1 Introduction

1.1 Preamble

Ecological studies on the freshwater fishes of the Alligator Rivers Region (maps 1 & 2) were carried out from August 1978 to December 1979 for the Office of the Supervising Scientist. The results of these studies are presented in three volumes.

Volume 1 (Research Report 4, Volume I) contains the overall introduction to these studies, a description of the physiography of the region, a brief description of the aquatic habitats and climate cycle, a summary of the results, and general conclusions and recommendations.

Volume 2 (Research Report 4, Volume II) considers the synecology of the freshwater fishes of the region. 'Synecology' is the study of the ecological relationships of particular communities or assemblages of organisms, in this case fish communities, with their environment.

This volume (SSR145) discusses the autecology of the fish species of the region. 'Autecology' is the study of the ecology of particular individuals, populations or single species.

1.2 Objectives of the autecological studies

Prior to the Ranger Uranium Environmental Inquiry (Fox et al 1977), the existing information on freshwater fishes of the Alligator Rivers Region (ARR) was primarily on taxonomy and distribution (Taylor 1964, Midgley 1973, Pollard 1974). Accordingly, the inquiry emphasised that existing biological and ecological information on the freshwater fishes of the Alligator Rivers Region was inadequate to predict either the effects of uranium mining and processing on the fish fauna or any long-term effects on the aquatic ecosystems. It was recognised that further research was required to provide basic background information on the environmental requirements, life histories and general biology of the freshwater fishes of the area.

The objectives of the ecological studies of the freshwater fishes of the ARR that are relevant to the autecological studies are:

1 (*Background information*) to collect and interpret basic biological and autecological data on the freshwater fishes of the ARR for use in evaluating the effects of possible changes associated with future uranium mining and processing in the area;

2 (*Detection methodologies*) to attempt to delineate those biological and ecological features of the fish fauna and variables of the aquatic environment that are most sensitive to these human-induced changes and that are likely to prove of greatest value in a continuing monitoring program, and to indicate how they can be most reliably sampled and usefully measured;

3 (*Prediction*) to gather more detailed biological and ecological data on selected fish species for use in the interpretation of data from future waste water toxicity studies.

In essence, the information in volume 3 is centred on identifying the location and timing of activities critical in the life cycle of the fish species considered. By relating this knowledge to information on the location and timing of mining-induced physical and chemical impacts, species most at risk can be identified – an important task in impact assessment.

Examination of the size composition of populations across habitats and seasons reveals, for example, where the nurseries are and when they are used. Similarly, examination of stomach

fullness and reproductive condition reveals, respectively, the main feeding and spawning areas and times. Not all fish species exposed to the impacts from mines are likely to be equally affected; information on feeding habits and reproductive strategies will help to identify those species. Knowledge of the environmental requirements of these species may also reveal their sensitivity to certain water-quality changes, or indicate that certain physical features, which may be prone to mining impacts, are important to a species' survival.

Knowledge of critical nursery, feeding and spawning areas and times, as well as, for example, feeding habits and reproductive strategies, is fundamental to the design of monitoring systems that aim to detect impacts, and toxicity studies that aim to predict wastewater impacts. To provide an early warning of impacts, monitoring systems and toxicity studies need to focus on sensitive features of the target fauna. Early life-history stages are usually most sensitive to water-quality changes, so where impacts coincide with nursery and spawning areas and times, such stages of the exposed fish species should be targeted. The feeding habits of particular species may also render them sensitive to water-quality changes by, for example, biomagnification effects in the case of peak carnivores, or exposure to disturbed contaminated sediments in the case of detritivores. Similarly, then, where water-quality impacts coincide with feeding areas and times, species representing a range of feeding habits should clearly be targeted.

1.3 The fauna

In 1980, a total of 59 fish taxa had been collected from the region; they are listed in phylogenetic order in volume 1 (table 1, pp 3–4). Fifty of these taxa are known from freshwater habitats.

During this study, 166 standard samples were taken from freshwaters, yielding 29 254 fish of 37 taxa in 18 families (The majority of the taxa were identified to the species level, however, two were subspecies of *Melanotaenia splendida*). In addition 39 sets of underwater observations were made in escarpment area sites, in which 6276 fish of 28 taxa yielded additional information.

