Research Report 9

Fish communities in sandy pools of Magela Creek, Alligator Rivers Region

D.J. Woodland and P.J.Ward

Supervising Scientist for
the Alligator Rivers Region

Supervising Scientist for the
Alligator Rivers Region

RESEARCH REPORT 9

Fish communities in sandy pools of Magela Creek, Alligator Rivers Region

D.J. Woodland and P.J. Ward

Australian Government Publishing Service
Canberra 1992

ISSN 0810-9966
ISBN 0644 25632 X

Supervising Scientist for the Alligator Rivers Region
P.O. Box 387, Bondi Junction
N.S.W. 2022, Australia

This Research Report was prepared by:
D.J. Woodland and P.J. Ward
Department of Zoology, University of New England, Armidale, NSW 2351
acting as consultants to the Supervising Scientist for the Alligators Rivers Region

The manuscript, submitted in 1982, represents the results of detailed field and laboratory studies of the fish inhabiting sandy pools of the area from August 1981 to November 1981

The Supervising Scientist for the Alligator Rivers Region manages the Alligator Rivers Region Research Institute, which conducts, co-ordinates and integrates research relating to the effects on the environment of uranium mining in the Alligator Rivers Region. Research findings of projects carried out under contract to the Supervising Scientist or undertaken by the Supervising Scientist's own staff may be published in the Research Report or Technical Memorandum series. Views expressed by authors do not necessarily reflect the views and policies of the Supervising Scientist, the Commonwealth Government or any collaborating organisation.

CONTENTS

ILLUSTRATIONS

Plates

Figures

ACKNOWLEDGMENTS

This study was funded by the Supervising Scientist for the Alligator Rivers Region. The assistance provided by the staff of the Office of the Supervising Scientist, Jabiru, is gratefully acknowledged. We wish to thank L. Baker, K. Bishop, J. Bywater, D. Clay, C. Humphrey, W. Ivantsoff, and T. Walker who made useful comments on the study or the initial report. The assistance provided by K. Bently (heavy metal and ammonia analyses), K. Brennan (identification of birds and trees), M. Cappo (identification of amphibians), R. Hobbs (statistical analyses), D. Stodellry (photography), R. Treloar (suspended solids analyses) and D. Walden (rotenone collection) is appreciated. Special thanks are also due to Stuart Cairns for considerable assistance with preparing the computer generated figures.

Since the completion of the study a number of changes have been made in the taxonomy of the fishes inhabiting the Alligator Rivers region; for example, several species have been described and allocated new specific names. Nomenclature has been standardised to Paxton et al. (1989) for about half the less derived families; the remaining more specialised groups have been named following Larson & Martin (1990). The authors thank John Merrick for standardisation and other editorial assistance.

ABSTRACT

Woodland, D.J. and Ward, P.J. (1992). Fish communities in sandy pools of Magela Creek, Alligator Rivers Region. Research Report 9. Supervising Scientist for the Alligator Rivers Region. Australian Government Publishing Service, Canberra.

Physico-chemical conditions, changes in fish communities and characteristics of species populations of eight permanent sandy pools along Magela Creek during the 1981 Dry season are described. Causes of mortality in each species, especially *Craterocephalus marianae*, were investigated.

Temperatures at the bottom of the pools ranged from 22.0-35.5°C. Dissolved oxygen concentrations (measured at 0800 - 0930h) were 0.8-6.7 mg/L at the bottom and 0.9-7.3 mg/L at the surface. During the same period: chlorophyll *a* concentrations were 6-178 μg/L; chlorophyll *b* concentrations 1-60 μg/L; chlorophyll *c* 0-7 μg/L at the surface. Suspended solids values were 3-58 mg/L; conductivities were 22-61 μS cm/L at the surface and 28-62 μS cm/L at the bottom. The pH values ranged from 5.3-7.7 at the bottom and 5.5-7.4 at the surface. Most of these parameters were very stressful for fish in the pools during October. In most water samples copper, lead and uranium were present in comparatively low concentrations (< 1.6 ppb); concentrations of cadmium, zinc and particularly manganese were higher (≤ 120 ppb). In sediment samples concentrations of manganese, zinc and copper were comparatively high (≤ 12.8 mg/kg).

The fish communities of the pools were diverse considering the apparent low heterogeneity of the habitat and the small size of the pools; most species appeared to be at high densities. Despite stressful conditions during the study period, all except one of the 20 species survived in at least a few pools - the exception was *Melanotaenia nigrans*. Major characteristics of the fish populations were: in biomass, *Leiopotherapon unicolor* and *Nematalosa erebi* were the dominant species; *C. marianae* was the most numerically abundant species at the beginning of the study period; most species were present in the pools as large juveniles or adults only, but *C. marianae*, *Glossogobius giurus* and *Melanotaenia splendida* occurred as fry and small juveniles as well; except for *Strongylura krefftii* and *G. giurus*, all species examined for reproductive characteristics were ripe in November; a few species (*N. erebi*, *Amniataba percoides*, *G. giurus*, *C. marianae*, *Glossamia aprion*) spawned during the study period; condition factors were generally low by comparison with other studies, except for *G. giurus*, *C. marianae*, *C. stercusmuscarum* and *G. aprion*.

Mortality was low (<50% of the original population) in most pools. In populations that did suffer high mortality, anoxic conditions may have been an important cause of mortality for *C. marianae*, *A. percoides* and *Pingalla midgleyi*. Predation by other fish was an important cause of mortality for at least one species (*C. marianae*); however, predation by birds was rare, especially as the Dry progressed. Condition factors and stomach fullness were low for most species, but, starvation was probably not a cause of mortality, except perhaps for *L. unicolor* in one pool.

These data suggest that pools might be important for the survival of *P. midgleyi* and *C. marianae* which are endemic in the Region. *C. marianae* might be useful as an 'indicator species' because it is particularly sensitive to heavy metals—although more data on lethal and sub-lethal tolerances are required.

1

Introduction

1.1 Background

Creeks of the Alligator Rivers Region leave a string of pools along their courses when they cease to flow during the Dry season. Many of these pools are in the main channels where the bottom is sand, and many persist for the duration of the Dry.

Even though research on the Region has been expanded greatly, few studies have been directed at these 'sandy pools'. Pollard (1974) collected fish from various sites, including sandy pools in Magela and Cooper creeks, and compiled a list of species of the Region; a new species *Piingalla midgleyi*, was described by Allen & Merrick (1984). Bishop et al. (1980) sampled several pools of Magela, Gulungul, Nourlangie and Cooper creeks during two Dry seasons. Ward (1982) investigated mortality in the hardyhead, *Craterocephalus marianae* (Ivantsoff et al. 1987), in pools of Magela Creek as part of the present study.

Studies of the fish communities inhabiting sandy pools are relevant to the Supervising Scientist's responsibilities of environmental protection (Humphrey et al. 1990). Firstly, the pools could be essential to the reproduction and survival of certain species. Secondly, as the Dry season progresses the pools diminish in size and their inhabitants could be subjected to extremes of various physical and biotic conditions. Consequently, documentation of changes in the fish communities under these conditions could be used to distinguish natural changes from any man induced changes in the future. Thirdly, as the sandy pools of the Magela and Gulungul creeks are in close proximity to the Ranger uranium mine and several orebodies, and as heavy metals usually lower the tolerance of fish to stressful physical and biotic conditions, the organisms of the sandy pools could - during the Dry season, at least - provide a sensitive 'early-warning' system in the event of any contamination from the mine site.

When considering the studies described below it is important to note that more recent investigations (Bishop & Harland 1982; Bishop & Walden 1990) have provided further insights into the importance of fish movement (migration) in Magela Creek and the effects of retension pond release on the local ichthyofauna.

1.2 Physico-chemical conditions

Physical and chemical conditions in the pools are described first; some factors were investigated because they might relate to mortality in freshwater fish, e.g. dissolved oxygen concentration. Conditions in the pools were probably more extreme than in other waterbodies of the Magela Creek system. Thus, for species surviving the Dry season in the pools, the levels described here may represent the most extreme conditions they are likely to meet. Other factors (chlorophyll concentrations, pH, turbidity) were investigated because they were useful for comparing water quality of the pools with that of other waterbodies.

Physical and chemical characteristics were determined monthly, in association with the sampling of the fish communities.

1.3 Community changes and mortality

In this part of the study, the species compositions of the fish communities are described. For each species six characteristics were considered: abundance, size structure, reproduction, condition and diet. Particular emphasis was placed on the elucidation of the causes of mortality.

Information on reproductive condition, condition factor and diet during the study

period was obtained from specimens collected from pools SN, F1, F2 and three nearby 'non-study' pools in August, September and October. Fish removed from these pools and the other study pools (N1, N2, N3, B2) at the end of the study provided information on these characteristics for November. Generally, only seven species (*Leiopotherapon unicolor*, *Craterocephalus marianae*, *Amniataba percoides*, *Strongylura krefftii*, *Nematalosa erebi*, *Pingalla midgleyi*, *Glossamia aprion*) were sufficiently abundant for useful information on reproductive condition, condition factors and diet to be obtained. Data on abundance and size structure were obtained from monthly total counts where fish were returned to the pools.

In using baseline data to assess the impact of mining on animal communities, it may sometimes be difficult to differentiate natural mortality from mortality resulting from pollution. The aim of this part of the study was to distinguish the most important environmental factors responsible for mortality of *Craterocephalus marianae* in the pools. An understanding of the causes of natural mortality may allow future studies to distinguish mortality of *Craterocephalus* species resulting from pollution.

There were several reasons for selecting *C. marianae* for such a study. Firstly, the species may be unique to the Roe and Drysdale rivers of northern Western Australia and the Alligator Rivers Region (W. Ivantsoff pers. comm.). Secondly, Bishop et al. (1980) found that *Craterocephalus marianae* was restricted to sandy pools and escarpment mainchannel waterbodies over the Dry season - the pools might be essential for the survival of the species. Finally, *C. marianae* is especially sensitive to heavy metals (Giles 1974) and by being restricted to the pool habitat during the 'Dry' the species might be particularly vulnerable should there be any heavy metal contamination from the Ranger site. Intolerance to heavy metals could be accentuated by deteriorating physical conditions in the pools as the Dry season progresses.

1.4 Objectives

The objectives of the present study were:

(i) to describe the physical and chemical conditions occurring in sandy pools of Magela Creek during a Dry season;

(ii) to describe changes in the species composition, abundances, growth, condition factors, and feeding activities of fish inhabiting the pools and, where possible, account for these by way of changes in the physico-chemical and biotic conditions occurring during the Dry season;

(iii) to ascertain if these pools were spawning sites for any species, or functioned as Dry season refuges for juveniles or breeding stock.

2

Materials and methods

2.1 The study area

Magela Creek (12°40'S, 135°55'E) flows in a northerly direction from the Arnhem Land Plateau to the East Alligator River (Fig. 1). The pools studied were along a 15 km section of this creek, adjacent to the site of the Ranger uranium mine. Detailed descriptions of the Magela Creek area and its climate were given by Christian & Aldrick (1977), Hart & McGregor (1980) and Williams (1979).

The sandy pools are formed by water scouring the sand from around trees when the creek is flowing. Upstream, they are usually deep and steep-sided, becoming shallow, with gently sloping sides downstream (Plate 1, Fig. 2). Apart from trees (*Pandanus aquaticus*, *Melaleuca argentea* and *M. viridiflora*), the creekbed is devoid of vegetation. Aquatic macrophytes were absent from the pools. (An epiphytic alga was present, but rare, in some pools.)

Eight pools in the main channel of Magela Creek were selected for study. Selection was based on size and substrate; only the largest pools with sandy substrates were chosen. When the study commenced in August 1981 the pools ranged from 1.1 to 1.8 m in depth and from 43 to 511 m^3 in volume (Table 2).

2.2 Study design

The study period lasted from August to November 1981. Physical and chemical conditions in the pools were monitored monthly. The fish communities were also sampled once a month. Pools SN, N1 and N2 were sampled twice in November; the flooding of the creek prevented a second sampling of the remaining pools at that time; see Table 1 for sample dates. Besides investigating any adverse changes in abiotic conditions in the pools, the effects of predation by birds and fish on the fish communities were also examined (Table 1). To test the extent of predation by birds, two pools (B1 and B2) were enclosed with 135 mm mesh nylon nets (Plate 2). To test the impact of fish predation, all piscivorous fish caught in monthly seines were removed from two pools (F1 and F2). These pools were also covered with 'bird net'. In addition, some of the piscivorous fish were removed from pool SN at the beginning of the study period.

Table 1. Sample numbers and calendar dates on which physical and chemical characteristics and fish communities of each pool were assessed. Details of the experimental treatment afforded each pool are also listed.

Sample number	Pond* and date							
	SN	N1	N2	N3	B1	B2	F1	F2
1	5 Aug	8 Aug	2 Aug	21 Aug	12 Aug	30 Aug	12 Aug	26 Aug
2	13 Sep	14 Sep	10 Sep	23 Sep	19 Sep	28 Sep	19 Sep	30 Sep
3	13 Oct	14 Oct	11 Oct	27 Oct	19 Oct	31 Oct	20 Oct	10 Nov
4	8 Nov	9 Nov	6 Nov	23 Nov	12 Nov	23 nov	11 Nov	20 Nov
5	18 Nov	19 Nov	19 Nov	-	-	-	-	-

* Experimental pond treatments were: some piscivorous fish removed (SN); no treatment (N1-N3); birds excluded (B1,B2); birds excluded and most piscivorous fish removed (F1,F2).

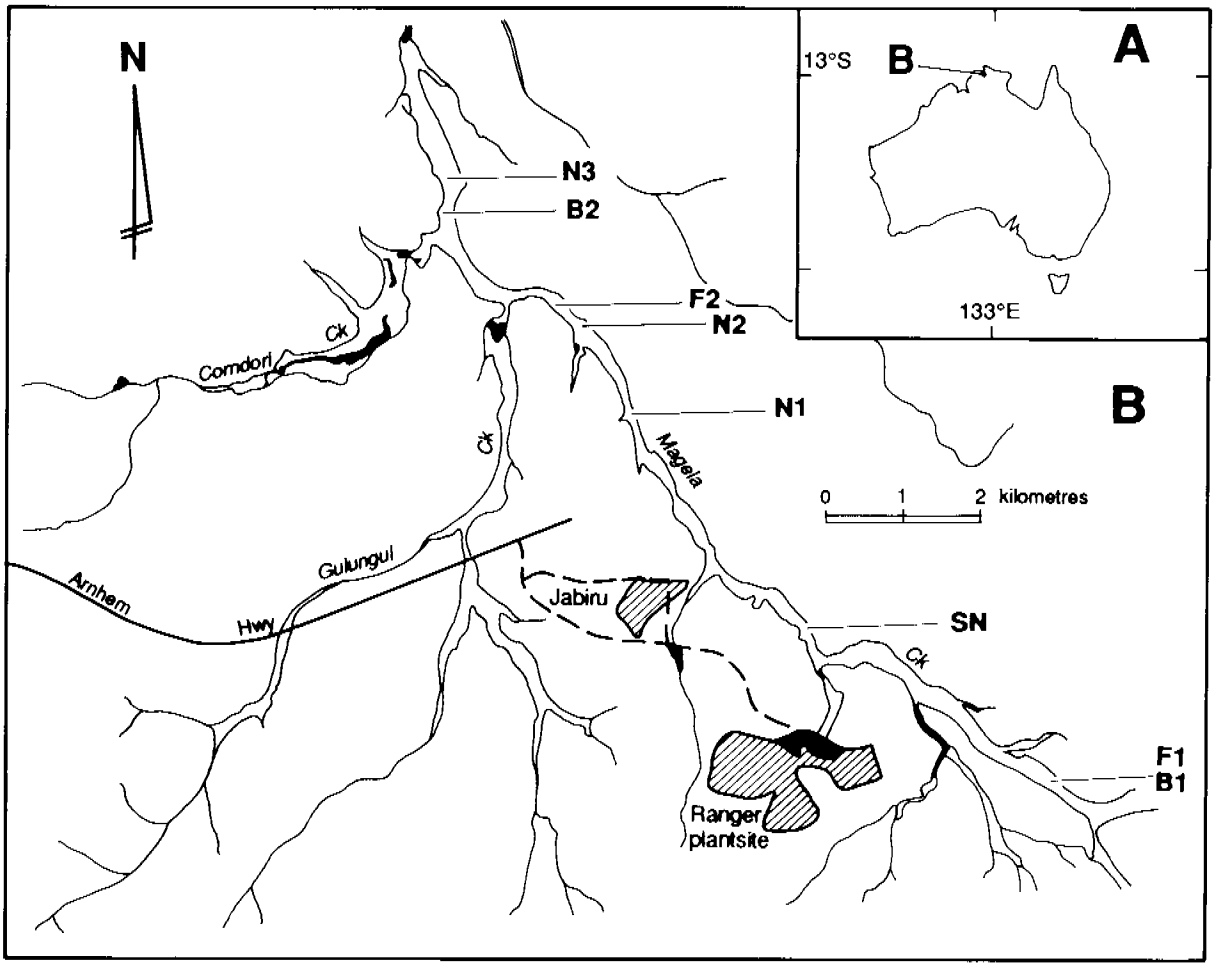

Figure 1. Study area. Map, drawn from Department of Lands and Housing aerial photographs, showing the course of Magela Creek and tributaries in the Dry season (permanent billabongs shown as solid bodies). The location of each pool studied is indicated.

2.3 Physico-chemical conditions

Pool size

A bathymetric map was made of each pool in August. A grid was formed over each pool and water depth was measured to the nearest 10 cm at each 2-metre interval. Water depth was measured in each pool at a standard location each month, allowing volumes to be estimated from the maps.

Temperature

A maximum-minimum thermometer, shaded in an open-ended PVC tube, was placed on the bottom of the deepest region of each pool. Another, attached to a steel post, was placed below the surface of the deepest region of pool SN and a third was placed on the bottom of the shallow 'Craterocephalus habitat' (any area of a pool less than 50 cm deep) of the same pool (water depth varied between 10 and 30 cm

(a)

(b)

(c)

Plate 1. A sandy pool (N2) of Magela Creek during the Dry season of 1981. Between 2 August *(a)* and 10 September *(b)* evaporation resulted in the formation of isolated puddles in foreground areas and to the left, causing stranding mortality in some fish species. Photograph *(c)* shows the pool towards the end of the study period (9 November).

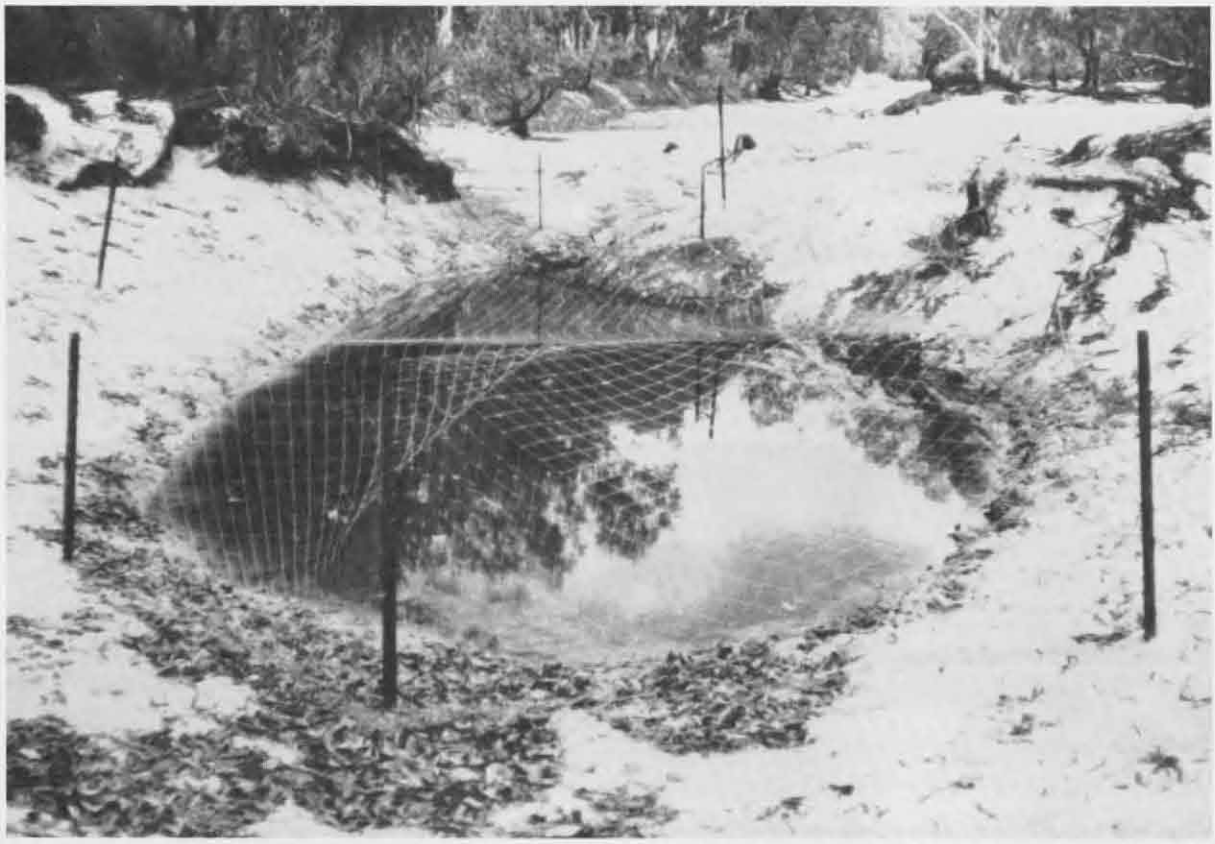

Plate 2. Bird net covering on pool B2 to prevent birds preying on fish. Four experimental pools were enclosed in bird net (B1,B2,F1,F2).

above these two thermometers). Maximum and minimum temperatures were recorded (nearest 0.5°C) for the interval of time elapsing between each sampling date. Thermometers used in the study were calibrated against an accurate standard thermometer.

Chlorophylls *a*, *b* and *c*

Water samples for chlorophyll analyses were obtained from each pool between 0830 and 1000 hours each month. Samples were taken from 10 cm below the surface of the deepest region of each pool. A measured volume of the sample (200 to 500 mL) was filtered immediately through a 47 μm glass-fibre filter. The filtrate was chilled until stored at -5.0°C. Chlorophyll concentrations were estimated to the nearest μg/L with a spectrophotometer (Varian Techtron, Superscan-3) according to the method described by Jeffrey & Humphrey (1975).

Oxygen

Water samples for the determination of dissolved oxygen concentrations were taken from each pool between 0800 and 0930 hours each month. Samples (300 mL) were taken from 1 cm above the bottom of the deepest region, 1 cm above the bottom of the 'Craterocephalus habitat' (10-20 cm deep), and 5 cm below the surface at the deepest region of each pool. Samples were fixed in the field and the concentrations of dissolved oxygen (nearest 0.1 mg/L) were determined according to the azide-modification of the Winkler technique (American Public Health Association 1976).

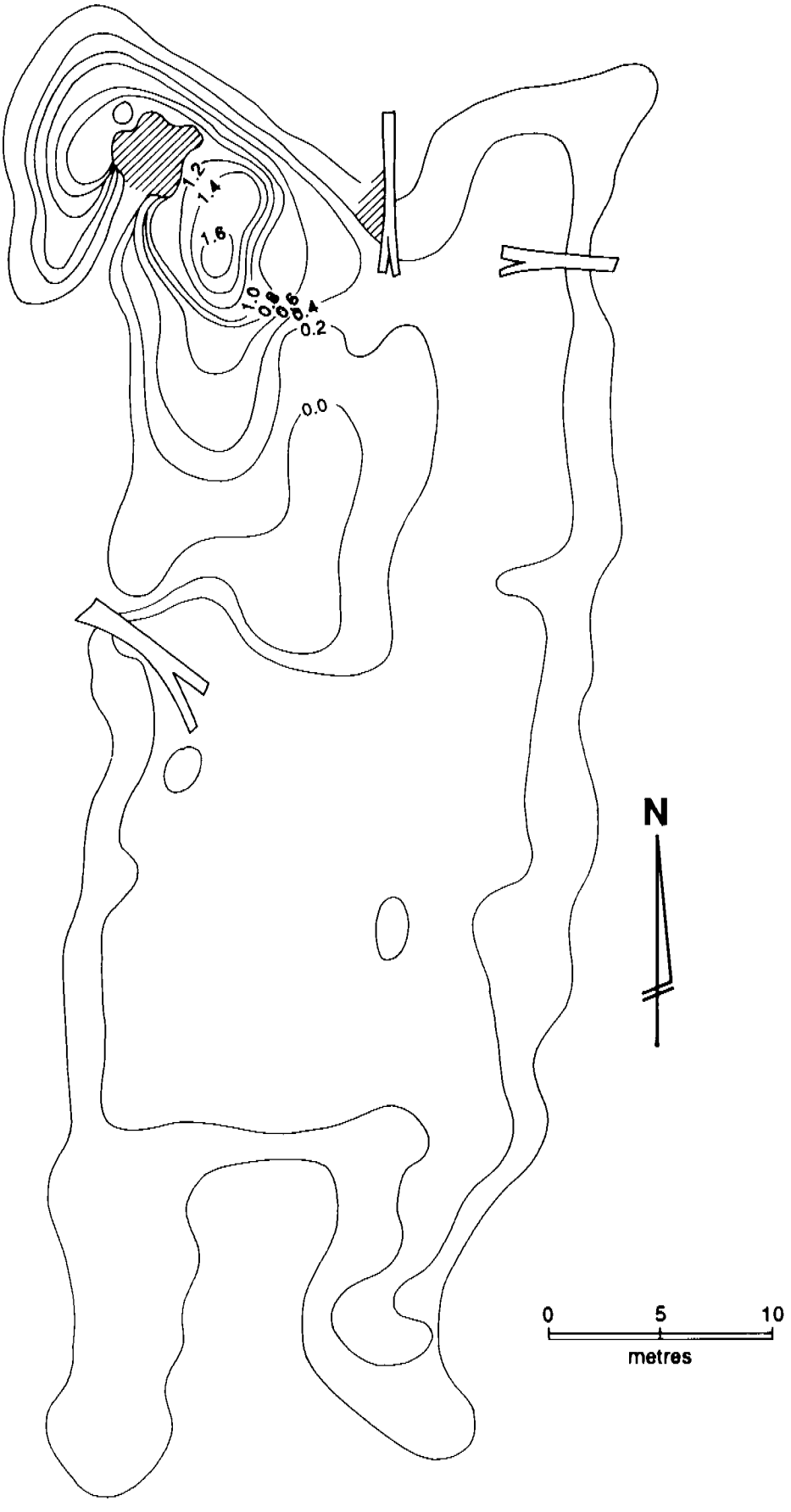

Figure 2. Example of a bathymetric map (pool N2). Water depth is shown in metres.

pH

Water samples were taken between 0800 and 0930 hours each month from the bottom of the deepest region, from the bottom of the 'Craterocephalus habitat' and 5 cm below the surface of each pool at the deepest region. The pH of each sample was determined in the field (nearest 0.1 pH unit) with a calibrated pH meter (Metrohm, Model E604).

Turbidity

The turbidity of each pool was estimated (nearest 0.1 m) with a standard Secchi disc between 0830 and 1000 hours each month.

Suspended solids

Water samples for the analysis of total suspended solids were taken from each pool between 0830 and 1000 hours each month. A one-litre sample was taken from 10 cm below the surface at the deepest region and chilled at 5.0°C until analysed. The concentration of suspended solids was estimated (nearest mg/L) according to the method described by the American Public Health Association (1976). A subsample of 200 mL was filtered through a 1 μm glass-fibre filter; the filtrate was dried (103.0 to 105.0°C) and weighed.

Conductivity

Water samples for the determination of conductivity were taken from 5 cm below the water surface and 1 cm above the bottom of the deepest region of each pool, between 0830 and 1000 hours each month. Conductivity was estimated (nearest μS/cm) with a calibrated conductivity meter (Metrohm, Model E518) within twelve hours of sampling.

Ammonia

Water samples (60 mL) were taken from 10 cm below the surface of each pool (except pools B1 and F1) between 1400 and 1600 hours on 14 October. Samples were taken in polyethylene bottles, tightly capped, with no air bubbles present. They were shaded from direct sunlight and chilled on ice until analysed. Within two hours of sampling, the concentration of ammonia was estimated (nearest 0.01 ppm) with a calibrated digital pH/mV meter (Orion Research, Model 701A) using an ammonia electrode (Orion Research, Model 95-10).

Heavy metals

Water samples for analyses of heavy metal concentrations were taken from pools SN and N2 on 22 September and from pools SN, N2, N3 and B1 on 20 November. All sample bottles were soaked in detergent, rinsed in distilled water, then soaked in 10% nitric acid for 7 days. From each pool, two one-litre water samples were taken from 10 cm below the surface of the water with polyethylene screw-top bottles and were fixed with 2.0 mL of nitric acid (Aristar, Ultrapure). The concentrations of copper, lead, zinc, manganese and cadmium were estimated (nearest 0.1 ppb) with an atomic absorption spectrophotometer (Varian Techtron, Model AA-775) according to the method described in *Ranger Analytical Methods* (unpub.). The concentrations of uranium were estimated (nearest 0.1 ppb) with a nitrogen laser (Scintrex) according to the method of direct determination described in *Ranger Analytical Methods* (unpub.).

For sediment analysis, two 60 mL samples were taken from the top centimetre of the substrate of each pool with Teflon screw-top jars. Samples were dried and 'digested' according to the method described in Pancontinental (1981); the concentrations of copper, lead, zinc, manganese and cadmium were estimated (nearest 0.1 ppb) with an atomic absorption spectrophotometer (Varian Techtron, Model AA-775) according to the method described in Pancontinental (1981).

2.4 Community changes

As noted in the acknowledgments a number of recent nomenclatural changes have been incorporated in the text. A note on the

status of the plotosids is also opposite at this point. Bishop et al. (1980) identified the plotosid catfish captured in their study as *Anodontiglanis dahli* Rendahl, *Tandanus ater* Perugia, *Neosiliurus hyrtlii* Steindachner, *Neosilurus* sp. and *Porochilus rendahli* Whitley; Pancontinental (1981) identified their species as *P. rendahli, Neosilurus sp., N. hyrtlii, Neosilurus ater* Paradice and Whitley and *Neosilurus glencoensis* Rendahl. According to the taxonomic key employed by Bishop et al. (1980) plotosid catfish collected in the present study were *T. ater* and *N. hyrtlii.*

Distribution and abundance

Baseline data on the abundance of fish species in the pools are presented; mortality in the populations of each pool was estimated and, where possible, its causes investigated. Population biomasses were also calculated in order to assess the relative 'importance' of each species in the pool communities.

The abundances of fish in each pool were estimated from monthly samplings. A seine net, of 19 mm mesh netting, was placed around the perimeter of the pool then drawn along the pool bottom by hand with the head of the net suspended above the water surface. While fish were restricted to one corner of the pool by the seine, the numbers not captured were estimated by an underwater survey. Fish captured in the seine were then removed from the water for length measurements, and returned to the pool.

