.50

Weight-Length Regressions for ♂,♀ Bony Bream at Zadow's Landing, 1983-1984



♀ n = 502
$r^2 = 0{\cdot}99$
$t_b = 225{\cdot}5$
$P < 0{\cdot}001$

♂ n = 420
$r^2 = 0{\cdot}98$
$t_b = 128{\cdot}0$
$P < 0{\cdot}001$

For ♀ vs. ♂
d = 1·77 (n.s.)

# DECEMBER LENGTH-FREQUENCIES OF SEINE CATCHES OF BONY BREAM AT POINT STURT

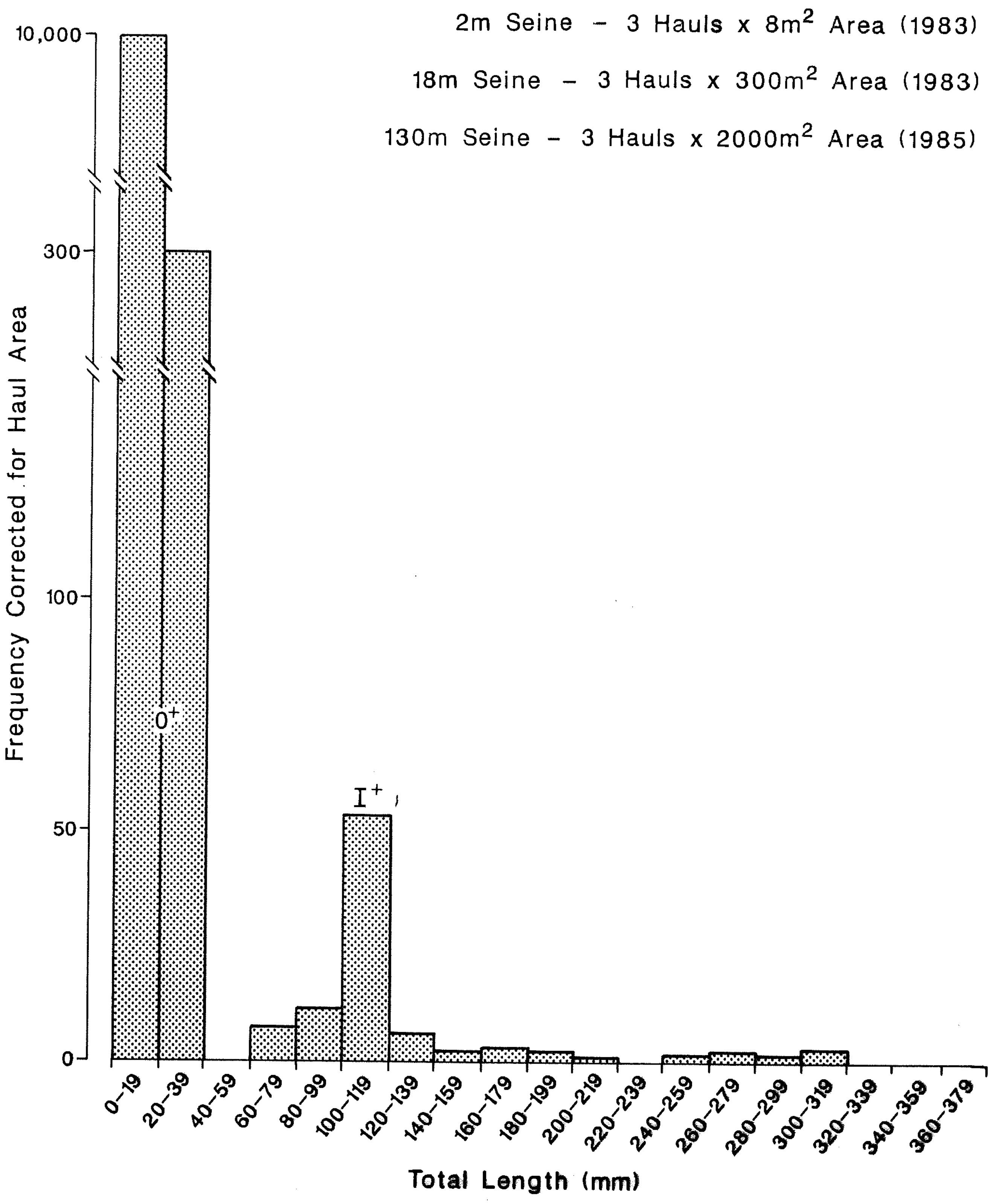
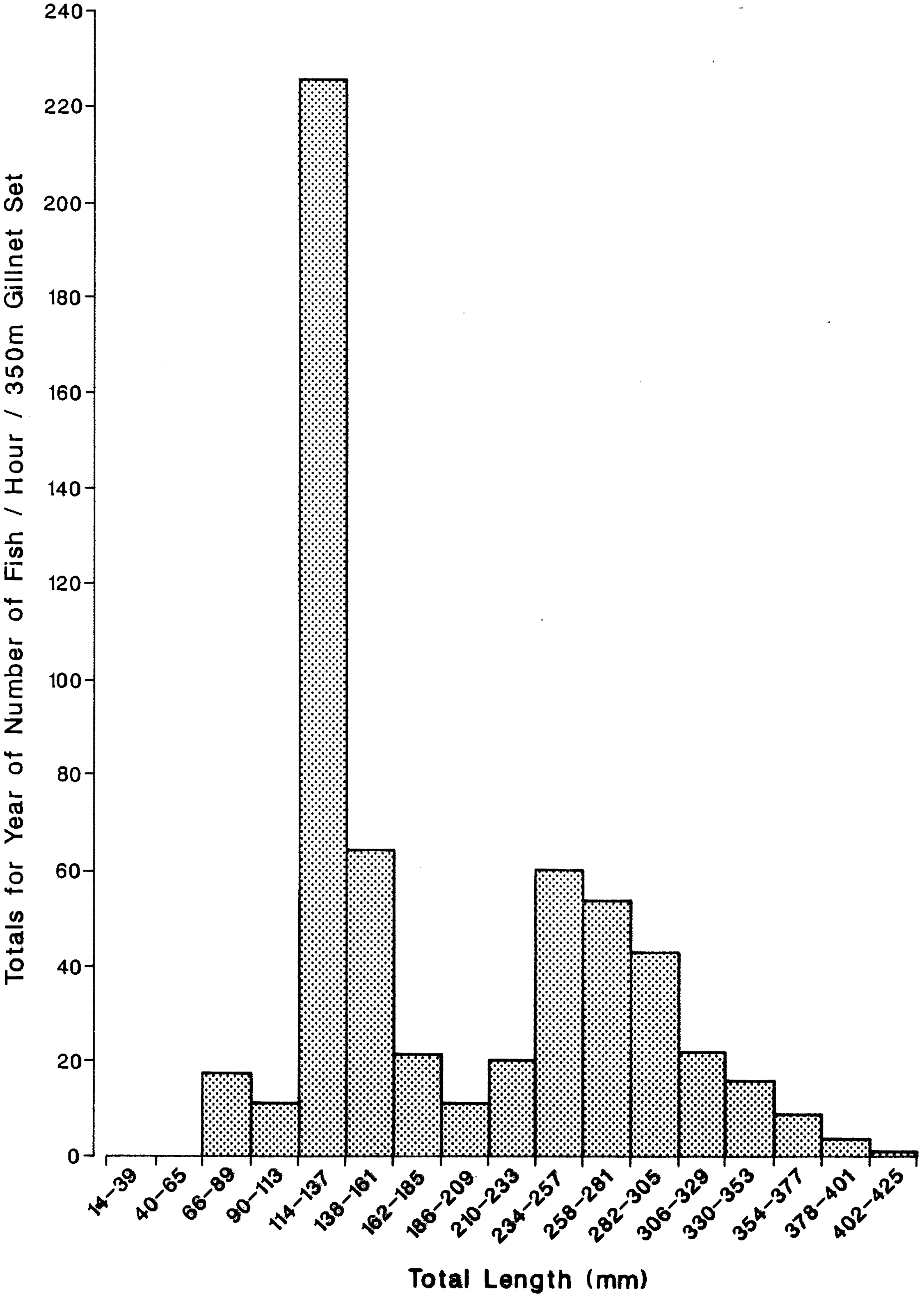


Fig.52



TOTAL GILLNET CATCH / EFFORT FOR BONY BREAM AT ZADOW'S LANDING, 1983 – 1984

### 3.5.3 Age

Bony bream have large readily shed cycloid scales, with well-marked annuli. Scale reading in bony bream provides useful data, but also presents certain difficulties. False annuli occur, particularly in certain positions such as between the first and second year-marks, but differ from year-marks chiefly in forming an incomplete and less distinct mark, and in being absent on more than 50% of scales from a given fish. The first annulus was often less distinct than those subsequently, but provided it was unbroken in both the anterior and posterior fields, it was accepted as a year-mark. Occasional deep scoring also occurs, and was not accepted as a year-mark. Blown or regrown scales invalidated some samples, particularly in older fish.

