# USE OF BIOLOGICAL MONITORING IN THE ASSESSMEN EFFECTS OF MINING WASTES ON AQUATIC ECOSYSTEM THE ALLIGATOR RIVERS REGION, TROPICAL NORTHERN AUSTRALIA

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(Received April 1989)

**Abstract.** The primary objective of the biological monitoring program of the ARRRI is to techniques and procedures to monitor and assess effects of the mining and processing of ores on ecosystems of the Region. Studies have been made in a seasonal tributary (Magela Creek) of t Alligator River near the Ranger Uranium Mine, and in the upper South Alligator River (SAR) r Coronation Hill gold, platinum and palladium prospect. Ranger and Coronation Hill are encl Kakadu National Park, environmental safeguards for which require the minimization of impair water quality in the aquatic ecosystems. Present studies on Magela Creek are designed to ve adequacy of release standards, based on biological tests, in protecting the aquatic environment and after releases of waste-water from Ranger during the Wet season. Detection of short-term will be sought by either creekside or *in situ* monitoring methods. The detection and assessment longer-term impacts, however, will rely chiefly on comparisons of post-release data with those of hi baselines. Such baseline information is provided by studies on the structure of macroinvertebrate communities and/or on concentrations of elements in organisms in those communities, in Magel and SAR catchments.

## 1. General Background

### 1.1. The heritage, the problems and the environmental controls

The Alligator Rivers Region (ARR) of tropical northern Australia contains d tive and scenic wilderness areas, an exceptionally diverse (for Australia) flor fauna, and an abundance of Aboriginal rock art of world significance. Two- of the Region has been declared a national park (Kakadu) while most of the R is on the Register of the National Estate, and Kakadu Stages 1 and 2 have entered onto the World Heritage List and the Convention on Wetlands of national Importance.

The Region also contains large, economically important, mineral reserves i ing uranium, gold, and platinum-group metals. Proposals to exploit such re in recent years (1970 onwards) have been surrounded by considerable public co ersy because of perceived threats to the cultural and natural heritage of the R During this time mining (for uranium) has been restricted to two sites in the R Both mines commenced construction in 1979 and are located within catchme seasonal tributaries of the East Alligator River, Ranger on Magela Cree Nabarlek on Cooper Creek. In recognition of the unique environment of the R environmental protection measures were established (the Environment Prote (EP) (ARR) Act 1978) following recommendations made by the Ranger Ura Environmental Inquiry in 1977 (Fox *et al.*, 1977).

The Supervising Scientist is a statutory officer appointed by the Commonw Government to implement the EP (ARR) Act. He has supervisory, coordinatior research roles considered necessary for the protection of the environment fron effects of uranium mining and processing operations. The research arm of the O of the Supervising Scientist is the Alligator Rivers Region Research Institute (A RI). Following the discovery of significant concentrations of gold and plati group metals in the upper South Alligator River catchment, a so-called "Co vation Zone" (in reality a zone for mineral exploration) was established and th (ARR) Act was amended in 1987 to extend the functions of the Office to ge mining operations in this specific area. Concurrent with this amendment was declaration of the lands surrounding this richly mineralized area as Stage 3 of Kak National Park.

A major environmental concern associated with the present and proposed mi developments within the ARR is the management of excess water that accumul each year within mine sites as a consequence of the seasonal, monsoonal rain Such waste-waters contain naturally-occurring substances (heavy metals, radic clides, suspended solids), at concentrations greater than those in adjacent nat surface waters and exotic chemicals (hydrocarbons, process chemicals) and there could pose an environmental risk if allowed to drain freely from a site. Beca surface waters are the chief vehicle for transport and dispersion of such wastes because aquatic organisms are continuously exposed to wastes and therefore at l risk (while wastes are present in a water), much of the research carried out at ARRRI has been centred on the aquatic ecosystems of the Region. The maintena of the biotic integrity, structural and functional, of ecosystems is the most cru aspect of ecosystem protection and only studies conducted on aquatic organisms define or be used to assess the overall effect of waste-waters on these organisms. T research at the ARRRI has focussed on the development of biological method the following areas:

(a) the identification, quantification and assessment of the effects on organi in natural surface waters of mine waste-waters (or other wastes) which enter the cr systems, in order to provide assurance of the absence of observable detriment to th organisms; and

(b) for specific water management problems involving controlled waste-wa releases, the laboratory determination of the toxicity of waste-waters of conc to a wide range of organisms in order to predict dilutions at and below wh no observable toxic effects will occur in any organism within exposed comr nities.

The Biological Monitoring Section of the ARRRI is responsible for Part 'a developments and procedures here are the central focus of this paper. Whilst t paper is concerned with the monitoring of aquatic environments predominantly us biological procedures, it is recognised that both biological and physico-ch monitoring are necessary in comprehensive environmental assessment. Mor valuable interpretative and predictive information may be gained where relatio between changes in water physico-chemistry (under both unpolluted and pc conditions) and organism response can be established.

It is appropriate at this point to highlight two quite probably unique factors - from the feature that the aquatic ecosystems under investigation were previous essentially unstudied – under which the work is carried out. The first factor present (Federal) Government's determination to ensure the highest level of en mental protection for the ecosystems under potential threat. For example, many other areas in Australia and overseas have environmental legislation in to prevent or reduce detrimental changes in aquatic ecosystems, only in few (e.g. Athabasca tar-sands mining, Alberta Environmental Centre, Canada) than the ARR does there exist *both* the necessary scientific knowledge (foste adequate funding of relevant research) and political mechanisms (fostered by degree of regulation overseen by one supervisory and coordinating author implement such legislation successfully. The second factor concerns the featu the objective of the impact assessment program in the ARR differs markedly others in Australia – for example in the Finniss River (Jeffree and Williams, Latrobe R. (e.g., Marchant *et al.*, 1984), King R. (Swain and White, 1985), Esk R. (e.g., Norris *et al.*, 1982), Molonglo R. (e.g., Weatherly *et al.*, 1967; N 1986), Murray R. (Walker, 1985) and in some urban creeks (e.g., Arthington 1983) – and indeed elsewhere in the world, in that it is focussed on the avo of detrimental changes in what are effectively pristine ecosystems, rather th assessment and rehabilitation of systems already degraded. To some extent differences have arisen because of the increase in concern and the developm effective legislation for environmental protection since the 1970s.

## 1.2. Major characteristics of the aquatic ecosystems of the ARR

The Alligator Rivers Region (ARR) is situated east of Darwin, Northern Te (Australia) and is broadly defined by the catchments of the West, South an Alligator Rivers (Figure 1). The major streams of the Region arise in the l leached sandstone of the Arnhem Land plateau, which occupies a large port the Region's eastern and southern sections, and consequently their water: extremely low concentrations of solutes. After flowing from the plateau th deeply incised escarpment valleys, the major streams occupy largely sandy and braided channels and flow through extensive and flat lowlands, to enter the l seasonally-inundated floodplains. Tributaries of the larger Alligator Rivers s Magela, Cooper and Nourlangie Creeks, have disjointed drainage lines as they their floodplains.

The climate of the Region is monsoonal, the Wet season occurring gei between November-March and the Dry between May-September; April and O are generally transitional months. Annual rainfall at Jabiru (Figure 2) ov

