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AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT

LUCAS HEIGHTS

THE ALLIGATOR RIVERS AREA FACT FINDING STUDY
FOUR AAEC REPORTS

by

N. F. CONWAY

D. R. DAVY

M. S. GILES

P.J.F. NEWTON (ed.)

D. A. POLLARD*

*NSW Department of Fisheries

June 1974

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ABSTRACT

The work described in this series of reports is part of the Joint Government-Industry Fact Finding Study carried out in the 'Uranium Province' of the Alligator Rivers Area, Northern Territory, during 1971–73. The primary objective was to determine the sensitivity of the existing environment to the range of potential pollutants arising from a uranium extractive industry.

A comprehensive ichthyography is given of species collected in the area. Results are reported of experimental and bioassay studies on selected flora and fauna exposed to heavy metals, raffinate and Alamine-336. Studies are also recorded on the chemical and radiological qualities of natural waters, the solubility of uranium in sediments, and the fate of dissolved trace elements in the drainage systems.

The radiological aspects of the area are discussed with specific reference to exposure routes, biological concentration factors, and the significance of natural and man made changes in levels of radiation to man and other biota in the region. Radon levels in costeans, core-sheds and bore water are recorded and discussed.

KEYWORDS

The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA–INIS–12 (INIS: Manual for Indexing) and IAEA–INIS–13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

Report I AQUATIC ECOSYSTEMS; DIET; ECOLOGY; FISHES; FRESH WATER; NORTHERN TERRITORY; RIVERS; URANIUM

Report II BIOASSAY; BIOLOGICAL EFFECTS; CONTAMINATION; COPPER CHLORIDES; DOSE LIMITS; ECOLOGY; FISHES; GRAMINEAE; GROUND WATER; LEAD NITRATES; NORTHERN TERRITORY; POLLUTION; POTASSIUM COMPOUNDS; RIVERS; TOXICITY; TROPICAL REGIONS; ZINC SULFATES

Report III ANIMALS; AQUATIC ECOSYSTEMS; COBALT; CONTAMINATION; COPPER; ECOLOGY; ELEMENTS; FISHES; FRESH WATER; GRAMINEAE; LEAD; MOLLUSCS; NORTHERN TERRITORY; RADIATION DOSES; RADIOECOLOGICAL CONCENTRATION; RADIONUCLIDE MIGRATION; RADIUM; RAIN; RIVERS; SOILS; TRACE ELEMENTS; UPTAKE; URANIUM; VEGETABLES; ZINC

Report IV ATMOSPHERES; DAUGHTER PRODUCTS; GROUND WATER; MINING; NORTHERN TERRITORY; RADIATION HAZARDS; RADIONUCLIDE MIGRATION; RADON; SAFETY; SAMPLING; URANIUM; WEATHER

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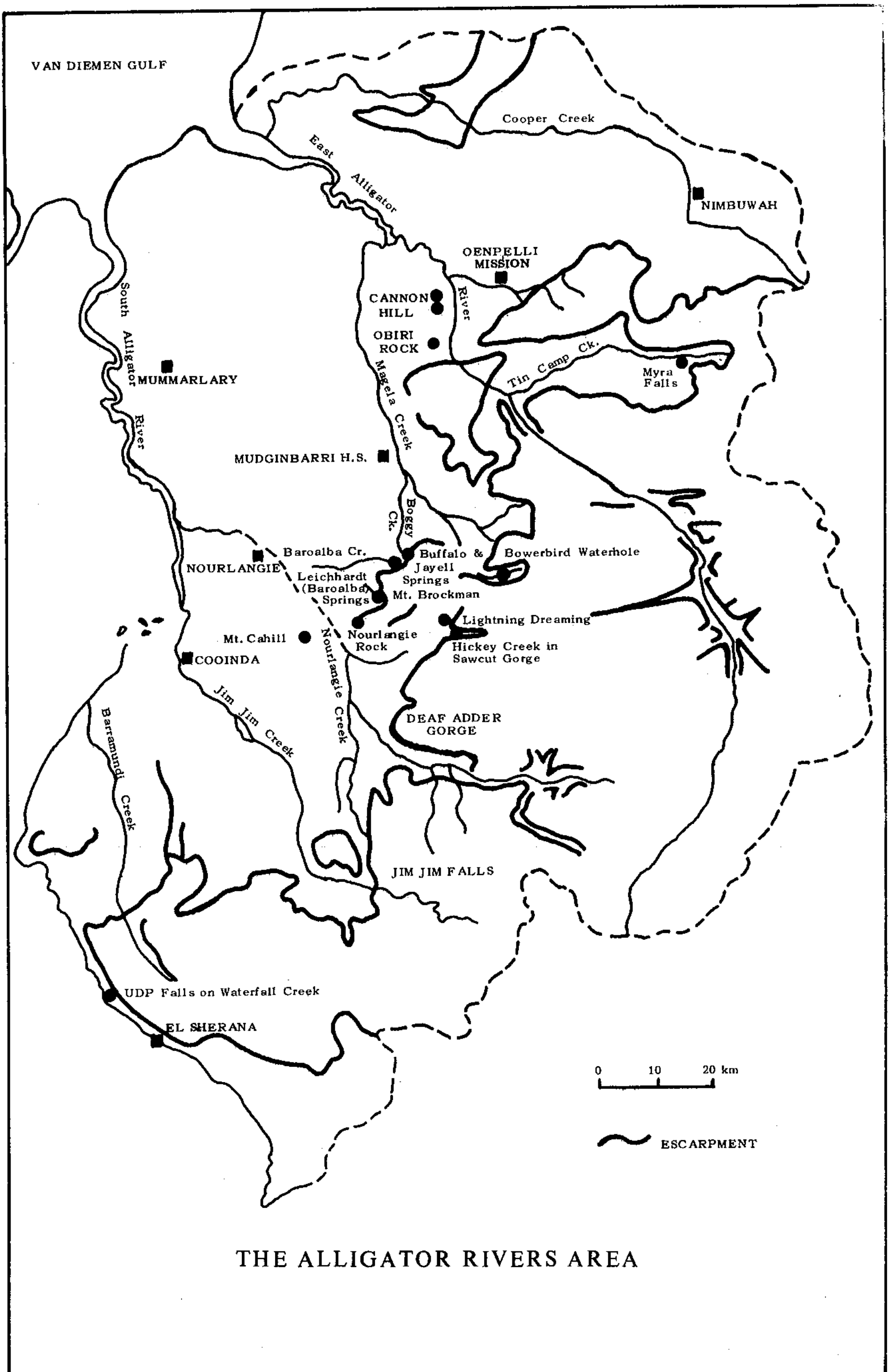

THE ALLIGATOR RIVERS AREA

FOREWORD

In November 1971, at the invitation of the then Northern Territory Administration, the Australian Atomic Energy Commission initiated an environmental study in the Alligator Rivers area. The primary purpose of this study was to define standards for mining effluents which would limit environmental deterioration to acceptable levels, and it was essentially a study of water quality. The standards obtained would allow the requirements for waste treatment and containment to be specified. Subsequently, this project was incorporated into the much broader Joint Government-Industry Factfinding Study and, while retaining its original purpose, has greatly benefited from the wider association. The AAEC is also indebted to the Joint Study organisation for its financial support in this work.

At all levels of government, the need for environmental assessment in the early phases of the planning of major new developments is now fully appreciated. The requirements for such assessment have frequently been set out in the form of guidelines, or embodied in legislation requiring developers to prepare environmental impact statements.

In broad terms, an environmental impact statement has three sections. The first section deals with the proposed development and the need for it in terms of national objectives. The second section describes the environment which is the subject of the proposed development. It should provide not only an adequate record of its existing state, with respect to all the indicators that may reasonably be invoked, but also should examine its sensitivity to changing conditions, with respect to the same set of indicators. The last section of the impact statement examines the options open to the developer in implementing his plans, including the option for non-development. It has to provide the cost-benefit analyses of these options, assessed in terms of the environmental endpoints.

Preparation of information for the first and last section of the impact statement is the prerogative of the developers, since they should possess the necessary expertise. The collection of information for the middle section of the impact statement became the terms of reference for the Joint Government-Industry Factfinding Study.

It is difficult to characterise an environment in isolation from likely proposals for development. Foremost in our minds were the possibilities of an intensified pastoral industry based on buffalo domestication, uranium mining, and the growth in tourism stemming from the construction of the Arnhem highway.

Since the AAEC programme was an attempt to assess water quality and the effect of development on it, the four reports presented here relate to specific aspects of this study. In the first report Dr. D.A. Pollard of the NSW State Fisheries presents taxonomic descriptions of the fishes of the Alligator Rivers. The cooperation of the NSW Chief Secretary's Department in allowing Pollard to participate in this work was very much appreciated.

For logistic convenience, much of the fish sampling described by Pollard was undertaken in conjunction with the early phases of the toxicological study presented by M.S. Giles. Giles' work deals with the sensitivity of fish species and also algae and vegetation to a range of chemical toxicants. For the combinations studied, fishes were the most sensitive in all cases.

The third report, by D.R. Davy and N.F. Conway, examines the water quality of the area to determine the geographical extent of the environment to which Giles' results might reasonably be taken to apply. It is concluded that they are applicable to the whole study area. This report also examines the fate, in a geobotanical, geochemical sense, of suspended and dissolved radioactive and non-radioactive elements that are carried in the river systems.

The Alligator Rivers area is rich in uranium mineralisation. Not unexpectedly, natural levels of radioactivity are higher than in many other areas of Australia. The pathways by which waterborne radioactivity lead to the exposure of man are characteristics of the local environment. These pathways are evaluated by Davy and Conway.

The fourth report presents the limited data collected on prevailing radon levels in the atmosphere.

The study team gratefully acknowledges the full cooperation and hospitality extended to them by officers of the Department of the Northern Territory, and the mining and pastoral companies represented in the study area.

D.R. Davy

D.R. DAVY
(Study Leader)

THE ALLIGATOR RIVERS AREA FACT FINDING STUDY

REPORT I

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)

by

D. A. POLLARD

New South Wales State Fisheries, Sydney

This Reprint is extracted from a series of reports published by the Australian Atomic Energy Commission. It should be cited
Conway, N.R., Davy, D.R., Giles, M.S., Newton, P.J.F. (ed.), and Pollard, D.A. (1974) – AAEC/E305

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1. INTRODUCTION

This report is based on the results of a survey of the fishes of the Magela Creek catchment, and some other sections of the East Alligator River system, carried out for the Australian Atomic Energy Commission during June and July 1972. The major part of the survey was conducted in conjunction with the collection of live fishes for use in bioassay experiments. These experiments were designed to determine the toxicities of a number of heavy metals, and also other toxicants expected to be present in uranium mining and processing waste-waters, to the aquatic fauna of the area. Such a comprehensive inventory of the ichthyofauna of the area was necessary to evaluate the effects of any possible future pollution of these river systems resulting from such changing land use.

The main emphasis of the survey was concentrated on the Magela Creek catchment, as this is the system containing most of the known uranium mineralisation. A more general survey of the fishes of the whole 'Uranium Province' has since been carried out by H. Midgley, for the Department of the Northern Territory, between September 1972 and July 1973.

The only significant previous survey of the fishes of this general area was carried out by R.R. Miller during the American-Australian Scientific Expedition to Arnhem Land in 1948, the results of which have only been published recently by Taylor (1964). Miller's survey covered both the marine and freshwater ichthyofauna of a number of localities in Arnhem Land, but only those collections made in the general vicinity of Oenpelli (East Alligator River system) will be referred to in the present report.

Other important sources on the freshwater fish fauna of this area include 'The Fishes of New Guinea' (Munro 1967) and 'Guide to Fishes' (Grant 1972). More general works containing useful reference material include 'Freshwater Fishes and Rivers of Australia' (Lake 1971) which contains colour photographs of most of the species mentioned, 'Handbook of Australian Fishes' (Munro 1956-1961) and 'Native Freshwater Fishes of Australia' (Whitley 1960).

2. SCOPE OF SPECIES DESCRIPTIONS

For each of the fishes collected from the Magela Creek catchment the following information is given:

Family Name: In general, that used follows the scheme outlined by Greenwood *et al.* (1966).

Scientific Name: As far as possible that currently accepted as valid, together with its author.

Common Names: Including those most generally accepted and those used locally in the Alligator Rivers area.

Aboriginal Name: Where possible that used in the Alligator Rivers area - usually Oenpelli.

Systematic Position: Notes on recent synonymies, sub-species, current taxonomic problems, and disagreements between authors on the systematic position of the species and its closer relatives.

Distribution: By drainage systems (generally following the scheme outlined by Lake 1971, pp.9-11 and end paper maps), and by State; mention is made also of occurrences in New Guinea and elsewhere in the Indo-Pacific region, where appropriate.

Description: A general description of the species' body shape, scales, lateral line, head, mouth, teeth, eyes and fins; its colour pattern and markings; the maximum recorded ranges of certain meristic characters including numbers of dorsal (D), anal (A), pectoral (P), and ventral (V) finrays, and lateral line (L.lat.) and predorsal scales; and the maximum recorded ranges of certain morphometric characters including head length (HL) and body depth (BD) as proportions of standard length (SL).

Maximum Size: Including both maximum recorded total length (TL) and weight, where available.

Habits: Notes on the salinity tolerance of the species (and/or its closer relatives), its favoured habitats, behaviour, general life history, and breeding biology, where information is available.

Diet: Notes on the food of the species (and/or its closer relatives), both from the literature and from observations, where available.

General Notes: Notes on the sporting and eating qualities of the species, where appropriate, and on any other features of particular interest to man.

Specimens Collected: Information on the locality, number of specimens, range of standard lengths, collector, collecting method, Australian Museum catalogue number and date for each collection, as well as the localities where the species was observed but not collected, and information on specimens collected by other workers from the area.

Less detailed information is given for those species collected from areas outside the Magela Creek catchment (other parts of the East Alligator River system, and tributaries of the South Alligator River system).

3. MATERIALS AND METHODS

A number of different collecting methods were used in an attempt to capture as many as possible of the species present, and these included the following:

- Seine net (~ 30 m x 13 mm mesh) - for most small schooling species over relatively shallow sandy bottoms.
- Cast nets (~ 4 m x 13 mm mesh, ~ 6.5 m x 19 mm mesh) - for most medium sized species in relatively shallow waterholes and around the vegetated shorelines of billabongs.
- Dip nets (~ 13 mm mesh prawn scoops, mosquito-netting insect nets) - for small species amongst inshore aquatic vegetation and schooling fry in open water of waterholes and billabongs.
- Mesh nets (~ 30 m x 150 mm and 180 mm mesh 'barramundi' nets) - for large silver barramundi and elasmobranchs in a billabong connected to the East Alligator River.
- Rod and line (trolling or casting large artificial lures) - for larger predatory species in billabongs and lagoons.
- Handlines (using baited hooks) - for larger species in billabongs and lagoons.

Specimens were preserved initially in 10 per cent formalin and later transferred to 50 per cent isopropanol. Representative samples of each species collected were deposited in the collections of the Australian Museum, Sydney.

4. COLLECTING LOCALITIES

The two main rivers of the Uranium Province, the East and South Alligator Rivers, drain into Van Diemen Gulf in the eastern sector of the Timor Sea drainage system (Lake 1971, p.10 and end paper maps). This major drainage system, which stretches westward from Cape Arnhem (the westernmost headland of the Gulf of Carpentaria) to include the Fitzroy River in Western Australia, has the second highest annual discharge (75×10^9 tonne) of the fifteen Australian drainage systems described by Lake (1971).

Tributaries of both the East and South Alligator Rivers originate in the deeply dissected rocky uplands of the Arnhem Land Plateau, and emerge via deep gorges in the escarpment to meander northwards across the broad coastal plain towards the sea. Most of this plain is converted to a vast inter-connected system of swamps and lagoons at the height of the wet season, but only the larger of the lowland lagoons and billabongs contain water by the end of the dry season, and of those that do, some become too hot and too deficient in dissolved oxygen to support fish life. Thus the fish faunas of many of these aquatic habitats on the coastal plain are replenished seasonally from either the main tidal river channels or the upland spring-fed tributaries of the plateau.

The following localities are those where collections were made by the author during the present study, and those where collections were made by other workers mentioned in the text.

4.1 East Alligator River System

(a) Magela Creek Catchment. Magela Creek, the main tributary of this river system, originates in the rocky uplands of the Arnhem Land Plateau.

(i) Magela Creek - 12°40' S and 132°55' E; the creek flows through flat wooded country between the Jabiru and Georgetown mining camps. This section of the creek was just flowing at the beginning of June, and by the end of July was reduced to a chain of separate waterholes along the otherwise dry stream course, most of which are dehydrated by the end of each dry season. The largest of these waterholes, which were up to two metres deep and about thirty metres long in early June, were less than one metre deep by late July. In general the bed of the creek was sandy, the water was fairly clear, and small quantities of submerged aquatic vegetation were present around the margins of some of the deeper waterholes in June. The vegetation fringing the shoreline was mainly *Pandanus*, the roots of which were often undercut along the banks of the deeper holes. This was the major collecting locality sampled during the present study.

(ii) Boggy Creek - 12°37' S and 132°52' E; a muddy waterhole of this small tributary of Magela Creek, to the west of Jabiru and just south of the southern boundary of Mudginbarri Station. This small waterhole was less than one metre deep, about ten metres long, contained turbid water, and had a mud bottom with some submerged aquatic vegetation around its margins.

(iii) Indium Billabong - 12°40' S and 132°54' E; just off Magela Creek, about two kilometres downstream from Georgetown. This small billabong was about thirty metres long and over three metres deep, contained turbid water, and had a muddy bottom, with considerable amounts of submerged aquatic vegetation around its more sandy margins, and some 'water lilies' floating on its surface.

(iv) Georgetown Billabong - 12°41' S and 132°56' E; just off Magela Creek, adjacent to Georgetown mining camp. Similar to Indium Billabong, but much larger in area (around 100 m x 300 m), with turbid water, a muddy bottom, and dense aquatic vegetation around its margins.

(v) Mudginbarri Lagoon - 12°35' S and 132°52' E; adjacent to the homestead of Mudginbarri cattle station. This lagoon was fairly deep (over three metres), about 1.5 kilometres long, contained fairly clear water, had a sand bottom in its southern part, and was mainly fringed with *Pandanus* and surrounded by dense scrub vegetation.

(vi) Leichhardt Lagoon - 12°33' S and 132°52' E; on the Magela Plain, to the north of Mudginbarri Lagoon. This is a very large lagoon, mainly surrounded by open country and thin scrub. Its waters were fairly clear, and it contained considerable quantities of aquatic vegetation in its shallower parts.

(vii) Ja Ja Lagoon - 12°32' S and 132°53' E; just to the north-north-east of Leichhardt Lagoon, and beside the road from Mudginbarri to Cahills Crossing. This lagoon is another large waterbody very similar to Leichhardt Lagoon.

(viii) Island Billabong - 12°33' S and 132°53' E; downstream from Mudginbarri Lagoon and upstream from Ja Ja Lagoon. This lagoon is similar to Mudginbarri Lagoon, and is described by Midgley (unpublished work) as follows; "Water clear. Heavy tree cover along banks. Areas of water weed. Sandy bottom". (This locality was sampled by Midgley in October 1972, but not by the author during the present study.)

(ix) Lagoon on Magela Plain - 12°25' S and 132°52' E; about eleven kilometres south-west of Cannon Hill. Midgley describes it as shallow and turbid, with a maximum depth of 1.5 metres, having isolated clumps of *Pandanus* on its banks, and situated on an open plain. (This locality was sampled by Midgley, but not by the author during the present study.)

(x) Upper Magela Creek - 12°45' S and 132°58' E; in the upper reaches of the creek near Bowerbird Camp. This part of Magela Creek is situated in the rocky upland country of the Arnhem

Land Plateau. In contrast to all of the preceding localities in the Magela Creek catchment, this locality is upstream of the 'Ranger I' uranium ore-body.

(xi) Anomaly II Costean - 12°44' S and 132°56' E; in the vicinity of the 'Ranger' ore-body near the base of Mount Brockman. This costean is an artificially dug trench, with sheer sides, about ten metres long, and containing about two metres of extremely turbid water.

(b) Other Localities in East Alligator Catchment. The East Alligator River also originates in the rocky uplands of the Arnhem Land Plateau and flows in a north-westerly direction across the coastal plain to the sea.

(i) Rock Hole Billabong - 12°27' S and 132°58' E; adjacent to the East Alligator River several kilometres upstream from Cahills Crossing, close to the upper limit of tidal influence, and directly connected to the main river course by a narrow channel. This billabong was about one kilometre long, over four metres deep in places, its water was fairly clear and generally fresh (though tidal), its bottom consisted of muddy sand and rock, and its shoreline was mainly rocky and in places fringed with *Pandanus*.

(ii) Cahills Crossing - 12°25' S and 132°51' E; just above where the main road crosses the East Alligator River via a causeway into Arnhem Land, and about ninety-five river kilometres upstream from the mouth. Here the river was about thirty metres wide, with a muddy bottom, and its waters very turbid and fairly fresh (though tidal).

(iii) Cahills Landing - 12°22' S and 132°58' E; a locality on the main river channel about ten kilometres downstream from, and generally similar to, Cahills Crossing, though the water at this locality was slightly brackish. (Locality sampled by the author, and by Miller in 1948; see Taylor 1964, p.52.)

(iv) Cannon Hill Lagoon - 12°22' S and 132°57' E; a large lagoon (about four kilometres long and over three metres deep) which is intermittently connected to the East Alligator River and subjected to tidal influence during high spring tides. Its waters are sometimes brackish and generally turbid, it contains little or no aquatic vegetation, and it is situated on an open plain. (Locality sampled by Midgley.)

(v) Red Lily Lagoon - 12°22' S and 132°58' E; a lagoon near Cannon Hill Lagoon, which is over one kilometre long, about two hund... metres wide and over two metres deep, and situated about eleven kilometres west-south-west of Oenpelli and three kilometres south-west of the East Alligator River, to the west of Cahills Landing. This lagoon is joined to the East Alligator during the wet season, had clear water, a mud bottom, and much aquatic vegetation (especially red lotus or 'lilies' around the shore-line.) (Locality sampled by Miller in 1948; see Taylor 1964, p.52).

(vi) Oenpelli (Unblonyan) Lagoon - 12°19' S and 133°03' E; a lagoon about 1.3 kilometres long, two hundred metres wide, and over two metres deep, fed by Oenpelli Creek and overflowing to the East Alligator River during the wet season. Its waters were fresh and clear, and it contained submerged aquatic vegetation *(Myriophyllum?)* and water lilies. (Locality sampled by Miller in 1948; see Taylor 1964, p.51.)

(vii) Oenpelli Creek - 12°23' S and 133°05' E, and 12°22' S and 133°05' E; two localities along this creek, which flows into Oenpelli Lagoon. The first was a small pool (about forty-five metres long, twelve metres wide, and at least one metre deep) on the sandstone escarpment above a sixty metre waterfall about eight kilometres south-south-east of Oenpelli, with slightly turbid water (due to an algal bloom), and a bottom of sand and rock. (Localities sampled by Miller; see Taylor 1964, pp.51-52.)

(viii) Fish Creek - 12°19' S and 133°12' E; two small pools (about 30 x 10 x 1 metre) on this tributary of Oenpelli Creek, which cascades off the escarpment about fifteen (?) kilometres east of Oenpelli, both with slightly turbid water and rock and sand bottoms. (Locality sampled by Miller; see Taylor 1964, pp. 51-52.)

(ix) Tin Camp Creek - 12°27' S and 133°10' E; a tributary entering the East Alligator River from the north-east in the rocky upland country of the plateau. Described by Midgley as consisting of "pools of still water with long shallow narrow runs between", with a bottom of sand and stones and heavy tree cover along the banks. (Locality sampled by Midgley.)

(x) Cooper Creek - 12°15' S and 133°22' E, and 12°03' S and 132°56' E; two localities on this tributary entering the East Alligator River from the north about ten kilometres upstream from its mouth. The first was a small sandy bottomed pool in the upper reaches, about eleven kilometres east of Queensland Mines' Nabarlek ore-body, which was about six metres long, three metres wide, and thirty centimetres deep. The second was a series of pools of different sizes up to two metres deep in the lower reaches in the vicinity of Mount Borradaile. (Locality sampled by Midgley.)

4.2 South Alligator River System

The South Alligator River originates in rocky upland country well to the south of the study area, from whence it flows northwards across the coastal plain to the sea. Nourlangie Creek and its three tributaries mentioned below also originate in the rocky uplands and flow north-westwards to enter the South Alligator River to the west of the main study area.

(i) Sawcut Creek - 12°55' S and 132°55' E; a tributary of Nourlangie Creek which emerges through a deep gorge in the escarpment about twenty-four kilometres east-south-east of the Noranda uranium mine. Here the creek comprises a string of long, rocky shored waterholes, some of which are over three metres deep, containing clear water. (Locality sampled by both the author and Midgley.)

(ii) Nourlangie Creek - 12°48' S and 132°42' E, and 12°52' S and 132°47' E; described by Midgley as a system of long waterholes, varying from about twenty to two hundred metres in width, and lined with dense *Pandanus*. Midgley's collections were made near the south-east corner of Woolwonga Aboriginal Reserve, and those of the author near Nourlangie Rock.

(iii) Deaf Adder Creek - 13°05' S and 132°54' E; another tributary of Nourlangie Creek, emerging from the escarpment to the south of Sawcut Creek. (Midgley's collections were made in a large pool where the creek emerged from the escarpment.)

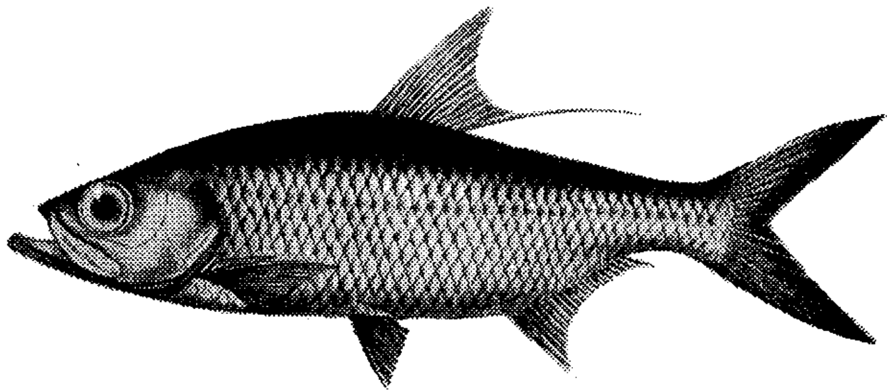
(iv) Baroalba Creek - (no latitude and longitude given, but around 12° 50' S and 132°50' E), locality near the headwaters of the creek, and described by Midgley as a narrow stream in a rocky gorge with heavy tree cover. (Locality sampled by Midgley.)

5. SPECIES COLLECTED FROM LOCALITIES IN THE MAGELA CREEK CATCHMENT

FAMILY MEGALOPIDAE

Megalops cyprinoides (Broussonet) Tarpon, Ox-eye Herring

Garlárlpa (Oenpelli)



(After Munro)

Systematic Position: Closely related to the Atlantic tarpon *Megalops atlanticus* (Cuvier and Valenciennes).

Distribution: Tropical Indo-Pacific region, from East Africa, across southern Asia and Pacific Islands to Tahiti, and northwards to Japan; around coastline of northern Australia (in north-east coast, Gulf of Carpentaria, Timor Sea, and Indian Ocean drainages) from northern New South Wales, through Queensland and the Northern Territory, and southwards to the far west of Western Australia.

Description: Body oblong and laterally compressed. Scales large; lateral line distinct. Mouth large with protruding lower jaw; teeth small. Throat with bony gular plate. Eyes large with adipose lids. Last dorsal finray very elongated; caudal fin strongly forked. Colour - olive to bluish green on back, sides more silvery, whitish below; head darker olive. Caudal fin yellowish, other fins greenish-yellow, dorsal fin with dusky margin. Finrays - D17-20; A24-31; P14-16; V10-11. Scales - L. lat. 36-40; predorsal 19-23. Body proportions - head length 3.5-3.8 in SL; body depth 3-4 in SL; body becomes more elongated with age.

Maximum Size: At least 1 m, but reputed to grow to over 1.5 m in length.

Habits: Essentially a marine species, though smaller specimens (usually between 20 and 50 cm in length) inhabit estuaries and are regularly found in freshwater rivers and creeks well above tidal influence, as well as in temporarily enclosed or landlocked lagoons and billabongs. Spawning is thought to take place in summer in estuaries and/or shallow inshore waters. Eggs are pelagic and larvae are of the *leptocephalus* type (*i.e.* ribbon-like). Fingerlings are often found in freshwater creeks immediately after the wet season. Larger juveniles are often found shoaling in the estuaries during the summer months.

Diet: Adults are predatory on crustaceans and smaller fish; juveniles will take insects at the water's surface. Larvae may be plankton feeders.

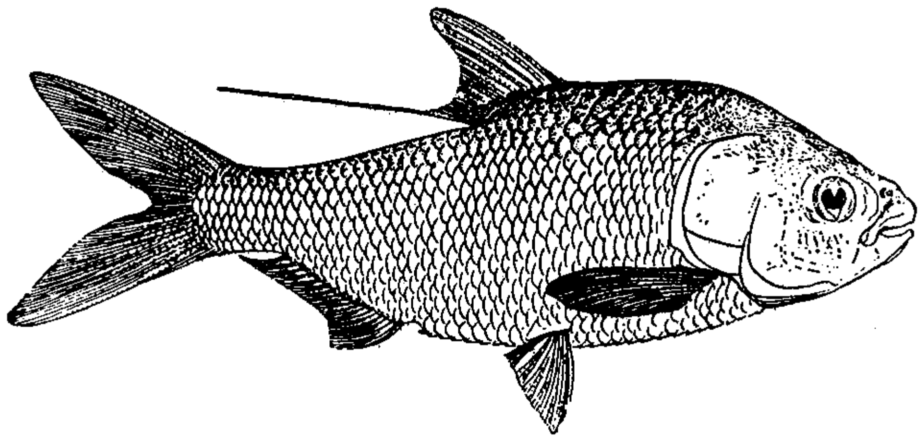
General Notes: A very hard-fighting sport fish, though not usually sought after for food as its flesh is soft, very bony, and relatively flavourless. This species, however, is raised for food in fishponds in India and Indonesia.

Specimens Collected: Mudginbarri Lagoon - 1 spec.; 267 mm SL; D. Pollard; rod, line and lure; Cat. No. I.16831.001; 13 July 1972.
Leichhardt Lagoon - 1 spec.; 280 mm SL (395 mm TL, 527 g wt.); M. Mann; rod, line and lure; Cat. No. I.16832.002; 18 July 1972.
Also reported to be fairly common in other similar lagoons nearby (*e.g.* Ja Ja Lagoon).
Large billabong at Oenpelli - 12 specs.; 156-236 mm SL; and Fish Creek (20 km E of Oenpelli) - 1 spec.; 169 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.59-60).

FAMILY CLUPEIDAE

Fluvialosa erebi (Günther) Leichhardtian Bony Bream, Freshwater Herring

Mahbiba (Oenpelli)



(After Munro)

Systematic Position: Many of the specimens collected fit more closely the description of *F. bulleri* (Whitley) than that of *F. erebi* given in Munro (1956). Taylor (1964), however, places *F. bulleri* in his synonomy of *F. erebi*, and the former is not listed as a separate species in Lake (1971).

Distribution: Timor Sea and Gulf of Carpentaria drainages of northern Western Australia, the Northern Territory, and north-western Queensland. The form occurring in some rivers of the Queensland east-coast drainage (*e.g.* Mary and Burdekin Rivers) may also belong to this species.

Description: Body strongly laterally compressed. Scales delicate and loosely attached; lateral line absent. Snout rounded; mouth sub-terminal; teeth absent. Last dorsal finray very elongated and filamentous; caudal fin strongly forked. Colour - silvery, dark-bluish above, lighter blue below, with faint black blotch on shoulder behind head. Fins colourless to yellowish. Finrays - D15-18; A21-26; P14-16; V8. Scales - lateral midline (head to caudal fin) 40-45; predorsal 17-19; about 30 sharp scutes along midline of abdomen. Body proportions - head length 3.1-3.3 in SL; body depth 2.2-2.6 in SL. Both body and last dorsal finray become more elongated with age.

Maximum Size: Reputedly reaches 40 cm in length and over 500 g in weight.

Habits: This species belongs to an essentially freshwater genus and thus probably completes its life cycle in freshwaters (the closely related genus *Nematalosa*, however, occurs mainly in the sea, although it too is often found in freshwaters). Often occurs in large schools in the shallow-water reaches of rivers.

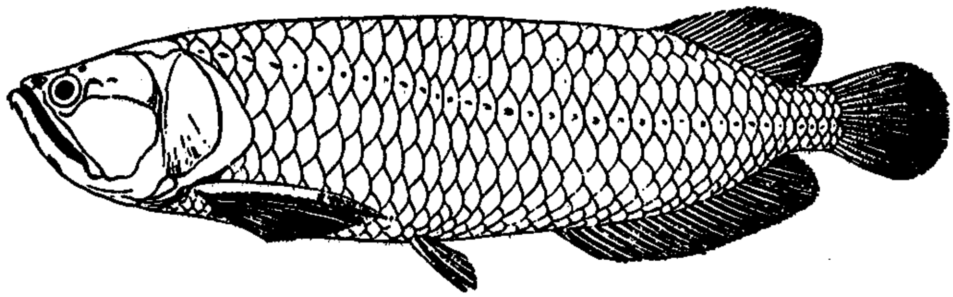
Diet: Predominantly a detritus and mud feeder *(iliophagous)*; also eats algae and other aquatic plants and sometimes small insects.

General Notes: Its flesh is not very palatable as it is often muddy and contains many fine bones, though fishes of this genus were canned in Australia on a small scale during World War II. These fish die rapidly after handling, as their scales are easily lost and they are very prone to fungus infection.

Specimens Collected: Magela Creek - 5 specs.; 89-110 mm SL; D. Pollard; cast net; Cat. Nos.I.16859.013 and .026; June-July 1972.
Indium Billabong - 4 specs.; 102-138 mm SL; D. Pollard and M. Mann; cast net; Cat. No. I.16826.001; 22 June 1972.
Georgetown Billabong - 1 spec.; 182 mm SL; M. Giles; cast net; Cat. No. I.16854.005; August 1972.
Rock Hole Billabong (off East Alligator River) - 1 spec.; 220 mm SL; D. Pollard; cast net; Cat. No. I.16830.001; 8 July 1972.
Nourlangie Creek (South Alligator River system) - 5 specs.; 120-192 mm SL; M. Giles; seine net; Cat. No. I.16833.001; 4 June 1972.
Also seen in waterholes along Boggy Creek, and large specimens seen while diving in Sawcut Creek (South Alligator River system). Fairly common in most of the larger water bodies in the Alligator Rivers area.
Large billabong at Oenpelli - 116 specs.; 14-332 mm SL; and Red Lily Lagoon (~ 11 km WSW of Oenpelli) - 4 specs.; 151-174 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.63-64).

FAMILY OSTEOGLOSSIDAE

Scleropages jardini (Saville-Kent) Northern Spotted Barramundi, Saratoga
Gooloδecheer (Oenpelli)



Sceleropages sp. (After Stead)

Systematic Position: Has previously been regarded as a sub-species of *S. leichardti* (Castelnau) - which occurs in the Fitzroy River system, Queensland east-coast drainage - but is listed as a separate species by Lake (1971). The family dates back to Eocene times (50 million years BP) and several genera of this 'living fossil' group occur in the Indo-Malayan area, in Brazil, and in the Nile.

Distribution: Gulf of Carpentaria and Timor Sea drainages of north-western Queensland and the Northern Territory; also in some southward flowing rivers in New Guinea.

Description: Body oblong, laterally compressed. Scales large and tough; lateral line distinct. Mouth large and oblique; jaws strong; palate bony; chin with two small barbels. Dorsal and anal fins set well back and rounded; pectoral fins elongated and fold against abdomen; caudal fin rounded. Colour - dark olive-green above, light olive-green below. Scales have pinkish-red crescentic markings on outer margins (each breaking up into 3 or 4 separate spots above lateral line). Head and fins have reddish markings. Eyes red. Finrays - D20; A31; V5. Scales - L. lat. 33-35; predorsal 28. Body proportions - head length 3.2-4.0 in SL; body depth 3.7-4.0 in SL.

Maximum Size: Grows to almost 1 m in length and to over 10 kg in weight.

Habits: A primary or 'true' freshwater fish, normally found in the still waters of billabongs, larger waterholes and lagoons, and not usually in the main channels of rivers. Appears to be more plentiful in upstream areas, in clean water, and away from competition with silver barramundi *(Lates calcarifer)*. Especially abundant in the rocky escarpment country bordering the Arnhem Land Plateau. Lurks by day under overhanging vegetation (*e.g. Pandanus*), snags, logs, and rocky ledges. Little is known about its biology but it is thought to require temperatures above 15°C for its survival. The very closely related Queensland species *S. leichardti,* which lives in the generally muddy waters of the Fitzroy River system, spawns in waterholes during spring when temperatures are above 23°C. This latter species usually spawns in its fourth year, and the female is a 'buccal incubator', brooding the eggs and then the larvae in her mouth until their yolk sacs are absorbed.

Diet: A predatory species, mainly feeding on crustaceans, smaller fishes and frogs, but also to some extent on insects. (The Queensland species is reputed to eat a greater proportion of insects from the water's surface.)

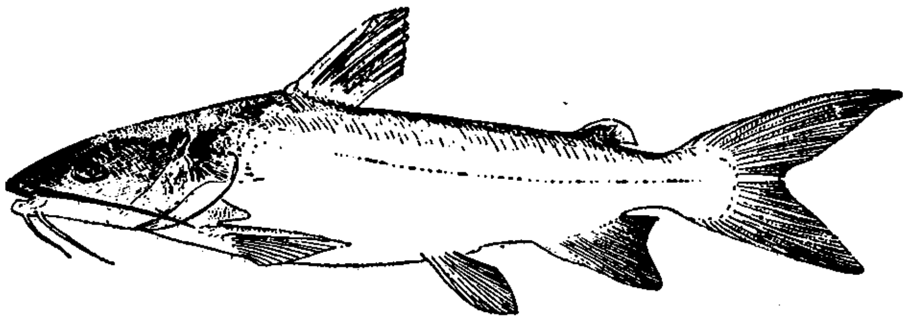
General Notes: A very hard-fighting sporting fish which will take dry flies and lures and which leaps spectacularly when hooked. Although small specimens are acceptable as food their flesh is bony, and that of larger specimens is relatively flavourless.

Specimens Collected: Mudginbarri Lagoon - 1 spec.; 575 mm SL; D. Pollard; rod, line and lure; Cat. No. I.16831.002; 13 July 1972.
Upper Magela Creek - 3 specs.; 280-427 mm; M. Giles and M. Mann; rod, line and lure; Cat. No. I.16856.001; August-November 1972.
Several more specimens were caught and released in Mudginbarri Lagoon; a large number were also caught and released, and several observed whilst diving in Sawcut Creek (South Alligator River system). Reputedly common in other large lagoons along the Magela Creek system.
Also reported to have been collected from 'Death' (= Deaf) Adder Creek (South Alligator River system) by Lake (1971). Taylor (1964), however, stated that; "The presence of this fish in Arnhem Land is questioned", apparently because Miller failed to collect it in Red Lily Lagoon in October 1948, although the Aboriginals at Oenpelli claimed that it occurred there.

FAMILY ARIIDAE

Hexanematichthys leptaspis (Bleeker) Lesser Salmon Catfish, Freshwater Fork-tailed Catfish

Mánmakájuári (Oenpelli)



Hexanematichthys sp. (After Whitley)

Systematic Position: Taylor (1964; p.83) states that; "*Arius* [= *Hexanematichthys*] *australis, Arius leptaspis* and *Arius stirlingi* are very similar morphologically" and,"it is unknown whether they are three species, or each represents population divergence within one species". Lake (1971) included all three under the name *H. leptaspis*. The majority of the specimens collected during the present study appeared to fit more closely the description of *H. australis* in Taylor (1964).

Distribution: Coastal drainages of northern Australia from northern New South Wales through Queensland and the Northern Territory to the far west of Western Australia; also in New Guinea.