The number of taxa per family from freshwaters was as follows:

Five taxa: Terapontidae[1]

Four taxa: Plotosidae

Three taxa: Ariidae,[2] Melanotaeniidae,[3] Ambassidae, Eleotrididae[4]

Two taxa: Atherinidae, Toxotidae, Gobiidae

One taxa: Carcharhinidae,[5] Megalopidae, Clupeidae, Osteoglossidae, Belonidae, Pseudomugilidae,[6] Synbranchidae, Centropomidae, Apogonidae, Mugilidae

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1 An additional terapontid species, the coal grunter (*Hephaestus carbo*), was recorded in the study area in 1988.

2 An additional ariid catfish species, the shovel-nosed catfish (*Arius midgleyi*), was recorded in the study area in May 1988.

3 An additional melanotaeniid species, the banded rainbow fish (*Melanotaenia trifasciata*), was recorded in the study area in 1988. The exquisite rainbowfish (*M. exquisita*) was also recorded in the upper South Alligator River system in the late 1980s.

4 Two additional eleotrid taxa, the poreless gudgeon (*Oxyeleotris nullipora*) and black-banded or giant gudgeon (*O. selheimi*), have subsequently been recorded.

There was some confusion between the various plotosid catfishes identified in the early stages of the study. The difficulties in identifying catfish species from the family Plotosidae are detailed in this volume.

Autecological data are presented on the 37 taxa in the 18 families listed above. Data on a single carcharhinid shark species, collected to date only from tidal freshwaters in the region, are also included. The quality of information presented on each species obviously varies with the number of specimens collected and the degree of representation across habitats and seasons. Table 1 (next page) gives an indication of this quality by listing, per taxa, the number of specimens examined for basic biological data.

Australia is the only scientifically developed nation with a marked lack of financial support for fundamental studies on its freshwater systems, despite the importance to the country of water as a basic and relatively scarce resource (Williams 1971). Certainly, very little work has been published on the ecology of our freshwater systems, and Lake (1971), in his book on the freshwater fishes and rivers of Australia, highlighted how little was known about our rivers and their fauna. The tropical freshwaters of Australia have been investigated in even less detail than the temperate freshwaters.[7] A summary of ichthyological studies of the freshwaters of the Australian tropical zoogeographic region is given in a previous volume (vol 1, p 2).

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5 Three additional carcharhinid taxa, pigeye shark (*Carcharhinus amboinengis*), Bizant River shark (*Glyphis* sp. A) and the Northern Speartooth shark (*Glyphis* sp. C), have subsequently been recorded in the study area in the late 1990s.

6 An additional pseudomugilid taxa, the spotted blue-eye (*Pseudomugil gertrudae*), was recorded in the study area in the early 1980s.

Accordingly, the revised number of taxa per family from freshwaters is as follows:

Six taxa:	Terapontidae
Five taxa:	Melanotaeniidae, Eleotrididae
Four taxa:	Carcharinidae, Ariidae, Plotosidae
Three taxa:	Ambassidae
Two taxa:	Atherinidae, Pseudomugilidae, Toxotidae, Gobiidae
One taxa:	Megalopidae, Clupeidae, Osteoglossidae, Belonidae, Synbranchidae, Centropomidae, Apogonidae, Mugilidae

7 A detailed survey of the freshwater fishes of Cape York Peninsula (Queensland) was undertaken in 1992–94 and later published by Herbert et al (1995). Cape York is primarily within the wet-dry tropics as is the Alligator Rivers Region. In 1993 freshwater fish surveying was undertaken in the wet tropics region of Queensland (Cooktown to Cardwell) and reported by Pusey and Kennard (1996) and Pusey et al (1995a). These Queensland surveys primarily had a synecological focus, although some autecological information did arise from the wet tropics investigation (ie a paper on feeding ecology — see Pusey et al 1995b).