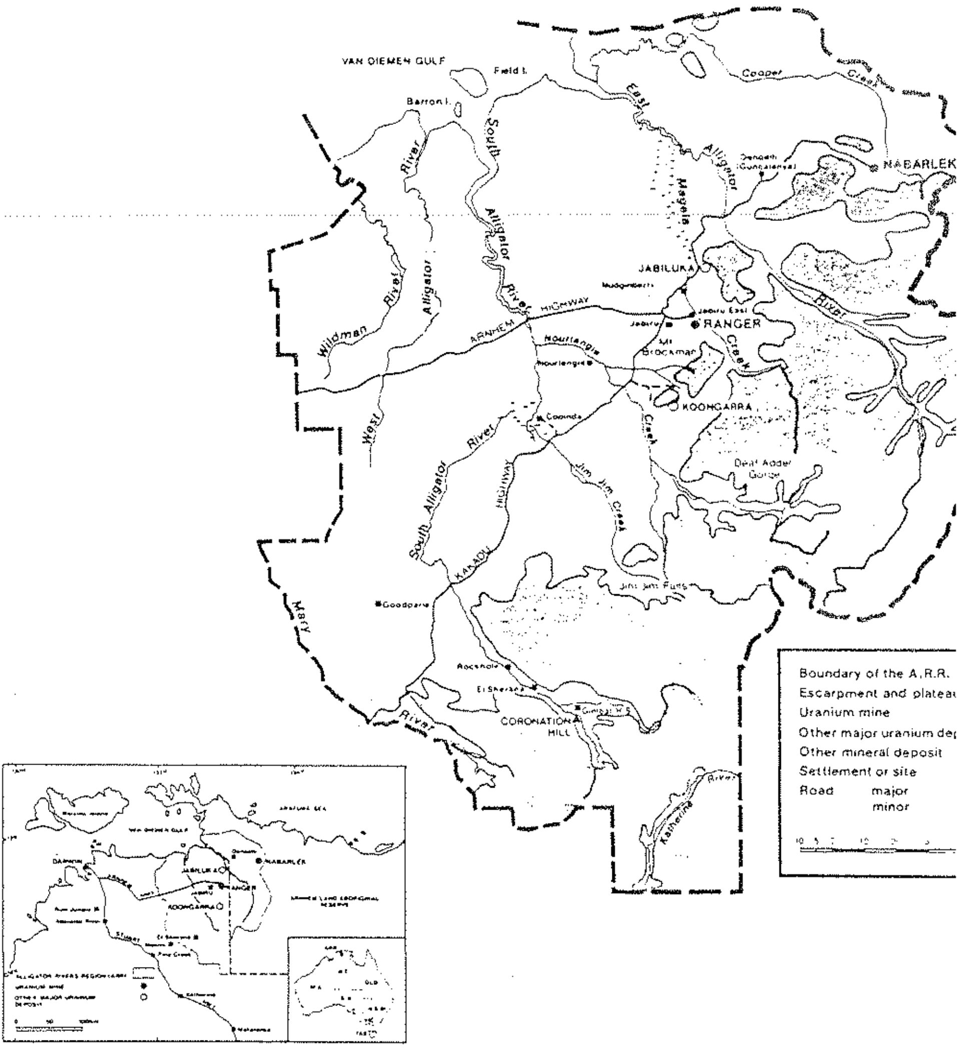



Fig. 1. The Alligator Rivers Region.

period 1971-1985 has averaged 1560 mm. Further inland towards the southern of the Region, however, rainfall is lower. In the upper South Alligator River Coronation Hill, for example, annual rainfall has been estimated to average a 1200 mm.

The marked seasonal occurrence of the rainfall means that flow along the e length of most streams of the Region occurs only from about January to Ma Magela Creek, total annual flow past Ranger averages about $400 \times 10^6$ m$^3$, but vary from one third to twice this volume. In the upper South Alligator River Coronation Hill, total annual flow is estimated to average about $107 \times 10^6$ m further 10 km downstream, however, the catchment of the river increases app

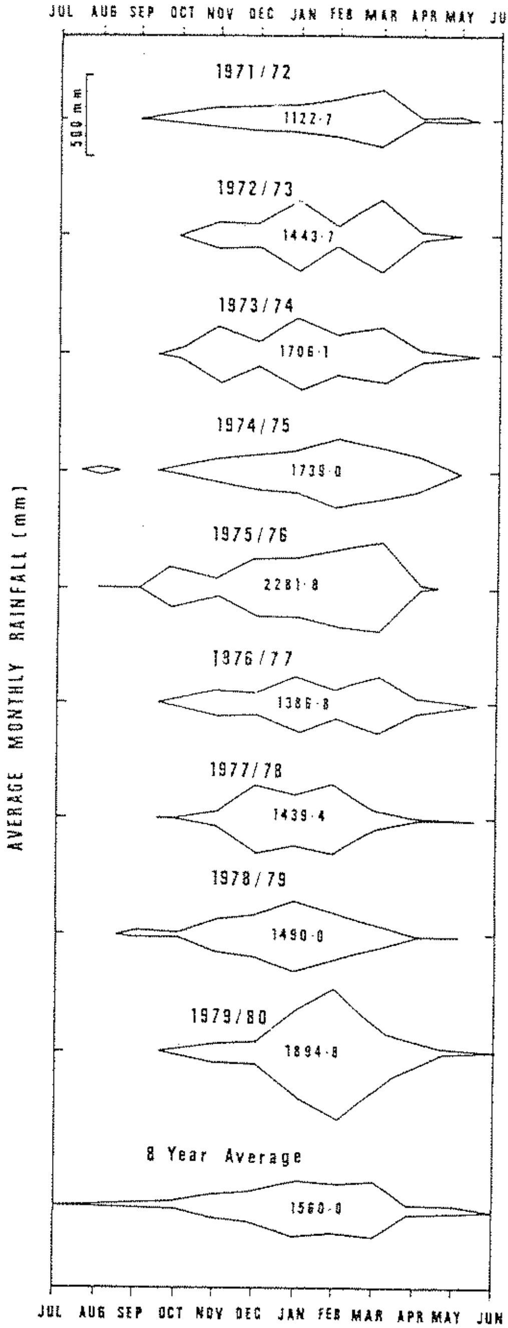



Fig. 2. Rainfall distribution at Jabiru during each Wet season, 1971-72 to 1979-80. (The numbers the shapes are the Wet season totals (mm).)

mately three-fold and thus discharge is substantially increased.) The Wet sea discharge pattern in the lowland sections of the streams, is one of a series of fl peaks following the more heavy periods of rain, super-imposed upon a base fl

Other than in the lower sections and estuaries of the South, East and V Alligator Rivers where flow is continuous, all flow ceases over much of the ler of all other streams during the Dry season, continuing only in short upstream secti fed by escarpment springs and seepage. Thus Magela Creek downstream of Rar flows only during each Wet season, whilst the South Alligator River near Coronai Hill flows all year. The temporary sections of streams, channels and floodplains out, and the remaining surface waters of each stream consist of strings of waterbo (billabongs) in which aquatic organisms of the lowlands become confined.

*Magela Creek*

Three separate classifications – 'blackflow', 'channel' and 'floodplain' – have t proposed for billabongs in Magela Creek (Hart and McGregor, 1980; Walker Tyler, 1985). 'Backflow billabongs' are situated near the confluence of fee tributaries with main stream channels of the lowlands and are separated from latter by natural levees; 'channel billabongs' are located within the main stre channels, and; 'floodplain billabongs' occur in depressions or remnants of chan on the floodplains.

Descriptions of the limnology of Magela Creek including billabong morphom and water quality are contained in Hart and McGregor (1980), Walker and T (1983), Tait *et al.* (1984), Brown *et al.* (1985), Hart *et al.* (1987) and ARRRI (198 and are only summarised briefly here.

During the Wet season proper (i.e., once a continuous flow has become estab ed), Magela Creek water is acidic (arithmetic mean pH 5.2, Hart *et al.*, 1987, 198 Wet season data). This results from the natural acidic quality of the rain and low buffering capacity of the catchment rocks and soils. Conductivity of the w is very low (5–17 $\mu S\ cm^{-1}$) as are concentrations of suspended materials (susper solids, 4–59 $mg\ L^{-1}$), major ions, nutrients and trace metals, including radic clides (Hart *et al., op. cit.*). Wet season waters are extremely soft with low buffe capacity, and have relatively high temperatures. Ionic concentrations have a cati order of Na > Mg ≃ Ca > K and an anionic order of $HCO_3$ > Cl > $SO_4$, althc in floodplain sites ionic dominance is ordered Na > Mg > Ca and Cl ≃ $HCO_3$ : $SO_4$.

At the cessation of creek flow and over the ensuing Dry season, billabong w quality generally 'deteriorates' considerably in all but the channel billabongs. T latter deep (up to 6 m), clear, well-oxygenated and sandy-bottomed waterbc (e.g., Mudginberri Billabong) tend to retain the chemical qualities of the Wet sea water throughout the year.

Littoral macrophytes occur in abundance in the shallower backflow and floodp billabongs (~ 0.5 and 1.2 m mean depth respectively). Senescence of these pl occurs generally at the end of each Wet season and, in floodplain billabong particular, this results in significant oxygen depletion occurring in bottom w from plant decomposition at this time. Turbidity generally increases in both of billabong during the Dry season (up to 150–250 NTU) as a result of bioge wind-generated resuspension of the fine clay sediments. Higher concentratic solutes resulting from either evaporation and/or inflow of mineralised ground result in higher conductivities in these billabong waters (up to 100 and 200 $\mu$S in backflow and floodplain billabongs respectively) over the Dry season, wi >> Mg, while in floodplain billabongs an anionic dominance of $SO_4$ occu

From a common pH of 5.0–5.6 in the Wet season, pH generally increa 6.2–6.9 at the beginning of the Dry season and thereafter declines in most billa to 4.0–5.0 over the Dry period. Water temperatures range from 22 °C in July to in November-December. Phytoplanktonic productivity increases over the Dry s from initial Wet season oligotrophy; increasing productivity generally proce a downstream direction and at their most fertile the billabongs range from oli phic-eutrophic.