Small species (*Craterocephalus marianae, C. stercusmuscarum, Glossogobius giurus* and *Mogurnda mogurnda*) and fry passed through the seine net. These species were sampled with a thrownet made of 2mm mesh netting. Only *C. marianae* occurred in sufficient numbers for useful estimates of abundance to be made by this procedure. The thrownet and methods employed to estimate the abundance of *Craterocephalus marianae* are described below. Occasionally large *C. marianae* (> 40 mm LCF) and *M. mogurnda* were retained by the seine net. When this happened these species were herded over the submerged head of the net to avoid 'handling' mortality.

At the end of the study period, pools SN, N1, N2, N3 and F2 were treated with rotenone and all fish present were collected. For each species, mortality was estimated as the difference between the actual abundance in November (determined by rotenone collection) and the 'estimated abundance' derived from the monthly nettings. (Pools F1 and B2 could not be treated with rotenone at the end of the study period; the estimates of abundance from the netting of these pools in November were assumed to be good estimates of actual abundance and were used to estimate mortality.)

All fish collected from pools SN, N1, N2, N3 and B2 at the end of the study were weighed, providing information on the biomass of each species population. Species were classified as being either *very abundant*, *abundant*, *common*, *rare* or *very rare* according to an arbitary system for both biomass and number of individuals.

Length frequencies

The size distributions of the species populations are described and temporal changes in length frequency distributions are considered in terms of growth and mortality.

The lengths (length to caudal fork or total length, where appropriate) of fish captured in the monthly seines were determined to the nearest cm before they were returned to the water; the lengths of specimens captured by thrownet and with rotenone were determined to the nearest mm.

Only length frequencies of *L. unicolor, N. erebi, A. percoides, C. marianae, P. midgleyi, T. chatareus* and *S. krefftii* were analysed; other species were too rare for useful information to be derived from the data. For some pools length frequencies of the above species were not analysed, either because they were too rare or their abundance had been manipulated by the researcher (to test the effects of predation by piscivorous fish). Adults were defined as those individuals larger than the smallest specimen captured that was 'mature'- see reproduction section below.

Reproduction

To assess the role of the sandy pools in the life cycles species present - to determine if the pools were spawning sites or functioned as refuges for juveniles or breeding stock - considerable reproductive data were collected.

Fish collected during the study were dissected either fresh or after they were frozen (except *G. giurus*, *C. marianae* and *C. stercusmuscarum* which were preserved in 10% phosphate-buffered formalin). Sex was determined and a 'maturity stage' was assigned according to a seven stage system developed by Pollard (1972):

Stage I (immature virgin): Testes and ovaries thin and threadlike, translucent and colourless; sexes usually indistinguishable.

Stage II (developing virgin or recovering spent): Testes thin and straplike, translucent and greyish, sometimes with melanophores. Ovaries more rounded, translucent and colourless, eggs not evident to the naked eye.

Stage III (developing): Testes thickening, opaque and greyish white, smooth texture, Ovaries thickening, opaque and pale yellowish, eggs small but visible to the naked eye.

Stage IV (maturing): Testes enlarged, opaque and whitish, smooth texture. Ovaries enlarged, opaque and yellowish, eggs large.

Stage V (mature): Testes fill most of body cavity, opaque and creamy white, smooth texture. Ovaries fill most of body cavity, opaque and yellow, eggs large.

Stage VI (ripe): Testes fill body cavity, opaque and pure white, smooth and crumbly texture, milt extruded by pressure on abdominal wall. Ovaries distend body cavity, translucent pale golden, eggs large and extruded by pressure on abdominal wall.

Stage VII (spent): Testes thin and flaccid, greyish, sometimes with white areas (residual sperm). Ovaries thin and flaccid, translucent and colourless to pale yellowish, sometimes contain large opaque-yellow residual eggs.

After Stage VII the gonads then regress to Stage II (recovering spent) in surviving spawners.

Only macroscopic characteristics were used to classify gonads under this system. For some small species it was necessary to examine the gonads under a low-power microscope.

To estimate the time at which a species was likely to spawn the specimens collected from the pools were first divided into 'adults' and 'juveniles'. 'Adults' were defined as those individuals that were larger than the smallest individual at Stage IV (mature). Stage IV (or maturer) specimens were expected to be in spawning condition within about a month of capture.

Condition

For most fish species collected, length was estimated to the nearest mm (LCF or TL where appropriate), and weight to the nearest 0.01 g. The length and weight of some large specimens of *S. krefftii* and *L. unicolor* were estimated to the nearest cm and nearest 0.1 g. The decrease in accuracy is unlikely to have made a significant difference to the estimates of condition factors for these specimens. Measurements were taken on fresh or frozen specimens, except for *C. marianae*, *C. stercusmuscarum* and *G. giurus* which were preserved in 10% phosphate-buffered formalin (these were analysed within ten days of capture). Preservation in formalin may alter the weight; for *Craterocephalus marianae* the estimated weight was adjusted for the effect of formalin (Appendix 1). The sensitivity of the balance employed to estimate weight was poor for very small specimens (Fig. 9). To limit the possible error in weight estimates to less than ± 10%, only specimens larger than 0.05 g were included in this part of the study.

The relative condition factor (K_n) of each specimen was estimated by the formula proposed by Le Cren (1951):

$$K_n = W_o/W$$

where W_o = estimated weight, and

W = weight predicted for the estimated length by the length/weight relationship of the species.

The length/weight relationships determined by Bishop et al. (1980) were used to predict 'W'. For example, Bishop et al. (1980) estimated the overall length/weight relationship of *N. erebi* to be:

$$W = 0.012\ L^{3.122}$$

where W = weight (g)
L = length (cm LCF).

Thus, for a 15 cm LCF specimen weighing 55.00 g,

$$W_o = 55.00\ g,$$
$$W = 0.012\ (15)^{3.122} g$$
$$= 56.39\ g,$$

and $K_n = 55.00/56.39$
$= 0.98$

Therefore the relative condition factors presented here provide an index of weight for length relative to that of the specimens analysed by Bishop et al. (1980), who estimated the length/weight relationship from data obtained from specimens captured in all seasons from most habitats of the Alligator Rivers Region. Fish with factors below unity have relatively poor weight for length and, conversely, fish with relative condition factors above unity were in better than average condition; condition normally falls suddenly with spawning.

Diet and feeding

Fish collected by seining or with rotenone were dissected either fresh or after they were frozen. A 'stomach-fullness index' was assigned to each specimen according to the subjective system employed by Bishop et al. (1980):

0 = empty
1 = 1/4 full
2 = 1/2 full
3 = 3/4 full
4 = full
5 = full and distended

Diet was determined according to the 'occurrence method' (Pillay 1953). Each item of the stomach contents was identified to the lowest possible taxon and, for each species, the number of stomachs in which each item occurred was expressed as a percentage of the total number of stomachs examined.

2.5 Mortality

The contributions of various factors to the mortality of *C. marianae* were investigated. Prior to 1981, workers in the Alligator Rivers Region classified one of the two local species of *Craterocephalus* as *C. marjoriae* (The other was correctly classified as *C. stercusmuscarum*). According to W. Ivantsoff (pers. comm.) the former was not *C. marjoriae* but a second species which was not described until 1987. In the present study, reports on *C. marjoriae* have been assumed to concern this new species *C. marianae*.

Seven 'abiotic' factors were considered likely to have caused mortality: stranding, anoxic conditions, elevated temperatures, elevated salinity, high concentrations of particulate matter, ammonia and heavy metals. To determine if the factor in question was in any way responsible for mortality, the levels occurring in the pools were compared to the tolerance levels determined by laboratory experiments, field surveys, or from published data. The contributions of three 'biotic' factors, (starvation, predation by birds and by fish) were also considered. To determine if either predation by birds or predation by fish were significant causes of mortality, mortality rates in pools where birds were excluded, in pools where piscivorous fish were removed and in 'untreated' pools were all compared. Information on the abundance of piscivorous birds in the vicinity of the pools and information on the diets of the fish inhabiting the pools were also considered. Starvation was investigated by comparing the weight of individuals that died from lack of food with the weight of specimens collected from the pools.

Sampling

Fish were sampled with a thrownet (Plate 3). The thrownet consisted of 2 mm mesh cotton netting (sufficiently small to retain all sizes of *C. marianae*) with a circular mouth of 0.41 m^2 held open by a steel hoop. The mouth was weighted with a 400 g lead rope. One 'sample' was taken from each pool every month. Samples were always taken between 0900 and 1300 hours. For each sample the thrownet was cast at least 10 times. The thrownet was cast at least 3 m away from the researcher to randomly selected coordinates on a one metre grid. The maximum and minimum depth of each cast was measured to the nearest 5 cm. All captured fish were stored in 10% (v:v) phosphate-buffered formalin.

When sampling the pool populations the thrownet was cast to randomly selected coordinates in water less than 50 cm deep only (samples from casts that landed in regions deeper than 50 cm were rejected).

Density and abundance

Laboratory experiments showed that water turbidity influenced the ability of *C. marianae* to avoid the thrownet. The turbidity (Secchi depth) of each pool was estimated prior to sampling and the number of individuals in each cast was adjusted according to the relationship between thrownet efficiency and turbidity (Appendix 2). Water depth was also found to influence the ability of *Craterocephalus marianae* to avoid the thrownet. The water depth at which each cast landed was recorded and the number of individuals in each cast was adjusted according to the relationship between thrownet efficiency and water depth.

The data were transformed according to Taylor's power law (Southwood 1978), because the frequency distribution of fish numbers in each cast was not normally distributed.

Transformed values (Z) for the number in each cast (X) were calculated from the equation:

$$Z = X^p$$

where $p = 1-b/2$

and b is the exponent in Taylor's power law:

$$s^2 = a\bar{x}^b$$

where s^2 = the variance in the number of *C. marianae* per cast in each sample,

$\bar{x}$ = the mean number per cast in each sample,

a = a constant.

The exponent 'b' was estimated from the regression line fitted by the sum of the least squares method for the logged variance of logged means from each sample, i.e. $\ln s^2 = \ln a + b \ln \bar{x}$. The transformation, estimated from all samples taken during this study, was $Z = x^{0.130}$. The transformed numbers formed a straight line when plotted against frequency on probability paper demonstrating that the equation did, indeed, transform the data to the normal distribution.

The number of *Craterocephalus marianae* in each cast was adjusted for the effects of turbidity and water depth then transformed by the equation. These values, averaged for each sample, provided an estimate of the density of *C. marianae* in the 'Craterocephalus habitat'. Densities were expressed in terms of area rather than in terms of volume because underwater observations indicated that *C. marianae* schools were distributed in two dimensions rather than three. The abundances of *C. marianae* were determined by multiplying mean densities by the area of the 'Craterocephalus habitat', determined from the bathymetric map of each pool.

Stranding

Stranding mortality is here defined as mortality that results from the loss, by evaporation or seepage, of water from an isolated waterbody. The pools were regularly surveyed to see if sections had become isolated from the main body as water levels fell.

The effect of stranding was investigated in two puddles of pool N2 on 26 to 29 August. The puddles were adjacent and of a similar shape and size (*c.* 20 x 7 x 5 cm). Puddle 'A' contained 35 *C. marianae* (*c.* 12-30 mm LCF) and puddle

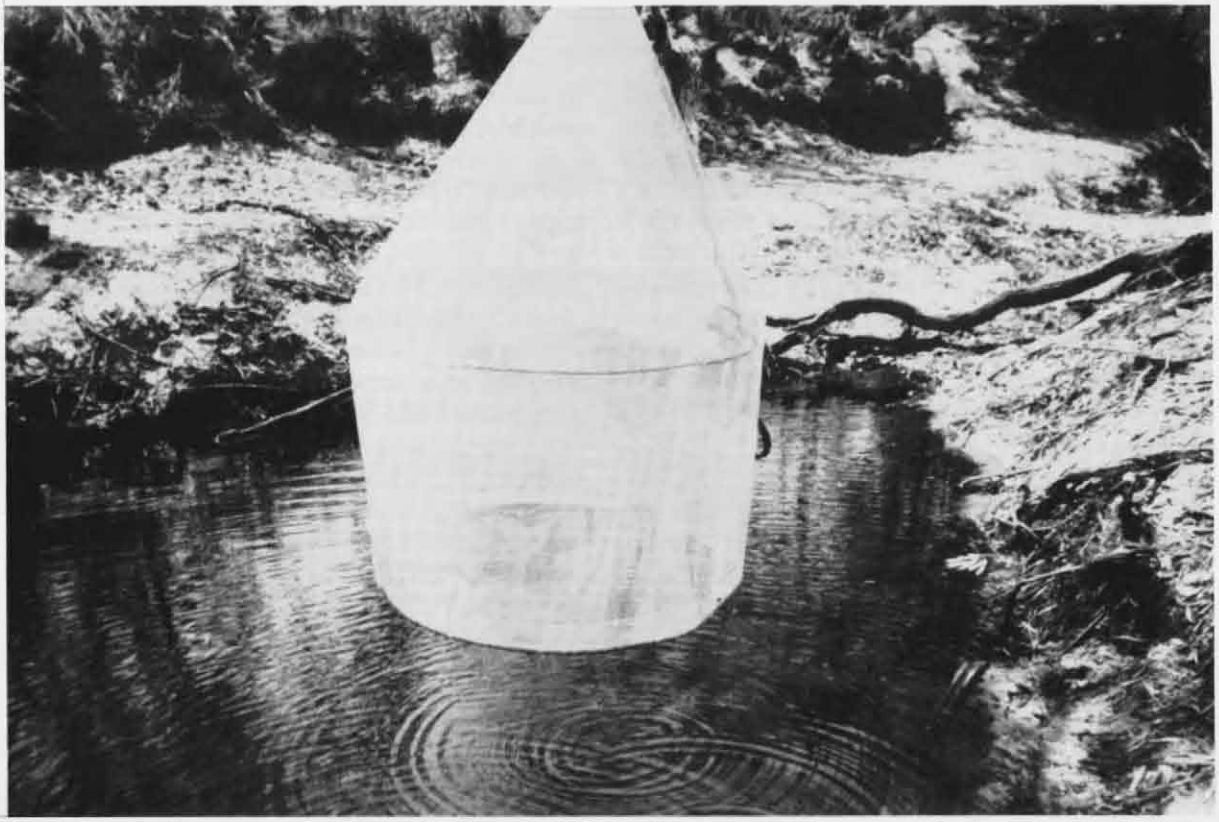

Plate 3. The 'thrownet' used for sampling the *Craterocephalus* populations. It was 1.3 m tall and had a circular weighted mouth held open at a diameter of 0.72 m by a 0.80m hoop.

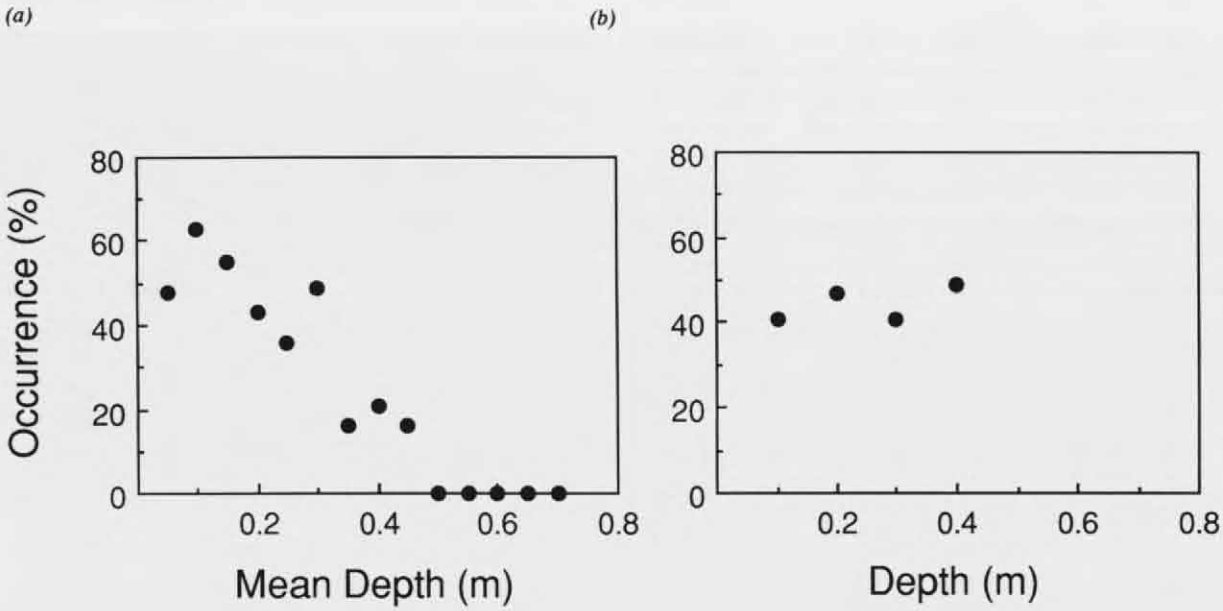

Figure 3. Distribution of *Craterocephalus* with depth. *(a)* shows the occurrence of *Craterocephalus* with respect to water depth (data obtained from thrownet casts for all pools). *(b)* shows the occurrence of *Craterocephalus* in casts made in a tank containing 33-38 individuals (Appendix 2), indicating that the depth preference was not an artifact of the sampling technique. Occurrence was the proportion of casts at a given depth in which *Craterocephalus* were caught.

'B' contained 40 individuals (*c.* 12-35 mm LCF). The sand around the edges of puddle A was smoothed so that the movements of terrestrial animals could be detected. Puddle B was enclosed in a 19 mm mesh net set 20 cm above the surface of the water with sides dug into the sand to prevent predation by terrestrial animals. A calibrated maximum-minimum thermometer was placed in this puddle.

Temperature

The tolerance of *C. marianae* to elevated temperatures was determined and compared to the maximum temperatures measured in the deepest region of the pools.

The diurnal variation in temperatures for the laboratory experiments were modelled on the conditions in pool SN on 20-21 September and 9-10 October. Every five hours temperatures were measured one cm above the bottom of the 'Craterocephalus habitat' and at the bottom of the deepest region.

More than 200 *C. marianae* were collected from three non-study pools and transferred to several 70-L aquaria containing pool water. Pool water was replaced by tapwater over five days. The fish were fed 'Fino Fin' Tropical Fish Food (Tetra Werke) twice daily. The aquaria were aerated and a flow-through system continuously flushed them with tapwater. Temperatures ranged between 29.0°C and 35.0°C each day during an acclimatisation period that lasted 30 days. After some initial mortality, attributed to mechanical damage during transport from the pools, no mortality was recorded in the stock aquaria.

Eighteen *C. marianae* (20-41 mm LCF) randomly selected from the stock aquaria were transferred to a 70-L aquarium of tapwater. These fish were fed 'Fino Fin' daily. Wastes and excess food were removed from the aquarium bottom and tapwater was added to maintain the volume. Water was agitated by a magnetic stirrer, oxygenated with three airstones and filtered with a glass-wool and charcoal filter. The aquarium was heated with four 240-watt aquarium heaters. A sheet of plastic was placed on top of the aquarium to reduce evaporation. Black plastic was fastened around the walls of the aquarium to reduce disturbance to the fish by the observer. A 16L : 8D photoperiod was provided. No mortality occurred after transfer to the aquarium or during the acclimatisation period of five days. Temperatures reached 35.0°C for 50 to 120 minutes each day of this acclimatisation period.

During the experiment maximum shade temperatures were monitored with a calibrated maximum-minimum thermometer (nearest 0.1°C). Because *C. marianae* moved to the surface when under thermal stress, maximum temperatures were measured two cm below the surface of the water. On each day the maximum temperature was increased artificially by 0.5-1.1°C on the previous day. Heaters were manipulated so temperatures simulated the diurnal variation measured in pool SN (Fig. 13*a*). Each day, the temperature was maintained within 1.0°C of the maximum for 120 minutes then allowed to fall overnight to 22.0-27.0°C. The length and weight of individuals dying each day were measured. The definition of 'death' was the cessation of opercular movement (Mathews & Hill 1977).

The experiment was repeated with 19 individuals (17-33 mm LCF) with the maximum temperature maintained for 150 minutes each day (Fig. 13*b*).

Tolerance to sudden changes

This atherinid may be exposed to sudden temperature changes when darting from the shallows to the deeper regions of a pool. The objective of this part of the study was to determine if *C. marianae* could tolerate such sudden temperature changes.

As part of an experiment to determine tolerance to high salinity (see salinity section), thirty *C. marianae*, randomly selected from the stock aquaria, were placed in a 2600-L tank of tapwater. There was no mortality after transport to the tank or during the acclimatisation period of 40 days. During the acclimatisation period the daily maximum temperatures were between 32.5 and 40.0°C and the daily minimum temperatures were between 24.0 and 28.0°C.

After the acclimatisation period all *C. marianae* were removed from the tank. The temperature was then 40.0°C. Ten fish were returned to the tank to act as a 'control', while 20 fish were transferred to a 70-L aquarium of tank water cooled to 22.0°C. After 5 minutes 10 of these fish were returned to the tank (39.5°C). The remaining 10 fish were kept in the cooled aquarium for 24 hours (temperatures fluctuated between 19.0 and 25.0°C) and then returned to the tank (39.0°C).

Oxygen

Tolerance was compared to the lowest concentrations occurring in the 'Craterocephalus habitat' to determine if anoxic conditions caused mortality.

Lower incipient lethal oxygen concentration

Seventeen individuals (14-40 mm LCF) randomly selected from the stock aquaria (Section 4.3; Temperature) were transferred to a cylindrical, 11-L glass container of tapwater. The water was agitated with a magnetic stirrer. No mortality occurred after transfer to the aquarium or during the acclimatisation period of three days (when oxygen concentration fell to 3.5-4.8 mg/L each day). For the experiment, fish in the container were exposed to a diurnal variation in oxygen modelled on that determined in the 'Craterocephalus habitat' of pool SN on 20-21 September and 9-10 October. In this pool, oxygen concentration fell at the rate of 0.4 mg/L/h overnight (Fig. 15). Oxygen concentrations should have followed a concave curve overnight, rather than the straight line depicted in Fig. 15, and then remained constant at the minimum concentration for some time before sunrise. Therefore it was decided to manipulate oxygen concentrations in the experiment so that they decreased more rapidly than by 0.4 mg/L, then to maintain the concentration at the minimum for an arbitrarily selected period (90-120 minutes). Temperatures were maintained at the same levels as occurred in the pools overnight.

During the experiment oxygen concentrations (nearest 0.1 mg/L) and temperatures (nearest 1.0°C) were monitored with an oxygen meter (Yellow Springs Instruments, Model 57). Before and after the experiment the oxygen meter was calibrated against a Winkler titration. During the experiment it was calibrated by the method described by the manufacturer.

The experiment consisted of five tests; one test was undertaken each day. For each test, minimum oxygen concentrations were allowed to fall by 0.2-0.6 mg/L/h by sealing the container so that there were no air bubbles present at the surface of the water. Oxygen concentrations were recorded every 15-30 minutes. Concentrations were allowed to fall, then maintained near the minimum for 90-120 minutes by loosening the seal of the container. Fish were unable to reach this surface region as the neck of the container was only 3 cm in diameter.

In many fish species tolerance to low levels of oxygen shows a circadian rhythm (Munshi et al. 1979). It was inconvenient to run each test so that the minimum concentration coincided with sunrise each day. Instead, the fish were exposed to a 16L : 8D photoperiod during the acclimatisation period and during the experiment such that 'sunrise' was shifted to late afternoon. During each test the container was covered and temperatures allowed to fall to below 30.0°C; after each test the container was aerated, heated to 32.0-35.0°C with a 240-watt aquarium heater and illuminated with two 240-watt lamps. Fish were fed 'Fino Fin' immediately after each test and dead individuals and wastes were removed from the container. The lengths of dead individuals were measured.

Salinity

Thirty individuals randomly selected from the stock aquaria were transferred to a 2600-L tank of tapwater with a sandy bottom. The fish fed on algae growing on the tank walls and microinvertebrates associated with the substrate. The experiment lasted for 40 days. Water was allowed to evaporate from the tank, simulating conditions in the pools. Conductivity (a measure of salinity) and dissolved oxygen concentrations in the tank

were determined between 0800 and 0930 hours at least once a week by conductivity meter and Winkler titrations; a calibrated thermometer was placed in the tank and daily maximum and minimum temperatures were recorded.

Starvation

To determine if starvation could have caused mortality of *C. marianae* during the study period it was decided to compare the weight for length of pool-dwelling *C. marianae* with that of individuals that had died from starvation induced in the laboratory.

Approximately 80 *C. marianae* (15-36 mm LCF) were randomly selected from the 'stock aquaria' and transferred to a 70-L aquarium of tapwater. The aquarium was aerated and a flow-through system continuously flushed it with tapwater; its top was covered to prevent the introduction of extraneous food. Fish were fed 'Fino Fin' twice daily and wastes were removed from the aquarium bottom. The stock aquaria adjacent to the experimental aquarium acted as 'controls' for the experiment; conditions, except for food, were identical in the experimental and the stock aquaria.

After six days under these conditions, feeding was terminated. After several days fish appeared to be ingesting microscopic particles coming from the tapwater. This presumed source of food was cut by filtering the inflowing water through a glass-wool and charcoal filter. The feeding behaviour subsequently stopped.

The aquarium was inspected for dead fish (those not responding to touch) at least once every four hours. Dead fish were dried immediately between sheets of blotting paper for 10 to 30 seconds before being weighed and measured. The weight of 12 dead *C. marianae* left in water for eight hours was found to decrease by almost 10%, so individuals dying overnight were discarded. The loss in weight after three hours was found to be less than 3%. The experiment was repeated using about 20 individuals (17-45 mm LCF).

Predation

To test the extent of bird predation on this species an enclosure treatment was used on four pools: B1, B2, F1 and F2 were enclosed in 'bird net' for the duration of the study. The nets appeared to act as a deterrent as well as a barrier to the entry of birds.

In anticipation of finding predation by birds on *C. marianae*, the occurrence of piscivorous birds at the other pools (SN, N1, N2, N3) was recorded. These pools were regularly observed from a distance for at least 10 minutes on 18 days and the numbers and behaviour of piscivorous birds within sight of the pool were recorded.

To investigate the extent of fish predation piscivorous species were removed from 3 pools (SN, F1, F2); mortalities in these pools were compared with the others.

3

Results

3.1 Physico-chemical conditions

Pool size

Maximum depths ranged between 1.1-1.9 m at the beginning and 0.6-1.5 m at the end of the study period (Table 2). Volumes of the pools ranged between approximately 100 and 443 m^3 at the beginning of August (Table 2). By November, volumes were between 30 and 257 m^3. A comparison of water lost from each pool (i.e. the change in depth between samples) and the water expected to be lost according to the meteorological records (i.e. the evaporation minus the rainfall occurring, between samples) revealed that in August/September some pools lost more water than expected (Table 3).

Temperature

The highest maximum temperature recorded at the bottom of the deepest region of the pools was 35.5°C (pools N2, B1 and F2); the lowest minimum temperature in the same region was 22.0°C (pool F1) (Table 4). Minimum and maximum temperatures tended to increase during the study period.

Temperatures in the 'Craterocephalus habitat' of pool SN ranged between 23.0 and 39.5°C, considerably more extreme than those in the deepest region of the same pool (26.0 to 32.0°C). Temperatures just beneath the surface above the deepest region of pool SN ranged from 23.5 to 32.0°C during the study period.

Chlorophylls *a*, *b* and *c*

Concentrations of chlorophyll *a* ranged between 6 and 178 μg/L (Table 5). Generally, the levels were significantly higher than those in the major billabongs of Magela Creek. Surface samples taken from the lagoons during the late Dry by Hart & McGregor (1980) had chlorophyll *a* concentrations of less than 24 μg/L. There was a trend of increasing chlorophyll *a* concentrations throughout the study; they were particularly high in pools N1 and N3 in November.

Chlorophyll *b* concentrations ranged between 1 and 60 μg/L (Table 5). Again, the highest concentrations were recorded in pools N1 and N3 in November. Chlorophyll *c* concentrations were less than 7 μg/L in the pools (Table 5). Chlorophylls *b* and *c* did not show any clear temporal trends during the study.

Oxygen

Oxygen concentrations at the bottom of the deepest region of each pool were lower than the concentrations recorded at the surface and in the 'Craterocephalus habitat' (Table 6). Concentrations at the bottom of the deepest regions were lowest in September and October. The lowest concentration (0.8 mg/L) was recorded in pools B2 and N2 in October. The lowest surface concentration (0.9 mg/L) was recorded in pool B2 in October and the lowest concentration in the 'Craterocephalus habitat' (1.4 mg/L) was recorded in pool B2 in October. Oxygen concentrations showed no obvious temporal trends during the study.

pH

The results showed that pool water was usually acidic (Table 7). The lowest pH (5.3) during the study was recorded at the bottom of pool B2 in October; the highest (7.7) was recorded in October in the 'Craterocephalus habitat' of pool SN and pool B1. The pH of the 'Craterocephalus habitat' and the surface region were usually at similar levels, while the bottom pH was often lower than in these two regions.

Table 2. Dimensions of each pool at the beginning (August) and end (November) of the study period and pool volumes on sampling dates. All measurements in metres or cubic metres (m^3). Pools are sequenced in order of location along the creek.

Pool	August			November			Volumes				
							Sample Number				
	Maximum depth	Maximum length	Maximum width	Maximum depth	Maximum length	Maximum width	1	2	3	4	5
B1	1.9	30	10	1.2	16	10	129	81	69	40	-
F1	1.6	24	12	1.2	18	8	95	68	48	48	-
SN	1.8	84	16	1.5	58	12	443	252	148	257	257
N1	1.5	36	14	0.6	20	8	241	102	50	50	43
N2	1.7	62	22	1.0	10	8	226	158	37	37	30
F2	1.1	18	8	0.6	12	6	56	21	36	36	-
B2	1.2	14	12	0.9	12	8	54	48	32	44	-
N3	1.4	66	14	0.9	50	12	391	257	154	154	-

Table 3. Changes in depth in each pool compared to the expected changes in depth (in parentheses). For each pool the expected change in depth was estimated as the amount of evaporation minus the amount of rainfall occurring between each sample. Values in centimetres. Evaporation and rainfall data were obtained from Ranger Meteorological Observations (unpubl.)

Pool	Sample Interval			
	1-2	2-3	3-4	4-5
B1	-30	-20	-30	-
	(-30)	(-20)	(-10)	
F1	-20	-20	0	-
	(-30)	(-20)	(-10)	
SN	-30	-20	+20	0
	(-30)	(-20)	(-20)	(-10)
N1	-50	-30	0	-10
	(-30)	(-20)	(-10)	(-10)
N2	-30	-40	0	-10
	(-30)	(-20)	(-10)	(-10)
F2	-20	-20	+10	-
	(-30)	(-10)	(0)	
B2	-30	-20	0	-
	(-20)	(-20)	(+10)	
N3	-30	-20	0	-
	(-30)	(-20)	(0)	

Table 4. Maximum and minimum pool temperatures (°C) throughout the study period. Maximum, lower figure of each pair, minimum, upper figure.