Description: Body oblong and robust. Skin tough and naked; lateral line well developed. Head depressed and armoured above with bony shields. Mouth wide and crescentic with three pairs of barbels; villiform teeth on jaws and in patches on palate. Single dorsal and paired pectoral spines strong and serrated; adipose dorsal fin present; caudal fin strongly forked. Colour - Dusky blue-grey to bronze above, more silvery-white below. Finrays - DI6-7; A16-20; PI9-10; V6. Scales - absent. Body proportions - head length 3-4 in SL; body depth 3-5 in SL; body proportions appear to vary considerably with size.

Maximum Size: Grows to over 10 kg in weight and reputedly to over 1 m in length.

Habits: This fish belongs to a predominantly marine family and is often captured in brackish or marine waters, especially in river estuaries. It was not previously known whether this species could complete its life cycle in fresh water, but this appears to be the case as males containing developing eggs in their mouths (the species is a buccal incubator or 'mouth-brooder') have been captured in the freshwater reaches of the Dawson and Gregory Rivers in Queensland (Lake 1971; p 23).

Diet: There appears to be no published information on the diet of this species, but the stomachs of specimens caught in the lagoons of the Magela Creek system contained the remains of eel-tailed catfishes *(Neosilurus* sp.*)*. This species was also readily taken by hook and line using freshwater mussels *(Velesunio* sp.*)* as bait.

General Notes: A reasonable sporting fish, the flesh of which is reputedly very good eating. Its dorsal and pectoral spines can inflict painful wounds if it is not handled carefully.

Specimens Collected: Indium Billabong - 4 specs.; 125-172 mm SL; D. Pollard and M. Mann; cast net; Cat. No. I.16826.002; 22 June 1973.
Georgetown Billabong - 1 spec.; 385 mm SL; D. Pollard; baited hook and line; Cat. No. I.16854.006; June-July 1972.

Numerous small specimens were observed around the shores of Indium Billabong, and numerous large specimens (to about 4 kg wt.) were captured using rod, line and lure in Ja Ja Lagoon.

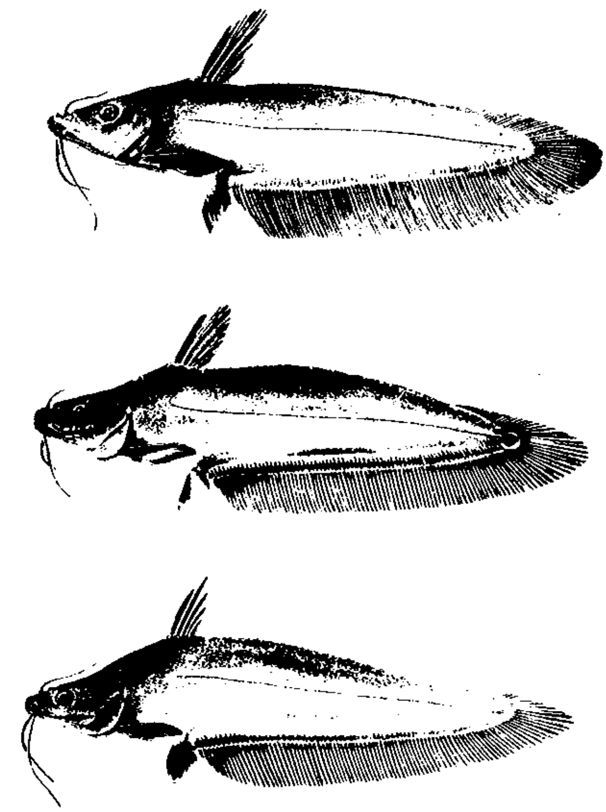
A small specimen (107 mm SL), which may belong to the related species *H. proximus*, was captured by cast net in tidal waters above the causeway at Cahills Crossing on the East Alligator River on 8 July 1972, (Cat. No. I.16827.001). A larger specimen was caught on a lure in Rock Hole Billabong, which is also tidal and connected to the main East Alligator River channel several kilometres upstream from the crossing.

Large billabong at Oenpelli - *H. "australis"*; 12 specs.; 201-435 mm SL; and East Alligator River at Cahills Landing (~ 10 km W of Oenpelli) - *H. "leptaspis"*; 14 specs.; 149-406 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.81-82).

FAMILY PLOTOSIDAE

Neosilurus spp. Freshwater Tandans, Eel-tailed Catfishes

Mahgool (Oenpelli)



Neosilurus spp. (After Taylor)

Systematic Position: With regard to the seven species of *Neosilurus* listed by Lake (1971; p.24) as occurring in the Timor Sea drainage, this author states that; "I have been unable to identify, with any certainty, the specimens in my collection. Original descriptions of some species are inadequate and rather than confuse the issue any further, I will not be definite about species until further studies are made". At least two species (all small and probably juvenile specimens) were captured during the present survey. One of them closely resembled the unnamed species illustrated in Lake (1971; Fig.35) and is here called the 'yellow-finned' species; the other appeared to have longer, more pigmented fins and a more heavily pigmented body and is here called the 'black-finned' species.

Distribution: This genus is distributed from north-eastern Queensland through the Gulf of Carpentaria and Timor Sea drainages of Queensland and the Northern Territory to the Indian Ocean drainage of the far west of

Western Australia. Some species also occur in New Guinea, and at least one in the Lake Eyre internal drainage basin.

Description: Body elongated with tapering tail; skin naked. Lateral line as a series of pores. Mouth sub-terminal with four pairs of barbels; teeth conical. Strong single dorsal and paired pectoral spines serrated and venomous; no adipose dorsal fin; dorsal portion of combined second dorsal-caudal-anal fin short based and anal portion long based. Colour - species 1 ('yellow-finned') silvery grey with translucent yellowish fins; species 2 ('black-finned') dark brown to black, mottled with greyish blotches, dark pigment extending onto fins. Finrays - DI5-7; 2nd DCA105-155; PI9-13; V10-15. Scales - absent. Body proportions - head length 4.0-5.5 in SL; body depth 4.5-6.0 in SL.

Maximum Size: Two species *(N. hyrtlii* and *N. ater)* are reputed to grow to 40 cm, although specimens of the remaining species have rarely been found greater than 20 cm in length. However, a specimen of the 'yellow-finned' species 54 cm in length and weighing 2 kg was captured by H. Midgley in Cannon Hill Lagoon during July 1973.

Habits: The genus *Neosilurus* belongs to a predominantly freshwater family with several marine and estuarine representatives, but virtually nothing is known about the habits or biology of the seven tropical Australian species included in it. The biology of the related southern species *Tandanus tandanus* from the Murray-Darling River system is relatively well known. This species spawns in spring and summer and deposits its eggs in a nest of gravel, which is guarded by the male. *Neosilurus* spp. appeared to inhabit most permanent and semi-permanent waterbodies in the Magela Creek system.

Diet: Nothing appears to be known of the diets of the various species of *Neosilurus*, but the related *Tandanus tandanus* is essentially a carnivorous bottom feeder on molluscs and crustaceans.

General Notes: These *Neosilurus* species are generally too small to provide any sport on rod and line, but larger specimens are reputedly very good eating. Their venomous spines can inflict painful wounds if they are not handled with care.

Specimens Collected: Magela Creek - 6 specs.; 94-187 mm SL; D. Pollard and M. Mann; cast net; Cat. No. I.16859.004 ('yellow-finned'); June-July 1972.

Georgetown Billabong - 5 specs.; 170-280 mm SL; M. Giles and M. Mann; cast net; Cat. No. I.16854.004 ('yellow-finned'); August-November 1972.

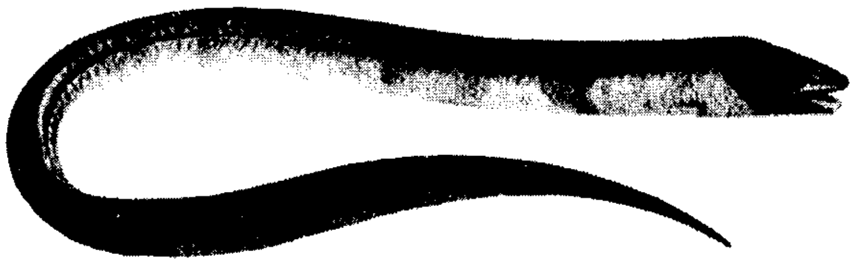
Specimens of 'yellow-finned' *Neosilurus* estimated to be between 30 and 40 cm in length were observed while diving in Sawcut Creek (South Alligator River system).

Magela Creek - 6 specs.; 121-164 mm SL; D. Pollard and M. Mann; cast net; Cat. Nos. I.16859.003, 008 and 025 ('black-finned'); June-July 1972.

Oenpelli area - 3 'species' of *Neosilurus*; 60-387 mm SL; R.Miller; October 1948 (designated *Tandanus ater, T. glencoensis and T. rendahli* in Taylor 1964; pp.92-97).

FAMILY SYNBRANCHIDAE

Synbranchus bengalensis (McClelland) One-gilled Eel, Swamp Eel



(After Munro)

Systematic Position: Closely related to the Asian species *S. marmoratus*.

Distribution: Timor Sea drainage of the Northern Territory and northern Western Australia; also throughout southern Asia.

Description: Body eel-like and naked. Lateral line well developed. Single gill opening on ventral surface. Teeth on jaws and palate. Eyes small. Dorsal and anal fins reduced to folds of skin confluent with caudal; pectoral and ventral fins absent. Colour - reddish brown, lighter beneath. Body proportions - head length 9-12 in distance from snout to vent; body depth 27-30 in TL.

Maximum Size: Grows to over 50 cm in length.

Habits: Inhabits fresh and brackish waters of coastal rivers and swamps, and also paddy fields in Asia. Its close relative *S. marmoratus* nests in the latter part of the wet season in a mud tunnel in marshes in Asia, and the male guards the eggs. Only a single juvenile specimen of *S. bengalensis* was collected during the present study, from a small muddy waterhole in the Magela Creek system.

Diet: Unknown.

General Notes: Apparently used for food in Asia.

Specimens Collected: Boggy Creek - 1 spec.; 58 mm TL; M. Mann; dip net; Cat. No. I.16834.001; July 1972.
This species was also collected by H. Midgley (who noted that it was rare) from Magela Creek near Jabiru in May-June 1973.
Large billabongs and creeks, Oenpelli area - 35 specs.; 60-282 mm TL; R. Miller; October 1948 (cited in Taylor 1964; pp.97-98).

FAMILY BELONIDAE

Strongylura kreffti (Günther) Freshwater Long-tom or Gar

Goorgabál (Oenpelli)

(After Munro)

Systematic Position: This genus is referred to as *Stenocaulus* by some authors.

Distribution: North-east coast, Gulf of Carpentaria, and Timor Sea drainages of Queensland, the Northern Territory, and northern Western Australia; also occurs in southward flowing rivers of New Guinea.

Description: Body elongated and relatively laterally compressed. Scales small; lateral line low on body. Jaws produced into a slender beak with needle-sharp teeth. Dorsal and anal fins well posterior and opposed; caudal fin slightly emarginate. Colour - olive-green above to silvery-yellowish-white below, occasional darker marks on sides, greenish-silver streaks along lateral midline posteriorly. Fins yellowish, dorsal and caudal fins often with darker margins. Finrays - D16-18; A19-21; P12-14; V6. Scales - L. lat. 170-190. Body proportions - head length 2.3-2.4 in SL; body depth 10-15 in SL; body becomes deeper and more compressed with age.

Maximum Size: Grows to at least 75 cm in length and to over 1 kg in weight.

Habits: This species is a member of a predominantly marine genus and family, but it appears to be restricted to freshwaters in northern Australia. It is normally a surface swimming and feeding species, but is also found lurking under overhanging vegetation and amongst submerged tree roots (*e.g. Pandanus*) during the hotter part of the day. Plentiful in larger waterholes, billabongs and lagoons of the Magela Creek system.

Diet: A predatory species feeding on smaller fishes (especially atherinids and melanotaeniids in the Magela Creek waterholes).

General Notes: Generally too small to be of any value as a sporting fish, but will take a lure readily. Its flesh is reputedly good eating, but most larger specimens examined contained nematode worms (*Eustrongylides* sp.) encysted in their muscle tissues.

Specimens Collected: Magela Creek - 6 specs.; 234-265 mm SL; D. Pollard and M. Mann; seine net; Cat. Nos. I.16859.014 and 015; June-July 1972.

Mudginbarri Lagoon - 1 spec.; 480 mm SL; D. Pollard; rod, line and lure; Cat. No. I.16831.003; July 1972.

Leichhardt Lagoon - 1 spec.; 473 mm SL; M. Mann; rod, line and lure; Cat. No. I.16832.001; July 1972.

Georgetown Billabong - 5 specs.; 432-500 mm SL; M. Giles and M. Mann; seine net; Cat. No. I.16854.002; August-November 1972.

Nourlangie Creek (South Alligator River system) - 5 specs.; 120-192 mm SL; M. Giles; seine net; Cat. No. I.16833.002; June 1972.

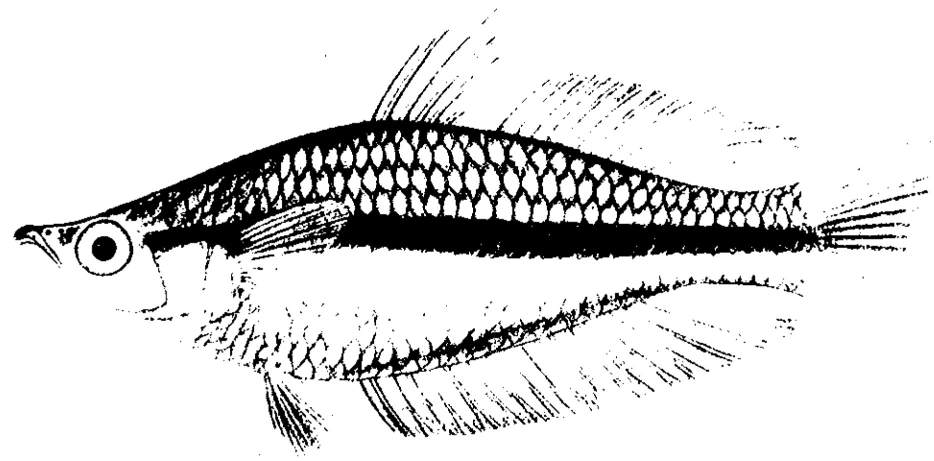
This species was also observed while diving in Sawcut Creek (South Alligator River system).

Large billabong at Oenpelli - 27 specs.; 36-635 mm SL; and Red Lily Lagoon 10 specs.; 271-319 mm SL; R. Miller; October 1948 (cited in Taylor 1964; p.100).

FAMILY MELANOTAENIIDAE

Melanotaenia nigrans (Richardson) — Mauve Rainbowfish, Black-banded Jewelfish

Emắtchenámura (Groote Eylandt)



(After Taylor)

Systematic Position: The melanotaeniids as a group are often placed within the family Atherinidae (*e.g.* in Taylor 1964), but the present author considers that they are sufficiently distinct to remain as a separate family, the Melanotaeniidae, the distribution of which is restricted to Australia and New Guinea. There seems to be considerable variation between both individuals and populations of the same 'species' of melanotaeniids in different river systems, and the systematics of the group is badly in need of revision.

Distribution: Gulf of Carpentaria and Timor Sea drainages of north-western Queensland, the Northern Territory, and northern Western Australia; also coastal streams of south-west Papua.

Description: Body oblong and laterally compressed. Scales large; lateral line absent. Snout pointed; mouth small and terminal; teeth small and conical. First and second dorsal fins narrowly separated; caudal fin emarginate. Colour - body silvery, greenish above with bluish-mauve tint on flanks, and lighter below; a broad dark stripe one scale wide from eye to tail base, with a faint orange stripe below; operculum with a pale orange spot. Scales with dark edges forming a fine meshwork; sometimes faint dusky streaks along flanks. Caudal fin yellowish; other fins pinkish; margins of dorsal and anal fins dusky. Finrays - 1st D4-6; 2nd D9-13; A16-21;

P12-15; V5-6. Scales - lateral midline (head to caudal fin) 32-36; predorsal 13-19. Body proportions - head length 3.5-4.0 in SL; body depth 2.5-3.5 in SL; body becomes more oval and elevated, and dorsal and ventral head profiles more concave, with age.

Maximum Size: Grows to about 12 cm in length.

Habits: This and all other melanotaeniids are permanent inhabitants of freshwaters. This species is a midwater swimmer and predominantly a surface feeder. The young are found mainly in the quiet, shallow backwaters of streams, and the adults in the deeper pools. Very little is known about the biology of this species, but the related species *M. fluviatilis* from the Murray-Darling River system spawns in early summer and deposits thread-bearing eggs on plants. During the present study large adult specimens were only collected from the muddy waters of an artificial costean dug during uranium prospecting operations, and juveniles over shallow sandy areas along Magela Creek.

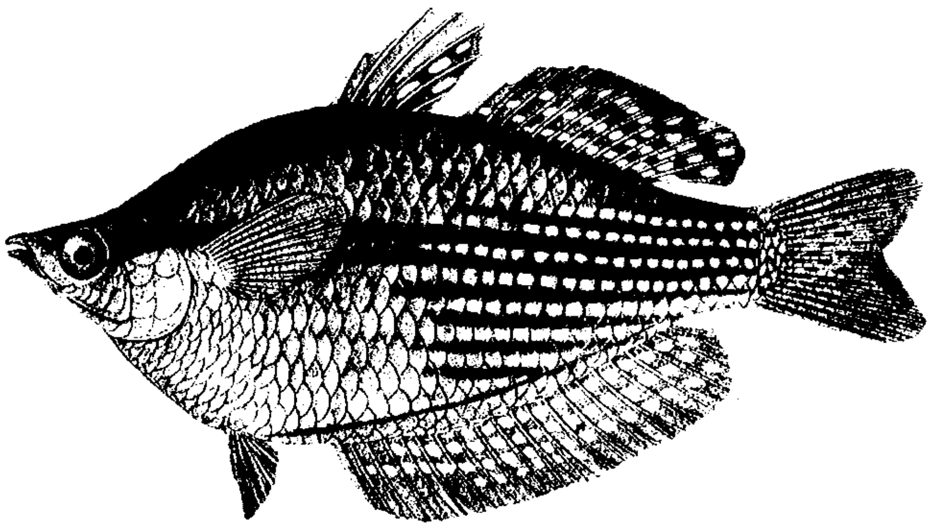
Diet: Adults eat mainly small insects and insect larvae (especially mosquito wrigglers) from the water's surface, and juveniles probably mainly zooplankton (*e.g.* copepods). *(M. fluviatilis* is also reputed to eat some algae.)

General Notes: This species, like some of the other Melanotaeniids, would probably make a good tropical aquarium fish. (The *M. "nigrans"* of aquarium books is in fact *M. fluviatilis,* and this latter species breeds readily in aquaria.)

Specimens Collected: Magela Creek - 3 specs.; 25-38 mm SL; D. Pollard and M. Mann; seine net; Cat. No. I.16859.011; June-July 1972.
Anomaly II Costean - 76 specs.; 30-59 mm SL; D. Pollard and M. Mann; seine and cast nets; Cat. Nos. I.16825.001 and 002; June-July 1972.
In addition to the above specimens, many more small juveniles were captured in Magela Creek, large specimens observed while diving in Sawcut Creek (South Alligator River system), and some large specimens observed in Cooper Creek (near Nabarlek).
Large billabong at Oenpelli - 31 specs.; 23-30 mm SL; and Fish Creek (below waterfall, about 6 km SSE of Oenpelli) - 16 specs.; 22-28 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.123-124).

FAMILY MELANOTAENIIDAE

Nematocentris maculata (Weber) Checkered Rainbowfish or Sunfish



(After Taylor)

Systematic Position: Referred to as *Melanotaenia rubrostriata* in Taylor (1964). May be conspecific with *N. splendida* of the Queensland north-east coast drainage. The genus *Nematocentris* (spelt *Nematocentrus* in Lake 1971) may be congeneric with *Melanotaenia*.

Distribution: Gulf of Carpentaria and Timor Sea drainages of north-western Queensland and the Northern Territory (and possibly also northern Western Australia); southern rivers of New Guinea.

Description: Body oblong and strongly laterally compressed. Scales large; lateral line absent. Snout pointed; mouth small and terminal; lower jaw protrudes with age; teeth small and conical, those on posterior part of upper jaw external and flared outwards. First and second dorsal fins narrowly separated; caudal fin emarginate. Colour - body olive above and more silvery below; narrow bright yellow-golden longitudinal lines along scale rows alternating with pale blue lines (especially posteriorly), heavier golden line along centre of flanks reaching forwards to eye. Yellow-orange spot on operculum. Fins bright yellow; caudal with lines of dark checks; posterior part of first dorsal, second dorsal and anal with lines of dusky-red checks. Finrays - 1st D5-7; 2nd D10-13; A18-22; P14-16; V6. Scales - lateral midline (head to caudal fin) 31-34; predorsal 13-17. Body proportions -

head length 3.7-4.0 in SL; body depth 2.2-3.6 in SL; body becomes much more oval and elevated, and dorsal and ventral head profiles more concave, with age.

Maximum Size: Grows to about 12 cm in length.

Habits: Little or nothing is known about the biology of this and related species (see notes for previous species). Larger specimens are common in waterholes of the Magela Creek system, and juveniles over shallow sandy areas together with *M. nigrans*, two species of atherinids, and a small ambassid.

Diet: Probably mainly insects (see notes for previous species).

General Notes: A much more colourful species than the preceding, but may be less suitable as an aquarium fish as it is prone to damage during capture and subsequent fungus infection in captivity (see notes for previous species).

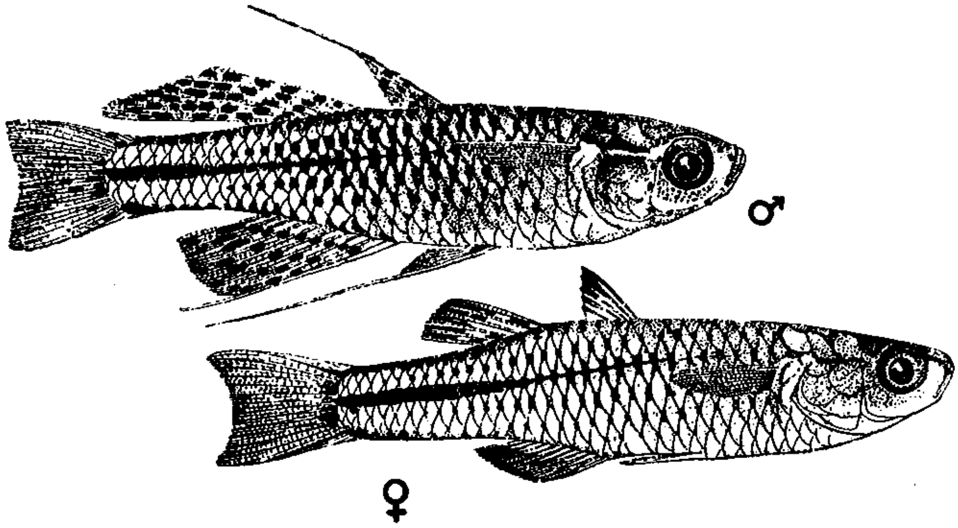
Specimens Collected: Magela Creek - 37 specs.; 24-88 mm SL; D. Pollard and M. Mann; seine and cast nets; Cat. Nos. I.16859.017 and I.16860.001; June-July 1972.

Adults plentiful in waterholes, billabongs and lagoons throughout Alligator Rivers area. Many small fry and juveniles present in Magela and Boggy Creeks during early July, adults also observed while diving in Sawcut Creek (South Alligator River system), and some large specimens observed in Coopers Creek (near Nabarlek).

Large billabong at Oenpelli - 112 specs.; 12-60 mm SL; Fish Creek - 24 specs.; 40-59 mm SL; Oenpelli Creek (below waterfall) - 11 specs.; 17-62 mm SL; and Red Lily Lagoon - 7 specs.; 33-95 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.126-127).

FAMILY PSEUDOMUGILIDAE

Pseudomugil tenellus (Taylor) Arnhem Land Blue-eye



Pseudomugil sp. (After Munro)

Systematic Position: The family Pseudomugilidae is often grouped in the Atherinidae but, as with the related Australian-New Guinean family Melanotaeniidae, the present author prefers the retention of a separate family for this relatively distinct group of fishes. The species *P. tenellus* was described by Taylor (1964) from specimens collected by R. Miller in 1948 from the Oenpelli area, and is fairly closely related to the other northern species *P. gertrudae* (Weber) which occurs in the north-east coast and Gulf of Carpentaria drainages of northern Queensland and the eastern Northern Territory, and in southern New Guinea and the Aru Islands.

Distribution: So far only recorded from the East Alligator River system of the Northern Territory (Timor Sea drainage).

Description: Body moderately elongate and slightly compressed. Scales large: lateral line absent. Mouth small, very oblique and subvertical; jaws with small curved villiform teeth, lower jaw terminal. Eyes large. Dorsal fins separated; dorsal, anal, and ventral, and sometimes pectoral fins, probably become elongated in male, the anterior rays in each case becoming filamentous (as in other species of *Pseudomugil*), during the breeding season. Colour - body yellowish brown, finely speckled above; scales narrowly outlined in brown; abdomen yellowish (with dark viscera showing through); head dark above and lighter below; eyes blue. Fins light yellowish to slightly dusky. As in other species of *Pseudomugil*, the male is probably more brightly coloured in the breeding season. Finrays - 1st D4-5; 2nd D6-7; A9-10; P12-13; V6. Scales - lateral midline (head to caudal fin) 27-29; predorsal 10-11. Body proportions - head length 3.3-3.5 in SL; body depth 4.7-4.8 in SL.

Maximum Size: Probably grows to about 4.0 cm in length.

Habits: Members of this genus usually inhabit coastal fresh or brackish waters, and are not usually found very far inland. Blue-eyes are usually found in large schools, and the eggs of those species that have been studied are normally laid in strings amongst aquatic vegetation.

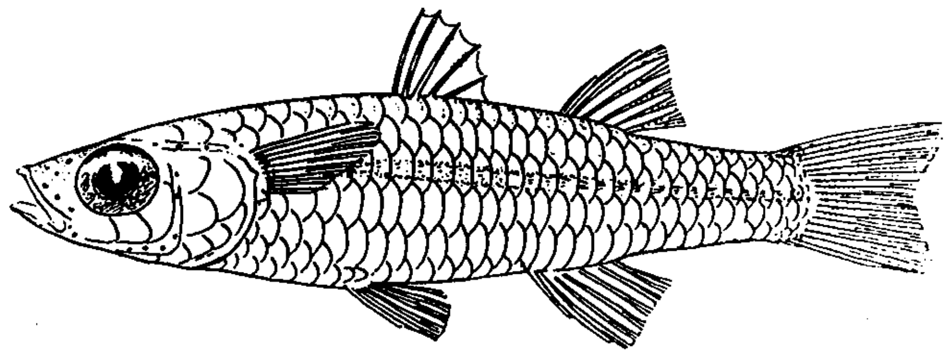
Diet: Although the diet of this species is unknown, other members of the genus are thought to be essentially plankton feeders and in freshwaters are known to consume large numbers of mosquito larvae from the water's surface.

General Notes: Blue-eyes make colourful and interesting aquarium fishes.

Specimens Collected: No specimens of *Pseudomugil* were collected by the author during June and July 1972, but fishes of this genus were collected from the Magela Creek system, including Magela Creek itself near Jabiru (where they were rare), and a lagoon on the Magela Plain about 11 km south-west of Cannon Hill (where they were common), by H. Midgley, in June 1973. Large billabong at Oenpelli - 156 specs.; 17-22 mm SL; Oenpelli Creek (below waterfall) - 2 specs.; 16-18 mm SL; and Red Lily Lagoon - 28 specs.; 15-26 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.132-134).

FAMILY ATHERINIDAE

Craterocephalus marjoriae (Whitley) Marjories Freshwater Hardyhead



(After Munro)

Systematic Position: Identity of this species (previously only recorded from Queensland east coast drainage) confirmed by V. Ivantsoff (School of Biological Sciences, Macquarie University).

Distribution: East coast, Gulf of Carpentaria, and Timor Sea drainages of Queensland and the Northern Territory.

Description: Body oblong and rounded in section (relatively stout bodied compared with other members of this genus). Scales large; lateral line absent. Head blunt, slightly depressed and forward sloping. Mouth oblique and terminal; jaws with very small teeth. First and second dorsal fins widely separated; caudal fin emarginate. Colour - body fawn to sandy-coloured, with a faint silvery line along mid flanks from pectoral to caudal fin bases. Dorsal surface darker with minute black speckles, paler below. Fins colourless. Finrays - 1st D4-6; 2nd D7-9; A7-9; P12-15; V6. Scales - lateral midline (head to caudal fin) 24-30; predorsal 10-13. Head length 3.0-3.9 in SL; body depth 3.7-4.5 in SL; body becoming stouter and deeper with age.

Maximum Size: Grows to at least 7 cm in length.

Habits: Genus mainly freshwater but also has representatives in estuarine and marine waters. Occurs in very large schools over shallow, sandy areas, and is one of the most plentiful species in Magela Creek and its associated sandy-bottomed waterholes.

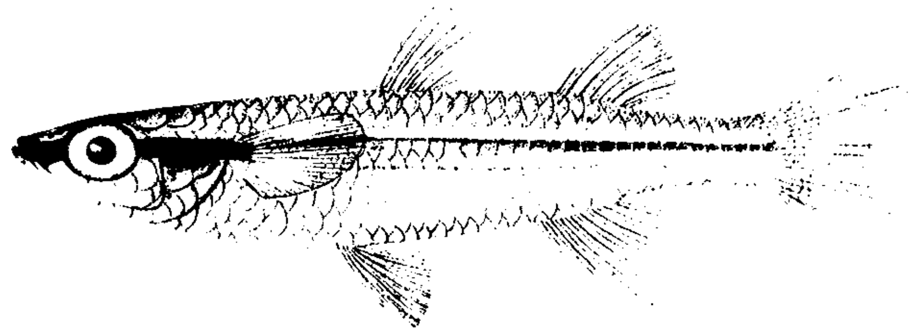
Diet: Unknown, but probably includes insect larvae and small insects from the water's surface; young may consume zooplanktonic crustaceans (*e.g.* copepods).

General Notes: A most abundant species, which is probably an important component of the food of many of the piscivorous species found in the Magela Creek waterholes.

Specimens Collected: Magela Creek - 59 specs.; 34-58 mm SL; D. Pollard, M. Mann and M. Giles; seine net; Cat. No. I.16859.027; June-July 1972. Mudginbarri Lagoon - 27 specs.; 25-44 mm SL; M. Giles and M. Mann; seine net; Cat. No. I.16857.001; August-November 1972.
Also observed whilst diving in Sawcut Creek (South Alligator River system). Although apparently an extremely common fish in the Alligator Rivers region, this species does not appear to have been collected by Miller in 1948, as no species resembling it is listed by Taylor (1964).

FAMILY ATHERINIDAE

Craterocephalus stercusmuscarum (Günther) Fly-speckled Hardyhead, Worrells Hardyhead



(After Taylor)

Systematic Position: The form collected is referable to the nominal species *C. worrelli* of the Gulf of Carpentaria and Timor Sea drainages, and the latter species is regarded as being conspecific with *C. stercusmuscarum* of the Queensland north-east coast drainage by V. Ivantsoff (private communication). It is referred to as *C. fluviatilis* (which is very similar but probably restricted to the Murray-Darling River system of south-eastern Australia) in Taylor (1964).

Distribution: North-east coast, Gulf of Carpentaria, and Timor Sea drainages of northern Queensland, the Northern Territory (and possibly also northern Western Australia).

Description: Body oblong, rounded in section and more elongated than in the preceding species. Lateral line absent. Head more pointed than in preceding species. Mouth moderately oblique and terminal; jaws with minute teeth. First and second dorsal fins widely separated; caudal emarginate. Colour - body translucent to yellowish, with dark to silvery line along mid flanks from snout tip (darkest), passing through pupil of eye, to caudal fin base (lightest). Fine dark speckles along scale rows in larger specimens, especially dorsally (extent of speckling in this species appears to be very variable and is much more pronounced in Queensland populations). Larger (gravid?) specimens with a bright yellow abdomen. Fins yellowish to colourless. Finrays - 1st D5-8; 2nd D7-9; A8-10; P11-14; V6. Scales - lateral midline (head to caudal fin) 30-34; predorsal 13-17. Body proportions - head length 3.6-4.3 in SL; body depth 4.8-5.6 in SL.

Maximum Size: Grows to about 7 cm in length.

Habits: Usually found schooling together with (though in much smaller numbers than) the preceding species (see notes for preceding species).

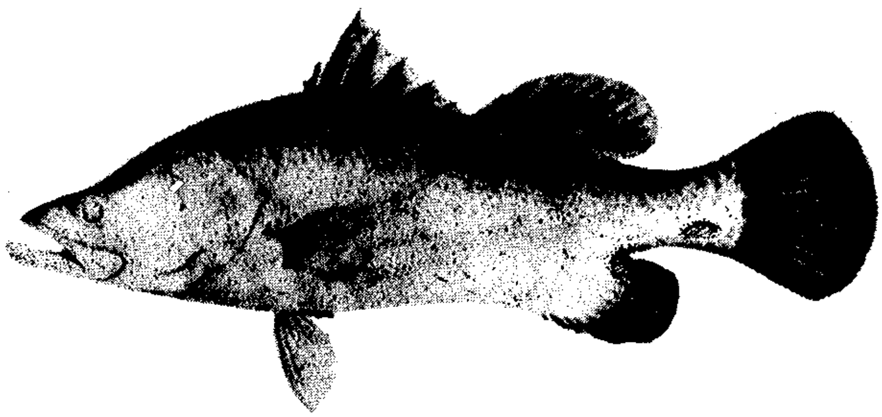
Diet: Unknown, but may include mosquito larvae (see notes for preceding species).

General Notes: Larger specimens of this species were relatively uncommon in the Magela Creek system.

Specimens Collected: Magela Creek - 62 specs.; 7-33 mm SL; D. Pollard and M. Mann; seine and dip nets; Cat. No.I.16859.007; June-July 1972. Large billabong at Oenpelli - 150 specs.; 9-37 mm SL; and Red Lily Lagoon - 1 spec.; 32 mm SL; R. Miller; October 1948 (cited by Taylor 1964; pp.137-138).

FAMILY CENTROPOMIDAE

Lates calcarifer (Bloch) Silver Barramundi, Giant Perch
Malalalk (Oenpelli)



(After Grant)

Systematic Position: Taylor (1964) and some other authors place this genus in a separate family (the Latidae). *Lates calcarifer* is closely related to the African Nile Perch, *Lates niloticus*.

Distribution: Rivers and estuaries of the tropical Indo-Pacific region, from China to the Persian Gulf, including New Guinea, and the north-east coast, Gulf of Carpentaria, Timor Sea, and Indian Ocean drainages of Queensland, the Northern Territory and Western Australia.

Description: Body oblong and moderately compressed. Scales large; lateral line well developed. Head pointed and separated from arched back by a marked concavity above eyes. Operculum with a single spine. Mouth large and protractile with villiform teeth on jaws. Dorsal fin in two parts united basally; dorsal and anal fins with scaly sheaths; caudal fin rounded. Colour - body greyish-green to golden bronze above, flanks silver, paler below. Fins grey to brown, paired fins paler. Eye bright pink. Finrays - D18-20; A10-11; P17; V5. Scales - L. lat. 52-61; predorsal 27-38. Body proportions - head length 2.7-2.8 in SL; body depth 3.0-3.1 in SL.

Maximum Size: Reputedly grows to over 1.5 m in length and over 60 kg in weight in Australian waters.

Habits: Adult fish generally live in freshwater reaches of coastal rivers and their associated billabongs and lagoons, and migrate downstream during early summer (at the beginning of the wet season) to spawn in the brackish tidal waters of the river estuaries. Juveniles migrate upstream into the freshwater reaches in late summer, about the end of the wet season. This species, unlike the related *L. niloticus*, cannot complete its life cycle in freshwater, and no self propagating landlocked populations are known.

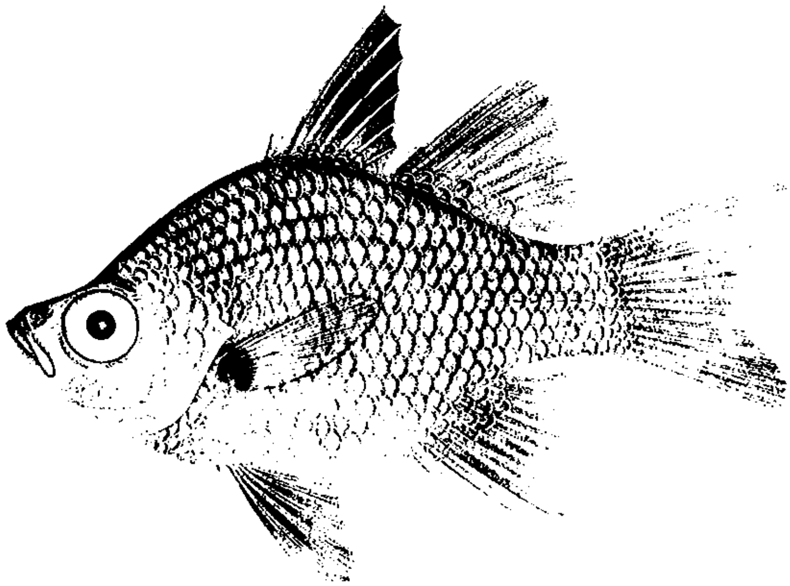
Diet: Adults are predatory, feeding mainly on smaller fishes and crustaceans; small juveniles also consume some insects and occasionally some plant material in freshwaters. Stomach contents of numerous small specimens from lagoons of the Magela Creek system (including Ja Ja, Leichhardt and Mudginbarri) include remains of eel-tailed catfishes (*Neosilurus* sp.) and other fishes, large shrimps (*Macrobrachium* sp.), and yabbies (*Cherax* sp.). Larger specimens from a billabong on the upper tidal reaches of the East Alligator River (Rock Hole Billabong) contained remains of mullet (family Mugilidae), eel-tailed catfishes (*Neosilurus* sp.), and other fishes.

General Notes: The silver barramundi is a magnificent sporting fish, on account of its size, its strength, its speed, and its often spectacular performance when hooked. It can be taken on large artificial lures and on live prawn and fish baits in both fresh and brackish waters. It is also probably the finest food fish in northern Australia, and supports a commercial mesh-net fishery in the river mouths.

Specimens Collected: Mudginbarri Lagoon - 1 spec.; 315 mm SL; D. Pollard; rod, line and lure; Cat. No. I.16831.004; 9 June 1972.
Cahills Crossing; 1 spec.; 141 mm SL; M. Mann; cast net; Cat. No. I.16827.002; 8 July 1972.
Numerous specimens between about 50 and 60 cm in length and 1.5 and 4 kg in weight were captured on lures in Mudginbarri, Ja Ja, and Leichhardt Lagoons, and 10 specimens between about 80 and 110 cm in length and 6 and 14 kg in weight using mesh-nets in Rock Hole Billabong, during June and July 1972. Also plentiful in the main channel of the East Alligator River,both above and below Cahills Crossing.
Large billabong at Oenpelli - 5 specs.; 280-370 mm SL; and Red Lily Lagoon - 3 specs.; 259-284 mm SL; R. Miller; October 1948 (cited in Taylor 1964; p. 165).

FAMILY CENTROPOMIDAE

Ambassis macleayi (Castelnau) Reticulated Perchlet or Chanda Perch



(After Taylor)

Systematic Position: Taylor and some other authors place this and related genera in a separate family (the Ambassidae).

Distribution: Gulf of Carpentaria and Timor Sea drainages of north-western Queensland and the Northern Territory (and possibly northern Western Australia?); southern rivers of New Guinea.

Description: Body elevated and strongly compressed. Scales large; lateral line interrupted and may be obsolete posteriorly. Head profile steep and concave above eyes. Mouth oblique with small conical teeth on jaws. Eyes large. Dorsal fin in two parts united basally; dorsal and anal fins with scaly sheaths; caudal fin strongly forked. Colour - body olive above, paler below. Scales with intense black margins forming strongly reticulated 'network' pattern. Fins dusky with paler margins; dark blotch at pectoral base. Finrays - D17-19; A11-13; P13-15; V6. Scales - L. lat. 25-29, predorsal 12-14. Body proportions - head length 2.6-3.0 in SL; body depth 2.2-2.3 in SL.

Maximum Size: Grows to about 10 cm in length.

Habits: Belongs to a family (and genus) with marine, estuarine and freshwater representatives. Little or nothing known about its biology, but seems to occur most commonly in turbid and heavily vegetated billabongs along the Magela Creek system.

Diet: Nothing known, but probably consumes small insects occurring amongst aquatic vegetation.