Prior to about 1980-1981, feral, Asian water buffalo (*Bubalus bubalis*) frequ the shallow billabongs of Magela Creek to wallow and feed, so reducing veget Since that period, however, a concerted campaign to eradicate buffalo from Ka has resulted in a virtual cessation of such activity. As a consequence, macro growth in backflow billabongs (in particular) has increased markedly, the p physically choking surface waters. During the Dry season, water quality ch associated with macrophyte proliferation include significant decreases in turb and oxygen depletion in bottom waters overnight.

*South Alligator River*

The SAR upstream of, and in the vicinity of, Coronation Hill (Figure 1) is bra though downstream of a point approximately 1 km below Coronation Hill, the is confined to a single channel. In these upper reaches, the river is perennial flow minimal in the mid-late Dry season (e.g., average, long-term estima discharge of 11.5 L/sec near Coronation Hill in September). The river is ch terised by shallow riffles alternating with short to long (up to 1 km) pools of 3 m in depth and these latter being bordered by dense growths of *Pandanus* sh The substrates consist of sand in the pools, and sand, gravel, cobbles or root in riffle areas and on and under incised banks. There is generally an absen aquatic macrophytes.

As is the case for waters in other parts of the ARR, Wet season water in the is moderately acidic (pH 5.6–6.5), soft, with low buffering capacity (alka 3–10 mg $L^{-1}$ $CaCO_3$), and has low concentrations of dissolved solutes (condu ty 15–30 $\mu S\ cm^{-1}$). In contrast to Magela Creek water (where Na is the dom cation), in the SAR ionic concentrations are in the order (for cations) Mg > N Ca and (for anions) $HCO_3 \simeq SO_4 \simeq Cl$. However, Dry season water qual the SAR differs in that hardness (alkalinity up to 55 mg $L^{-1}$ $CaCO_3$), pH (6.8 and conductivity (100–130 $\mu S\ cm^{-1}$) increase considerably as a result of seepa groundwater into the river. Cationic balance shifts to Mg > Ca > Na whils anions $HCO_3 >> SO_4 = Cl$. Dry season turbidity is generally very low (< 10 N although in the Wet season it may be very high after storm events as a result of ru from disturbed parts of the catchment. Water temperatures range from 17 °C (. to 30 °C (October-December).

## 1.3. Monitoring Strategies

### *Choice of Methods for Monitoring*

The methods to be used in a biological monitoring program depend upon the n of the problem as well as availability of expertise. The variety of habitats in the and the particular test objectives require use of a variety of techniques. Prog have been established for the purpose of seeking to provide early warnir short-term impacts that might arise from the deliberate and controlled relea excess mine waste-waters into ARR streams during the Wet season (e.g. release Magela Creek by Ranger) as well as to detect possible longer-term impacts, espe where release may take place over periods of years. In the latter instance, or in in the case of prospective discharges (e.g., Coronation Hill) where problems (il are as yet unknown, baseline information on the identity, abundance and distrib of organisms is being obtained for the purpose of detecting and quantifying term effects.

Methods that have been used worldwide for biological monitoring in (1) bioassays; (2) early detection systems (physiological, behavioural, biochemi histopathological); (3) indicator organisms (presence or absence); (4) autecol or population studies; (5) community structure (or function) and; (6) bioacc lation. Obviously, where answers are obtained from a multiplicity of techniq firmer basis exists for evaluating an effect, and at the ARRRI, the above me (with the particular exception of '3') have been (or will be) employed in one or another. (Problems in the use of indicator organisms in monitoring ac ecosystems have been discussed by Cairns (1974) and Campbell (1982).) The cation of these techniques for biological monitoring in the ARR is discusse evaluated below.

### *Choice of Organisms for Monitoring*

The choice of organisms to be used in biological monitoring is to some governed by both the objective of the investigation and the requirement c technique employed. Long-lived species for example, are desirable in bioacc lation studies because they integrate long-term exposures to particular substanc thus provide information on equilibrium concentrations, particularly for subs with low biological turn-over rates. Thus typically, fish and bivalve mollusc been considered the most suitable organisms for study. For short-term, field says and other early-detection systems used in the field, organisms readily vis the eye assist in timely detection, quantification and assessment of resp

Accordingly, microorganisms (algae, protozoa) are not particularly suitab study. Otherwise, no organism, or group of related organisms is thought of as more or less representative of the entire aquatic community than is any other in of sensitivity (Cairns, 1982); species differ in their sensitivity to different subs so that within communities the response of any particular species will depend identity of the substance (Hellawell, 1988). As a consequence, no single grou been selected by workers in the field, and whilst an approach that incorp 'representative' groups from several major taxa might be considered ideal, rare resources and time available to achieve this.

Hellawell (1978, 1986) provided a comprehensive and critical appraisal relative merits of different groups of organisms for use in biological survei programs and concluded that, in general, macroinvertebrate communities we most extensively used, probably because they offered potentially, a wide ra sensitivities and a complex interacting system. Indeed in Australia, stud macroinvertebrate communities have been successfully used a number of tir problems of biological monitoring and assessment of water quality and app be the ecological unit most frequently used in such programs. These studi reviewed in Norris and Georges (1986).

In comparison, fish communities have rarely been used anywhere (incl Australia) in comprehensive monitoring programs, a fact deplored by Karr (1986) who advocate (for various reasons) the use of fish community structure i programs. Lake (1986) advised against the use of fish on the basis tha communities in Australia have been modified by the presence of introduced sp and also because species richness is generally low. However these characteristi only typical of communities found in southern Australia; very few introduced s are present in fish communities in the Timor Sea and Gulf drainages of tr northern Australia (none in the ARR) and species richness in this area is hi world standards (Bishop and Forbes, 1988).

It is considered by the present authors both impractical and unnecessary to m all facets of biological communities. Thus, groups such as bacteria, Alga Protozoa have not been considered for study. This is because, apart from res constraints, knowledge of the taxonomy, biology and/or ecology of these gro inadequate. Furthermore, studies on the zooplankton (Tait *et al.*, 1984) anc toplankton (Kessell and Tyler, 1983) of Magela Creek showed there to be such and inexplicable spatial and short-term temporal variation in community str at both broad and micro-scales, that it would appear to preclude these groups being useful in biological monitoring. Rather, benthic macroinvertebrate an communities (or representative populations or assemblages within communities) are regarded as more practical and useful choices. Benthic macro tebrates are diverse and abundant in ARR streams and have many inherer traditional virtues for study (Hellawell, 1978, 1986). In the sense of 'tradition group of organisms is a popular one and consequently, sampling technique methods of data analysis are well established. Fish in ARR streams are sin diverse and abundant, but additionally and importantly, are conspicuous. Ind their high public 'profile', their utilisation by man, and the fact that they are a top of many aquatic food webs are considered compelling arguments for t inclusion in ARRRI monitoring programs. While a sensitivity of fishes to cha in water quality and physical environment have been demonstrated worldw including Australia (e.g. Weatherley *et al.*, 1967; Jeffree and Williams, 1 Arthington *et al.*, 1983), additional advantages for study include the low c rapidity and ease at which data may be collected and analysed. In contrast to ben macroinvertebrates communities, however (which reflect conditions at the sit sampling), fishes, many of which are highly mobile, more readily reflect overall w quality throughout the extent of the stream in which they move.

### *Environmental Variability in Relation to Biological Monitoring*

Both a high level of variability in environmental conditions and therefore a high l of 'unpredictability' have been considered characteristic of Australian freshw ecosystems (Norris and Georges, 1986). This was also the conclusion of Fox *e* (1977) who in discussing workers concerned with environmental protection surveillance of aquatic ecosystems in the ARR stated that:

> They would face great difficulties in establishing baseline biological data aga which changes could be assessed. The variability between years is such that m years of measurement would be required to record natural fluctuations in s things as water quality and species composition and populations.

However, the implication that as a consequence of variability, monitoring waters and/or biota in the Region would be particularly or uniquely different fr elsewhere must be questioned. For example, the Wet season discharge rate Magela Creek (and at the time that any waste discharges might be made) is proba no more variable than flows in rivers elsewhere in Australia. Water quality (chemi and temperature) vary remarkably little, and probably much less than in m streams either in Australia or elsewhere in the world. More importantly, howe the scientific advisors of Fox *et al.* (1977) appear to misunderstand something of w environmental monitoring involves. Typically in monitoring, 'spatial' controls ( upstream of a discharge point) are available and these take into account biolog variation associated with natural variations in stream discharge rate and wa quality. Where historical data are to be used (i.e. the use of 'temporal' controls assess 'impact' or 'absence of impact' then the situation becomes more problem and the statement by Fox *et al.* has more reality.