Pool	Sample Interval			
	1-2	2-3	3-4	4-5
SN (C. habitat)	23.5	23.0	28.0	28.5
	35.0	38.0	39.5	33.5
SN (surface)	23.5	24.5	27.0	28.0
	31.5	32.0	31.5	-
SN (bottom)	26.0	27.0	29.5	30.5
	27.5	28.0	30.5	32.0
N1	25.0	22.5	28.0	29.5
	26.0	28.5	31.5	32.0
N2	24.5	24.5	28.5	28.5
	27.0	28.5	35.5	35.5
N3	25.0	24.0	27.0	-
	31.0	31.0	32.0	-
B1	23.0	23.5	28.0	-
	28.0	27.0	31.0	-
B2	27.5	29.0	28.0	-
	31.5	35.0	34.5	-
F1	22.0	24.0	28.0	-
	29.0	28.0	30.0	-
F2	24.0	23.5	27.0	-
	31.5	35.0	35.5	-

Table 5. Concentration of chlorophyll *a*, *b* and *c* (mg/L) 10 cm below the surface of each pool.

Chlorophyll	Sample Number	Pool							
		SN	N1	N2	N3	B1	B2	F1	F2
a	1	26	10	-	8	9	17	16	16
	2	23	26	25	43	14	22	13	36
	3	35	55	32	36	22	54	6	32
	4	24	76	33	93	18	55	10	21
	5	23	178	14	-	-	-	-	-
b	1	10	4	-	3	3	5	4	5
	2	6	7	6	14	5	5	5	12
	3	9	14	10	12	6	11	2	7
	4	8	38	8	30	4	10	4	6
	5	5	60	1	-	-	-	-	-
c	1	7	3	-	5	2	4	4	2
	2	3	4	2	0	5	2	0	1
	3	0	2	4	1	2	2	1	4
	4	2	1	4	4	7	3	0	2
	5	1	1	0	-	-	-	-	-

Table 6. Concentrations of dissolved oxygen (mg/L) at 3 sites in each pool.

Site	Sample Number	Pool SN	N1	N2	N3	B1	B2	F1	F2
At bottom of deepest region of each pool	1	6.7	5.3	5.6	3.1	4.8	1.8	3.6	5.9
	2	3.2	2.2	3.3	4.5	2.2	1.0	2.5	4.5
	3	3.1	3.1	0.8	2.1	2.6	0.8	3.2	3.0
	4	4.1	4.7	1.9	3.2	3.9	1.2	4.0	4.5
	5	3.9	4.3	1.6	-	-	-	-	-
At 5 cm depth in deepest region of each pool	1	7.3	5.8	6.4	3.3	5.4	2.1	4.8	5.9
	2	5.0	2.5	3.8	5.0	2.5	1.0	3.4	4.5
	3	3.2	3.2	1.3	2.9	2.9	0.9	3.3	3.6
	4	5.0	5.6	2.9	5.6	4.6	0.2	4.3	4.6
	5	4.1	6.0	2.2	-	-	-	-	-
At bottom of Craterocephalus habitat of each pool	1	5.8	4.0	5.0	3.9	5.8	3.5	4.7	6.0
	2	3.9	4.0	3.9	5.9	3.3	1.4	2.5	5.0
	3	5.3	4.0	1.8	4.7	3.2	1.7	4.1	3.8
	4	8.1	5.7	3.6	8.1	4.6	2.6	4.9	5.6
	5	5.1	6.4	2.3	-	-	-	-	-

Table 7. The pH of water samples taken from 3 sites in each pool.

Site	Sample Number	Pool SN	N1	N2	N3	B1	B2	F1	F2
At bottom of deepest region of each pool	1	6.9	6.3	6.9	6.4	6.6	6.4	6.9	6.6
	2	6.2	-	6.4	6.1	6.6	5.3	5.6	5.8
	3	7.4	7.0	7.3	6.1	7.5	6.4	7.1	5.5
	4	6.4	6.4	6.6	5.9	6.1	6.4	6.3	6.2
	5	6.9	6.3	6.2	-	-	-	-	-
At 5 cm depth in deepest region of each pool	1	5.6	6.6	7.2	6.6	6.8	6.3	7.0	6.7
	2	6.0	-	6.2	6.2	6.7	5.8	5.5	6.2
	3	7.4	6.8	7.2	6.4	7.6	6.6	7.1	5.6
	4	6.3	6.5	6.2	6.1	6.3	6.4	6.1	6.4
	5	6.8	6.5	6.5	-	-	-	-	-
At bottom of Craterocephalus habitat of each pool	1	6.4	6.7	-	-	-	6.5	-	6.7
	2	6.2	-	6.3	6.0	6.7	6.0	5.6	6.3
	3	7.7	6.9	7.4	6.6	7.7	6.5	7.4	6.0
	4	6.0	6.8	6.4	6.6	6.2	6.8	6.8	6.4
	5	6.3	6.9	6.1	-	-	-	-	-

Table 8. The Secchi depth (m) in each pool during the study period.

Pool	Sample Number 1	2	3	4	5
SN	1.0	1.1	0.9	0.9	1.1
N1	-	1.0	0.6	0.5	0.4
N2	-	0.9	0.8	1.0	1.1
N3	1.3	0.6	0.6	0.5	-
B1	1.5	1.4	1.3	1.2	-
B2	0.8	0.7	0.6	0.6	-
F1	0.7	1.4	0.6	0.5	-
F2	0.6	0.6	0.5	0.8	-

pH showed no obvious temporal trends during the study.

Turbidity

Secchi depth ranged between 0.4 and 1.5 m in the pools during the study period (Table 8). Secchi depths estimated in November (sample numbers 4 and 5) were usually lower than those estimated earlier in the study period. As expected, Secchi depth appeared to be correlated with both the concentrations of chlorophylls and those of suspended solids.

Suspended solids

The concentrations were highest in most pools in October and November. The highest (58 mg/L) was recorded in pool N1 in November and the lowest (3 mg/L) was recorded in pool SN in September (Table 9). During a field survey (25 September) a particularly turbid pool was found adjacent to pool F1. This pool contained numerous *C. marianae*.

Conductivity

The highest (62 μS/cm) was recorded at the bottom of pool B2 in October and the lowest (22 μS/cm) was recorded at the surface of pool B1 in August (Table 10). There was no apparent stratification of the water with respect to conductivity. As water evaporated from the pools, conductivity was expected to increase. However, the data showed no consistent temporal trends. The diurnal variation in conductivity was investigated in pool SN on 20 September. Conductivity showed a diurnal pattern with the highest levels occurring in the late afternoon, about 10 μS/cm higher than the level determined between 0800 and 0930.

Ammonia

The results (Table 11) showed only one excessively high concentration of ammonia - 0.15 ppm in pool N2. The high concentration in this pool is attributed to buffalo excrement present at the time of sampling.

Heavy Metals

For water samples, copper, lead and uranium were present at levels only slightly above the detection limits of the methods employed (Table 12). Relatively high levels of manganese were present in all pools (68.2-120.0 ppb); concentrations of zinc were high in pools SN (21.1 ppb) and N3 (14.5 ppb) and cadmium was high in pool SN (26.4 ppb).

Concentrations of cadmium and lead were relatively low in sediment samples of all pools; zinc and manganese were high in pools SN (6.6 and 8.2 ppb) and N3 (4.2 and 12.8 ppb) and copper was high in pool SN (6.3 ppb) (Table 13). Pool SN was the pool closest to the uranium mine and had the highest levels of most heavy metals.

3.2 Community changes

Mortality in some species was found to be low in certain pools. Temporal changes in the length frequency distributions of these species in these pools may be attributed almost entirely to growth. In other species mortality was found to be high in some pools; changes in the length frequency distributions of these populations may be entirely or partly the result of size-dependent mortality. Analysis of length frequency distributions can also indicate if recruitment, following spawning, has occurred in the pools.

Distribution and abundance

Some species, such as *Leiopotherapon unicolor* and the plotosid catfish were adept at avoiding the seine and their abundances were frequently underestimated. In several cases, mortality could not be estimated from seine catches because the estimated abundance was less than the actual abundance.

Leiopotherapon unicolor: The spangled grunter, *L. unicolor*, occurred in all of the

Table 9. The concentrations of suspended solids (mg/L) in water samples taken 10 cm below the surface of each pool during the study period. See Table 1 for sample dates.

Pool	Sample Number				
	1	2	3	4	5
SN	7	3	4	17	16
N1	15	8	22	43	58
N2	-	3	17	4	10
N3	5	11	20	9	45
B1	7	17	5	10	-
B2	13	16	14	32	-
F1	15	11	18	15	-
F2	18	23	23	21	-

Table 10. Conductivity (uS/cm) of water samples taken 5 cm below the surface (upper figure) and one cm above the bottom of the deepest region of each pool (lower figure) during the study period. See Table 1 for sample dates.

Pool	Sample Number				
	1	2	3	4	5
SN	33	35	41	53	61
	55*	36	38	52	59
N1	26	31	29	32	34
	28	40	27	31	34
N2	26	32	51	45	42
	33	34	52	45	42
N3	34	40	42	39	31
	33	39	32	43	30
B1	22	36	46	32	-
	28	36	42	32	-
B2	35	46	58	53	-
	35	46	62	52	-
F1	27	32	32	31	-
	31	32	29	31	-
F2	-	40	42	32	-
	-	37	38	32	-

*Anomalous reading, perhaps due to instrument error.

Table 11. Ammonia concentrations in various pools on 14 October.

Pool	Ammonia Concentration (ppm)
SN	0.01
N1	0.01
N2	0.15
N3	0.03
B2	0.01
F2	0.01

Table 12. Heavy metal concentrations in the water of various pools. Values are given for the mean concentration of each heavy metal determined in replicate water samples taken on 22 Sep. and 20 Nov., days 53 and 112 (standard deviation of each mean appears in brackets). The detection limits estimated for the methods employed are shown for each metal. The tolerances (96-hr TL_m) to each metal of *Craterocephalus marianae* estimated by Giles (1974) are also provided.

	Heavy Metal Concentrations (ppb)											
	Cu		Pb		Mn		Zn		Cd		U	
Day	53	112	53	112	53	112	53	112	53	112	53	112
Pool												
B1	-	1.9 (1.5)	-	0.6 (0.1)	-	68.2 (2.1)	-	10.8 (4.7)	-	5.1 (0.8)	-	0.5 (0.0)
SN	1.2 (0.2)	0.7 (0.1)	1.6 (1.1)	1.6 (0.6)	106.2 (0.4)	107.3 (7.1)	10.8 (2.1)	21.1 (3.0)	-	26.4 (33.1)	0.1 (0.0)	0.4 (0.1)
N2	-	0.4 (0.1)	-	0.5 (0.4)	-	87.4 (2.6)	-	5.4 (3.3)	-	5.1 (0.1)	-	0.4 (0.1)
N3	1.3 (0.2)	0.4 (0.1)	0.9 (0.4)	1.5 (0.6)	>120.0 -	111.3 (7.6)	7.4 (0.8)	14.5 (6.9)	-	5.5 (0.3)	0.1 (0.0)	0.4 (0.0)
Detection limits	0.7		1.3		1.1		0.6		0.1			
TL_m	40.0		180.0		2220.0		140.0		-		3700.0	

Table 13. Heavy metal concentrations in the sediment of various pools. Values are given for the mean concentration of each heavy metal determined in replicate sediment samples taken on 22 Sep. and 20 Nov., days 53 and 112 (standard deviation of each mean appears in brackets). The detection limits estimated for the methods employed are also shown.

	Heavy Metal Concentrations (ppb)									
	Cu		Pb		Mn		Zn		Cd	
Day	53	112	53	112	53	112	53	112	53	112
Pool										
B1	-	0.2 (0.0)	-	0.2 (0.0)	-	5.3 (3.8)	-	1.6 (0.8)	-	-
SN	-	6.3 (0.6)	0.6 (0.0)	0.0 (0.0)	3.7 (2.3)	8.2 (0.6)	1.1 (0.1)	6.6 (7.8)	0.0 (0.0)	-
N2	-	1.6 (0.6)	-	0.0 (0.0)	-	2.0 (0.1)	-	1.0 (0.7)	-	-
N3	0.1 (0.2)	1.8 (1.4)	0.6 (0.2)	0.0 (0.0)	9.4 (0.2)	12.8 (1.3)	4.2 (3.5)	1.3 (0.4)	0.0 (0.0)	-
Detection limits	0.1		0.1		0.1		0.1		0.1	

Table 14. The distribution of fish in sandy pools along Magela Creek. (Pools are listed in order of location along the creek).

Species	Pool							
	B1	F1	SN	N1	N2	F2	B2	N3
Ambassis spp.	-							+
A. percoides	+	*	+	+	+	*	+	+
C. marianae	+	+	+	+	+	+	-	+
C. stercusmuscarum	+	+	+	+	+	-	+	+
G. aprion	-	*	+	+	+		+	+
G. giurus	+	+	+	+	+	+	+	+
H. fuliginosus				+	+			+
Arius sp.					+			
L. unicolor	+	*	+	+	+	*	+	+
M. cyprinoides							+	
M. splendida	+	+	+	+	+		-	-
M. nigrans	-							-
M. mogurnda	-	-	-	-	+	+	+	+
N. erebi	+	-	+	+	+	+	+	+
O. gutturale								+
O. lineolatus	+	*	+	+	+	*	+	+
P. midgleyi	+	+		+	+	+	+	+
Plotosid catfish	+	+	+	+	+	+	+	+
S. jardinii		*	+	+	+		+	+
S. krefftii	+	*	+	-	+	*	-	+
T. chatareus	-	*	+	+	+	*	-	+

+ present throughout the study period
- present at the beginning of the study period only
* present, but removed by the researcher
(no symbol) absent

study pools (Table 14). In the pools that were subjected to rotenone treatment in November *L. unicolor* was *common* to *very abundant* in terms of both biomass and number of individuals - it was the 'dominant' species in most pools (Tables 15, 16).

L. unicolor survived the entire study period in all pools except those where they were removed by the researcher for the purpose of testing the effects of predation by piscivorous fish. This species was one of the most difficult to capture by seining and its total abundance was frequently underestimated (Table 17). Mortality could only be estimated in pool B1 (at least 23% of the original population perished over the study period) and pool B2 (at least 39% perished).

Of the other pools, stranding was found to be responsible for some mortality in pool N1. On 16 October, 36 *L. unicolor* were collected, using rotenone, from a small section of pool N1. This section had become separated from the main body and eventually evaporated, so that all fish present would have perished as a result of stranding. Note that this occurred in pools N2 (August) and N1 (October); stranding did not occur in these two pools at other times during the study period or in the other pools studied.

Nematalosa erebi: The bony bream, *N. erebi*, occurred in all pools (Table 14) and was generally more abundant in downstream pools. In November this species was still *common* to *very abundant* in most pools, in terms of both biomass and number of individuals (Table 15, 16).

N. erebi survived the entire study period in all pools, except, perhaps in F1. Disregarding those pools with small populations initially (pools SN, B1, F1), the highest mortality occurred in pool N3 where at least 49% of the original population perished (Table 17). The lowest mortality occurred in pool N1 (1% perished).

Amniataba percoides: The banded grunter, *A. percoides*, occurred in all pools (Table 14) and was generally more abundant in downstream pools. In November it was *rare* to *common* in most pools in terms of both biomass and number of individuals (Tables 15, 16).

A. percoides survived the entire study period in all the pools (except those where removed by the researcher). Nevertheless, sampling indicated high mortality in half the pools, the highest mortality occurring in pools N2 (at least 96% of the original population perished) and B2 (at least 87% perished) (Table 17).

Scleropages jardinii: The saratoga, *S. jardinii* occurred in all except two pools (B1 and F1) (Table 14). This species was *common* to *rare* in most pools in terms of biomass (Table 16), and *rare* to *very rare* in terms of number of individuals - only one or two individuals per pool (Table 15). *S. jardinii* survived the entire study period in all the pools (except where removed by the researcher).

Glossamia aprion: The mouth almighty, *G. aprion*, occurred in all pools except one (pool F2) (Table 14). They were *rare* in most pools in terms of biomass (Table 16) and *rare* to *common* in terms of number of individuals (Table 15). *G. aprion* survived the entire study period in all pools except B1 and those pools where they were removed by the researcher. Mortality was highest in pool N3 (at least 38% of the original population perished) (Table 17).

Glossogobius giurus: The flat-headed goby, *G. giurus*, occurred in all pools (Table 14). This species was *rare* in most pools in terms of biomass (Table 16) and *rare* to *common* in terms of number of individuals (Table 15). *G. giurus* survived the entire study period in all pools.

Pingalla midgleyi: The black-blotched anal fin grunter occurred in all except one pool (N1) (Table 14). In most pools this species was *rare* in terms of both biomass and the number of individuals (Tables 15 ,16). *P. midgleyi* survived the entire study period in all pools. Sampling indicated that mortality was low in most pools except in pool B2 where at least 88% of the original population perished over the study period (Table 17). The mortality coincided with the anoxic conditions that occurred in this pool in October.

Toxotes chatareus: The archerfish, *T. chatareus*, occurred in all pools (Table 14). In most pools it was *rare* in terms of both biomass and number of individuals (Tables 15, 16). Some *T. chatareus* survived the entire study period in all pools except B1 and B2 and those pools where they were removed by the researcher. Sampling indicated that high mortality of *T. chatareus* occurred in most pools during the study period (Table 17). The highest mortality occurred in pool N3 where at least 86% of the original population perished.

Craterocephalus marianae: This species of hardyhead occurred in all pools (Table 14). It was *rare* in the pools in terms of biomass (Table 16) and *common* in terms of number of individuals (Table 15). In terms of numbers, *C. marianae* was the 'dominant' species in most pools at the beginning of the study period. Although subject to high mortality during the study, some survived the entire study period in all pools except B2. The causes of mortality are considered in detail later in this paper.

Oxyeleotris lineolata: The sleepy cod occurred in all pools (Table 14). It was *rare* in terms of biomass in most pools (Table 16) and *very rare* in terms of numbers - only one of two individuals per pool (Table 15). *O. lineolata* survived the

Table 15. The abundance, in terms of number of individuals, of fish species in various pools in November.

Species	Pool				
	SN	N1	N2	N3	B2
L. unicolor	common	v. abundant	v. abundant	common	common
N. erebi	rare	v. abundant	v. abundant	common	common
A. percoides	common	v. abundant	rare	common	rare
C. marianae	v. abundant	common	common		
G. giurus	rare	common	rare	v. abundant	rare
G. aprion	rare	rare	common	rare	rare
S. jardinii	v. rare	rare	rare	v. rare	rare
T. chatareus	rare	rare	rare	rare	
C. stercusmuscarum		rare	rare	rare	v. rare
P. midgleyi	rare		rare	rare	
H. fuliginosus		rare	rare	rare	
M. splendida	rare	rare	rare		
O. lineolata	v. rare	rare	v. rare	v. rare	rare
S. krefftii	rare			v. rare	
M. cyprinoides					rare
Arius sp.		rare			
M. mogurnda			rare	v. rare	
Ambassis spp.				rare	
O. gutturale				rare	

> 1.50 individuals per m^3	v. abundant
1.25 to 1.50 individuals per m^3	abundant
0.25 to 1.25 individuals per m^3	common
0.01 to 0.25 individuals per m^3	rare
0 to 0.01 individuals per m^3	v. rare
absent	(no term)

Table 16. The abundance, in terms of biomass, of fish species in various pools in November.

Species	Pool				
	SN	N1	N2	N3	B2
L. unicolor	common	v. abundant	v. abundant	common	common
N. erebi	rare	v. abundant	v. abundant	common	common
A. percoides	rare	common	rare	common	rare
S. jardinii	rare	common	common	rare	rare
G. aprion	rare	rare	rare	rare	rare
G. giurus	rare	rare	rare	rare	v. rare
P. midgleyi	rare		rare	rare	rare
T. chatareus	rare	rare	rare	rare	
C. marianae	rare	rare	rare	rare	
O. lineolata	v. rare	rare	rare	rare	rare
H. fuliginosus		rare	rare	rare	
C. stercusmuscarum		rare	v. rare	v. rare	v. rare
S. krefftii	rare			rare	
M. splendida	v. rare	v. rare	v. rare		
M. cyprinoides					common
M. mogurnda			v. rare	v. rare	
Arius sp.		rare			
Ambassis spp.				v. rare	
O. gutturale				v. rare	

> 30 g/m^3	v. abundant
25 to 30 g/m^3	abundant
5 to 25 g/m^3	common
0.1 to 5 g/m^3	rare
0 to 0.1 g/m^3	v. rare
absent	(no term)

entire study period in all pools (except where removed by the researcher).

Hephaestus fuliginosus: The sooty grunter, *H. fuliginosus*, occurred in only three pools (N1, N2 and N3) (Table 14). In most pools it was *rare* in terms of both biomass and number of individuals (Tables 15,16). *H. fuliginosus* survived the entire study period in all three pools.

Craterocephalus stercusmuscarum: The fly-speckled hardyhead, *C. stercusmuscarum*, occurred in all pools (Table 14). This species was *very rare* in terms of biomass in most pools (Table 16) and *rare* in terms of number of individuals (Table 15). *C. stercusmuscarum* survived the entire study period in all pools except pool F2.

Strongylura krefftii: The freshwater longtom, *S. krefftii* occurred in all pools (Table 14). It was *rare* in terms of biomass in most pools (Table 16) and *rare* to *very rare* in terms of number of individuals (Table 15).

During the study period *S. krefftii* suffered high mortality. It did not survive in pools N1 and B2. (It was removed by the researcher, from pools F1 and F2). Of the other pools, mortality was highest in pool N3 (at least 95% of the original population perished) and lowest in pool B1 (at least 67% perished) (Table 17). Most mortality appeared to have occurred before October.

Melanotaenia splendida: This species of rainbow-fish occurred in all pools except pool F2 (Table 14), and was generally more abundant in upstream pools. *M. splendida* was *very rare* in terms of biomass in most pools (Table 16) and *rare* in terms of numbers (Table 15). This species survived the study period in pools B1, F1, SN, N1, N2 and B2 but not in pools B2 or N3.

Megalops cyprinoides: The tarpon, *M. cyprinoides* occurred only in pool B2 (Table 14) - where it was *common* in terms of biomass (Table 16) and *rare* in terms of the number of individuals - only three fish (Table 15). All *M. cyprinoides* survived the study period in this pool.

Mogurnda mogurnda: The purple-spotted gudgeon, *M. mogurnda* occurred initially in all pools, but only survived the entire study period in pools N2, F2, B2 and N3. In terms of biomass this species was *very rare* in the pools in which it was still present in November (Table 16), and *rare* to *very rare* in terms of number of individuals (Table 15).

Arius sp.: The fork-tailed catfish was present in only one pool (N1) - one individual present (Tables 14, 15, 16).

Ambassis spp.: Several *Ambassis* spp. were collected from pools B2 and N3 (Table 14). They did not survive the study period in pool B2.

Ophisternon gutturale: The one-gilled eel, *O. gutturale* occurred only in pool N3 (Table 14), where it was *very rare* in terms of biomass (Table 16) and *rare* in terms of number of individuals (Table 15). It survived the entire study period in this pool.

Plotosid catfish: All plotosid catfish have been grouped together, pending the publication of a taxonomic revision of the Plotosidae. Plotosid catfish occurred in all pools (Table 14). A general assessment is that they were *common* to *abundant* in most pools and *rare* to *common* in terms of number of individuals. The catfish were the most difficult fish to capture by seine net and there are no accurate data available on temporal changes in their abundance. Plotosid catfish survived the entire study period in all pools.

Length frequencies

Leiopotherapon unicolor: The *L. unicolor* populations consisted of large juveniles (60-80 mm LCF) and small and large adults (90-220 mm LCF) (Table 18). The effects of growth and size-dependent mortality on the length frequency distributions was not assessed because the mortality rate of *L. unicolor* could not be estimated.

Nematalosa erebi: The *N. erebi* populations consisted of small and large adults (120-210 mm LCF) and large juveniles (100-110 mm LCF) (Table 19). Small juveniles (20-50 mm LCF), which were probably spawned in October, were

Table 17. Estimated and actual (*) abundances of *L. unicolor* in each pool. Measurable mortality, both the proportion of the original population and number of individuals that perished over the study period, is also shown. See Table 1 for sample dates.

		Sample number					Mortality	
Species	Pool	1	2	3	4	5	numbers	%
L. unicolor	SN	32 (-25)[1]	22	71	14	91*	-	-
	N1	122	26	128 (-36)[2]	128	132*	-	-
	N2	12	24	45	16	56*	-	-
	N3	18	17	31	40*	-	-	-
	B1	26	15	25	20	-	6	23
	B2	11	46	22	28*	-	18	39
	F1	23 (-23)[3]	15 (-15)[3]	12 (-12)[3]	8	-	-	-
	F2	16 (-16)[3]	43 (-43)[3]	7 (-7)[3]	2*	-	-	-
N. erebi	SN	12 (-4)[1]	2	3	4	5*	3	38
	N1	69	72	77	80	79*	1	1
	N2	33	78	93	54	83*	10	11
	N3	17	105	102	56*	-	49	47
	B1	1	1	0	1	-	0	0
	B2	18	42	46	32*	-	14	30
	F1	2	1	2	0	-	2	100
	F2	23	19	22	22*	-	1	4
A. percoides	SN	17 (-24)[1]	19	53	20	68*	-	-
	N1	71	32	39 (-22)[2]	49	69*	-	-
	N2	51	53	76	6	3*	73	96
	N3	31	50	53	83*	-	-	-
	B1	13	4	3	4	-	9	69
	B2	14	52	35	7*	-	45	87
	F1	5	25 (-24)[3]	15 (-15)[3]	2	-	-	-
	F2	0	0	0	3*	-	-	-
G. aprion	SN	2	2	5	2	7*	-	-
	N1	2	3	1	3	2*	1	33
	N2	1	1	1	0	9*	-	-
	N3	0	21	10	13*	-	8	38
	B1	1	0	0	0	-	1	100
	B2	0	3	2	1*	-	2	67
	F1	1 (-1)[3]	6 (-6)[3]	4 (-4)[3]	1	-	-	-
	F2	6 (-6)[3]	0	0	0*	-	-	-
P. midgleyi	SN	25	27	28	15	32*	-	-
	N1	0	0	0	0	0*	-	-
	N2	0	1	3	6	7*	-	-
	N3	22	24	30	30*	-	0	0
	B1	1	1	1	1	-	0	0
	B2	0	16	13	2*	-	14	88
	F1	7 (-5)[3]	2	17 (-17)[3]	5	-	-	-
	F2	0	5 (-4)[3]	0	1*	-	0	-

...cont.

Table 17. (Continued)

Species	Pool	Sample number 1	2	3	4	5	Mortality numbers	%
T. chatareus	SN	6	4	5	5	2*	3	50
	N1	19	20	14 (-2)[2]	14	8*	10	56
	N2	11	11	7	1	1*	10	91
	N3	37	25	16	5*	-	32	86
	B1	2	0	0	0	-	2	100
	B2	4	2	1	0*	-	4	100
	F1	2 (-1)[3]	1 (-1)[3]	0	0	-	-	-
	F2	0	0	2 (-2)[3]	0*	-	-	-
S. krefftii	SN	32 (-5)[1]	20	8	9	5*	22	81
	N1	17	6	0	0	0*	17	100
	N2	29	32	5	1	0*	32	100
	N3	54	7	6	2*	-	52	96
	B1	9	7	5	3*	-	6	67
	B2	11	4	0	0*	-	11	100
	F1	10 (-10)[3]	0	0	0	-	-	-
	F2	6 (-6)[3]	0	0	0*	-	-	-

* collected after rotenone application, i.e. **actual** abundance
1 removed by gill net for N.S.W. State Fisheries
2 removed from the section separated from the main body where stranding would have occurred.
3 removed by the researcher for the purpose of testing the effect of piscivorous fish.

Table 18. Length frequency (percentage) distributions of *L. unicolor* in various pools during the study period.

Pool	Date (1981)	Size Class (mm LCF) 60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	N
SN	6 Aug.				20	20		20	30	10									10
	13 Sept.					19	5	14	29	24		5	5						21
	12 Oct.				3	24	20	22		7	10	7	3	3					59
	9 Nov.					9	18	46	18	9									11
	17 Nov.	2	1		3	17	22	22	10	6	4	8	1	2					90
N1	9 Aug.						22	33	33		11								9
	14 Sept.	5			19	5	10	14		10	24		5	5	5				21
	15 Oct.			2	4	5	9	15	13	13	9	9	15	9	2				57
	10 Nov.*	1	1	1	4	7	9	20	11	13	12	8	9	2	2	1			127
					4	12	19	13	15	12	12	2	10	2					52
N2	3 Aug.							50	50										2
	10 Sept.	7				7	13	27		13		27	7						15
	11 Oct.					10	17	31	21	7	2	5	2	5					42
	6 Nov.					6	19	44	6	6	6	13							16
	19 Nov.*					5	7	30	16	4	12	7	12	4	2				57
N3	22 Aug.	9			9	27		18	18	9	9								11
	24 Sept.					7	20	20	7	13		7		13	7		7		15
	28 Oct.					13	13	16	16	6	6	10	16				3		31
	24 Nov.*			5	10	15	7	17	12	5	2	10	10	2			2	2	41

* collected after rotenone application.

collected from pools SN and N3 in November. Changes in length frequency distributions indicated growth of less than 30 mm during the four months of the study period.

Amniataba percoides: The *A. percoides* populations consisted of small adults (70-120 mm LCF) and a few large juveniles (50-60 mm LCF). Small juveniles (10-40 mm LCF) were collected from pool N3 in November.

Pingalla midgleyi: The populations of *P. midgleyi* encompassed a relatively narrow range of sizes - mostly small adults (80-120 mm LCF) and a few large juveniles (60-70 mm LCF) (Table 21). Because mortality of this species was low or absent during the study period, temporal changes in length frequency distributions in most pools can be attributed almost entirely to growth. The data show low growth rates - an increment of less than 10 mm during the study period for the primary size class.

Craterocephalus marianae: The populations of *C. marianae* consisted of small and large juveniles (10-22 mm LCF), small adults (23-38 mm LCF) and a few large adults (39-84 mm LCF). Fry (8-9 mm LCF), presumed to be *C. marianae*, were collected from most pools in August.

The populations appeared to be made up of two or three age classes. One age class, consisting of fry and juveniles (*i.e.*, 8-22 mm LCF), constituted more than 80% of the *C. marianae* populations of most pools in August (Table 22). *Craterocephalus* larger than 64 mm LCF were rare (only four specimens were captured during the study).

Mortality of *Craterocephalus marianae* was low or absent in pools F1 and F2. Length frequency distributions indicate growth of 10-30 mm in these pools during the study period for the primary size class. Size-dependent mortality of *C. marianae* is considered in detail in a subsequent section.

Strongylura krefftii: The *S. krefftii* populations consisted of small and large adults (320-550 mm LCF) and large juveniles (230-310 mm LCF) (Table 23). Mortality of *S. krefftii* was high in all pools during the study period.