General Notes: This and other freshwater representatives of the genus make attractive aquarium fishes.

Specimens Collected: Indium Billabong - 2 specs.; 42-47 mm SL; D. Pollard; cast net; Cat. No. I.16826.003; 22 June 1972.

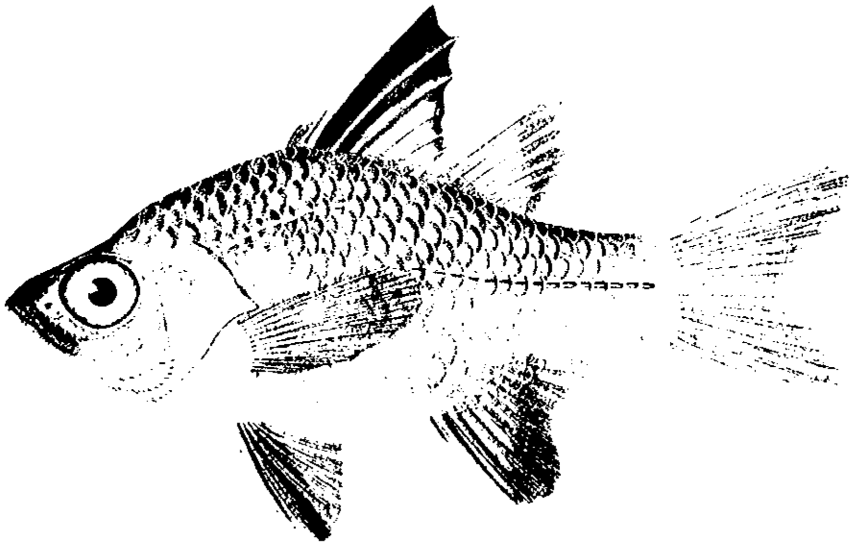
Small billabong next to Indium Billabong (just off Magela Creek) - 11 specs.; 29-68 mm SL; D. Pollard and M. Mann; cast net; Cat. Nos. I.16859.016 and 021; June-July 1972.

Hot pool off Mudginbarri Lagoon - 4 specs.; 29-64 mm SL; M. Giles and M. Mann; seine net; Cat. No.I.16855.002; August-November 1972.

Large billabong at Oenpelli - 183 specs.; 13-50 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.147-148).

FAMILY CENTROPOMIDAE

Ambassis agrammus (Günther) Sail-fin Perchlet or Chanda Perch



(After Taylor)

Systematic Position: See notes on family for preceding species. This species may include *A. agassizi* (Steindachner).

Distribution: North-east coast, Gulf of Carpentaria, and Timor Sea drainages of Queensland, the Northern Territory (and possibly northern Western Australia?); may also occur in southern rivers of New Guinea.

Description: Body elevated and strongly compressed. Scales large; lateral line almost completely obsolete. Head concave above eyes. Mouth oblique with small conical teeth on jaws. Eyes large. Dorsal fin in two parts united basally; dorsal and anal fins with scaly sheaths; caudal fin strongly forked. Colour - body translucent, pale greenish-olive above with slightly darker scale margins, somewhat lighter below. Fin membrane between 2nd and 3rd dorsal fin spines black. Outer parts of soft dorsal, anal and ventral fins dusky. Finrays - D15-18; A10-12. P11-13; V6. Scales - lateral midline (head to caudal fin) 25-29; predorsal 14-16. Body proportions - head length 2.5-2.6 in SL; body depth 2.3-2.5 in SL.

Maximum Size: Grows to about 7 cm in length.

Habits: See notes for preceding species. Little or nothing known about its biology, but seems to occur most commonly over shallow sandy areas (schools of small juveniles together with atherinids and small melanotaeniids), and also in shallow vegetated areas.

Diet: Nothing known, but probably consumes small insect larvae (adults) and planktonic crustaceans (juveniles).

General Notes: See notes for preceding species.

Specimens Collected: Magela Creek - 110 specs.; 18-30 mm SL; D. Pollard, M. Giles and M. Mann; seine and dip nets; Cat. Nos. I.16859.023 and 024; June-July 1972.

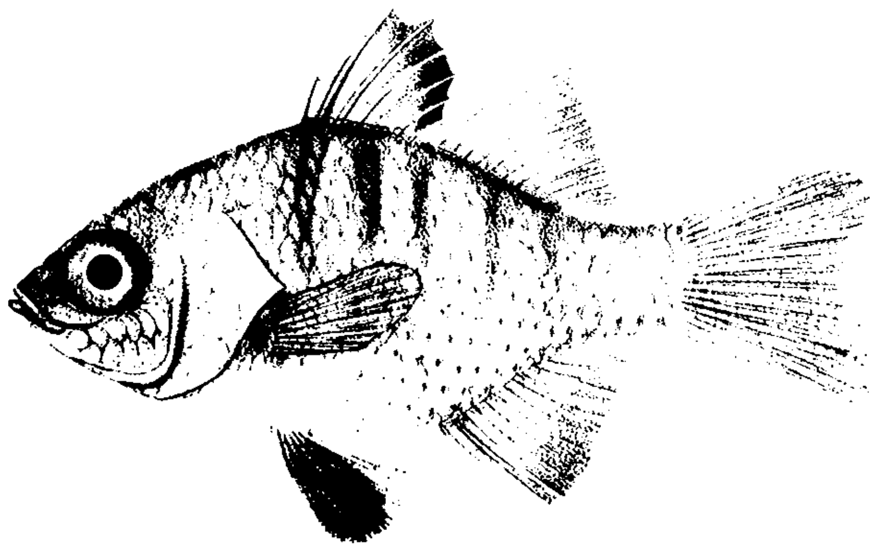
Hot pool off Mudginbarri Lagoon - 60 specs.; 24-25 mm SL; M. Giles and M. Mann; seine net; Cat. No. I.16855.001; August-November 1972.

Also plentiful in similar habitats in Boggy Creek.

Large billabong at Oenpelli - 41 specs.; 16-35 mm SL; Fish Creek - 64 specs.; 20-39 SL; Oenpelli Creek - 5 specs.; 15-22 mm SL; and Red Lily Lagoon - 83 specs.; 15-22 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.145-146).

FAMILY CENTROPOMIDAE

Denariusa bandata (Whitley) Penny Fish



(After Taylor)

Systematic Position: This is the only species in the monotypic genus *Denariusa,* which is fairly closely related to the genus *Ambassis*.

Distribution: Timor Sea and Gulf of Carpentaria drainages of the Northern Territory (and north-western Queensland?); southern rivers of New Guinea.

Description: Body oval and compressed. Scales large; lateral line obsolete. Head profile with very slight concavity above eyes. Mouth small and oblique with small conical teeth. Eyes large. Dorsal fin in two parts united basally; dorsal and anal fins with scaly sheaths; caudal fin forked. Colour - body light silvery brown, with darker scale margins, paler below; several (about six) irregular, narrow, darker vertical bars on back and flanks. Outer half of spinous dorsal fin and whole of ventral fins darkly pigmented; outer halves of soft dorsal and anal fins dusky; caudal and pectoral fins translucent-yellowish. Finrays - D17-19; A11-12; P9-10; V6. Scales - lateral midline (head to caudal fin) 21-27; predorsal 11-17. Body proportions - head length 2.5 in SL; body depth 2.3 in SL.

Maximum Size: Grows to almost 5 cm in length.

Habits: Little or nothing known about its biology, but apparently occurs in vast numbers after the end of the wet season in water bodies on the coastal plains.

Diet: Nothing known, but adults probably consume small insect larvae such as mosquito wrigglers.

General Notes: Would probably be suitable as an aquarium fish.

Specimens Collected: No specimens of this species were collected by the author during June and July 1972, but some were captured in the Magela Creek system by H. Midgley, including Island Billabong (where they were common) in September-October 1972, and Georgetown Billabong and Magela Creek near Jabiru (where they were rare) in May-June 1973.

Large billabong at Oenpelli - 1 spec.; 20 mm SL; and from Red Lily Lagoon - 23 specs.; 18-25 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.150-152).

FAMILY THERAPONIDAE

Madigania unicolor (Günther) Spangled Grunter, Jewel Perch

Bood (Oenpelli)

(After Grant)

Systematic Position: Referred to as *Terapon unicolor* by Taylor (1964).

Distribution: A very wide ranging species, found in the north-east coast, Gulf of Carpentaria, Timor Sea, Indian Ocean, Lake Eyre internal, Bulloo internal, and Murray-Darling drainage systems of Queensland, the Northern Territory, Western Australia, and New South Wales.

Description: Body oblong and moderately compressed. Scales moderate; lateral line distinct. Head blunt and rounded. Mouth large; jaws with moderately large villiform teeth. Caudal fin slightly emarginate. Colour - body greyish to silvery with small golden-brown spots, darker above and paler below. Fins yellowish to colourless; lower part of caudal with a dark blotch in juveniles. Finrays - D21-25; A10-12; P14-16; V6. Scales - L. lat. 46; predorsal 18. Body proportions - head length 2.7-3.1 in SL; body depth 2.5-2.9 in SL.

Maximum Size: Grows to over 25 cm in length and reputedly to over 500 g in weight.

Habits: Belongs to a family with marine, estuarine and freshwater representatives, but this species is strictly an inhabitant of freshwaters. Tolerant of high water temperatures and can reputedly aestivate (buried in the mud of dried out watercourses). Breeds prolifically in small waterbodies during summer and is usually very abundant throughout most of its range.

Diet: Feeds principally on freshwater shrimps and insects, but will readily consume smaller fishes.

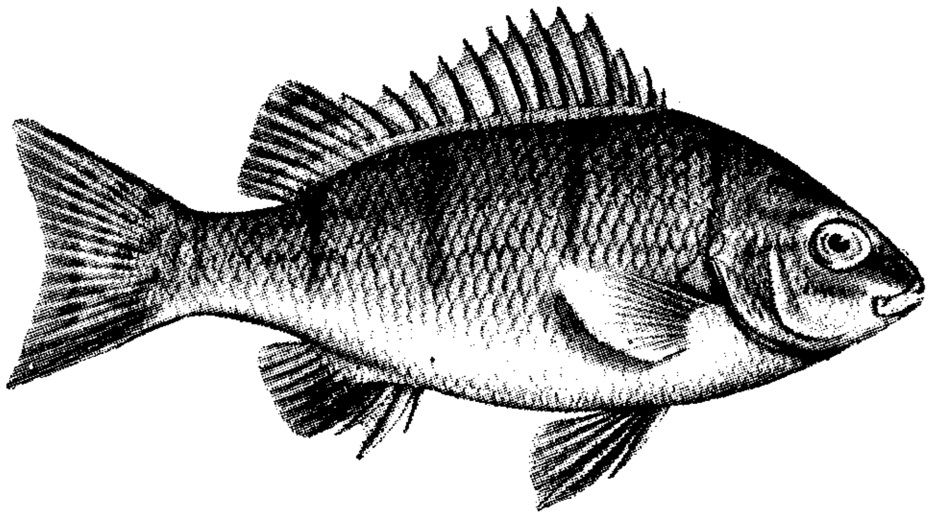
General Notes: A good eating fish in spite of its generally small size. Like most members of its family, it may make grunting noises when removed from the water.

Specimens Collected: Magela Creek - 75 specs.; 39-139 mm SL; D. Pollard and M. Mann; cast net; Cat. Nos.I.16828.001, 002 and 003, and I.16859.001; June-July 1972.
Common in almost all waterbodies of the Magela Creek system.
Sawcut Creek (South Alligator River system) - 1 spec.; 156 mm SL; D. Pollard; rod, line and lure; Cat. No. I.16829.001; 16 July 1972.
Large billabong at Oenpelli - 16 specs.; 85-204 mm SL; Fish Creek - 22 specs.; 39-135 mm SL; Oenpelli Creek - 37 specs.; 41-119 mm SL; and Red Lily Lagoon - 4 specs.; 116-184 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.186-188).

FAMILY THERAPONIDAE

Amniataba percoides (Günther) Black-striped Grunter

Mándidi (Oenpelli)



(After Whitley)

Systematic Position: Referred to as *Terapon percoides* by Taylor (1964). There may be three subspecies according to Whitley (1960).

Distribution: North-east coast, Gulf of Carpentaria, Timor Sea, Indian Ocean, and Lake Eyre internal drainage basins of Queensland, the Northern Territory, and Western Australia.

Description: Body perchlike, oblong and compressed. Scales moderate; lateral line distinct. Head relatively pointed. Mouth moderate to small; jaws with villiform teeth. Caudal fin emarginate. Colour - body light brownish above to paler and yellowish-silver below, with five narrow black bars across back down to middle of flanks and black markings on top of head. Dark mark at caudal base. Fins yellowish; outer margins of dorsal fin dusky; lower part of caudal fin with a dark blotch. Finrays - D22-23; A10-11; P13-15; V6. Scales - L. lat. 37-44. Body proportions - head length 2.9-3.3 in SL; body depth 2.3-2.5 in SL.

Maximum Size: Grows to about 20 cm in length.

Habits: Notes on family as for preceding species. Seems to be strictly an inhabitant of freshwaters. Found together with the preceding species in generally the same habitats in the Magela Creek system, but usually in smaller numbers.

Diet: Similar to that of preceding species, but with few or no small fish being eaten.

General Notes: Generally too small to be considered as a food species, but would make an attractive aquarium fish.

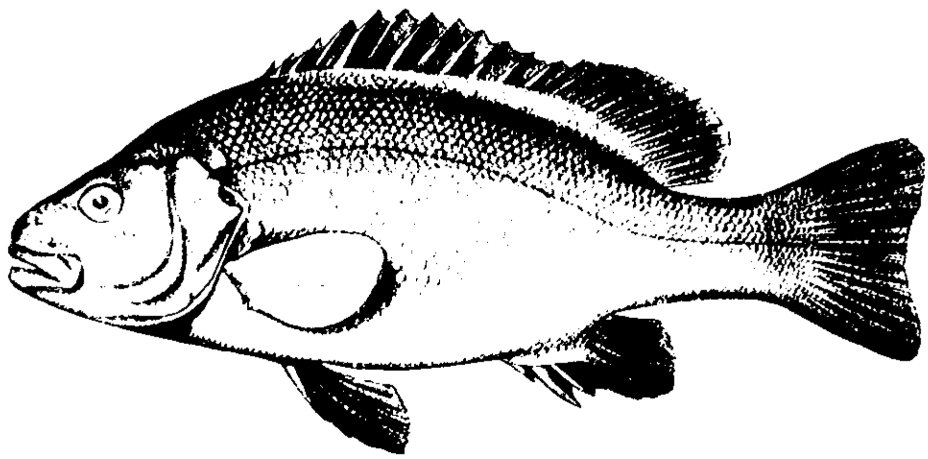
Specimens Collected: Magela Creek - 37 specs.; 13-81 mm SL; D. Pollard and M. Mann; cast and seine nets; Cat. No. I.16859.020; June-July 1972.

Indium Billabong - 6 specs.; 23-97 mm SL; D. Pollard and M. Mann; cast net; Cat. No. I.16826.005; June-July 1972.

Large billabong at Oenpelli - 39 specs.; 80-137 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.188-189).

FAMILY THERAPONIDAE

Hephaestus fuliginosus (Macleay) Sooty Grunter, Black Bream



(After Grant)

Systematic Position: This species was previously considered to be restricted to the north-east coast drainage of Queensland, with a separate species, *Hephaestus bancrofti* (Ogilby and McCulloch), occurring in the Gulf of Carpentaria and Timor Sea drainages of north-western Queensland, the Northern Territory, and northern Western Australia. However, the group is currently being revised by J. Merrick (School of Biological Sciences, University of Sydney) who considers that these two species should be grouped together under the single species name *fuliginosus*. This genus, together with a number of others, is referred to as *Therapon* by some authors.

Distribution: North-east coast, Gulf of Carpentaria and Timor Sea drainages of Queensland, the Northern Territory, and northern Western Australia.

Description: Body oblong to oval, compressed and robust. Scales moderate; lateral line distinct. Head blunt and moderately rounded, slightly concave above eyes. Mouth moderate; jaws with villiform teeth. Caudal fin slightly emarginate. Colour - body dark bronze-brown to almost black, more silvery on abdomen. Fins dusky. Juveniles more silvery, with dark blotch on anal fin. Finrays - D24-25; A11-12; P15-16; V6. Scales - L. lat. 57-61. Body proportions - head length 2.8-3.2 in SL; body depth 2.7-2.8 in SL.

Maximum Size: Reputed to grow to a weight of about 2 kg and a length of around 40 cm in the Gulf of Carpentaria and Timor Sea drainages.

Habits: A strictly freshwater species, usually found in the rocky upper reaches of coastal rivers, often together with *Scleropages jardini* in the Alligator Rivers area (and, like this latter species, away from competition with *Lates calcarifer*). Reputedly breeds during the wet season when streams are in flood.

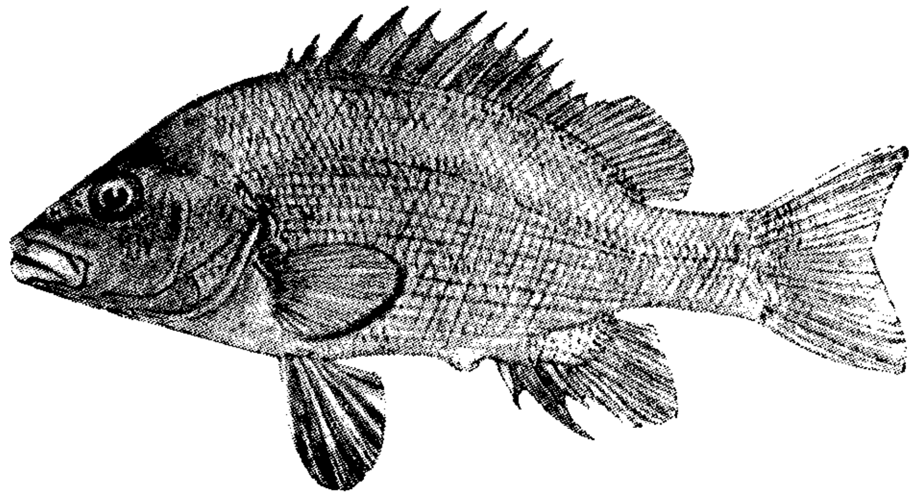
Diet: This species is omnivorous, and its diet consists of up to 80 per cent plant material (including algae and often the small fruits or berries of terrestrial plants, (*e.g.* in Sawcut Creek), as well as some crustaceans and insects. Although reputedly not a fish eater, this species can be taken readily on large artificial fishlike lures.

General Notes: An excellent sporting fish on light tackle, which will readily take lures or flies, as well as a variety of baits. Its flesh is edible, but not highly esteemed (its quality probably being a reflection of the fish's omnivorous diet).

Specimens Collected: Magela Creek - 1 spec.; 57 mm SL (juvenile); D. Pollard; cast net; Cat. No. I.16859.006; June 1972.
Upper Magela Creek - 1 spec.; 192 mm SL; M. Giles; rod, line and lure; Cat. No. I.16856.002; August-November 1972.
A number of other juvenile specimens were observed under and around submerged tree roots in the waterholes of Magela Creek near Jabiru while diving.
Sawcut Creek (South Alligator River system) - 2 specs.; 193-285 mm SL; D. Pollard and M. Giles; rod, line and lure; Cat. No. I.16829.002; July 1972.
Another 6 adult specimens were caught, and many more seen while diving, in Sawcut Creek.
This species was not collected by R. Miller in 1948, no doubt because he made no collections in the upper reaches of streams and rocky upland billabongs normally inhabited by large populations of this species (and large populations of *Scleropages jardini*, which he also failed to collect).

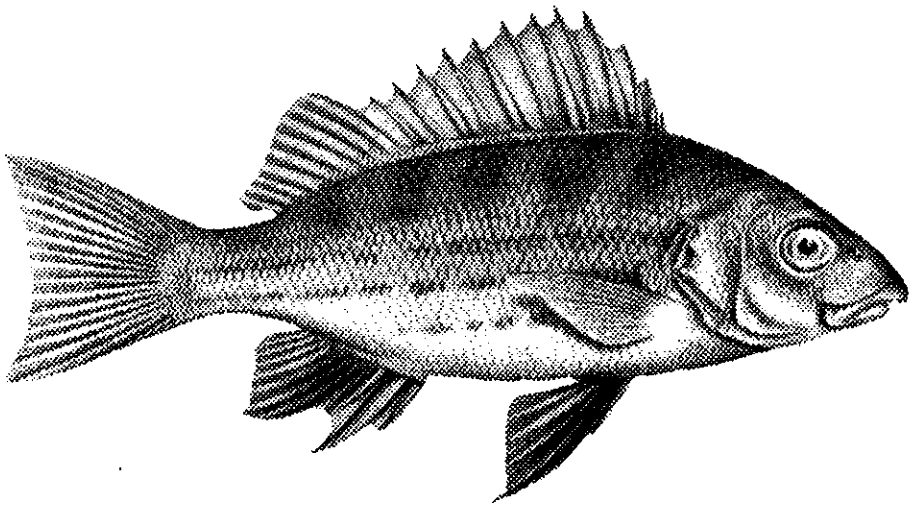
Another fairly similar-looking juvenile theraponid, differing from juvenile *H. fuliginosus* in having a more pointed snout and no black blotch on the anal fin, was collected together with the latter species in Magela Creek in June 1972 - 2 specs.; 67-70 mm SL; D. Pollard; cast net; Cat. Nos. I.16859.009 and 010. This may have been the same species as that collected in Tin Camp Creek and Deaf Adder Creek by H. Midgley (referred to by him as '*Therapon* sp. - sharp-nosed'). This species appears to fit the general description of

Mesopristes sp. (possibly *alligatoris* (Rendahl)), previously recorded from northern Western Australia), but with only juvenile specimens to hand this identification cannot yet be confirmed. Larger specimens of this species were also observed while diving in Sawcut Creek (South Alligator River system).



Mesopristes sp. (After Whitley)

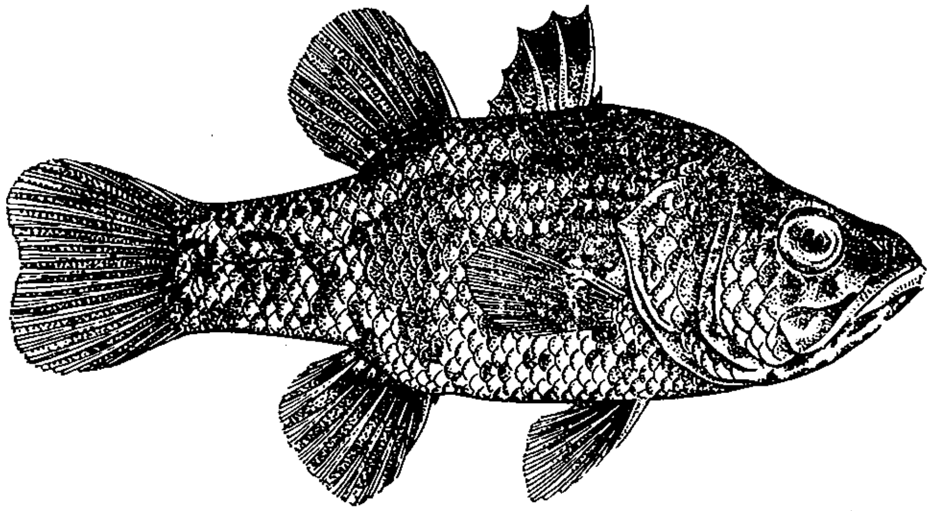
Another species of juvenile theraponid was also collected from Magela Creek in June 1972 (together with the previous two) - 4 specs.; 62-66 mm SL; D. Pollard; cast net; Cat. Nos. I.16859.018 and 019. This third species differed from the previous two in having a slightly less deep and less compressed body, and an overhanging upper lip giving the mouth a sub-terminal, tapir's snout-like appearance. The fins were yellowish, with a dark blotch on the anal fin, and the body was silvery with faint dusky markings on the flanks. This species appeared to fit the general description of *Mesopristes cancellatus* (Cuvier), the tapiroid grunter, previously only recorded from New Guinea (Munro 1967; p.323). Large specimens of the same species were also observed while diving in Sawcut Creek (South Alligator River system). Midgley collected juvenile specimens of what may have been this species in the same area of Magela Creek as the present collection in May-June 1973 (referred to by him as '*Therapon* sp. - black spot anal').



Mesopristes cancellatus (After Munro)

FAMILY APOGONIDAE

Glossamia aprion (Richardson) Mouth Almighty, Queensland Mouthbrooder



(After Munro)

Systematic Position: This species is sometimes separated into two subspecies, *G. aprion aprion* from northern Western Australia, the Northern Territory and northern Queensland, and *G. aprion gilli* from southern Queensland and far northern New South Wales.

Distribution: East coast, Gulf of Carpentaria and Timor Sea drainages of northern New South Wales, Queensland, the Northern Territory and northern Western Australia; also occurs in southern rivers of New Guinea.

Description: Body oblong, compressed and rather elevated. Scales moderate; lateral line distinct. Head with a marked concavity above eyes. Mouth very large; jaws with villiform teeth; lower jaw protrudes slightly. Caudal fin slightly emarginate with rounded lobes. Colour - body creamish with irregular brown-olive bars and blotches, abdomen lighter. Outer half of first dorsal fin dusky, other fins with irregular brownish markings. Finrays - 1st D6; 2nd D11-12; A10-12; P12-13; V6. Scales - L. lat. 37-43. Body proportions - head length 2.4-2.6 in SL; body depth 2.4-2.6 in SL.

Maximum Size: Reputedly reaches about 20 cm in length and about 700 g in weight.

Habits: A strictly freshwater species, although it belongs to a predominantly marine family. This species is a buccal incubator, and the male broods the eggs in its mouth.

Diet: Carnivorous, probably feeding upon small fish, crustaceans, and aquatic insects.

General Notes: Reputedly a good eating fish in spite of its generally small size. Does not seem to survive well in aquaria as it is prone to fungus infection.

Specimens Collected: Magela Creek - 12 specs.; 27-100 mm SL; D. Pollard and M. Mann; cast net; Cat. Nos. I.16859.028 and 029; June-July 1972.

Indium Billabong - 12 specs.; 39-98 mm SL; D. Pollard and M. Mann; cast net; Cat. No. I.16826.004; June-July 1972.

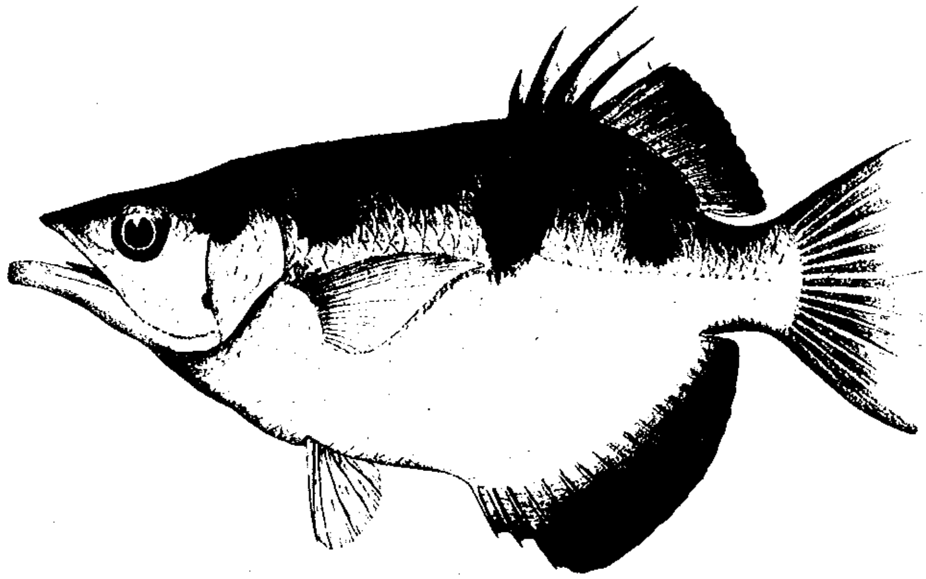
Georgetown Billabong - 6 specs.; 33-125 mm SL; M. Giles and M. Mann; seine net; Cat. No.I.16854.003; August-November 1972.

Large billabong at Oenpelli - 90 specs.; 30-111 mm SL; Oenpelli Creek - 19 specs.; 58-91 mm SL; and Red Lily Lagoon - 17 specs.; 17-112 mm SL; R. Miller; October 1948 (cited in Taylor 1964; p.162).

FAMILY TOXOTIDAE

Toxotes chatareus (Hamilton-Buchanan) Archer Fish, Rifle Fish

Nárlgan (Oenpelli)



(After Grant)

Systematic Position: Family includes a number of species restricted to the central Indo-Pacific region; mainly found in brackish waters of estuaries.

Distribution: North-east coast, Gulf of Carpentaria, and Timor Sea drainages of Queensland, the Northern Territory and northern Western Australia; also occurs in West New Guinea, and apparently extends to parts of tropical southern Asia *(e.g.* India and Ceylon, *etc.*).

Description: Body elongate to oval, compressed, straight backed to dorsal fins, and rather rhomboidal. Scales small to moderate; lateral line distinct. Mouth large and protractile with grooved palate; jaws with short rounded to villiform teeth; lower jaw slightly projecting. Dorsal and anal fins opposite and positioned posteriorly; caudal fin emarginate. Colour - body golden to yellowish above and more silvery below, with five irregular broad bars on dorsal flanks. Dorsal and anal fins and bases of other fins dusky, outer parts more yellowish. Finrays - D17-19; A19-20; P10-14; V6. Scales - L. lat. 31-36; predorsal 22. Body proportions - head length 2.7-3.3 in SL; body depth 2.0-2.3 in SL.

Maximum Size: Grows to over 30 cm in length and to about 700 g in weight.

Habits: Found from brackish estuaries and river mouths up to hundreds of kilometres inland in freshwaters, and appears to be common in all permanent freshwaters in the Alligator Rivers area. *Toxotes* can knock insects into the water from overhanging vegetation at distances of over a metre with a jet of water from its specially adapted mouth.

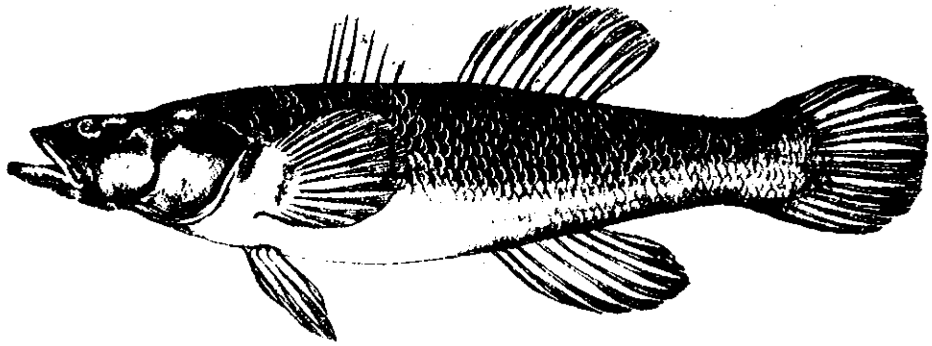
Diet: Includes insects, shrimps, small fish, and reputedly some berries falling into the water from terrestrial vegetation.

General Notes: Large specimens provide excellent sport on light tackle and will take small artificial lures and dry flies. The flesh is reputedly good eating, and smaller specimens live readily in aquaria.

Specimens Collected: Magela Creek - 7 specs.; 58-78 mm SL; D. Pollard and M. Mann; cast net; Cat. No. I.16859.002; June-July 1972.
Mudginbarri Lagoon - 1 spec.; 240 mm SL (300 mm TL, 620 g weight); D. Pollard; rod, line and lure; Cat. No. I.16831.005; 10 June 1972.
Large specimens seen in most permanent billabongs and lagoons and while diving in Sawcut Creek.
Large billabong at Oenpelli - 16 specs.; 18-191 mm SL; R. Miller; October 1948 (cited in Taylor 1964; pp.222-224).

FAMILY ELEOTRIDAE

Oxyeleotris lineolatus (Steindachner) Sleepy Cod, Sleeper



(After Grant)

Systematic Position: Some authors lump the Indo-Pacific eleotrids (the gudgeons) together with the gobies in a single family, the Gobiidae, but the present author considers them distinct enough to warrant their retention in a separate family, the Eleotridae. Small specimens fitting the colour-pattern description of *Bunaka herwerdenii* (Weber) collected in the Alligator Rivers area may be juvenile *O. lineolatus*.

Distribution: North-east coast, Gulf of Carpentaria and Timor Sea drainages of Queensland, the Northern Territory, and northern Western Australia; also occurs in New Guinea.

Description: Body elongate and cylindrical anteriorly. Scales moderate; lateral line absent. Head broad, depressed and concave above eyes. Mouth large and oblique; lower jaw protruding; jaws with bands of villiform teeth. Ventral fins separate; caudal fin rounded. Colour - body dark brown above, somewhat paler below, with indistinct cloudy markings on flanks. Fins generally dusky. What appear to be juveniles of this species have a broad dark band along the flanks terminating at the caudal fin base. Finrays - 1st D6; 2nd D10; A8-10; P17-18; V6. Scales - lateral midline (head to caudal fin) 60-64. Body proportions - head length 2.7-3.0 in SL; body depth 4.5-5.5 in SL.

Maximum Size: Grows to about 50 cm in length and reputedly to about 3 kg in weight.

Habits: Most members of the family are inhabitants of freshwaters, but many are found in brackish estuarine and a number in purely marine environments. *Oxyeleotris* appears to be a permanent inhabitant of freshwaters and is usually found in heavily vegetated pools and billabongs, often lying sluggishly amongst vegetation in shallow water around the shoreline.

Diet: This species appears to be an opportunistic carnivore, eating crustaceans, insects, and small fishes.

General Notes: Can be caught on a baited hook and line, but is an extremely sluggish fish in relation to its size. Its flesh, however, is firm and white and of excellent eating quality, although in the Magela Creek area it often contains encysted nematode *(Eustrongylides* sp.*)* larvae. It can sometimes be caught with a hand net when found lying 'asleep' in the shallows.

Specimens Collected: Indium Billabong - 2 specs.; 265-290 mm SL; D. Pollard and M. Mann; cast net; Cat. Nos. I.16826.007 and 008; July 1972.

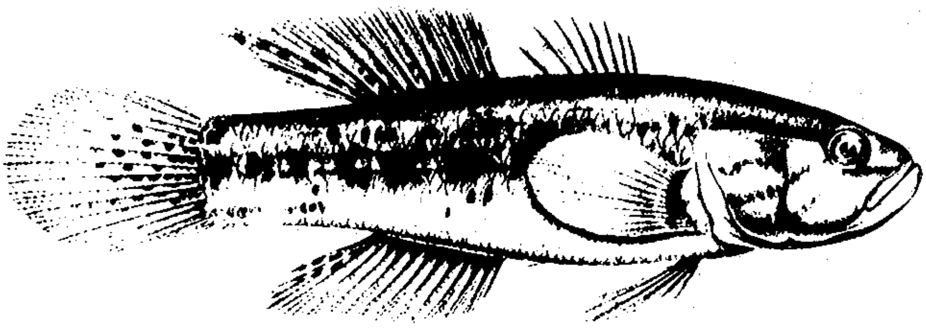
Georgetown Billabong - 7 specs.; 175-420 mm SL; M. Giles and M. Mann; seine net; Cat. No. I.16854.001; August-November 1972.

In addition to these larger adult specimens, a number of small specimens between 5 and 10 cm in length were captured using dip nets amongst the vegetation fringing waterholes along Magela Creek. These small specimens resemble the colour-pattern description of the closely related mud gudgeon, *Bunaka herwerdenii*, having a broad dark band running along each side and terminating at the base of the caudal fin. These specimens are suspected by the author to be but a juvenile colour-phase of *Oxyeleotris*.

This species may have been, and probably was, collected by R. Miller in the Oenpelli area in 1948, but the eleotrids were not dealt with by Taylor (1964) in his monograph on the fishes collected during this expedition.

FAMILY ELEOTRIDAE

Mogurnda mogurnda (Richardson) Purple-spotted Gudgeon



(After Grant)

Systematic Position: Closely related to (and apparently regarded as synonymous with by Lake 1971) *M. striata* (Steindachner) from the Murray-Darling River system. A third species *M. australis* (Krefft) occurs in the east coast drainages of New South Wales and southern Queensland.

Distribution: North-east coast, Gulf of Carpentaria, Timor Sea, and Lake Eyre internal drainages of Queensland, the Northern Territory, and northern Western Australia; also occurs in New Guinea.

Description: Body elongate, rounded and slightly compressed. Scales moderate; lateral line absent. Head cylindrical and obtusely rounded. Mouth moderately large and oblique; teeth in jaws in several rows. Ventral fins separate; caudal fin rounded. Colour - body fawnish-brown, paler below, numerous dark purplish-brown to reddish spots on flanks. Two parallel purplish oblique lines from eye across cheek and operculum, and another across operculum to pectoral fin base. Dorsal, anal and caudal fins with reddish to dusky spots on basal half. Finrays - 1st D7-9; 2nd D13-15; A12-16; P16; V6. Scales - lateral midline (head to caudal fin) 38-48; predorsal 18-20. Body proportions - head length 3.3-3.5 in SL; body depth 3.5-4.0 in SL.

Maximum Size: Grows to almost 20 cm in length.

Habits: See notes on family for preceding species. *Mogurnda* is a permanent inhabitant of freshwaters and appears to occur in most waterbodies in the Alligator Rivers region. The largest concentrations and largest specimens of this species were collected from a water-filled, artificial, turbid costean dug for uranium exploration purposes.

Diet: Like the preceding species, *Mogurnda* appears to be an opportunistic carnivore, eating insects, crustaceans and probably also small fishes.

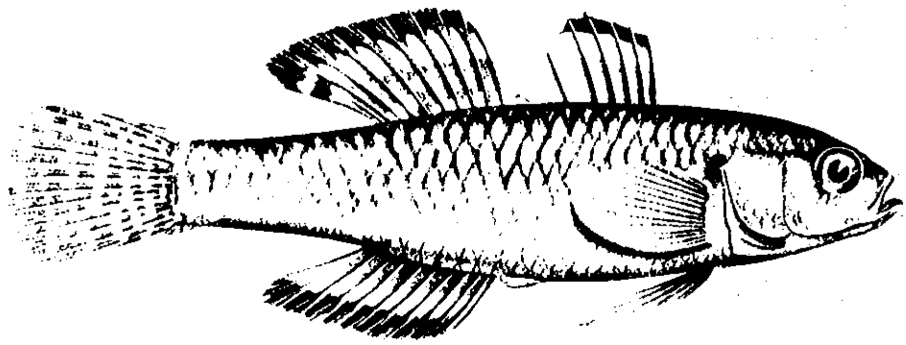
General Notes: This species, like the closely related *M. striata*, makes an excellent aquarium fish which will breed readily under aquarium conditions.

Specimens Collected: Indium Billabong - 7 specs.; 39-60 mm SL; D. Pollard and M. Mann; cast net; Cat. No. I.16826.006; July 1972. Anomaly II Costean - 2 specs.; 88-89 mm SL; D. Pollard; cast net; Cat. No. I.16825.003; July 1972.

This species may have been collected by Miller in the Oenpelli area in 1948, but the family was not dealt with by Taylor (1964) in his monograph on the fishes of the area (see notes for preceding species).

FAMILY ELEOTRIDAE

Hypseleotris simplex (Castelnau) Northern Carp-gudgeon



Hypseleotris sp. (After Grant)

Systematic Position: *Hypseleotris (= Carassiops) simplex* is closely related to (and regarded by some authors as synonymous with) *H. compressus* (Krefft), which appears to replace it in the east coast drainages of Queensland and New South Wales (together with the smaller and less common species *H. galli* (Ogilby)). A fourth species, *H. klunzingeri* (Ogilby), occurs in the Murray-Darling River system.

Distribution: Gulf of Carpentaria, Timor Sea, and Indian Ocean drainages of north-western Queensland, the Northern Territory and Western Australia; also occurs in the coastal streams of southern New Guinea.

Description: Body elongate and compressed. Scales moderate to large; lateral line absent. Head compressed and more rounded in males than in females. Mouth small and oblique; jaws with small villiform teeth. Ventral fins separate; dorsal and anal fin rays longer in male; caudal fin rounded. Colour - body greenish yellow, with darker brownish margins to scales, darker above, with a black blotch on shoulder, and paler below. Body becomes brighter green and head reddish, and dorsal and anal fins become banded in black, red, white and blue, and sometimes also yellow and violet during the breeding season, the males displaying the brighter colouration. Finrays - 1st D6; 2nd D10-11; A10-11; P13-15; V6. Scales - lateral midline (head to caudal fin) 27-30; predorsal 15. Body proportions - head length 3.5-3.6 in SL; body depth 3.2-4.6 in SL.