Table 1 List of fish taxa ranked by the number of specimens examined for basic biological information

Fish species	Number of specimens	Rank no	Quartile	Report section
Melanotaenia splendida australis	2	1	Lower	3.15
Toxotes lorentzi	2	1	Lower	3.30
Ophisternon gutturale	2	2	Lower	3.19
Carcharhinus leucas	7	3	Lower	3.1
Arius proximus	9	4	Lower	3.6
Scleropages jardinii	16	5	Lower	3.4
Anodontiglanis dahli	31	6	Lower	3.8
Arius graeffei	41	7	Lower	3.7
Neosilurus colour-type 'B'	42	8	Lower	3.10
Syncomistes butleri	43	9	Lower	3.27
Glossogobius aureus	53	10	Lower middle	3.34
Hephaestus fuliginosus	54	11	Lower middle	3.25
Lates calcarifer	62	12	Lower middle	3.20
Hypseleotris compressa	70	13	Lower middle	3.35
Pingalla midgleyi	85	14	Lower middle	3.28
Neosilurus ater	106	15	Lower middle	3.9
Neosilurus hyrtlii	125	16	Lower middle	3.10
Oxyeleotris lineolata	134	17	Lower middle	3.37
Neosilurus colour-type 'C'	147	18	Lower middle	3.11
Megalops cyprinoides	155	19	Lower middle	3.2
Liza alata	211	20	Upper middle	3.32
Neosilurus colour-type 'A'	224	21	Upper middle	3.9
Strongylura krefftii	224	22	Upper middle	3.12
Pseudomugil tenellus	232	23	Upper middle	3.16
Mogurnda mogurnda	263	24	Upper middle	3.36
Glossogobius giuris	278	25	Upper middle	3.33
Toxotes chatareus	290	26	Upper middle	3.31
Porochilus rendahli	328	27	Upper middle	3.11
Leiopotherapon unicolor	439	28	Upper middle	3.26
Melanotaenia nigrans	579	29	Upper middle	3.13
Amniataba percoides	581	30	Upper	3.24
Arius leptaspis	740	31	Upper	3.5
Nematalosa erebi	845	32	Upper	3.3
Glossamia aprion	1020	33	Upper	3.29
Denariusa bandata	1340	34	Upper	3.23
Craterocephalus marianae	1730	35	Upper	3.17
Craterocephalus stercusmuscarum	1976	36	Upper	3.18
Ambassis macleayi	2028	37	Upper	3.22
Ambassis agrammus	3381	38	Upper	3.21
Melanotaenia splendida inornata	3636	39	Upper	3.14

A few specimens of *Melanotaenia splendida australis* (section 3.15) were collected in the South Alligator River system but none were examined for basic biological information.

2 Materials and methods

2.1 Sampling design

Seasons

From August 1978 to December 1979, fish were collected during the following eight sampling periods:

Mid-dry 1978	Mid-dry 1979
Late-dry 1978	Late-dry 1979
Early-wet 1978–79	Early-wet 1979–80
Mid-wet 1978–79	Late-wet–Early-dry 1979

Sampling was least extensive during the first (pilot survey; Pollard & Bishop 1978) and last periods. In the intervening periods a large set of *regular* sites was consistently sampled, and some sites were sampled *occasionally* to augment information on fish distributions. Sampling was timed to coincide with the periods of greatest biological activity, based on the Wet-Dry seasonal cycle of events (see 'Aquatic seasons' in Explanatory notes) rather than on fixed time intervals. The relationships between sampling period, the Wet-Dry seasonal cycle, water flow and date are given in volume 1 (table 3, p 15).

The sampling regime provided a base for examining the gathered biological and autecological data to identify the timing of activities critical in the life cycle of the fish species.

Sites and habitats

The ecological effects of any controlled or uncontrolled releases of wastes from the Ranger Uranium Mines Pty Ltd development near Jabiru would be expected to become apparent first in Coonjimba, Gulungul, Georgetown and Djalkmara Creeks and their associated waterbodies in the Magela Creek system. An intensive program to regularly sample the freshwater fishes in these areas was thus undertaken as a part of a monitoring program for the whole Magela Creek system. Upstream 'control' sites representative of habitats downstream of the Ranger site were also sampled regularly as were out-of-catchment 'control' sites in the Nourlangie Creek system (this system drains into the South Alligator while Magela Creek drains into the East Alligator River; Bishop et al (1990) showed that differences exist between the fish faunas in these systems). The fish faunas of sites adjacent to the other three major uranium deposits (Jabiluka, Koongarra and Nabarlek) were sampled occasionally, as were other sites outside the Magela catchment, to provide additional information on fish distributions.