Because the ARR is located in an area of Australia in which seasonal ra unfailingly occur and in which year-to-year variation in stream discharge is parti larly low (Figure 3), the problems commonly associated with the use of histor data elsewhere are considered to be relatively insignificant where impact is to assessed by comparison of year-to-year faunal data. The major difficulty encoun ed in making such comparisons in the ARR is that of minimising the large compon of variation associated with the responses of organisms to the extremely regul

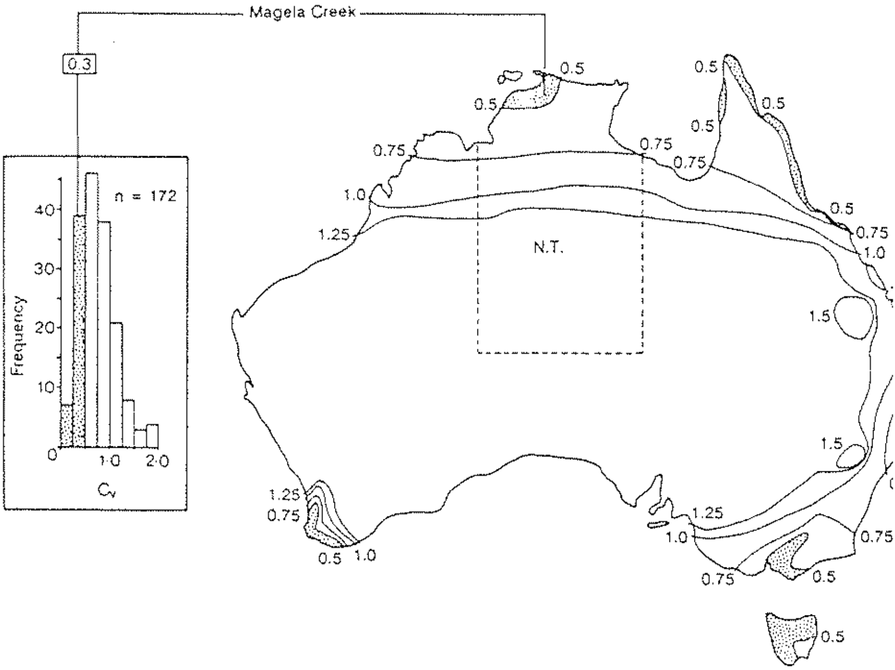



Fig. 3. Map of Australia showing contours of coefficients of variation ($C_v$) of annual discharge c
Drawn after McMahon (1979) who examined hydrological data from 172 rivers (see frequency hi
of $C_v$s for these rivers to the left). The Northern Territory (N.T.) contours have been modified fo
data supplied by the N.T. Water Division. Stippled areas have $C_v < 0.5$.

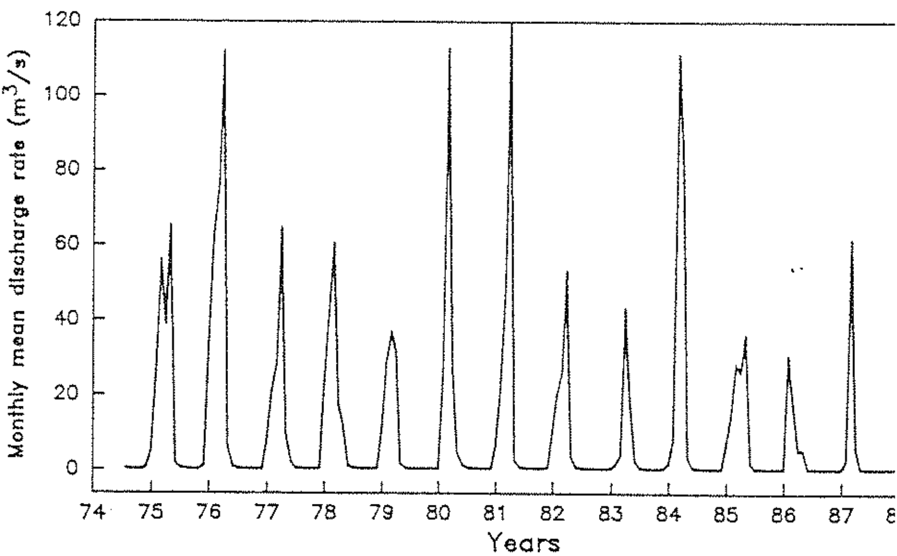



Fig. 4. Monthly mean discharge rates for Magela Creek (Gauging Station GS8210009) between 1
1988.

'pulses' of creek flow (Figure 4) within each Wet season. This factor is more dealt with in this region, where rainfall is seasonally well-defined (the ARR is lc in a drainage division (Timor Sea) with the most restricted seasonal discha Australia – eighty percent of discharge occurs within three consecutive m (McMahon, 1979) and is effectively 'constant' from year-to-year comparec elsewhere, and so its monthly variations can be subsumed into consideratic 'constant' overall, annual discharge.

There exist in the ARR sources of environmental variability other than hydrologically-induced, the most notable being those associated with the pr ation of aquatic macrophytes in billabongs following the large-scale removal o water buffalo since 1980-81. Whilst the response of some components of the to these year-to-year changes has been predictable (see later 'structure o communities in backflow billabongs'), and hence possible to account foı monitoring program, many complications arise from such changes, partic when they vary from site to site.

Mining companies in the ARR have tended to emphasise monitoring prc associated with environmental variability and state that it may be impossible to long-term impacts, if any, on aquatic ecosystems caused by the release of waste-waters (e.g., Bywater, 1988). Corresponding to this emphasis, mining panies have invested very little effort, and the regulatory authority, the NT D ment of Mines and Energy none, in developing biological monitoring techn Willingness to obtain and understand ecological information which can p insights as to how to account for natural environmental variation in a moni system is the key to such development.

## 2. Biological Monitoring of Mine Waste-Water Releases to Magela Cre

### 2.1. Background

*Problems of Direct Discharge of Ranger Waste-Waters to Magela Creek*

Studies of the aquatic ecosystem in Magela Creek near the Ranger projec (Figure 5) are designed principally to address problems of waste-water releas the mine site direct to the creek. Constituents which are present in these wa concentrations much greater than those at which they occur in local creek include a variety of metals (e.g. manganese, magnesium and including radionu along with sulphate and ammonia. Additionally, ratios of biologically-es 'bulk' elements (e.g., calcium, magnesium) substantially different from those in the local natural surface waters, occur in some of the waste-waters.

Controlled release of waste-water into Magela Creek during the Wet seas been recommended by ARRRI as a solution to this problem, with minimum d requirements being determined from pre-release biological testing of the waters. Biological monitoring will be used to determine the adequacy of minimum dilution requirements in protecting the ecosystem, by examini

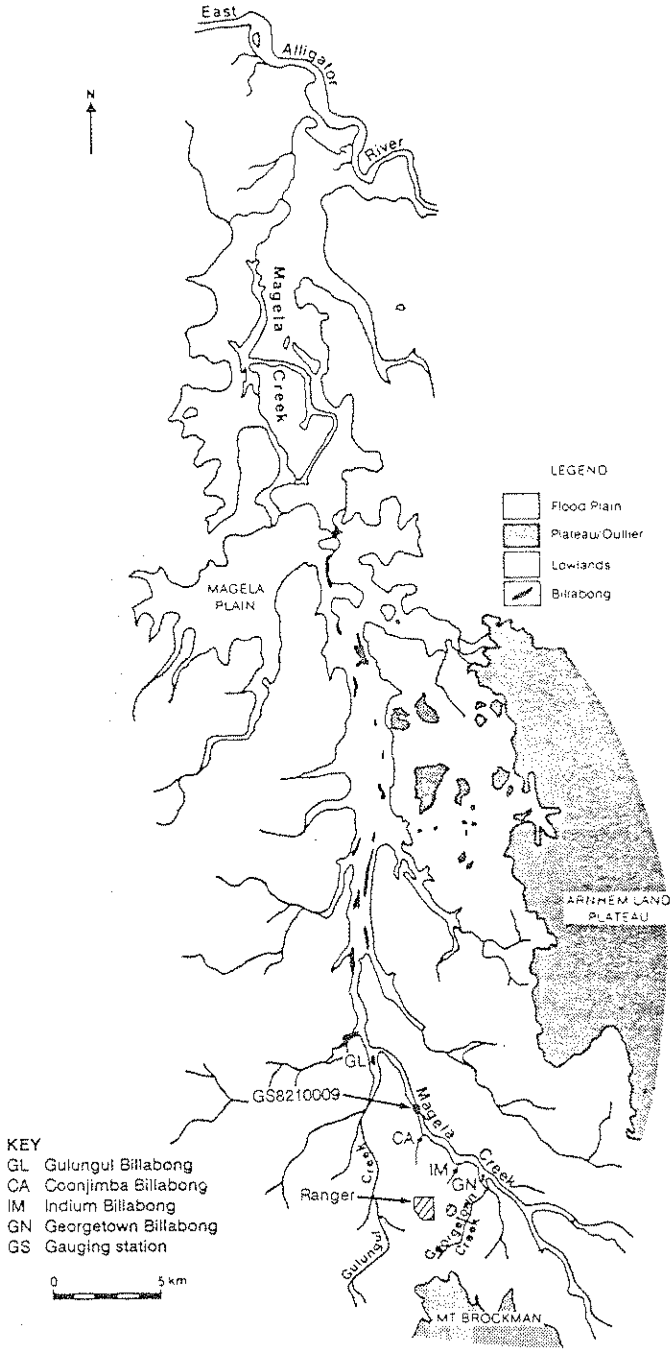



Fig. 5. The Magela Creek system. The outlet of Ranger's waste-water pipe is located one k: downstream of Georgetown Billabong (GN).

response of aquatic biota exposed to the waste-waters within the creek system du and after releases. This two-fold approach to the management of water relea aimed at ensuring that the aquatic ecosystems are protected and that unaccep changes are prevented. Similar dual approaches have been investigated in the U. within the Naugatuck River, Connecticut (Mount *et al.*, 1986), and Skeleton Cr Oklahoma (Norberg-King and Mount, 1986).