The plot of mean scale length beyond the last annulus shows a clear annual cycle in ages I+ and II+ fish, with the new annulus appearing in October-November, with Spring growth (Fig. 53). Growth beyond this annulus is rapid through Summer, and declines in Winter, with evidence of growth cessation and even scale resorption in June-July. The pattern for III+ fish is similar, but growth is much slower, and the period of annulus formation consequently less clearly marked. However it appears that the annulus is a valid year-mark for fish to age III+. (It should be noted that because annulus formation takes place in October, and spawning in December-January, there is a discrepancy between length at annulus and length at age.) Beyond this age, there is no clear annual pattern of growth and renewal of the post-annulus scale (Fig. 54). This may be because reproductive stress complicates annulus formation in older fish, or the growth increments are small and resorption at the scale edge is considerable during times of stress, or annulus formation in older fish only occurs in seasons of

Fig.53

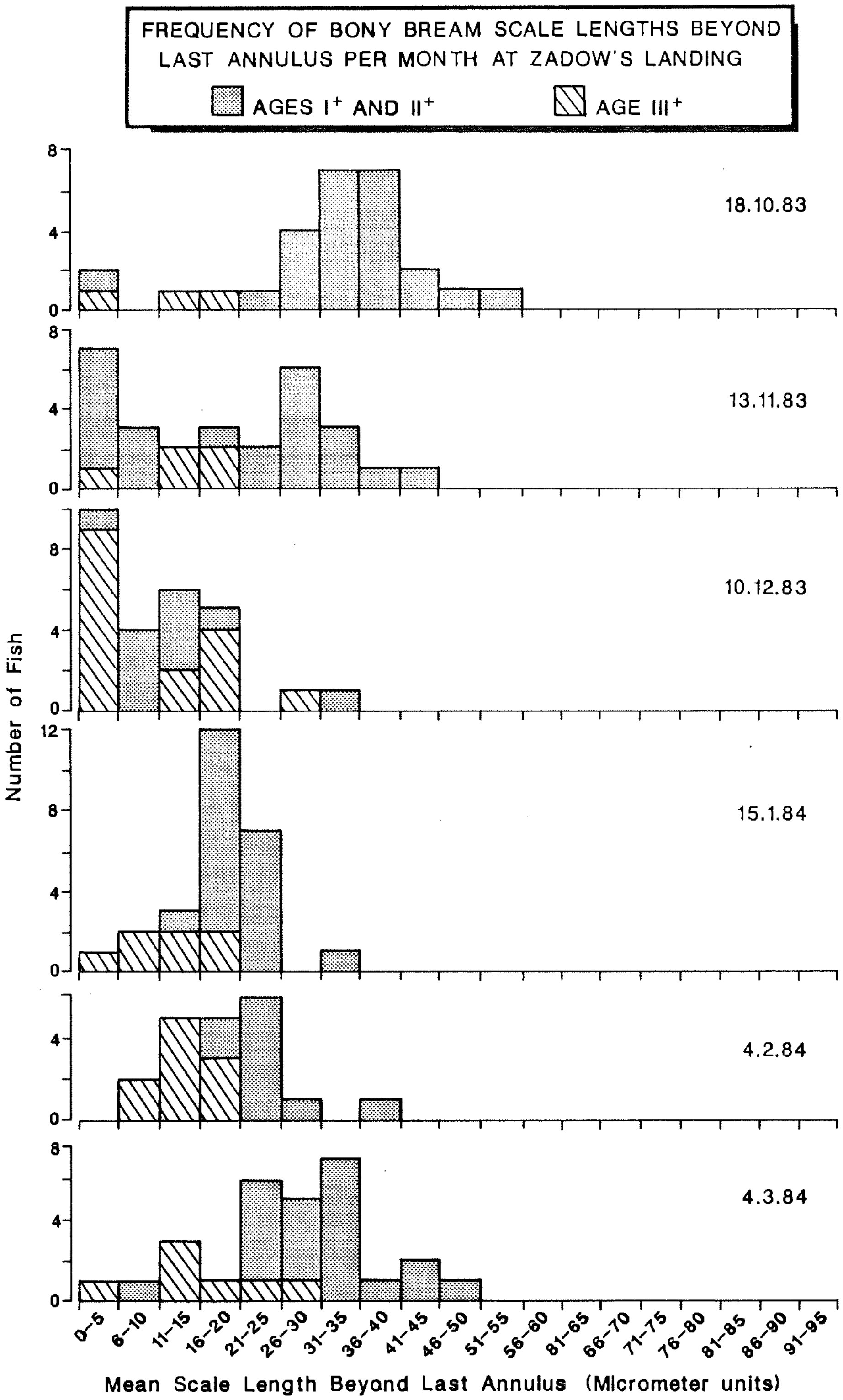

FREQUENCY OF BONY BREAM SCALE LENGTHS BEYOND LAST ANNULUS PER MONTH AT ZADOW'S LANDING
AGES I+ AND II+
AGE III+
18.10.83
13.11.83
10.12.83
15.1.84
4.2.84
4.3.84
Number of Fish
0
4
8
12
0-5
6-10
11-15
16-20
21-25
26-30
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
Mean Scale Length Beyond Last Annulus (Micrometer units)

Fig.53
(cont.)

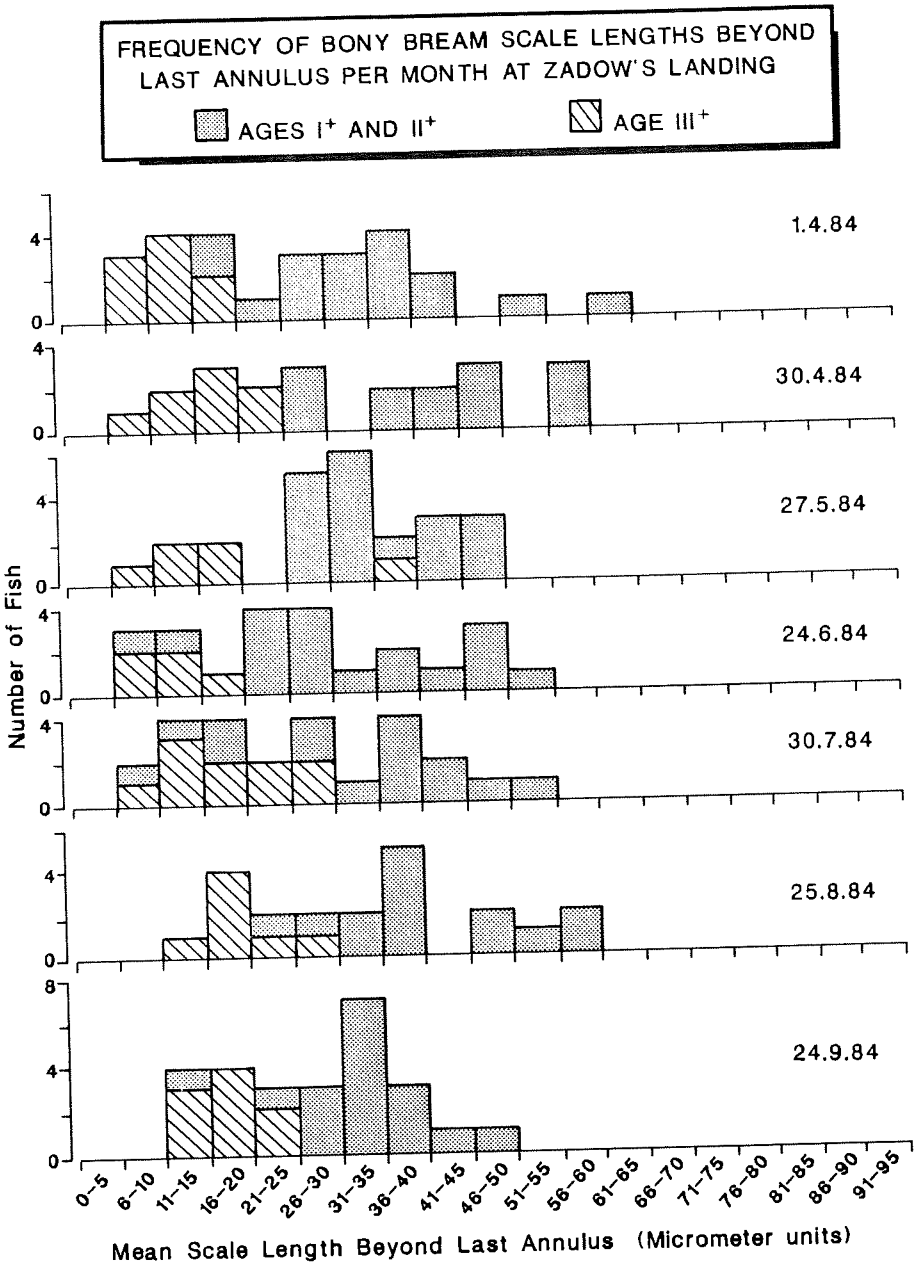

FREQUENCY OF BONY BREAM SCALE LENGTHS BEYOND LAST ANNULUS PER MONTH AT ZADOW'S LANDING
AGES I$^+$ AND II$^+$
AGE III$^+$
1.4.84
30.4.84
27.5.84
24.6.84
30.7.84
25.8.84
24.9.84
Number of Fish
0
4
8
0-5
6-10
11-15
16-20
21-25
26-30
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
Mean Scale Length Beyond Last Annulus (Micrometer units)

Fig.53

(cont.)