Maximum Size: Grows to about 10 cm in length.

Habits: All species in this genus appear to be restricted to freshwaters. The adhesive eggs are usually attached to a rock or similar submerged surface and guarded by the male, who fans and aerates them with his fins until they hatch.

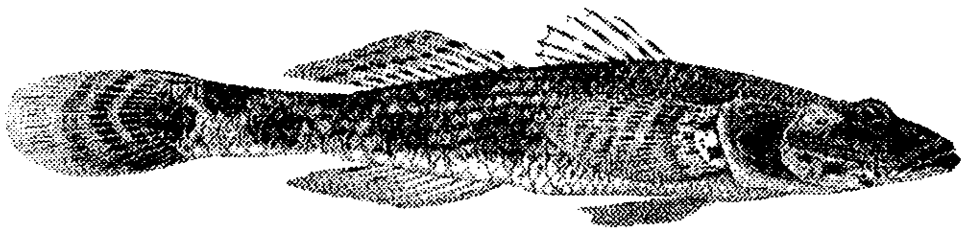
Diet: Mainly small insects (fishes of this genus are renowned as destroyers of mosquito larvae).

General Notes: This and the other related species in the genus make excellent aquarium fishes, both because of their bright colouration and because of their interesting breeding behaviour.

Specimens Collected: No specimens of this species were collected by the author during June and July 1972, but some were captured in the Magela Creek system by H. Midgley, including Island Billabong (where they were rare), and a lagoon on the Magela Plain (where they were common), during September-October 1972. The eleotrids collected by R. Miller in 1948 were not dealt with by Taylor (1964).

FAMILY GOBIIDAE

Glossogobius giurus (Hamilton-Buchanan) Flat-headed Goby



(After Munro)

Systematic Position: The present species is probably synonymous with the widespread Indo-Pacific species *G. gutum* (Hamilton-Buchanan).

Distribution: North-east coast, Gulf of Carpentaria, Timor Sea, and Indian Ocean drainages of northern Queensland, the Northern Territory and Western Australia; also in New Guinea, and throughout the Indo-Pacific area from East Africa to the Pacific Islands.

Description: Body elongate, cylindrical anteriorly, tapering and compressed posteriorly. Scales small; lateral line absent. Head depressed and tapering. Mouth large and oblique with lower jaw projecting; jaws with pointed teeth. Ventral fins fused to form a disc-like sucker; caudal fin obtusely pointed. Colour - sand coloured to olive above and paler below, a number of dusky blotches on flanks, and dark spots on sides of head. Fins yellowish to colourless with some spots and darker margins. Finrays - 1st D6; 2nd D9-10; A8-9; P17-21; V6. Scales - lateral midline (head to caudal fin) 30-36; predorsal 21-30. Body proportions - head length 2.8-3.3 in SL; body depth 5.2-5.6 in SL.

Maximum Size: Grows to over 35 cm in length.

Habits: A number of species of *Glossogobius* are distributed in the Indo-Pacific region, some occurring in marine waters (*e.g.* on coral reefs and pearl banks in Ceylon), some in brackish estuaries, and some in freshwaters (*e.g.* in mountain torrents in the New Guinea highlands). *Glossogobius giurus* is probably one of the most widely distributed of these various species, and is found from marine coastal to inland freshwaters. Little appears to be known about the biology of this or the other species of *Glossogobius*. It is one of the least common fishes in the Magela Creek area, only two adult and two juvenile specimens having been collected from vegetation around the banks of waterholes along Magela Creek during two months' intensive collecting.

Diet: Unknown, but is probably an opportunistic carnivore.

General Notes: Although this species reaches a reasonably large size, no information is available on its eating qualities.

Specimens Collected: Magela Creek - 2 specs.; 79-81 mm SL; D. Pollard and M. Mann; dip and cast nets; Cat. No. I.16859.005; July 1972. Magela Creek - 2 specs.; 19-21 mm SL (small juveniles); M. Mann; dip net; Cat. No. I.16859.022; July 1972.

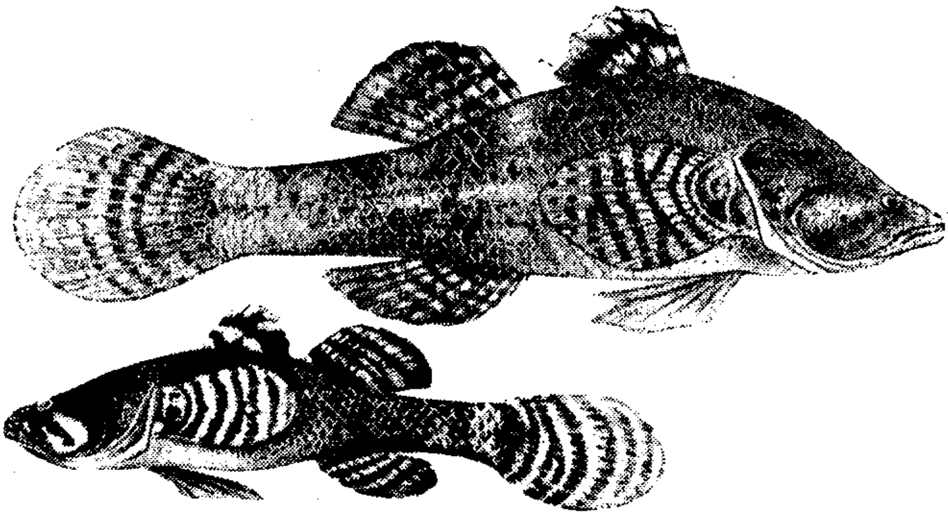
Further specimens of this species, which appears to be fairly rare in the Magela Creek system, were collected by H. Midgley from Georgetown Billabong using rotenone in September-October 1972 and in June 1973, and from Island Billabong in September-October 1972; both localities and in the Magela Creek system.

It is not known whether this species was collected by R. Miller in the Oenpelli area in 1948, as the collections he made of the family Gobiidae were not dealt with by Taylor (1964).

6. ADDITIONAL SPECIES COLLECTED FROM OTHER LOCALITIES IN THE EAST ALLIGATOR AND SOUTH ALLIGATOR RIVER SYSTEMS

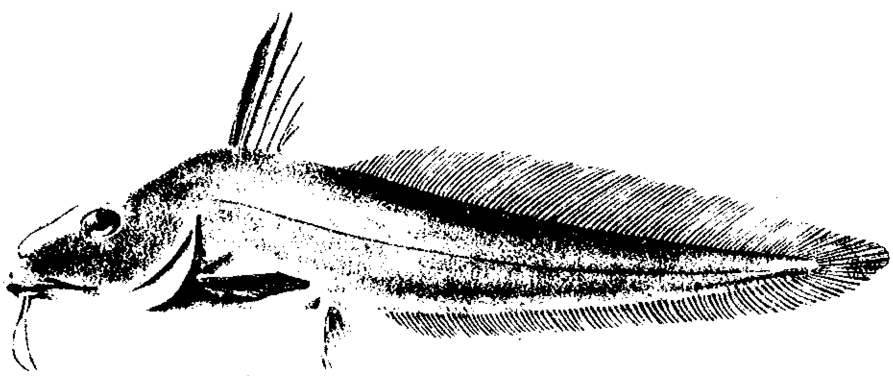
Other freshwater fishes have been collected from the Alligator Rivers area, but they have not been found, so far, in the Magela Creek system. These include:

- the small eyed sleeper *Prionobutis microps* (Weber), family Eleotridae, from Cannon Hill Lagoon (1 specimen only collected);



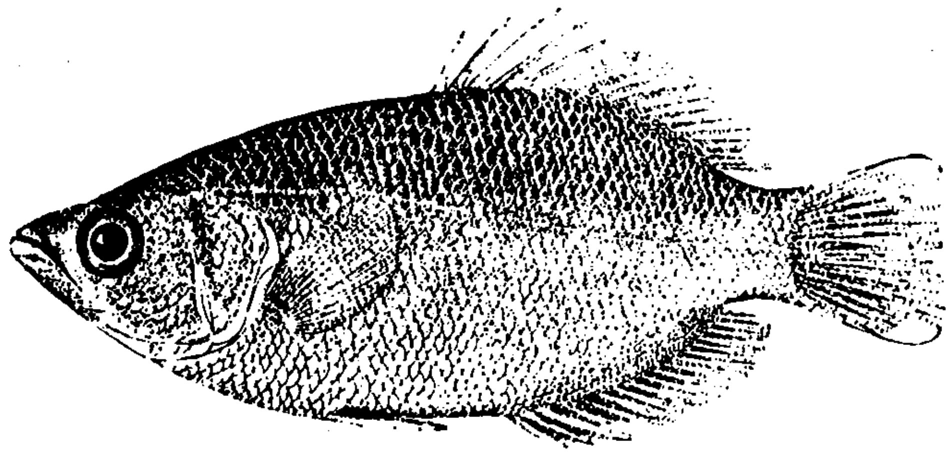
Adult and Juvenile (After Whitley)

- the toothless catfish *Anodontiglanis dahli* (Rendahl), family Plotosidae, from Cooper Creek, Deaf Adder Creek, and Baroalba Creek (the latter two being tributaries of the South Alligator River system);



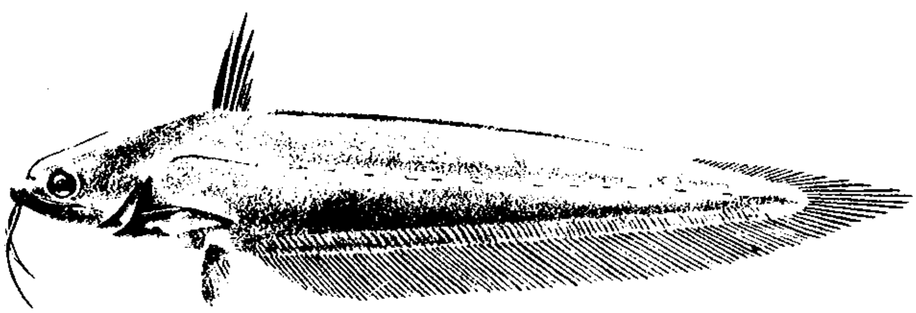
(After Taylor)

- and the primitive archer fish *Protoxotes lorentzi* (Weber), family Toxotidae, from Sawcut Creek, Deaf Adder Creek, and Baroalba Creek (three tributaries of the South Alligator River system) were all collected by H. Midgley in 1972 and 1973;



(After Whitley)

- Obbes catfish *Porochilus obbesi* (Weber), family Plotosidae, from Fish Creek (a tributary of Oenpelli Creek, East Alligator River system), were collected by R. Miller in 1948 (cited in Taylor 1964; pp.90-92).

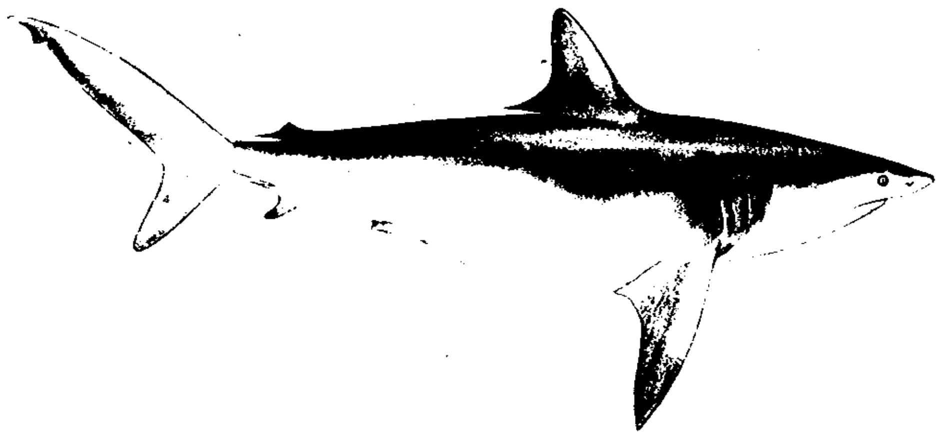


(After Taylor)

In addition to the 'freshwater' species collected from the Magela Creek system and other freshwater habitats in the Alligator Rivers area, a number of other species of fishes of more marine affinities were either collected from or observed in the East Alligator River itself above Cahills Crossing and in Rock Hole Billabong, both localities where the river is still tidal though its waters are generally fresh.

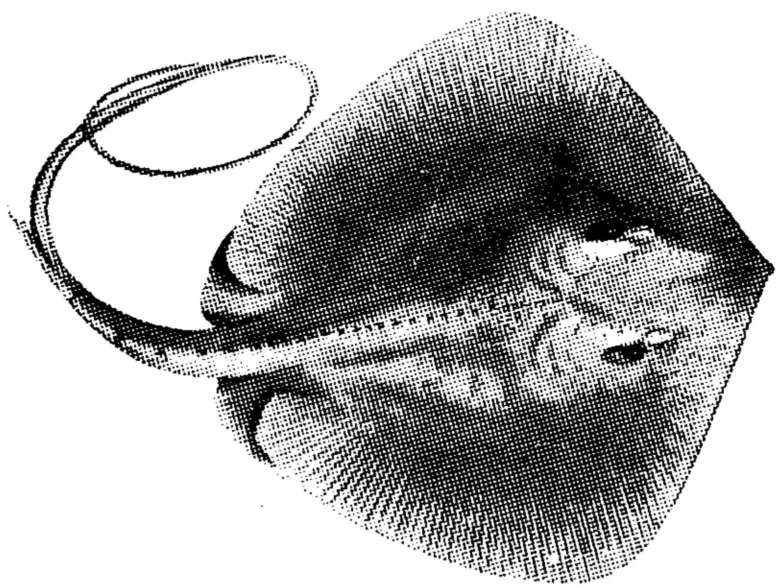
These species included three genera of elasmobranchs, all of which are renowned for their penetration into the freshwater reaches of rivers, mainly in northern Australia namely:

- the river whaler shark *Carcharhinus* sp. (*mckaili* ?), family Carcharhinidae;



Carcharhinus sp. (After Grant)

- the brown river stingray *Dasyatis* sp. *(fluviorum?)*, family Dasyatidae;



Dasyatis sp. (After Grant)

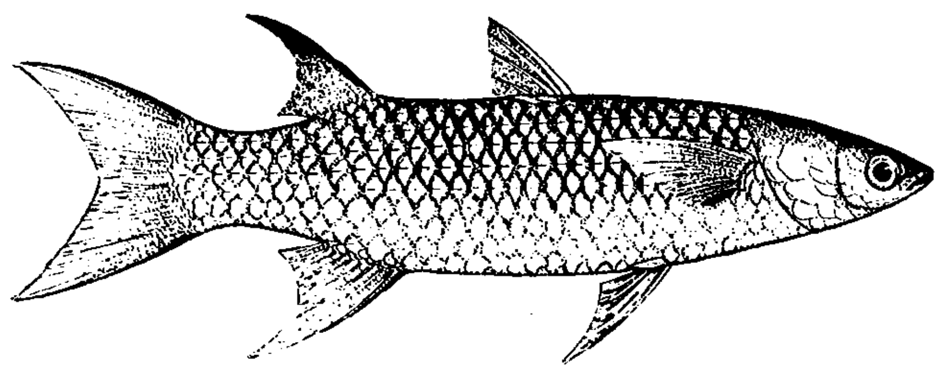
- and the river sawfish *Pristis* sp. (*leichardtii?*), family Pristidae.

Pristis sp. (After Grant)

Of these, three specimens of *Carcharhinus* (70-170 cm in length and up to 14 kg in weight) and two of *Pristis* (120-180 cm in length) were caught in large-mesh gill nets in Rock Hole Billabong and the narrow channel connecting it to the main channel of the East Alligator River. Taylor (1964; p.56) states that "Miller indicated in his notes that a single species of shark was fairly abundant in the East Alligator River, but unfortunately he did not have facilities for preserving more than the single head". The specimen mentioned was captured at Cahills Landing (about 10 km downstream from Cahills Crossing) and was identified as *C. mckaili* by Taylor (1964). A single specimen of *Dasyatis* (about 50 cm across the disc) was observed by the author, captured on a baited line from the main river channel in the vicinity of Cahills Landing. All three of these elasmobranch species were also captured by H. Midgley in Cannon Hill Lagoon (which often has a direct connection to the East Alligator River) during July 1973.

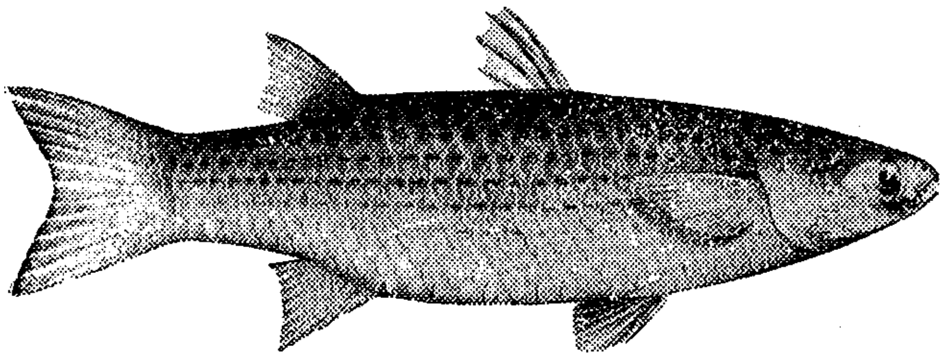
Three species of grey mullets (family Mugilidae) were also present upstream of Cahills Crossing. These included:

- the Ord River mullet *Liza diadema* (Gilchrist and Thompson), which was present in very large numbers in Rock Hole Billabong, and of which many were captured using cast nets from a boat at night (2 specs.; 183-213 mm SL; Cat. No. I.16830.002);



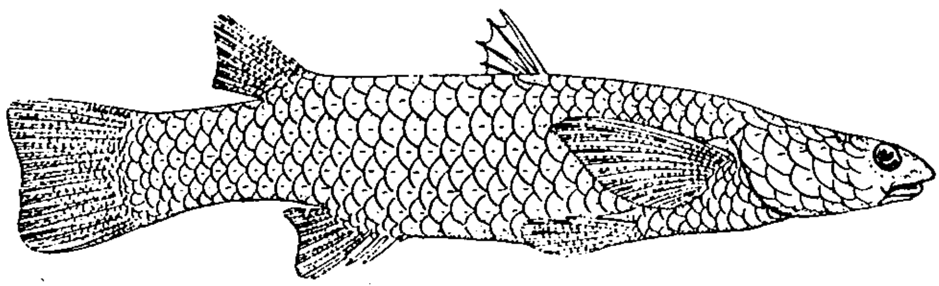
(After Munro)

- the greenbacked mullet *Liza dussumieri(?)* (Valenciennes), which was captured by cast net at Cahills Crossing (1 spec.; 82 mm SL; Cat. No. I.16827.003);



(After Munro)

- and the mud mullet *Squalomugil nasutus* (De Vis), which was observed in large surface schools in the vicinity of Cahills Crossing and in many places downstream of this locality.

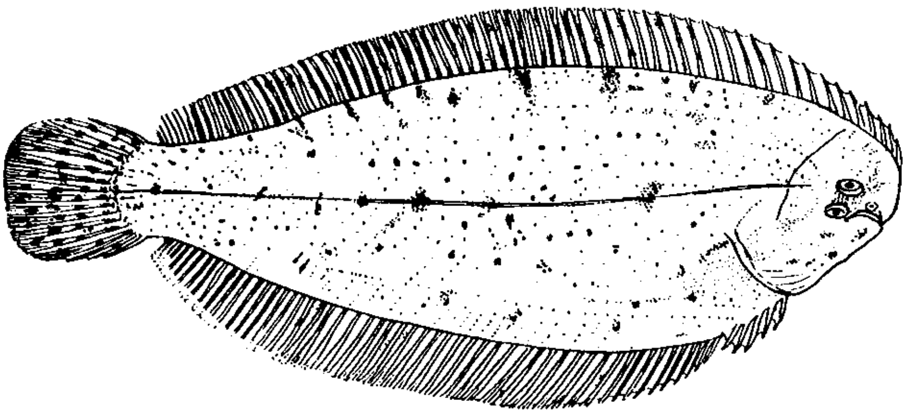


(After Munro)

H. Midgley also collected two unidentified species of mullets from Cannon Hill Lagoon in 1972-73.

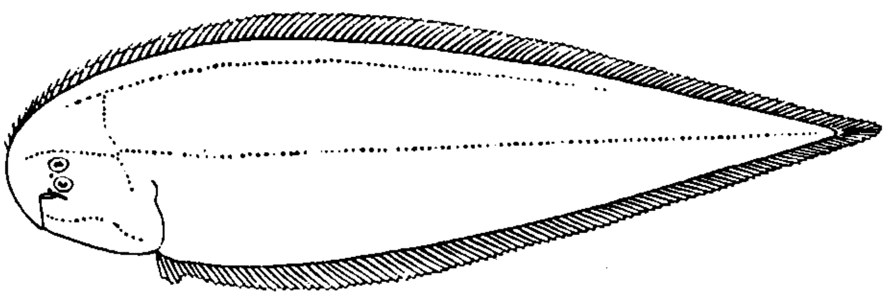
In October 1948, R. Miller collected *L. diadema* in the billabong at Oenpelli - 6 specs.; 192-233 mm SL; and in Red Lily Lagoon - 13 specs.; 123-195 mm SL; (referred to as *Chelon diadema* in Taylor 1964; p.119), and *S. nasutus* in the East Alligator River at Cahills Landing - 23 specs.; 27-113 mm SL (cited in Taylor 1964; p.121).

Several specimens of the tailed sole, *Aseraggodes klunzingeri* (Weber), family Soleidae, were captured in Rock Hole Billabong and at Cahills Crossing using cast nets - 2 specs.; 60-61 mm SL; Cat. No. I.16830.001; and this and another unidentified species of sole were also collected by H. Midgley from Cannon Hill Lagoon.



(After Whitley)

In October 1948, R. Miller collected a further species of sole, the tongue sole *Cynoglossus heterolepis* (Weber), family Cynoglossidae, from the East Alligator River at Cahills Landing - 6 specs.; 53-132 mm SL (cited in Taylor 1964; p.294).

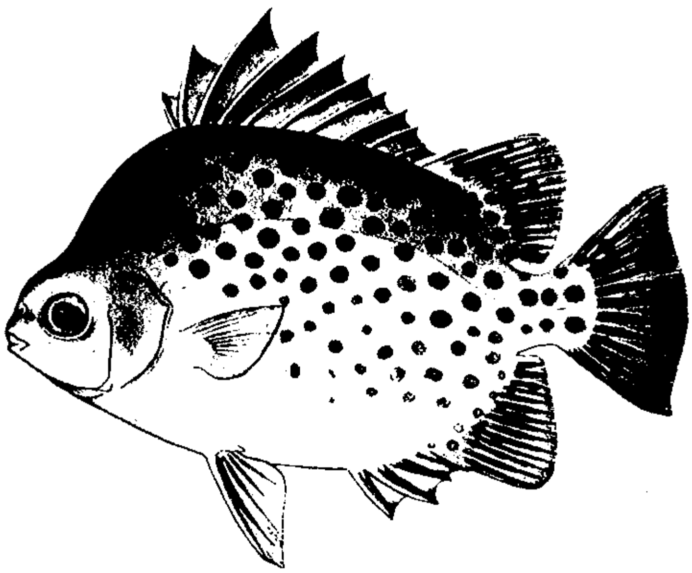


Cynoglossus sp. (After Munro)

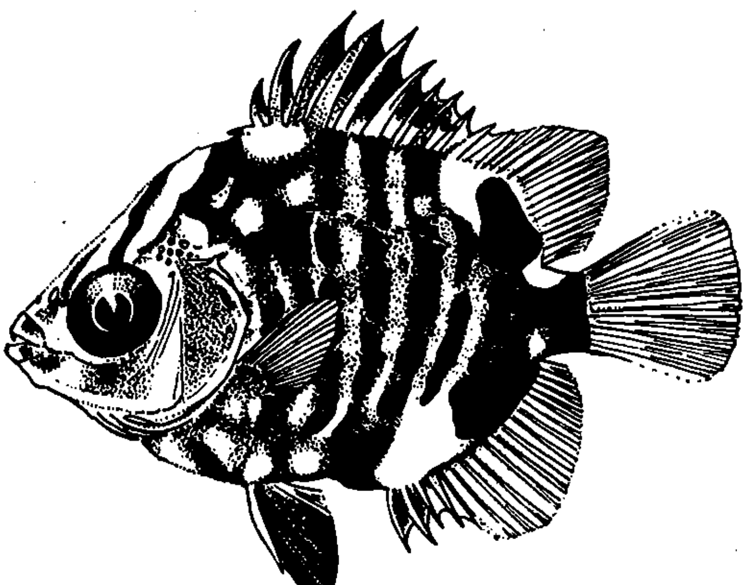
In addition to the above, R. Miller also collected the garfish *Zenarchopterus caudovittatus* (Weber), family Hemiramphidae, from Cahills Landing - 5 specs.; 44-122 mm SL (cited in Taylor 1964; pp.106-107).

(After Taylor)

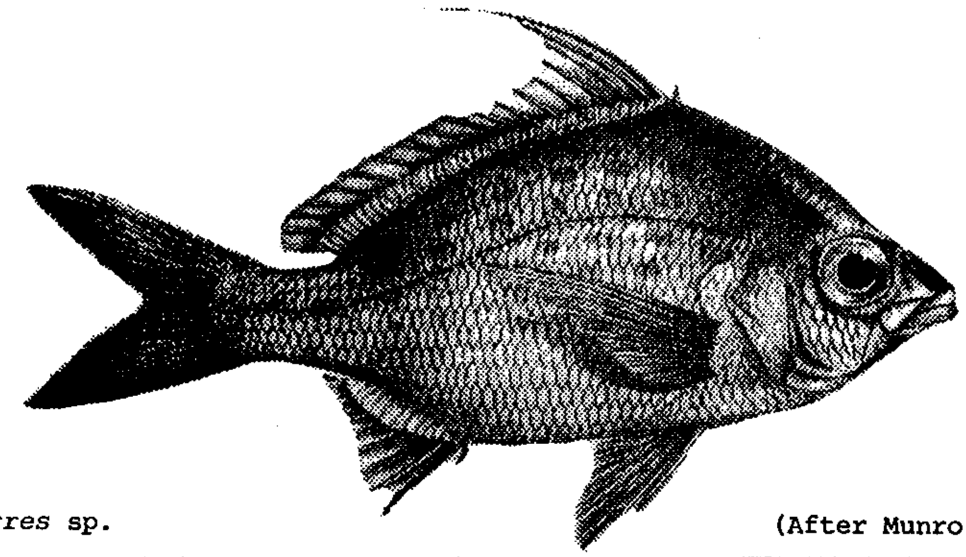
In July 1973 H. Midgley collected a species of butterfish *Scatophagus* sp., family Scatophagidae;



Scatophagus sp. (Adult) (After Grant)



Scatophagus sp. (Juvenile) (After Grant) and a species of silverbelly *Gerres* sp., family Gerridae, from Cannon Hill Lagoon in July 1973.



Gerres sp. (After Munro)

7. DISCUSSION

Of the twenty-eight species of fishes collected from the Magela Creek catchment, all but one (*Scleropages*, family Osteoglossidae) belong to predominantly marine or marine-derived families. However, of the species themselves, only six are regularly recorded from brackish estuarine waters (*Megalops*, *Hexanematichthys*, *Pseudomugil*, *Lates*, *Toxotes* and *Glossogobius*), and the rest can be regarded as 'true' freshwater fishes.

With regard to the geographical distributions of these fishes, in addition to their occurrence in the Timor Sea drainage of the western Northern Territory and northern Western Australia, twenty-two (and possibly twenty-four) are found also in the Gulf of Carpentaria drainage of the eastern Northern Territory and western Queensland, fourteen (and possible seventeen) in rivers of southern New Guinea, thirteen (and possibly sixteen) in the north-east coast drainage of Queensland, seven in the Indian Ocean drainage of the far west of Western Australia, five (and possibly nine) in the rivers of northern New Guinea, five are widely distributed in the central Indo-Pacific region, and only two are found in the south-east coast drainage of northern New South Wales. This pattern of distribution lends support to the recognition of a single Northern Australian drainage system, the Leichhardtian 'Fluvifaunula', encompassing the Timor Sea and Gulf of Carpentaria drainages described by Lake (1971), with the fauna of this drainage having close zoogeographic affinities with the faunas of both the southern New Guinea and north-east coast drainages.

With regard to their diets, of the twenty-eight species, twenty-five could probably be regarded as generally carnivorous, with possibly four of these (*Megalops, Scleropages, Strongylura* and *Lates*) being predominantly predators on fishes and larger crustaceans, and the remainder eating mainly smaller aquatic arthropods. Two species (the melanotaeniids) probably also consume considerable amounts of aquatic plant material, and may thus be classed as omnivores (although two of the carnivores, *Hephaestus* and *Toxotes*, are also reported to consume berries from terrestrial plants). A single species (*Fluvialosa*) was apparently predominantly iliophagous (a mud or detritus feeder), and none were found to be exclusively herbivorous.

Of the twenty-eight species, five (and possible six) could be regarded as sport fishes, eight (and possibly ten) as food fishes, and fourteen as potential aquarium species.

In addition to the twenty-eight species collected from the Magela Creek catchment, three additional freshwater species (*Porochilus, Anodontiglanis* and *Prionobutis*), and at least eleven predominantly marine species (three elasmobranchs, three mugilids, two soles, a garfish, a butterfish and a silverbelly) were also recorded from other tributaries or the main channel of the East Alligator River system. Only a single species (*Protoxotes*) was recorded from the South Alligator but not from the East Alligator system. This gives a total of at least forty-three species from the whole 'Uranium Province'.

In conclusion then, that section of the Magela Creek catchment within a 20 km radius of Mudginbarri station has a fish fauna of at least twenty-eight freshwater species (compared, for instance, with a total of twenty-seven native species present in the entire Murray-Darling system, the most extensive river system in Australia). The richness and diversity, and the scientific interest, of this ichthyofauna, as well as its importance for food and sport to Aborigines and other residents of the area, thus warrants the most careful consideration of any proposed changes in land use in the Alligator Rivers area.

8. ACKNOWLEDGEMENTS

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Atherinidae). The author also thanks Des Davy (AAECRE Environment & Public Health Division, Lucas Heights) for arranging the author's participation in this survey.

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THE ALLIGATOR RIVERS AREA FACT FINDING STUDY

REPORT II

TOXICITY STUDIES ON AQUATIC ORGANISMS AND GRASS-SEDGE COMMUNITIES IN THE MAGELA CREEK AREA

by

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CONTENTS

1. INTRODUCTION

This study was designed to establish the relative and, wherever possible, the absolute toxicities of those substances likely to be released during the mining and processing of uranium in the East Alligator Rivers area. This report is not a definitive study on the toxicity of heavy metals to the species from the study area because time and effort precluded this. The aim was to examine a range of organisms from the area, particularly fishes, and to assess their relative sensitivities to possible pollutants. In this context, apart from the actual mined areas, it was considered that the most vulnerable species would be those from the communities of the creeks downstream from the proposed mines and on the banks of those creeks where inundation occurs.

Little could be found in the literature on the effect of heavy metals on tropical species. As well as this, the unusual geological and climatological conditions made it essential that local organisms should be tested in the field using natural waters from the area.

Since it was possible to set up a field laboratory at Jabiru near the Ranger prospect, organisms and water from the nearby Magela Creek were used for all of the experiments except for some laboratory work on unicellular algae.

Some qualitative work was also done on the effects of possible contaminants on the plants of a natural grass sedge community on the banks of the Magela Creek. For convenience the work on aquatic organisms has been reported separately from that on grass sedge plains.

2. DESCRIPTION OF THE HABITATS STUDIED

The catchment of the Magela Creek lies to the south and east of the Ranger prospect and includes areas draining the known orebodies. The main creek has a coarse sandy bottom and its waters are clear and soft, containing low levels of dissolved metals (Table 1).

At the end of the dry season only a few waterholes remain along the course of the Magela and these are mainly billabongs (*i.e.* separate parallel channels) which have a fine particle silt as their bottom material.

After the first storms of the wet season, the creek begins to flow with water which has been heated while draining from the catchment. Between 28 November 1972 and 10 December 1972, temperatures of 36°C and 38°C were recorded. Subsequent rains brought water with temperatures between 28°C and 30°C.

During January, February and March the creek overflows and inundates surrounding low areas to a depth of about 1 m. Usually, by April, the water levels have begun to fall and, by May, the sedges begin to emerge from the shallow water. Flow stops during June or July and the water level in the remaining waterholes drops at the rate of about 1 cm per day due to a combination of evaporation and seepage.

Two distinct aquatic habitats can be distinguished: the sandy creek and the billabong. Georgetown may be considered a typical billabong. It lies near the Ranger No.1 orebody and receives runoff and possible seepage from there. It has gently sloping sides composed of fine silt which support grass sedge communities during the dry season. It has not been known to dry up completely and its waters are warm, turbid and, to some extent, eutrophic.

In contrast, the creek itself has steeper banks, a coarse sandy bottom and does not support grass sedge communities. The waterholes may dry up completely, except for some of the larger ones such as that at Mudjinbarri, and the water is cooler, clear and soft.

Surface water temperatures vary by about 2°C to 5°C diurnally, and by about 16°C seasonally. The lowest temperature (22°C) was recorded in July and the highest (39°C) in December.

Table 1 compares the chemical and physical properties of water from three waterbodies: the Magela Creek course, Georgetown Billabong and Mudjinbarri Billabong. The last is a deep clear permanent waterhole.

3. STUDIES ON AQUATIC ORGANISMS

3.1 Methods

3.1.1 Acute toxicity testing

To determine the median tolerance limit after 96 hours of exposure to a toxicant (TL_{m96}) the method for static bioassay outlined by APHA (1971) was followed.

Five dilutions of toxicant were used in a geometrically descending order of concentration together with one control tank. The range of dilutions was spread over 1 to 1.5 orders of magnitude to save time in preliminary testing. Results have been interpolated graphically, using log linear paper and drawing a line between the two concentrations immediately above and below the 50% survival level. The results shown in Table 2 were obtained from single experiments only, except for the case of uranium with hardyheads where two experiments were done and the range of values quoted.

Eighteen to twenty organisms were used in each tank for experiments with hardyheads, fry and *Macrobrachium* sp. while six fish were used in each tank for those on striped grunters, spangled grunters and catfish.

Dilution water was obtained from the Magela Creek. During October and November 1972, and also in June and July 1973, it was necessary to filter it through charcoal filters before use to maintain the fish in the control tank. Care was taken that this water was exposed to food grade plastics only and fresh polythene liners were used with each experiment. Glass aquariums, without linings of polythene, were used for experiments involving Alamine-336.

Hardyheads *(Craterocephalus marjoriae)*, which are a schooling fish 3 to 5 cm long, and which occur in sufficient numbers for practical laboratory use, were chosen as the standard test species. Where possible other organisms were tested similarly, but in some cases, only two dilutions were used so that only their sensitivity relative to hardyheads was determined.

Fish were said to be dead when opercular movement ceased and *Macrobrachium* sp. were said to be dead when they would not react to stimulus by a glass rod.

All the fish tested came from the sandy creek habitat except for one experiment using catfish from Georgetown. *Macrobrachium* sp. was obtained from a billabong similar to Georgetown on Boggy Creek.

The salts used in the tests were uranyl nitrate ($UO_2.(NO_3)_2.6H_2O$), copper chloride ($CuCl_2.2H_2O$), lead nitrate ($Pb(NO_3)_2$), zinc sulphate ($ZnSO_4.7H_2O$) and potassium permanganate ($KMnO_4$).

Throughout the experiments checks on the levels of toxicant in solution weremade using an atomic absorption spectrophotometer (Varian type 1000) to measure copper, lead and zinc and a u.v. spectrophotometer (Unicam type SP600). to measure uranium. The pH was held between 6.9 and 7.1, depending on the pH of the control water, and the temperature was held between 23°C and 25.5°C.

3.1.2 Fish census

A census of fish in the Magela Creek channel and also in Georgetown billabong was taken during June 1973. The creek was still running at this time. Areas were netted off and the internal volume was estimated after which the fish were intoxicated using 'Chemfish'. Any fish which floated to the top during the ensuing four hours were removed by hand net scooping and this was followed by seine netting in an attempt to recover those fish which sank.

3.2 Results

3.2.1 Acute toxicity testing

The results of the acute toxicity experiments are shown in Table 2. The graphs used in the interpolations are available for inspection from the author. The levels quoted are related to the initial toxicant added.

The scientific names for the test organisms are Striped grunter *(Amniataba percoides)*, Spangled grunter *(Madigania unicolor)*, Catfish *(Neosilurus* sp.*)*. The fry could not be identified. They were caught from schools in the shallow areas inhabited by hardyheads and are probably hardyheads of two species plus some *Nematocentrus* sp.

Hardyheads were also tested in solutions of $MnCl_2.4H_2O$ from 160 mg ℓ^{-1} down to 3 mg ℓ^{-1}. Solutions, above 40 mg ℓ^{-1} killed all the fish in 96 hours. Solutions between 40 mg ℓ^{-1} and 3 mg ℓ^{-1} killed about 40 to 50% in all cases. This anomalous result was attributed initially to permanganate ion formation, but subsequent experiments showed that this was not the case and further experiments using manganese should be done.

Hardyheads were tested for their survival in groundwater taken from both the Ranger No.1 orebody and the Koongarra orebody. They were also tested in water from Georgetown Billabong. After an exposure of six days the experiments were terminated; in all cases the fish were unaffected. Table 3 gives the concentrations of the major heavy metals contained in these groundwaters.

All the fish killed in the experiment with Alamine-336 died within the first 24 hours. At this time, all the fish in the lower concentrations were showing obvious distress but had completely recovered after 48 hours. A similar effect will be described in the section dealing with vegetation. These observations would point to a time effect, probably brought about by some chemical alteration, which reduces the toxicity of Alamine-336.

3.2.2 Fish census

The results of the fish census at Georgetown Billabong and Magela Creek are given in Table 4.

4. STUDIES ON GRASS SEDGE PLAINS

As mentioned earlier, grass and sedge meadows grow on the damp fine particled soils which surround many of the billabongs and these areas could become exposed to toxicants during floods. Typically these areas have a plant cover which consists of 80% grass *(Pseudoraphis spinescens)*, 20% sedge *(Fimbristylis denudata)* with some other species, mainly the water snowdrop *(Nymphoides minima)*. During the dry season the sedges remain green and are grazed by geese and buffalo.

4.1 Methods

Duplicate plots with areas of 1 m^2 each were laid out in Latin squares format on a typical plain and subjected by slurrying to fine sediment loads of 10 kg m^{-2}, 20 kg m^{-2}, 30 kg m^{-2}, 40 kg m^{-2}, 50 kg m^{-2} and 60 kg m^{-2}. Plant growth was followed by regular observation and photography. Natural grazing continued throughout the period of observation.

Other plots similarly laid out were watered with solutions of uranyl nitrate, copper sulphate, zinc sulphate and lead nitrate to give the following dosages:

- U^{++++} (50 g, 10 g and 1 g per m^2)
- Cu^{++} (10 g, 1 g and 0.1 g per m^2)
- Zn^{++} (10 g, 1 g and 0.1 g per m^2)
- Pb^{++} (100 g, 10 g and 1 g per m^2)

In each case the salts were neutralised before watering and the solutions were applied, at the rate of 5 litres per day at the maximum possible concentration, until the total dose had been given. Growth was recorded by photography. Two months after the first applications samples of grass and soil from the 0-3 cm and the 10-13 cm horizons were taken from the plots to which the highest doses had been applied. 190 points of rain had fallen prior to this sampling.

Plots were also dosed with the solvent Alamine-336, which was dispersed in water. Doses equivalent to 1 mℓ, 10 mℓ and 50 mℓ of Alamine-336 per m^2 were delivered in a single application.

All applications were to plots which had complete vegetation cover.