The biological monitoring objectives here are: (a) the development of monito techniques and procedures to detect and quantify adverse effects, acute or chr (should such occur), of released waste-waters on aquatic organisms; and (b) description (where adverse effects do occur) of the impact of waste-waters on aqu organisms and assessment of the possible significance in the ecosystem.

### *Geographical Coverage of Monitoring*

In Magela Creek, biological monitoring is carried out on seasonally-flowing wa in channels and permanent billabongs up to 20 km downstream of the Ranger r discharge point. Most effort has focussed on the 12 km section of Magela C between the waste discharge point and Mudginberri Billabong, where short-t impacts of released waste-water might first occur and be detectable (Figure 5). C monitoring programs are designed to detect effects, either delayed in expressio chronic, i.e. that only show up in the longer-term. Breeding failures or delayed ef on fish larvae, for example, could result in responses evident only at later date poor year-class abundance in populations or species absence from communiti

Of particular potential concern in environmental protection, however, are chr effects that might occur at floodplain-deposition sites below Mudginberri Billab (up to Jabiluka Billabong) but also, to a lesser extent, in 'backflow' billabongs (e Gulungul Billabong) between Ranger and Mudginberri that may act as 'sinks' metals (Figure 5). Techniques and procedures are being developed therefore, for : where it is considered such deposition could occur so that early detection of poten long-term effects can be made.

### *Structure of the Monitoring Program*

A schematic representation of release-impact monitoring studies presently under in Magela Creek is shown in Figure 6. These studies can be separated into two ma groups, one designed to detect short-term effects (i.e., effects which occur by end of the Wet season), the other focussed on longer-term effects. Within th studies of short-term effects, there also exists a major division which relate whether or not detection is early (i.e. between commencement of release and : 5 days after a release) or delayed. Some of those addressing short-term effects, a provide data useful for detecting longer-term effects.

It should be stressed that up to the time of writing (late 1988), no waters have b released from the waterbodies in Ranger's Restricted Release Zone (RRZ). Th waterbodies, which generally contain the highest concentrations of hazardous c stituents are subject to strict control. Waste-waters have, however, been relea

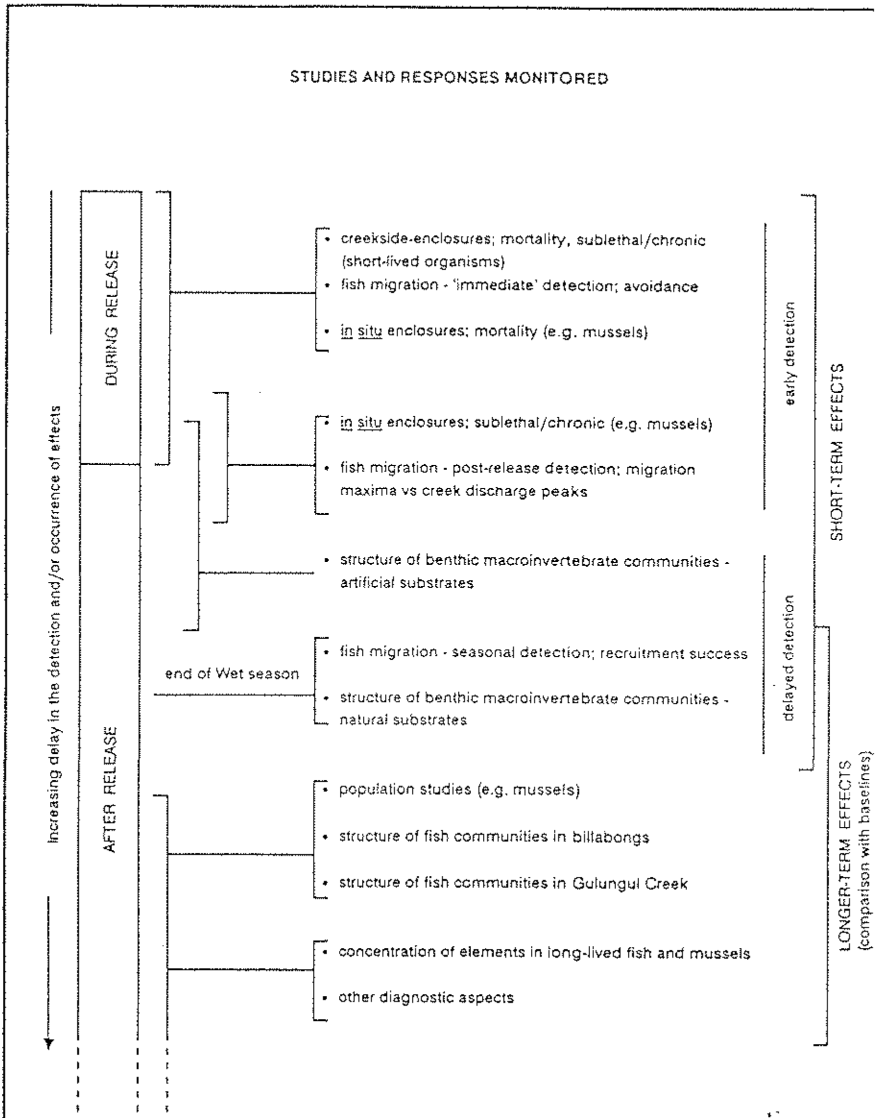



Fig. 6. Studies in the ARRRI biological monitoring program aimed at ensuring protection of the environment during and after Ranger waste-water releases into Magela Creek.

from two sedimentation ponds, Retention Ponds 1 (RP1) and 4 (RP4), whi outside of the RRZ, the latter of which receives run-off from waste rock dı

## 2.2. Early detection of short-term effects

An important consideration in managing release of waste-water is that of se to detect harmful responses occurring (in this case where release is intermitte the time of making the release so that discharge rates can be promptly adj thereby reducing the risk of significant adverse changes occurring in the ecosyst This desirable situation might be achieved, by biological 'early detection syste using either 'creekside' or *in situ* monitoring methods, both with captive organis or observations on behavioural (avoidance) responses of natural fish populations communities in Magela Creek, as described below. An important peripheral go the employment of the early detection systems using captive organisms is tha seeking information about the responses of sensitive organisms and/or life sta In this way, it will be possible to verify the adequacy of laboratory-derived rel standards based on toxicity tests employing equally sensitive end-points.

At present, largely 'whole-body' responses of organisms have been used for monitoring of short-term effects of waste-waters upon organisms in Magela Cr However, the ARRRI is to extend monitoring of short-term effects to inc sensitive and diagnostic, histological and biochemical indicators of early patholo changes known, from laboratory experimental studies, to be correlated u conditions of extended exposure, with longer-term detrimental effects on gro reproduction or survival. Automated 'early warning systems' such as those descr and reviewed by Cairns and van der Schalie (1982), have not been considerec biological monitoring of wastes in the ARR. (In such systems, a rapid physiolo or behavioural response of an organism to adverse water quality is detecte instrumentation, to give immediate warning at some pre-selected level of respo Such devices have been used in Europe and North America, but apparently received little attention in Australia (Norris and Georges, 1986). However, ce inherent weaknesses (Brown, 1976) detract from their application here.) Fu description of creekside and *in situ* methods used to monitor 'whole-body' respo of organisms is given below:

'Creekside monitoring' consists of the exposure of organisms in containers sitioned on the creek bank through which a flow of appropriately diluted waste-v pumped from Magela Creek takes place, enabling observations to be made co uously during the period of release. (*Continuous* monitoring of this sort ha important advantage over *in situ* methods where continuous or regular observa is not possible and where access to the organisms may be difficult at high creek f (> 20 cumecs).)