A summary table of regular and occasional sampling sites, grouped according to drainage systems, geographical zones and habitat types is also given in volume 1 (table 5, p 19). The sites, site codes, grid references, and latitude and longitude are listed in volume 1 (table 4, pp 16–18). Appendix 1 (this volume) details the sites alphabetically by site code. Map 1 in this volume shows the major drainage systems and geographic zones examined. Map 2 and appendix 8 illustrate site locations with respect to the drainage systems and the mining operations in the Alligator Rivers Region.

The sampling sites were selected to represent the following ten freshwater habitats:

- plateau area habitat (two sites sampled occasionally);

- escarpment area habitats, consisting of mainchannel area habitats (two sites sampled regularly and six sites occasionally), seasonal feeder streams (one site sampled regularly and three sites occasionally) and perennial streams (two sites sampled regularly and one site occasionally);
- lowland habitats, containing sandy creek beds with pools or channels (three sites sampled regularly and eight sites occasionally) and backflow billabongs (ten sites sampled regularly and ten sites occasionally);
- corridor habitat (three sites sampled regularly and seven sites occasionally);
- upper floodplain billabong habitat (four sites sampled regularly);
- lower (riverine) floodplain billabong habitat (two sites sampled occasionally); and
- artificial habitat (five sites sampled occasionally).

A detailed description of these habitats is given in volume 2 (section 2.2, pp 5–14) and illustrated in plates 1–6 of the same volume.

For habitats represented by regular sampling sites, this habitat classification system provided a base for examining the gathered biological and autecological data to identify the location of activities critical in the life cycle of the fish species. Depending on the study objectives, and the availability of specimens for particular laboratory examinations, the habitat classification system included finer divisions, such as position upstream or downstream of the Ranger mine, or types of lowland backflow billabongs.

2.2 Recording of environmental data

Habitat–structural, physico–chemical and general habitat variables (relating to the whole waterbody, rather than the immediate fishing area) were collected for each site sampled during the study period. The recording methods are described in detail in volume 1 (section 3.2, pp 15–20; data cards A and E are given in appendixes 1 and 2 of that volume).

2.3 Collection and observation of fishes

The techniques used to obtain a representative fish community sample at each site are described in detail in volume 1 (section 3.3, pp 20–21). Two standard (regular and repeatable) collecting methods were used: gillnetting with multiple-mesh-sized monofilament nets (gn) and seine netting (sa). In escarpment sites where these methods would be likely to create an undesirable fishing pressure, underwater observations were substituted. Other collecting and observation methods were used occasionally: spears, lines, castnets, dipnets, poisoning and natural fish kills.

2.4 Field procedures

These procedures are described in detail in volume 1 (section 3.4, p 21). Information on fish catches and fish species found at the sampling sites were listed by species name and number on data card B (see this volume, appendix 2; species names are updated) in the field.

Each card line in appendix 1 contained the sample reference number corresponding to that on the environmental card A (see volume 1, appendix 1, pp 39–40) and the general habitat card E (volume 1, appendix 2).

Small fish (less than about 60 mm in length) collected with seine nets and by other methods were preserved intact in 10% (v/v) formalin; larger fish (over 60 mm in length) first had their body cavities slit to help preserve the stomach contents. Where practical, samples of larger fish collected with gillnets were deep-frozen overnight and processed later in the laboratory (see next section) after thawing – usually the following day. Those that could not be deep-frozen (eg on extended field trips) were preserved in 10% formalin.

2.5 Laboratory and data analysis procedures

The fish samples were either rinsed to remove formalin or thawed, and the following details were recorded: length in millimetres (length to caudal fork [LCF] for fish with forked tails, or total length [TL] for fish with rounded tails); weight (to the nearest 1 g, or 0.1 g for small fish); gonad weight (0.01 g, or 0.001 g for small fish); gonad stage on a seven-point scale after Pollard (1972) (variations from this method are noted in the text); stomach fullness (details given later in 'Feeding habits'); and an identification number for each fish. Each detail was recorded on a separate card line on data card C (see this volume, appendix 3). This card line also contained the reference number of the sample and the species name and code, so that biological information from a given fish could be related to the species and environmental data. The above data were summarised for each species on card B, where the total number of fish caught, their total weight (g), and maximum and minimum lengths (mm LCF or TL) were recorded.

Size composition

Length frequency

The length increments used in the length–frequency distribution (either 10, 5 or 2 mm LCF or TL) were decided on for each species according to the mean length of specimens captured during the study. The increments used for each species are apparent on the respective length-frequency distribution figures.