Because the Alamine-336 produced chlorosis in the trial plots laboratory work was started using unicellular algae (*Chlamydomonas* sp.). The cells were cultured in open flasks in a medium consisting of the following additives in each litre:

2.42 g tris buffer	0.022 g $ZnSO_4.7H_2O$
1.0 mℓ glacial acetic acid	0.011 g H_3BO_3
0.136 g KH_2PO_4	0.005 g $MnCl_2.4H_2O$
0.4 g NH_4Cl	0.005 g $FeSO_4.7H_2O$
0.05 g $CaCl_2.2H_2O$	0.0016 g $CoCl_2.6H_2O$
0.1 g $MgSO_4.7H_2O$	0.0016 g $CuSO_4.5H_2O$
0.05 g EDTA	0.0011 g $(NH_4)_6\ Mo_7O_{24}.4H_2O$

Alamine-336, kerosene and a mixture of 5% Alamine-336 in kerosene (V:V) were used as toxicants. In each case the toxicant was added to the medium and the combined solution shaken for three hours before the addition of the inoculum.

Duplicate cultures were incubated over saturating light from fluorescent tubes at 25°C and the progress of growth was followed by regular cell counts using a haemocytometer. Each flask was shaken for five minutes, three times per day.

4.2 Results

The fine sediment slurrying experiment showed that growth was not impeded on the 10 kg m^{-2} and 20 kg m^{-2} plots but was reduced on those which received 30 kg m^{-2} and 40 kg m^{-2}. Applications of 50 kg m^{-2} and 60 kg m^{-2} stopped growth completely.

The applications of heavy metal ions produced no discernible change in the areas treated. The levels of the heavy metals found in grass and soil in the plots receiving the highest doses are compared with those of the plots receiving no dose (controls) in Table 5. Results are single values obtained by mixing and splitting samples from the duplicate plots.

The roots of the plants in the plot could not be found deeper than 10 cm in the soil, so plants were exposed to the maximum dose presented. It can be seen from the table that with the exception of copper most of the heavy metals were found to be in the plants or on the leaves of the plants.

Alamine-336 applications produced chlorosis in all plots within a day of application from which the plots receiving 50 mℓ and 10 mℓ did not recover. The results of the laboratory examinations of Alamine-336 on *Chlamydomonas* are given in Table 6. The values presented are the average of the duplicate samples. They reveal a time delay in recuperation of the test flasks of the order of 24 hours for concentrations below 25 mg ℓ^{-1}. Also, it was observed that cells tended to clump and encyst when first exposed to Alamine-336 at these concentrations but divided freely again after the same period of time.

Both kerosene and 5% Alamine in kerosene affected the cultures at all concentrations investigated with a synergistic effect being evident in the mixture.

5. DISCUSSION

5.1 Aquatic Organisms

It was fortunate that the hardyhead was chosen as the standard test fish since it also proved to be the most sensitive. Its absence from Georgetown could be caused by water chemistry, since some of the heavy metal values shown in Table 1 appear higher than tolerable, but the six-day test in that water suggests that this is not so; many other factors such as increased turbidity, high temperature, presence of large predators, wallowing buffalo and the lack of shallow sandy areas could be involved.

The figures obtained for the 96-hour median tolerance limits reflect acute lethal effects only and some allowance must be made for long term chronic effects. This is usually done by multiplying the 96-hour TL_m by an 'application factor' which will reduce it sufficiently to take into account the latter effects. A recent review of the literature on this subject has been done by Sprague (1971).

The US philosophy in this regard, as set out by the US National Technical Advisory Committee (1968), suggests an application factor of 0.1 for samples taken at any time or place in the receiving stream and 0.05 in an average sample of the receiving water collected over 24 hours.

If one applies the application factor of 0.1 to the 96-hour TL_m for copper on hardyheads the result comes close to the natural level in the Magela Creek (Table 2). Natural levels of soluble heavy metals which are higher than would be allowed by this formulation have been measured at Georgetown, which is near a known ore body, and in Mudjinbarri Billabong which is not. All these high levels were measured during the last month of the dry season.

Minor fish kills were observed in the lagoons at this time, and also it became impossible to keep experimental fish alive in the laboratory for more than two days. Natural populations were stressed by a number of factors which included high temperatures (up to 35°C), reduced oxygen because of increased temperature, lowered water levels, low pH (down to 5.5) and an increase in dissolved heavy metals, all of which would increase their susceptibility to disease. Any addition of heavy metals at this stage would have been deleterious.

The study of application factors is being pursued to quantify them more closely. This sort of work, which takes into account sublethal effects such as growth rate, fertility, changes in behaviour, *etc.*, is difficult and requires long-term experimentation. It is hoped that changes in behaviour patterns may be used as a parameter to determine stress points in the exposure to toxicants.

The groundwater tests showed no effect on the fish after six days despite the fact that the metal ions were present in mixtures which would produce synergistic effects. This is probably due to the hardness of the water. Jones (1964) quotes work done on rainbow trout in which copper solutions made up with soft water (12 mg ℓ^{-1} as $CaCO_3$) proved toxic down to about 0.06 mg ℓ^{-1} Cu. The use of hard water (320 mg ℓ^{-1} as $CaCO_3$), however, raised the limiting concentration to about 0.6 mg ℓ^{-1} Cu.

In another work, Lloyd (1960), reported a decrease in the toxicity of zinc with a similar increase in hardness, and it has been shown that lead in harder waters tends to precipitate and becomes innocuous to fish (Water Pollution Research 1960).

Consideration of these phenomena has led the Canadian Department of the Environment to suggest a special set of application factors for use in fixing criteria for the discharge of copper (CDE 1972). Applying the Canadian criteria to the figures for copper quoted by Jones (1962) water could be discharged at 0.008 and 0.018 mg ℓ^{-1} Cu^{++} for water of hardness 12 mg ℓ^{-1} as $CaCO_3$ and for water of hardness 320 mg ℓ^{-1} as $CaCO_3$ respectively.

This means that further bioassays are needed in which copper and zinc are added to the groundwaters so that 96-hour median tolerance limits may be determined. Relevant application factors may then be applied which would allow for sublethal effects.

The tests of groundwater to date only apply to water from 45.7 m (150 ft) depth and above. Water from deeper levels, which will be encountered as the pit deepens, will most likely change in character and may become saline.

5.2 Vegetation Studies

The tests carried out were qualitative only and the experiment does not duplicate the conditions which would prevail when the plants are emerging after the wet season. However they give a strong indication that the plant systems are less sensitive than fish since the doses delivered were two orders of magnitude above those which would be deleterious to fish, assuming that the plains were flooded to a depth of 2 m.

Since the grasses and sedges are shallow rooted, the effect of long term buildup at levels of discharge based on fish toxicity would also be taken into account. The effect on deeper rooted species such as paperbark trees (*Melaleuca* sp.) cannot be predicted.

The toxicity of Alamine-336 to phytoplankton is again adequately covered by the levels for fish (*i.e.* 2 mg ℓ^{-1} for chronic exposure) but the combined effect of kerosene and Alamine-336 has not been defined. The latter effect together with the reduced toxicity of Alamine-336 after 24 hours will be investigated both with *Chlamydomonas* and fish.

6. ACKNOWLEDGEMENTS

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TABLE 1

COMPOSITION OF SOME NATURAL WATERS

Component		Magela Creek (mg ℓ^{-1})	Georgetown Billabong ($\mu g\ g^{-1}$)		Mudjinbarri Waterhole ($\mu g\ g^{-1}$)	
			Average	Peak*	Average	Peak*
Uranium		0.0004	0.04	0.7	0.03	0.17
Copper		<0.005	<0.05	0.160	<0.06	
Zinc		0.03	0.05	1.0		
Lead		0.03	0.03	0.050	<0.02	
Silicon		0.002	11	19		
Iron		0.4				
Calcium		0.58	1.5	2.2	0.32	
Magnesium		1.07	3.0	8.0		
Manganese		0.04				
Potassium		0.7	3.0	4.0		
Sodium		4.3	7.5	10.0		
Suspended solids		8.4	~1,000†		10	22
Hardness (as $CaCO_3$)		10	16			
Temperature (°C)	May	25.3				
	July	23.9	27.5			
	Sept	25.5	30.0			
	Dec	38.0	39.0			

* *Peak values found in November and December.*

† *Result of two values only.*

TABLE 2

RESULTS OF ACUTE TOXICITY TESTS

Organism	96 hour TL_m (mg ℓ^{-1})							Average Body Weight (g)
	U	Cu	Pb	Zn	(MnO_4)	Raffinate (Neutral)	Alamine 336	
Hardyheads	4.0-4.5	0.04	0.18(22)	0.14	22	88×10^3	18	1.1
Fry	3.7*(39)	0.08*(1)	2.1*(6)	0.3*(1)				0.23
Striped Grunter	2.5(14)	>0.1(10)	>0.3(18)	0.2(0)				6.7
Spangled Grunter	4.1	>0.1	>0.3	>0.2				22.5
Catfish	72†							37.1
Macrobrachium sp.	>5(3)	0.17(6)	0.5(30)	0.43(11)				0.25

( ) *Bracketed figures are average % loss of toxicant during the experiment.*

* *48 hour TL_m.*

† *Catfish taken from Georgetown Billabong.*

TABLE 3

CHEMICAL COMPOSITION OF GROUNDWATERS FROM KOONGARRA AND RANGER OREBODIES

Component	Koongarra Borehole near Costean No. 1 ($\mu g\ g^{-1}$)	Ranger Borehole S1/2 ($\mu g\ g^{-1}$)
Uranium	0.04	0.13
Copper	<0.04	0.02
Zinc	0.03	0.04
Lead	0.002	0.02
Hardness (as $CaCO_3$)	118	276
pH (Units)	7.3	7.1
Radium ($pCi\ \ell^{-1}$)	17	130

TABLE 4

FISH CENSUS RESULTS* (14 AND 15 JUNE 1973)

	Number of Individuals (No. per 180 m^3)		Mass per Individual (g)	
	Magela Ck.	Georgetown	Magela Ck.	Georgetown
Fluviolosa erebi	50	10	23	25
Ambassis macleayi	28	204	0.6	0.7
Toxotes chartareus	12	3	11	11
Amniataba percoides	64	16	8.2	10
Madigania unicolor	39	22	15	24
Synbranchus bengalensis	1		2	
Pseudomugil sp.	2		0.2	
Glossamia aprion	26	31	5.4	11.5
Neosilurus sp. (blackfin)	19	11	12.8	30.3
Neosilurus sp. (yellowfin)	13	82	12.6	15.0
Strongylura kreffti	10	3	57	35
Oxyeleotris lineolatus	19	20	7.6	154
Therapon sp. (black anal fin)	16		8.8	
Mogurnda mogurnda	17		2.8	
Craterocephalus marjoriae	20		0.8	
Nematocentrus maculata	16	45	1.3	1.4
Craterocephalus worelli	11	1	0.3	0.5
Melanotaeniid sp. (? Nematocentrus)	15		0.6	
Denariusa bandata	7	0.5	0.4	0.4
Glossogobius giuris		0.5		0.5
Hexanematichthys leptaspis		1.5		31
Scleropages jardini, *Megalops cyprinoides*, *Lates calcarifer*, *Mogurnda mogurnda* — were subsequently caught in Georgetown outside the netted area				

* *These results are for a single census only.*

TABLE 5

LEVELS OF HEAVY METALS IN GRASS AND SOIL

	U ($\mu g\ g^{-1}$)	Pb ($\mu g\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)	Zn ($\mu g\ g^{-1}$)
	Fresh Weight	Fresh Weight	Fresh Weight	Fresh Weight
Grass (dosed)	4,750	5,770	124	875
Grass (control)	0.008	1.8	0.7	3.2
	Dry Weight	Dry Weight	Dry Weight	Dry Weight
Soil 0-3 cm (dosed)	152	760	242	162
Soil 0-3 cm (control)	2	90	25	50
Soil 10-13 cm (dosed)	17	335	24	40
Soil 10-13 cm (control)	7	21	8	20

TABLE 6

CHLAMYDOMONAS CELLS SURVIVING (AS A PERCENTAGE OF CONTROL) IN MIXTURES OF ALAMINE-336 KEROSENE AND 5% ALAMINE-336 IN KEROSENE

Elapsed Time (hours) / Concentration (mg ℓ^{-1} V:V)	22			46			70			94			166		
	al	k	k+al	al	k	k+al	al	k	k+al	al	k	k+al	al	k	k+al
45	41			11*			9*			8*			8*		
40	43	68	49	11*	39	13*	9*	53	9*	8*	52	9*	8*	60	9*
35	39	59	41	13	31	11*	11	32	8*	29	42	8*	98*	46	8*
30	59	63	36	83	35	10*	81	36	7*	92	38	7*		45	7*
28	40			29			78			78			90		
25	69	70	65	97	59	51	92	69	37	106	71	39		68	
20	75	65	70	101	75	62	105	68	33	100	63	55			
15		74	66		99	74		75	47		88	64			
12	79			113			91			112					
10		68	65		94	66		81	46		88	60			

al *Alamine-336.*

k *Kerosene volume equivalent to 5% Alamine-336 in Kerosene.*

k+al *5% Alamine in Kerosene (V:V) to give quoted concentration of Alamine-336 alone.*

* *Dead cells only remaining in culture.*

THE ALLIGATOR RIVERS AREA FACT FINDING STUDY

REPORT III

ENVIRONMENTAL STUDIES
NORTHERN TERRITORY URANIUM PROVINCE
1971/73

by

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1. INTRODUCTION

The environmental study programme for the Alligator Rivers area of the Northern Territory initiated by the AAEC in November 1971 had five primary aims:

- To extend the geographical area for which the basic data on the toxicity of a range of potential contaminants for aquatic organisms is applicable. The toxicity work (Part II of this report) was carried out predominantly with waters from the Magela Creek catchment; water quality parameters (pH, hardness, temperature, levels of calcium, magnesium, iron, *etc.*) provide the connecting link to other catchments.
- To determine the capacity of potential local mine environments for the range of waste constituents. The toxicity studies lead to the specification of maximum permissible concentrations for the contaminants considered. The differences between these levels and those occurring naturally are the capacities of that environment for the waste constituents.
- To provide conservative estimates for the fate, in a geobotanical and geochemical sense, of discharged wastes. As the maximum permissible concentrations for the waste constituents are of the same order as naturally occurring levels, a study of the latter provides a good indicator of what will happen to the former. A prerequisite for this approach is a knowledge of the mineralisation in the area.
- To determine biological reconcentrating mechanisms. This is achieved by measuring the concentration of elemental constituents of each trophic level in the biosphere. This 'base-line' data also provides a valuable check of any long-term buildups arising from development programmes.
- To specify exposure routes as a consequence of which discharged radioactivity would lead to the exposure of man and other elements of the biota. This is a prerequisite to the calculation of allowable discharge limits for radioactivity.

Any survey programme includes some compromise with respect to sampling location, frequency and the list of chemical analyses carried out on each sample. For the water quality work, the Department of Northern Territory (DONT) and AAEC programmes were combined; DONT collected samples during the wet season and the AAEC during the dry season. The wet season sampling was more dispersed and, for each site, less regular than that for the dry season which was more or less restricted to areas up and down stream of known uranium mineralisation. In particular, many permanent wet land sites were included so that changes in water quality during the dry season could be followed.

Whereas DONT carried out their normal water quality measurements on each sample, the AAEC analytical programme was restricted to those elements believed to be potential contaminants from a uranium extractive industry. This selection was guided by the results from the *ad hoc* experiments detailed in Appendix A. All water samples handled by the AAEC were filtered (0.43 μ Millipore papers) and the filtrate and sediment analysed separately.

About 500 water samples were processed by DONT and around 1,500 samples by the AAEC for a grand total of some 24,000 analytical determinations. Each organisation is reporting separately on its results.

It is not the purpose of this paper to present the AAEC's data in detail (an output from a line printer or card punch is available on request). Instead, only a selection of data is included to illustrate the more important characteristics of the Alligator Rivers environment.

2. GENERAL DESCRIPTION OF THE AREA

The rainfall of the area is strongly seasonal. It is negligible between April and October, then builds up steeply to high monthly averages in January and February, and drops after March even more steeply than it rises. In contrast to the seasonal fluctuations of the rainfall, temperatures are relatively even and high. Evaporation is substantial and a free water surface would, averaged over a year, show a loss of some 2.17 m after a rainfall of 1.33 m.

Three major physiographic units are present: alluvial valleys and plains, low hills and ridges and the escarpment backed by the Arnhem Land plateau.

The alluvial material varies from extensive sand deposits in the valleys of the rivers draining the sandstone plateau to subcoastal black soil plains in the lower reaches. The plains, of gradient 1 in 2,000, are subject to annual flooding which, in places, is to a depth of about 2 m for a period of up to six months.

On the steeper slopes and narrow alluvial flats streams are markedly seasonal and during the seven months' dry season few continue to flow. Despite this, water tables remain high.

The dissected escarpment rises vertically to 200 m forming steep sided gorges with numerous waterfalls during the wet season. On the plateau the high and fluctuating water table causes marked subsurface weathering of the rock. The land systems of much of the region have been described by Story *et al.* (1969).

The drastic change in climate largely determines the ecology of the area. Plant species must be able to tolerate waterlogged conditions during the monsoons as well as the dry conditions which follow. On the plain, reeds flourish during the wet season, but the ground subsequently becomes bare with severe cracking to polygons about 25-30 cm across, the cracks being up to 15 cm wide. The plains are of immense importance to magpie geese *(Anseranas semipalmata)*. Conservation of the black soil plains is a prerequisite to the survival of this species (Frith 1967). Large herds of water buffalo also graze the plains which are held as pastoral leases and support two abattoirs - Mudginbarri and Oenpelli - as well as mobile plants. Mudginbarri draws process water from Magela Creek.

Closely associated with the flood plains, but topographically separated from them, are long shallow depressions with uncoordinated drainage, that are permanently waterlogged and under water weed and paperbark *(Melaleuca leucadendron)*. These swamp areas provide valuable dry season refuges for waterfowl. The Woolwonga reserve contains a large area of such swamps.

Further upstream discrete zones of vegetation can be seen clearly when the floodwaters recede. Away from the stream there is first a sedge meadow then a strip of paperbarks followed by a zone which includes *Pandanus* and *Eugenia* sp. (native apples). Beyond this is a small grassy plain which gives way to a *Eucalyptus* woodland as the ground rises.

Two main types of billabong are seen. Class I has a sandy bottom, steep sides and is usually the larger; it is generally parallel to the main river course and could be remnants of former river systems. Class II, which has a substrate of impervious fine particle black clay and gradually sloping sides generally exists when a condition of back flow of flood water prevails. Class II billabongs develop more extensive sedge meadows on the margins during the dry season and the water becomes turbid and warmer. Commonly, the bottom muds become anaerobic and a dense layer of microalgae forms on the top in the warmer areas with water temperatures from 32°C. Water temperatures reach 40°C by the end of the dry season.

At the end of the dry season, billabongs of Class I are clearer and cooler and present a more moderate environment. Barramundi, a popular sporting and commercial fish, spawn in the estuaries and migrate to the fresh water river/billabong system as juveniles during the next wet season. They may remain in the billabongs for many years, preying on a great variety of smaller fish and crustacea.

3. COMPARATIVE WATER QUALITY OF PERENNIAL STREAMS AND ASSOCIATIONS

The perennial streams with their associations harbour the breeding stock of aquatic organisms during the dry season. During the subsequent wet season breeding is prolific and the geographical dispersion is extensive. Conservation of the perennial streams and associations is therefore crucial to the preservation of the diversity of aquatic organisms.

3.1 Perennial Springs

Three groups of perennial springs exist in the area. Group I has low flow rates (< 1,000 m^3 day^{-1}) and takes the form of seepage at the foot of the escarpment. Dense vegetation is very localised and the forest floor has a high organic content. The distribution coefficient for thorium from water to soil is high so that selective absorption of thorium-230 from the water transported uranium series occurs and this in turn leads to higher than average values of radium-226 and its daughters in the forest floor soil. The concentration of radium-226 drops off rapidly with soil depth (a factor of 10 over 25 cm) and the radium-226/lead-210 ratio indicates that about 50% of radon-222 is lost to the atmosphere. Within a time scale determined by the lead-210 half-life (~20 y), there is no evidence for differential ionic movement of lead and radium. The organic debris has levels of copper, lead and cobalt a factor of 5-10 higher than that of the underlying sandy soil strata but this is more likely to be related to concentrating mechanisms by vegetation than to any selective adsorption process within the soil. Elsewhere in this report, these areas will be described as peat anomalies. Table 1 compares the water quality of this group of systems. Table 2 indicates the ionic distribution with soil depth for one of them. Here, as elsewhere, a single valued result indicates an average; a value range indicates a suspected seasonal variation.

The second group of perennial springs are associated with gorges in the escarpment and involve a large number of independent seeps. The dam providing drinking water to Oenpelli is fed by a spring of this group. They differ from perennial creeks only in their radon-226 content which is up to a factor of 10 higher.

Leichhardt Spring (map coordinates 3-668862) is the only known spring of the third group. Physically the flow (~10,000 m^3 day^{-1}) is predominantly from a single fault so that the stream and associated vegetation develops spontaneously. Chemically, it is more mineralised (Cu: 0.04 mg ℓ^{-1}), and has a lower pH (5.1) during the dry season than the other springs. This site was not included in the fish survey work but interesting *Macrobrachium* diversity has been reported by others. Because of the associated vegetation the sediment from the creek has a high organic content (> 10%) with good exchange characteristics.

3.2 Perennial Streams

The East Alligator River, Tin Camp Creek, Magela Creek and Sawcut Creek are perennial in their upper reaches. Only the last mentioned was included regularly in the AAEC sampling programme, but adequate samples were taken within the DONT-AAEC programme to attain meaningful comparative results.

3.2.1 Water quality

Table 5 summarises the water quality of the perennial streams. An indication of the seasonal variation in the water quality of perennial streams is given in Table 6.

Tables 5 and 6 illustrate several generalisations that hold for the permanent wet lands of the area.

Radium levels in the water tend to rise during the dry season but at no stage are the changes dramatic. By contrast, uranium levels rise significantly during the dry season in the permanent streams and dramatically in the permanent billabongs (see Section 3.3.2). With the limits of detection for the analytical methods used, no conclusions can be reached on the seasonal trends in the concentrations of the other heavy metals in perennial streams.

For the perennial streams with their predominantly sandy bottoms and fairly dense bank vegetation, the exchange characteristics of the bottom sediments are very variable. With this qualification, the indicated distribution coefficient (K_d) for radium, uranium, copper and lead is of the order of 1,000, 1,000, 10 and < 100 respectively. Note that these values would apply only to a well oxygenated, soft water situation.

The suspended solids remain low throughout the year (~5 mg ℓ^{-1}) and, as such, contribute no more (and generally very much less) to the total heavy metal load of the watercourse than do the dissolved solids.

3.3 Class I Billabongs

In the main it is only the billabongs with steep sides and sandy bottoms (Class I) that harbour, during the dry season, significant aquatic breeding stock for the next wet season. Five such billabongs were sampled routinely.

3.3.1 Comparative water quality

The water quality of the Class I billabongs is given in Table 7. The figures given in brackets under 'uranium' *etc.* are values recorded at that site during November/December 1972. The unbracketed values are the averages for the remainder of the year.

3.3.2 Seasonal variation

The waters of Class I billabongs contain, as do the perennial streams, large quantities of dissolved and suspended organic material which lead to a brown tannin colouration and renders it acidic. The water is poorly buffered so the pH can fluctuate rapidly.

The most striking seasonal variation in water quality is the order of magnitude change that occurs in the uranium concentration at the end of the dry season. This is illustrated by Table 8.

The contrast between dissolved uranium levels for November 1971 and November 1972 was common throughout the area. Thunderstorm rainfall was frequent during October/November 1971, but during 1972 there was little or no rain until mid November. As a result the November 1972 water levels were lower, the temperatures higher and algal blooms more common. With less free water available to stock and waterfowl it is probable that billabongs were much more turbid at the end of 1972 than at the end of 1971. (At site 1-196402 suspended solids were less than 5.2 mg ℓ^{-1} through September. By early November the value was 45 mg ℓ^{-1}.)

3.4 Magela Channel

At the end of August 1972, the Magela channel was continuous from Leichhardt Billabong (4-688187) to the Magela swamps (~4-650300). By early November only isolated pools remained and the Magela swamps were dry. As a result of waterfowl, catfish and buffalo activities, the Magela channel waters are always very turbid (> 1,000 mg ℓ^{-1} suspended solids) but the barramundi, catfish and sleepy cod populations seem unaffected. Water temperatures are always high and reached 40°C during 1972.

Only two sections of the Magela channel were sampled regularly - Ja Ja Lagoon (3-705147) and a section a little downstream from Ja Ja (3-708157). Infrequent sampling of other locations was also carried out. Table 9 summarises the results.

The poor quality of Ja Ja Lagoon by the end of the dry season is indicated in Table 10.

3.5 Class II Billabongs

This class of billabong has a saucer shaped depth contour, a clay substrate and fairly extensive sedge meadows that give way to paperbark. They provide an important refuge for geese towards the end of the dry season as well as being a waterhole for wildlife and stock.

The clay substrate is quite impervious to water and, in contrast to the Class I billabongs, they are hydrologically isolated from the water table. Evaporation/transpiration water losses do not vary substantially during the dry season. For example, at Boggy Creek waterhole (3-701027) the average weekly water loss was:

6 July to 14 August 72	5.6 cm
14 August to 2 October 72	6.7 cm
2 October to 6 November 72	6.6 cm

At least through until early October these losses are about 1 cm per week less than that from Class I billabongs *e.g.* Indium Pool (3-738985) had the following losses:

8 June to 9 August 72	7.1 cm
9 August to 8 September 72	6.7 cm
8 September to 27 September 72	7.0 cm
27 September to 11 October 72	6.7 cm
11 October to 24 October 72	6.0 cm
24 October to 5 November 72	5.8 cm.

Almost invariably the Class II billabongs are associated with, and probably result from, back flow conditions during the wet season. In turn this leads to significant deposition of organic debris and natural eutrophication. Prolific water lily growth occurs in the early part of the dry season, and the bottom muds are anaerobic by November.

Within this class of billabong there are two sub-classes (A and B) which differ in not having or having a perched water table associated with them.

3.5.1 Water quality of Class IIA billabongs

This class of billabong, being completely hydrologically isolated, is most variable with respect to permanency of water. The sampling programme, based on November 1971 observations, was meant to include systems of this class for each known area of uranium mineralisation. In fact, several of the selected sites had dried out completely by September 1972. A summary of the water quality for this class is presented in Table 11. Again, the figures in the brackets indicate the extreme values recorded in November.

These systems are very turbid and, by November, are maintained at about

2,500 mg ℓ^{-1} of suspended solids by feeding geese.

3.5.2 Water quality of Class IIB billabongs

Only two billabongs were positively identified as being of this type - Georgetown (3-752974) and the junction of Boggy Creek and the tributary draining the regional centre (3-690002). In terms of water quality, the ingress of water from the associated perched water table causes these billabongs to be similar to the Magela channel rather than to billabongs of type IIA. They also harbour significant aquatic breeding stock during the dry season. Table 12 summarises the water quality of these systems and Table 13 presents the seasonal variation of one of them (Georgetown).

4. SOLUBILITY OF URANIUM HELD IN SEDIMENTS

There were two man-made reservoirs, of age less than one year, in the area at the start of the sampling programme. Gauge board logging established that their water losses were substantially the same as natural systems so their seasonal variation in water quality is of interest. The basic difference between these dams and natural counterparts are no fouling by buffalo, no feeding by waterfowl and a very low aquatic biomass. Results are presented in Table 14.

To some extent dam 1-184378 is a special situation; during late 1971 it was used to supply cooling water to diamond drills and there is little doubt that much soluble radium-226 and possibly some uranium ore chips were transported to it as a result. Nevertheless, it seems clear that these systems also show dramatic changes in uranium levels towards the end of the dry season. These observations support the belief that anaerobic conditions develop at the mud/water interface, destroy the oxidised microzone and thereby liberate the uranium held by the microzone as adsorption complexes.

For this explanation to hold, soluble ferrous iron, manganese and uranium would need to parallel each other with perhaps some time lag at least between a significant increase in manganese and that for iron. Table 15 combines DONT's data on total iron with the AAEC's uranium and manganese data for some samples collected during November 1972. While the trend is as expected, detailed analysis is not possible because the iron data refers to total iron (ferrous plus ferric).

5. FATE OF DISSOLVED TRACE ELEMENTS

For discharged wastes to be environmentally acceptable, not only must their concentration at the point of discharge be non-toxic to aquatic organisms and the associated vegetation fringe, but also their ultimate fate must be such that long term buildup mechanisms do not lead to any insidious effects.

Within the Alligator Rivers area at least four potential buildup areas exist.

Neither the Magela nor Nourlangie Creek systems are continuous in their lower reaches. Their flood plains are therefore sinks for much of the dissolved and suspended solids carried by the river systems during the wet season.

Class II billabongs, with their associated backup of floodwater during the wet season, could also accumulate contaminants by sedimentation and adsorption.

Closely associated with the flood plains, but topographically separated from them, are long shallow depressions with uncoordinated drainage that are permanently waterlogged, and under water weed and paperbark. These areas too are potential waste accumulators.

5.1 Water-Soil Transfer

5.1.1. Magela Plains

Composite soil samples to 1 m depth were collected from the Magela Plains area. Results of analyses on these are presented in Table 16.

The trend of the results suggests the following:

(a) Lead-210 is in disequilibrium with its uranium parent being about twice as plentiful.

(b) There is an apparent source of copper mineralisation near the region with map co-ordinates 4-270240.

(c) The main source of uranium to the plains is from the south but it becomes reasonably dispersed over the plains area.

(d) The calcium magnesium ratio of the soil has little effect on trace element adsorption.

(e) Zinc is the most mobile of the heavy elements studied and is most likely to have highest concentration at the fringe of the flood plain.

(f) The range and distribution of lead levels are near normal for a sedimentary plain.

Some trenches were also dug and the vertical distribution of trace elements determined. Results are given in Table 17. If the reasonable assumption is made that the heavy metal input to the Magela Plains is predominantly from the south, then the following generalisations follow:

(a) There is no marked change in heavy metal content down the Magela channel, nor of the channel bottom in comparison with the levee bank.

(b) Disequilibrium exists between uranium-238, radium-226 and lead-210 the approximate ratios being 1:2:3. As the curie ratio of uranium: radium for water entering the Magela Plains is about 1:8 in the filtrate and about 1:1 for the filtrate plus suspended solids, there must be some loss of uranium bearing sediments before the Magela Creek water reaches the black soil plains. An 'external' source (presumably radium in the groundwater) of radon-222 is also indicated.

(c) The results are consistent with the hypothesis that a mixing mechanism for deposited sediments is operative and that the mixing mechanism has a time period that is short by comparison with the time variation in fallout caesium-137 deposition. For a non-cracking clay soil, caesium-137 levels decrease rapidly with increasing soil depth.

During the wet season, the presence of geese and buffalo ensures that the flood waters over the plains are turbid. Conditions are ideal for adsorption onto the clay particles of any dissolved heavy metals. It is thought that this adsorbed material will remain near the surface during the subsequent dry season but that the early showers of the next wet season will transport it into the large cracks that have developed in the soil profile by this time. In such a situation pollutants introduced to the plains area do not accumulate near the surface but instead are fairly uniformly mixed through 1-3 m of black clay (*i.e.* to the depth of the cracks).

Almost all of the soil samples were also assayed by gamma spectroscopy. The average result and standard deviation of these analyses of the Magela Plain soil samples were:

Gamma Energy (MeV)	0.05	0.25	0.35	1.1
Radioactivity (arbitrary unit)	34	3.3	17.5	7.3
Standard deviation	4.6	0.5	2.7	0.8

The reasonably constant percentage standard deviation and its relatively low value provide further evidence that the natural radioactivity entering the system is distributed fairly uniformly through the flood plain soil and that no preferential movement of any radon daughter occurs.

5.1.2 Woolwonga Plains

It is expected that much of any contaminant load carried by Koongarra

Creek will be deposited in the flood plain where Koongarra Creek joins Nourlangie Creek. For this reason the Woolwonga Plains are less likely to be contaminated than the Magela Plains and accordingly were sampled in less detail. The sampling was restricted to those parts of the plains with local depressions of 20-50 cm, grey in colour, and having fine (7 cm x 7 cm) matrix cracking (scald areas), to the bed of Nourlangie Creek and to its levee banks. The results are given in Table 18. What variation there is, is not obviously related to the class of soil sample.

5.1.3 Class II billabongs

As the water recedes in Class II billabongs soluble pollutants could be adsorbed onto the clay sediments quite efficiently because of the high sediment/solute ratio. As a check on this, soil samples (1 m depth composites) were collected from longitudinal (S-N) and transverse (E-W) transects of Georgetown Billabong during November 1972 when the system was almost dry. Results are presented in Tables 19 and 20.

The apparent low metal content of the soil from the transverse extremity is partly attributed to the paperbark tree growth that occurs there, and the type of soil. The results indicate that there is no marked preferential absorption/adsorption of ions from the water by the soil at the receding water line.

Although few samples were collected, indications are that the vertical mixing of uranium through the soil profile is less complete for Class II billabongs than it is for the black soil plains. For example, the back flow area in the tributary draining the regional centre had the following distribution:

Depth (cm)	Concentration in Ash							
	pCi g^{-1}			mg ℓ^{-1}				
	U	Ra	^{210}Pb	Cu	Zn	Pb	Ca	Mg
Surface	2.5	1.7	2.4	6.2	3.8	19	160	250
50	1.2	0.6	2.3	6.1	2.8	19	100	100

Analyses on sedge meadow soil samples collected from elsewhere in the area are shown in Table 21.

5.1.4 Swamp depressions

Only the swamp depression associated with the Magela black soil plains was studied. Results are given in Table 22.

At the shallow (W, 4-600276) of this swamp, a transect of the sedge soil yielded the results shown in Table 23.

In terms of known mineralisation, the major input of heavy metals would be expected from the east. However the results indicate that for surface and near surface samples (soil, sediment, macroalgae), a well mixed situation can be assumed. It is only the more deep-rooted paperbarks that provide an indication of the source of uranium.

5.2 Soil-Vegetation Transfer

Plant materials,and not the water or atmosphere, provide the main source of minerals to animals and people. The factors influencing the trace element content of plants are, therefore, major determinants of dietary intakes of these elements. The concentration of all minerals in plants depends on five basic, interdependent factors: the species of plant, the soil on which it has grown, the seasonal conditions, the stage of maturity and the mineral content of water.

Thus Beeson is reported by Underwood (1971) as investigating seventeen grass species grown together on a sandy loam soil and sampled at the same time, and finding the cobalt concentration to range from 0.05 to 0.14, the copper from 4.5 to 21.1 and the manganese from 96 to 815 $\mu g\ g^{-1}$ (dry basis).

Plants react to a lack (or excess) of an available element in the soil, either by limiting their growth, by reducing (or increasing) the concentration of the element in their tissues or, more usually, by both at the same time. The amount of certain plant-extractable trace elements are often much greater on poorly drained than on well drained soils of the same association. Underwood (1971) reports that cobalt, nickel and molybdenum are markedly influenced by this condition whereas copper is not. In several cases the cobalt content of plants on waterlogged soils was 10-20 times greater than that of the controls. The uptake of trace elements by plants is influenced further by the acidity of the soil. Cobalt, nickel and, to a smaller extent copper and manganese, are poorly absorbed from calcareous soils, whereas molybdenum absorption is greater from such soils than from those which are acid. Most investigators have observed a fall in copper, zinc, cobalt, nickel and molybdenum with advancing maturity. Our very limited results indicated the reverse.

5.2.1 Pasture grasses

No attempt was made to sample specific pasture grasses. The collection method was to further crop those grasses that had been cropped by buffalo. Some results are presented in Table 24. The first three sampling sites were the Class II billabongs associated with Ranger I Anomaly, Baroalba Creek and the Jabiluka Anomaly. With this limited number of samples firm conclusions are impossible. There is however a suggestion that the grasses are discriminating against uranium.

5.2.2 *Pandanus* palms

The ripe fruit from *Pandanus* palms were sampled to see if they would provide a convenient indicator for water quality of the associated stream and as a check on concentrating mechanisms since they are eaten by Aborigines. Table 25 summarises the results. The coordinates given are those for the nearby water sampling site. An inspection of results obtained from samples collected during November 1971 and November 1972 did not reflect the dramatic difference in uranium content of the water between these two periods. Further, samples taken down the Magela channel showed no significant variation in heavy metal content. Accordingly, in preparing Table 25 averaging was carried out wherever possible. It is concluded that *Pandanus* fruit is a worthwhile biological indicator for copper and zinc but that it would not be a significant source of trace element nutrition.

5.2.3 Paperbarks *(Melaleuca Leucadendron)*

Results presented in Table 22 suggest that paperbark leaves might provide a measure of the uranium content of the groundwater and soil beneath their base. Evidence of this is provided from samples collected along the west bank of Georgetown Billabong, results for which are presented in Table 26. A comparison of these results with those for nearby soil samples (Table 19) shows that for uranium, but not for other heavy metals including radium, the content of the leaves parallels that of the soil.

Table 27 presents results for paperbark leaves sampled from the fringe of the Magela black soil plains. Note that those samples with the higher uranium content lie on a line joining the Magela channel area to the Magela Springs area.

Within the Alligator Rivers area, the Magela Springs is about the only area of permanent water, outside of Woolwonga, that persists during the driest of dry seasons. In November 1972 the density of geese in Woolwonga at Nourlangie Creek near its junction with the South Alligator River was about the same as that at the Magela Springs area. Further work to better define the origin of the spring water seems warranted.

5.2.4 Cultivated Vegetables

A pilot scale market garden was set up at Jabiru. The crops were raised from seed with normal practices. All watering was done with water from the local bore supply which was periodically analysed for heavy metal content. The crops were harvested at maturity and subsequently analysed for heavy metals. Results are presented in Table 28.

With respect to the incident water (uranium = 1 pCi ℓ^{-1}; radium-226 = 3.0 pCi ℓ^{-1}) several of the vegetables grown exhibited substantial biological concentration factors. The radiological significance of the uranium and radium results will be discussed in Section 6.2.4. For the remainder, bearing in mind the relative human consumption of water and vegetables and the low concentration of heavy metals acceptable to aquatic organisms, only the concentration of lead by Chinese cabbages needs further investigation in terms of the variation in concentration factor with pollutant load of the irrigation water (see Appendix B for general discussion).

5.2.5 Native fruits

Native apples *(Eugenia* sp.*)* and native figs *(Ficus henneana)* are eaten by Aborigines. As a check on possible biological concentrating mechanisms, samples were collected in season. Results of analyses are given in Table 29. The location refers to the nearest regular water sampling point.

The radiological significance of the uranium and radium results is discussed subsequently; for the remainder, no significant concentrating mechanism is involved.

5.2.6 Water lily *(Nymphaea* sp.*)*

Water lilies are not convenient biological indicators for water quality, in part because soil remnants are difficult to remove from the root system and in part because they are not widely distributed by the end of the dry season.

Lily stems are eaten by Aborigines and some sampling was done with this in mind. The results are presented in Table 30. The radiological significance of these results is discussed subsequently; the heavy metal contents are of no consequence.

5.2.7 Eucalypt

A knowledge of the radioactive element content of eucalypt leaves is needed for an estimate of the radiation dose consuming insects would receive. More importantly, deep-rooted trees could provide a biological monitor for sub-surface loss of embanked wastes generated by uranium milling operations. To evaluate both these factors, leaves of stringybark *(E. tetradonta)*, bloodwood *(E. bleeseri)*, and woollybutt *(E. longifolia)* were collected from areas of known uranium mineralisation and from areas believed to be barren in mineralisation. Results are presented in Table 31. Asterisked columns represent averages of two or more samples. It appears from these results that eucalypt leaves could prove useful in supplementing bore holes in monitoring for seepage losses from tailings embankments.

5.3 Plant-Animal Transfer

The functional forms of the trace elements and their concentrations must be maintained within fairly narrow limits if the growth, health and fertility of animals are to remain unimpaired. Underwood (1971) has reviewed this topic in detail and the following summary is from that source.

Copper. In Western Australia, sheep and cattle grazing pastures containing 3-4 $\mu g\ g^{-1}$ copper or less, and with molybdenum concentrations usually below 1.5 $\mu g\ g^{-1}$, exhibit a wide range of copper deficiency symptoms and subnormal concentrations of copper in the liver. Pastures containing 4-6 $\mu g\ g^{-1}$ dry weight, and similarly relatively low in molybdenum, provide sufficient copper for cattle.

Copper and molybdenum are antagonistic and the action of molybdenum in blocking the metabolism of copper is augmented by high levels of sulphate. Pastures in parts of England containing 7-14 $\mu g\ g^{-1}$ copper (dry weight) can result in subnormal status in cattle.