Studies made during release of Ranger RP4 water in March 1985 (ARRRI, 1 and subsequently (described below), utilising the creekside monitoring system d oped for this work, allowed successful rearing and observation of 'whole-b responses of a number of species of aquatic macroinvertebrates (including an shrimp, nymphs of several species of mayfly, two species of freshwater snails juvenile freshwater mussels). Responses sought were varied and included a nu of sub-lethal, chronic end-points as well as acute effects. A number of the respo met the important criterion of providing the required early feed-back in that were immediate, quickly recognised, readily visible, and quickly quantifiable

Although not providing a method for continuous observation, *in situ* sys provide the most realistic information on the effects of releases in the short-because organisms are held in cages or containers sited within the stream itself organisms may respond to the fluctuations of the creek environment. F advantages over creekside testing methods are that *in situ* monitoring avoi constraints of need for elaborate equipment, it is relatively maintenance-fre 'systems' may easily be placed at strategic sites along Magela Creek where th most effectively monitor releases.

*In situ* methods that have been tested in Magela Creek are the containm organisms either in mesh-covered, perspex cylinders that are tied to submergec of stream-dwelling shrubs *(Pandanus)* or in mesh-covered containers that are along the creek edges with their upper rims flush with the level of the surrou substrate. So far, the responses of juvenile and adult freshwater mussels (*Vel. angasi*) (see below) have shown most promise in both types of *in situ* cor respectively.

Studies undertaken on freshwater mussels and fish migrations in Magela have been underway for the longest period of time (i.e. since 1985) and have pr therefore, the most comprehensive information available yet on the early det of short-term effects arising from Ranger waste-water releases. Details of studies are provided below.

### 2.2.1. *Freshwater Mussels* (Velesunio angasi)

Little attention has been paid by biologists to roles that freshwater mussels play in the monitoring of water quality and of pollution other than their detecting bioaccumulation (Havlik and Marking, 1987). Such studies in the AI described in Allison and Simpson (1983), ARRRI (1984, 1985, 1987a, 1987 Jeffree and Simpson (1984, 1986). Two sensitive stages in the life cycle freshwater mussel, *Velesunio angasi*, have been employed at the ARRRI fo detection of effects arising from mine waste-water releases, namely the reproc response of adult female mussels and growth and mortality of newly-metamor juvenile mussels.

#### *Adult Mussels*

Spawning and breeding of *V. angasi* in waterbodies of Magela Creek are rep processes and under suitable conditions occur year-round. Reproductive cyc continuous: each cycle is of about 9–10 days duration and culminates in rel mature larvae ('glochidia') from marsupial portions of the inner gills of adult f (where they are held and nurtured) to the surrounding waters (Humphre Simpson, 1985; Humphrey, unpublished data). Upon their release and in or further development to occur, the glochidia must attach themselves to the fins of a fish and spend a short period (about 5 days) there as obligate paras they fail to become attached to a host fish, they perish. After this period they themselves from the fish as metamorphosed, free-living juveniles. Because ephemeral nature of their environment, breeding by mussels resident in the channel of Magela Creek is confined to the Wet season (the mussels at tl aestivating in the creek banks during the Dry season). During this period bree is recurrent, although the rate of larval production by these creek mussels ma reduced by low water temperatures or even cease at periods of protracted, creek-flow.

During March and April 1985, water was discharged from Ranger's Reter Pond 4 (RP4) of the Ranger uranium mine into the Magela Creek over three peri from 12 to 19 March inclusive; for one day beginning the morning of 22 March; from 15 to 19 April inclusive. The chemical composition of the water in RP 6 March 1985 is given in Table I.

During the March release, female mussels in the vicinity of the discharge point monitored to discern whether their reproductive activity was affected by the inc ing RP4 waters. Mussels from the channel receiving RP4 waters were sampled al and below the discharge point before, during and after discharge. After remov mussels reproductive activity was assessed in two ways: (i) the marsupia of disse females were examined for the presence of and stages of development of emb and larvae, and (ii) an index of the abundance of larvae present in the marsupia calculated, using the ratio of inner gill weight to total weight of the visceral n

Prior to RP4 discharge, reproductive activity (measured as above) in mu upstream and downstream of the outflow pipe was similar. Five days after c mencement of the discharge, however, an effect was observed in mussels sam from 4 sites between the point of discharge and 120 m downstream. Over distance, a decrease both in the proportion of females bearing embryos and la (Figure 7) and in the quantity of larvae present in the marsupia of females (Figu was found. These observations contrasted with the higher reproductive activit mussels, sampled at the same time, upstream of the release pipe. The patterr downstream sites were evidence of suppression of gonadal activity and larval duction during RP4 discharge; while the developing larvae present one week ea ('pre-release', Figure 7) had matured by the time of sampling 'during release', little or no further breeding was initiated in mussels sampled between the release and 60 m downstream. For this proportion of the population, the marsupia rema

TABLE I

Chemical composition of retention pond 4 water, 6 March 1985[a]

| Chemical variable | | Chemical variable | |
|---|---|---|---|
| Conductivity ($\mu$S cm$^{-1}$) | 150 | Nitrate (mg L$^{-1}$) | 0.16 |
| pH | 7.8 | Sulphate (mg L$^{-1}$) | 24 |
| Sodium (mg L$^{-1}$) | 3.1 | Copper ($\mu$g L$^{-1}$) | 2 |
| Potassium (mg L$^{-1}$) | 1.1 | Lead ($\mu$g L$^{-1}$) | <1 |
| Magnesium (mg L$^{-1}$) | 18 | Manganese ($\mu$g L$^{-1}$) | 28 |
| Calcium (mg L$^{-1}$) | 1.8 | Zinc ($\mu$g L$^{-1}$) | 1 |
| Chloride (mg L$^{-1}$) | 4.0 | Uranium ($\mu$g L$^{-1}$) | 35 |
| Phosphate (mg L$^{-1}$) | 0.02 | Radium (Bq L$^{-1}$) | 0.13 |

[a] Information supplied by Ranger Uranium Mines.

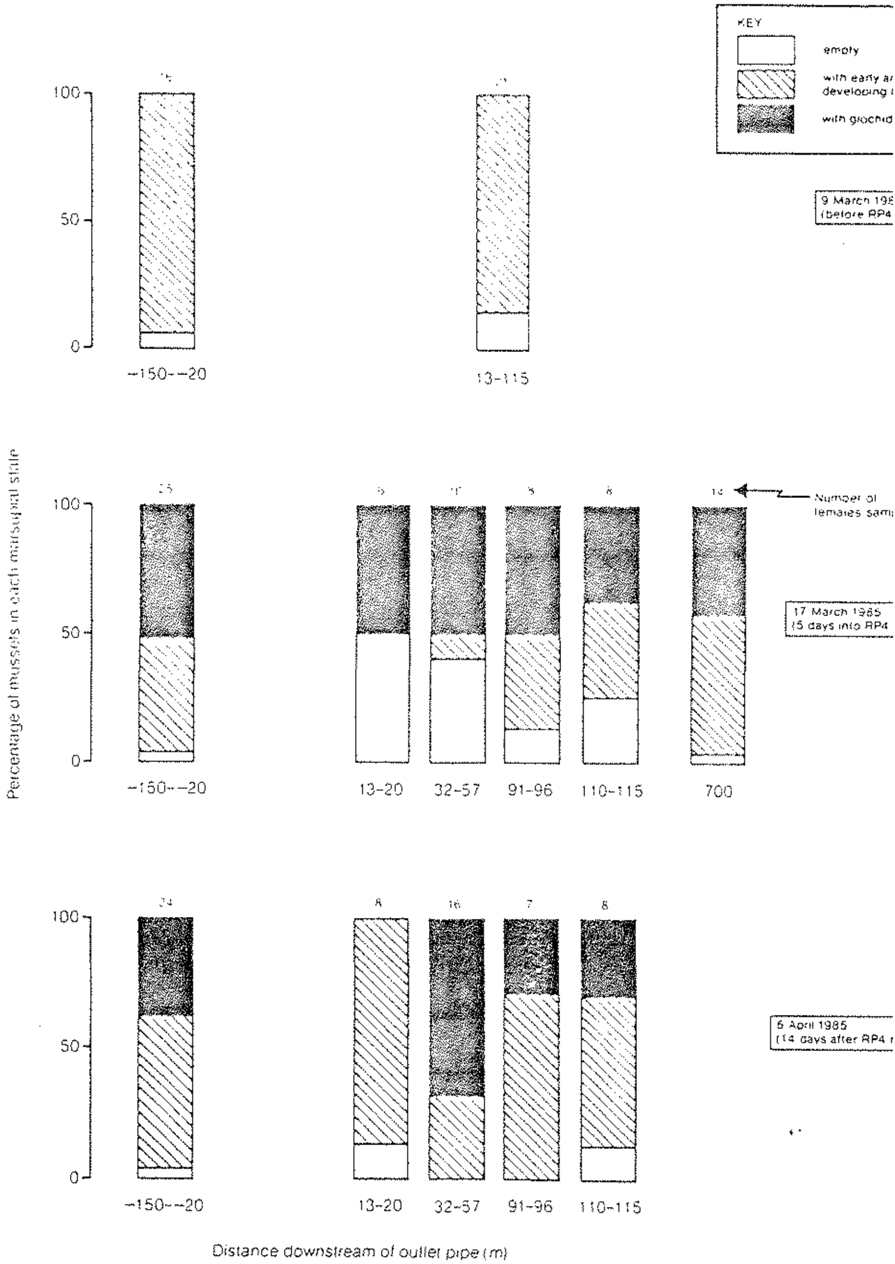



Fig. 7. Marsupial states of female mussels in Magela Creek, 1985.