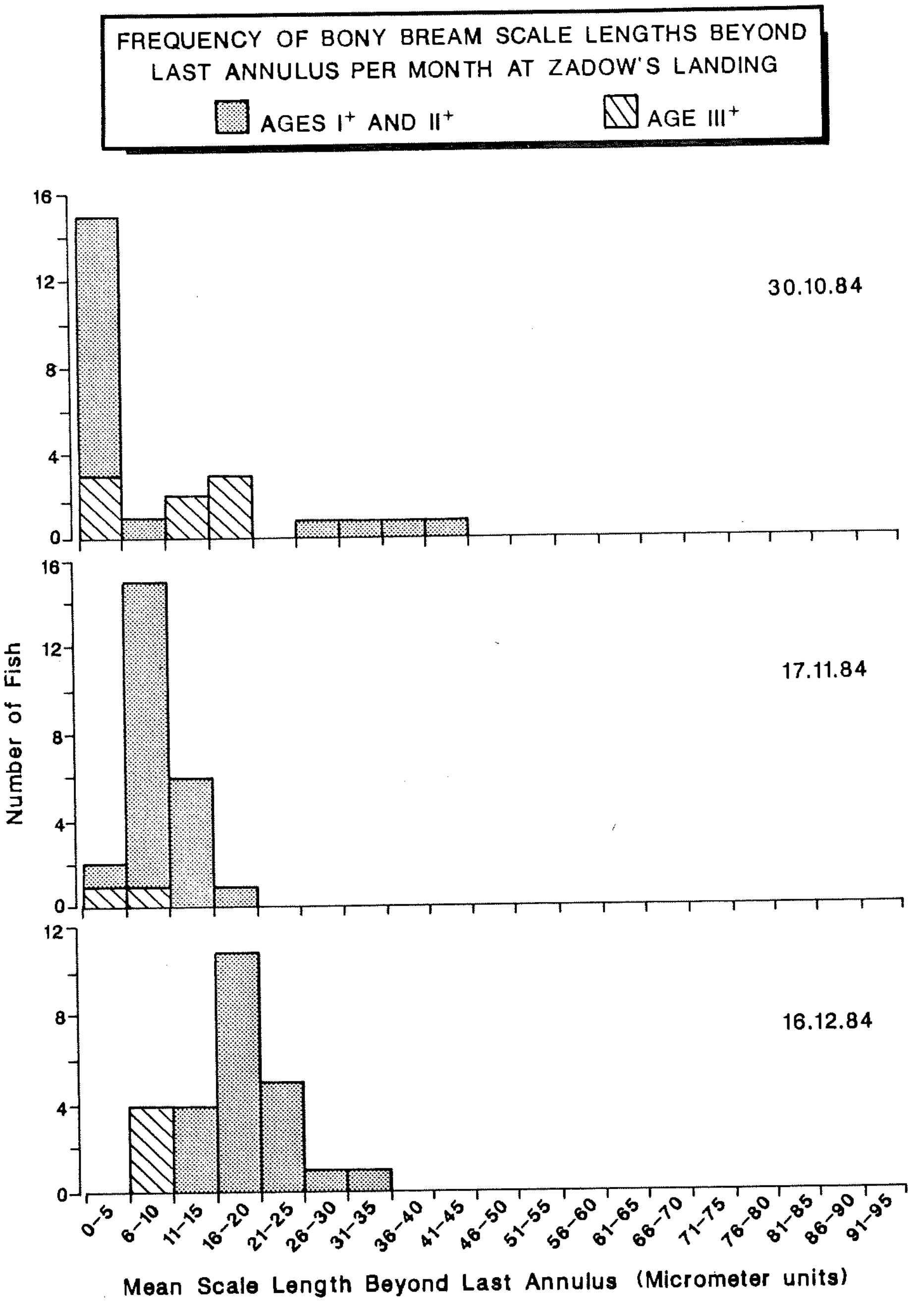

FREQUENCY OF BONY BREAM SCALE LENGTHS BEYOND LAST ANNULUS PER MONTH AT ZADOW'S LANDING
AGES I⁺ AND II⁺
AGE III⁺
30.10.84
17.11.84
16.12.84
Number of Fish
0
4
8
12
16
0-5
6-10
11-15
16-20
21-25
26-30
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
Mean Scale Length Beyond Last Annulus (Micrometer units)

Fig.54

FREQUENCY OF BONY BREAM SCALE LENGTHS BEYOND LAST ANNULUS PER MONTH AT ZADOW'S LANDING

AGES IV⁺ →

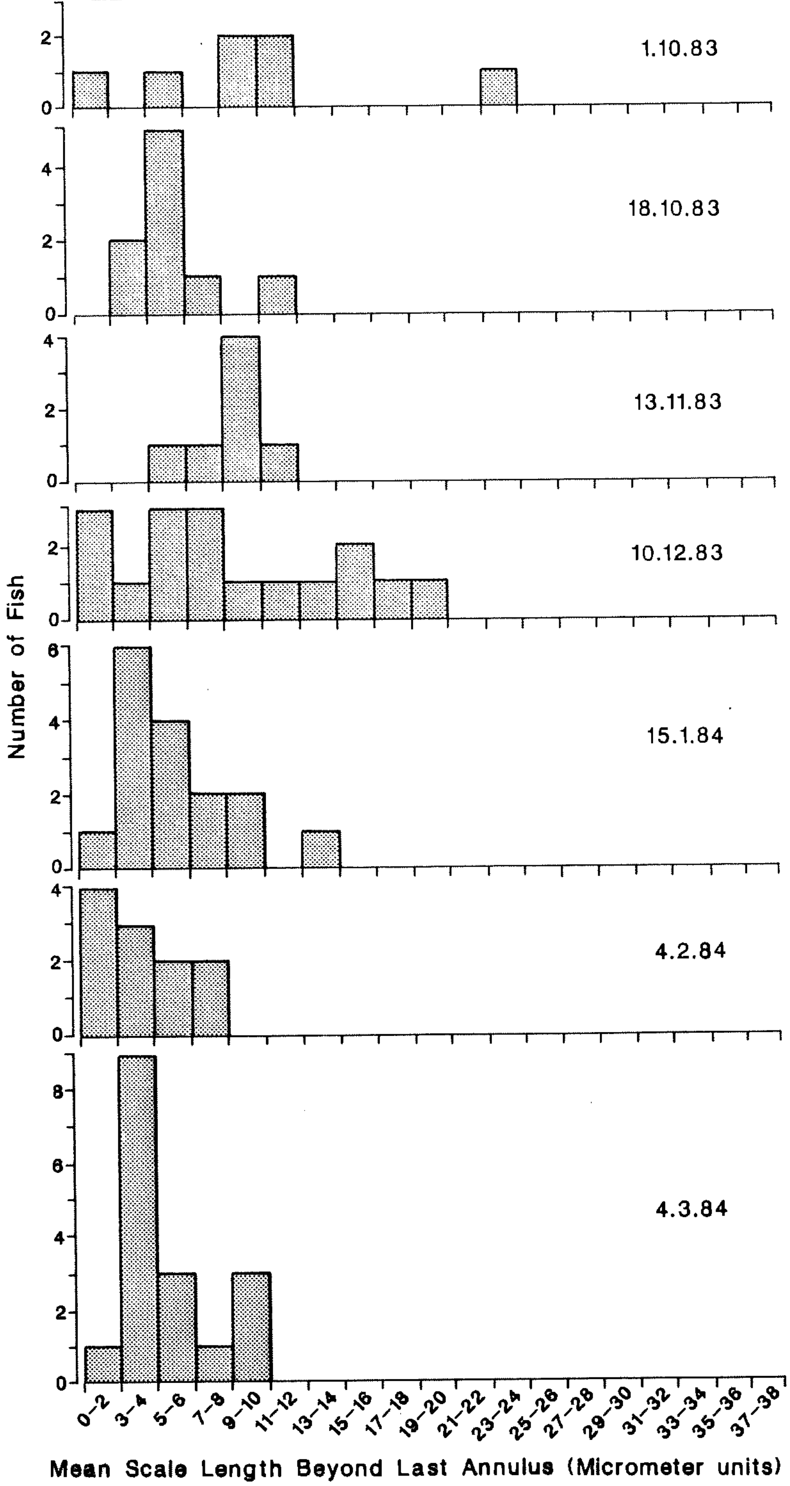
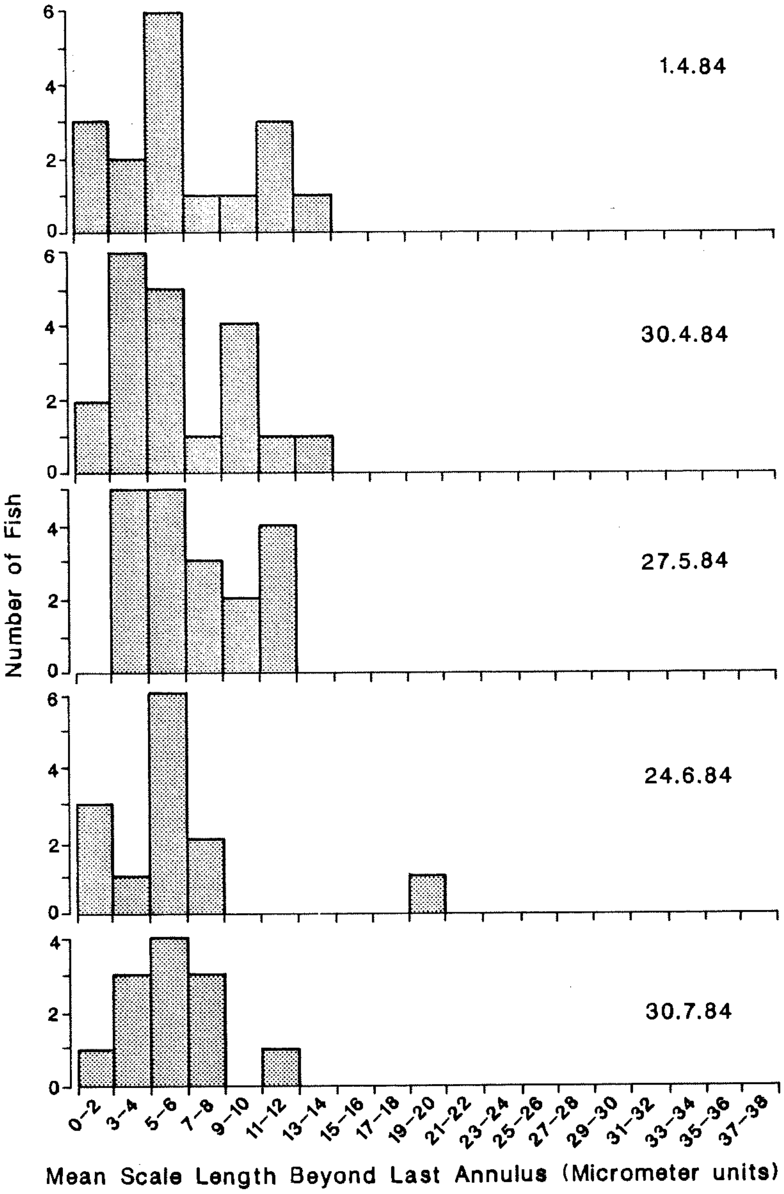


Fig.54
(cont.)