In all animals, the continued ingestion of copper in excess of requirements leads to some accumulation in the tissues, especially in the liver. Sheep are the most susceptible of all domestic livestock to copper toxicity, pasture with 10-15 $\mu g\ g^{-1}$ copper and 0.1-0.2 $\mu g\ g^{-1}$ molybdenum (dry weight) inducing chronic copper poisoning. Cattle appear to be less so and copper pasture levels as high as 80 $\mu g\ g^{-1}$ could be acceptable.

For a given set of conditions, the copper content of cattle tissue exhibits marked individual variation. On a normal diet, the copper content of cattle flesh, kidney and liver is in the region of 3, 20 and 200 $\mu g\ g^{-1}$ (dry weight). For twenty three beasts on a normal diet, the liver content ranged from 23 to 409 $\mu g\ g^{-1}$ and for fifty one beasts on a copper deficient diet, the range was 3 to 32 for an average of 11.5 $\mu g\ g^{-1}$.

Cobalt. The vitamin B_{12} is the functional form of cobalt in ruminant metabolism and cobalt deficiency is, in effect, a B_{12} deficiency. The distribution of retained cobalt varies little between species and is of the order of 0.25 in the kidney, 0.15 in the liver and 0.1-0.2 in tissue for animals on a normal diet. Under a cobalt deficient diet, levels drop to 0.02-0.05 $\mu g\ g^{-1}$ (dry basis). Under grazing conditions, lambs are the most sensitive to cobalt deficiency, followed by mature sheep, calves and mature cattle in that order. Pastures containing 0.07-0.08 μg g^{-1} cobalt in the dry state appear to be just adequate for sheep and cattle. Cobalt has a fairly low order of toxicity in all species. A dietary intake of 150 μg g^{-1} cobalt can be tolerated by sheep for periods of at least eight weeks without harmful effects.

Zinc. The minimum zinc requirements of sheep and cattle vary with the criteria of adequacy employed and, apparently, also with the type of diet consumed. Different workers have reported that signs of zinc deficiency, responsive to zinc treatment, occur in cattle where the pasture contains 18-42 μg g^{-1}, 19-83 μg g^{-1} and an estimated 28-50 μg g^{-1} zinc. Zinc is relatively non-toxic to birds and mammals and a wide margin of safety exists between normal intakes and those likely to produce deleterious effects. Lambs and feeder cattle are somewhat less tolerant of high zinc intakes than are rats, pigs and poultry, 1,000 μg g^{-1} zinc causing depressed feed consumption.

Lead. The lead content of cattle tissue generally lies in the range 0.3-1.5 μg g^{-1}, with an average of 0.5 μg g^{-1}. Levels higher than 10 μg g^{-1} in the liver and 40 μg g^{-1} in the kidneys are claimed to be of diagnostic significance. Up to certain intakes, lead excretion virtually keeps pace with ingestion so that retention in the tissues is negligible. In sheep no lead is retained with pasture of 3 μg g^{-1}, but above this quantity lead is retained in increasing quantities by the tissue.

5.3.1 Buffalo

During 1972 the buffalo meat works in the Alligator Rivers area functioned on a reduced killing season. Sampling was therefore limited to five occasions, the data obtained being given in Table 32.

The radiological significance of the uranium and radium-226 levels is discussed subsequently. The copper, cobalt and lead levels appear to be near normal and consistent with the analyses of pasture grasses. Normal zinc levels for cattle are not known; the listed results agree well with values for human material.

5.3.2 Geese

Goose samples were obtained in season from the Magela and Nourlangie areas. Care was taken to avoid sections of flesh near the shot damaged areas but, nevertheless, values for lead concentration must remain suspect. Results of analyses are given in Table 33.

6. RADIOLOGICAL ASPECTS

Standards for the discharge of radioactive materials differ from those for chemical pollutants, which are based on the concept of threshold limiting values below which unwanted effects are not seen. Radiation protection standards are based on the assumptions that unwanted effects occur in linear relation to total radiation dose, irrespective of its level, and that their extent is not changed by variations in the rate at which the dose is given. These assumptions imply that there is no safe level, or threshold, for radiation dose and allow a simple extrapolation to low doses from what is known of the magnitude of effects from higher doses. The limited human data available derive almost exclusively from medium- and high-dose experience with the effects of radiotherapy and nuclear weapons. Linear extrapolation in this way is likely to be conservative, that is it will overestimate, rather than underestimate, possible effects. It also requires that primary standards be phrased in terms of time-integrated exposure.

The International Commission on Radiological Protection (ICRP) has issued recommendations on acceptable limits of exposure for which it is claimed that the benefit derived from the activity leading to the exposure is likely to exceed the risk that is involved. For workers employed in the nuclear industry the recommended primary standard for whole body irradiation is 5 rem y^{-1}. Knowing the biological accumulation factor, distribution in the body and the biological half-life for each element, the primary standard is used to calculate a maximum permissible concentration of all isotopes in air and water. These derived levels are calculated for an assumed air intake of 20 m^3 day^{-1} and an assumed water intake of 2.2 ℓ day^{-1}, 1 ℓ of which comes from ingested food.

In a general population exposed to a given radionuclide, there usually exist one or two groups whose age, occupation, diet, location or recreational habits are such that their exposure is higher than that of other people. Such a group is designated a critical group which becomes the reference point for all subsequent radiological calculations. Where the amount of radioactive waste to be discharged is known to be small, the eating and recreational habits *etc.* of the critical group are often defined arbitrarily rather than by census. Critical groups arbitrarily defined are generally extreme in terms of national averages.

The primary standard recommended by the ICRP for members of the critical group is 0.1 times that for occupational workers *viz* 0.5 rem y^{-1}. For the population at large a further restraint is placed on the average dose; this must be kept within 5 rem per generation which is taken as being 30 years.

All the ICRP recommendations apply to man-made sources (*i.e.* over and above those levels occurring naturally) but excluding medical uses. No attempt is made to apportion the allowable dose between contributing industries (nuclear weapon testing, uranium mining, power generation, television reception and so on).

For a mixture of radionuclides the allowable concentration is, when all components are known, simply the weighted sum. When the exact mixture is unknown, the allowable concentration is set at that of the most hazardous component.

In Australia the National Health and Medical Research Council adopted the ICRP recommendations for occupational exposure but to date has not made any recommendations for members of the general public. All States have Radioactive Substances Acts or Health Acts governing the use of radiation and radioactive materials for their respective territories but the Australian Government has no such act for Commonwealth Territories.

6.1 Exposure Routes

The way by which discharged radioactivity finally leads to the exposure of man is defined as an exposure route. At least five exposure routes can be identified for the Alligator Rivers area. These are the consumption of mussel and fish from contaminated water, the consumption of contaminated water, the consumption of buffalo, geese *etc.*, grazing contaminated pasture and the consumption of fruit and vegetables cultivated on contaminated ground and/or irrigated with contaminated water.

To calculate the allowable concentration of any radioisotope involved in an exposure route, it is first necessary to determine the biological concentration factor for that element in the particular food web.

6.2 Biological Concentration Factors

Chemical elements (unlike biocides) frequently undergo biological accumulation because of metabolic demands. The mathematical form of concentrating mechanisms can generally be determined uniquely and the range of possibilities is discussed in Appendix B.

6.2.1 Mussels

Mussels concentrate uranium from surrounding water when the environmental levels are low. Results obtained from mussels collected throughout the area during 1972/73 are presented in Table 34 and plotted in Figure 1.

Many factors contribute to the variability in the results. Frequently, it was not possible to collect a representative sample of mussel size which ended up biased to the juvenile or large adult ends of the size spectrum. Perhaps more importantly, the concentration factor is calculated from two measurements of uranium both of which are frequently near the limit of detection (2×10^{-11} for uranium in water).

Nevertheless, the results clearly indicate that the concentration factor decreases as the available uranium increases. The slope of the curve is well approximated at -1 on a log-log plot, indicating that the concentrating mechanism acts as if the mussel was maintaining a regulated pool of uranium at a level of about 80 $\mu g\ kg^{-1}$.

During November 1972, when the environmental levels of uranium were high, mussels effectively discriminated against uranium (*e.g.* CF = 0.02 when the uranium concentration in water was 150 $\mu g\ \ell^{-1}$). It is not known whether this discrimination is strictly metabolic or due, in part, to the mussels becoming dormant under the high water temperatures and high turbidity that then existed.

The concentration factors for radium by mussels presented in Table 34 are plotted in Figure 2. There is no real justification for separating the November 1971 data from the rest; the November 1971 data was quite different to that of the following year and was more normal. Until the metabolism of radium by mussels is better understood it seems wiser to be conservative and assume that higher concentration factors apply for the end of the dry season.

From the trend in the data it seems clear that the concentration factor decreases as the environmental level increases. The high degree of scatter in the results indicates that factors other than simply the environmental level of radium are involved. However, an analysis of the data ruled out the possibility that the mechanism was one of discrimination against radium during the metabolism of magnesium and calcium.

The last mentioned, though not a major factor, is involved to some extent. The radium/calcium ratio for water is typically 10^{-9}, for mussel flesh 5×10^{-11} and for mussel shell 10^{-12}. However the data, rather than converging to a concentration factor of 1 at a water calcium level of 1,800 mg ℓ^{-1} (that of calcium in mussel flesh), remained independent of the level of water calcium.

As a further check on radium/calcium accumulation/discrimination and to provide information on the rate of equilibration to prevailing radium levels, mussels were cultivated in two classes of water and serially sacrificed over a two month period. The waters used were from a bore in the Ranger I Anomaly area (hardness 276 mg ℓ^{-1}, Ca 5.2 mg ℓ^{-1}, Mg 30.6 mg ℓ^{-1} with 151 pCi ℓ^{-1} of radium-226) and from Leichhardt Spring (hardness 18 mg ℓ^{-1}, Ca 0.34 mg ℓ^{-1}, Mg 0.25 mg ℓ^{-1} with 1.9 pCi ℓ^{-1} of radium-226). Results are presented in Table 35.

The general trend of the results confirms that the concentration factors for uranium and radium by mussels decrease as environmental levels increase. Initially, the mussels had a higher than average uranium/radium ratio which was maintained during the experiment. The inferred concentration factors for radium are consistent with values obtained in the field (Figure 2). This demonstrates that the magnesium/calcium ratio ($\sim$ 6 for bore water, $\sim$ 1 for surface water) is not an important variable for the uptake of radium by mussels.

The copper, zinc, cobalt and lead levels of the water were neither known accurately enough nor covered an adequate enough range to determine the concentrating mechanisms involved. Copper levels in mussels were fairly uniform in samples from the Cooper Creek, Magela Creek and Sawcut Creek areas and averaged 1.38 $\mu g\ g^{-1}$ on a fresh weight basis. The indicated concentration factor is then 300. For lead and cobalt, values were more variable, the averages being 1.0 and 0.5 $\mu g\ g^{-1}$ for indicated concentration factors of 50 and > 500. For zinc, the averaged fresh weight concentration was 30 $\mu g\ g^{-1}$ for a concentration factor of 100.

6.2.2 Fish

During the year, 18 cm gill nets were used to obtain fish samples. Results of analyses for uranium and radium are presented in Table 36.

In barramundi flesh, lead and cobalt levels were generally below the level of detection, copper averaged 0.16 $\mu g\ g^{-1}$ (CF $\simeq$ 50) and zinc averaged 7.0 $\mu g\ g^{-1}$ for a concentration factor of about 1,000. The other fish species contained similar amounts of copper, lead, zinc and cobalt. Crocodile flesh contained 12 $\mu g\ g^{-1}$ zinc (CF $\simeq$ 1,000) and unmeasurable quantities of copper, lead and cobalt. Its liver contained 20 $\mu g\ g^{-1}$ zinc and 3 $\mu g\ g^{-1}$ copper (CF $\simeq$ 2,000 and 1,000 respectively).

6.2.3 Buffalo and Goose

The analytical results on buffalo material are for animals whose grazing areas are unknown. Within this limitation, it has to be assumed that the average of the results represents the average of all grazing areas. For the Magela Plains this is not an unreasonable assumption. Section 5.1.1 established that there is no marked variation in the heavy metal content of the soil from the plains. This is not true for some grazing areas of more limited extent. For example, the northern fringes of the Ja Ja Lagoon, which were dry by September, had radium-226 soil concentrations of up to 20 pCi g^{-1}. By contrast, the average for the Magela Plains was $\sim$ 1 pCi g^{-1}. The sampling of buffalo was not extensive enough to average down any high values that may have occurred as a result of selective grazing of areas with high radium-226 levels. For this reason, calculations based on the average buffalo results are conservative to an unknown degree.

The uranium and radium concentrations in buffalo flesh are equilibrium values associated with the input of these elements to the Magela Plains as dissolved and suspended soils. The waters entering the Magela Plains come predominantly from the Magela catchment. During the 1971/72 wet season, periodic sampling of the Magela was carried out. Results for radium-226 and uranium are given in Table 37.

To a first approximation, the radium-226 input to the Magela Plains is simply the runoff from the catchment (about 870 km^2) of Magela Creek (2×10^8 m^3 y^{-1}) times the average content of that water. For the samples specified in Table 37, the quantity of radium carried as suspended solids averages at 0.07 pCi ℓ^{-1}, that for the dissolved state at 0.47 pCi ℓ^{-1}. The net annual input of radium to the Magela Plains is of the order of 0.1 Ci.

For uranium, the quantity carried as suspended solids averages at 0.27 pCi ℓ^{-1}, significantly above that carried in the dissolved state (0.15 pCi ℓ^{-1}). The net annual input of uranium to the Magela Plains is also about 0.1 Ci.

The radiological significance of these levels at this time, to hypothetical people consuming only locally produced foodstuffs, is considered subsequently (Section 6.4). However, even if there were no local inhabitants, the fact that buffalo meat is produced from the Magela Plains means that there must be radiological restraints placed on discharges of radium and uranium to the Magela system.

Depending on assumed consumption of buffalo by man (taken here as 370 g day^{-1}), the derived level for radium-226 is 0.06 pCi g^{-1} and for uranium, 6.9 pCi g^{-1}. From Table 32, the averages of measured values for radium-226 and uranium in buffalo flesh are 0.024 and 0.017 pCi g^{-1} respectively (0.005 and 0.0034 pCi g^{-1} (fresh weight)). Thus, solely on radiological grounds, allowable extra annual imputs of uranium and radium to the Magela area are 200 Ci and 1.2 Ci respectively.

For geese the situation is more complicated. The areas they prefer (Class II billabongs) are the same ones that undergo fairly rapid changes in the aqueous levels of uranium and radium. Further, while any particular goose tends to spend a lot of time in a given flock, this behaviour is not invariable. Thus the average radium and uranium content of goose flesh cannot be translated fairly in terms of the averaged content of the grazed sedge, *etc*.

In compiling Table 38, this type of averaging has been carried out. The only redeeming factor is that man's consumption of goose is not an important factor in determining acceptable releases for radium and uranium.

6.2.4 Vegetables and fruits

By adopting the market garden approach for vegetables and uncultivated trees for fruit samples, no information is obtained on the way the concentration factor varies with the pollutant load of the irrigation water.

At least for Chinese cabbages this information is available from the work of others. P. Yamanoto & K. Masuda of the Hygienic Laboratory of Okayama Prefecture, Okayama (private communication) grew Chinese cabbage (variety *Hayainidori*, 65-day type) under water culture containing a range of uranyl ions and uranyl carbonate complex anions. They also investigated the uptake of uranium by Chinese cabbage from different types of soil (volcanic, sandy and alluvial) previously spiked with uranium to levels ranging from 1.0 μg g^{-1} to 92 μg g^{-1}. Some of their results are reproduced in Figures 3 and 4. The main conclusions were that the concentration factor decreased with period of growth and decreasing pH and that the chemical form of the uranium makes little difference.

The water used to irrigate the Jabiru garden averaged 2.6 μg ℓ^{-1} of uranium (~ 1 pCi ℓ^{-1}). If we extrapolate the Japanese data (log-log plot over 3 orders of magnitude), the indicated concentration factor for a uranium solution of 1 pCi ℓ^{-1} is 12 and in remarkable agreement with the value obtained (Table 28).

In this report it has been assumed that other vegetables also have concentration factors for uranium that vary as if the metabolism of uranium followed that for a regulated pool.

No published data exists on the variation of concentration factors for radium with aqueous radium concentration. If it is assumed that water used to irrigate crops and fruit trees is also used for drinking purposes then this is of little consequence. The allowable concentration of radium-226 in drinking water will presumably be set at 3 pCi ℓ^{-1} or 10 pCi ℓ^{-1}. The water used to irrigate the market garden averaged about 3 pCi ℓ^{-1} so that no great error is involved by using the concentration factors indicated in Table 28.

6.3 Critical Group

No attempt was made to define a critical group by census. The food consumptions assumed in the next section are rough estimates. They are based on some observations, communication with the Welfare Branch of the Department of Northern Territory and a belief that the most exposed person would be an

Aborigine employed near a mine and spending October/November on walkabout in the immediate area.

6.4 Radiation Dose Commitment

In Table 38 the radiation dose commitment to a hypothetical critical group is calculated for naturally occurring radioactivity and for those levels of radioactivity that may be prescribed by legislation or other means. For the latter it is assumed that the standard set will be the lower of the limits set to protect man or the biota other than man.

It is quite evident from this table that if discharge limits for radium-226 were based on maximum permissible concentrations for drinking water, the annual intake would exceed (by a factor of 8) the acceptable annual limit of 8 nCi.

Legislated limits for radium-226 discharges must contain two main factors: a maximum concentration limit that is based on the water use downstream from the release and a total annual release limit. If two or more companies were discharging to a common area then both the concentration and total limits would need to be apportioned. The apportionment could be on the basis of production, unit differential cost of pollution abatement, *etc.*

Naturally, as a result of post operational surveillance, it would be possible to refine the concentrating mechanisms implied in Table 38 and thus the derived discharge limits.

6.5 Dose to the Biota

Of the organisms investigated, mussels have the highest concentration factors for uranium and radium. These concentration factors (related as they are to water concentration) are of the same order as the distribution coefficient between sediment and water. Thus, even without any bio-accumulation, benthos organisms will receive a dose from α particles about equal to that received by mussels and a greater γ-dose (the underlying mud represents an unshielded, infinitely thick, self-absorbing γ source).

Bioaccumulation of radium by a range of aquatic organisms has been reported. Tsivoglou *et al* (1956) found factors of 500-1,400 for filamentous algae and aquatic insects while vascular water plants have been found to have concentration factors ranging up to 780, (Havlik 1967).

By far the highest recorded value is for the green algae *(Ankistrodesmus falcatus* var. *a cicularis)* for which the concentration factor would be, as a result of surface adsorption, some 50,000 at a radium concentration of 10 pCi ℓ^{-1} (Havlik 1971). However, as the author points out, expressing the concentration factor in terms of activity of weight of algae versus water weight is of doubtful value because such concentrations of algae can never be realised under natural conditions and probably not under experimental conditions.

There are two difficulties associated with calculating doses to the biota. Firstly, in the uranium-lead radioactive chain, most of the decay energy is in the form of α particles whose range in tissue is about 50 μm. The tissue dose is therefore very dependent on the distribution of the α emitter. For benthos organisms, the size of the organism is of paramount importance; for example a shell thickness of ~ 20 μm would shield the organism against α particles originating from the surrounding mud.

Secondly, there is the difficulty in associating a particular value for the relative biological effectiveness (RBE) of the energy deposited by α particles with respect to energy deposited by β and γ particles. RBE values are generally a function of damage, numerically decreasing as degree of damage increases. RBE is also a function of α particle energy and therefore varies over the range of the particle. For particular situations, exact solutions are possible (Davy 1967, 1968), but they are not attempted here.

An upper value of dose rates received from natural radioactivity is obtained by considering, say, a minute fish egg buried in the mud of a peat anomaly, and by assuming that the concentration factor for each decay product is equal to the distribution coefficient ($\sim 10^4$). Further, the RBE is set at 10 for all the α decay energy as is done for radiation protection purposes.

The highest concentration of radium-226 found in an aquatic habitat was 120 pCi g^{-1} and at this location the radon-222 was half the radium-226 equilibrium value. The dose rate to the hypothetical egg would then be 1.3 rem day^{-1} from α particles, 0.01 rem day^{-1} from β particles and 0.001 rem day^{-1} from γ rays. Had the whole radioactivity series from thorium-230 to polonium-210 been in equilibrium, then the dose rate would be 2 rem day^{-1}.

No doubt peat anomalies with higher radium-226 values exist in the area, so it is possible (in terms of Appendix C) that natural radioactivity could contribute to speciation in some isolated microhabitats.

If discharge limits for any mining/milling are based on potential food production for human consumption, dose rates to the biota will be much less than 1 rem day^{-1} as a result of the operation. No effect on the biota would be expected from radioactivity.

7. DISCUSSION

As discussed by Giles in Part II of this report, the water quality parameters determined for one watercourse which are most important in determining the applicability of toxicity data to other watercourses are hardness, pH and water temperature. The presence of other heavy metals, in addition to the one whose toxicity is being assessed, is also important. The toxicity of combinations of toxic agents may be more than simply additive since there may be synergistic effects.

The water qualities of the streams and associations in the Alligator Rivers system are very similar and the following generalisations apply:

- The waters are very soft (1-10 mg ℓ^{-1} $CaCO_3$ equivalent) with a calcium/magnesium ratio near 1 and a calcium concentration in the range 0.2-2 mg ℓ^{-1}.
- The waters are slightly acidic, poorly buffered and exhibit marked pH changes.
- The natural levels of heavy metals are very low. For the Magela system, the copper concentration is about 0.003 ℓ^{-1} and for the Cooper Creek system about 0.005 mg ℓ^{-1}. Lead values are also fairly constant ($\sim$ 0.02 mg ℓ^{-1}) as are the values for zinc concentration ($\sim$ 0.04 mg ℓ^{-1}).

There are three minor exceptions to these generalisations. A section of Tin Camp Creek has harder water (15-50 mg ℓ^{-1} $CaCO_3$ equivalent) than elsewhere in that stream. The lower reaches of Cooper Creek have a calcium/magnesium ratio greater than unity and the ratio increases as the dry season progresses. Leichhardt Spring, the headwater of Baroalba Creek, is more mineralised than other perennial waters (Cu $\sim$ 0.04 mg ℓ^{-1}, Zn $\sim$ 0.06 mg ℓ^{-1}).

By the end of a severe dry season there is a deterioration in water quality. This is most marked for that class of billabong which is formed as a result of backflow during the wet season. Certain generalisations are true for the deterioration, these being:

- The uranium content of the waters changes by orders of magnitude during the last few weeks of the dry season. This change is most dramatic for backflow situations where levels can reach > 1.0 mg ℓ^{-1}.
- Significant increases in radium-226 levels occur. For example, recorded values for a billabong in Aedes flat increased from 2.1 to 13.6 pCi ℓ^{-1} during the period mid October to mid November.

- Hardness values increase by up to a factor of five, generally under a fairly static calcium/magnesium ratio.
- Turbidity increases and, for those billabongs frequented by geese, to near the physical limit for the sediment size involved (3,000 mg ℓ^{-1}).
- The environmental levels of zinc, manganese and iron also increase. For zinc, the values reached (0.2-0.4 mg ℓ^{-1}) are close to acute toxic levels for some fish species in an unacclimatised situation.
- Water temperatures become high with values of 36-40°C being the rule rather than the exception.

All but the last of these dry season changes are explainable in terms of anaerobic bacteria breaking down the microzone at the mud/water interface. The system need not be naturally eutrophic for this to occur; one year's collection of organic debris is more than adequate. The important factor is presumably oxygen depletion as a result of high water temperatures. There is a possibility that in one or two systems the anaerobic conditions become so well established as to produce hydrogen sulphide and, by chemical reactions, lower heavy metal concentrations.

None of the generalisations or exceptions, nor the more detailed summary of results presented in Tables 1 to 14, invalidate the wide application of the toxicity data to the Alligator Rivers area. The more detailed results, however, do demonstrate that the capacity of the aquatic environment for copper, manganese and zinc wastes is extremely small. During the early part of the wet season, fish are breeding prolifically and the chosen value for the application factor must be low. Assuming that it lies in the range 0.02-0.1, then the allowable copper and zinc concentrations would overlap the prevailing environmental levels within the normal analytical uncertainties. The levels of copper and zinc existing at the end of the wet season are the starting points for the subsequent end-of-dry season build up. By the end of the dry season, conditions are such that fish are being stressed by high temperatures, low oxygen, disease, high turbidity and perhaps high environmental levels of heavy metals as well. Thus even if an application factor for this time period was set high, say 0.1-0.2, the inferred environmental capacity for copper, zinc and manganese wastes would still be very small. A similar conclusion applies to the capacity for discharged acidity. This results from the poor buffering capacity of the Alligator Rivers water.

The study of the black soil flood plains associated with the Magela and Nourlangie catchments indicates that the calcium/magnesium ratio of the soil does not play a major role in trace element adsorption. There is no marked change in heavy metal content down the Magela channel nor of the concentrations in the channel versus those of the levee banks and general flood plains. Measurements on the soil profile are fairly consistent with the hypothesis that a mixing mechanism for deposited sediments is operative and that the mixing mechanism has a time period that is short in comparison with the time variation in fallout caesium-137 deposition. It is thought that the mixing results from the washing of sediments, deposited during the last wet season into the large cracks developed during the dry season, by the early showers of the next wet season. Thus pollutants introduced to the plains area do not accumulate near the surface but instead are mixed through 1-3 m of black soil.

The accumulation of waterborne contaminants at backflow situations results from at least two factors. At these situations the silty clays are deposited and they have much better exchange capacities than those of the sand which is deposited in the main streams draining the escarpment. Further, for some weeks after the end of the wet season these situations continue to collect water from subsurface seepage. This seepage is richer in dissolved solids than the average runoff during the wet season.

From present results it is not possible to predict the rate and degree of mixing of contaminants in the soil profile associated with Class II billabongs. In certain circumstances, introduced contaminants would establish a well defined profile. For example, the distribution of heavy metals in a sandy soil core taken from the fringe of the tails dump from the South Alligator workings was:

Soil Depth (cm)	Concentration in Ash						Ash/ Dry wt.
	pCi g^{-1}		mg ℓ^{-1}				
	U	Ra	Co	Cu	Zn	Pb	
3-8	0.26	5.6	3.0	2.5	7.0	4	0.94
23-28	13.0	5.6	4.0	15.0	14.0	190	0.92
38-46	0.7	7.2	4.0	3.0	10.0	4	0.94

Mining in this area ceased some 13 years ago

The fruit from *pandanus* growing in this fringe had a radium content of 0.4 pCi g^{-1} (FW).

Heavy metal levels in soils and pastures are generally low and approaching deficiency. There seems little doubt that if discharges of copper, zinc and lead are regulated to preserve aquatic life there will be no chance of the pastures becoming toxic for grazing animals. If a risk exists then it relates to copper deficiency. Molybdenum present in tailings may exist as molybdenate; as such its velocity in ground water would be greater than that for a copper ion. Preferential leakage of molybdenate could decrease the copper/molybdenum ratio in pasture grass and thus lead to copper deficiency in grazing animals.

It would be useful to analyse all collected botanical samples for molybdenum to determine its status in the area. A biological indicator might be found for molybdenum in the way that *pandanus* has been found for copper and zinc and eucalypt for uranium.

During the wet season, disequilibrium exists between the radium-226 and uranium-238 content of waters from the main drainage systems. On a curie basis, the radium/uranium ratio averages 8.0, with extreme values being two orders of magnitude on either side. Values on the high side appear to be related to streams that drain areas containing radiometric anomalies, are relatively hard and have a high calcium/magnesium ratio. The lower values relate to streams that are soft, have a calcium/magnesium ratio of about one and drain small areas with reasonable slopes.

If suspended sediments are included before determining the radium/uranium curie ratio, then the degree of disequilibrium is substantially reduced. For example, in Table 37 dealing with Magela Creek the total uranium and radium are in an equilibrium ratio. The distribution of uranium with respect to particle size is not known. The geographical distribution of deposited uranium cannot be predicted and samples may show further disequilibrium.

Not enough sediment samples have been analysed for radium for definitive statements on their radium/uranium curie ratio to be made. Indications are that, irrespective of origin, radium is more abundant than uranium and the value found for the black soil plains sediments (radium/uranium $\simeq$ 2) is a reasonable approximation for all other areas. The exception to this is the Magela Springs. There uranium is more abundant than radium, the curie ratio being ~ 9.

The average disequilibrium ratios found for other classes of sample were:

Sample type	Disequilibrium ratio (radium/ uranium)	Sample type	Disequilibrium ratio (radium/ uranium)
Grass	-	Buffalo (flesh)	1.4
Pandanus fruit	5	Buffalo (liver)	23.0
Native fruit	12	Buffalo (kidney)	1.6
Water lily	3	Goose (flesh)	0.2
Cultivated vegetable	44	Mussel (flesh)	23.0
Eucalypt leaves	1-15	Mussel (shell)	13.0

Because of varying land use in the vicinity of each uranium deposit there could be differing restraints placed on the discharge of radium. For the Ranger I and Jabiluka deposits all the exposure routes listed in Table 38 apply. For the Nabarlek deposit, restraints arising from market gardening and the eating of goose flesh are inappropriate, while for the Koongarra deposit there is no exposure route associated with market gardening or buffalo meat production. The latter conclusion assumes that the proposed National Park will be created and that feral buffalo in Parks and Reserves will continue to be used only as pet food.

The species of algae that dominate at particular water temperatures in the Alligator Rivers area have not been classified nor have their concentration factors for radium been determined. It is possible that the species composition in November 1972 was different to that of November 1971 and that their concentration factors were also different. Such differences would be reflected in differing concentration factors for radium by mussels with water temperature being the controlling factor.

If mussels are to be used as a biological indicator for aqueous radium-226 concentrations (and they would seem to be very useful for this), further study into the controlling factors for bioaccumulation is warranted.

8. CONCLUSIONS

The main conclusions resulting from this study are:

(i) The results of the toxicity studies in the Magela Creek area can be applied throughout the Alligator Rivers region.

(ii) Non-radioactive heavy metals are the most restrictive waste constituent for the formulation of discharge authorisations. If these were met by a uranium extractive industry, other waste constituents (*e.g.* amines, acidity) would be accounted for automatically.

(iii) Of the radioactive heavy metals radium-226 is the most restrictive. The most limiting exposure routes relate to drinking water, consumption of buffalo and market gardening. Discharge limits for radium-226 will need terms expressed in both input concentration and annual input.

(iv) The radiological hazard to biota other than man will be absent if man is protected as in (iii) above.

(v) Sufficient information is available to formulate conservative discharge authorisations for all known economic uranium deposits.

(vi) In order to refine discharge limits, proportional water sampling devices need to be installed on Magela Creek and the drainage system for the Jabiluka deposit. A much more extensive sampling of buffalo is also needed.

(vii) As a prerequisite to a surveillance programme for tailings dams, detailed eucalypt sampling is recommended.

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TABLE 1

WATER QUALITY OF PERENNIAL SPRINGS (GROUP I)

Location	pH	Hardness	Temp.	Ca/Mg	Cu	Zn	Pb	U	Ra
1:50000		mg ℓ^{-1} $CaCO_3$	°C	ratio	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	µg ℓ^{-1}	pCi ℓ^{-1}
3-706785	5.9	2-9	24-37	~ 1	< 0.04	< 0.1	0.03	0.5-65	7.4
3-724796	5.9	4	24-30	~ 1	< 0.04	< 0.1	< 0.02	0.02-36	-
3-669804*	5.7	4	-	~ 1	< 0.04	< 0.1	< 0.04	6	3.5
3-646763*	5.4	2	-	~ 1	< 0.04	< 0.1	< 0.02	0.2-2.4	-

* *4 separate samples*

TABLE 2

IONIC SOIL PROFILE: PEAT ANOMALY 3-706785

Depth	U	^{226}Ra*	^{210}Pb*	Cu	Co	Pb
Surface	5.8	120	52	2.2	1.0	2.0
25 cm	0.6	16	5.7	0.6	< 0.1	< 0.5

* *pCi g^{-1}; all other values in mg ℓ^{-1}*

TABLE 3

WATER QUALITY OF PERENNIAL SPRINGS (GROUP II)

Location	pH	Hardness	Temp.	Ca/Mg	Cu	Pb	Zn	U	Ra
1:50000		mg ℓ^{-1} $CaCO_3$	°C	ratio	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	µg ℓ^{-1}	pCi ℓ^{-1}
1-918269	6.0	9	24-30	2	< 0.04	0.02	< 0.1	0.4-32	0.6
1-186235	6.5	8	24-30	1			< 0.1	0.4	0.11-1.6
3-725891*	5.8	5	-	1	< 0.04	0.02	< 0.1	1.0	6.4
3-684808*	5.6	8	-	2	< 0.03	0.02	< 0.1	0.8	0.4

* *2 samples only*

TABLE 4

WATER QUALITY OF LEICHHARDT SPRINGS (3-668862)

Sample	Pb	Cu	Zn	U	Ra
	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	pCi kg^{-1}
Water	0.005	0.04	0.06	0.04	2.7
Sediments	4.2	3.1	21	1.9	-
Suspended solids	0.002	0.002	0.007	0.005	-

TABLE 5

WATER QUALITY OF PERENNIAL STREAMS

Creek System	Location	pH	Hardness	Temp.	Ca/Mg	Cu	Zn	Pb	Co	U	Ra
	1:50000		mg ℓ^{-1} $CaCO_3$	°C	ratio	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	μg ℓ^{-1}	pCi ℓ^{-1}
Tin Camp	1-155237	6.2	7	26	1	< 0.05	< 0.1	0.02	< 0.04	0.43	0.6
	1-965198	6.7	15-50	-	1	< 0.03	< 0.1	< 0.02	< 0.004	< 0.05	5.0
	1-100237	6.5	7-20	-	1	< 0.07	< 0.1	0.02	< 0.002	0.48	0.3
E. Alligator	2-164959	6.0	3	24-29	1	< 0.05	< 0.1	< 0.02	< 0.004	0.23	1.5
	2-890150	6.4	8	-	1	< 0.03	< 0.1	< 0.02	< 0.006	0.29	0.1
	2-897140	6.5	7	24-34	1	< 0.07	< 0.1	0.02	< 0.006	0.18	0.2
	2-964070	6.2	6	24-32	< 1	< 0.03	< 0.1	0.03	< 0.003	0.20	0.1
(tidal)	4-786253	6.4	20-60	-	1-8	< 0.006	< 0.1	0.03	< 0.008	1-30	-
Magela	2-877867	4-6.2	4	-	1	< 0.03	< 0.1	0.02	< 0.004	0.23	0.1-1.1
	2-843924	4-6.4	4	-	1	< 0.03	< 0.1	0.02	< 0.004	0.6	0.6
Sawcut	3-750718	6.3	10	24-35	1-2	< 0.04	< 0.1	0.02	< 0.004	0.8	0.6

TABLE 6

SEASONAL VARIATION OF SOME WATER QUALITY PARAMETERS FOR SAWCUT CREEK (3-750718)

Date	Sample type	Cu $mg\ \ell^{-1}$	Pb $mg\ \ell^{-1}$	Co $mg\ \ell^{-1}$	U $mg\ \ell^{-1}$	Ra $pCi\ g^{-1}$
7 Nov. 71	Water	0.04	< 0.03	< 0.004	0.0007	0.0016
	suspension	0.008	< 0.03	< 0.004	0.001	-
	sediments	0.95	1.6	1.4	1.3	2.5
23 June 72	Water	< 0.07	< 0.02	< 0.006	0.00002	0.00009
	suspension	0.075	< 0.002	< 0.002	0.00003	-
	(as solids)	21.0	0.6	< 0.6	0.008	
30 June 72	Water	< 0.07	< 0.02	< 0.006	0.00018	0.00031
	suspension	0.002	< 0.002	< 0.0005	0.0005	-
	sediments	15.0	< 1.0	25.0	0.06	0.14
5 Aug. 72	Water	< 0.06	< 0.02	< 0.01	0.00007	0.00037
	suspension	0.06	0.001	< 0.0005	0.00008	-
	sediments	0.1	< 0.9	< 0.2	0.06	0.05
20 Sept. 72	Water	< 0.04	< 0.02	< 0.004	0.0002	-
	suspension	0.005	0.0008	< 0.0005	0.00015	-
	(as solids)	1.0	0.2	< 0.2	0.044	-
	sediments	0.15	< 0.7	< 0.2	0.1	0.07
4 Oct. 72	Water	< 0.05	0.025	< 0.002	0.001	0.00061
	suspension	0.009	0.003	< 0.002	0.00048	-
	(as solids)	1.0	0.3	< 0.02	0.05	-
10 Oct. 72	Water	< 0.04	0.02	< 0.01	0.0028	0.00056
	suspension	0.003	0.001	0.003	0.0001	-
	(as solids)	1.6	0.5	< 0.02	0.053	
10 Nov. 72				Zn*		
	Water	< 0.06	0.02	0.05	0.0021	0.00075
	suspension	0.001	0.0006	1.1	0.00008	-
	(as solids)	30.0	20.0	3,800	3.0	-
	sediments	0.4	2.0	6.9	0.07	0.1
22 Jan. 73	Water	0.1	< 0.005	0.03	0.00008	-
	suspension	0.05	0.001	0.015	0.00013	-
	(as solids)	6,000	170	1,800	15.0	-

* *Attributed to installation of galvanised iron gauging station*

(as solids) refers to suspended material analysed on a g/g basis.