Where sample sizes permitted, three length-frequency distributions per species are examined: overall (all sites and seasons combined), seasonal changes (1978 Late-dry to 1979 Late-dry) and habitat differences per catchment. For the Magela Creek catchment, a detailed habitat breakup is presented, resulting in the following separations: lowland sandy creek upstream of the Ranger Mine (RM), lowland sandy creek downstream of the RM, lowland shallow backflow billabongs upstream of the RM, lowland shallow backflow billabongs downstream of the RM, lowland channel backflow billabongs (all downstream of the RM), sandy corridor waterbodies, muddy anabranch corridor waterbodies, and floodplain billabongs. The corridor billabong ID, being transitional in character with floodplain billabongs, was grouped with the latter habitats. These separations, corresponding site allocations, and the shading key for the figures are given in appendix 5.

Condition factor

Relative condition factors (K) were calculated for seasonal collections of fish using the equation:

$$K = W_s / aL_s^{\,b}$$

where W_s and L_s are the mean weights and lengths (geometric means were used as log-normality was assumed), respectively, for season *s*; *a* is a constant and *b* is the exponent in the overall length-weight relationship.

Environmental associations

Environmental features commonly associated with particular fish species were taken as an initial indication of the environmental requirements of the species. Definitions and analytical origins of the terms used are given below:

Quarters

For each environmental variable (eg pH, temperature, DO), the mean value associated with each fish species (or colour form in the case of the plotosid catfishes) was calculated. The 36 species studied were then ranked for that environmental variable in ascending order of these means. After ranking they were divided into four quarters: species with ranks 1–9 (the lowest mean values) constituted the lower quarter; species with ranks 10–18 formed the lower-middle quarter; those with ranks 19–27 the upper-middle quarter; and those with ranks 28–36 the upper quarter. If data were not available for all 36 species, these numbers changed accordingly.

Aquatic vegetation dominance

The amount of cover provided by four defined types of vegetation was estimated by a rank number, from 0 to 6 (see volume 1, appendix 1). A further rank number (7) was given to submerged terrestrial vegetation.

The total dominance of each vegetation type was calculated by using equation:

$$TD_j = \sum_{i=0}^{5} N_{ij}\, x_i,$$

where TD_j = total dominance for fish species j,

N_{ij} = frequency of occurrence of rank i for fish species j, and

x_i = rank number (0 to 5 only).

This total dominance score was converted to a percentage of the sum of the total dominance scores for all four vegetation types for a particular fish species j, ie percentage dominance (PD) of vegetation type k is given by:

$$PD = TD_{jk} \times 100 / \sum_{k=1}^{4} TD_{jk},$$

The accuracy of this percentage dominance score decreases as sample size decreases.

Vegetation-occurrence index

This index was obtained by dividing the number of times there was vegetation in association with a particular species found at a sample site, by the total number of times the cover of aquatic vegetation was estimated at all sample sites associated with that species. Thus, the vegetation-occurrence index effectively estimated the frequency (expressed as a percentage) at which the fish species was found in waters with vegetation. The accuracy of this index decreases with smaller sample size.

Substrate dominance

As defined in volume 1 (appendix 1), dominant and subdominant substrates were noted for the species found at each site sampled. Seven types of substrates were listed. Each time a substrate was considered dominant it was given a rank of 2, and each time a substrate was subdominant it was ranked 1. These values were summed for each substrate type to give a final weighted score of total substrate dominance. This dominance total was converted into a percentage dominance figure by dividing it by the sum of total dominance for all substrate types.

Reproduction

Estimation of gonad maturity stages

When a fish was first captured, gentle pressure was applied to its abdominal area to see whether milt or eggs were extruded. At dissection, the gonads were observed by cutting away the abdominal wall. A seven-stage system adapted from Pollard (1972) was used: maturity stages were subjectively assigned according to the appearance and size of the gonads in the body cavity. As a number of unrelated species were examined, a generalised staging system was developed. Any features differing from the general system are outlined in the section on that particular species.

The changes in macroscopic appearance of the gonads are:

Stage I (immature virgin)

Gonads thin and threadlike, translucent and colourless; sexes usually indistinguishable.