FREQUENCY OF BONY BREAM SCALE LENGTHS BEYOND LAST ANNULUS PER MONTH AT ZADOW'S LANDING

AGES IV+ →



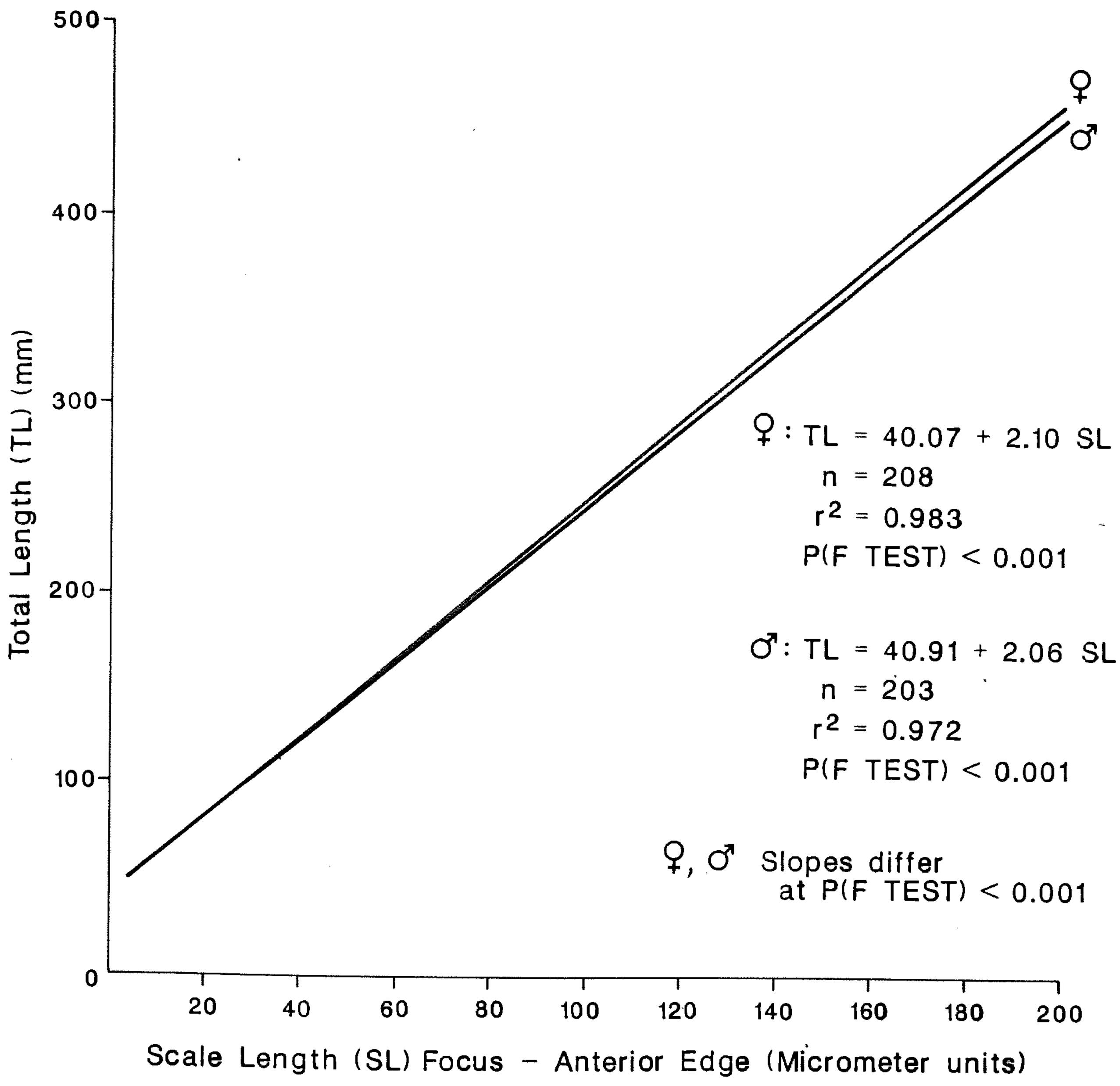
exceptional growth. Both a larger sample and calibration against another ageing technique will be necessary to elucidate this, but it seems most likely that scale ageing underestimates true age for older bony bream. (Calibration of scale ageing against ageing of fin-spine sections is proposed in collaboration with Dr. John Harris, of N.S.W. Fisheries.)

The scale length (SL)-total length (TL) regressions are highly significant for both sexes (F-test, P(females)<0.001, P(males)<0.001) Fig. 55); and the slopes of these regressions are significantly different (d statistic, P>0.001). Such a difference is unusual and difficult to explain in a species where sexual dimorphism is otherwise so slight. The final plots of total length at age (corrected from the respective male and female TL-SL regressions) give the expected assymptotic curve for both sexes, with rapid growth in the early years tapering off to negligible growth in older fish (Fig. 56). Rapid early growth may be advantageous, as it seems to be for D. cepedianum, to outgrow predators (Fagan & Fitzpatrick 1978).

Attempts to use ELEFAN I (Pauly & David 1981) to analyse gillnet and 130m seine catches for length - frequency peaks denoting age-classes were not successful, partly because of the selectivity of the gillnets, partly because of an apparent tendency of bony bream to school by size-class, and partly because beyond age II+, there is strong overlap of year-classes. No clear progression of age-class peaks is apparent in the gill-net length-frequency plot (Fig. 57). However, inspection of the length - frequency plots of 130m seine hauls for 1985-86 (Fig. 58) reveals a progression of peaks which trace the growth of ages O+ and I+. The October mean lengths of these age-classes - (O+ = 70 mm, I+ = 160 mm) correspond approximately with the lengths at annulus formation