TABLE 7

A SUMMARY OF WATER QUALITY FOR CLASS I BILLABONGS

(Bracketed figures are values recorded in November/December 1972)

Location	pH	Hardness	Temp.	Ca/Mg	Cu	Pb	Co	U	Ra
1:50000		mg ℓ^{-1} $CaCO_3$	°C	ratio	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	μg ℓ^{-1}	pCi ℓ^{-1}
3-690040	6.3	6	25-(39)	1	< 0.04	0.02	< 0.004	8.0 (150)	0.5 (2.6)
1-196402	6.2	5	24-(34)	1-2	< 0.04	0.02	< 0.01	0.5 (110)	0.8
3-691067	6.1	7	24-(36)	2	(0.06)	0.02	< 0.01	0.2 (170)	0.4
4-820282	6.4	10	24-(29)	2-3	< 0.04	0.02	< 0.01	3.8 (45)	1.0 (2.3)
3-599763	6.2	8	25-(33)	2	(0.08)	0.02	< 0.002	1.0 (21)	0.8

TABLE 8

SEASONAL VARIATION IN WATER QUALITY FOR A CLASS I BILLABONG (1-196402)

Date	pH	Hardness mg ℓ^{-1} $CaCO_3$	U in solution μg ℓ^{-1}	Suspended solids		Sediments mg ℓ^{-1}	Ra pCi ℓ^{-1}
				μg ℓ^{-1} (solution)	mg ℓ^{-1} (solid)		
2 Nov. 71	-	-	0.1	-	1.4	1.2	0.74
10 June 72	6.3	2	2.4	0.19	-	0.42	0.21
21 July 72	6.0	5	0.2	0.8	-	0.42	0.32
18 Aug. 72	6.1	9	0.34	0.27	0.06	0.8	0.72
22 Sept.72	6.0	3	1.9	0.1	20.0	1.5	0.73
1 Nov. 72	4.6	20	112.0	0.35	7.8	0.2	1.8

TABLE 9

WATER QUALITY OF MAGELA CHANNEL

Location	pH	Hardness	Temp.	Ca/Mg	Cu	Zn	Pb	Co	U	Ra
1:50000		mg ℓ^{-1} $CaCO_3$	°C	ratio	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	µg ℓ^{-1}	pCi ℓ^{-1}
3-705147	6.2-4.3	17	26-33	0.5-1	< 0.04	< 0.1	0.02	< 0.01	2.1	0.3-1.3
3-705147*	4.2	17	34	0.6	0.08	0.42	0.02		1,050	0.35(1.5)
3-708157	6.1-3.6	22-110	27-35	0.5-1	< 0.04	< 0.1	0.02	0.01	0.7-230	0.5-0.8
3-708157*					0.04	0.15	0.007	< 0.01	33	-
4-645272					< 0.04	< 0.1	0.02	< 0.03	0.24	-
4-673240*	5.8	31	32	1.5	0.08	0.1	0.005	-	15.0	0.51
4-720271	6.1-5.2	18	32	1	< 0.07	< 0.1	< 0.01	< 0.007	0.6	0.1-1.0
4-678216*	5.2	30	34	2	0.08	0.15	0.02	< 0.01	150.0	0.41
4-688188*	5.9	25	34	2	< 0.04	0.09	0.01	< 0.01	47.0	1.46

* *Sampling date: 7 November 1972.*

TABLE 10

WATER QUALITY OF JA JA LAGOON ON 15 NOVEMBER 1972

Sample type	U	Cu	Zn	Pb	Ra
	µg kg^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	pCi ℓ^{-1}
Filtrate	1,050	0.08	0.42	0.02	0.35
suspension	1.2	0.006	0.027	0.02	-
(as solids)	3,000	15.0	68.0	50.0	-

TABLE 11

WATER QUALITY OF CLASS IIA BILLABONGS

Location	pH	Hardness	Temp.	Ca/Mg	Cu	Zn	Pb	Co	U	Ra
1:50000		mg ℓ^{-1} $CaCO_3$	°C	ratio	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	µg ℓ^{-1}	pCi ℓ^{-1}
3-724994	6.1 (4.2)	7 (17)	24-40	1.2 (5)	< 0.04 (0.08)	< 0.1 (0.25)	< 0.02	< 0.006	0.5 (320)	2.3
3-736089	5.3 (3.6)	10 (19)	25-39	0.2-1	< 0.04 (0.06)	< 0.1 (0.2)	< 0.02 (0.05)	< 0.006	1.7 (110)	3.3
3-700028	5.7	10 (29)	24-42	0.5-2	< 0.04 (0.15)	< 0.1 (0.1)	< 0.02 (0.07)	< 0.006	1.5 (68)	0.9
3-607767	4.2-3.9	25 (110)	25-37	2	< 0.04		(0.04)	< 0.003	(670)	3.9

TABLE 12

WATER QUALITY OF CLASS IIB BILLABONGS

Location	pH	Hardness	Temp.	Ca/Mg	Cu	Zn	Pb	Co	U	Ra
1:50000		mg ℓ^{-1} $CaCO_3$	°C	ratio	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	µg ℓ^{-1}	pCi ℓ^{-1}
3-752974	6.5-5.9	10	24-33	1-3	< 0.04 (0.16)	0.03	0.03 (0.05)	< 0.005	0.5 (780)	3.3
3-690002	6.6-5.5	12	27-34	1-3	< 0.03	< 0.1	0.02	< 0.003	1.8 (3.4)	4.0 (6.2)

TABLE 13

SEASONAL VARIATION OF SOME WATER QUALITY PARAMETERS FOR GEORGETOWN BILLABONG (3-752974)

Date	Sample type	Cu mg ℓ^{-1}	Pb mg ℓ^{-1}	Co mg ℓ^{-1}	U mg ℓ^{-1}	Ra pCi g^{-1}
7 Nov. 71	Water	< 0.03	< 0.02	< 0.006	6.6×10^{-3}	8.5×10^{-3}
	suspension	0.04	< 0.03	0.055	1.6×10^{-3}	2.7×10^{-3}
	sediments	5.2	3.5	4.3	3.8	-
5 June 72	Water	< 0.07	0.025	< 0.006	4.0×10^{-5}	1.3×10^{-3}
	suspension	0.007	0.001	< 0.001	1.8×10^{-4}	5×10^{-5}
	sediments	2.0	1.5	0.5	0.21	-
6 July 72	Water	< 0.07	0.025	< 0.006	4×10^{-5}	1.3×10^{-3}
	suspension	0.007	0.001	< 0.001	1.8×10^{-4}	5×10^{-5}
	sediments	2.0	2.0	1.0	0.7	0.42
23 Aug. 72	Water	< 0.04	0.02	< 0.003	8.8×10^{-4}	3.5×10^{-3}
	suspension	0.025	0.003	0.025	3.1×10^{-3}	-
	sediments	0.4	< 0.7	0.4	0.6	0.12
22 Sept. 72	Water	< 0.04	0.05	< 0.003	8×10^{-4}	
	suspension	0.001	< 0.001	< 0.001	$< 1 \times 10^{-5}$	
6 Oct. 72	Water	< 0.06	0.02	< 0.01	1.0×10^{-1}	9.2×10^{-4}
	suspension	0.04	0.01	0.04	4.0×10^{-3}	
	sediments	-	-	-	-	0.45
				Zn		
13 Nov. 72	Water	0.12	0.025	0.95	0.78	3.2×10^{-3}
	suspension	0.02	< 0.005	0.09	7.6×10^{-3}	-
	sediments	1.5	6.0	-	0.9	0.96
29 Nov. 72	Water	0.16	0.02	0.03	0.011	4.5×10^{-3}
	suspension	0.02	0.004	0.06	2.6×10^{-3}	

TABLE 14

WATER QUALITY OF MAN-MADE DAMS

Date	Location 1-184378				Location 1-168365			
	pH	Temp.	U	Ra	pH	Temp.	U	Ra
		°C	μg ℓ^{-1}	pCi ℓ^{-1}		°C	μg ℓ^{-1}	pCi ℓ^{-1}
7 Nov. 71	-	-	< 0.06	14.7	-	-	1.0	0.74
10 June 72	6.5	-	1.9	0.22	6.0	-	1.5	0.1
21 July 72	6.6	32	0.3	0.91	6.3	29.5	0.4	2.0
16 Aug. 72	6.9	33	0.62	-	5.8	32	1.3	-
22 Sept. 72	6.9	35	88.0	-	6.2	32	27	-
1 Nov. 72	6.5	38.3	4.8	-	5.9	35	96	-

TABLE 15

IRON, MANGANESE AND URANIUM LEVELS IN SOME SAMPLES COLLECTED DURING NOVEMBER 1972

Location (1:50000)	pH	Fe	Mn	U
		mg ℓ^{-1}	mg ℓ^{-1}	μg ℓ^{-1}
1-184378	6.5	8.0	< 0.01	4.8
1-168365	5.9	0.2	< 0.01	96
3-705147	4.3	13.0	0.1	1,050
3-708157	4.8	9.2	0.3	33
4-673340	5.2	31.0	0.02	15
4-678216	5.2	19.0	0.05	150
4-688188	5.9	2.6	< 0.01	47
3-736089	4.3	9.6	0.02	104
3-700028	5.4	29.0	0.2	68
3-724994	4.2	*	0.1	320
3-607767	3.9	*	0.4	670

* *Too much interference for determination.*

TABLE 16

ANALYSIS OF SOIL SAMPLES FROM THE MAGELA PLAINS*

(Lead values in pCi g^{-1}; all others in $\mu g\ g^{-1}$)

Location (1:50000)	U	^{210}Pb	Ca	Mg	Cu	Zn	Pb	Ash/ dry wt.
4-691193	3.1	2.8	19	480	1.0	4.0	4.3	0.86
4-688203	0.95	0.8	730	2,000	< 1.0	1.6	3.0	0.85
4-685210	2.6	2.3	200	330	1.3	4.5	6.2	0.87
4-690214	1.6	1.8	160	230	< 1.0	4.8	6.0	0.92
4-678216	1.3	1.0	1,140	1,120	< 1.0	8.5	8.3	0.96
4-681218	2.2	2.3	1,000	520	1.5	7.9	6.6	0.83
4-677226	2.2	2.2	450	540	< 1.0	5.1	6.2	0.84
4-690230	1.9	1.6	730	530	1.3	6.0	7.0	0.89
4-675235	2.6	1.3	750	1,360	< 1.0	12.5	6.6	0.93
4-670240		0.7	-	-	0.6	4.4	8.0	0.91
4-683247	2.6	1.0	530	870	< 1.0	9.7	9.0	0.93
4-664240	1.1	0.3	710	690	4.5	4.8	7.8	0.92
4-666240	1.1	1.1	850	900	3.5	6.6	6.9	0.89
4-668240	1.0	0.7	87	740	4.6	4.1	4.9	0.91
4-670240	1.2	2.0	-	-	0.9	3.7	6.0	0.89
4-630252	0.9	1.4	690	1,350	1.5	9.6	14.0	0.89
4-683257	1.9	1.0	380	340	1.3	5.0	11.0	0.95
4-645254	0.92	2.0	120	760	3.8	7.2	9.2	0.90
4-677256	1.5	1.0	-	-	0.5	2.7	6.0	0.91
4-623269	3.6	0.9	460	200	2.8	3.2	9.2	0.92
4-644273	1.0	1.5	690	890	2.7	12.3	13.0	0.82
4-617273	7.4	1.0	610	320	2.4	4.8	4.6	0.70
4-698290	1.3	0.8	1,080	790	< 1.0	12.0	7.8	0.92
4-688290	1.4	0.8	420	530	< 1.0	9.7	9.0	0.93
4-680290	1.9	0.9	330	470	< 1.0	5.4	4.6	0.91
4-652294	1.6	1.6	790	800	1.0	8.5	11.0	0.86
4-664294	1.6	2.9	530	800	< 1.0	9.3	12.0	0.85
4-652308	1.7	1.7	520	600	1.0	7.2	9.7	0.92
4-636318	1.5	1.0	1,230	950	< 1.0	10.0	8.7	0.93
4-650340	1.0	2.5	780	210	8.6	5.6	4.6	0.96
4-650344	3.2	1.5	610	450	< 1.0	4.2	7.9	0.95
4-650346	2.6	1.2	540	670	< 1.0	6.5	8.0	0.92

* *1 m depth composites.*

TABLE 17

VERTICAL DISTRIBUTION OF RADIOACTIVE AND STABLE ELEMENTS IN SOIL SAMPLES FROM MAGELA PLAINS

Location (1:50000)	Depth	Concentration in Ash							Ash/ Dry wt.
		pCi g^{-1}				μg g^{-1}			
		U	^{226}Ra	^{210}Pb	^{137}Cs	Cu	Pb	Zn	
4-670240*	Surface	0.2	0.5	0.7	0.1	0.6	8.0	4.4	0.89
(West bank	0.5 m	0.3	0.8	0.8	0.14	0.8	9.0	3.5	
levee)	1.0 m	0.6	0.7	0.8	0.1	0.6	9.0	4.0	
	1.5 m	0.3	1.0	1.1	0.1	0.5	6.0	4.0	
4-670240	Surface	0.4	0.5	2.0	0.27	0.9	6.0	3.5	0.89
(East bank)	0.5 m	0.3	0.5	1.3	0.17	0.6	7.0	3.5	
4-677256	Surface	0.5	0.9	1.0	0.31	0.5	6.0	2.7	
(East bank)	0.8 m	0.4	0.3	0.9	0.26	0.6	7.0	3.6	0.94
4-644273	Surface	0.5	0.5	1.7	0.27	1.1	7.0	4.9	0.90
(West bank)	0.8 m	0.4	0.3	0.9	0.22	0.5	6.0	2.5	
4-664272*	Surface	0.3		1.5	-	2.7	13.0	12.3	0.83
(channel)	0.8 m	0.25		1.6	-	0.6	10.0	7.6	0.91
4-652294*	Surface	0.4		1.6	-	1.0	11.0	8.5	0.86
('swamps')	0.8 m	0.3		1.0	-	0.8	14.0	8.8	0.94

* *Dried out.*

TABLE 18

TRACE ELEMENT CONTENT OF SOIL SAMPLES FROM THE WOOLWONGA BLACK SOIL PLAINS

(1 m Depth Composites)

Location (1:50000)	U	Cu	Zn	Pb
	$\mu g\ g^{-1}$			
4-358927	1.6	1.7	11.0	7.7
4-350925	1.4	2.0	9.8	6.6
4-343923	1.7	1.1	10.5	8.7
4-338925	1.6	< 1.0	8.3	8.7
4-330918	1.9	< 1.0	9.1	8.2
4-325916	2.1	2.3	9.5	12.0
4-318908	1.4	< 1.0	9.8	9.2

TABLE 19

LONGITUDINAL DISTRIBUTION OF HEAVY METALS IN SOIL FROM GEORGETOWN BILLABONG

(1 m Depth Composites)

Location (1:50000)	Concentration in Ash								Ash/ Dry wt.
	$pCi\ g^{-1}$			$\mu g\ g^{-1}$					
	U	^{226}Ra	^{210}Pb	Cu	Zn	Pb	Ca	Mg	
3-749963	3.2	1.0	6.8	9.3	3.2	5.5	160	320	0.97
3-752965	7.2	2.1	2.0	9.3	3.9	9.1	150	400	0.97
3-755968	1.8	1.0	2.9	9.3	3.9	8.1	110	280	0.95*
3-754971	2.0	0.84	6.2	8.3	4.8	6.0	180	220	0.91
3-752975	1.5	1.2	1.8	7.1	2.8	5.9	230	160	0.95*

* *Sandy soil.*

TABLE 20

TRANSVERSE DISTRIBUTION OF HEAVY METALS IN SOIL FROM GEORGETOWN BILLABONG

(1 m Depth Composites)

Location (1:50000)	Concentration in Ash							Ash/ Dry wt.
	pCi g^{-1}				μg g^{-1}			
	U	^{226}Ra	^{210}Pb	^{137}Cs	Zn	Pb	Cu	
3-756970	10.2	5.8	12.0	< 0.1	4.6	9.5	7.4	0.93
3-755970	9.9	4.9	7.3	0.2	3.0	8.7	5.2	0.94
3-754970	2.6	2.1	1.5	< 0.1	1.5	4.7	5.7	0.98

TABLE 21

ANALYSIS OF SEDGE MEADOW SOIL SAMPLES

Location (1:50000)	Concentration in Ash								Ash/ Dry wt.
	pCi g^{-1}			μg g^{-1}					
	U	^{226}Ra	^{210}Pb	Cu	Zn	Pb	Ca	Mg	
3-356970	2.4		2.5	13	5.5	9.6	1,800	500	0.92
3-734968	2.3		1.4	7.4	1.6	10.0	10	60	0.95
3-604764	0.4	0.12	19.5	5.4	2.7	4.0	160	140	0.89

The high ^{210}Pb level at the Koongarra Creek (3-604764) backflow area indicates a significant ^{222}Rn input to the area.

TABLE 22

THE VARIATION IN ELEMENTAL CONCENTRATION ALONG A SWAMP DEPRESSION

Location (1:50000)	Sample type	Concentration in Dry Material					
		pCi g^{-1}		μg g^{-1}			
		U	^{226}Ra	Co	Cu	Pb	Zn
4-624279	Sediment	0.58	0.02	2.6	0.4	3.7	10.3
4-618278		0.38	0.03	2.4	0.2	1.0	7.8
4-609277		0.60	0.02	3.8	0.7	3.1	4.8
4-600276		1.10	0.23	3.9	0.5	3.1	3.0
4-624279	Macro-algae	0.068	0.19	0.6	1.7	2.3	4.8
4-618278		0.12		1.7	2.6	5.1	7.2
4-609277		0.17	0.60	1.7	2.1	2.5	5.5
4-624279	Paper-bark leaves	0.007	0.004	0.3	0.3	1.2	2.2
4-618278		0.005	0.006	0.5	0.5	1.2	2.6
4-609277		0.003	0.02	0.2	0.6	0.6	3.5
4-600276		0.0008	0.03	0.4	0.6	0.8	3.2

TABLE 23

HEAVY METAL CONTENT OF THE BLACK TOP SOIL ACROSS THE SEDGE MEADOWS

Distance (m) (N→S)	Concentration in Ash						Ash/ Dry wt.
	pCi g^{-1}			μg g^{-1}			
	U	^{210}Pb	^{137}Cs	Cu	Pb	Zn	
12	2.0	3.1	< 0.1	1.0	9.2	1.7	0.85
24	1.9	2.9	0.2	1.1	12.0	1.2	0.91
36	1.2	2.9	0.1	1.2	11.0	1.1	0.93
48	1.0	1.3	< 0.1	1.6	14.0	1.2	0.94
60	1.2	2.3	0.1	1.0	15.0	1.6	0.91

TABLE 24

A COMPARISON OF HEAVY METAL CONTENT OF SOIL AND PASTURE GRASSES

Location (1:50000)	Sample type	Concentration in Dry Material				
		pCi g^{-1}		µg g^{-1}		
		U	^{226}Ra	Cu	Zn	Pb
3-752974	Soil	1.5	1.2	7.1	2.8	5.9
	Grass	0.013	0.16	3.9	7.2	0.6
	Grass*	0.005	0.06	0.9	6.8	2.3
3-562862	Soil	0.36		0.4	-	3.6
	Grass	0.021	0.65	1.44	-	1.4
3-708157	Soil	1.2	0.5	0.9	9.4	5.4
	Grass	0.14	0.39	8.6	8.6	< 2.2
4-690213	Soil	0.5		< 0.9	4.4	5.5
	Grass	0.053	0.3	8.7	4.2	< 6.0

* *New growth (12 December 1972).*

TABLE 25

HEAVY METAL CONTENT OF *PANDANUS* PALM FRUIT

(µg g^{-1} Ash; Ash/Fresh Wt.~ 2%)

Location (1:50000)	U	Co	Cu	Pb	Zn
1-196402	0.56	20	170	< 30	340
1-182378	0.36	30	100	< 30	190
1-179371	0.44	12	130	< 30	200
1-168364	0.24	10	100	< 30	200
1-196486	0.44	20	120	< 30	310
Magela Channel	0.51	20	70	50	315
3-694994	0.46	15	200	< 30	330
3-843924	0.47	15	160	< 30	170
3-796926	0.63	15	320	20	210
3-963039	0.09	-	260	8	420
3-735970	0.12	-	150	3	180
3-706785*	0.80	15	100	40	350
3-599762	0.49	15	240	20	530
3-752718	1.2	12	90	< 30	280
3-665840	0.8	10	190	40	3,280
3-604764	1.2	10	250	40	720

* *Peat anomaly.*

TABLE 26

HEAVY METAL CONTENT OF PAPERBARK LEAVES

FROM GEORGETOWN BILLABONG

Location (1:50000)	Concentration in Dry Material				
	U	Cu	Co	Pb	Ra
	pCi g^{-1}	μg g^{-1}	μg g^{-1}	μg g^{-1}	pCi g^{-1}
3-749963	0.030	3.9	2.0	1.1	0.11
3-752965	0.040	2.2	1.7	2.2	0.05
3-755968	0.023	1.7	1.9	1.0	0.02
3-754971	0.014	1.1	1.3	4.4	0.01
3-752975	0.014	3.3	0.8	5.0	0.08

TABLE 27

HEAVY METAL CONTENT OF PAPERBARK LEAVES

FROM THE MAGELA PLAINS FRINGE

Location (1:50000)	Concentration in Dry Material				
	U	Cu	Co	Pb	Zn
	pCi g^{-1}	μg g^{-1}	μg g^{-1}	μg g^{-1}	μg g^{-1}
4-691193	0.0068	1.0	-	0.1	6.9
4-688203	0.0077	11.1	-	0.5	9.8
4-670232	0.039	2.6	-	0.4	5.2
4-664240	0.034	1.4	1.65	4.4	7.3
4-650245	0.024	1.1	0.5	5.4	5.6
4-630252	0.023	0.8	1.9	2.1	5.2
4-645254	0.022	1.4	1.0	6.8	6.3
4-652308	0.012	1.9	1.9	9.0	6.8
4-650346	0.0075	1.9	-	0.2	8.0

TABLE 28

HEAVY METAL CONTENT OF VEGETABLES

Vegetable	Concentration in Fresh Material					
	pCi g^{-1}		µg g^{-1}			
	U	^{226}Ra	Cu	Co	Pb	Zn
Tomato	0.001	0.005	0.66	< 0.11	< 0.33	5.1
Cucumber	0.0014	0.007	0.25	< 0.05	0.2	2.4
Cabbages (red)	0.009	0.05	0.19	0.19	0.76	7.2
Cabbages (Chinese)	0.012	0.06	0.14	0.34	3.4	29.0
Radish	0.0027	0.046	0.20	< 0.05	< 0.3	5.7
Sweet corn	0.0067	0.001	2.10	0.23	< 0.5	36.0
Beans (string)	0.01	0.07	0.90	0.15	0.3	6.5
Beetroot	0.03	0.05	0.64	< 0.16	< 0.5	12.6
Mangoes (M)*	0.0028	0.01	0.72	0.18	< 0.3	1.8
Mangoes (O)*	0.0019	0.004	0.96	< 0.08	< 0.3	2.9

* *M = Mudginbarri*   *O = Oenpelli*

TABLE 29

HEAVY METAL CONTENT OF NATIVE FRUITS

Location (1:50000)	Sample type	Concentration in Fresh Material				
		pCi g^{-1}		μg g^{-1}		
		U	^{226}Ra	Cu	Co	Pb
1-196402	Apple	0.001	-	0.9	0.2	0.3
1-182378	Apple	0.001	-	0.4	0.2	0.25
1-179371	Apple	0.005	0.02	1.1	< 0.5	< 1.0
1-179371	Figs	0.004	0.03	0.8	0.3	< 0.4
1-179371	Figs *(G)*	0.005	-	2.5	< 0.1	0.3
1-196486	Figs *(G)*	0.002	-	1.8	0.1	< 0.3
3-599762	Figs *(G)*	0.003	0.05	1.4	4.6	0.2
3-752718	Apple	0.007	0.03	0.5	0.1	< 0.2
3-706785*	Apple	0.001	0.004	0.4	0.1	< 0.2
3-669804	Apple	0.001		1.2	0.1	< 0.4
4-664240	Apple	0.003		1.1	0.2	< 0.3
3-669804	Plums	0.003		0.4	0.3	0.5
3-668862	Apple	0.001	0.42	0.7	< 0.1	< 0.3
3-695994†	Apple	0.010	0.09	1.0	0.3	< 0.8
2-843924	Apple	0.004		0.8	0.1	< 0.2
3-724994	Apple	0.001		1.3	0.2	0.4
3-772953	Figs	0.002	0.04	1.7	0.5	0.7
3-772953	Apple	-	0.01	-	-	-
3-796926	Apple	0.009	0.04	-	-	-

* *Peat anomaly.*

† *Regional centre backflow situation.*

(G) Green.

TABLE 30

HEAVY METAL CONTENT OF WATER LILIES

Location (1:50000)	Concentration in Fresh Material				
	pCi g^{-1}		µg g^{-1}		
	U	^{226}Ra	Cu	Co	Pb
3-562862*	0.013	0.12	0.54	0.54	1.4
1-196402	0.022	0.03	0.33	0.33	0.5
1-182378	0.008	0.06	0.52	0.23	0.2

* *Baroalba backflow.*

TABLE 31

HEAVY METAL CONTENT OF EUCALYPT LEAVES

Location (1:50000)	Sample type	Concentration in Ash					
		pCi g^{-1}		µg g^{-1}			
		U	^{226}Ra	Cu	Zn	Pb	Co
Nabarlek*	Stringybark	38	320	140	360	50	20
Nabarlek*	Bloodwood	45	670	130	450	80	230
(barren)*	Bloodwood	3	3	110	590	55	550
(barren)	Stringybark	78	73	190	350	70	10
Ranger I	Bloodwood	97		160	520	40	370
Ranger I*	Stringybark	1.4		130	530	2	-
(barren)	Bloodwood	0.1		120	340	2	-
3-706785	Stringybark	0.2	12	30	330	60	15
3-664830	Stringybark	0.7		130	730	100	25
3-664830	Woollybutt	1.3		75	330	60	20
3-630970	Stringybark	0.4	1	100	200	40	10
3-684000*	Stringybark	0.8	2	90	450	30	-
3-684000*	Bloodwood	1.0		80	560	45	20

(barren) relates to preceding ore body in table.

* *Represent averages of two or more samples.*

TABLE 32

HEAVY METAL CONTENT OF BUFFALO

(Average Value and Range)

Material	Concentration in Dry Material* (Average and Range)					
	$pCi\ g^{-1}$		$\mu g\ g^{-1}$			
	U	Ra	Cu	Co	Pb	Zn
Flesh	0.017	0.024	3.7	< 0.4	< 0.3	148
	(0.008-0.04)	(0.005-0.05)	(1.2-9.6)			(50-230)
Liver	0.002	0.045	95	1.3	2.9	142
	(0.004-0.022)	(0.01-0.1)	(1.5-250)	(0.5-3.6)	(0.5-5.6)	(85-160)
Kidney	0.043	0.07	13.4	< 0.5	< 1.0	82
	(0.008-0.06)	(0.04-0.1)	(4-40)			(60-105)

* *Assumed as 20% of fresh weight.*

TABLE 33

HEAVY METAL CONTENT OF GOOSE MATERIAL

(Average Value and Range)

Material	Concentration in Dry Material* (Average and Range)					
	$pCi\ g^{-1}$		$\mu g\ g^{-1}$			
	U	Ra	Cu	Co	Pb	Zn
Flesh	0.033	0.007	9.4	1.0	-	146
	(0.022-0.038)	(0.002-0.01)	(2.6-12)	-	(< 2-50)	(70-295)
Liver	0.018	0.011	30	0.13	5.2	207
	(0.005-0.05)	(0.003-0.02)	(21-36)	-	(1.6-14)	(160-305)
Bone †	0.07	0.2	13	11.4	26	82

* *Assumed as 20% of fresh weight.*

† *Composite sample.*

TABLE 34

CONCENTRATION FACTORS FOR URANIUM AND RADIUM BY MUSSELS

Location (1:50000)	Date	Water Conc. U	Water Conc. Ra	Mussel Conc. U	Mussel Conc. Ra	Concentration Factor U	Concentration Factor Ra
		μg ℓ$^{-1}$	pCi ℓ$^{-1}$	μg g^{-1}	pCi g^{-1}		
1-196402*	2 Nov. 71	0.1	0.74	0.10	3.00	1,000	4,050
1-196402*	10 June 72	0.19	0.21	0.26	1.28	1,380	6,100
1-186376*	10 June 72	0.12	0.41	0.07	0.11	580	270
1-196535	3 Nov. 71	< 0.06	0.48	0.03	0.33	> 500	690
1-196486	14 Nov. 72	0.5	1.84	0.05	0.07	102	38
4-812269	3 Nov. 71	2.8	0.37	0.06	4.48	22	12,100
4-763673	9 June 72	27.0	1.9	0.14	0.04	5	21
3-680997	13 July 72	0.15	6.1	0.02	0.14	153	23
3-599762	7 Nov. 71	2.5	1.0	0.04	1.53	16	1,500
3-599762	20 Sept. 72	0.37	0.26	0.05	0.06	132	230
3-599762	10 Oct. 72	9.5	1.05	0.02	0.09	2	86
3-599762	10 Nov. 72	21.0	0.72	0.01	0.05	0.4	69
3-752718	7 Nov. 71	0.7	1.6	0.01	2.45	17	1,520
3-752718	5 Aug. 72	0.07	0.37	0.004	0.20	51	540
3-752975	4 Nov. 71	6.6	8.45	0.23	1.92	35	230
3-752975	6 July 72	1.6	1.3	0.02	0.12	13	94
3-752975	23 Aug. 72	0.88	3.5	0.02	0.26	28	75
3-752975	6 Oct. 72	104	0.92	0.20	0.36	2	390
3-752975	6 Nov. 72	11.2	3.0	0.008	0.03	0.7	10
3-752975	2 Dec. 72	11.2	4.5	0.02	0.05	1.8	11
3-694003	10 July 72	0.19	2.00	0.03	0.14	158	70
2-843924	30 Sept. 72	9.6	0.47	0.055	0.49	6	1,040
2-843924	30 Aug. 72	0.54	0.8	0.01	0.26	20	330
3-693039	8 June 72	0.5	0.09	0.017	0.14	34	1,550
3-693039	6 July 72	0.3	0.5	0.17	0.47	560	940
3-693039	2 Oct. 72	17.0	0.54	0.034	0.11	2	200
3-693039	6 Nov. 72	150	2.5	0.004	0.10	0.02	40
3-691067	24 Aug. 72	0.26	0.19	0.0025	0.03	9.6	158
3-691067	8 Nov. 72	20.8	0.1	0.044	0.05	2	460

* *Single mussel only.*

TABLE 35

UPTAKE OF URANIUM AND RADIUM BY MUSSELS UNDER CULTIVATION

Elapsed Time (days)	Concentration in Flesh ($pCi\ g^{-1}$)			
	Bore Water Medium		Spring Water Medium	
	U	Ra	U	Ra
0	0.3	0.08	0.30	0.08
17	3.1	0.11	0.75	0.54
34	1.3	0.07	0.44	1.16
50	1.2	0.11	0.75	0.33

TABLE 36

CONCENTRATION FACTOR FOR URANIUM AND RADIUM IN FISH

Sample type	Conc. in Water $pCi\ \ell^{-1}$		Conc. in Flesh $pCi\ g^{-1}$		Concentration Factor	
	U	Ra	U	Ra	U	Ra
Barramundi	0.95	0.37	0.0015	0.025	1.6	68
	35.4	0.92	0.034	0.01	1.0	11
	0.43	0.28	0.01	0.005	12	18
	0.23	0.20	0.004	0.07	17	350
	0.65	0.46	0.0008	0.07	1.2	150
	0.44	2.96	0.0034	0.23	8	78
Catfish	2.24	8.45	< 0.0003	0.035	< 0.1	4
	35.40	0.92	0.017	0.004	0.5	4.3
	0.43	0.28	0.0001	0.001	23	36
	0.65	0.46	0.0007	0.020	1	43
Saratoga	0.08	0.68	0.005	0.14	63	206
	0.43	0.28	0.002	0.03	70	107
Black bream	5.10	1.10	0.012	0.08	2.3	70
	0.19	0.80	0.0026	0.10	14	120
Crocodile						
(flesh)	0.44	2.96	0.001	0.03	2	10
(liver)	0.44	2.96	0.015	0.01	34	3

TABLE 37

RADIUM-226 AND URANIUM CONCENTRATIONS FOR MAGELA CREEK DURING THE 1971/72 WET SEASON ($pCi\ \ell^{-1}$)

Date	^{226}Ra	U	Date	^{226}Ra	U
25 Jan. 72	0.04	0.18	22 March 72	0.43	0.07
19 Feb. 72	1.39	0.07	14 April 72	0.12	0.11
24 Feb. 72	0.41	0.13	3 June 72	0.06	0.48
4 March 72	0.09	0.11	19 June 72	0.90	0.02

TABLE 38

DOSE COMMITMENT FOR A HYPOTHETICAL CRITICAL GROUP

Exposure Route	Assumed Consumption (kg y^{-1})	Concentration Factor at Natural plus Man-made Levels				Natural Level *3		Natural plus Man-made Level *3		Yearly Intake (nCi) Natural		Natural plus Man-made	
		U	Ra	U	Ra	U	Ra	U	Ra	U	Ra	U	Ra
Water	730	-	-	-	-	0.7	1.7	120	11.7	0.51	1.24	88	8.5
Buffalo	200	*1	*1	*1	*1	0.0034	0.0048	0.0034	0.12	0.68	0.96	0.68 *2	22
Fish	40	10	11	1	11	0.001	0.019	0.04	0.13	0.12	0.76	4.8	5.2
Cultivated vegetables	70	9	11	3	11	0.008	0.033	0.32	0.11	0.60	2.3	22.4	9.9
Cultivated fruit	20	9	11	3	11	0.0024	0.007	0.11	0.023	0.05	0.14	2.1	0.6
Crocodile	15	2	10	2	10	0.0005	0.017	0.001	0.06	0.02	0.26	0.12	1.8
Native fruit	5	9	30	3	30	0.003	0.03	0.12	0.7	0.02	0.15	0.6	3.5
Native vegetables	5	9	40	3	40	0.013	0.045	0.56	1.1	0.07	0.23	2.8	5.5
Goose	5	*1	*1	*1	*1	0.007	0.0014	0.96	0.04	0.04	0.007	4.8 *2	0.2
Mussels	2	30	650	0.2	140	0.027	1.2	0.027	1.2	0.14	2.4	0.14	2.4

*1 *The change in the uranium and radium content of buffalo and goose flesh resulting from changes in the uranium and radium content of the water that floods the grazing area is taken as one of direct proportionality to the levels established for the Magela catchment/Magela Plains system.*

*2 *On fragmentary evidence, the accumulation of uranium by geese and buffalo is taken as exchangeable and regulated pools respectively.*

*3 *Units are pCi* ℓ^{-1} *for water and pCi* g^{-1} *(fresh weight) for all others.*

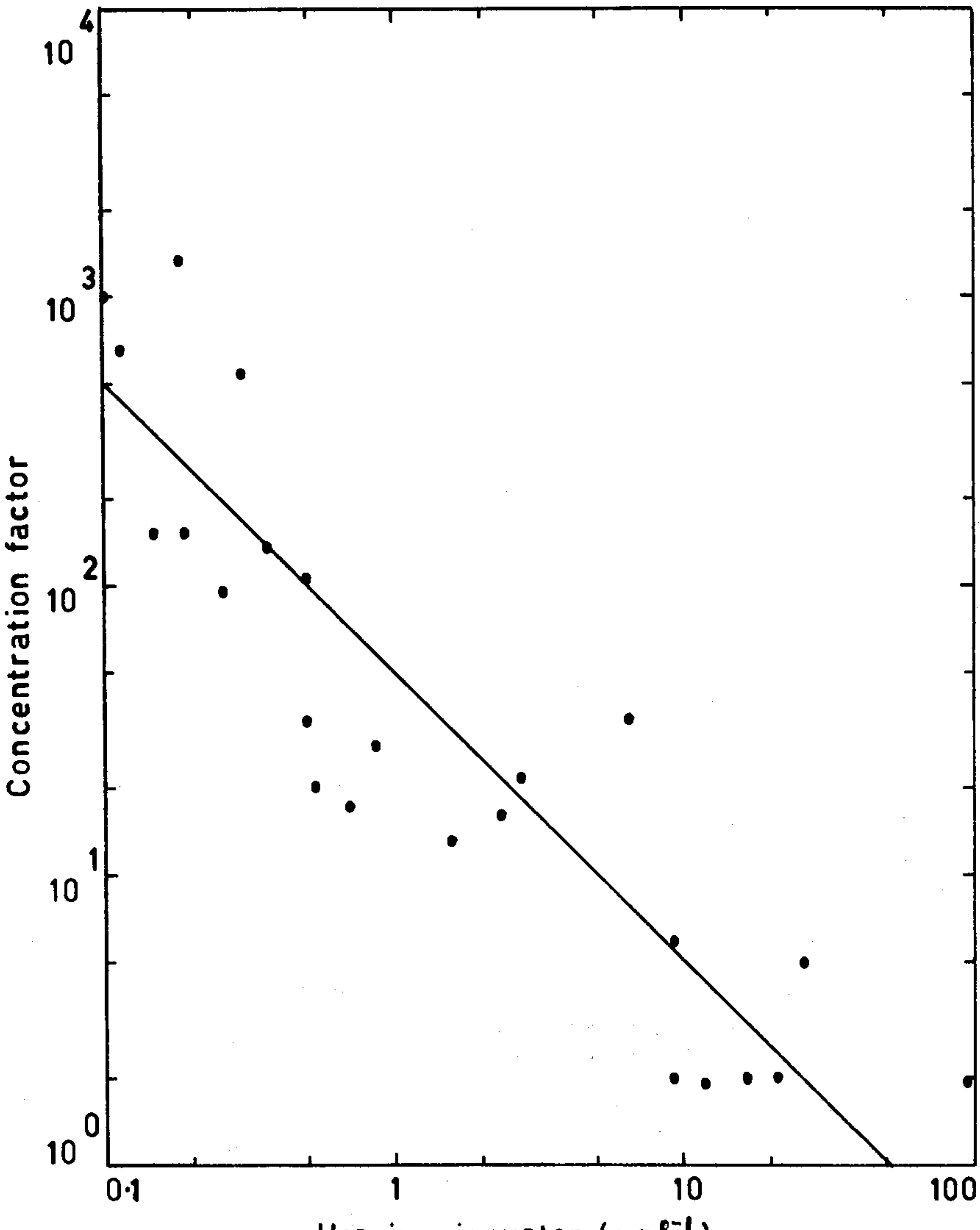

FIGURE 1. CONCENTRATION FACTOR FOR URANIUM BY MUSSELS

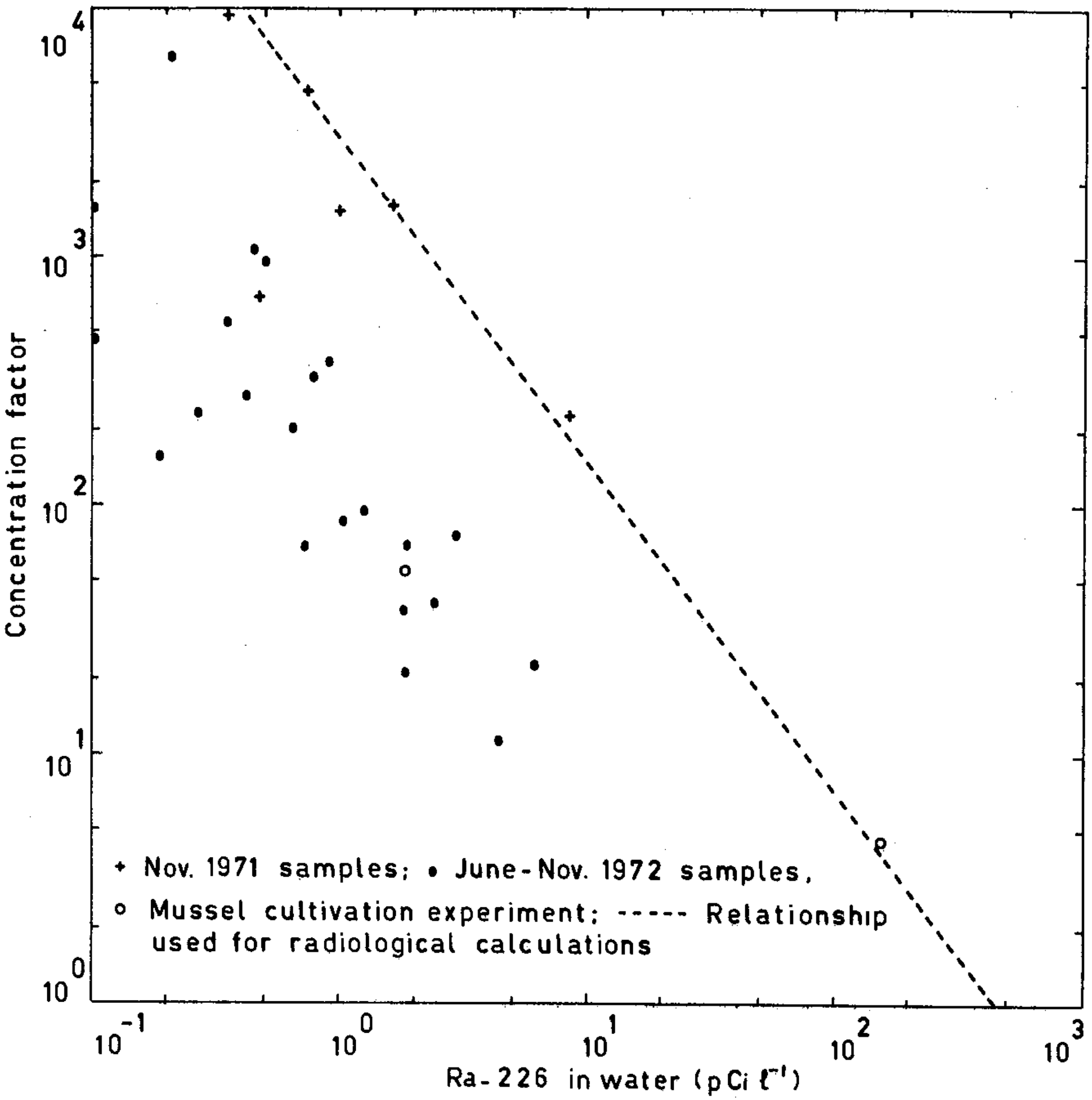

FIGURE 2. CONCENTRATION FACTOR FOR RADIUM BY MUSSELS

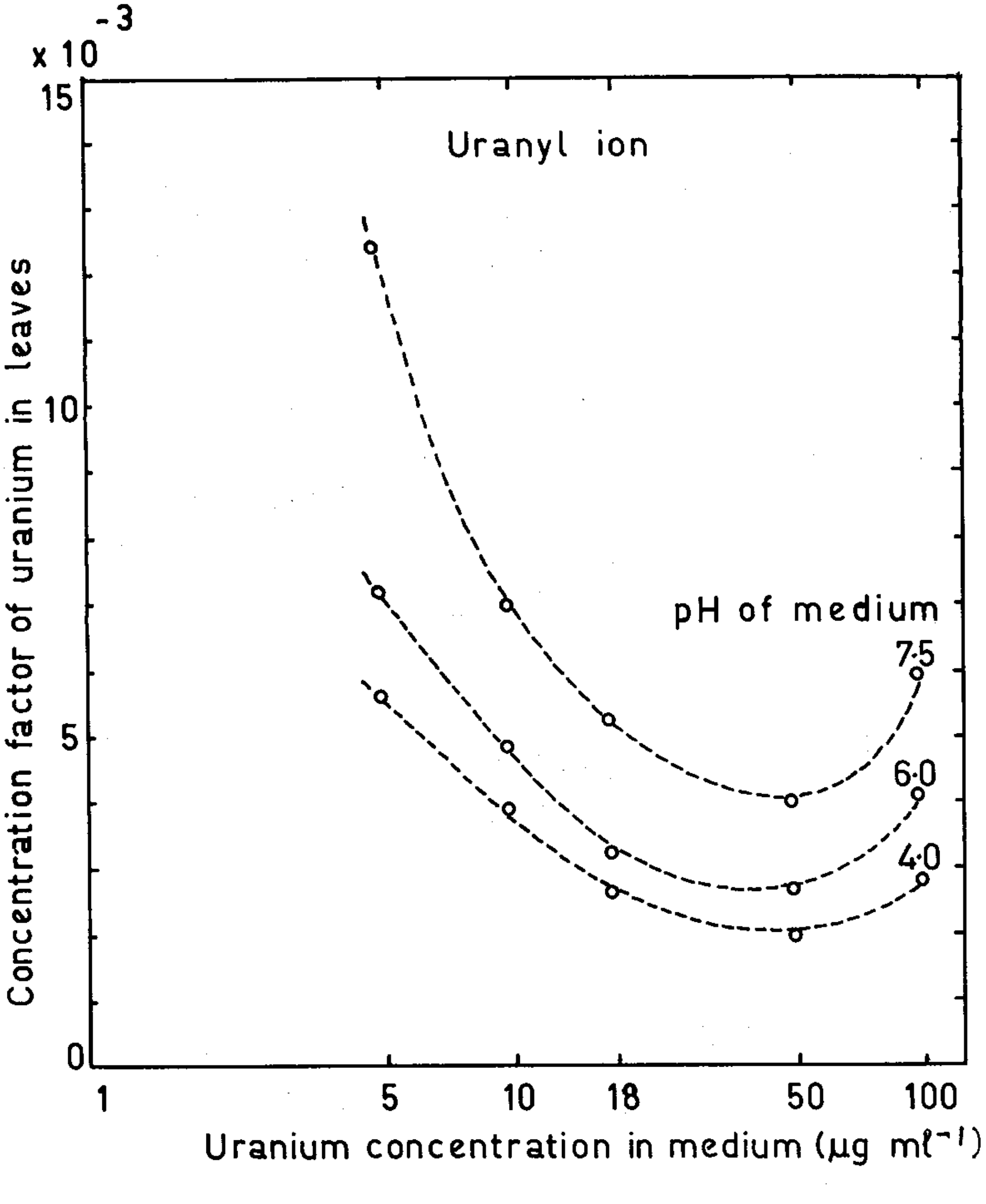

FIGURE 3. RELATION OF CONCENTRATION FACTOR OF URANIUM IN LEAVES AND URANIUM IN MEDIUM (after P. Yamanoto and K. Masuda, private communication)