Stage II (developing virgin/recovering spent)

Testes: thin and straplike, translucent and greyish. Ovaries: more rounded, usually translucent and colourless; eggs not visible to the naked eye.

Stage III (developing)

Testes: thickening opaque and greyish white. Ovaries: thickening, opaque; small, pale yellowish eggs may be visible to the naked eye.

Stage IV (maturing)

Testes: swollen, elongated, often extend ¾ of the way along length of body cavity. Ovaries: swollen, rounded, extend ¾ way along length of body cavity; larger, opaque, yellow eggs clearly visible.

Stage V (mature)

Testes: may extend length of body cavity; opaque white, generally with a smooth creamy texture. Ovaries: may fill body cavity and distend abdominal wall; large yellow eggs often translucent.

Stage VI (ripe)

Testes: as in V; milt may be extruded from fresh specimens by pressure on abdominal wall. Ovaries: as in V; eggs translucent yellow, free of ovarian connective tissue; may be extruded by pressure on the abdominal wall in fresh specimens.

Stage VII (spent)

Testes: thin, flaccid, straplike; blood vessels and ‘bruising’ evident; may contain white areas of residual sperm. Ovaries: hollow, thin and flaccid; sac-like; may contain both residual and undeveloped eggs; blood vessels and ‘bruising’ evident.

As ‘bruising’ subsides and residual eggs and sperm are resorbed, stage VII gonads became stage II and the maturation cycle may begin anew.

Slides of histological sections of gonad tissue stained with eosin and haematoxylin were prepared where determination of the gonad stage of small fishes proved difficult. Gonad staging was then confirmed or reassessed after the sections were examined under a high-power microscope.

Length at first maturity

The method for estimating the length at which fish first become sexually mature was adapted from State Pollution Control Commission (1981). Fish recorded with gonad stages later than III were considered capable of spawning during the forthcoming reproductive season. The length at first maturity (LFM) was therefore considered to be the length at which 50% of the fish examined had a gonadal maturity stage later than stage III, using the following method:

The highest percentage of fish with gonads at stages later than III in any two-monthly sample was plotted against fish length. A line of best fit was plotted by eye through the scatter points in the length range from where the percentage of stage IV–VII gonads was first greater than zero to where it consistently equalled 100%. A horizontal line was drawn from the 50% maturity level on the y-axis to intersect the line of best fit. The x coordinate of the intersection point was taken to give the estimated LFM.

This method was used because it avoids basing the LFM on a few isolated, sexually precocious individuals. Any problems arising from this method were generally due to small sample sizes; small samples of fish captured mainly outside their breeding season may result in a biased estimate of LFM. In these cases, the position of the line of best fit was allowed to be influenced more by the scatter points for mature fish collected in the breeding season than by the scatter points for those collected outside the breeding season. Species that are aseasonal spawners would not be expected to have 100% mature individuals in any given sample; in such cases the position of the upper end of the line of best fit was determined by the percentage of scatter points much lower than the 100% level.

Fish smaller than the LFM of the particular species are termed ‘juvenile’, and fish equal to or greater than the LFM are termed ‘adult’. Any fish – juvenile or adult – with a gonad stage less than IV is termed ‘immature’; it may be either an immature virgin or an adult outside the breeding season with regressed gonads.

Gonadosomatic and gonad maturity stage indices

Both fish and gonad weights were used to calculate the gonadosomatic index (GSI), using the formula:

GSI = gonad weight (g) / total fish weight (g) x 100

The gonad maturity stage index (GMSI) was calculated as the mean gonad maturity stage of all adult fish (ie those of length greater than or equal to the LFM). In calculating the mean, stage VII gonads (ie spent) were assigned the same value as stage II.

Reproductive development was assumed to be accurately delineated by changes in the mean GSI of adult fish calculated for each season. The use of GMSI to determine accurately the reproductive development period was also assumed to be valid, as discussed by State Pollution Control Commission (1981).

Estimation of reproductive development and spawning periods

Reproductive development was assessed by plotting mean GSI and GMSI (for adult fish) against sampling season. The period of reproductive development was arbitrarily defined as the period of time encompassed by obvious peaks that rise from and return to the resting level on the GMSI and GSI plots. The spawning period was defined as the range of seasons during which fish were found with gonads at maturity stage VI (ripe), or the seasons including or just before the capture of stage VII (spent) individuals. The data on reproductive biology are, where sufficient, summarised in a composite figure for each species.