empty. Furthermore, unlike the condition of those females which harboured glc ia at the upstream sites (where the marsupia were full [Figure 8]), there wer glochidia in the marsupia of females in the corresponding condition sampled be the release pipe and 120 m downstream during release. This suggested eith

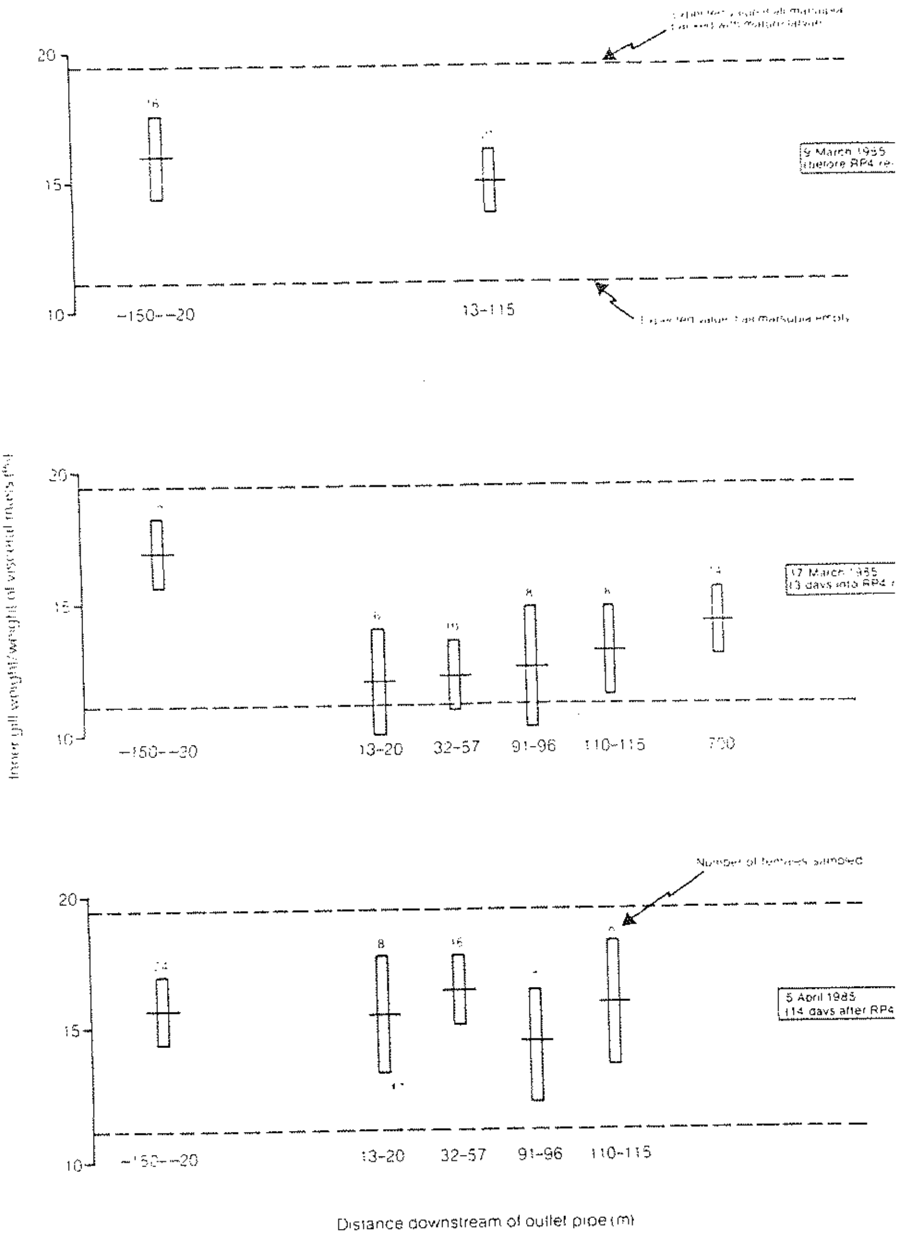



Fig. 8. Occurrence of larvae in marsupia of female mussels in Magela Creek, 1985.

occurrence of abortion or of an unusually protracted release of larvae in females.

In mussels sampled after the RP4 discharge had ceased, the stage of development at the two downstream sites closest to the pipe outlet (within while similar among mussels from the same site, differed between the two site both differed from all of the other sites sampled (Figure 7). The similar reprod patterns observed in mussels within each of the two sites indicated a synchr the recommencement of spawning and breeding following a breeding ces during release. Recommencement of breeding activity in mussels at the tw immediately downstream of the waste pipe outlet lagged several days behind a in mussels sampled from further downstream (30–60 m) (i.e. the development between 'early and developing larvae' and 'mature glochidia'). It is most likel at this site (30–60 m) most mussels had recommenced breeding some 8–9 days to sampling (because the reproductive cycle occurs over a 9–10 day perio mussels were sampled with mostly glochidia in the marsupia), or 5–6 days aft last day of RP4 release. Thus, it is likely that reproductive activity in mussels the downstream site closest (< 20 m) to the discharge point had only recomm a few days prior to sampling, or 8–9 days after RP4 release.

The decrease in reproductive activity of mussels from downstream site correlated with higher conductivity of the stream caused by the mine waste- discharge. However, the specific property of RP4 waters responsible for suppr of reproductive activity in mussels is not known.

In years subsequent to 1985, reproductive activity of adult female mussels not be used to routinely monitor the effects of mine waste-water released into M Creek during the Wet season. During releases from RP4 in these years – 24-29 J ry 1986 and 1-19 February 1987 – average daily flow in Magela Creek for the part exceeded 25 cumecs, and no mussels sampled from the section of Magela upstream of Mudginberri Billabong were breeding. This cessation of breedin be the result of lower water temperatures, reduced light intensity and, possibly sperm dilution that accompany sustained, high creek discharge during peric intense monsoonal activity over the Region. However, the evidence suggest factors other than these may be involved. Water quality in this section of M Creek is probably adverse in quality (see below) at high creek-flow and the stressful to some organisms. Two particular examples of adverse respon organisms exposed to these waters may be cited:

(1) *Freshwater mussel glochidia:* While potentially sensitive attributes of freshwater mussel such as reproduction are not readily amenable to laboratory the 'snapping' response of glochidia (the behaviour by which they attach them to the host fishes) can be examined in the laboratory. At ARRRI, a toxicity te pre-release screening of mine waste-waters has been developed using gloc responses (mortality and behaviour) (ARRRI, 1987). Normally, in Dry s billabong water or Wet season creek water collected near Ranger outside of r periods and when creek flow is less than 20 cumecs the median period of sur of glochidia is about 5 days, although there is only about 20% natural morta a period of 4 days exposure. However, water collected from Magela Creek a creek flow (> 20 cumecs) can be naturally lethal to glochidia. Thus, in labo trials with glochidia conducted between 3-6 February 1986, when discha

Magela Creek exceeded 20 cumecs, 90% mortality had occurred in creek water v 24 hours of exposure compared with 10% mortality within 24 hours and only within 96 hours, of glochidia exposed to demineralised water (Table II).