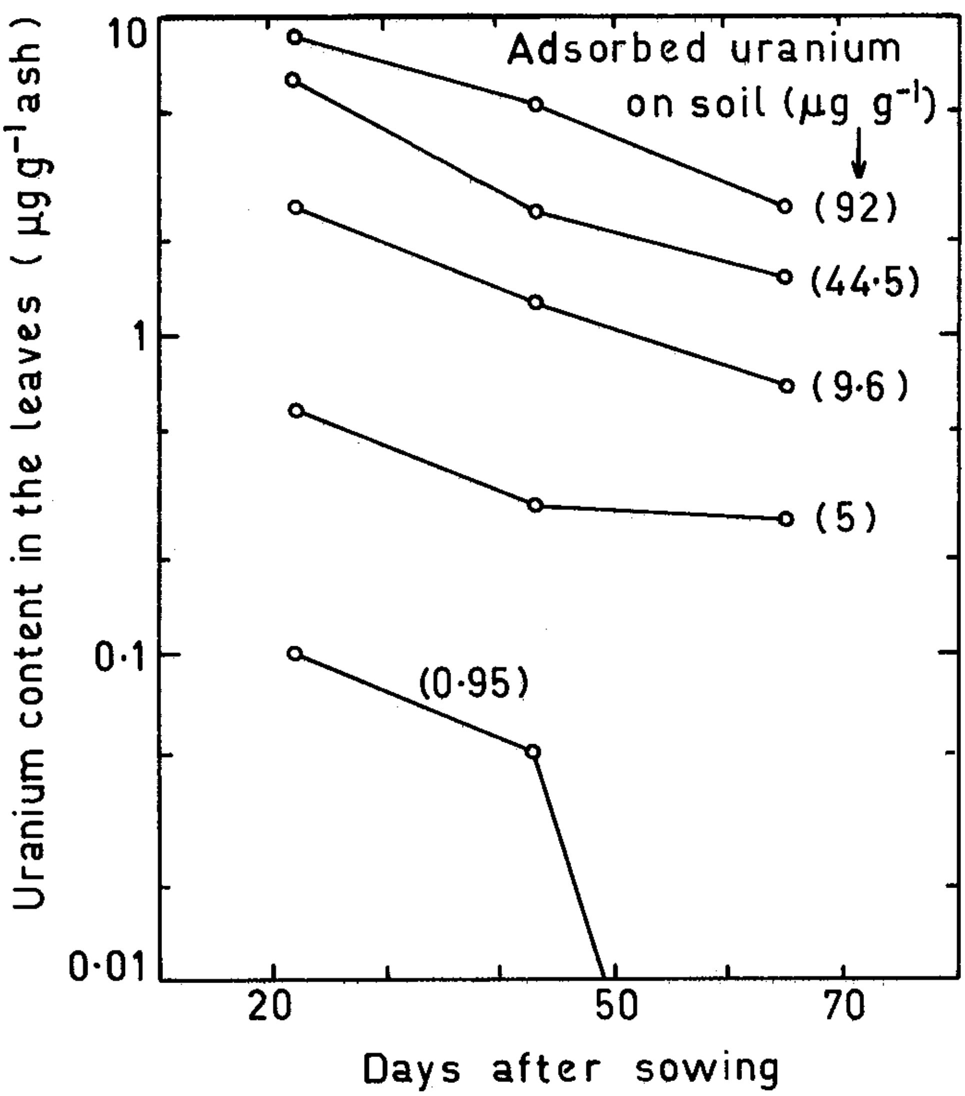

FIGURE 4. THE RELATION OF URANIUM ADSORPTION BY CHINESE CABBAGE AND THE GROWTH STAGE ON ALLUVIAL SOIL (after P. Yamanoto and K. Masuda, private communication)

APPENDIX A

SOURCE AND NATURE OF WASTES

The source and nature of potential pollutants resulting from a uranium extractive industry using open cut methods in an area with a high water table are:

Source	Potential Waste
Top soil dump	Suspended solids in creek systems.
Overburden dump	Suspended solids, dissolved radium-226, uranium, zinc, lead, copper and other heavy metals.
Ore dumps	As above.
Pit water	Dissolved radon-222, radium-226 and heavy metals.
Neutralised raffinate (seepage and runoff from tailings dam)	Radium-226, uranium and other heavy metals, amines, acidity, soluble sulphates.

OVERBURDEN DUMP Water standing in costeans is a reasonable approximation to water that has seeped through overburden dumps. Complications will arise if the costean water has at some time been used to cool diamond drills. An alternative approximation to water seeping through an overburden dump is to simply shake representative soil with water. Note that if the overburden material contains iron pyrites or other sulphide ore,neither of these approximations are realistic unless the water in contact with the soil is held at a pH of about 2.5. Table A1 indicates results from the areas with the major uranium deposits.

ORE DUMP Ranger Uranium Mines (RUM) set up two pilot scale ore piles, one of a few kg, the other being 100 tonnes. The former was almost freely exposed to the atmosphere for the duration of the 1972 dry season. During the 1972/73 wet season, rainwater funnelled through the smaller pile and the combined runoff plus seepage from the larger pile was regularly collected. RUM will no doubt report the full results but odd samples were analysed by the AAEC in order to estimate the magnitude of the problem. Results are given in Table A2. An indication of the way the radium-226 content changed during the progression of the wet season is presented below:

Date	U ($pCi\ \ell^{-1}$)	Ra ($pCi\ \ell^{-1}$)
11-26 Nov. 72	180	860
27-28 Nov. 72	147	370
29-30 Nov. 72	103	-
13 Dec. 72 to 1 Jan. 73	20	30
4-8 Jan. 73	38	41

Copper, zinc and lead values were also quite variable (see Table A2) but not regularly with time.

PIT WATER An approximation to the pit water that would enter an opencut mine in the early stages of development is the ground water saturating the ore body. Analyses on water pumped from several cased bores were consistent with respect to radium and uranium levels but fairly variable in zinc levels, a little of which may have been due to the casing material. The values given in Table A2 apply to the Ranger I anomaly I ore body. Samples from Koongarra differed from these with respect to zinc and radium (1.2 mg ℓ^{-1} and 16-26 pCi ℓ^{-1}) and that from Nabarlek with respect to uranium and radium levels (320 pCi ℓ^{-1} and 56 pCi ℓ^{-1}). The disequilibrium uranium/radium at Nabarlek is opposite to that for the other deposits. Apparently the secondary mineralisation covering the massive pitchblende is preventing weathering of the primary ore. During an opencut mining operation, the quality and quantity of the groundwater entering the pit will continually change.

RAFFINATE Analytical results for mock raffinate from Ranger ore are given in Table A2. Note in particular the dramatic improvement in water quality brought about by raising the pH from 2.0 to 7.8.

Detailed analyses on mock raffinate manufactured from Koongarra and Nabarlek ores are not available but, from work done by Amdel on the AAEC's behalf, it would appear that there is no dramatic difference between Nabarlek raffinate and Ranger raffinate.

TAILS In planning the survey programme it was assumed that uranium processing in the Alligator Rivers area would, of necessity, involve raising the pH of the raffinate above neutrality, permanent impounding of the tailings and raffinate and a tailings embankment constructed from material other than tailing sands. Under such conditions, the potential pollutants from the tails result only by seepage from the tailings dam.

Work done by Amdel indicates that such seepage would contain:

Tails	Cu (mg ℓ^{-1})	Zn (mg ℓ^{-1})	^{226}Ra (pCi ℓ^{-1})
Nabarlek	0.1-1.0	0.02-0.2	1,000-4,000
Ranger I	~ 0.1	0.04-0.4	~ 200

TABLE A1

HEAVY METAL CONTENT OF WATER FROM COSTEANS

Location	Concentration in water					
	pCi ℓ^{-1}		mg ℓ^{-1}			
	U	Ra	Cu	Co	Pb	Zn
Ranger I (1)	41	1,200	0.03	< 0.05	0.07	-
Koongarra (2)	2.5	6.4	0.1	-	0.002	0.5

(1) Believed cotaminated.

(2) Average of six costeans.

TABLE A2

ANALYTICAL RESULTS FOR SIGNIFICANT POLLUTANTS IN EACH WASTE STREAM

(Radioactivity is expressed in units of pCi ℓ^{-1}, all other results are in mg ℓ^{-1})

Pollutant	Source of Pollutant			
	Overburden Ore Dump	Pit Water	Raffinate	
			pH 2	pH 7.8
Total hardness	170	70-170	-	-
Ca	1-2	2	260	450
Mg	3-4	16-40	3,400	2,270
HCO_3		75-200	-	-
Fe		1	1,900	< 0.1
Zn	0.06-0.09	0.1-1.0	4.4	0.08
Cu	0.03-0.1	< 0.05	6.2	0.05
Pb	0.1-0.8	< 0.01	4.5	0.6
U	20-180	0.2	0.43	0.02
Co	0.005	< 0.006	2.4	-
^{226}Ra	20-860	100	218	23
^{222}Rn	-	2×10^5	-	-
As	< 0.04	< 0.05	10	3.3
Mo			< 0.2	-
Mn	< 0.08	0.1	1,170	26
Ni	< 0.1	< 0.1	18.2	< 0.1
PO_4			700	8.7
Amine	-	-	13.6	1.9

APPENDIX B

BIOLOGICAL CONCENTRATION FACTORS

The biota obtains its elemental needs by absorption, adsorption and ingestion. Conversely, they may be lost by exchange, excretion and decomposition.

The concentration of an element in an aquatic organism is usually expressed as a concentration factor, the ratio of the amount of element per unit weight of organism to that of an equal weight of water. For a concentration factor to be valid, the element in the organism and in the water must be in equilibrium, *i.e.* the rate of uptake is balanced by turnover or exchange.

Phytoplankton concentrate ionic elements mainly by absorption and particulate material by surface adsorption. Zooplankton may accumulate elements either directly from water or from feeding on phytoplankton. Shellfish may also concentrate elements while filtering phytoplankton or detritus from the water but carnivorous fish are limited to those elements that can pass through membranes, are biologically essential or have similar chemical characteristics to essential elements.

Elements can enter the food web at any trophic level but their transfer to higher trophic levels varies considerably with individual elements and the species involved. Elements concentrated on primary producers by surface adsorption seldom progress beyond the second trophic level. In contrast to pesticides which increase at each higher trophic level, elements rarely increase at each higher trophic level and most often are concentrated to the greatest extent at the low trophic level, but sometimes the concentrations go up and down from one trophic level to another.

Biological concentration factors are generally discussed in terms of one of two postulated metabolic pools - an exchangeable pool, characterised by a rapid turnover rate and a magnitude that varies in response to changes in surrounding concentrations, or a second type of pool characterised by a magnitude which is maintained by the organism at a relatively constant proportion of the organism's mass. A pool of this type if frequently termed regulated metabolic pool.

EXCHANGEABLE POOL The uptake of a stable element by a simple organism which directly concentrates the element from a reservoir of constant concentration can be approximated by:

$$\frac{dq}{dt} = \frac{I_w C}{m} - rq$$

where

m = mass

q = concentration per unit mass of organism

C = concentration of the element in water

I_w = intake rate constant

r = removal rate constant for biological elimination.

At equilibrium then;

$$q_{eq} = \frac{I_w C}{mr}$$

and the concentration factor (CF) is

$$CF = \frac{I_w}{mr} \ .$$

Metabolic processes giving rise to large concentration factors are thus generally characterised by fast intake rates and slow elimination rates. Note that for an exchangeable pool CF is independent of the concentration.

REGULATED POOL For a regulated pool, the concentration of the element in the organism is maintained at some level, say E. Then:

$$q_{eq} = \frac{I_w C}{mr} = E \ .$$

To maintain this level under varying environmental conditions, the uptake and excretion rate constants must be related so that there is no accumulation

$$\frac{I_w}{mr} = \frac{E}{C}$$

and $$CF = \frac{I_w}{mr} = \frac{E}{C}$$

and $$\ln (CF) = \ln E - \ln C \ .$$

Thus, for this case a log-log plot should be linear with an intercept equal to the concentration of the element in the regulated pool and vary inversely with the concentration in the environment.

DISCRIMINATION EFFECTS For two elements, A and B, of similar chemical behaviour (*e.g.* radium and calcium) one will generally be more essential for metabolic processes and the other will be discriminated against. The observed ratio (OR) of the concentration (X) of these elements in the organism will then be, for an exchangeable pool

$$OR = \frac{X_A/X_B}{C_A/C_B} = \frac{(CF)_A}{(CF)_B}$$

For a regulated pool, the elements will compete with each other, *i.e.*

$$E = \frac{X_A}{m} + \frac{X_B}{m}$$

If B is the essential element then

$$(CF)_B = \frac{E}{C_B} \left\{\frac{1}{1 + (OR)_w \; C_A/C_B}\right\}$$

and

$$(CF)_A = \frac{E \; (OR)_w}{C_B} \left\{\frac{1}{1 + (OR)_w \; C_A/C_B}\right\}$$

In the Alligator Rivers area, calcium levels are generally a few mg ℓ^{-1} and radium levels are of the order of 1 pCi ℓ^{-1}. Thus $C_A/C_B \sim 10^{-9}$.

If the expression in the braces approximates to unity then $(CF)_B$, for the essential element, retains the characteristics of a regulated pool (*e.g.* dependent on the concentration of B in the environment) but $(CF)_A$ varies with the environmental concentration of B. If the concentration of B is kept fixed while the concentration of A is varied then

$$\frac{X_A}{m} = (CF)_A \; C_A$$

so that the exchangeable type of behaviour is exhibited by non-essential minor elements when their concentration is increased while maintaining the concentration of related essential elements constant.

APPENDIX C
EFFECTS OF RADIATION

BIOTA OTHER THAN MAN The effects of radiation from environmental radioactivity on aquatic ecosystems have not been demonstrated except in areas of extremely high concentrations near atomic bomb test sites.

Aquatic organisms can be exposed to external radiation by radioactive water, sediments, adjacent organisms and radionuclides adsorbed to their body coverings. They can be irradiated also by internally deposited radionuclides which have been ingested in food and water or absorbed directly. Radiation, if delivered in sufficient quantities, can damage individual organisms by reducing the rate of growth, shortening the life span, reducing fecundity and changing behaviour.

For death to result immediately, both the dose and dose rate must be high. The more primitive organisms are usually more resistant than the more advanced animals but there is considerable variation between related species. For man, the lethal dose in rem for 50% survival (LD-50) is about 500; for fish between 800 and 1,500; for crustacea 200-100,000; for mollusca 5,000-50,000 and for algae 10,000-100,000 (Donaldson 1963). Doses of these orders are impossible from a uranium extractive industry.

Different stages in the life cycle of a species also differ in sensitivity to radiation. Gametes and eggs through the one cell stage are very sensitive to radiation; for example, during mitosis of the single cell of silver salmon the LD-50 is 16 rem when delivered at a high dose rate (Donaldson & Forster 1957). Welander (1954) found that the sensitivity of rainbow trout decreases throughout early development:

Stage	LD-50 (rem)
Gametes	50-100
1 cell	58
32 cell	313
Germ ring	454-461
Eye	415-904
Adult	1,500

This relation appears to be the general rule for other species. Sensitivity to radiation is correlated with the metabolic rate of the cell, the dormant eggs of aquatic invertebrates being especially resistant.

Most of the qualifications on threshold dose-rates needed to produce particular end points relate only to β and γ irradiations. There are good biophysical reasons, with ample radiobiological confirmation, to support the contention that for α irradiations dose-rate is of minor importance.

Chronic irradiation of the eggs of brown trout by immersion for 58 days in strontium-90 contaminated water at a dose-rate of about 3 rem day^{-1} increased alevin length slightly but significantly (Brown & Templeton 1964). Chronic irradiation of trout sperm will produce visible teratogenic defects, the dose required to double the natural incidence of an eye malformation being 50 rem (McGregor & Newcombe 1972).

The most significant aspects of environmental radiation are the effects on animal populations rather than on individuals. If the adverse effects of radiation occur simultaneously with other unsatisfactory conditions, such as high temperatures, excessive predation, high turbidity, *etc.* the population could be reduced to a greater extent than if the radiation was absent. Such interactions of environmental factors, where a change in the level of one factor is reflected by a change in the tolerance of an organism for another, have been established for many combinations (*e.g.* salinity and temperature).

The interaction of three environmental factors (radiation, salinity and temperature) upon morphometrical changes and growth of post larval pinfish was determined by White (1969). Of nine different body characteristics measured, radiation affected two, salinity affected five and temperature affected all nine. Interactions between radiation and salinity were found in four of the characteristics, and interactions of radiation with temperatures for eight of them. Similar positive interactions have been demonstrated (Angelovic, White & Davis 1969, Angelovic & Engel 1970); the doses involved in these studies were very high, ranging from 2,000-6,000 rem.

Experiments to determine the effects of radiation on some algal, invertebrate and primary consumer populations have been conducted. Doses of some 100 rem day^{-1} were needed to produce changes in productivity.

The fecundity of mosquito fish living in a contaminated lake, the sediments of which delivered a daily dose of 10 rem, was investigated by Blaylock (1972). Although notably more dead embryos and abnormalities were observed in the irradiated broods, a significantly larger brood size occurred in the irradiated than in the non-irradiated control population.

Establishing the occurrence of a genetic change in a population is more difficult than detecting somatic damage. Most mutations would be deleterious and would be eliminated through an inability of the genotype to compete with others in the population. The probability of a mutation finding expression is highest in inbred populations, *e.g.* salmon which spawn in the same stream in which they are reared. Bonham & Donaldson (1972) inspected 4,400 pre-migratory chinook salmon smolts *(oncorhynchus tshawytscha)* to determine sex. Nearly half of the smolts of seven of the year classes had been irradiated for their first 80 days of life at doses from 0.5 rem day^{-1} the first year to a maximum of 50 rem day^{-1} the last year. Sex ratios were unaffected by 5 rem day^{-1} or less but at 10 or more rem day^{-1} gonadal development was retarded.

MAN Following the discovery of X-rays and natural radioactivity at the end of the nineteenth century it was soon discovered that exposure to ionising radiation could have adverse effects on health. Large doses of radiation (more than a few hundred rem) caused immediate effects from which there might or might not be recovery, depending on the dose and fraction of the body exposed. It was also found that exposure resulted in an increased incidence of cancer and leukaemia in later years. Animal experiments also showed that radiation exposure resulted in increased mutation rates - the offspring of exposed animals were more likely to suffer from genetically caused ill-health. These findings are the basis for setting limits to exposure for occupational radiation workers which, with one exception (uranium miners), have been found to be readily achievable with, to date, no demonstrable adverse effects on the health of those exposed up to the limits.

Figures for the risk of cancer as a function of dose have been collected over the past two decades or so from as many sources as possible. These sources are thoroughly reviewed in UNSCEAR (1972) and BEIR (1972). It should be noted that the figures obtained relate in the main to persons who received doses of more than 100 rem over short periods of time and that no information is available on the biological effects of doses less than 1 rem spread over months or years. It is therefore necessary to make some assumption about the way in which the risk falls as dose decreases, and the period over which it is received increases. The simplest assumption is that the risk is proportional to the dose and that the period over which it is received is of no consequence. There are some grounds for supposing (at least in some cases) that risk decreases as dose rate decreases. The assumption that risk is proportional to dose is therefore generally considered to be conservative, *i.e.* likely to overestimate the consequences of low doses.

THE RISK OF CANCER FOLLOWING RADIATION EXPOSURE The major observed carcinogenic consequences of human exposure to external radiation are summarised in Table C1. Two points will be noted from this table. Firstly, there is considerable uncertainty in the risk factors. This arises from the statistical nature of the observations. In every case, the risk factors are based on the observation of a certain number of cases in an exposed population as compared with a somewhat smaller number expected or observed in a similar but unexposed population. Unless the observed excess is large compared with expectation, the degree of uncertainty indicated is unavoidable. Secondly, the risk factors are based on observations over a period of 20 years or so. The observations are sufficient to show that the risk rate does vary with time but not to give any indication of likely rates outside the observation period. For leukaemia, the risk rate rises over the first 10 years following exposure and then drops, although it is still positive at 20 years. For other cancers, it is not clear whether or not the peak risk rate has been reached at about 20 years. (The observation of radiation induced cancer becomes more difficult the older the population becomes because the natural incidence rises rapidly for most forms as age increases. It may well be therefore that observations over the next 20 years will not add much to current assessment of risks, except for those in the irradiated populations who were children at the time of exposure.)

GENETIC EFFECTS OF RADIATION EXPOSURE Despite follow-up of irradiated human populations there is an almost complete absence of direct information on radiation induced genetic effects in man. It is therefore necessary to extrapolate from the very large amount of animal data in order to estimate the possible genetic consequences of radiation exposure in man (UNSCEAR 1972, BEIR 1972). This introduces rather more uncertainty into the assessment of genetic consequences than arises from the assessment of carcinogenic risks. Further difficulty arises inasmuch as the consequences of genetic defects vary very widely. At one extreme a genetic defect may cause foetal death and abortion, and at the other extreme it may be responsible for slightly reduced resistance to infection in the adult and only a minor decrease in well-being. Those defects which lead to severe disability in the live born are generally regarded as most adverse, although in terms of public health if there were a very much larger number of minor defects than major, the overall significance of the minor defects could be the greater. However, the existence and frequency of such minor defects is not well established and studies of irradiated animal populations suggest they are not significant.

As an indication of the magnitude of the genetic consequences of human exposure to radiation, UNSCEAR (1972) has estimated, on the basis of mouse data, that a parental gonad dose of 1 rem gives rise to somewhere between 6 and 15 live births per million in the first generation suffering from genetic disease, with a total number over all generations of around 300. As the birth rate in developed communities is of the order of 2 per cent of the total population per year the first generation incidence rate is 1.2 to 3.0 x 10^{-7} per year per rem averaged over the total population. This is at least a factor of 20 down on the annual cancer incidence per rem, although this factor is offset by the cases occurring in subsequent generations, so that the total number of cases of genetic disease and of cancer appear to be the same.

TABLE C1

RISK FACTORS FOR CANCER AS A RESULT OF EXTERNAL RADIATION EXPOSURE

Type of Cancer and Period of Observation	Cases per Year per Million Persons per rad	
	UNSCEAR Risk Factors	BEIR Risk Factors
Leukaemia (for approx. 20 years)	0.7-2	1-2
Thyroid (approx. 20 years)	1-2 (Male) 2-4 (Female)	1.6-9.3 (children)
Breast (approx. 25 years)	0.25-6 (Female)	1-8.4 (Female) (best value = 6)
Lung (approx. 25 years)	0.6-2	0.1-1.6
Other	Approx. 2	0.1-1 (bone) 0.1-6 (stomach) 0.2-8 (other) 0.4-2.4 (total)

The US collection of data on the medical histories of uranium miners related to their estimated exposure gives an overall risk of subsequently developing lung cancer of about 5 x 10^{-4} after a year's exposure at the working level (i.e. 500 cases over 25 years per million workers exposed to 12 WLM) (Watson 1973). WLM = Working level month.

THE ALLIGATOR RIVERS AREA FACT FINDING STUDY

REPORT IV

ENVIRONMENTAL LEVELS OF RADON-222

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CONTENTS

1. INTRODUCTION

In the early 1920s, it was suggested that the presence of radon in the mine atmospheres was the cause of lung cancer in miners employed in the Schneeberg-Jachymov areas of the Erz mountains. It is now clearly established that much of the excess lung cancer in miners has a radiogenic origin.

2. THE IMPORTANCE OF RADON DAUGHTERS

The principal radiation dose to the lung resulting from the inhalation of air containing radon is not from the gas itself but is attributable to α radiation from the short-lived radon daughters whose half-lives are short in relation to any possible mode of elimination from the lungs.

Table 1 shows the natural uranium decay series together with the half-life, mode of decay and decay energy for each daughter product.

Because of the importance of the α decay energy from radon daughter products a special unit, the working level (WL), has been introduced. The WL is defined as any combination of the short-lived decay products of radon in one litre of air which will result in the ultimate emission by them of 1.3×10^5 MeV of α particle energy. If radon gas was present at a concentration of 100 pCi ℓ^{-1} and if all daughter products were in equilibrium then the decay energy concentration would be 1 WL. Table 2 indicates why this is so.

3. FACTORS AFFECTING ATMOSPHERIC LEVELS OF RADON

The level of radon in the atmosphere is influenced by many factors. In this report, the problem is simplified by reference to one of two major categories:

- A stable atmosphere with calm conditions and dry terrain (strong inversion conditions).
- An unstable atmosphere with a prevailing wind and a simple, static synoptic weather chart (well mixed conditions).

In the Alligator Rivers area the conditions during most 24-hour periods at any particular location will range between these two extremes. Frequently, radon levels will change by more than two orders of magnitude. Spot measurements done under conditions other than those of the two extremes are valueless unless the prevailing meteorological parameters can be specified accurately. During the study period no such meteorological observations were made.

3.1 Strong Inversion Conditions

During periods of strong inversions the prevailing radon level depends almost exclusively on the emissivity of the underlying soil for radon. This in turn depends on the nearness of uranium mineralisation, the presence of radon rich groundwater, the type of soil and its moisture content; local geology is also important.

If conditions are not perfectly still, the presence, or otherwise, of topographical features is of great importance. Mechanically generated air turbulence is an important mixing mechanism in the lower atmosphere.

3.2 Well-Mixed Conditions

Unstable meteorological conditions exist most frequently during daylight hours when solar heating of the ground induces convective mixing. If strong winds are also present, mechanical turbulence adds to the mixing process.

For such conditions the prevailing radon level characterises the origin of the air mass and the terrain over which it has passed. The transit period of interest is one of some days' duration.

If radon measurements are carried out under a complete range of synoptic conditions it is possible, in time, to build up a 'rose' of natural radon levels. This has not been done in the Alligator Rivers area.

4. FACTORS AFFECTING RADON DAUGHTER CONCENTRATIONS

Terrestrial radium is the source of atmospheric radon. Radon concentrations are therefore greatest at the earth-atmosphere interface. Any movement of air will dilute these surface concentrations and prevent the radon daughter products building up to equilibrium. Table 3 indicates the effect of ventilation in establishing disequilibrium in the radon daughter chain. Table 4 lists the change in dose, relative to that for an equilibrium mixture, that occurs with increasing disequilibrium.

5. FACTORS AFFECTING RADON CONCENTRATION IN GROUNDWATER

Groundwater, in passing through uranium mineralisation, dissolves some of the radon gas. Groundwater velocities are generally in the range of cm to m per day so that high values of radon in water are indicative of nearby uranium mineralisation.

From results presented later it appears that groundwater movement provides ideal conditions for the removal of radon daughters. Extreme disequilibrium in the radon daughter chain was a characteristic of all groundwater samples analysed.

6. SAMPLING PROGRAMME

Because of the lack of a meteorological programme, radon sampling was restricted to well-defined local situations.

6.1 Methods

6.1.1 Radon in air concentration

Known volumes of air were passed through activated charcoal traps held at ~80°C in a dry ice-alcohol slurry. Prior to the charcoal trap atmospheric moisture was removed by a molecular sieve trap. After sampling, the traps were sealed and dispatched to Lucas Heights for radon determinations on an emanation rig described elsewhere (Davy & Conway 1973)

Because of logistic difficulties in the supply of dry ice, this technique was used infrequently.

6.1.2 Radon in water concentrations

About 20 ℓ of sample was collected in polythene drums and then saturated with sodium chloride. This provided condensation nuclei for the subsequent step. Some 40 ℓ of compressed air was passed through the sample to remove ~85% of the dissolved radon. The emerging air was passed either through a charcoal trap (Section 6.1.1) or used to inflate a meteorological balloon. In the latter case, the radon was allowed to build up to equilibrium with its daughters before expelling it through a glass fibre filter paper. The α activity of the particulate retained by the filter paper was subsequently counted using a zinc sulphide scintillator/photomultiplier device.

Significant quantities of radon daughters plate out on the balloon. This quantity was estimated by determining the surface α activity on the rubber and was proved to be a fairly constant percentage of the total concentration. The charcoal trap method provided an independent calibration of the balloon technique.

6.1.3 Radon daughter concentrations

Known volumes of air were sampled through glass fibre papers and subsequently the α activity of the deposited particulate was measured. When the initial count rate was high enough, the decay of the daughter products was followed.

6.2 Data Reduction

The deposited α activity on a filter paper from an air sample depends on radon concentration, degree of disequilibrium, sampling rate, sampling period and the time delay between sampling and counting. Various methods can be used for data reduction and these are detailed elsewhere (Davy & Conway 1973).

The results presented below take one of two forms. For a specified sampling time and delay time, the recorded count-rate can be directly related to WL for an accuracy of $\pm$ 20% irrespective of initial daughter disequilibrium (Rolle 1972).

If the daughter decay curve is followed, correction factors related to sampling period and initial disequilibrium can be estimated. The final result can then be expressed in terms of a radon concentration which, if present in equilibrium with its daughters, would give rise to the measured α activity.

When radon and WL concentrations are measured separately (by charcoal trap and air filtering methods, respectively) a working level ratio (WLR) can be estimated. This is a direct measure of the degree of disequilibrium.

7. RESULTS

7.1 Radon Levels in Costeans

Radon levels in costeans at the Ranger I (Anomalies I and II), Koongarra and Nabarlek deposits were measured. In each case measurements were done during mid-afternoon, early evening and early morning to cover periods of maximum and minimum atmospheric dispersion.

The costean at Nabarlek was one dug to massive pitchblende but which subsequently had partly caved in during the 1971/1972 wet season.

At Ranger I (Anomaly I) the costean was unique. It was formed by a trench digger to a depth of ~5 m with a width of 1 m through ore of above average grade. The Ranger I (Anomaly II) costean was of slit-trench proportions while that at Koongarra was a shallow, full-blade bulldozer cut.

Table 5 presents results for the more conventional costeans. The results for the Ranger I (Anomaly I) costean are presented in Table 6.

7.2 Radon Levels in Core-sheds

Measurements in core-sheds were done during evenings with still conditions that were judged as representing inversion conditions. Results are presented in Table 7.

7.3 Radon Levels in Bore Water

Radon levels in bore water were investigated for only one ore body - Ranger I (Anomaly I). It is this groundwater that has the highest radium-226 content (70-150 pCi ℓ^{-1}). Results are presented in Table 8.

8. DISCUSSION

The draft code of practice for the mining and milling of uranium ores recommends an annual dose limit of 4 WL - months for occupational workers*, *i.e.* a maximum concentration of 0.33 WL averaged over 40 h per week and 52 weeks per year employment. There is no genetic dose associated with inhaled radon daughters so the maximum concentration of 'man-made' radon daughters will be 0.008 WL (averaged over 168 h per week, 52 weeks per year) for continuous exposure of members of the general public.

The International Commission on Radiological Protection (ICRP) makes no recommendations on allowable concentrations of radon gas in drinking

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* *This limit is to be reviewed by no later than 1 January 1975.*

water. If the normal methods of calculation are followed, the allowable concentration for members of the general public would be 100 nCi ℓ^{-1}. While this number can have no official status it is obviously in the right region. Suomela & Kahlos (1972), using slightly different models for transit time in the gut, have reached similar conclusions.

As was the case for environmental levels of radium-226, the important point here is that ICRP and related recommendations refer only to 'man-made' levels over and above those levels that occur naturally.

The work described in this report had two purposes. Firstly, it was meant to demonstrate to companies planning uranium mining by open cut methods that, under inversion conditions, quite high levels of radon might occur in the pit and that the level is dependent on many factors including ore grade, groundwater, local wind turbulence, mechanical mixing, *etc*. Secondly, it was meant to demonstrate that detailed meteorological data is a prerequisite for reliable calculations of the radon concentration that will be experienced at, say, the Regional Centre, due to mining operations. Presumably, what is important here is the atmospheric stability categories that prevail in the hours preceding sunset and the first few hours after sunrise. It is believed that these aims were achieved.

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TABLE 1

URANIUM RADIOACTIVE DECAY SERIES

(Minor branches not shown)

Radioelement	Isotope	Radiation	Half Life	Remarks
Uranium I ↓	$^{238}_{92}U$	α, γ	4.5×10^9 y	
Uranium X_1 ↓	$^{234}_{90}Th$	β, γ	24.1 d	β rays in uranium metal and ore come from these
Uranium X_2 ↓	$^{234}_{91}Pa$	β, γ	1.14 min	
Uranium II ↓	$^{234}_{92}U$	α, γ	2.5×10^5 y	
Ionium ↓	$^{230}_{90}Th$	α, γ	80,000 y	
Radium ↓	$^{226}_{88}Ra$	α, γ	1,620 y	
Radon ↓	$^{222}_{86}Rn$*	α	3.83 d	gas
Radium A ↓	$^{218}_{84}Po$*	α	3.05 min	collects on dust in mine
Radium B ↓	$^{214}_{82}Pb$	β, γ	26.8 min	β and γ rays in mine come from these
Radium C ↓	$^{214}_{83}Bi$	β, γ	19.7 min	
Radium C^1 ↓	$^{214}_{84}Po$*	α	1.64×10^{-4} s	collects on dust in mine
Radium D ↓	$^{210}_{82}Pb$	β	22 y	
Radium E ↓	$^{210}_{83}Bi$	β	5 d	
Radium F ↓	$^{210}_{84}Po$*	α	140 d	
Radium G (stable)	$^{206}_{82}Pb$	-	-	

* *Constitutes the α hazard in mining, etc.*

TABLE 2

THE RELEVANT DATA USED TO DERIVE THE WL

Nuclide	α Energy (MeV)	Half Life (min)	No. Atoms in 100 pCi	Ultimate α Energy/Atom	Total Ultimate α Energy (MeV/100 pCi)
RaA	6.00	3.05	977	6.00 + 7.68	0.134×10^5
RaB	0	26.8	8,580	7.68	0.659×10^5
RaC	0	19.7	6,310	7.68	0.485×10^5
RaC^1	7.68	10^{-6}	0.0008	7.68	0.000×10^5
				Total	1.278×10^5
				Round up to	1.3×10^5

TABLE 3

CHANGE IN RADON DAUGHTER RATIOS WITH INCREASING VENTILATION (CHANGES PER HOUR)

(After Breslin, George & Weinstein 1969)

Ventilation (h^{-1})	$^{214}Pb/^{214}Po$	$^{214}Bi/^{214}Po$
0	1	1
0.5	0.7	0.6
1.0	0.5	0.4
2.0	0.3	0.22
3.0	0.25	0.14

TABLE 4

INHALATION HAZARD OF NON-EQUILIBRIUM RADON-DAUGHTER MIXTURES

Equilibrium Ratios	% of Equilibrium Dose
1, 1, 1, 1.	100
1, 1, 0.90, 0.80	87.5
1, 0.90, 0.80, 0.70	77.4
1, 0.85, 0.65, 0.45	59.8
1, 0.75, 0.50, 0.30	45.3
1, 0.75, 0.40, 0.15	34.3
1, 0.50, 0.25, 0.10	21.9
1, 0.35, 0.15, 0.05	13.4
1, 0.25, 0.10, 0.05	9.6
1, 0.15, 0.08, 0.03	6.9

TABLE 5

RADON DAUGHTER LEVELS IN COSTEANS

Date	Time	Location	WL	Remarks
20 Aug. 72	06.45	Nabarlek (QMC4-5)	8.3	Clear sky no wind
	07.30	Nabarlek (QMC4-5)	8.7	
	12.30	Nabarlek (QMC4-5)	0.14	
6 Aug. 72	11.30	Koongarra (Costean No.3)	0.03	Clear sky wind ~ 1 knot
	19.00	Koongarra (Costean No.3)	0.09	100% cloud no wind
7 Aug. 72	07.00	Koongarra (Costean No.3)	0.55	20% cloud no wind

TABLE 6

THE EFFECT OF METEOROLOGICAL CONDITIONS ON RADON DAUGHTER LEVELS IN A TRENCH COSTEAN (RANGER I ANOMALY I, 3-4 AUG. 72)

Time	Meteorological Conditions	WL
15.30	Cumulus, large base 40% cover	14.6
16.35	Cumulus, large base 20% cover	6.9
19.05	Still	22.6
22.05	Gusty easterly	0.7
07.00	Still	10.9
09.45	Gusty easterly, no cloud cover	0.3*

* *WLR = 8.1.*

TABLE 7

RADON LEVEL IN CORE-SHEDS

Date	Time	Location	WL
21 Aug. 72	08.00	Nabarlek	0.11
7 Aug. 72	19.30	Koongarra	0.06
28 June 72	06.00	Jabiru	0.19

TABLE 8

RADIOACTIVITY IN GROUND WATER OBTAINED DURING DRAW-DOWN TESTING OF RANGER I ANOMALY I

Bore No.	Time into test (h)	U_{nat}	^{226}Ra	^{222}Rn	^{210}Pb*
		(pCi ℓ^{-1})			
S1/8	0.25	2.6	11	-	0.83
	1.45	28	9.5	-	0.25
	2.5	20	12.8	-	0.36
S1/3	0.05	160	70.4	4 x 10^5	1.6
	1.5	293	81	-	1.8
	2.75	408	138	-	2.1
	4.0	320	97	-	2.4
	0.75	-	-	1.3 x 10^5	-
	4.6	103	125	1.1 x 10^5	-
	8.5	73	292	9.5 x 10^4	-
	11.25	-	-	1.1 x 10^5	-
	15.3	-	-	1.1 x 10^5	-
	16.3	71	104	1.1 x 10^5	-
	23.5	-	-	1.1 x 10^5	-
	25.3	-	-	1.1 x 10^5	-
S1/14	0.5	3.8	23	2 x 10^4	-

* *The ratio of lead-210 in the filtrate to that in the 'solids' of the slurry averaged 75 on a per unit volume basis.*