Fig.55

BODY LENGTH vs SCALE LENGTH RELATION FOR BONY BREAM
AT ZADOW'S LANDING, 1983 – 1984

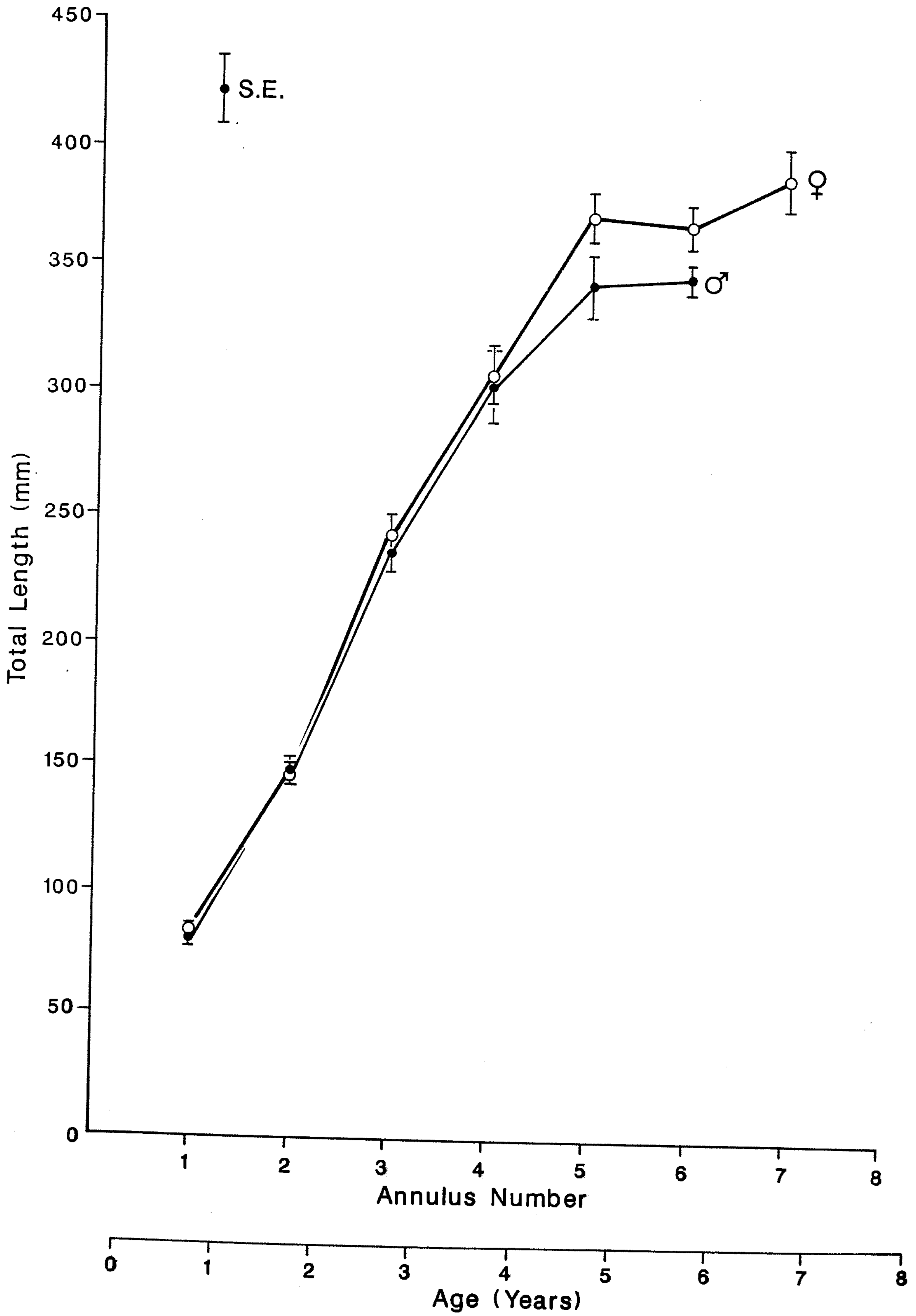


♀: $TL = 40.07 + 2.10\ SL$
$n = 208$
$r^2 = 0.983$
$P(F\ TEST) < 0.001$

♂: $TL = 40.91 + 2.06\ SL$
$n = 203$
$r^2 = 0.972$
$P(F\ TEST) < 0.001$

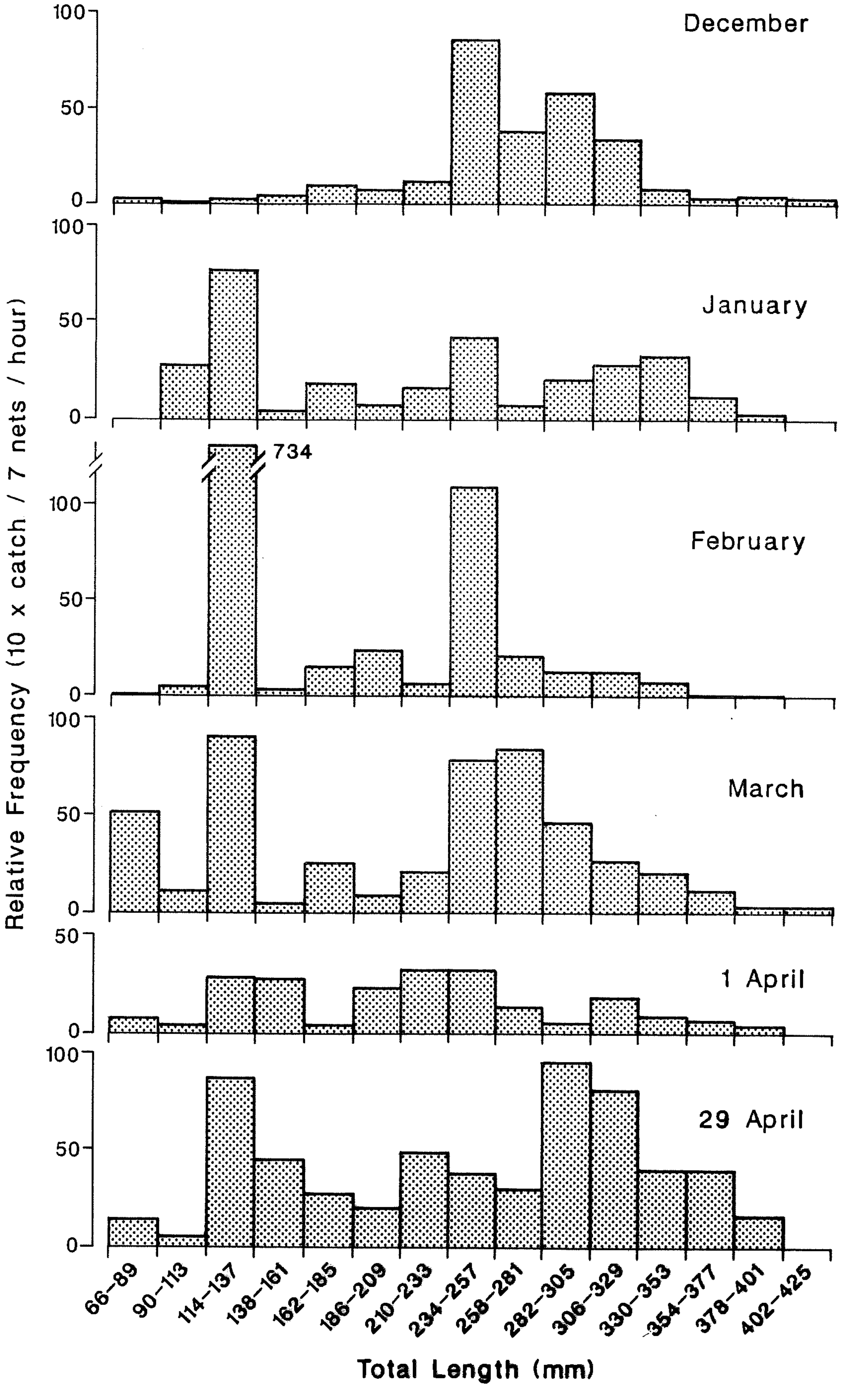
♀, ♂ Slopes differ
at $P(F\ TEST) < 0.001$

# GROWTH CURVES FOR ♂, ♀ BONY BREAM AT ZADOW'S LANDING, 1983 - 1984



LENGTH-FREQUENCIES OF MONTHLY GILLNET CATCHES OF BONY BREAM AT ZADOW'S LANDING, 1983 - 1984

Fig.57



# LENGTH-FREQUENCIES OF MONTHLY GILLNET CATCHES OF BONY BREAM AT ZADOW'S LANDING, 1983 - 1984

Fig.57

(cont.)

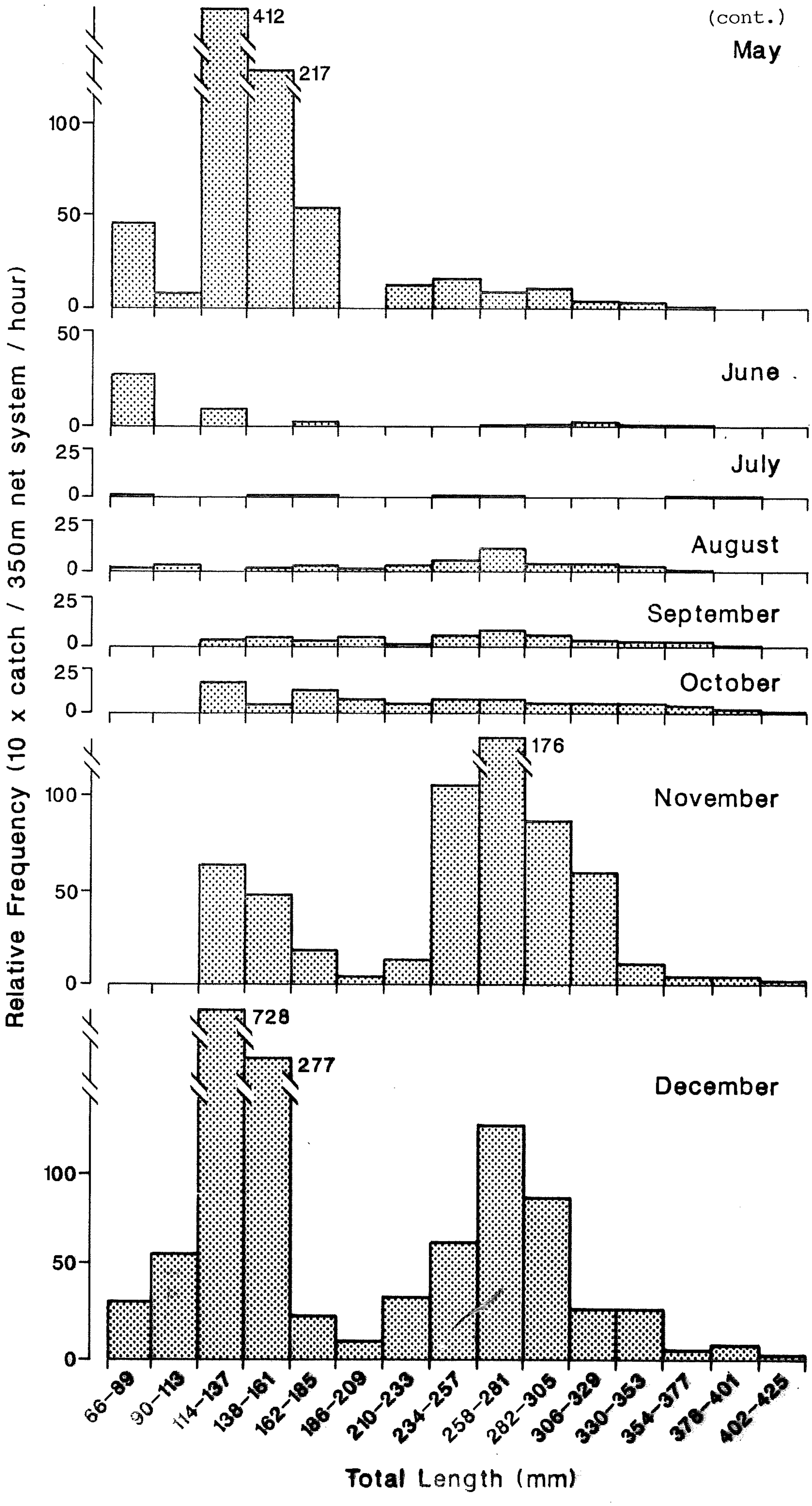
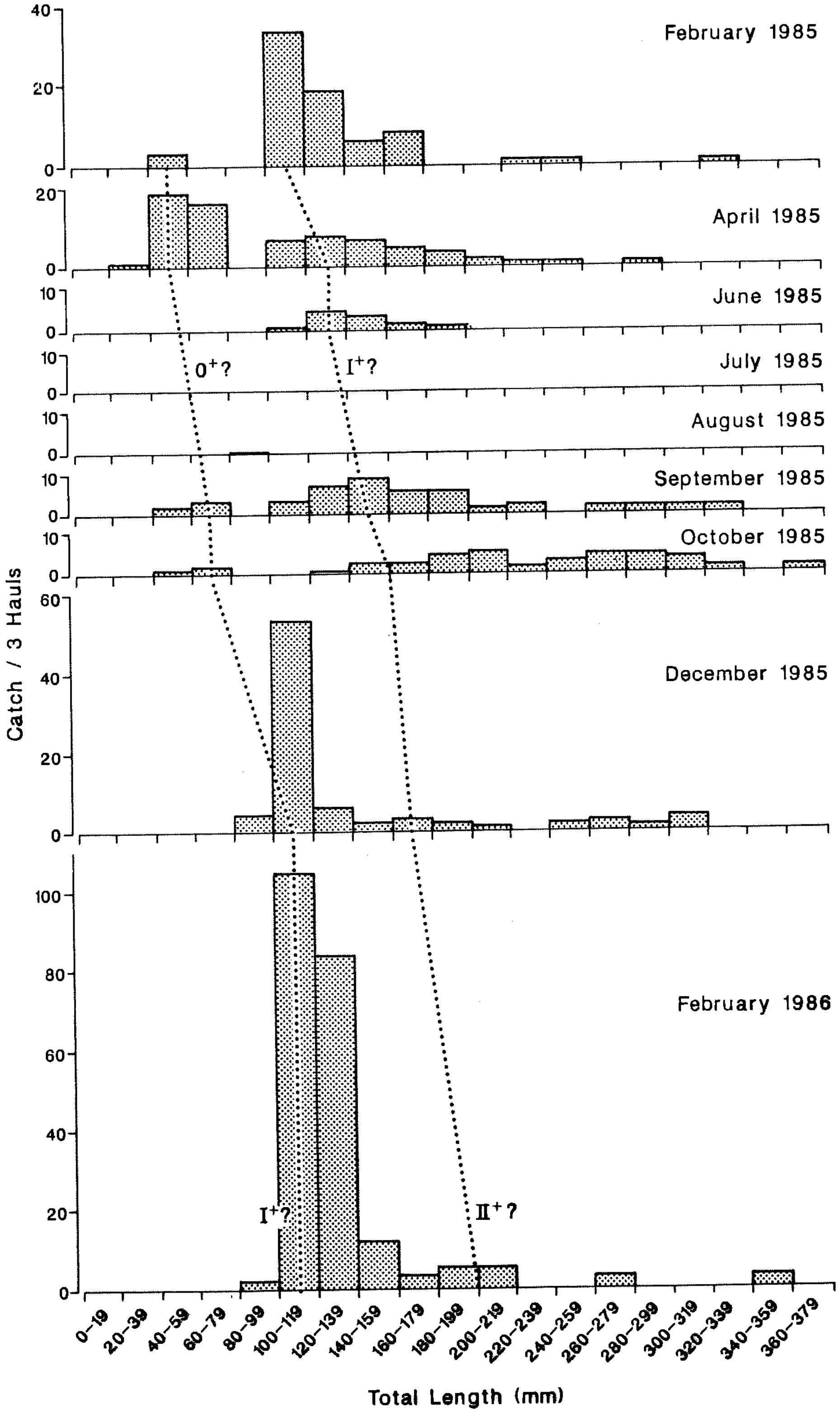