Other species: The populations of *Glossamia aprion* consisted of small adults (70-130 mm TL) and a few large adults (140-180 mm TL). Juveniles (30-40 mm TL), collected from pool SN in November, were probably spawned during the study period. The *Glossogobius giurus* populations consisted of individuals presumed to be small and large juveniles and small adults (11-100 mm TL) and a few presumed to be large adults (100-166 mm TL). *G. giurus* of 8-10 mm TL, collected from pool N3 in November, were probably spawned during the study period. The populations of *Oxyeleotris lineolatus* consisted of small and large adults (250-450 mm TL) and a few large juveniles (152-250 mm TL). The *Hephaestus fuliginosus* populations consisted of large juveniles (66-120 mm LCF). The populations of *Craterocephalus stercusmuscarum* consisted of small and large juveniles (10-22 mm LCF) and small adults (23-45 mm LCF). The *Melanotaenia splendida* populations consisted of small and large juveniles (11-23 mm LCF), small adults (24-30 mm LCF) and a few large adults (70-110 mm LCF). The populations of *Mogurnda mogurnda* consisted of small adults (37-60 mm TL). *Scleropages jardinii* collected from the pools ranged between 230 and 290 mm TL. Plotosid catfish ranged between 100 and 183 mm TL.

Reproduction

Pingalla midgleyi: The gonads of 92 *P. midgleyi* (63-130 mm LCF) were examined. Thirty-seven individuals were female (68-96mm LCF), 38 were male (65-130 mm LCF) and 18 could not be sexed (63-93 mm LCF). The smallest adult female was 68 mm LCF and the smallest adult male was 72 mm LCF. Average gonad maturity stage of adult male and female *Pingalla midgleyi* was highest in November (Table 24, Fig. 4).

The percentage of male and female *P. midgleyi* captured during the time of spawning (October and November) Stage IV (mature) or later was estimated for each 5 mm size class (according to the method

Table 19. Length frequency (percentage) distributions of *N. erebi*, *A. percoides* and *P. midgleyi* in various pools.

Pool	Date (1981)	Size Class (mm LCF)																				N
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	
N. erebi																						
SN	6 Aug.												11	33	44	11						9
	13 Sept.																		100			2
	12 Oct.																		33	67		3
	9. Nov.													75	25							4
	17 Nov.*		20[+]	60[+]	20[+]															60	20	20	5[+]+6
N1	9 Aug.										10	32	29	29			2						63
	14 Sept.											11	25	41	23	1		1					72
	15 Oct.											5	25	45	23	1							77
	10 Nov.											3	28	49	19	1							78
	19 Nov.*												12	22	34	24	3	3	2				59
N2	3 Aug.											18	47	29	6								17
	10 Sept.											4	23	35	26	8	1						79
	11 Oct.											1	12	41	37	8		1					98
	6 Nov.												9	47	31	9							55
	19 Nov.*												10	46	36	7	2						59
N3	22 Aug.													24	35	35	6						17
	24 Sept.												1	13	33	33	13	5	2				100
	28 Oct.													7	30	42	11	9	1				102
	24 Nov.*		13[+]	61[+]	13[+]	13[+]								6	40	37	4	12	2				38[+]+52
A. percoides																						
SN	6 Aug.							18	46	27	9												11
	13 Sept.						5	10	30	45	10												20
	12 Oct.							11	64	15	8	2											53
	9 Nov.							10	48	29	10	5											21
	17 Nov.*									20	20	20	20	30	20								26
N1	9 Aug.							15	52	31	2												54
	14 Sept.							6	35	52	6												31
	15 Oct.							9	35	50	6												34
	10 Nov.					2	4	2	40	46	6												48
N2	3 Aug.						8	36	24	24	8												25
	10 Sept.							19	17	55	23	2	2										53
	11 Oct.								22	40	31	6											67
	6 Nov.							50		33	17												6
	19 Nov.*							100															3
N3	22 Aug.								40	40	20												10
	24 Sept.						12	19	26	33	7	2											42
	28 Oct.						4	16	34	42	4												50
	24 Nov.*	6[+]	47[+]	44[+]	3[+]		5	24	33	32	6				34[+]								84
B2	30 Aug.							25		75													4
	28 Sept.					2	7	17	35	30	7	2											46
	31 Oct.						12	21	33	24	6	3											33
	23 Nov.*							29	43	29													7
P. midgleyi																						
SN	6 Aug.							38	38	25													8
	13 Sept.					4		22	63	11													27
	12 Oct.					21		71	27														28
	19 Nov.					8		67	25														12
	17 Nov.*					33		50	8				8										12
N3	22 Aug.					10		30	50	10													10
	24 Sept.					23		68	9														22
	28 Oct.					20		63	17														30
	24 Nov.*					10		66	24														29
B2	30 Aug.																						0
	28 Sept.								67	33													15
	31 Oct.								31	69													13
	23 Nov.*								50	50													2

* collected after rotenone application.

[+] frequencies calculated separately from the main size class.

Table 20. Length frequency (percentage) distributions of *C. marianae* in the pools during the study period.

Pool	Calendar Date	Size Class (mm LCF)																																		N
	(1981)	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	
SN	5 Aug.	5	3	13	11	21	13	6	4	2	3	2	4	3	2	2	2		1	2	1	1		1													203
	13 Sept.				3	6	11	25	19	16	12	2	4	3						1		1															148
	12 Oct.										3	9	14	9	3	3	3	6	9	9	6	6	6	3	3	3	3		3		3						35
	8 Nov.																		17	17				33						17			17				6
	17 Nov.				4	7	11	18	21	4	4							4	11				4	7					4	4								28
N1	8 Aug.		5	8	8	8	14	11	10	6	3	5	3	4	3	1			3	3		3	1	1			1					1					79
	14 Sept.				7		5	2	10	15	20	15	7	7	10		2																				41
	14 Oct.															10	10	13	13	20	7	7	7		10	3						3					31
	9 Nov.												100																								1
	10 Nov.																																				0
N2	2 Aug.	2	16	8	21	11	13	7	3	1	3	1		1								1				1	1										154
	10 Sept.		1	2	16	13	13	11	14	14	3	2	1		1	2	1			2	1		1	1				1									94
	11 Oct.						3		13	13	13	27	3	7	3	3	3	3			3			3														30
	6 Nov.																		25	13	13	13	13				25										8
	19 Nov.																																				0
N3	21 Aug.					2	11	17	17	8	8	5	11	5	5	5	3	3	2	2				2													66
	23 Sept.							5			9	5	9	9	14	23	9		9		5	5															22
	27 Oct.																																				0
	24 Nov.																											50		50							2
B1	12 Aug.				9	8	5	6	8	16	14	16	2	2	2	2	3		2	2				2		2	3										64
	19 Sept.				1	5	17	14	6	5	5	4	6	15	10	6	3		2																		99
	19 Oct.											13	25	13	13		13	13	13																		8
	12 Nov.																								50		50										2
F1	12 Aug.	9	13	10	8	6	8	14	13	8	5	1	1		1		1	1	1	1				1						1							104
	19 Sept.			5	5			5		15	5	5	15	5			5		10	5					5		15										20
	20 Oct.											21		14	21	21		7	7					7													14
	11 Nov.															50		50																			2
F2	26 Aug.	1	2	14	27	19	15	12	4	5	1			1	1	1																					113
	30 Sept.													4	4	12	8	24	28	12		4	4														25
	10 Nov.																				10			20	10	10	10	10										10
	20 Nov.																											100									1

Table 21. Length frequency (percentage) distributions of *S. krefftii* in various pools during the study period.

Pool	Date	Size Class (mm)																																N
	(1981)	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360	370	380	390	400	410	420	430	440	450	460	470	480	490	500	510	520	530	
SN	6 Aug.					4	4	4	8	12	4	12		16			8		4		12						4			4	4					24
	14 Sept.								7	14		7						7		7		21	7	7		7		7		7					14
	12 Oct.																			13		25					25		25			13				8
	9 Nov.																			20	10	10	10	10	10	10						10		10		10
	17 Nov.*																					20	40				20	20								5
N1	9 Aug.				6	12	6		6	12		18		6	6							6			12			6						6	17
	14 Sept.									17				17						17		33				17									6
	15 Oct.																																			0
	10 Nov.																																			0
	19 Nov.*																																			0
N2	3 Aug.						14	7	7				7					7	14			7	7		7			7						14	14
	10 Sept.						3	6	6			6	6	6	10				6		3	6	10	3	3	3		10	3		3		3			31
	11 Oct.																				20		20				20		20	20						5
	6 Nov.																					1														0
	19 Nov.*																																			0
N3	22 Aug.					4	4	11	7	11	7	18	5	11	4	2	2						7		2			5								55
	24 Sept.																					20		20	20			20							20	5
	28 Oct.*											17							17						17		33								17	6
	24 Nov.*																							50		50										2

* Sample collected after rotenone application.

described by Davis (1982). The length at first maturity (the length at which 50 per cent of specimens were Stage IV or later) was estimated to be 70-75 mm LCF for males and 70-80 mm LCF for females (Table 23). Ovaries of ripe females contained 950 eggs on average (± 200, 95% CL).

Craterocephalus stercusmuscarum: The gonads of 149 *C. stercusmuscarum* (17-41 mm LCF) were examined. Sixty-six individuals were female (17-41 mm LCF), fifty-five were male (18-39 mm LCF) and 28 could not be sexed (17-22 mm LCF). The smallest adult male and female were both 22 mm LCF. Females maintained well-developed ovaries throughout the study period with some ripe specimens collected in November (Table 22, Fig. 5). The gonad maturity stage of females appeared to be relatively constant during the study period.

Craterocephalus marianae: The gonads of 409 *C. marianae* (20-84 mm LCF) were examined. Two hundred and fourteen individuals were female (20-84 mm LCF), 131 were male (22-44 mm LCF) and 63 could not be sexed. Smaller size classes (20-24 mm LCF) contained a higher proportion of identifiable females than did larger size classes. The smallest adult male was 24 mm LCF and the smallest adult female was 22 mm LCF. Many *C. marianae* had well-developed gonads throughout the present study (Table 22, Fig. 6).

The average gonad maturity stage of females increased during the study period and many collected in November were ripe. The maturity stage of males appeared to be more constant and generally lower than that of females (but this may be attributed to inherent difficulties in distinguishing the maturity stages of male *C. marianae*). The length at first maturity was estimated according to the method described for *Pingalla midgleyi*. The length at first maturity was 24-25 and 25-26 mm LCF for males and females, respectively (Table 24).

Leiopotherapon unicolor: The gonads of 355 *L. unicolor* (54-226 mm LCF) were examined. One hundred and twenty-nine individuals were female (85-225 mm LCF), 199 were male (63-226 mm LCF) and 27 could not be sexed (54-137 mm LCF). The smallest adult female was 81 mm LCF and the smallest adult male was 86 mm LCF. Gonad maturity stage of males and females was low at the beginning of the study period then increased in October and November (Table 22, Fig. 7).

Amniataba percoides: The gonads of 126 *A. percoides* (43-129 mm LCF) were examined. Sixty-one individuals were female (43-91 mm LCF), 56 were male (66-129 mm LCF) and nine could not be sexed (50-85 mm LCF). The smallest adult female was 64 mm LCF and the smallest adult male was 65 mm LCF. For most of the study period gonads showed little development (Table 22, Fig. 8).

Nematalosa erebi: Only specimens collected in November were studied. The gonads of 126 *N. erebi* (111-205 mm LCF) were examined. Sixty-one individuals were female (117-205 mm LCF), 57 were male (111-193 mm LCF) and eight could not be sexed (112-138 mm LCF). The smallest adult male was 120 mm LCF and the smallest adult female was 118 mm LCF. The gonad maturity stage of adults was high with many Stage VI (ripe) females collected (Table 22).

Strongylura krefftii: This species was only collected in August and September. The data for these two months were combined. Of 55 *S. krefftii* (225-480 mm LCF), 38 were female (255-473 mm LCF), 8 were male (270-480 mm LCF) and 9 could not be sexed (225-334 mm LCF). The smallest adult female was 420 mm LCF.

Glossogobius giurus: The gonads of 50 *G. giurus* (25-84 mm TL) were examined. Nine individuals were female (35-84 mm TL), 11 were male (28-67 mm TL) and 30 could not be sexed (25-63 mm TL). The most mature individual collected during the present study was only at Stage II (developing or recovering spent).

Condition

Five species spawned during the study period; thus both spawned and spent

Table 22. The gonad maturity stage of males (M) and females (F) of each species sampled from the pools. Mean ($\bar{x}$), standard deviation (SD) and the number of specimens analysed (N) are provided for each month.

Species	Sex	Statistic	Month Aug.	Sept.	Oct.	Nov.
P. midgleyi	F	$\bar{x}$	2.0	-	2.8	5.4
		SD	0	-	1.91	1.24
		N	4	0	8	26
	M	$\bar{x}$	2.0	-	2.8	4.1
		SD	0	-	1.03	1.06
		N	2	0	10	24
C. marianae	F	$\bar{x}$	3.0	3.2	3.5	4.3
		SD	1.07	1.83	1.29	1.06
		N	40	35	35	53
	M	$\bar{x}$	3.2	3.1	3.7	3.9
		SD	0.86	1.22	0.94	0.87
		N	25	11	26	47
C. stercusmuscarum	F	$\bar{x}$	4.1	3.1	4.7	4.7
		SD	1.58	0.92	0.76	0.89
		N	18	21	7	12
	M	$\bar{x}$	3.4	2.7	3.4	3.9
		SD	0.70	0.86	1.30	0.60
		N	17	17	8	9
L. unicolor	F	$\bar{x}$	2.2	1.9	3.6	3.9
		SD	0.64	0.88	1.61	1.41
		N	38	20	13	81
	M	$\bar{x}$	2.1	1.7	3.0	3.4
		SD	0.07	0.72	1.04	1.03
		N	14	15	23	151
N. erebi	F	$\bar{x}$	-	-	-	4.1
		SD	-	-	-	1.23
		N	0	0	0	57
	M	$\bar{x}$	-	-	-	3.7
		SD	-	-	-	1.14
		N	0	0	0	47
A. percoides	F	$\bar{x}$	2.3	-	1.5	3.8
		SD	0.57	-	1.29	1.19
		N	18	0	4	40
	M	$\bar{x}$	2.1	-	2.0	3.3
		SD	0.33	-	0.00	1.24
		N	9	0	6	46
S. krefftii	F	$\bar{x}$	-	2.9	-	-
		SD	-	1.00	-	-
		N	-	18	0	0
	M	$\bar{x}$	-	2.0	-	-
		SD	-	0.82	-	-
		N	-	7	0	0

specimens contributed to the relative condition factors for these species.

Nematalosa erebi: Only *N. erebi* collected in November were analysed. On average, relative condition factors of *N. erebi* were low in this month (Table 25).

Pingalla midgleyi: The relative condition factors of *P. midgleyi* were low in August and October and then increased to unity in November (Fig. 10, Table 25).

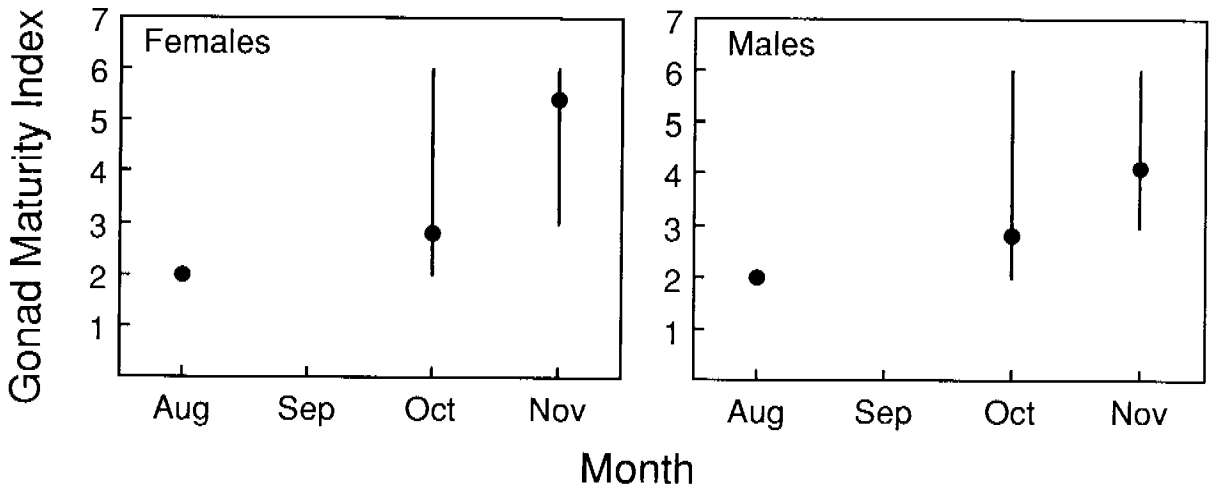

Figure 4. Temporal changes in the gonad maturity indices of adult male and female *Pingalla midgleyi* in the sandy pools of Magela Creek (means and ranges). Seine net and rotenone samples were combined; see Table 22 for sample sizes.

Table 23. Variation in the proportion of mature (*i.e.* Stage IV or later) *P. midgleyi* with size. The number of specimens (n) examined for each length class is also shown. Data are from October and November.

Length Class (mm)	Females		Males	
	% mature	n	% mature	n
61-65	0	2	0	1
66-70	67	3	0	4
71-75	0	5	70	10
76-80	71	17	67	13
81-85	100	6	71	7
86-90	100	2	100	2
91+	100	2	100	1

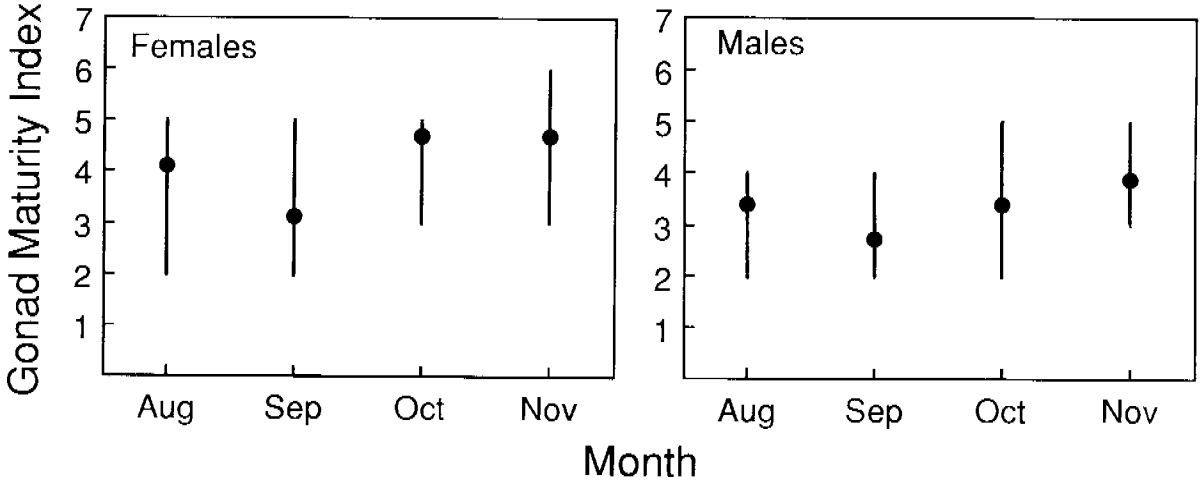

Figure 5. Temporal changes in the gonad maturity indices of adult male and female *Craterocephalus stercusmuscarum* in the sandy pools of Magela Creek (means and ranges). Seine net and rotenone samples were combined; see Table 22 for sample sizes.

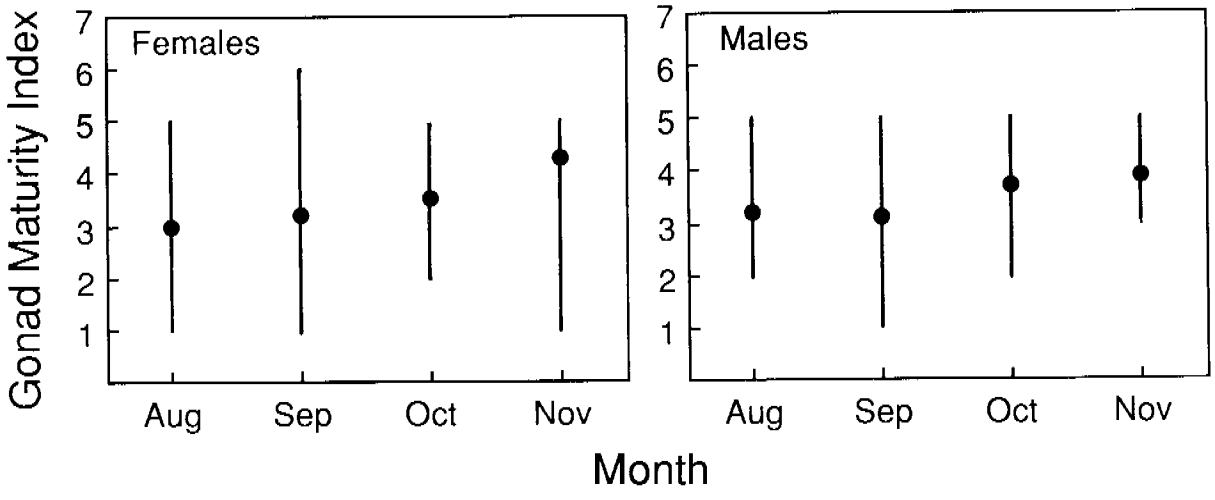

Figure 6. Temporal changes in the gonad maturity indices of adult male and female *Craterocephalus marianae* in the sandy pools of Magela Creek (means and ranges). Seine net and rotenone samples were combined; see Table 22 for sample sizes.

Table 24. Variation in the proportion of 'mature' (i.e. Stage IV or later) *C. marianae* with size. The number of specimens (n) examined for each length class is also shown.

Length Class (mm)	Females		Males	
	% mature	n	% mature	n
20	0	5	0	1
21	0	7	0	3
22	9	11	0	3
23	17	6	0	1
24	40	5	34	3
25	40	10	80	5
26	63	8	50	4
27	63	6	71	7
28	100	5	43	7
29	20	5	57	7
30	100	8	60	5
31	75	4	50	4
32	83	6	71	7
33	100	7	71	7
34	86	22	85	20

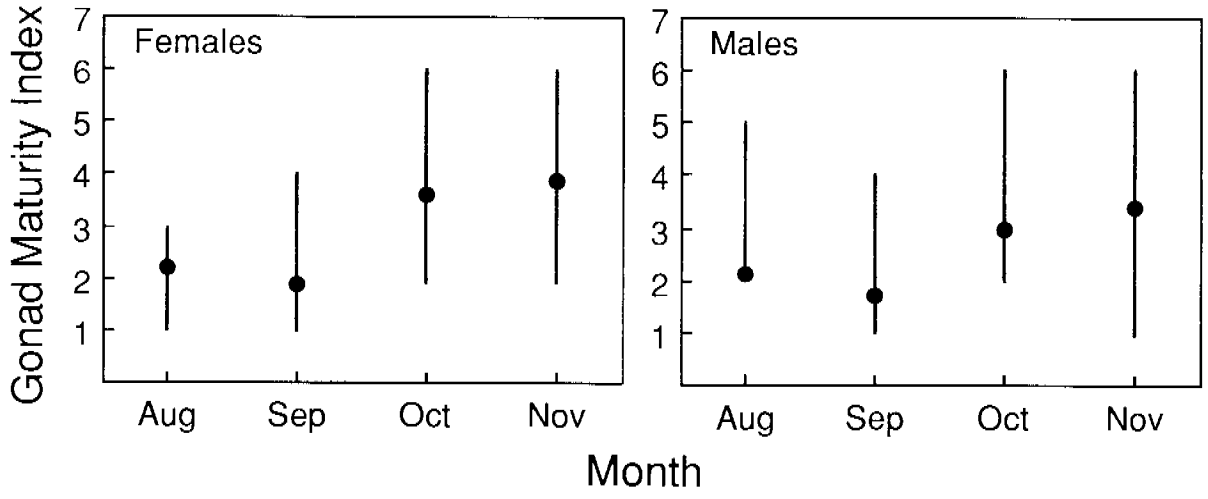

Figure 7. Temporal changes in the gonad maturity indices of adult male and female *Leiopotherapon unicolor* in the sandy pools of Magela Creek (means and ranges). Seine net and rotenone samples were combined; see Table 22 for sample sizes.

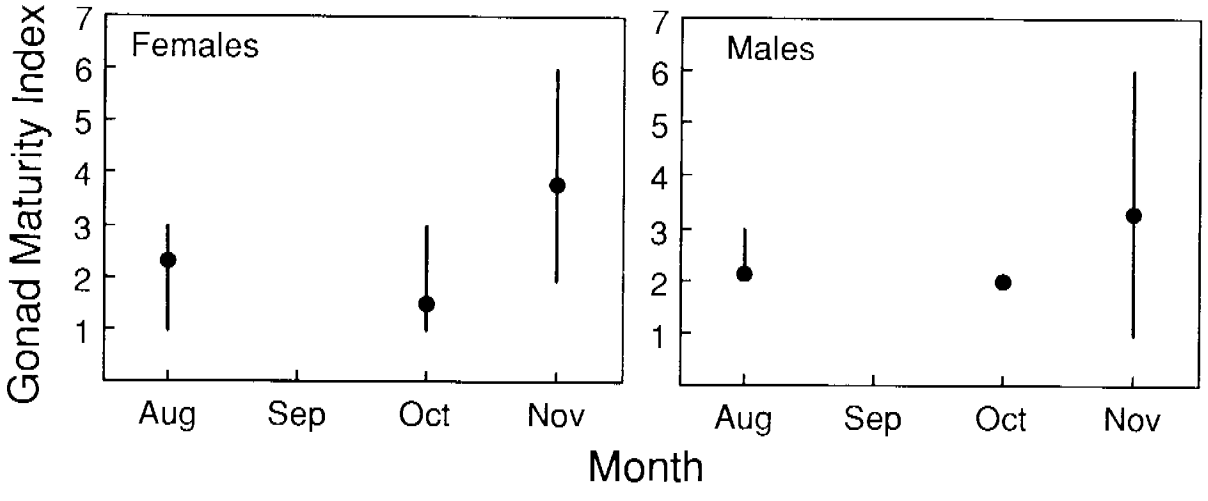

Figure 8. Temporal changes in the gonad maturity indices of adult male and female *Amniataba percoides* in the sandy pools of Magela Creek (means and ranges). Seine net and rotenone samples were combined; see Table 22 for sample sizes.

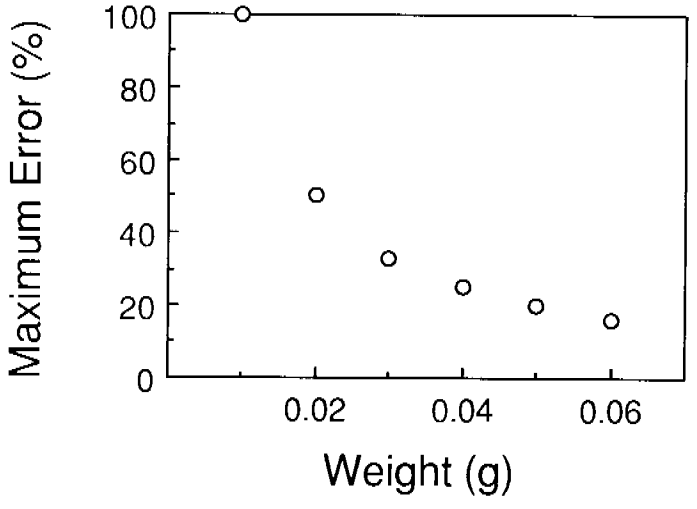

Figure 9. The potential effect of fish size on error in the determination of the weight of very small fish. Error is the percentage change caused by a 0.01g deviation from a specimen's true weight.

Table 25. Relative condition factors (K_n) of species collected from the pools during the study period. Mean relative condition factors ($\bar{x}$), standard deviation (SD) and the number of specimens analysed (N) are provided for each month. The length/weight relationship estimated by Bishop et al. (1980) used to estimate the relative condition factors is also shown for each species ('W' is the weight in grams and 'L' is length in centimetres).

		Month			
Species	Statistics	Aug.	Sept.	Oct.	Nov.
N. erebi	$\bar{x}$	-	-	-	0.94
($W = 0.0120\ L^{3.122}$)	SD	-	-	-	0.21
	N	0	0	0	204
P. midgleyi	$\bar{x}$	0.91	-	0.89	1.00
($W = 0.0146\ L^{3.157}$)	SD	0.12	-	0.11	0.11
	N	12	0	30	56
C. marianae	$\bar{x}$	1.01	1.01	0.95	0.98
($W = 0.0143\ L^{2.945}$)	SD	0.17	0.13	0.10	0.10
	N	134	106	90	422
C. stercusmuscarum	$\bar{x}$	1.07	0.98	1.04	0.98
($W = 0.0110\ L^{2.880}$)	SD	0.64	0.12	0.18	0.11
	N	53	21	18	39
G. giurus	$\bar{x}$	-	1.09	1.01	0.98
($W = 0.0103\ L^{2.775}$)	SD	-	0.25	0.10	0.12
	N	0	15	20	126
A. percoides	$\bar{x}$	0.91	0.65	0.80	0.89
($W = 0.0185\ L^{3.055}$)	SD	0.13	0.08	0.09	0.19
	N	36	2	25	169
L. unicolor	$\bar{x}$	0.90	0.86	0.87	0.80
($W = 0.0204\ L^{2.949}$)	SD	0.12	0.11	0.09	0.21
	N	42	32	24	301
G. aprion	$\bar{x}$	-	0.97	1.05	0.93
($W = 0.0109\ L^{3.167}$)	SD	-	0.10	0.09	0.23
	N	0	20	12	35

Craterocephalus marianae: During the study period relative condition factors of this species showed no significant deviation from unity (Fig. 10, Table 25).

Craterocephalus stercusmuscarum: The relative condition factors of *C. stercusmuscarum* were constant throughout the study period and on average showed no deviation from unity (Fig. 10, Table 25).

Glossogobius giurus: Relative condition factors of *G. giurus* showed no obvious temporal trends during the study period, remaining around unity (Table 25, Fig. 10).

Amniataba percoides: Relative condition factors of *A. percoides* were around unity at the beginning of the study period; they fell in October and then increased to around unity in November (Table 25, Fig. 10). The pattern of change in condition appeared to be correlated with stomach fullness.

Leiopotherapon unicolor: The relative condition factors of *L. unicolor* collected from the pools were especially low (Table 25). On average, condition decreased during the study period, reaching the lowest levels in November (Fig. 10). Many specimens captured in October and November were noticeably emaciated, indicating that some *L. unicolor* were starving (emaciated specimens did not have unusually high parasite loads). Despite the poor condition of *L. unicolor*, gonads were well developed in November, including the gonads of some emaciated specimens.