Spawning sites

The spawning sites of each species were assumed to be the habitats from which fish with gonads at maturity stages VI (ripe) and VII (spent), or small juvenile fish, were collected.

Sex ratio

The numbers of identifiable males and females captured over each sampling period, and the numbers of adults of each sex (ie with lengths equal to or greater than their respective LFM), were noted for each species. The sex ratios for both the total catches of a species and the adults only were calculated and compared with expected values using a chi-square test (Zar 1974). Differences between these two values were examined for changes in sex ratio within each season.

Fecundity and oocyte diameter

Ovaries from stage V (mature) females were preserved for two weeks in 10% formalin and then transferred to 75% alcohol. Each preserved ovary was weighed and dissected; where the two lobes of the ovary were nearly the same size, only one lobe was dissected. Often eggs of several size-classes were present, representing different stages of oocyte development. Only the largest size-class of eggs was counted for the fecundity estimate. Either total counts were made by teasing the eggs away from the ovary tissue, or a smaller section of ovary was removed and weighed, the eggs in the subsample were counted, and the total fecundity was estimated by multiplying back to the original weight of the gonad.

For each ovary, the diameters of ten oocytes from the largest size-class were measured, and either the range or the mean and standard deviation, or both, were calculated. The mean oocyte diameter for the species was the average of the individual means if more than one ovary was dissected.

Feeding habits

Stomach fullness

Stomach fullness was recorded on a five-point scale after Ball (1961). Details of this are given in the data card C (appendix 3, column 77). Fullness was examined to give an indication of important feeding sites and times. A detailed habitat break-up is presented and this follows the separations used to examine habitat differences in length-frequency distributions.

Stomach contents data

The stomach contents of each fish were analysed under a dissecting microscope by the points (estimated volumetric) and occurrence methods (Pollard 1973). The percentage volume of each food type in the stomach contents was recorded to the nearest 5% on card lines in data card D (see appendix 4). Card D also contained the sample reference number, the fish species code, and the individual fish's number so that stomach contents data for a given fish could be related to the biological and environmental data. The data are presented to show seasonal and habitat differences in feeding habits.

Grouping of stomach contents data

The diet of each species was the mean of the sub-means of the stomach contents in all habitats and seasons. These sub-means were rounded off to the nearest 1%, which sometimes generated an error of up to ± 2%; in these instances only the unidentified organic material component was adjusted (to minimise distortion of the identifiable diet components) to absorb the ± 2% rounding-off error and make the diet total for each species 100%; this made the sub-

means more useful as relative abundance data. Bait material and alimentary tract parasites were excluded from this examination and therefore the sub-means were corrected by a factor of 100/(100 – n), where n = % parasites and/or bait material (and sub-means were again corrected to add up to 100%).

Some of the rarer food items were then grouped on a taxonomic basis (though not at any particular phylogenetic level), leaving a total of 60 food groups. Emphasis in these selective groupings was given to relatively widespread occurrence of a food item amongst the different species and to items represented in high proportions in the diets of individual species. These data were then analysed to compare different species' diets, using the CSIRO TAXON library programs CANMAR/MULCLAS, GROUPER, GOWER and GOWECOR.

The 60 food items were further grouped to 27 items (again on a taxonomic basis at various phylogenetic levels). These groupings were used in pie diagrams showing the main components of the diets of each species, which also illustrated the main differences in the diet. As a consequence the invertebrate food items are revealed in more detail than the plant or vertebrate food components (the invertebrates tended to be more varied and specialised and to reflect a more distinct partitioning of resources, whereas the various vertebrate and plant components tended to be less specific in stratifying the feeding preferences of the different species). In the diagrams, the aquatic and terrestrial components of the diet are separated and the outer circles are used to group the food items (again taxonomically) for broader comparisons.

Macroscopic parasites, predators, movements and mortality

Parasites on fish were noted during the study. The information (including the position of the parasite in or on the body of the fish) was recorded so it could be related to the rest of the data.

An examination of the incidence of parasite infestations across habitats and seasons helps identify sites and times when fish are likely to be naturally stressed. The information obtained is presented in the Discussion section.

Information on predators, movements and mortality, most of which is derived from published literature, is also presented in the Discussion.