Fig.58

LENGTH-FREQUENCIES OF 130m SEINE CATCHES OF BONY BREAM AT POINT STURT



(i.e. in October) derived from scale analysis (i.e.length at annulus I = 81, at II = 148 mm). Considering that the 130m seine data is for a different year than the scale data, this correspondence is good, and provides further validation of the scale-ageing of these age-groups.

Since only the first three years' data is based on validated year-marks, the rest of each curve (for older fish) must be considered provisional. Furthermore, the necessity to age a random sample from the population (to avoid distortion of the curve) means that numbers in the higher year-classes are low. However, weighted mean back-calculated total lengths at each annulus (Table 3) correspond well with directly observed lengths at all ages except II, so it was thought worthwhile to provide a complete analysis of the curves. Of the range of curves fitted to the age-TL data, the best fit for both sexes is provided by quadratic equations; for females TL = -44.9 + 123.3A - 8.7A2 (r2 = 0.98, P(F-test)<0.001), and for males TL = -44.3 + 123.6A - 9.6A2 (r2 = 0.99, P(F-test)<0.001). Von Bertalanffy curves were fitted by the method of Rafail (1973), and provided significant curves (males P(Chi-square)<0.001, females P(Chi-square)<0.005) which were quite different for the two sexes (Table 4). In particular, K and Lmax were 0.44 and 369.5mm for males, 0.11 and 745.9 for females. This may be compared with K = 0.17 and Lmax = 381 mm for the Perth herring, both sexes combined (Chubb & Potter 1986). Male bony bream appear to reach maximum size much faster, females slower than this cogener. Actual maximum ages and lengths observed (but not included in the age-length curve) were 10 years and 480mm for females, 8 years and 405 mm for males. Over the whole range, female mean lengths at age are significantly higher than male (paired samples t-test, P<0.02), and this difference increases with age. However, a comparison of the slopes of

Table 3

## BONY BREAM: MEAN BACK-CALCULATED TL (MM)AT EACH ANNULUS

AGE GROUP N - FEMALES

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 1 | 72 | 81.7 | | | | | | |
| 2 | 49 | 78.5 | 147.3 | | | | | |
| 3 | 22 | 83.9 | 175.6 | 244.6 | | | | |
| 4 | 8 | 98.2 | 191.1 | 269.5 | 309.2 | | | |
| 5 | 4 | 118.7 | 196.9 | 269.1 | 315.3 | 372.0 | | |
| 6 | 7 | 88.1 | 166.8 | 240.0 | 295.4 | 335.9 | 369.9 | |
| 7 | 3 | 93.9 | 186.9 | 264.1 | 314.5 | 337.8 | 360.4 | 388.8 |
| WEIGHTED MEANS | | 83.2 | 162.6 | 252.0 | 306.6 | 346.6 | 367.1 | 388.8 |

AGE GROUP N - MALES

| | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | 81 | 80.2 | | | | | |
| 2 | 42 | 79.2 | 148.4 | | | | |
| 3 | 23 | 84.9 | 175.6 | 236.7 | | | |
| 4 | 5 | 98.8 | 192.9 | 268.0 | 302.6 | | |
| 5 | 6 | 95.9 | 170.5 | 241.8 | 293.0 | 344.0 | |
| 6 | 3 | 83.4 | 153.6 | 220.1 | 270.8 | 313.1 | 347.5 |
| WEIGHTED MEANS | | 81.8 | 161.0 | 240.4 | 291.7 | 333.7 | 347.5 |

# VON BERTALANFFY GROWTH FOR BONY BREAM IN THE LOWER MURRAY

| SEX | AGE | OBS. TL | EXP. TL | EQUATION |
|---|---|---|---|---|
| MALE | 1 | 80.2 | 51.7 | Lt = 370[1-e(-.44(t-.66))] |
| | 2 | 148.4 | 164.4 | P(Chi-square)<0.001 |
| | 3 | 236.7 | 237.2 | |
| | 4 | 302.6 | 284.1 | |
| | 5 | 344.0 | 314.4 | |
| | 6 | 347.5 | 334.0 | |
| | 7 | 349.0 | 346.6 | |
| FEMALE | 1 | 81.7 | 105.2 | Lt = 746[1-e(-.11(t-.38))] |
| | 2 | 147.3 | 171.9 | P(Chi-square)<0.005 |
| | 3 | 244.6 | 231.6 | |
| | 4 | 309.2 | 285.1 | |
| | 5 | 372.0 | 333.1 | |
| | 6 | 369.9 | 376.0 | |
| | 7 | 388.8 | 414.5 | |

the male and female linear log-log regressions shows no significant difference (d-statistic). There is no difference in the growth curves of males and females for D. petenense, but males have a higher mortality rate (Johnson 1970). Male and female Perth herring show no significant difference in mean lengths at age or in the slopes of the scale radius - total length regressions (Chubb & Potter 1986).

A clear seasonal pattern of growth is not evident in the length - frequencies of 130m seine catches, partly because of the winter collapse in catches, partly because samples were too infrequent. The lengths at age, maximum lengths and maximum ages derived in this study may be compared with those suggested for bony bream in the middle Murray (Cadwallader 1977) and in the Magela Creek (Bishop et al. in prep.), with the Perth herring in the Swan estuary (Chubb & Potter 1986), and with D. cepedianum at two sites in the United States (Bodola 1966, Jester & Jensen 1972) (Table 5). There is great variation in growth rate of D. cepedianum from different parts of the United States, with populations growing both faster and slower than bony bream. There is a similar contrast between growth rates estimated for bony bream in the middle and lower Murray; the present study gives a slower overall growth rate and greater longevity than either Cadwallader (1977) or Bishop et al. (in prep.). The Perth herring has more rapid early growth, but grows more slowly after age II. The bony bream in the present study was found to be as long-lived and to grow nearly as large as D. cepedianum.

# GIZZARD SHADS - MEAN LENGTHS AT ANNULI

*Dorosoma cepedianum* (Jester & Jensen 1972) (Miller 1960)

| Annulus | I | II | III | IV | V | VI | VII | VIII | AMAX | LMAX | WMAX |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean TL | 94 | 151 | 183 | 219 | 254 | 273 | 291 | 324 | X | 521 | |
| *Dorosoma cepedianum* (Bodola 1966) | | | | | | | | | | | |
| (male) | 141 | 273 | 313 | 343 | 349 | | | | | | |
| (female) | 140 | 285 | 335 | 364 | 386 | | | | | | |
| *Nematalosa vlaminghi* (Chubb & Potter 1986) | | | | | | | | | | | |
| | 90 | 162 | 172 | 200 | 218 | 271 | 311 | 286 | | 361 | 555 |
| *Nematalosa erebi* (Cadwallader 1977) (Llewellyn 1983) | | | | | | | | | | | |
| | 67 | 173 | 245 | 340 | 387 | | | | | 470 | 2000 |
| *Nematalosa erebi* (Bishop et al in prep.) | | | | | | | | | | | |
| | 186 | | | | | | | | | | |
| *Nematalosa erebi* (Present study) | | | | | | | | | | | |
| (male) | 80 | 148 | 237 | 303 | 344 | 348 | | | VIII | 405 | 574 |
| (female) | 82 | 147 | 245 | 309 | 372 | 370 | 389 | | X | 480 | 953 |

## 4. SUMMARY

1. The bony bream is the dominant fish species in the lower Murray.

2. The lake site is favoured over the river site by older fish and as a breeding ground.

3. Breeding is distinctly seasonal, not flood-cued. A single batch of ova is spawned per season.

4. Eggs and larvae are small and the yolk-sack period is short.. Early larvae are identifiable from myomere count, later larvae from dorsal fin position.