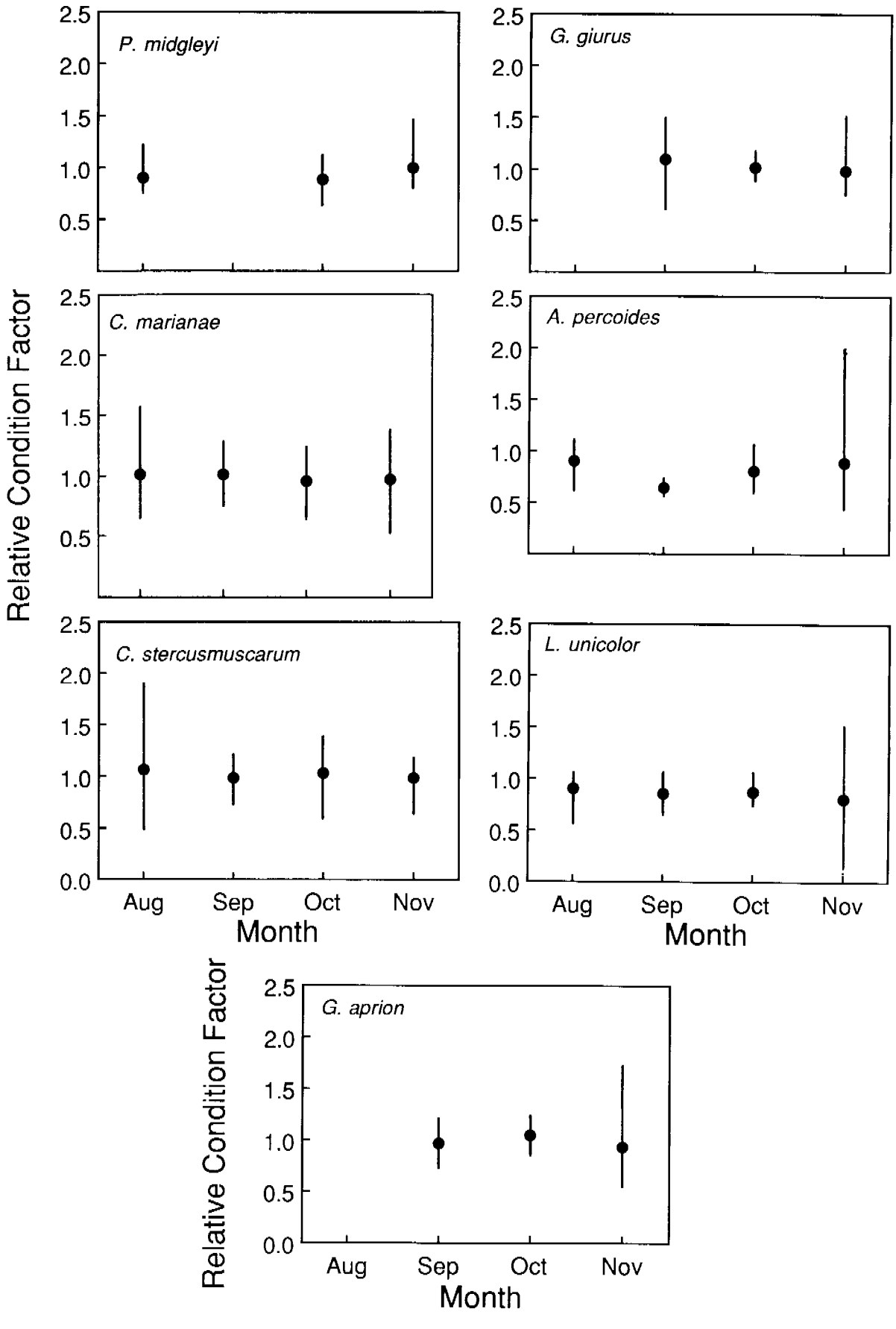

Figure 10 Temporal changes in the means and ranges of the relative condition factors (K_n) of various species collected from the pools. Only relative condition factors of specimens larger than 0.05g were included.

Glossamia aprion: Relative condition factors were around unity in September and October and decreased slightly in November (Table 25, Fig. 10).

Diet and feeding

For several species (*L. unicolor*, *G. aprion*, *S. krefftii*, *A. percoides* and *P. midgleyi*) stomach fullness was estimated and stomach contents were analysed.

Leiopotherapon unicolor: A comparison of fish captured by seining and those collected with rotenone from the same pool immediately after seining indicated that rotenone influenced the stomach contents of this species. Rotenone did not appear to influence the stomach contents of the other species studied.

L. unicolor consumed a variety of foods; many of the 232 specimens examined contained teleosts (this item occurred in 38% of the specimens), various species of coleoptera (32%), an epiphyte (15%) and terrestrial dipterans (14%). Nine per cent of the *L. unicolor* had empty stomachs (Table 26). Feeding activity (measured as mean stomach fullness) showed no significant change during the study period (Table 27).

Glossamia aprion: Of the 51 specimens examined, many contained teleosts (16%), corixid bugs (14%), and gerrids (8%). Twenty-seven per cent had empty stomachs (Table 26). Feeding activity appeared to decline as the Dry season progressed (Table 27).

Strongylura krefftii: Forty-two per cent of the 57 specimens examined had empty stomachs (feeding activity declined during the study period) (Table 27). Of those containing food, most had consumed teleosts (37%) (Table 26).

Amniataba percoides: This species mostly ate aquatic invertebrates: 38% of the 131 specimens examined contained dipteran larvae, 27% contained cladocerans, 23% contained conchostracans and 20% contained copepods (Table 26). Only 3% had empty stomachs and feeding activity did not vary during the study period (Table 27).

Pingalla midgleyi: Most of the 52 *P. midgleyi* examined contained filamentous algae (98%); many contained diatoms (44%) (Table 26). Some specimens also contained small aquatic invertebrates which may have been consumed incidentally with the algae. None had empty stomachs and feeding activity did not vary during the study period (Table 27).

3.3 Mortality

To investigate the causes of mortality in *C. marianae* populations, it was first necessary to estimate the mortality in each pool throughout the study period. Mortality (the proportion of each population perishing over a period of time) was calculated from changes in abundances (total numbers in each pool) which were in turn determined from monthly estimates of density (numbers per m^2) and pool area.

Density and abundance

At the commencement of the study in August, pool N2 probably had the largest population of *Craterocephalus marianae* (maximum likelihood estimate of 1750 individuals) and pools B2 and F2 probably had the smallest (45 and 72 individuals, respectively) (Table 29). The abundances of *C. marianae* decreased in all pools during the study period, but some fish survived the entire study period in all except pool B2. Although not occurring in thrownet samples taken in November, rotenone treatment at that time showed that a few *C. marianae* had survived the entire study period in pools N1 and N2. Sampling showed that the mortality in pool B2 was 'catastrophic' (all perished); this occurred between 30 August and 28 September. Mortality was high in the 'untreated' pools: N1 (*c.* 100% of the original population perished), N2 (*c.* 100%) and N3 (93%), and in pool B1 (89%), a pool from which birds were excluded. Mortality was lower in pools SN (79%), F1 (78%) and F2 (76%). Pool SN had some piscivorous fish removed and pools F1 and F2 had most piscivorous fish removed.

Table 26. Stomach contents of various fish species. For each species occurrence is expressed as the percentage of the total number of specimens examined (n) containing the food item.

	Species				
Items	*L. unicolor*	*G. aprion*	*S. kreffii*	*A. percoides*	*P. midgleyi*
Aquatic Plants					
diatoms	2			2	44
epiphytes	15				
filamentous algae	1			3	98
Terrestrial Plants	8	2		19	13
Aquatic Animals					
Arthropoda					
Arachnida (*Hydracarina* sp.)	2			4	4
Crustacea					
Conchostraca	1	2		23	8
Cladocera	7			27	21
Copepoda				20	19
Decapoda (*Caridina* sp.)	3	6	2	2	
Unidentified	1	2		3	
Insecta					
Coleoptera	32			1	
Diptera (larvae)	8		5	38	17
Hemiptera					
Corixidae		14			
Gerridae	4	8	2		
Odonata (larvae)	3	6		1	
Trichoptera		6			10
Unidentified	3	2			
Teleostei					
A. percoides	1				
Ambassis spp.			2		
C. marianae	7	6	3		
M. mogurnda			2		
M. splendida	2				
Plotosid catfish			2		
Unidentified	28	10	28	17	
Terrestrial Animals					
Amphibia (frog)	1				
Insecta					
Diptera (adults)	14		3	7	1
Hymenoptera	3				
Odonata (adults)	1				
Orthoptera	1	2			
Unidentified Organic Matter	8	14	17	21	21
Sand	9			28	42
Empty	9	27	42	3	0
(n)	232	51	27	135	52
Length Range of Fish Specimens (mm LCF or TL)	81-225	65-132	259-480	43-129	62-96

Table 27. The stomach-fullness of various species sampled from the pools. Mean ($\bar{x}$), standard deviation (SD) and the number of specimens analysed (N) are provided for each month.

Species	Statistic	Month			
		August	September	October	November
P. midgleyi	$\bar{x}$	2.43	-	2.95	3.38
	SD	1.40	-	1.09	0.71
	N	7	-	22	24
A. percoides	$\bar{x}$	2.39	-	2.00	3.12
	SD	1.14	-	0.82	1.24
	N	18	-	10	51
L. unicolor	$\bar{x}$	2.30	2.17	3.15	2.70
	SD	1.49	1.90	1.35	1.46
	N	56	23	20	133
G. aprion	$\bar{x}$	4.00	2.45	2.00	1.42
	SD	-	1.73	1.63	1.57
	N	1	20	13	19
S. krefftii	$\bar{x}$	1.40	1.33	-	0.44
	SD	1.79	1.23	-	0.53
	N	30	12	-	9

Sampling will have reduced the abundance of *C. marianae*. Sampling mortality (F) was estimated as the percentage of the original population removed in each monthly thrownet sample, *i.e.*:

$$F = Z/N \times 100$$

where: Z = the number of individuals removed in the sample, transformed according to the equation given above, and

N = the actual abundance estimated from the August sampling.

In half of the pools each sample removed less than 1% of the original population (Table 31). However, sampling mortality was comparatively high in pool F2 (2.7% of the original population over the entire study period). As previously mentioned, mortality in this pool was the lowest of all the pools studied.

Stranding

Stranding of *Craterocephalus marianae* occurred only in pool N2, when a large shallow section was cut off from the main pool during August (Plate 1). Throughout this month further evaporation resulted inthe formation of many separate puddles. These puddles contained numerous *C. marianae* and some *G. giurus*, *A. percoides* and *Macrobrachium* sp.

The puddles were inspected after two days. The maximum depth of both was then 2 cm. No *C. marianae* were present in puddle A; footprints, probably of an ibis, were noted around its edge. All *C. marianae* were alive in the netted puddle; but on the following day all but three specimens were lying dead on the moist sand (the three survivors were in 1 cm of water). Temperatures ranged between 19.0 and 33.0°C during the period of investigation.

Table 28. Summary of biological information obtained for each fish species occurring in the pools. Species are listed in order of abundance as biomass in November (abundance as number of individuals is also indicated).

Species	Distribution[1]		Abundance[2]	Mortality[3]	Size Structure	Maturity	Mean Monthly Kn[4]
	Aug.	Nov.	(Nov.)				
Leiopotherapon unicolor	all pools	all pools	common to v. abundant	-	large juveniles, small and large adults	many ripe in Nov.	0.08-0.90
Nematalosa erebi	all pools	all pools	common to v. abundant	low	large juveniles, small and large adults	many ripe in Nov., some spawned in Oct. or Nov.	0.94
Amniataba percoides	all pools	all pools	rare to common	high	large juveniles, small adults	some ripe in Nov. some spawned in Oct. or Nov.	0.80-0.91
Plotosid catfish	all pools	all pools	rare to common	-	-	-	-
Scleropages jardinii	most pools	most pools	rare to v. rare	-	small adults	-	-
Glossamia aprion	most pools	most pools	rare to common	low to high	small and large adults	some spawned in Oct. or Nov.	0.93-1.05
Glossogobius giurus	all pools	all pools	rare to common	-	small and large juveniles, small and large adults	resting; some spawned in Oct. Nov.	0.98-1.09
Pingalla midgleyi	most pools	most pools	rare	low	large juveniles and small	many ripe in Nov. adults	0.89-0.91
Toxotes chatareus	all pools	most pools	rare	high	large juveniles and small adults	-	-
Craterocephalus marianae	all pools	most pools	common	high	fry, small and large juveniles, small and large adults	many ripe in Nov. some spawned in Oct. or Nov.	0.95-1.01
Oxyeleotris lineolata	all pools	all pools	v. rare	-	large juveniles, small and large adults	-	-
Hephaestus fuliginosus	few pools	few pools	rare	-	large juveniles and small adults	-	-
Craterocephalus stercusmuscarum	all pools	most pools	rare	-	large juveniles and small adults	some ripe in Nov.	0.98-1.07
Strongylura krefftii	all pools	few pools	rare to v. rare	high	large juveniles, small and large adults	resting	-
Melanotaenia splendida	all pools	most pools	rare	-	small and large juveniles, small and large adults	-	-
Megalops cyprinoides	all pools	most pools	rare	-	-	-	-
Mogurnda mogurnda	all pools	most pools	rare to v. rare	-	small adults	-	-

Table 28. (Continued)

Species	Distribution[1]		Abundance[2]	Mortality[3]	Size Structure	Maturity	Mean Monthly Kn[4]
	Aug.	Nov.	(Nov.)				
Arius sp.	few pools	few pools	v. rare	-	-	-	-
Ambassis spp.	few pools	few pools	v. rare	-	-	-	-
Ophisternon gutturale	few pools	few pools	rare	-	-	-	-

[1] 'most pools' is 50% or more of those pools studied 'few pools' is less than 50%.

[2] v. abundant > 1.50 individuals per m^3
abundant 1.25-1.50 individuals per m^3
common 0.25-1.25 individuals per m^3
rare 0.01-0.25 individuals per m^3
v. rare < 0.01 individuals per m^3

[3] 'low' mortality is where 50% or less of the populations of most pools perished during the study period; 'high' is where more than 50% perished.

[4] relative condition factors (Kn) were estimated from the length weight relationships estimated by Bishop et al. 1980)

Temperature

Maximum temperatures at the bottom of the deepest region of pool SN were lower than maximum temperatures in other regions so the deepest region of each pool was designated the 'refuge area'. The data (Fig. 12) show that, in both regions, temperatures were within 1.0°C of the maximum temperature attained for periods of no more than 120-150 minutes.

With respect to length and condition factor the *C. marianae* tested were representative of the pool populations in October (Table 32). This was also the month in which the highest temperatures occurred in the pools.

The maximum recorded temperature in the coolest (deepest) part of any pool was 35.5°C.

The test populations tolerated temperatures of 36.5°C for 120 minutes and 37.0°C for 150 minutes without incurring mortality (Table 34). Above these temperatures mortality increased, reaching 100% at 41.2 and 40.3°C, respectively. Mortality was size-dependent in the 120 minute experiment ($0.001 < P < 0.002$) in that larger individuals had a lower tolerance (Fig. 14). There was no evidence for size-dependent mortality in the 150 minute experiment ($0.10 < P < 0.05$).

The 120 and 150 minute exposures to the maximum temperatures matched the duration of periods of high temperatures in the pools on October 9. October 9 was a typically hot day; the maximum and minimum air temperatures were within 0.4°C and 0.1°C of the mean monthly maximum and mean monthly minimum measured at Jabiru. The maximum air temperature on this day was only 3.1°C lower than the maximum air temperature recorded during the entire study period (Ranger Uranium Mines meteorological observations unpub).

Elevated temperatures decrease the solubility of oxygen and hence oxygen concentrations in the pools should be lower during the warmest period of the day. However, sampling indicated that oxygen concentrations were highest during the warmest periods of the day, probably as a result of high photosynthetic activity at this time (Fig. 15). During the experiments oxygen concentrations were maintained

above 6.3 mg/L, simulating the levels in the pools when the highest temperatures occurred.

On average the *C. marianae* tested were significantly longer and had a significantly higher condition factor than the fish in the pools (Table 32).

There was no mortality in this experiment, demonstrating that *C. marianae* can tolerate sudden temperature changes of from 40.0° to 22.0°C and 22.0° to 40.0°C. The greatest difference in temperature between 'Craterocephalus habitat' and the deepest region was less than 7.0°C, measured in pool SN on 20 September.
The lowest minimum temperature recorded in the deepest region of any pool was 22.5°C; *C. marianae* survived a temperature of 19.0°C for 24 hours.

Oxygen

Oxygen in the 'Craterocephalus habitat'

During the study the lowest dissolved oxygen concentrations in the 'Craterocephalus habitat' were recorded in pools B2 (1.4 mg/L), N2 (1.8 mg/L), F1 (2.5 mg/L) and B1 (3.2 mg/L). The concentrations determined in water samples taken from the 'Craterocephalus habitat' of pool SN at sunrise (0545 to 0615 hours) on 21 September and 10 October were 2.8 and 3.4 mg/L, which were 1.5 and 1.9 mg/L less than the concentrations determined in samples taken between 0800 and 0930 on the same days (Fig. 15). Thus if this differential (1.5-1.9 mg/L) is applied to the other pools, the oxygen concentrations occurring in the 'Craterocephalus habitats' may have been less than 0.1 mg/L in poolB2, less than 0.3 mg/L in pool N2, between 0.6 and 1.0 mg/L in pool F1 and between 1.3 and 1.7 mg/L in pool B1.

At the completion of the experiment ten *C. marianae* from the stock aquaria were transferred to the container which was aerated. None of these fish were dead after 24 hours, suggesting that anoxic conditions rather than an accumulation of metabolic wastes as the cause of mortality.

With respect to length, the *Craterocephalus* tested were representative of the populations of the pools in October when the lowest oxygen concentrations were recorded in the pools (Table 32). The results (Table 34) showed that mortality commenced when the 90-minute minimum concentration was less than 1.7 mg/L. Tolerance was size-dependent ($0.005 < P < 0.01$), with smaller individuals more susceptible to death. Difficulties were experienced in manipulating the decrease in oxygen concentration. In the experiment, oxygen decreased more rapidly than in the pools; this may have resulted in the lethal concentration being underestimated.

Salinity

The stocks tested were significantly longer and had a significantly higher condition factor than the populations of the pools in October (Table 32).

Daily maximum temperatures ranged between 32.5 and 40.0°C and daily minimum temperatures ranged between 24.0 and 28.0°C; oxygen concentrations ranged between 1.8 and 4.9 mg/L.

Conductivity was between 213 and 467 µS/cm during the experiment but no *C. marianae* died; the maximum salinity measured in the pools was 62 µS/cm.

Starvation

The experimental populations were comparable to pool *C. marianae* with respect to length (Table 32). No mortality occurred in the 'stock aquaria'.

Temperatures in the experimental aquarium (27.0-34.0°C) were similar to those in the pools. Hence metabolic rates of the experimental and pool fish would have been similar and the survival time in these experiments should be applicable to the field situation. Mortality commenced within seven days of the termination of feeding in the first experiment and within six days in the second experiment (Fig. 16).

Table 29. Estimates of abundance of *C. marianae* in each pool during the study period (80% confidence intervals of estimates in parentheses). Mortality (proportion of original population that perished over the entire study period) is also shown. See Table 1 for sample dates.

Pool	Sample Number					Mortality
	1	2	3	4	5	(%)
SN	995 (± 302)	474 (± 172)	314 (± 115)	202 (± 123)	208 (± 99)	79
N1	406 (± 134)	109 (± 56)	72 (± 44)	22 (± 30)	0*	100
N2	1750 (± 527)	139 (± 53)	28 (± 27)	28 (± 26)	0*	100
N3	200 (± 103)	83 (± 60)	0*	15 (± 20)	-	93
B1	153 (± 46)	107 (± 31)	53 (± 26)	17 (± 17)	-	89
B2	45 (± 27)	0	0	0	-	100
F1	151 (± 55)	74 (± 33)	50 (± 39)	33 (± 22)	-	78
F2	72 (± 42)	35 (± 18)	34 (± 24)	17 (± 15)	-	76

* Although not occurring in thrownet samples, later samples or rotenone treatment showed that *C. marianae* were present in these pools at these times.

Table 30. Sampling mortality in each *C. marianae* population during the study period. Sampling mortality was estimated as the percentage of the original population (absolute abundance) removed by each sample. See Table 1 for sample dates.

Pool	Sample Number				Total
	1	2	3	4	
SN	0.1	0.1	0.1	0.1	0.3
N1	0.2	0.2	0.2	0.1	0.6
N2	0.0	0.0	0.0	0.0	0.2
N3	0.4	0.3	0.0	*	0.7
B1	0.5	0.5	0.3	*	1.3
B2	1.4	0.0	0.0	*	1.4
F1	0.5	0.4	0.4	*	1.2
F2	1.0	0.9	0.8	*	2.7

* Of no consequence (*i.e.* the final sample of the pool for the study period).

Table 31. Relative density (individuals per m^2) of *C. marianae* in each pool during the study period (variance of each estimate in parentheses). See Table 1 for sample dates.

Pool	Sample Number				
	1	2	3	4	5
SN	1.91 (2.82)	1.53 (2.91)	1.23 (2.08)	0.65 (1.38)	0.67 (1.50)
N1	2.08 (2.75)	0.98 (2.27)	0.73 (1.74)	0.22 (0.55)	0
N2	1.86 (2.61)	1.60 (2.88)	0.53 (1.61)	0.53 (1.38)	0
N3	1.10 (2.64)	0.47 (1.14)	0	0.10 (0.24)	-
B1	1.78 (2.36)	2.02 (2.60)	1.00 (1.74)	0.33 (0.77)	-
B2	0.86 (1.65)	0	0	0	-
F1	2.07 (2.64)	1.51 (2.15)	1.20 (2.19)	0.78 (1.10)	-
F2	1.24 (3.08)	1.53 (2.20)	0.91 (1.88)	0.47 (0.80)	-

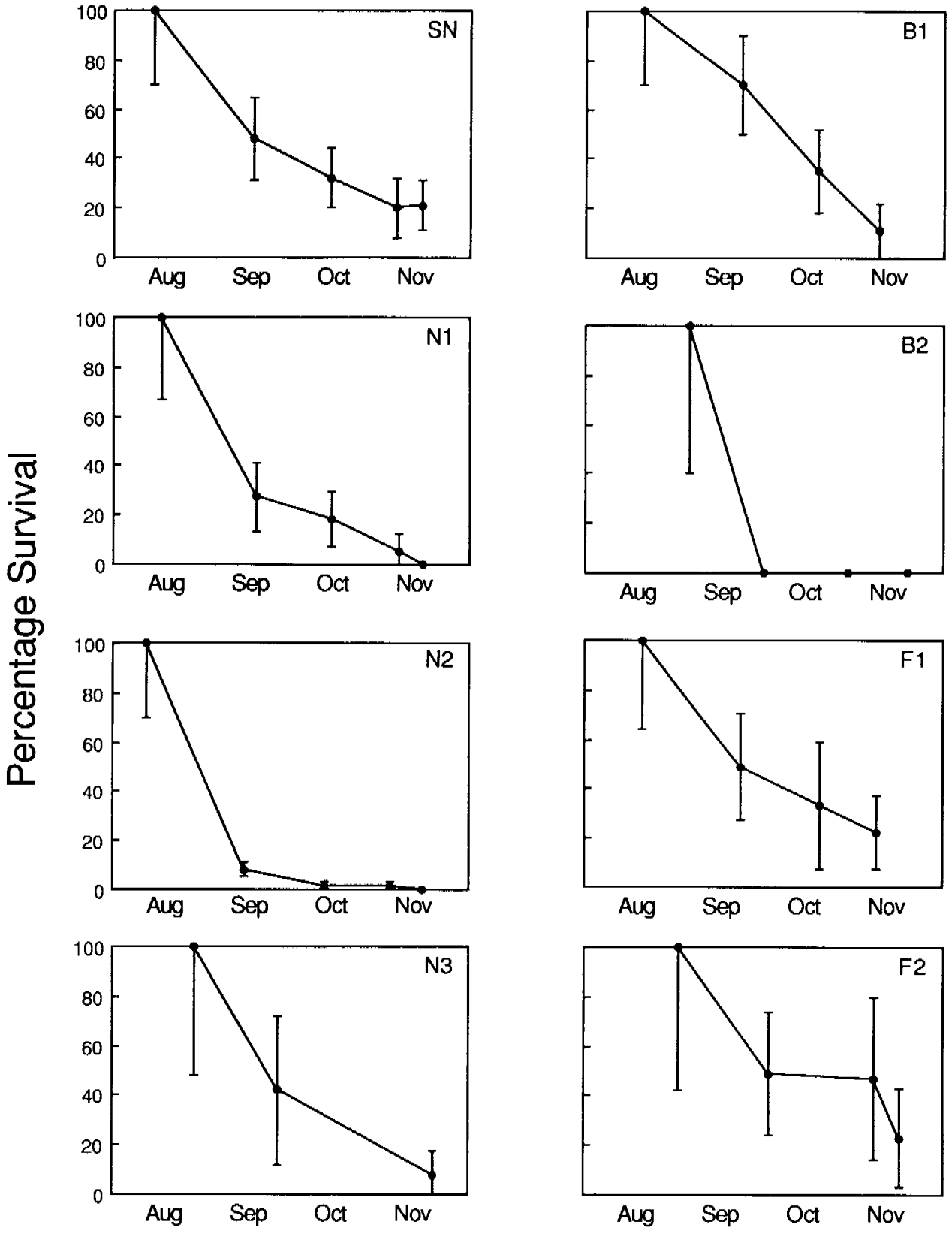

Figure 11. Survival of *Craterocephalus marianae* in the pools over the study period, expressed as a percentage of the estimated sizes of the original populations in each pool. The maximum likelihood estimates of population sizes are indicated by the dots, and the bars represent the 80 per cent confidence intervals for these estimates. The code names of the pools appear in the top right hand corner of each graph. The raw data are in Table 30.

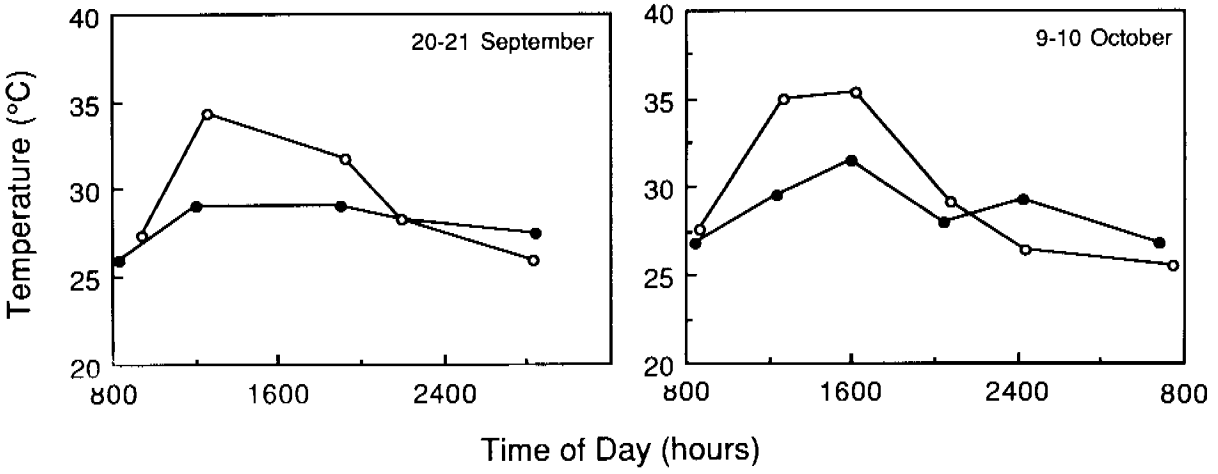

Figure 12. The diurnal variation in temperatures measured in pool SN on 20 September and 9 October. Temperatures at the bottom of the deepest region are indicated by solid symbols and temperatures at the bottom of the 'Craterocephalus habitat' by open symbols.

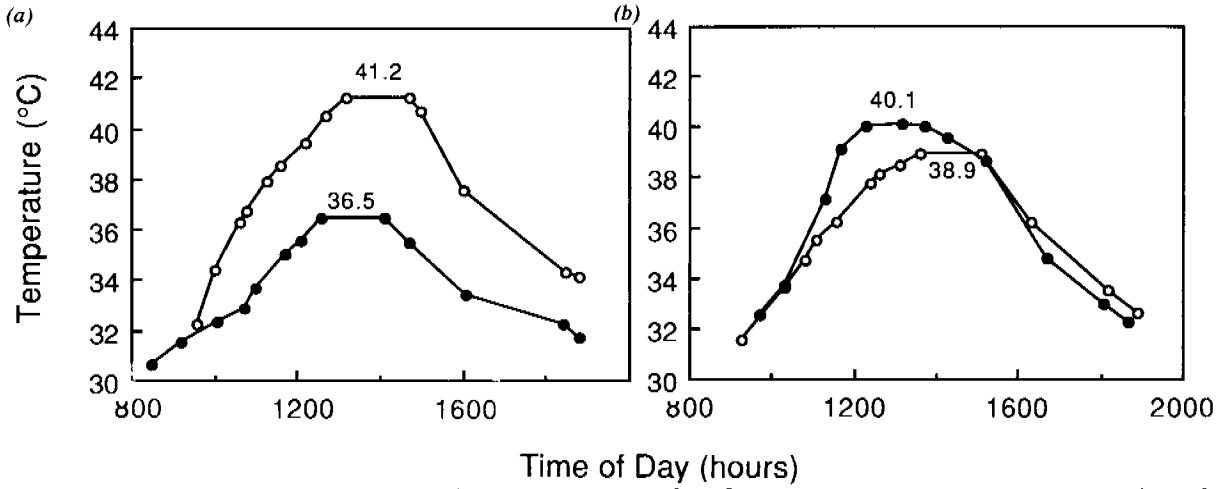

Figure 13. Examples of the diurnal variation of temperatures that *C. marianae* were exposed to during the thermal tolerance experiments. *(a)* shows the temperatures on two separate days of the first experiment where temperature was elevated then maintained at the maximum for a period of 120 minutes. *(b)* shows temperatures on two day of the second experiment where the maximum was maintained for 150 minutes. The maximum temperature for each day of each experiment is indicated.

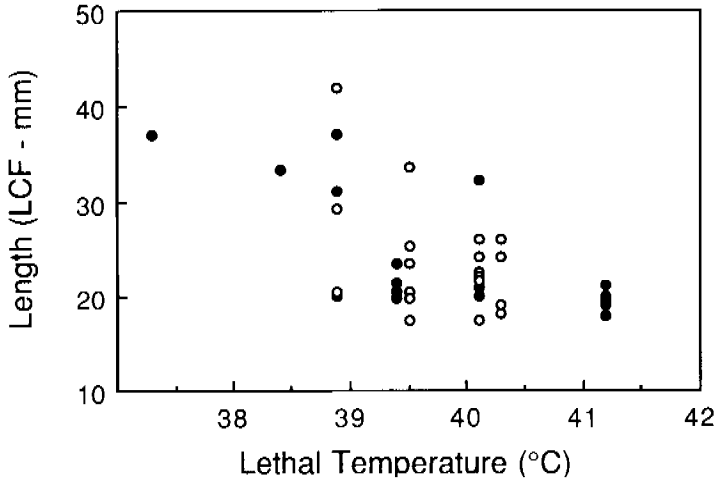

Figure 14. Relationship between size and upper lethal temperature for *C. marianae* under controlled laboratory conditions. Solid symbols are values for the first experiment when the duration of exposure to the maximum temperatures was 120 minutes. Open symbols are values for the second experiment when the duration of the maximum was 150 minutes.

Table 32. Comparison of *C. marianae* populations used in experiments and natural populations. For each population the critical level, $\underline{t}\ 0.05\ (2)\ (\underline{y}_1 + \underline{y}_2)$, and test statistic are provided for the null hypothesis $\underline{u}_1 = \underline{u}_2$, *i.e.*, that the mean size or the mean relative condition factor of the test population was the same as that for the natural populations. The natural populations in October were selected for the comparison because, with respect to the factors tested, conditions were generally most extreme at this time (Part 1). Relative condition factors estimated according to the formula described in Section 2.4.

Population	Length (mm LCF)						Condition Factor				
	(n)	Range	Mean	SD	Test statistic	Critical level	Range	Mean	SD	Test statistic	Critical level
Natural (Oct.)	65	13-37	22	5.25	-	-	0.7-1.4	1.0	0.01	-	-
Thermal tolerance	37	17-41	24	6.15	1.732	2.028	0.7-1.2	1.0	0.12	0.00	1.028
Sudden temperature change and salinity tolerance	30	21-38	28	5.22	4.913	2.045	1.0-1.2	1.1	0.01	4.48	2.045
Oxygen tolerance	16	14-41	26	6.97	2.324	2.131	-	-	-	-	-
Weight for length at starvation	70	15-45	24	6.73	2.071	1.995	-	-	-	-	-

Table 33. The effect of elevated temperatures on mortality of *C. marianae* under laboratory controlled conditions. Results are for two experiments in which the maximum temperatures were sustained for 120 and 150 minutes, respectively.

Day	Maximum Temperature (°C)	Duration (minutes)	Mortality (No. of individuals)	Mortality (% of total)
1-5	35.0	30-120	0	0
6	36.5	120	0	0
7	37.3	120	1	6
8	38.4	120	1	11
9	38.9	120	3	28
10	39.4	120	4	50
11	40.1	120	3	67
12	41.2	120	6	100
1-5	35.5	30-150	0	0
6	37.0	150	0	0
7	38.9	150	3	16
8	39.5	150	6	47
9	40.1	150	6	79
10	40.3	150	4	100

Table 34. The effect of dissolved oxygen concentration on mortality of 17 *C. marianae* under laboratory controlled conditions.

Rate of decrease in 0_2(mg/L)	Minimum 0_2 concentration (mg/L)	Duration of minimum (minutes)	Temperature (°C)	Mortalty (% of total)
-	2.3	120	-	0
0.6	1.7	90	28	0
1.1	1.5	90	27	24
0.2	1.1	120	28	41
0.6	0.3	-	32	100

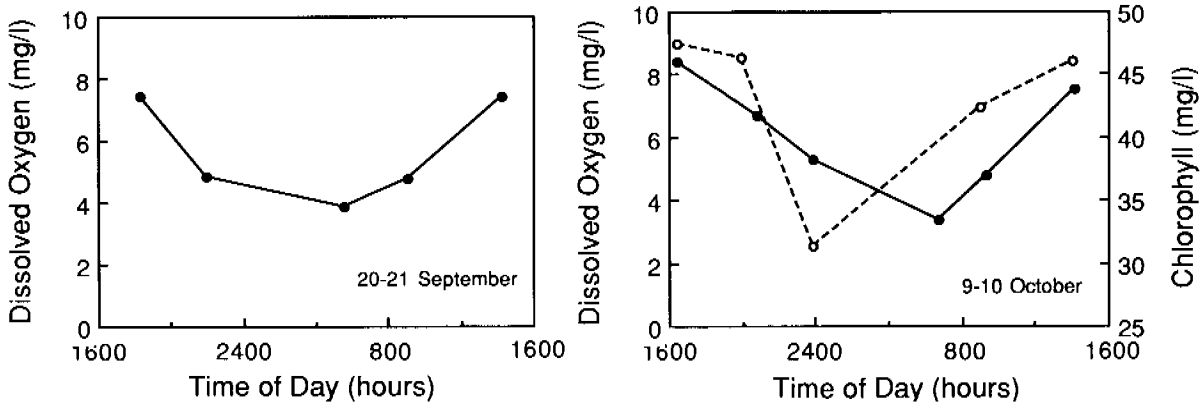

Figure 15. Diurnal variation in dissolved oxygen (solid symbols) and chlorophyll concentrations (open symbols) in the 'Craterocephalus habitat' of pool SN.

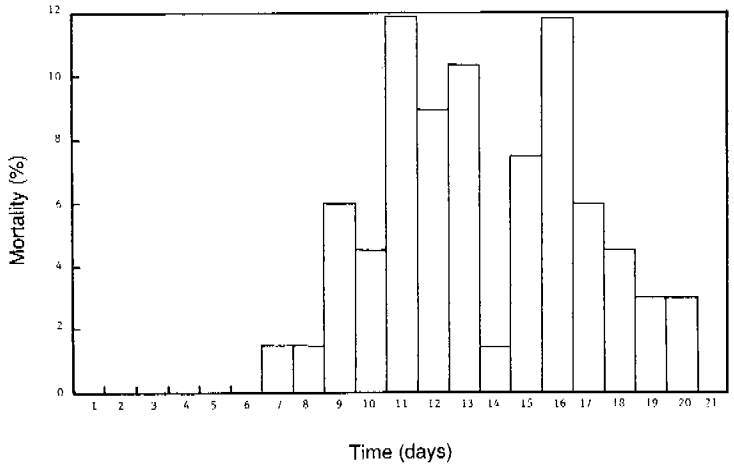

Figure 16. Distribution of mortality from starvation with time for a population of 55 *Craterocephalus* in a laboratory aquarium. Values are provided for the first experiment only. Day 0 corresponds to the termination of feeding.

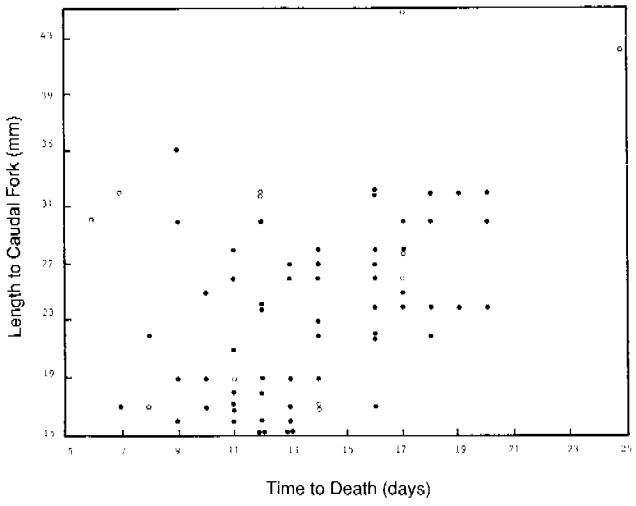

Figure 17. The distribution of the size of *Craterocephalus* dying from starvation with time. Solid symbols indicate values for the first experiment and open symbols indicate values for the second experiment. Day 0 corresponds to the termination of feeding.

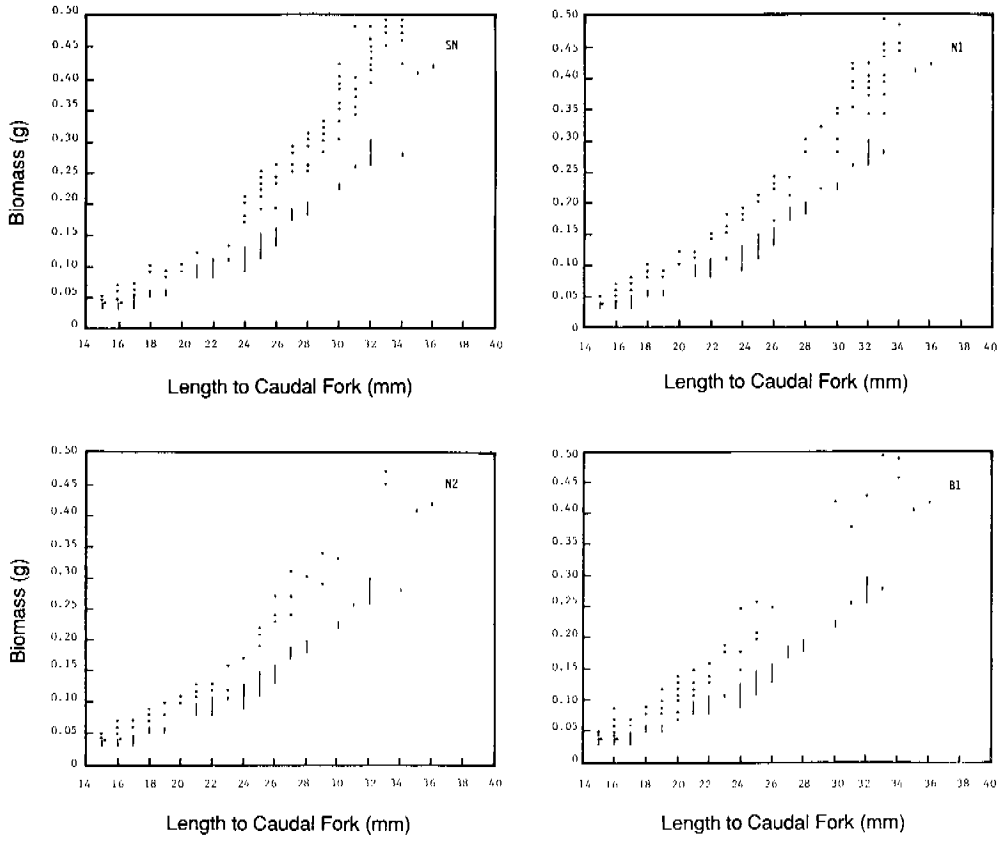

Figure 18. Examples of weight for length of *C. marianae* collected from the pools compared to that of fish known to have died from starvation in the laboratory experiments. Vertical lines indicate the range of weights estimated for individuals starved to death in the experiments. Solid symbols indicate weights estimated for individuals collected from the pools (one symbol may represent more than one individual). The code name of the pool is shown in the right hand corner of each graph.

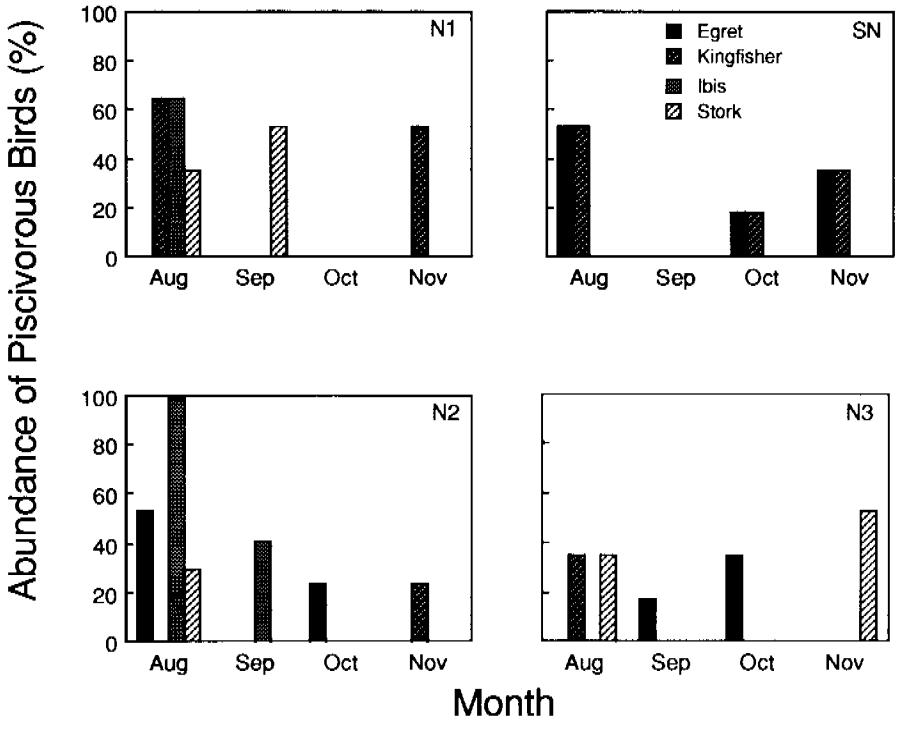

Figure 19. Temporal changes in the prevalence of piscivorous birds at each pool, other than those covered with bird nets. Prevalence was estimated for each month as the percentage of observations during that month when the species was present. The code for each pool is shown in the top right hand corner. The full names of the species are: great egret, azure kingfisher, straw-necked ibis and black-necked stork.

Mortality occurred over periods lasting 13 and 19 days in the first and second experiments, respectively, with most of the *C. marianae* dying 9 to 17 days after the termination of feeding. The distribution of mortality with time appeared to be bimodal (Fig. 17). The bimodality of survival times might be the result of sex differences.

Mortality due to starvation was size-dependent for the first experiment ($0.001 < P < 0.002$), with smaller individuals dying before larger individuals (Fig. 17).

However, mortality was not demonstrably size dependent in the second experiment ($0.2 < P < 0.1$). Differences in individual condition are unlikely to have contributed to size dependence because the fish were provided with excess food for more than 30 days in the 'stock aquaria' prior to the experiment. The variation is attributed to sex differences. No macroscopic parasites or abnormalities were noticed on any specimen.

The weights of specimens collected from the pools were above the weight of starved specimens (Fig. 18), usually 15% greater than the weight of starved specimens of identical length. *C. marianae* dying from starvation in the experiments were obviously emaciated; no emaciated individuals were found in pool samples. If there had been a shortage of food in the pools, fish living at high densities should have had lower condition factors than those living at low densities. Mean relative condition factors of the pool populations were independent of density ($0.20 < P < 0.50$) for pools SN, N1, N2, N3, B1 and ($0.10 < P < 0.20$) for pools F1 and F2.

Predation

Mortality of *C. marianae* in pool B2 is not considered here because it has been explained adequately as the result of anoxic conditions. Eighty-nine per cent of the original *C. marianae* population of B1 (birds excluded, piscivorous fish present) perished over the study period. This was a similar mortality rate to that which occurred in pools N1, N2 and N3 (birds not excluded, piscivorous fish present), where 100%, 100% and 93% of each population perished respectively. Mortality rates in pools B1, N1, N2 and N3 were higher than the rates that occurred in pool SN (birds not excluded, some piscivorous fish removed) and pools F1 and F2 (birds excluded and most piscivorous fish removed), where 79%, 78% and 76% of the populations perished, respectively.

Only four piscivorous birds were observed in the immediate vicinity of the pools during the study period. The black-necked stork, *X. asiaticus*, was potentially the most important predator.

It was observed feeding on high densities of *C. marianae* in small puddles near pool N2. However, it probably switched to larger species when foraging in the larger pools. But black-necked stork appeared to be infrequent visitors to the pools; there was a total of only eight sightings for all four pools during 18 bird censuses (Fig. 19).

Straw-necked ibis, *T. spinicollis*, were observed occasionally in the vicinity of pools. While not regarded as piscivorous (Anon. 1976) they were observed at puddles of pool N2 and might have taken *C. marianae* in this situation. The great egret, *Egreta alba*, was the most common piscivore at the pools (Fig. 19), but was only observed feeding on invertebrates and small frogs (*Ranidella* spp.) at the edges. Finally, most pools, including those covered with bird nets, had one resident azure kingfisher, *C. azureas*. The azure kingfisher has been documented as a piscivore (Anon. 1976), but was never observed to take *C. marianae* or any other fish during the present study.

4

Discussion

4.1 Physico-chemical conditions

Pool size

The excessive volume loss demonstrated in August/September was attributed to water seeping out of the pools through the substrate.

Temperature

The overall increase in temperatures was probably the result of both increasing ambient temperatures and decreasing pool volumes. Differences in pool depth, volume, direct sunlight (i.e. shading), turbidity and wind disturbance may have contributed to the different temperature regimes of the pools.

Chlorophylls *a b* and *c*, oxygen and pH

More data on the diurnal variation in oxygen levels are required, especially on the duration of minimal concentrations. When low concentrations were recorded in pools N2, B1 and F1, chlorophyll values were lower than when the diurnal variations were measured in pool SN - the minimum concentrations may have been lower than estimated for these pools.

Further, the estimate of the lethal concentration obtained in the laboratory experiment may not be applicable to the populations of the pools; *C. marianae* may possess adaptations for tolerating anoxic conditions which were suppressed under the laboratory conditions. In response to anoxic conditions most freshwater fish species swim at the water surface, gulping oxygenated water at the interface to permit survival (Lowe-McConnell 1964, 1969; Lewis 1970; Kushlan 1974). Under thermal stress *C. marianae* was also observed to swim at the water surface and this may also be a response to anoxic conditions. In the experiment individuals were not able to swim at an oxygenated interface and so the lethal limits in nature may be higher than estimated.

Temperatures in the pools should not have accentuated mortality due to anoxic conditions because the periods of minimum oxygen concentration corresponded to periods of minimum temperature in the pools and in the experiment. On the other hand, anoxic conditions may have indirectly caused mortality in *C. marianae* by influencing other factors. Swimming at the interface in response to anoxic conditions could result in this species being more available to piscivorous fish (assuming they were more tolerant to anoxic conditions and fed at night), and more vulnerable to predation in general.

Other stressful factors may have influenced tolerance of anoxic conditions. Heath et al. (1980) cited evidence of the capacity for anaerobic metabolism to be correlated with the condition of fish. The weights of individuals tested in this experiment were not recorded and so condition factor could not be estimated. However, the individuals tested were randomly selected from the stock aquaria and so should have had a similar condition factor to those used for the determination of lethal temperatures (Table 32). On average the condition factors of *C. marianae* used in those experiments were the same as or higher than fish in the pools, so the condition of the fish used should have only improved their tolerance to anoxic conditions.

Carbon dioxide may modify tolerance to anoxic conditions. Mathews & Hill (1977) found that fish were less tolerant of anoxic conditions in water with high concentrations of carbon dioxide because

blood pH was lowered, reducing oxygen carrying capacity. Data on the pH of water samples taken from the pools have been presented. Catastrophic mortality may not have occurred in the *C. marianae* populations of pools N2 and B1 because the low oxygen concentrations in these pools were associated with pH higher than in pool B2. Catastrophic mortality did not occur in pool F1 where low oxygen concentrations coincided with pH lower than in pool B2, implying that pH did not adversely influence tolerance to anoxic conditions.

Suspended solids

High concentrations of suspended particulate matter may cause mortality in fish by clogging the gills or by causing mechanical damage (Reichenbach-Klinke 1973; Munro 1978). The aim of this part of the study was to determine if *C. marianae* could survive higher concentrations of suspended solids than those occurring naturally in the pools.

Concentrations of suspended solids were not expected to vary diurnally or between samples (seining resulted in an increase of only 6 mg/L in pool N3), so 58 mg/L should be close to the maximum occurring in the pools.

A water sample taken from the very turbid pool (adjacent to F1) contained an estimated 348 mg/L of suspended solids, considerably higher than the maximum concentration occurring in the study pools. Hence high concentrations of suspended solids are concluded not to have caused mortality in this species.

Conductivity

Conductivities in the pools were noticeably lower than those measured in billabongs of the Magela Creek system during the Dry season (Bishop et al. 1980; Hart & McGregor 1980).

When collecting fish for the stock aquaria, it was observed that transferring *C. marianae* from pool water to tapwater resulted in substantial mortality. This mortality was attributed to a sudden increase in salinity because the conductivity of the tapwater was 100-200 μS/cm higher than the pool water. On the other hand, negligible mortality occurred when pool water was gradually changed to tapwater over a period of five days. It is unlikely that a sudden increase in salinity, exceeding 100-200 μS/cm in five days, could occur in the pools during the Dry season. Thunderstorms are common in the Magela Creek area in December and might cause a sudden decrease in salinity in the pools. However, conductivity in pool B1 before and after a thunderstorm was found to decrease by no more than 5 μS/cm. Thus a lethal decrease in salinity in the pools is unlikely to occur.

Freshwater fish may die when exposed to low salinities (Wedemeyer et al. 1976). Lowest salinity at the surface of the water of the pools during the study period was 27 μS/cm. Data presented by Bishop et al. (1980) showed that *C. marianae* were often found in regions of Magela Creek during the Wet season where conductivity was less than 10 μS/cm. Therefore, low salinity should not have directly caused mortality in this species during the study period.

Ammonia

Ammonia is a metabolic product produced by microorganisms and most aquatic animals (Munro 1978). High concentrations of ammonia are toxic to fish because ammonia decreases the ability of their blood to carry oxygen (Brockway 1950; Wedemeyer et al. 1976). In aquatic habitats the water volume is usually sufficient to dilute the ammonia to harmless concentrations (Brockway 1950). However, in small, isolated waterbodies the dilution factor is reduced and toxic concentrations may result, especially if the pH of the water is high (Wedemeyer et al. 1976). On 14 October one of the study pools had a 'high' level of ammonia, 0.15 ppm in pool N2. In the others the range was 0.01-0.03 pp. This high concentration of ammonia was attributed to the presence of buffalo excrement in the pool. It should be noted, however, that excrement was present in this pool on only this one occasion and no other study pool ever contained buffalo

excrement. Further, at the time that the various ammonia concentrations were determined, pH was higher and oxygen concentrations were lower in the pools than at other times during the study. As quantities of organic matter (i.e., buffalo excrement), low oxygen concentrations and high pH increase ammonia concentration (Wedemeyer et al. 1976), the ammonia concentrations determined on 14 October are likely to be near the maximum concentrations that occurred in any of the study pools during the study period. A field survey on 14 October revealed a small temporary pool (downstream of pool SN) containing large quantities of buffalo excrement. The concentration of ammonia determined in a water sample taken from this pool was exceptionally high, 7.73 ppm. As this pool contained numerous *C. marianae*, it may be concluded that ammonia did not reach toxic levels in the study pools.

Ammonia is the most toxic of the metabolic waste products. Concentrations of other metabolic products may be expected to fluctuate in proportion to ammonia (Brockway 1950). Thus, it may be concluded that other metabolic products should not have caused mortality in *C. marianae* populations.

Heavy metals

Small concentrations of contaminants, such as heavy metals leached from mineral deposits, may kill aquatic animals (Bryan 1976; McKim et al. 1976; Wedemeyer et al. 1976). Magela Creek drains the eastern sector of the Ranger plant (Fig. 1) and orebodies of the area (Christian & Aldrick 1977), all potential sources of heavy metals. Although mortality in fish populations might be expected to result mainly from a sudden discharge of effluents (Paling 1971), evaporation during the Dry might increase the concentrations of contaminants in pools significantly. Resident fish would be unable to avoid any lethal concentrations of contaminants as they might in larger waterbodies. In addition, the effects of contaminants on the fish could be enhanced by stressful physiological conditions in pools. Concentrations were of the same magnitude as those measured in Magela Creek by Giles (1974). No conclusions can be drawn regarding the evaporative concentration of metals because only two pools were sampled twice, and one of these pools actually increased in volume during the interval between samples.

The concentrations of copper, lead, manganese, zinc and uranium determined in water samples were well below the median tolerance limits (96-h TL_m) estimated for *C. marianae* by Giles (1974) (Table 12). Generally, juvenile fish have a lower tolerance to toxicants than adults (Wedemeyer et al. 1976). As Giles (1974) tested large specimens ($\bar{x}$ = 1.1 g or *c.* 34 mm LCF), median tolerance limits might be lower for smaller individuals (such as comprised the bulk of the populations of *C. marianae* in the present study). However, Giles (1974) also tested 'fry' which, although not identified, were suspected to be *C. marianae*. Nevertheless the median tolerance limits of fry were similar to those of larger *C. marianae* for most heavy metals.

The duration of exposure to heavy metals is another problem in applying the experimentally determined median tolerance limits to the pool populations. The median tolerance limits were determined by Giles for a 96-hour exposure, but *C. marianae* are trapped in the pools for more than 120 days with no means of avoiding toxicants. Furthermore, the median tolerance limit corresponds to the concentration at which 50% of a population is expected to die, but of course deaths occur at lower concentrations. On the other hand, concentrations in the pools are not expected to increase rapidly through evaporation, so *C. marianae* might be able to adjust to and tolerate the toxicants.

Factors such as high concentrations of suspended solids, low pH and oxygen concentrations may influence the toxicity or concentration of heavy metals (Paling 1971; Bryan 1976; Wedemeyer et al. 1976); thus the concentrations estimated in the pools may have been higher at other times during the study period. Regrettably, heavy metal concentrations were not measured in pool B2 when catastrophic mortality of its *C. marianae* population occurred. However, there was no reason to suspect that heavy

metal concentrations were higher at the time in this pool than in the other study pools.

The US National Technical Advisory Committee (1968, *in* Giles 1974) suggested that a factor of 0.1 (termed the 'application factor') be applied to the 96-h median tolerance limit to give a 'safety level' for aquatic animals. If this factor is applied to the median tolerance limits obtained by Giles (1974) the concentrations in the pools for some heavy metals were around the safety level (Table 12). The safety margin should allow for any sublethal effects of a toxicant which might act detrimentally on physiological processes and lead to mortality from other causes, e.g. asphyxiation and predation by fish (McKim et al. 1976). It is possible that sublethal effects of contaminants may have contributed to mortality in the *Craterocephalus* populations, but such effects cannot be distinguished here; extensive studies on the sublethal effects of contaminants on this species are necessary.

4.2 Community Changes

Distribution and abundance

As background to specific comments (below) about distribution and abundance the following general comments on mortality are relevant.

The absence of any 'catastrophic' mortality (where all individuals died at the same time) suggests that mortality was probably not due to 'abiotic factors'. Starvation was not likely to have been an important cause of mortality in *N. erebi*; the relative condition factors were generally high, but the causes of death were not obvious. By contrast, the average numbers of *S. krefftii* with empty stomachs were especially high and some specimens collected during the study were noticeably emaciated. The incidence of parasitism (*Eustrongylides* sp.) was particularly high in the specimens examined. Hence, starvation and parasitism may have contributed to mortality in long toms. *S. krefftii* was amongst the species that died during a 'fish-kill' in Leichhardt Billabong which Bishop (1980) attributed to anoxic conditions. In the present study, no *S. krefftii* survived after September in pool B2 and this may have been due to anoxic conditions occurring at this time; similarly, the high mortality that occurred in pool N2 in October coincided with low oxygen concentrations. High temperatures also coincided with high mortality of *S. krefftii* in these pools, so heat stress may have been a contributing factor.

Mortality was low in pool F2 (piscivorous fish removed and birds excluded) suggesting that either predation by fish or predation by birds may have caused mortality. On the other hand, mortality was also low in pool N2 (piscivorous fish not removed) but was high in pool B2 (birds excluded; piscivorous fish not removed). Mortality was a high in pools B1 and B2 (birds excluded) as in those pools not covered with bird nets. Neither predation by fish nor predation by birds can be concluded to have been responsible for mortality in *N. erebi*; however, *S. krefftii* were observed preying on *A. percoides* in pool SN on one occasion and juvenile *A. percoides* were found in the stomachs of *L. unicolor*; clearly, predation by fish might also be an important mortality factor.

Some mortality may be attributed to stranding; on 16 October, 22 *A. percoides* were collected from the section separated from the main body of pool N1 and several *A. percoides* were isolated in small puddles as pool N2 receded during August. One dead individual was found floating in pool B2 (28 September) and one in pool F1 (19 October), implicating 'abiotic factors'; dissolved oxygen concentrations and pH were very low in pool B2 on 28 September.

Sampling by seine net did not appear to have contributed to mortality (except, perhaps, in *Strongylura krefftii*). Firstly, fish were only momentarily removed from the water and were always capable of swimming away when returned. Secondly, the seine net was of a fine mesh so that abrasion, which may result in fungal infections was unlikely (no damaged or diseased fish were found during the study). Finally, many estimates of abundance showed abundance had not changed since the previous estimate (if seining had

contributed markedly to the mortality, abundance should have shown a tendency to decrease in *all* pools). *S. krefftii* were sometimes disoriented when returned to the water, swimming at the surface. The numbers of *S. krefftii* invariably decreased from one sample to the next, indicating that seining may have contributed to the mortality of this species.

From examination of the data the following specific conclusions can be drawn.

Length frequencies

Llewellyn (1973) found that *L. unicolor* required at least 12 months to reach adulthood; Bishop et al. (1980) suggested that *L. unicolor* grow 10 mm in six months. Hence the large juveniles collected from pools N1 and N3 in November would not have been spawned during the study period.

For *N. erebi* mortality during the study period appeared to be independent of size; temporal changes in the length frequency distributions of the population subject to high mortality (*i.e.*, pool N3) was no different from that in populations where mortality was low (*i.e.* pools N1 and N2).

The small *A. percoides* juveniles collected in N3 in November were probably spawned in October or November. Mortality of *A. percoides* was high in some pools but length frequency distributions showed no obvious trends, suggesting that mortality was probably not size-dependent (Table 20).

Because mortality of *P. midgleyi* was low or absent during the study period, temporal changes in length frequency distributions in most pools can be attributed almost entirely to growth.

The primary size class of *C. marianae* (8-22 mm LCF) is expected to have been spawned in the mid and late-Wet and early-Dry seasons of 1981. A numerically smaller size class, consisting of adults (23-64 mm LCF), was probably produced in the previous year. Individuals over 64 mm LCF may have constituted a third age class.

Temporal changes in length frequency distributions of *S. krefftii* indicated that mortality was probably size-dependent, with small individuals more susceptible.

Reproduction

P. midgleyi captured in November were frequently ripe, suggesting that spawning occurs in the late-Dry season in the pools or in the early-Wet in the creek. As the sandy pools are the only location where ripe *Pingalla midgleyi* have ever been recorded it may be concluded that the pools are important refuges for *P. midgleyi* breeding stock. In their study Bishop et al. (1980) captured few adult *P. midgleyi* and were unable to estimate fecundity or the 'length at first maturity'.

Bishop et al. (1980) concluded that spawning in *Craterocephalus stercusmuscarum* extended from the late-Dry to the mid-Wet season. Results of the present study partly supported this conclusion. However, small juveniles (10-15 mm LCF) were collected in the pools in the early-Dry, suggesting that the spawning period is more extensive than previously thought.

The higher proportion of female *C. marianae* may be an artefact. There is an inherent difficulty in sexing immature male fish, thus more males than females are likely to be classed as 'sex indeterminate'. Almost half the *Craterocephalus marianae* (20-24 mm LCF) could not be sexed; if these individuals were males, the overall proportion of females would have been 47%. Bishop et al. (1980) suggested that *C. marianae* spawns in the early-Wet season. The presence of small juveniles (10-15 mm LCF) at the beginning of the study period showed that spawning occurred not only in the Wet season but also in the early-Dry season. Length-frequency data indicated that some *C. marianae* spawned in several pools in October or November.

Bishop et al. (1980) concluded that *L. unicolor* spawned during the late-Dry and early-Wet seasons. In the present study many ripe males and females were collected

in November, supporting this conclusion. However, the pools are probably not an important refuge for the reproductive stock. *L. unicolor* is distributed throughout the Alligator Rivers Region and is known to spawn in a variety of habitats (Bishop et al. 1980).

Some *Amniataba percoides* specimens collected in November were ripe, supporting the conclusion of Bishop et al. (1980) that spawning occurred in the late-Dry or early-Wet. Nevertheless, the presence of small juvenile *A. percoides* (8-11 mm LCF) in pool N3 in September showed that spawning is not restricted to one season.

The results support the conclusion of Bishop et al. (1980) that spawning in *N. erebi.* is most common during the early-Wet season. However, the presence of small juveniles (30-50 mm LCF) in some pools showed that spawning may occur in the late-Wet and early-Dry seasons.