5. Males are less abundant overall and particularly in the larger size-classes.

6. Fecundity is high and increases with fish size, as does reproductive effort.

7. Bony bream mature early, males earlier than females, but females rapidly overtake males.

8. Juvenile bony bream are planktivorous, adults are filter-feeding detritivores.

9. In young fish, condition is low in late Winter, probably reflecting a Winter fast. Older fish maintain a more stable condition over Winter, but show a more pronounced effect of spawning stress. Condition in males is more variable than in females.

10. Mortality is very high in 0+ fish, but falls steeply after age III, so there is a large stable population of older fish.

11. Growth is rapid in the first four years of life, but declines from about age five and TL 340-360 mm. Females grow larger and live longer than males. Seasonal growth reflects the cycles shown in condition, with a winter halt or even recession in young fish.

Bony bream are in many respects typical gizzard shads. They feed low in the food chain, have high reproductive potential and high early mortality, favour warm, turbid, shallow waters, are stressed by Winter cold, and are characteristically abundant. However, in some respects bony bream (at least in the lower Murray) are less typical. They are exceeded in maximum size only by _D. cepedianum_, and are probably equally long-lived. Longevity gives their populations security against extinction of the broodstock by, for example, prolonged drought. Large size may lower mortality by improving metabolic efficiency, reducing cold stress, and giving immunity from all but the largest predators. These advantages coexist with the early sexual maturity which gives gizzard shads the capability for rapid population recovery. Further, bony bream seem able to flourish on a diet (of fine detritus) which is at a lower trophic level than that of most gizzard shads, and gives them - in Australia's turbid waters- an ample and secure food base.

## 5. RECOMMENDATIONS

### 5.4 The bony bream fishery

(i) Principal mortality in the population is in the 0+ year-class. This is clearly not due to the fishery. However, if the fishery were to expand substantially - for example to produce a canned or minced product-consideration should be given to focussing effort on this age-class, perhaps using surface trawls.

(ii) Mortality in older fish appears to be low; bony bream longevity is high for a gizzard shad, and there is a substantial population of older fish. The fishery is not having an obvious effect on this population. However, population stability depends on retaining a brood stock of older fish, which are highly fecund, and will tide over years of poor recruitment. Monitoring of the population age-structure therefore should be a priority.

(iii) The fishery is heavily dependent on the lakes environment both for the bulk of the catch, and because of major spawning off the lake shores. Although bony bream are well-adapted to a flood-drought hydrology (Puckridge 1988), a change to the hydrological regime of the lakes might drastically alter spawning and migration patterns. The likely impact of any such change should be thoroughly researched.

(iv) Restoration of estuarine conditions, for example by relocation of the barrages, could be an effective way of converting bony bream biomass into biomass of more commercially valuable species, such as mulloway. It would be likely, however, to substantially reduce population densities of bony bream.

(v) The bony bream fishery uses minimum gillnet mesh sizes of 50 mm, which catch fish of mean TL = 138-209 mm. The median lengths at maturity are 159mm for males, 199mm for females. Therefore some reproduction is taking place before recruitment to the fishery, but pre-reproductive fish are being caught. This does not appear to be affecting stocks at present, but there is potentially a problem here. Proportions of fish caught commercially in the different mesh sizes through the year need to be determined, and if the pre-reproductive catch is high, consideration should be given to lifting the minimum mesh size to 70 mm and/or targeting high mortality 0+ fish.

(vi) A research program into some of the questions raised by this study should be considered, for example:

a. What is the overall pattern of spawning grounds in the lower Murray?

b. What are the seasonal and diurnal patterns of movement of bony bream juveniles and adults in the lower Murray?

c. To what extent are the lake and river populations separate stocks?

d. How does the size-structure of the commercial catch relate to the length - % maturity relation?

e. What are the natural and fishing mortality rates in the population?

f. What are the present and future prospects for higher-value commercial uses (e.g. canning, pickling) of this substantial resource?

## 5.2 Bony bream as a forage fish

(i) Criteria for evaluating the suitability of potential forage species have been developed for the United States impoundment stocking programs (Ney 1981). Suitable species must be:

a. Prolific - i.e. have high reproductive potential: Bony bream, with early maturity and high fecundity, have exceptional reproductive potential.

b. Stable in abundance: Bony bream catch rates have been relatively stable in the last five years. The longevity of bony bream provides stability to the broodstock, and conditions in the impoundment environments intended for stocking are likely to be stable.

c. Trophically efficient - i.e. feed at a low trophic level: Adult bony bream, more than almost any other Australian freshwater fish, fulfil this requirement.

d. Vulnerable to predation: Juvenile bony bream form a major component of the diets of many of the major freshwater commercial species. However adult bony bream are only vulnerable to top predators like Murray cod, barramundi and ariid catfishes. Situations of over-abundance of larger, predator-proof gizzard shads in United States impoundments are now dealt with by stocking top predators (Noble 1981).

e. Non-emigrating: Bony bream, particularly juveniles, are certainly mobile in unregulated river systems, and are effective colonizers (Kowarsky & Ross 1981, Puckridge 1988). However, since they are naturally widespread in nearly all Australian warmwater catchments, such colonization should not normally be cause for concern.

f. Innocuous to other species: Larval and juvenile bony bream are zooplanktivores, and so will compete for food with the young of predator species. However, larval fish of any forage species would do the same. Bony bream have the advantage of being indigenous to most catchments, and so the larvae of most local predator species should have adapted to compete with larval bony bream. Adult bony bream, being unique in Australian freshwaters as microphagic detritivores, have no substantial trophic competition with other indigenous species.

(ii) Additional features

a. Bony bream are pre-adapted to impounded waters. Their spawning is not flood-dependent, and impoundment provides an enlarged and stable sediment surface upon which to feed (see also Miller 1960, Jacobs & Swink 1983). Bony bream are not apparently dependent on high densities of aquatic macrophytes, and flourish in the open, less vegetated waters often found in impoundments.

b. Bony bream are relatively free of parasites, although they are found in the lower Murray with occasional trematode cercaria. They are subject to attack by the fungi Saprolegnia and Achlya; the former is species-specific, but the latter, which is common in warmer northern waters, affects a range of species, and could be a problem in sub-optimal conditions.

c. Adults are not readily maintained in captivity. They show no interest in artificial diets, and appear to require waters with a high suspended load and algal densities, which they collect by skimming or mid-water filter-feeding, usually in schools. Therefore intensive aquaculture of the species would be difficult. However they flourish in earthen ponds and dams.

## 6. REFERENCES

ALLEN G.R. (1982) pp. 28-31 In A field guide to the inland fishes of Western Australia. W. Aust. Mus. Perth. 28-31

ANNIGERI G.G. (1967) Maturation of the intra-ovarian eggs and the spawning periodicities in a few fishes of the Mangalore area based on ova-diameter measurements. Indian J. Fish. 10:23-32.

ATKINS B. (in prep) Feeding ecology of Nematalosa erebi in the lower Murray River.

BABU RAO M. (1965) Biological studies on the gizzard shad Anodontostoma chacunda (Hamilton). J. Mar. Biol. Ass. India. 7(1):89-101.

BAGLIN R.E. & KILAMBI R.V. (1968) Maturity and spawning periodicity of the gizzard shad (Dorosoma cepedianum) in Beaver Reservoir. Proc. Arkansas Acad. Sci. 22:38-43.

BAILEY N.T.J. (1959) Statistical Methods in Biology. Hodder & Stoughton, London.

BALON E.K. (1975) Reproductive guilds of fishes: a proposal and definition. J. Fish. Res. Bd. Can. 32(6):821-864.

BEACHAM T.D. (1983) Variability in median size and age at sexual maturity of cod <u>Gadus</u> <u>morhua</u> on the Scotian shelf in the Northwest Atlantic Ocean. U. S. Fish. Wildl. Serv. Fish. Bull. 81(2):303-321.

BEUMER J.P. (1978) Feeding ecology of four fishes from a mangrove creek in North Queensland. J. Fish. Biol. 12(5):475-490.

BISHOP K.A., ALLEN S.A., POLLARD D.A. & COOK M.J. (in prep) Ecological studies on the freshwater fishes of the Alligator Rivers region IV: Autecology of families Carcharhindae to Plotosidae). Supervising Scientist Report Series (SSR28).

BODOLA A. (1966) Life history of the gizzard shad <u>Dorosoma</u> <u>cepedianum</u> (Le Seur) in western Lake Erie. Fish. Bull. U.S. Fish Wildl. Serv. 65:391-425.

CADWALLADER P.L. (1977) J.O. Langtry's 1949-50 Murray River investigations. Fisheries and Wildlife Paper Vic. No.13. Ministry for Conservation.

CADWALLADER P.L. (1983) A review of fish stocking in the larger reservoirs of Australia and New Zealand. F.A.O. Fisheries Circular No. 757.

CHUBB C.F. & POTTER I.C. (1984) The reproductive biology and estuarine movements of the gizzard shad, <u>Nematalosa</u> <u>vlaminghi</u> (Munro). J. Fish. Biol. 25:527-543.

CHUBB C.F. & POTTER I.C. (1986) Age, growth and condition of the Perth herring, <u>Nematalosa</u> <u>vlaminghi</u> (Dorosomatinae) in the Swan estuary, South Western Australia. Aust. J. Mar. Freshw. Res. 37(1):105-112.