Bishop et al. (1980) reported a Stage IV *Strongylura krefftii* female of 317 mm LCF, so this length is accepted as the smallest adult female. As no adult males were collected during the present study the value of 267 mm LCF (Bishop et al. 1980) was accepted as the smallest adult male. Bishop et al. (1980) found that *S. krefftii* spawned during the late-Dry and early-Wet season and, as expected, the specimens collected in the present study showed no gonad maturation in August/September (Table 24).

Neither this study, nor that of Bishop et al. (1980) could determine the time or site of spawning for *G. giurus*. Nevertheless, small juveniles (10-15 mm TL) were common in the pools during August. Thus spawning may occur in the creek during the late-Wet or in the pools in the early-Dry season.

Condition

Condition, or relative weight for length, may reflect the 'health' of a fish. Hence estimates of condition can indicate how vulnerable a fish population might be to environmental stresses, such as heavy metal pollution. However, since estimates of condition will be influenced by stomach fullness, gonad development and spawning condition (Le Cren 1951; Weatherly 1972), these factors should be taken into account when assessing condition in fish populations.

For some fish, the length/weight relationship of males may be different from that of females and an overall length/weight relationship should not be used to estimate condition factors. Bishop et al. (1980) did not differentiate between the length/weight relationship of males and females of the species they studied. For *N. erebi*, *P. midgleyi*, *C. marianae*, *A. percoides*, *L. unicolor* and *G. aprion* collected in the present study, the slope coefficients and y-intercepts of the length/weight relationships of males were found to be no different from those of females.

The average gonad maturity stage of these *N. erebi* was high suggesting that somatic tissue was sacrificed for gonad development. With *Pingalla midgleyi* the increased condition in November might have been the result of either high average stomach fullness or the advanced gonad development noted for this species at this time.

As with *N. erebi*, *Craterocephalus marianae* condition did not increase with the gonad development that occurred in November, suggesting that somatic tissue was sacrificed for gonad development. *C. stercusmuscarum* condition estimated in the present study did not show a dramatic fall during the Dry season as found by Bishop et al. (1980).

Bishop et al. (1980) suggested that environmental conditions in the late-Dry and early-Wet seasons were quite favourable to *G. giurus*; the relative condition factors presented here support this conclusion.

Although most *L. unicolor* collected in October and November had food in their stomachs, the food supply available in the pools may have consisted of 'emergency foodstuffs' only (Pillay 1953) which might only have slowed starvation and not prevented it. The decreased condition of *Glossamia aprion* in November might have

been the result of low average stomach fullness in the specimens collected at this time.

Because the y-intercept of the length/weight relationship for male *S. krefftii* collected in the present study was significantly different from that for females ($P << 0.001$), it was not valid to group the length/weight data for male and female *S. krefftii* and estimate relative condition factors from the combined length/weight relationship of Bishop et al. (1980). Hence relative condition factors of *S. krefftii* were not investigated in this section. Data were not available on the lengths and weights of male and female *C. stercusmuscarum* or *G. giurus* separately. For these species the length/weight relationships were assumed to be the same for males and females and relative condition factors were estimated.

Diet and feeding

'Fullness' reflects feeding activity, which may indicate if food was in short supply in the pools. Data on contents and fullness of *L. unicolor* that had been collected with rotenone were not analysed; however, interspecific sensitivities may partially explain the observations. The rotenone influence on *L. unicolor* stomach contents may have been due to some species (e.g. *C. marianae, G. giurus*) being incapacitated by the ichthyocide before *L. unicolor* was affected - allowing *L. unicolor* to consume them before dying themselves.

In the other species analysed feeding activity did not appear to vary, or it declined, during the study period.

4.3 Mortality

Sampling

Preliminary sampling and observations suggested that *C. marianae* preferred water less than 50 cm deep (Fig. 3). This apparent depth preference was found not to be an artefact of the sampling technique: thrownet samples of *C. marianae* at varying depths in a large tank (Appendix 2) were equally likely to contain *C. marianae*, irrespective of water depth (Fig. 3). Note, however, that efficiency, i.e. estimated density per absolute density, did decline with increasing depth.

Density and abundance

Had sampling mortality been taken into account, there would have been a more marked difference in mortality between pool F2 and the other pools.

Bishop et al. (1980) found decreased survival rates for larger *C. marianae*. Mortality of *C. marianae*, determined in the present study, also appeared to be 'size-dependent'. Considering the 'primary size class' only, in most pools the length modes tended to show smaller shifts between samples where mortality was high than where mortality was low. For example, the mode in pool SN shifted only from 13 mm to 14 mm in August (when mortality was high) but from 14 to 19 mm in September (when mortality was lower. Hence larger individuals of the primary size class are concluded to have had higher mortality rates.

It may be concluded that fish predation was a significant cause of mortality in pool B1 and the 'untreated' pools. Mortality in most pools was highest in August and September, especially in pool N2 where 92% of the population perished (Fig. 11).

Finally, mortality did not appear to be related to density. The relative densities of *Craterocephalus marianae* persistently decreased in all pools (Table 32). Thus, mortality of this species was probably not related to their density.

Stranding

A variety of abiotic and biotic factors have been demonstrated to contribute to stranding mortality in fish populations. The physico-chemical and biotic conditions peculiar to small waterbodies include elevated temperatures and anoxic conditions (Larrimore et al. 1959; Tramer 1977;

Kushlan 1980), starvation (Saiki & Tash 1978), predation (Roberts 1972; Blaber 1973; Kushlan 1976), and desiccation (Beebe 1945).

Observations showed that stranding mortality occurred in pool N2 in August, with terrestrial predators and scavengers being the proximal cause of death. On several occasions during this month, one black-necked stork, *Xenorhynchus asiaticus*, and several straw-necked ibis, *Threskiornis spinicollis*, were observed wading through puddles at pool N2. It was concluded that in this case these birds contributed to stranding mortality of *C. marianae*. Water monitors, *Varanus mertensi* and *V. mitchelli*, also prey on fish stranded in puddles (J. Bywater pers. comm.), but neither were observed in the vicinity of pool N2. Water temperatures at the time did not exceed the lethal temperature determined for this atherinid; however, later in the Dry season temperatures in isolated puddles did sometimes exceed the lethal temperature (see next section). Piscivorous fish, *G. aprion*, *L. unicolor* and *S. krefftii* were not associated with stranding mortality. Starvation was unlikely to be a contributory factor. Mortality occurred abruptly rather than extending over an extended period as predicted by starvation experiments. Furthermore, eight *C. marianae* collected from puddle B had a minimum condition factor of 0.96, well above that expected of a starving individual.

The fall in *Craterocephalus marianae* density noted in pool N2 between the first and second sampling dates and direct observations showed that this species was not necessarily able to avoid stranding by moving away from regions in the process of becoming isolated.

Temperature

Temperatures in freshwater habitats in the tropics are, of course, usually much higher than in temperate regions. Although tropical fish will be more tolerant to elevated temperatures than temperate species, there will still be an upper lethal limit. For most fish the only option available for preventing thermal death is to seek cooler 'refuge areas' in their habitat (Norris 1963; Lowe & Heath 1969).

Temperatures of small waterbodies are expected to show a greater range than those of larger waterbodies. Fish may die when exposed to a sudden temperature change (Schmidt-Nielsen 1975). *C. marianae* might be exposed to a drastic temperature change when moving from the 'Craterocephalus habitat' to the deeper region of a pool. Hence the ability of this species to survive a sudden temperature change was also investigated.

Upper incipient lethal temperatures and tolerance to sudden changes

The upper incipient lethal temperature of an organism is the upper temperature at which mortality commences (Fry 1971). To obtain an estimate of the upper incipient lethal temperature for determining if elevated pool temperatures could have caused mortality in *C. marianae*, laboratory experiments were used to simulate natural conditions. Experimental stocks were exposed to diurnal variations in temperature that were similar to those in the pools, with the maximum temperatures elevated until the lethal temperature was reached.

Although the *C. marianae* tested were significantly longer and had a significantly higher condition factor than the fish in the pools (Table 31), the differences in length and condition factor should not have increased tolerance to a temperature change because larger individuals were less tolerant of high temperatures.

Comparing the sudden temperature change tolerances determined and the differences measured in the field between 'Craterocephalus habitat' and the deepest region (less than 7.0°C, measured in pool SN on 20 September), it is clear that darting from the shallows to the deeper regions or *vice versa* should not have directly caused mortality. It was also demonstrated that low temperatures did not directly cause mortality.

Craterocephalus marianae survived higher temperatures and greater temperature changes in the laboratory than they would have experienced in the study pools during

the study period. Although the maximum temperature recorded in the 'Craterocephalus habitat' (39.5°C) exceeded the estimated upper incipient lethal temperature (36.5°C), the maximum temperature recorded in the deepest region of any pool did not exceed 35.5°C (Section 3.1). Temperature preference is well documented in freshwater fish, *e.g.*, *Cyprinodon macularius* (Lowe & Heath 1969); some fish species may make excursions into areas where temperatures exceed the estimated tolerance level, regularly retreating to cooler areas *e.g.*, *Craterocephalus dalhousensis* (Ivantsoff & Glover 1974). *Craterocephalus* were observed to move to shaded, presumably cooler, areas when temperatures exceeded 39.0°C in the tank. When temperatures were lethal in the 'Craterocephalus habitat', *C. marianae* would move to cooler regions in the pools.

Temperatures in small temporary pools along Magela Creek occasionally exceeded 40.0°C. High temperatures could cause mortality of this species trapped in such pools because cool refuge areas were not available. Populations eventually perished in temporary pools as a result of desiccation or by predation by terrestrial animals, if not as a result of heat.

Nevertheless high temperatures may have indirectly increased mortality by making *C. marianae* more susceptible to other environmental factors. There must be some survival value associated with the 'Craterocephalus habitat', probably predator avoidance or food availability. Predation may have increased when high temperatures forced *C. marianae* to move into deeper, cooler regions.

Oxygen

Oxygen levels in tropical pools reach a minimum at sunrise each day (Nasar & Datta-Munshi 1974). Most fish are capable of tolerating anoxic conditions for limited periods of time but must eventually avoid asphyxiation by seeking areas where oxygen concentrations are higher (Wedemeyer et al. 1976; Leach et al. 1977).

Oxygen in the 'Craterocephalus habitat'

The lowest oxygen levels, determined in samples taken between 0800 and 0930, were unlikely to be the lowest occurring in the 'Craterocephalus habitats'.

Preliminary sampling showed that in pool SN overnight oxygen levels in the 'Craterocephalus habitat' were higher than both those at the surface above the deepest region and at the bottom of the deepest region. Hence, the 'Craterocephalus habitat' can be regarded as the refuge area where anoxic conditions might be avoided. Of course, the application of differentials to the pools assumes that: (1) there were no major variations in oxygen concentrations in the pools between samples; and (2) the diurnal pattern in oxygen concentration in pool SN was the same for all pools.

Wind and temperature probably did not cause significant variations in dissolved oxygen in the periods between samples. Firstly, because it was usually calm during the night until about 1000 hours and, secondly, because the range of temperatures of the water samples was less than 7.0°C ($\bar{x}$ = 30.2°C ± 1.7 SD). In support of this contention the oxygen concentrations measured in several pools (SN, B1, N3) showed less than a 0.6 mg/L variation one to five days after measurement. Therefore it was reasonable to assume that there was little variation in pools between samplings.

The second assumption, that the diurnal pattern in oxygen concentration in pool SN was the same for all pools, is more difficult to justify. Oxygen levels in aquatic habitats are usually dependent on the activities of plants and microorganisms (Kushlan 1974; Nasar & Datta-Munshi 1974; Barica 1975; Kushlan & Hunt 1979). Differences in the abundance of phytoplankton between pools would be expected to have had most influence on the lowest oxygen concentrations. Macrophytes and detritus were rare in most pools. The diurnal pattern in oxygen concentration was closely correlated with the diurnal pattern in total chlorophyll concentration (*i.e.*, concentration of chlorophyll *a* + *b* + *c*) in pool SN on 9-10 October (Fig. 15).

However, the total chlorophyll concentration determined in samples taken between 0930 and 1000 hours were poorly correlated with oxygen concentrations determined between 0800 and 0930 hours of each pool during the study from the 'Craterocephalus habitat' ($r = 0.46$), surface ($r = 0.25$) or bottom of the deepest region ($r = -0.12$). Thus the diurnal variation in oxygen concentration may have been dependent on the abundance of phytoplankton, but the maximum and minimum oxygen concentrations were probably modified by other factors. The quality of organic matter in the pools may have had a modifying influence: leaf litter was particularly abundant in pool B2 (where the lowest oxygen concentrations occurred); buffalo excrement was noted in pool N2 when low oxygen concentrations were also recorded. Shading (pool B2 was the most shaded pool) and the biomass of fish might also be important factors affecting oxygen levels in the pools. Despite the problems associated with applying the differential, the estimate of the lowest oxygen concentrations occurring in the 'Craterocephalus habitats' were the best available.

Lower incipient lethal oxygen concentration

The object of this experiment was to determine the lower incipient lethal oxygen concentrations for *C. marianae*. The lower incipient lethal oxygen concentration is defined as the lowest oxygen concentration at which mortality commences (Fry 1971). Since the duration of anoxic conditions is an important parameter of mortality (Heath et al. 1980), test stocks were exposed to diurnal variations in dissolved oxygen similar to that in the pools, with the minimum concentration decreased until the lethal level was reached.

Oxygen concentrations in the 'Craterocephalus habitat' of pool B2 dropped below the estimated lethal concentration for more than 90 minutes between 30 August and 28 September. Estimates of the size of the *C. marianae* population of this pool during this period did reveal catastrophic mortality, implicating anoxic conditions as the cause.

Oxygen concentrations in the 'Craterocephalus habitat' of pools N2, B1 and F1 may have dropped below the estimated lethal concentration for more than 90 minutes. Catastrophic mortality did not occur in these pools at these times suggesting that the minimum concentrations in the pools were higher than estimated, or that either the lethal concentration was lower than estimated or anoxic conditions caused selective rather than catastrophic mortality. As mentioned above, the estimate of the relationship between the oxygen concentration in the 0800-0930 sample and the minimum concentration in the pool may be unreliable. Clearly, more data on the diurnal variation in oxygen concentrations are required, especially with respect to the duration of the minimum concentration. When low oxygen concentrations were recorded in pools N2, B1 and F1, chlorophyll concentrations were lower than when the diurnal variations were measured in pool SN - the minimum concentrations may have been higher than estimated in these pools.

Finally, the estimate of the lethal concentration obtained in the laboratory experiment may not be applicable to the populations of the pools; *C. marianae* may possess adaptations for tolerating anoxic conditions which were suppressed under the laboratory conditions. In response to anoxic conditions most freshwater fish species swim at the water surface, gulping oxygenated water at the interface to permit survival (Lowe-McConnell 1964, 1969; Lewis 1970; Kushlan 1974). Under thermal stress *C. marianae* was also observed to swim at the water surface and this may also be a response to anoxic conditions. In the experiment individuals were not able to swim at an oxygenated interface and so the lethal limits in nature may be higher than estimated.

Temperatures in the pools should not have accentuated mortality due to anoxic conditions because the periods of minimum oxygen concentration corresponded to periods of minimum temperature in the pools and in the experiment. On the other hand, anoxic conditions may have indirectly caused mortality in *C. marianae* by

influencing other factors. Swimming at the interface in response to anoxic conditions could result in this species being more available to piscivorous fish (assuming they were more tolerant to anoxic conditions and fed at night), and more vulnerable to predation in general.

Other stressful factors may have influenced tolerance of anoxic conditions. Heath et al. (1980) cited evidence of the capacity for anaerobic metabolism to be correlated with the condition of fish. The weights of individuals tested in this experiment were not recorded and so condition factor could not be estimated. However, the individuals tested were randomly selected from the stock aquaria and so should have had a similar condition factor to those used for the determination of lethal temperatures (Table 32). On average the condition factors of *C. marianae* used in those experiments were the same as or higher than fish in the pools, so the condition of the fish used should have only improved their tolerance to anoxic conditions.

Carbon dioxide may modify tolerance to anoxic conditions. Mathews & Hill (1977) found that fish were less tolerant of anoxic conditions in water with high concentrations of carbon dioxide because blood pH was lowered, reducing oxygen carrying capacity. Data on the pH of water samples taken from the pools were presented in an earlier section. Catastrophic mortality may not have occurred in the *C. marianae* populations of pools N2 and B1 because the low oxygen concentrations in these pools were associated with pH higher than in pool B2. Catastrophic mortality did not occur in pool F1 where low oxygen concentrations coincided with pH lower than in pool B2, implying that pH did not adversely influence tolerance to anoxic conditions.

Anoxic conditions are concluded to have either directly or indirectly caused mortality in the *C. marianae* population of pool B2. No definite conclusions regarding the role of anoxic conditions in causing mortality in other pools can be made as more information is required on the diurnal variation in oxygen concentrations and the tolerance of this species to anoxic conditions.

Salinity

Freshwater fish may die when exposed to high salinities (Wedemeyer et al. 1976). The aim of this part of the study was to determine if *C. marianae* could survive salinities higher than those occurring in the pools. The differences in length and condition factors were assumed to have no affect on tolerance.

During the experiment the physical conditions in the tank were as extreme as in the pools.

The salinity tolerated in the experiment was still well above that occurring in the pools when diurnal variations are taken into account. The diurnal variation in conductivity was investigated in pool SN on 20 September. Conductivity showed a diurnal pattern with the highest levels occurring in the late afternoon, about 10 μS/cm higher than the level determined between 0800 and 0930. Elevated salinities are concluded not to have caused mortality in the pools during the study period.

When collecting fish for the stock aquaria, it was observed that transferring *C. marianae* from pool water to tapwater resulted in substantial mortality. This mortality was attributed to a sudden increase in salinity because the conductivity of the tapwater was 100-200 μS/cm higher than the pool water. On the other hand, negligible mortality occurred when pool water was gradually changed to tapwater over a period of five days. It is unlikely that a sudden increase in salinity, exceeding 100-200 μS/cm in five days, could occur in the pools during the Dry season. Thunderstorms are common in the Magela Creek area in December and might cause a sudden decrease in salinity in the pools. However, conductivity in pool B1 before and after a thunderstorm was found to decrease by no more than 5 μS/cm. Thus a lethal decrease in salinity in the pools is unlikely to occur.

Starvation

Food supply may ultimately limit the size of animal populations but rarely is starvation the direct cause of mortality (Krebs 1978). Weatherly (1972) suggested

that intraspecific competition in fish populations should result in reduced growth rates so that density-dependent mortality will be replaced by density-dependent growth. Nevertheless, deaths of *C. marianae* through starvation are conceivable: the food supply - this species feeds on chironomids, leptocerids, harpacticoid copepods and cladocerans - should decrease as the pools diminish in size. Being small animals, *C. marianae* are not expected to survive for many days without food.

As gonads could act as a reserve and ovaries are usually larger than testes, females should be able to survive without food for longer periods of time than males, and individuals with mature gonads should survive for longer than immature individuals (Donaldson et al. 1979). Size-dependent mortality might also be attributed to parasitism or disease. Juveniles should have a higher weight specific metabolic rate and a greater protein requirement than adults (Schmidt-Neilsen 1975). Thus adults should survive longer without food than juveniles.

As no mortality occurred in the stock aquaria it was considered that losses in the experiment could be attributed solely to starvation. Although the weights of a few specimens were near the 'starvation weight', this may be attributed to errors in weighing or recording of data as more than 1000 specimens were analysed during the study. And while the *C. marianae* collected from the pools may have been closer to the 'starvation weight' than indicated by the data because the weight of held specimens included gut contents, the weight of the gut contents would add only 2-3% to the body weight. Finally, that starvation could have contributed significantly to mortality is inconsistent with two observations

Starvation is concluded not to have been *directly* responsible for mortality of, at least, large *C. marianae* (*i.e.* < 17 mm LCF) during the study period. Whether starvation could have indirectly contributed to mortality, for example by making weakened fish more vulnerable to predation, is, of course, another matter.

Predation

Predation by piscivorous birds can be a significant source of mortality in freshwater fish, especially those living in shallow habitats (Blaber 1973; Kushlan 1974, 1979; Tramer 1977; Batchelor 1978; Odgen et al. 1978; Whitfield 1978). At least ten species of piscivorous birds occur in the Magela Creek area (K. Brennan pers. comm.). The objective of this part of the study was to determine the impact of piscivorous birds on *C. marianae*.

As for the black-necked stork it is unlikely that the ibis preyed on *C. marianae* in large pools where concentrations and availability were much lower than in the small puddles.

General observations indicated that, except for the azure kingfisher, most piscivorous birds retreated from the pools, probably to the permanent lagoons after August. Although the pools may have represented a concentrated supply of seemingly easily accessible food they were not exploited heavily or systematically by piscivorous birds. It was concluded that piscivorous birds were not a major cause of mortality in *C. marianae*.

For many fish, predation by other fish is acknowledged to be a major cause of mortality, especially for juveniles (Paling 1971; Roberts 1972; Wolfe 1978). The aim of this part of the study was to determine if predation by fish caused significant mortality in the *C. marianae* populations.

The high mortality rates in pools F1 and F2 in August, before all their piscivorous fish had been removed, suggests that predation by piscivorous fish is an important mortality factor.

In addition to the three species analysed other piscivorous species (*S. jardinii*, *O. lineolatus*, *A. leptaspis* and *C. megalops*) also occurred in the pools. These may be discounted as having caused significant mortality because they were rare in the pools and none of the specimens examined contained *C. marianae*. Because *L. unicolor* was by far the most abundant piscivore it

was concluded that this species was the most important predator of *C. marianae*. It was not possible to determine predation rates; to do this, information on the quantities of *Craterocephalus* consumed would be required.

Mortality in *C. marianae* populations was postulated to be size-dependent - larger individuals appeared to be more susceptible. Although juvenile fish are generally thought to be more susceptible to predation (Weatherly 1972), *Craterocephalus* juveniles may have been better able to avoid predators than adults. Perhaps the schooling of juveniles (larger individuals are usually solitary or occur in small schools) or reduced visibility to predators (Zaret & Kerfoot 1975; Macan 1977; Pitcher 1980) contributed to their lowered mortality.

Other factors

Other factors, not specifically investigated in the present study, may have contributed to mortality of *C. marianae*. Parasites and disease can cause mortality of fish, especially when fish are at high densities or under stress (Reichenbach-Klinke 1973; Wedemeyer et al. 1976). Several *C. marianae* collected from pool F2 on November 14 had a fungal infection of the fins and mortality was high in this pool at this time. However, of the several hundred specimens examined, there was only one clear case of parasitism (a nematode in the body cavity). Nevertheless, no firm conclusions can be drawn about the importance of parasites or disease as mortality factors: hosts may become more susceptible to other parasites or diseases when under stress and parasites affecting vital organs may not be obvious to the casual observer (Paling 1971).

C. marianae may have been preyed on by animals other than piscivorous fish. However, the only other possible predator in the pools was the water scorpion (Family Nepidae, *Laccotrephes* sp.) which appeared to be rare. Thus piscivorous fish were probably the major, if not the only predator on this species.

In addition to pollutants, various natural substances may be toxic to fish. Bark of the freshwater mangrove, *Barringtonia acutangula* which occurs in the area, is known to be toxic. However, no *B. acutangula* occurred in the immediate vicinity of the study pools. Blooms of the phytoplanktonic *Microcystis* spp., may be toxic to fish. These species may occur in the Magela Creek system (T. Walker pers. comm.) but there is no evidence to suggest that they caused mortality.

REFERENCES

Allen, G.R. & Merrick, J.R. (1984). A new species of freshwater grunter (Pisces: Teraponidae) from northern Australia. *The Beagle, Occ. Pap. NT. Mus.* **1(8)**, 75-80.

American Public Health Association (1976). *Standard Methods for the Examination of Water and Wastewater. Fourteenth Edition*. American Public Health Association, American Water Works Association and Water Pollution Control Federation: Washington.

Anonymous (1976). *Reader's Digest Complete Book of Australian Birds*. Reader's Digest: Sydney.

Barica, J. (1975). Summerkill risk in prairie ponds and possibilities of its prediction. *J. Fish. Res. Bd. Can.* **32**, 1283-1288.

Batchelor, G.R. (1978). Population structure and apparent predation on the red-breasted kurper, *Tilapia rendalli*, in a northern Transvaal impoundment. *S. Afr. J. Wildl. Res.* **8**, 39-41.

Beebe, W. (1945). Vertebrate fauna of a tropical Dry season mud-hole. *Zoologica* (N.Y.) **30**, 81-88.

Bishop, K.A. (1980). Fish kills in relation to physical and chemical changes in Magela Creek (East Alligator River System, Northern Territory) at the beginning of the tropical Wet season. *Aust. Zool.* **20**, 485-500.

Bishop, K.A., Allen, S.A., Pollard, D.A. & Cook, M.J. (1980). Ecological studies on the fishes of the Alligator Rivers Region, Northern Territory. Open File Record **23**, Supervising Scientist for the Alligator Rivers Region.

Bishop, K.A. & Harland, W.G. (1982). Further ecological studies (I) on the freshwater fishes of the Alligator Rivers Region. Open File Record **34**, Supervising Scientist for the Alligator Rivers Region.

Bishop, K.A. & Walden, D. (1990). The effects of the 1985 Ranger uranium RP4 water releases on the movements of fish along Magela Creek. Open File Record **67**, Supervising Scientist for the Alligator Rivers Region.

Blaber, S.J. (1973). Population size and mortality of the marine teleost *Rhabdosargus holubi* (Pisces: Sparidae) in a closed estuary. *Mar. Biol.* **21**, 219-225.

Brockway, D.R. (1950). Metabolic products and their effects. *Prog. Fish. Cult.* **12**, 127-129.

Bryan, G.W. (1976). Some aspects of heavy metal tolerance in aquatic organisms. *In*: A.P. Lockwood (ed.) *Effects of Pollutants on Aquatic Organisms*. Cambridge University Press: London.

Christian, C.S. & Aldrick, J.M. (1977). *Alligator Rivers Study. A Review Report of the Alligator Rivers Region Environmental Fact-finding Study*. Australian Government Publishing Service: Canberra.

Davis, T.L.O. (1982). Maturity and sexuality in barramundi, *Lates calcarifer* (Bloch), in the Northern Territory and south-eastern Gulf of Carpentaria. *Aust. J. Mar. Freshw. Res.* **33**, 529-545.

Donaldson, E.M., Fagerlund, U.H., Higgs, D.A. & McBride, J.R. (1979). Hormonal enchancement of growth. In: W.S. Hoar, D.J. Randall & J.R. Brett (eds) *Fish Physiology, Volume VIII. Bioenergetics and Growth*. Academic Press: New York.

Fry, F.E. (1971). The effect of environmental factors on the physiology of fish. In: W.S. Hoar & D.J. Randall (eds) *Fish Physiology. Volume VI. Environmental Relations and Behaviour*. Academic Press: New York.

Giles, M.S. (1974). Toxicity studies on aquatic organisms and grass-sedge communities in the Magela Creek. Report III. In: P.J.F. Newton (ed.) *The Alligator Rivers Area Fact Finding Study: Four AAEC Reports*. Australian Atomic Energy Commission, Lucas Heights: Sydney.

Hart, B.T. & McGregor, R.J. (1980). Limnological survey of eight billabongs in the Magela Creek catchment, Northern Territory. *Aust. J. Mar. Freshw. Res.* **31**, 611-626.

Heath, A.G., Burton, D.T. & Smith, M.J. (1980). Anaerobic metabolism in fishes: Environmental thresholds and time dependence. *Rev. Can. Biol.* **39**, 123-128.

Humphrey, C.L., Bishop, K.A. & Brown, V.M. (1990). Use of biological monitoring in the assessment of effects of mining wastes on aquatic ecosystems of the Alligator Rivers Region, tropical northern Australia. *Environmental Monitoring and Assessment* **14**, 139-181.

Ivantsoff, W., Crowley, L.E.L.M. & Allen, G.R. (1987). Descriptions of three new species and one subspecies of freshwater hardyhead (Pisces: Atherindae: *Craterocephalus*) from Australia. *Rec. Aust. Mus.* **13 (2)**, 171-188.

Ivantsoff, W. & Glover, C.J. (1974). *Craterocephalus dalhousiensis* n. sp., a sexually dimorphic freshwater teleost (Atherinidae) from South Australia. *Aust. Zool.* **18**, 88-98.

Jeffrey, S.W. & Humphrey, G.F. (1975). New spectrophotometric equations for determining chlorophylls *a, b,* c_1 and c_2 in higher plants, algae and natural phytoplankton. *Biochem. Physiol. Pflanzen* **191**, 191-196.

Krebs, C.J. (1978). *Ecology. The Experimental Analysis of Distribution and Abundance*. Harper and Row: New York.

Kushlan, J.A. (1974). Effects of a natural fish kill on the water quality, plankton, and fish population of a pond in the Big Cypress Swamp, Florida. *Trans. Am. Fish. Soc.* **103**, 235-243.

Kushlan, J.A. (1976). Wading bird predation in a seasonally fluctuating pond. *Auk* **93**, 464-476.

Kushlan, J.A. (1979). Feeding ecology and prey selection in the white ibis. *Condor* **81**, 376-389.

Kushlan, J.A. (1980). Population fluctuations of Everglades fish. *Copeia* **1980**, 870-874.

Kushlan, J.A. & Hunt, P.B. (1979). Limnology of an alligator pond in south Florida. *Florida Scientist* **42**, 65-84.

Larrimore, R.S., Childers, W.F. & Heckrotte, C. (1959). Destruction and re-establishment of stream fish and invertebrates affected by drought. *Trans. Am. Fish. Soc.* **88**, 261-285.

Larson, H.K. & Martin, K.C. (1990). *Freshwater Fishes of the Northern Territory*. Handbook Series No. 1, Northern Territory Museum of Arts and Sciences, Darwin. 102 pp.

Leach, J.H., Johnson, M.G., Kelso, J.R., Hartmann, J., Nümman, W. & Entz, B. (1977). Responses of percid fishes and their habitats to eutrophication. *J. Fish. Res. Bd. Can.* **34**, 1964-1971.

Le Cren, E.D. (1951). The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *J. Anim. Ecol.* **20**, 201-219.

Lewis, W.M. Jr. (1970). Morphological adaptations of cyprinodontoids for inhabiting oxygen deficient waters. *Copeia* **1970**, 319-326.

Llewellyn, L.C. (1973). Spawning, development, and temperature tolerance of the spangled perch, *Madigania unicolor* (GÜnther), from inland waters in Australia. *Aust. J. Mar. Freshw. Res.* **24**, 73-94.

Lowe, C.H. & Heath, W.G. (1969). Behavioural and physiological response to temperature in the desert pupfish *Cyprinodon macularius*. *Physiol. Zool.* **42**, 53-59.

Lowe-McConnell, R.H. (1964). The fishes of the Rupununi savana district of British Guiana, South America *J. Linn. Soc. (Zool.)* **45**, 103-144.

Lowe-McConnell, R.H. (1969). Speciation in tropical freshwater fishes. *Biol. J. Linn. Soc.* **1**, 51-75.

Macan, T.T. (1977). The influence of predation on the composition of fresh-water animal communites. *Biol. Rev.* **52**, 45-70.