DELSMAN H.C. (1926b) Fish eggs and larvae from the Java Sea. Treubia 8:389-394.

DEVANESAN D.W. & CHIDAMBARAM K. (1941) On two kinds of fish eggs hatched out in the laboratory of Western Hill Biology Station. Calicut. Curr. Sci. 10:259-261.

FAGAN J.A. & FITZPATRICK L.C. (1978) Allocation of secondary production to growth and reproduction by gizzard shad (Dorosoma cepedianum) in Lake Lewisville, Texas, U.S.A. Southwest. Nat. 23(2):247-262.

GERDES J.H. & McCONNELL W.S. (1963) Food habits and spawning of the threadfin shad in a small desert impoundment. J.Ariz. Acad. Sci. 2:113-116.

HOUSER A. & BRYANT H.E. (1967) Sampling reservoir fish populations using mid water trawls. pp 391-404 In Reservoir Fishery Resources Symposium. Res. Committee of the Southern Div. Amer. Fish. Soc. Bethesda, Maryland, U.S.A.

HUTCHINS J.B. (1977) The freshwater fish fauna of the Drysdale River National Park, North Kimberley, Western Australia In Kabay E.D. & Burbidge A.A.(eds) A biological survey of the Drysdale River National Park in August 1975. Wildl. Res. Bull. W.Aust. 6:102-109.

JACOB P.K. (1948) Natural history of the gizzard shad (Anodontostoma chacunda) and its fishery on the west coast of Madras province. J. Bombay Nat. Hist. Soc. 48:159-160.

JENKINS R.M. (1974) Reservoir management prognosis: migraines or miracles? Proc. Ann. Conf. Southeastern Assoc. Game & Fish Comm. 27:374-385.

JENKINS R.M. & MORAIS D.J. (1978) Prey-predator relations in the predator - stocking evaluation reservoirs. Proc. Ann. Conf. South Eastern Association Fish and Wildlife Agencies 30:141-157.

JESTER D.B. & JENSEN B.L. (1972) Life history and ecology of the gizzard shad (Dorosoma cepedianum) with reference to Elephant Butte Lake. New Mex. State Univ. Agric. Exp. Sta. Res. Rept. 218:1-56.

JHINGRAN V.G. & GOPALAKRISHNAN V. (1973) Estuarine fisheries resources of India in relation to adjacent seas. J. Mar. Biol. Ass. India 15:323-334.

JOHNSON J.E. (1970) Age, growth and population dynamics of threadfin shad (Dorosoma petenense) in central Arizona reservoirs. Trans. Amer. Fish. Soc. 99(4):739-753.

JOHNSON J.E. (1971) Maturity and fecundity of threadfin shad (Dorosoma petenense) in Arizona reservoirs. Trans Amer. Fish. Soc. 100:74-85.

KILAMBI R.V. & BAGLIN R.E. (1969a) Fecundity of the gizzard shad (Dorosoma cepedianum) in Beaver and Bull Shoals reservoirs. Amer. Midland Nat. 82:444-449.

KILAMBI R.V. & BAGLIN R.E. (1969b) Fecundity of the threadfin shad (Dorosoma petenense) in Beaver and Bull Shoals reservoirs. Trans. Amer. Fish. Soc. 98:320-322.

KUTKUHN J.H. (1957) Utilization of plankton by juvenile gizzard shad in a shallow prairie lake. Trans. Amer. Fish. Soc. 87:80-103.

LAKE J.S. (1971) Freshwater Fishes and Rivers of Australia. Thomas Nelson, Melbourne.

LESLIE P. H., PERRY J. S. & WATSON J. S. (1945) The determination of the median body-weight at which female rats reach maturity. Proc. Zool. Soc. Lond. 115:473-488.

LITTLEJOHN S., HOLLAND L., JACOBSON R., HUSTON M. & HORNUNG J. (1985) Habits and habitats of fishes in the upper Mississippi River. U.S. Fish Wildlife Serv. Natl. Fishery Res. Lab. Information Pamphlet. June 1985. 20pp.

LLEWELLYN L.C. (1983) The distribution of fish in N.S.W. Aust. Soc. Limnol. Special Publication 7.

LLOYD L.N. & WALKER K.F. (1986) Distribution and conservation status of small freshwater fish in the River Murray, South Australia. Trans. R. Soc. S.A. 110(2):49-57.

McGOWAN M.F. & BERRY F.H. (1984) Clupeiformes: Development and relationships In Ontogeny and Systematics of Fishes. Amer. Soc. Ichthyol. Herpetol. Spec. Pub. 1.

MACKINNON M.R. (1984) Culture of barramundi and other estuarine and freshwater fish. pp 56-70 In Pollock B.R. & Quinn R.H. (eds.) The potential for aquaculture in Queensland. Queensland Department Primary Industries Seminar, Brisbane 24-25 Mar. 1983.

McKAY R.J. (1984) Curator of Fishes, Queensland Museum. Pers. comm.

MADDEN K. M. (1951) Gizzard shad suppresses Black Hawk Lake fish populations. Iowa Conserv. 10(12):185, 191-192.

MANN R.H.K. & MILLS C.A. (1985) Variations in the sizes of gonads, eggs and larvae of the dace, Leuciscus leuciscus. Envir. Biol. Fishes 13(4):277-287.

MERRICK J.R. & MIDGLEY S.H. (1985) Note on the winter diet of golden perch in Queensland. Proc. R. Soc. Qld. 96:61-62.

MERRICK J.R. & SCHMIDA G.E. (1984) Australian Freshwater Fishes: Biology and Management. Griffin Press, Adelaide.

MILLER R.R. (1960) Systematics and biology of the gizzard shad (Dorosoma cepedianum) and related fishes. Fish. Bull. U.S. Fish Wildl. Service. 60(173):371- 392.

MILWARD N.E. (1965b) Comparison of weight-length ratios between Murray cod from the Murray and Darling River systems. Aus. Soc. Limnol. Newsletter 4(1):11-12.

MOODY H.L. (1957) A fisheries study of Lake Panasoffkee, Florida. Quart. J. Flor. Acad. Sci. 20(1):21-88.

MORRISSY N.M. (1986) Fisheries biologist (Western Australian Marine Research Laboratories, Department of Fisheries and Wildlife), unpub. data.

NELSON G.J. & ROTHMAN M.N. (1973) The species of gizzard shad (Dorosomatinae)- with particular reference to the Indo-Pacific region. Bull. Amer. Mus. Nat. Hist. 150(2):131-206.

NEY J.J. (1981) Evolution of forage-fish management in lakes and reservoirs. Trans. Am. Fish. Soc. 110:725-728.

NOBLE R.L. (1981) Management of forage fishes in impoundments of the southern United States. Trans. Am. Fish Soc. 110:738-750.

PAHL B.G. & WILLFAHRT G. (1962) Growth study of young gizzard shad. Minnesota Acad. Sci. 30:22-25.

PAULY D. & DAVID N. (1981) ELEFAN 1, a BASIC program for the objective extraction of growth parameters from length-frequency data. Meeresforschung 28:205-211.

PIERCE R.J., WISSING T.E., JAWORSKI J.G., GIVENS R.N. & MEGREY B.A. (1980) Energy storage and utilization patterns of gizzard shad in Acton Lake, Ohio. Trans. Amer. Fish. Soc. 109:611-616.

PIERCE R.J., WISSING T.E., MEGREY B.A. (1981b) Aspects of the feeding ecology of gizzard shad in Acton Lake, Ohio. Trans. Am. Fish. Soc. 110(3):391-395.

POLLARD D.A. (1972) The biology of Galaxias maculatus III Structure of gonads. Aust. J. Mar. Freshwat. Res. 23(1):17-38.

PUCKRIDGE J.T. (1988) The aquatic fauna of the North-west branch of Cooper Creek In The Coongie Lakes Study. Reid J.R. & Gillen J. Dept. Envir. & Planning Consultants Report.

RAFAIL S.Z. (1973) A simple and precise method for fitting a Von Bertalanffy Growth Curve. Marine Biology 19:354-358.

ROHLF F.J. & SOKAL R.R. (1981) Statistical tables. 2nd edition. W,H.Freeman & Co. N.Y.

RUELLO N.V. (1976) Observations on some massive fish kills in Lake Eyre. Aust. J. Mar. Freshwat. Res. 27:667-671.

SOUTH AUSTRALIAN DEPARTMENT OF FISHERIES (1987) Catch, effort and value of production of South Australian Fisheries. SAFISH 11(1):10-24.

SHELTON W.L. (1972) Comparative reproductive biology of gizzard shad (Dorosoma cepedianum) and the threadfin shad (Dorosoma petenense) in Lake Texoma, Oklahoma. Unpub. PhD dissert. University of Oklahoma.

SHELTON W.L. & STEPHENS P.R. (1980) Comparative embryology and early development of threadfin shad (Dorosoma petenense). Prog. Fish. Cult. 42(1):34-41.

SOKAL R.R. & ROHLF F.J. (1981) Biometry, 2nd edition. W.H. Freeman & Co. San Francisco.

THOMSON J.M. (1957) The size at maturity and spawning times of some Western Australian estuarine fishes. Fish. Bull. West. Aust 8:1-8.

VENKATARAMANUJAM K. & RAMAMOORTHI K. (1974) Studies of the seasonal abundance of the fish eggs and larvae of Porto Novo waters. Indian J. Fish. 21:454-462.

WEATHERLEY A. H. (1977) Perca fluviatilis in Australia. J. Fish. Res. Bd. Can. 34(10):1464-1466.

WARNER E.N. (1941) Studies on the embryology and early life history of the gizzard shad, Dorosoma cepedianum. Doctoral thesis, Ohio State Uni. (unpub.). 101 pp.

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