Mathews, W.J. & Hill, L.G. (1977). Tolerance of the red shiner, *Notropis lutrensis* (Cyprinidae) to environmental parameters. *Southwest Nat.* **16**, 55-63.

McKim, J.M., Anderson, R.L., Benoit, D.A., Speharand, R.L. & Stokes, G.N. (1976). Effects of pollution of freshwater fish. *J. Water. Pollut. Control Fed.* **48**, 1544-1620.

Munro, A.L. (1978). The aquatic environment. In: R.J. Roberts (ed.) *Fish Pathology*. Bailliere Tindall: London.

Munshi, J.S.D., Patra, A.K., Biswas, N. & Ojha, J. (1979). Interspecific variations in the circadian rhythm of bimodal oxygen uptake in four species of murrels. *Jap. J. Ichthyol.* **26**, 69-74.

Nasar, S.A.K. & Datta-Munshi, J. (1974). Seasonal variations in the physico-chemical and biological properties of a tropical shallow pond. *Jap. J. Ecol.* **24**, 255-259.

Norris, K.S. (1963). The functions of temperature in the ecology of the percoid fish *Girella nigricans* (Ayers). *Ecol. Monogr.* **32**, 23-62.

Ogden, J.C., Kushlan, J.A. & Tilmant, J.T. (1978). *The Food Habitats and Nesting Success of Wood Storks in Everglades National Park, 1974*. U.S. Department of the Interior, National Park Service Natural Resources Report Number 16.

Paling, J.E. (1971). Causes of mortality. *In*: W.E. Ricker (ed.) *Methods for the Assessment of Fish Production in Freshwaters. Second Edition*. Blackwell Scientific Publications: Oxford.

Pancontinental (1981). *A Review of Jabiluka Environmental Studies*. Pancontinental Mining Ltd., Sydney.

Paxton, J.R., Hoese, D.F., Allen, G.R. & Hanley, J.E. 1989. *Zoological Catalogue of Australia. Volume 7. Pisces. Petromyzontidae to Carangidae*. Australian Government Publishing Service, Canberra. 665pp.

Pillay, T.V.R. (1953). A critique of the methods of study of food of fishes. *J. Zool. Soc. India* **4**, 186-200.

Pitcher, T.J. (1980). Some ecological consequences of fish school volumes. *Freshw. Biol.* **10**, 539-544.

Pollard, D.A. (1972). The biology of a landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). *Aust. J. Mar. Freshw. Res.* **23**, 27-38.

Pollard, D.A. (1974). The freshwater fishes of the Alligator Rivers 'Uranium Province' Area (Top End, Northern Territory), with particular reference to the Magela Creek Catchment (East Alligator River System). Report I *In*: P.J.F. Newton (ed.) *The Alligator Rivers Area Facting Finding Study. Four AAEC Reports*. Australian Atomic Energy Commission, Lucas Heights: Sydney.

Reichenbach-Klinke, H.H. (1973). *Fish Pathology*. T.F.H.: Neptune City, N.J.

Roberts, T.R. (1972). Ecology of Fishes in the Amazon and Congo Basins. *Bull. Mus. Comp. Zool. Harv.* **143**, 117-147.

Saiki, M.K. & Tash, J.C. (1978). Unusual population dynamics in largemouth bass, *Micropterus salmoides* caused by a seasonally fluctuating food supply. *Amer. Midl. Nat.*, **100**, 116-125.

Schmidt-Neilsen, K. (1975). *Animal Physiology. Adaptation and Environment*. Cambridge University Press: London.

Southwood, T.R.E. (1978). *Ecological Methods with Particular Reference to the Study of Insect Populations*. Chapman and Hall: London.

Tramer, E.J. (1977). Catastrophic mortality of stream fishes trapped in shrinking pools. *Amer. Midl. Nat.* **77**, 116-127.

Ward, P.J. (1982). The causes of mortality in pool dwelling *Craterocephalus* sp. (Pisces: Atherinidae) in Magela Creek, Northern Territory, during the 'Dry' season. Unpub. M.Sc. Prelim. Thesis, University of New England.

Weatherly, A.H. (1972). *Growth and Ecology of Fish Populations*. Academic Press: London.

Wedemeyer, G.A., Meyer, F.P. & Smith, L. (1976). *Environmental Stress and Fish Diseases*. T.F.H.: Neptune City, N.J.

Whitfield, A.K. (1978). Relationship between fish and piscivorous bird densities at Lake St. Lucia. *S. Afr. J. Sci.* **74**, 478.

Williams, A.R. (1979). Vegetation and stream pattern as indicators of water movement on the Magela Floodplain, Northern Territory. *Aust. J. Ecol.* **4**, 239-247.

Wolfe, J.R. (1978). Mortality. *In*: R.T. Lackey & W.A. Hubert (eds) *Analysis of Exploited Fish Populations*. Virginia Polytechnic Institute and State University: Blacksburg.

Zaret, T.M. & Kerfoot, W.C. (1975). Fish predation on *Bosmina longirostris*: Body-size selection versus visibility selection. *Ecology* **56**, 232-237.

APPENDIX 1

Effect of formalin on weight of Craterocephalus marianae

C. marianae from a Magela Creek pool were separated into eleven LCF size classes (increments of 1 mm). Lengths of individuals (nearest mm) and the weight (nearest 0.01 g) of each class were determined. Specimens were then placed in 60 mL of the 10% phosphate-buffered formalin. At 5 hours, 2 days, 4 days, 7 days and 10 days they were removed from the formalin and the lengths of individuals and weight of each class were estimated; then each size class was returned to the formalin. Specimens were dried between sheets of blotting paper for 10 to 30 seconds before the class was weighed. Lengths and weights were averaged with respect to the number of individuals in the class. Preservation in 10% formalin had no detectable effect on the length of *C. marianae* but did result in an increase in weight which was dependent on the duration of storage (Table 35). Consequently, the weights collected during the study were adjusted according to the relationship between weight and the duration of storage (Table 36).

Table 35. The effect of the duration of storage in formalin on the weight of eleven 1 mm size classes of *C. marianae* Values are given as the mean weight (g) in each size class. The number of individuals (n) in each class is indicated.

Duration of storage (days)	Size Class (mm LCF)										
	11.5-12.5	13.5-14.5	15.5-16.5	17.5-18.5	19.5-20.5	21.5-22.5	23.5-24.5	25.5-26.5	27.5-28.5	29.5-30.5	35.5-36.5
0.0	0.027	0.037	0.056	0.079	0.108	0.139	0.190	0.233	0.270	0.330	0.535
0.2	0.027	0.037	0.057	0.081	0.108	0.142	0.190	0.230	0.300	0.350	0.575
2.0	0.027	0.037	0.057	0.079	0.108	0.138	0.190	0.253	0.300	0.360	0.585
4.0	0.027	0.037	0.057	0.081	0.108	0.145	0.190	0.253	0.300	0.360	0.590
7.0	0.027	0.037	0.057	0.079	0.108	0.144	0.192	0.253	0.310	0.360	0.596
10.0	0.027	0.036	0.057	0.080	0.108	0.142	0.192	0.253	0.310	0.360	0.596
(n)	10	10	10	10	12	10	6	3	1	1	2

Table 36. Adjustment of the weight of *C. marianae* for the effect of storage in formalin. For each time period the adjustment of 'estimated weight' ($\hat{W}$) to 'actual weight' (W) is $W = \hat{W} - (a + b \cdot W)$, where b and a are the slope coefficeint and y-intercept from the regression line (fitted by the sum of the least squares method) of change in W on W (i.e. $\Delta W = a + b \cdot W$) estimated from the experiment. The reference number for a test of the significance of each regression (i.e. $H_0: B = 0$) is given. The minimum estimated weight of a specimen for which formalin will cause a 0.01 g or greater increase is also shown for each time period.

Duration of storage (days)	b	a	Reference Number	Minimum Weight (g)
0 - 1	0.08	-0.01	25	0.14
1 - 3	0.11	-0.01	26	0.12
3 - 6	0.11	-0.01	27	0.12
6 - 9	0.13	-0.01	28	0.11
9 - 11	0.13	-0.01	29	0.11

APPENDIX 2

Effect of turbidity and water depth on thrownet catching efficiency

Turbidity and water depth were considered to be the most important variables influencing the ability of *C. marianae* to avoid the thrownet. The effects of these variables were investigated in a cylindrical 1260 L tank (area = 2.7 m^2) of tapwater containing a known number of *C. marianae* (33 to 38 individuals; 18-40 mm LCF) randomly selected from the stock aquaria; one sample of the tank population was taken on a given day. A test sampling involved 34 casts of the thrownet, each directed to a different area of the tank. At least five minutes elapsed between each cast. The number of individuals captured in each cast was recorded. To reduce mortality, individuals were counted in the water while enclosed in the thrownet (only five individuals died during the experiment). Turbidity, measured as Secchi depth, was manipulated by adding fine silt obtained from a Magela Creek billabong to the tank. Thrownet samples were taken when Secchi depth was 15, 30 and 40 cm and in 'clear' water; water depth was constant, at 40 cm. 'Clear' water was assumed to be equivalent to water with a Secchi depth of 2.0 m (the maximum Secchi depth recorded during the study).

C. marianae were assumed to be distributed in two dimensions rather than in three dimensions, implying that changes in tank volume caused by the alteration of water depth did not alter density. In the second stage of the experiment water depth was altered. Thrownet samples were taken when water depth was 10, 20, 30 and 40 cm in 'clear' water (*i.e.* in water with a Secchi depth of 2.0 m).

The percentage efficiency (E) was estimated for each thrownet cast as:

$$E = \frac{\hat{d}}{\bar{d}} \times 100 \quad 0$$

where,

$\hat{d}$ = the density estimated from the cast (individuals/m^2),

d = the absolute density (individuals per m^2).

The equation:

$$E = 30.6\ D_s^{-0.481}$$

where,

E = percentage efficiency (E < 100%).

D_s = Secchi depth (m),

was estimated by fitting a regression line by the sum of the least squares method to log efficiency on log Secchi depth, i.e., $\ln E = \ln a + b \ln D_s$ (Fig. 20). This power relationship had a higher correlation coefficient than the linear relationship, $E = a + b D_s$ (-0.93 vs -0.80). Turbidity had a statistically significant effect on efficiency ($P << 0.001$).

At the beginning of the study the Secchi depth of each pool was measured before and after thrownet sampling. Sampling was found to have no detectable effect on turbidity. Subsequently, Secchi depth was only measured before sampling. So as to minimise the possible error in the estimate of density, the number of *C. marianae* captured in each cast made during the study were adjusted for the effect of turbidity such that the estimates were equivalent to casts made in water where Secchi depth was 95 cm (this was the mean Secchi depth of all samples taken during the study) rather than to when Secchi depth was 9 cm and thrownet efficiency was 100%. Hence the number of *C. marianae* captured in casts made when the Secchi depth was more than 95 cm, were increased

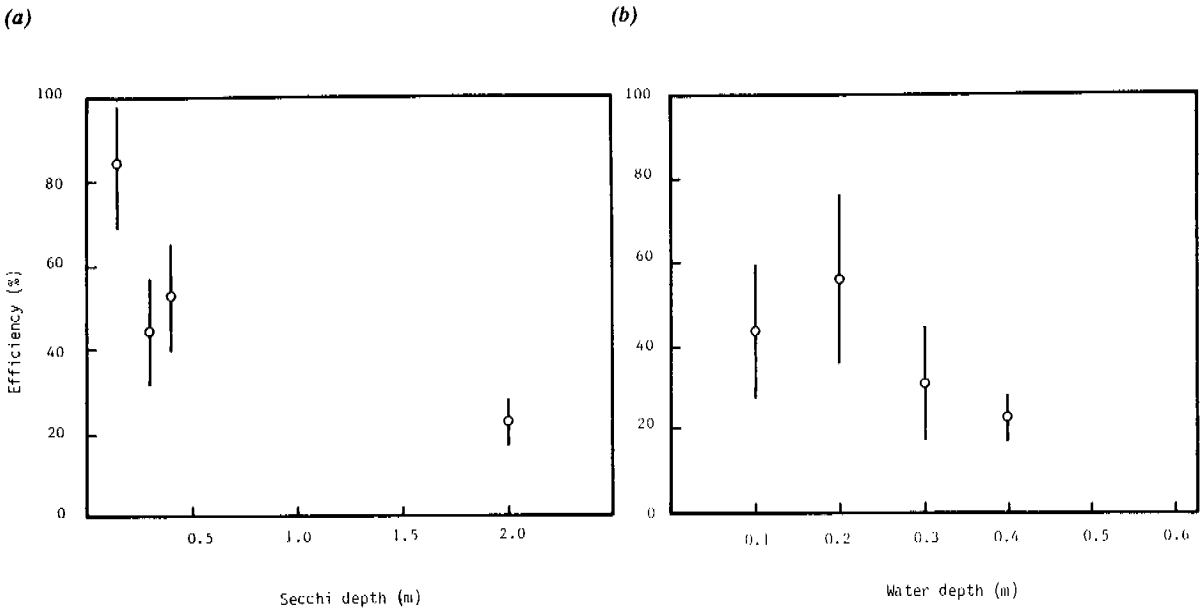

Figure 20. Effect of turbidity and water depth on the efficiency of the thrownet, as estimated by sampling *Craterocephalus marianae* in a tank. Open symbols indicate the mean percentage efficiency (i.e., estimated density/absolute density) and vertical lines indicate 80 percent confidence intervals for the mean (*a*) shows the effect of turbidity (measured as Secchi depth) on efficiency for a constant water depth of 40 cm and (*b*) shows the effect of water depth on efficiency in water with a Secchi depth of 2.0 m.

by the estimated reduction in efficiency; casts made when Secchi depth was less than 95 cm were reduced by the estimated increase in efficiency.

The equation:

$$E = 60.1 - 88.4\ D_w$$

where,

E = percentage efficiency (E < 100%)
D_w = water depth (m),

was estimated by fitting a regression line to the data by the sum of the least squares method (Fig. 20). In this case a linear regression was superior to a power form of the regression, i.e. $E = aD_w^{-b}$; it had a higher correlation coefficient (-0.78 vs -0.53). Water depth was found to have a significant effect on efficiency ($0.20 < P < 0.50$).

During sampling the maximum and minimum water depth of each cast were measured to the nearest 5 cm. The number of *C. marianae* captured in each cast, previously adjusted for the effects of turbidity were adjusted so they were equivalent to casts landing in water 22 cm deep (the mean depth of all casts made during the study).

The adjustment of *C. marianae* densities by estimates of thrownet efficiency obtained by sampling individuals in a tank may be criticised on several grounds. Firstly, the tank had a surface area of 2.7 m^2, only seven times greater than the area sampled by the thrownet. The 'fishable' area of the tank would be reduced by the tank walls interfering with the thrownet. However, this interference is expected to have been minimal because the tank walls were sloping (10° from the vertical) so the mouth of the thrownet was able to slide down the wall when landing in this area. On the other hand, the ability of *C. marianae* to avoid the thrownet might have been influenced by the tank. The tank walls might have restricted vision of the airborne thrownet or restricted the area available for *C. marianae* to escape, increasing the

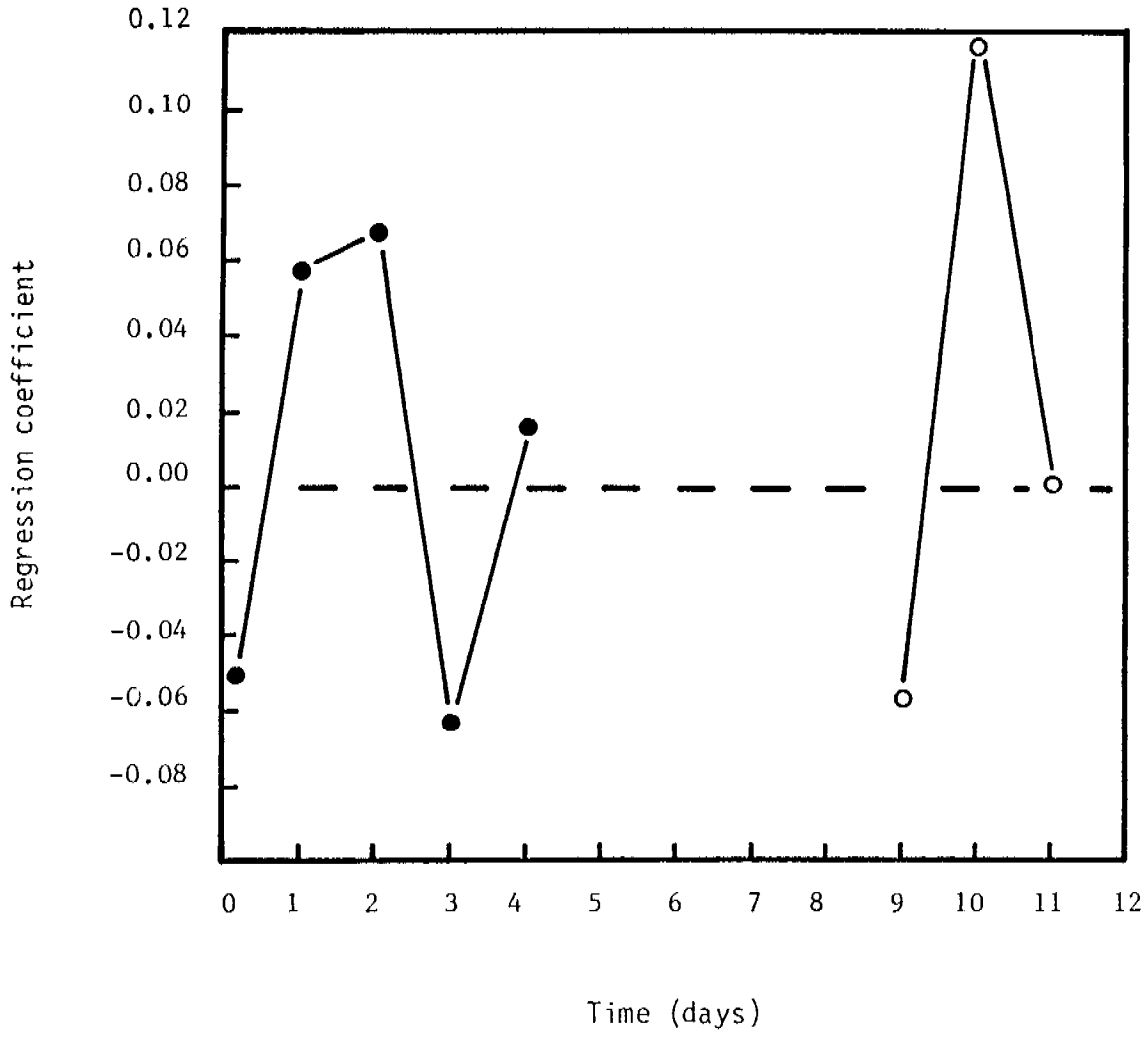

Figure 21. The relationship between the effect of the number of thrownet casts on the efficiency of the thrownet for each tank sample. The effect of the number of casts (C) on the efficiency (E) was measured as the regression coefficient (b) in the equation $E = a + bC$. A 'b' value greater than zero suggests that efficiency increased with successive casts and *vice versa* for a value less than zero. Solid symbols indicate the samples when water depth was altered, open symbols indicate the samples when turbidity was altered.

efficiency of the thrownet. Nevertheless, these effects should not have influenced the estimation of efficiency because conditions were constant for all of the samples; only turbidity and water depth were altered. In addition, the value of the exponent, 'b', in Taylor's power law for the tank samples was not significantly different from that of samples of the pools ($0.02 < P < 0.01$). The value of 'b' appears to be an index of the aggregation of a population (Southwood 1978) so it is concluded that, as far as sampling was concerned, the tank did not influence the distribution of *C. marianae* and thus should not have affected the efficiency of the thrownet.

The same individuals were used throughout the trials and this might have influenced the efficiency of the thrownet. Efficiency could have fallen in successive casts through individuals learning to avoid the thrownet or could have increased as fish became exhausted or damaged. There was no trend, however in efficiency with successive casts; the number caught in successive casts increased across four samples (30, 31, 32, 33), decreased across

three samples (34, 35, 36) and did not change in one (sample 37). Neither was there a trend in the efficiency of successive casts with time (Fig. 21). It is concluded that using the same individuals did not influence the estimate of thrownet efficiency.

Finally, the interaction of turbidity and water depth in influencing thrownet efficiency was not considered. Other variables, such as the behaviour of *C. marianae* schools under different conditions, may have influenced the precision of sampling. A parsimonious decision was necessary and these variables were not considered.

Despite these criticisms of the estimation of thrownet efficiency, the adjustment of numbers must give more precise estimates of density than those from the raw data. Originally, it was envisaged that thrownet efficiency would be estimated at the end of the study period by comparing estimates of density obtained by thrownet, with the absolute density obtained by rotenoning each pool. Unfortunately the thrownet samples taken at the end of the study period coincided with the lowest densities of *C. marianae* and a useful comparison of estimated and absolute density could not be made.

SUPERVISING SCIENTIST FOR THE ALLIGATOR RIVERS REGION RESEARCH PUBLICATIONS

Alligator Rivers Region Research Institute Research Report 1983-84
Alligator Rivers Region Research Institute Annual Research Summary 1984-85
Alligator Rivers Region Research Institute Annual Research Summary 1985-86
Alligator Rivers Region Research Institute Annual Research Summary 1986-87
Alligator Rivers Region Research Institute Annual Research Summary 1987-88
Alligator Rivers Region Research Institute Annual Research Summary 1988-89
Alligator Rivers Region Research Institute Annual Research Summary 1989-90
Alligator Rivers Region Research Institute Annual Research Summary 1990-91 (in press)

Research Reports (RR) and Technical Memoranda (TM)

RR 1	The macroinvertebrates of Magela Creek, Northern Territory. April 1982 (pb, mf - 46 pp.)	R. Marchant
RR 2	Water quality characteristics of eight billabongs in the Magela Creek catchment. December 1982 (pb, mf - 60 pp.)	B.T. Hart & R.J. McGregor
RR 3	A limnological survey of the Alligator Rivers Region. I. Diatoms (Bacillariophyceae) of the Region. August 1983 (pb, mf - 160 pp.)	D.P. Thomas
	*A limnological survey of the Alligator Rivers Region. II. Freshwater algae, exclusive of diatoms. 1986 (pb, mf - 176 pp.)	H.U. Ling & P.A. Tyler
RR 4	*Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume I. Outline of the study, summary, conclusions and recommendations. 1986 (pb, mf - 63 pp.)	K.A. Bishop, S.A. Allen, D.A. Pollard & M.G. Cook
	Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume II. Synecology. 1990 (pb - 155 pp.)	K.A. Bishop, S.A. Allen, D.A. Pollard & M.G. Cook
	Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory, Volume III. Autocology. (in press)	K.A. Bishop, S.A. Allen, D.A. Pollard & M.G. Cook
RR 5	Macrophyte vegetation of the Magela Creek flood plain, Alligator Rivers Region, Northern Territory. March 1989 (pb - 41 pp.)	C.M. Finlayson, B.J. Bailey & I.D. Cowie
RR 6	Modern sedimentation and late Quaternary evolution of the Magela Creek plain. (in press)	R.J. Wasson
RR 7	Routine analysis of naturally occurring radionuclides in environmental samples by alpha-particle spectrometry. (in press)	P. Martin & G. Hancock
RR 8	Transport of naturally occurring radionuclides in the surface waters of the Magela Creek and flood plain, northern Australia. (in press)	A.S. Murray, A. Johnston, P. Martin, G. Hancock, R. Marten & J. Pfitzner
RR 9	Fish communities in sandy pools of Magela Creek, Alligator Rivers Region (pb - 88 pp.)	D.J. Woodland & P.J. Ward
TM 1	Transport of trace metals in the Magela Creek system, Northern Territory. I. Concentrations and loads of iron, manganese, cadmium, copper, lead and zinc during flood periods in the 1978-1979 Wet season. December 1981 (pb, mf - 27 pp.)	B.T. Hart, S.H.R. Davies & P.A. Thomas
TM 2	Transport of trace metals in the Magela Creek system, Northern Territory. II. Trace metals in the Magela Creek billabongs at the end of the 1978 Dry season. December 1981 (pb, mf - 23 pp.)	S.H.R. Davies & B.T. Hart

TM 3	Transport of trace metals in the Magela Creek system, Northern Territory. III. Billabong sediments. December 1981 (pb, mf - 24 pp.)	P.A. Thomas, S.H.R. Davies & B.T. Hart
TM 4	The foraging behaviour of herons and egrets on the Magela Creek flood plain, Northern Territory. March 1982 (pb, mf - 20 pp.)	H.R. Recher & R.T. Holmes
TM 5	Flocculation of retention pond water. May 1982 (pb, mf - 8 pp.)	B.T. Hart & R.J. McGregor
TM 6	Dietary pathways through lizards of the Alligator Rivers Region Northern Territory. July 1984 (pb, mf - 15 pp.)	C.D. James, S.R. Morton, R.W. Braithwaite & J.C. Wombey
TM 7	Capacity of waters in the Magela Creek system, Northern Territory, to complex copper and cadmium. August 1984 (pb, mf - 42 pp.)	B.T. Hart & S.H.R. Davies
TM 8	Acute toxicity of copper and zinc to three fish species from the Alligator Rivers Region. August 1984 (pb, mf - 31 pp.)	L. Baker & D. Walden
TM 9	Textural characteristics and heavy metal concentrations in billabong sediments from the Magela Creek system, northern Australia. October 1984 (pb, mf - 39 pp.)	P.A. Thomas & B.T. Hart
TM 10	Oxidation of manganese(II) in Island Billabong water. October 1984 (pb, mf - 11 pp.)	B.T. Hart & M.J. Jones
TM 11	*In situ* experiments to determine the uptake of copper by the aquatic macrophyte *Najas tenuifolia* R.Br. December 1984 (pb, mf - 13 pp.)	B.T. Hart, M.J. Jones & P. Breen
TM 12	Use of plastic enclosures in determining the effects of heavy metals added to Gulungul Billabong. January 1985 (pb, mf - 25 pp.)	B.T. Hart, M.J. Jones & P. Bek
TM 13	Fate of heavy metals in the Magela Creek system, northern Australia. I. Experiments with plastic enclosures placed in Island Billabong during the 1980 Dry season: heavy metals. May 1985 (pb, mf - 46 pp.)	B.T. Hart, M.J. Jones & P. Bek
TM 14	Fate of heavy metals in the Magela Creek system, northern Australia. II. Experiments with plastic enclosures placed in Island Billabong during the 1980 Dry season: limnology and phytoplankton. May 1985 (pb, mf - 32 pp.)	B.T. Hart, M.J. Jones, P. Bek & J. Kessell
TM 15	Use of fluorometric dye tracing to simulate dispersion of discharge from a mine site. A study of the Magela Creek system, March 1978. January 1986 (pb, mf - 51 pp.)	D.I. Smith, P.C. Young & R.J. Goldberg
TM 16	Diets and abundances of aquatic and semi-aquatic reptiles in the Alligator Rivers Region. July 1986 (pb, mf - 57 pp.)	R. Shine
TM 17	Plants of the Alligator Rivers Region, Northern Territory. August 1986 (pb, mf - 54 pp.)	I.E. Cowie & C.M. Finlayson
TM 18	The taxonomy and seasonal population dynamics of some Magela Creek flood plain microcrustaceans (Cladocera and Copepoda) September 1986 (pb, mf - 80 pp.)	M.E. Julli
TM 19	Frogs of the Magela Creek system. January 1987 (pb, mf - 46 pp.)	M.J. Tyler & G.A. Crook
TM 20	Radiation exposure of members of the public resulting from operation of the Ranger Uranium Mine. December 1987 (pb, mf - 22 pp.)	A. Johnston
TM 21	Interlaboratory comparison of the measurement of uranium in urine. June 1988 (pb - 24 pp.)	T. Anttonen, B.N. Noller & D.A. Woods
TM 22	Biology and early development of eight fish species from the Alligator Rivers Region. June 1988 (pb - 68 pp.)	W. Ivantsoff, L.E.L.M. Crowley, E. Howe & G. Semple
TM 23	Alien plants in the Alligator Rivers Region, Northern Territory, Australia. September 1988 (pb - 34 pp.)	I.D. Cowie, C.M. Finlayson & B.J. Bailey

TM 24	The determination of zinc in Magela Creek water. April 1989 (pb - 26 pp.)	C.A.A. LeGras & B.N. Noller
TM 25	Element concentrations in the freshwater mussel, *Velesunio angasi*, in the Alligator Rivers Region. June 1989 (pb - 262 pp.)	H.E. Allison & R.D. Simpson
TM 26	A simple computer model for terrestrial and solar radiation transfer. August 1989 (pb - 60 pp.)	I.M. Vardavas & L.M. Cannon
TM 27	Annual rainfall statistics for stations in the Top End of Australia: normal and log-normal distribution analysis. August 1992 (pb - 34 pp.)	I.M. Vardavas
TM 28	A study of the reproducibility of water conditions between small enclosures and a tropical waterbody. November 1989 (pb - 20 pp.)	B.N. Noller, T.P. McBride, C.W. Hunt & B.T. Hart
TM 29	Concentration of radon and radon daughters during semi-dry tailings deposition by QML at Nabarlek (1985-88). December 1989 (pb - 35 pp.)	D.A. Woods
TM 30	The development of a regulatory mechanism for the control of water release from Ranger Uranium Mine. June 1990 (pb - 31 pp.)	M.W. Carter
TM 31	Investigation of the erosional stability of waste rock dumps under simulated rainfall: a proposal. December 1990 (pb - 56 pp.)	S.J. Riley & T.J. East
TM 32	The terrestrial and semiaquatic reptiles (Lacertilia, Serpentes) of the Magela Creek region, Northern Territory. November 1990 (pb - 86 pp.)	R.A. Sadlier
TM 33	In vitro dissolution of uranium mill products by the batch replacement method. February 1991 (pb - 24 pp.)	D.R. Stockwell, K.W. Bentley & C.B. Kerr
TM 34	Soils and Hydrology of Ranger Uranium Mine Sites in relation to application of retention pond water. October 1991 (pb - 69 pp.)	C.J. Chartres, P.H. Walker, I.R. Willett, T.J. East, R.F. Cull, T. Talsma & W.J. Bond
TM 35	The determination of low concentrations of sodium, potassium, magnesium, calcium and strontium in natural waters by graphite furnace AAS. December 1991 (pb - 18 pp.)	C.A.A. LeGras & B.N. Noller
TM 36	Heavy metals in waterbirds from the Magela Creek flood plain, Alligator Rivers Region, Northern Territory, Australia. February 1992 (pb - 59 pp.)	K.G. Brennan, B.N. Noller, C. LeGras, S.R. Morton & P.L. Dostine
TM 37	Isolation and culture of five species of five freshwater algae from the Alligator Rivers Region, Northern Territory. August 1992 (pb - 30 pp.)	A. Padovan
TM 38	Radiotoxicity hazard classification: the basis and development of a new list. (in press)	M.W. Carter, P. Burns & L. Munslow-Davies
TM 39	Toxic effects of cyanide on aquatic animals of the Alligator Rivers Region. August 1992 (pb - 17 pp.)	G.D. Rippon, C.A. LeGras, R.V. Hyne & P.J. Cusbert