(2) *Larval rainbowfish* (Melanotaenia splendia inornata): In trials conduct March 1988 outside of periods of waste-water releases, larval rainbowfish reared in the creekside monitoring system beside Magela Creek (described ab to assess their suitability for monitoring short-term effects of mine waste-releases. Different numbers and age-classes of fish were tested in the trials, as sl in Table III. While mortality in each trial was consistently lowest at the l number of fish (i.e. 6/container), the greater mortality occurring at the l number in trials No. 2(1) and No. 3 (in contrast to the situation in other t

TABLE II

Mortality of glochidia during February 1986 after consecutive days of exposure to Magela Creek and demineralised water

| Date | Creek water | | | Demineralised water | | |
|---|---|---|---|---|---|---|
| | Mortality (out of 10) | pH | Conductivity ($\mu$S cm$^{-1}$) | Mortality (out of 10) | pH | Conduc ($\mu$S cm |
| 3.2.1986 | 9 | 6.0 | 15.9 | 1 | 7.1 | 7.6 |
| 4.2.1986 | 9 | 5.8 | 14.6 | 1 | 7.2 | 11.4 |
| 5.2.1986 | 10 | 6.3 | 18.0 | 3 | 7.0 | 8.6 |
| 6.2.1986 | – | 6.0 | 15.2 | 4 | 7.0 | 5.3 |

TABLE III

Survival of larval rainbowfish at different densities in creekside monitoring trials during 1987-8 season

| | Trial No. | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1(1)[a] | 1(2)[b] | 2(1)[a] | 2(2)[b] | 3[a] | 4[a] | 5[c] |
| Time and duration of trial (March) | 7–10 | 7–11 | 15–18 | 15–18 | 16–19 | 21–26 | 21 |
| Duration of trial | 4 days | 5 days | 4 days | 4 days | 4 days | 6 days | 6 |
| Initial age of fish (days) | 0–1 | 14 | 3–4 | 14 | 0–1 | 1–2 | 1– |
| Percentage mortality at end of test period for initial number per container | | | | | | | |
| of: 24 | 37 | – | 96 | – | 50 | 44 | 75 |
| 20 | – | 20–25 | – | 80–90 | – | – | – |
| 12 | 42 | – | 83 | – | 48 | 92 | 67 |
| 6 | 17 | – | 33 | – | 50 | 17 | 17 |
| Number of test days for which creek discharge exceeded 10 cumecs | 0 | 0 | 2 | 2 | 1 | 0 | 0 |

[a] 1.5 L container;
[b] results of Bywater (1988) for 4 replicate trials run concurrently with those of ARRRI – 20 L con
[c] 9 L container

was associated with discharge in the creek exceeding 10 cumecs, and thus exp of fish to the different water quality of these higher discharge waters (Table III' results of Bywater (1988) who ran trials concurrently with those of AR corroborate these results; in two trials each using 4 replicates, each of t' 14-day-old rainbowfish, mortality was much greater in the second trial whe: charge in the creek exceeded 10 cumecs (Table III).

Thus, waters in the temporary reach of Magela Creek dring high flows ap to be naturally lethal to freshwater mussel glochidia and larval rainbowfish same stressful agent may be responsible for the observed suppression of breed adult mussels during these periods. The reason for this is not known. At tim high flow (> 10 cumecs) there is an increase in the acidity of the stream wa these upper reaches of Magela Creek, with typically a reduction in pH from to 4.9 (Noller and Hunt, pers. comm.), presumably associated in part with the run-off of rainwater and consequent reduced contact time with soils and rocks rainwater itself has an enhanced acidity, caused by the presence of weak or acids, particularly formic and acetic (bush-fire derived products) (Noller *et al.*, 1 Consequently, at such times salts of these acids (both substances of very low tox as well as increased concentrations of humic and fulvic acids from vegetatio catchment soils (Noller and Hunt, *op. cit.)* are likely to be present. In con the concentrations of metals (another possible factor) in water at high flow-rat very low. Plant toxins (e.g. saponins, derived from the riverine shrub, *Ba. tonia acutangula,* and recognised ichthyocides (Bishop *et al.*, 1982)) may al leached from plant debris on flooded banks or from inundated portions of sh at high flow to give concentrations which might be harmful, particular the more sensitive larval stages of organisms. However, it is not known whe for example, elevated $H^+$ concentrations, plant toxins, ionic imbalance, rec availability of essential trace metals (because of their increased complexati high concentrations of humic acids), or osmotic stress might be responsible. ' represent some of the factors that would need examination if seeking to resolv problems.

However, it is not necessary to resolve the problem in order to recognise the ap potential impact in these monitoring studies. Clearly, some components o aquatic fauna live under sub-optimum conditions during high flows in Magela ( and such organisms/life-stages may therefore, not be suitable for monit short-term effects of waste-water release during these periods. (It is worth no nevertheless, that the lethal effects observed in this section of Magela Creek d necessarily extend to other portions of the creek. The main breeding and nu areas for many fish species for example, are the still or slow-flowing surface w occurring in well-vegetated backflow billabongs and floodplains of the catchı During the Wet season proper, acidity decreases while concentrations of majo increase, in a downstream direction on Magela floodplain, due possibly t influence of groundwater enriched in salts (Hart *et al.*, 1987) and the large quar of aquatic plants through which waters pass. Similar neutralizing and modi influences upon possible toxic agents may also occur in backflow billabongs, the mitigating adverse effects upon aquatic organisms.)

While the breeding response of mussels in the temporary reach of Magela C appears not to be useful for monitoring waste discharge during periods of protra high creek-flow, a technique of detecting delayed effects using this response, waste release and when creek discharge has subsided sufficiently for breedi recommence, could be employed. Knowing that the reproductive cycle of *V. a* is 9–10 days long (and ideally, sampling mussels within this period after waste re and associated high creek flow), an adverse response to previous release wou detected when the reproductive cycle (once this restarts) downstream of the discl point was found to be asynchronous with that of mussels located upstrea Ranger. Such asynchrony was observed in the March 1985 RP4 release as desc above (and as shown in Figure 7).

Apart from breeding cessation during periods of high creek flow, further prob in attempting to use breeding responses of female mussels to monitor waste disc arise in that if after every release, mussels were removed and killed in order to o relevant information (e.g., March, 1985). The relatively small stocks of m resident in the temporary channels of Magela Creek downstream of Ranger v then soon be depleted using this technique. A non-destructive method of n examination has therefore been developed to overcome this problem. This co of placing female mussels in mesh-covered containers filled with stream substrat deploying these devices at strategic sites along the creek edges. As required (su before and after the time of mine water releases), mussels are removed fro containers in the stream and placed in shallow water in small containe the laboratory. Disturbance of female mussels in this fashion causes abortion c bryos and larvae so that quantitative information on the reproductive conditi a mussel at that time can be assessed (namely whether each female was bree the stages of larval development present and the number of embryos and l present). The female mussels can then be returned to their respective containe returned to the monitoring location in the stream. Using this method, the sa males may be used to assess water quality following waste-water release number of years.

### *Juvenile Mussels*

Using the techniques developed by Hudson and Isom (1984), juvenile, free-liv *angasi* recently metamorphosed and excysted from host fish tissues, have successfully reared in the laboratory at ARRRI. In toxicity tests, growth (at of juvenile mussels has been shown to be impaired by exposure to low concentr of some Ranger waste-waters (ARRRI, 1986). This response therefore, as v mortality of juvenile mussels held in creekside tanks or *in situ* is being exami a potential useful means of monitoring waste-water releases.

During the 1987-88 Wet season, juvenile mussels were successfully reared one-day-old in both the creekside system and *in situ* enclosures described abo the creekside trial undertaken in March 1988, mortality on Day 7 amc containers each initially holding 50 mussels ranged from 0% to 20% (mean m 7%). From an initial size of 266 $\mu$m, mussels had almost doubled in size by of exposure in four containers for which growth information was av (Table IV). The mesh size of the net covering the top of the containers did not to affect growth or survival of mussels. In concurrent *in situ* trials, mortal also low ranging between 4–12 percent by Day 7, in the 6 cylinders used, wl animals had more than doubled in size (Table IV). Growth rates depended mesh-size of the container covers being greater with increasing mesh-siz presumably the higher turnover of water and greater availability of potenti items, Table IV).

The only requirement for successful field rearing of one-day-old mussels constant turnover of creek water and thus this method differs from static lab rearing methods where additions of silt to culture waters are necessary (Huds Isom, 1984). Not since Howard (1922) first reared newly-transformed mussels in floating crates in the Mississippi River (USA) has similar success been ac Howard (1922) did not report on the survival of mussels in his trials, the report being the first to document high natural survival in containers in the fi to evaluate the potential of juvenile mussels for use in field monitoring o quality. While not yet tested under conditions of waste-water release, mortal growth would be suitable end-points in the testing of this life-stage.

### 2.2.2. *Fish Migration*

One marked phenomenon in the dynamics of fish communities in Magela C the upstream migration (past Ranger) to permanent waters of massive num adults and juveniles of many species along the stream edge following Wet spawning and feeding in downstream creek, billabong and floodplain habit prior to cessation of flow. This movement constitutes an essential survival st serious impairment of which would be a marked ecological impact. In orde in a position to judge whether or not any release of waste-waters from Ranger i these migrations, daily counts of fish moving past a selected site have been n four Wet seasons, 1985-88. Details of the counting method used in the vici the Ranger pipe outlet have been given by Bishop (1987). (The novel, direc method used for characterising migrations is made possible because of tl clarity of Magela Creek waters during most of the Wet season.)

Examination of the data obtained, particularly in relation to changing hydrc conditions, and releases of waste-water from Ranger, has indicated three appı which may be useful for determining whether released waste-waters have or h impaired upstream migrations. The factor distinguishing these approaches difference in the period of time between response and its detection. Two c approaches may be used in the early-detection of harmful responses; th approach may be used in the delayed-detection of responses and is descr Section 2.3.2.

TABLE IV

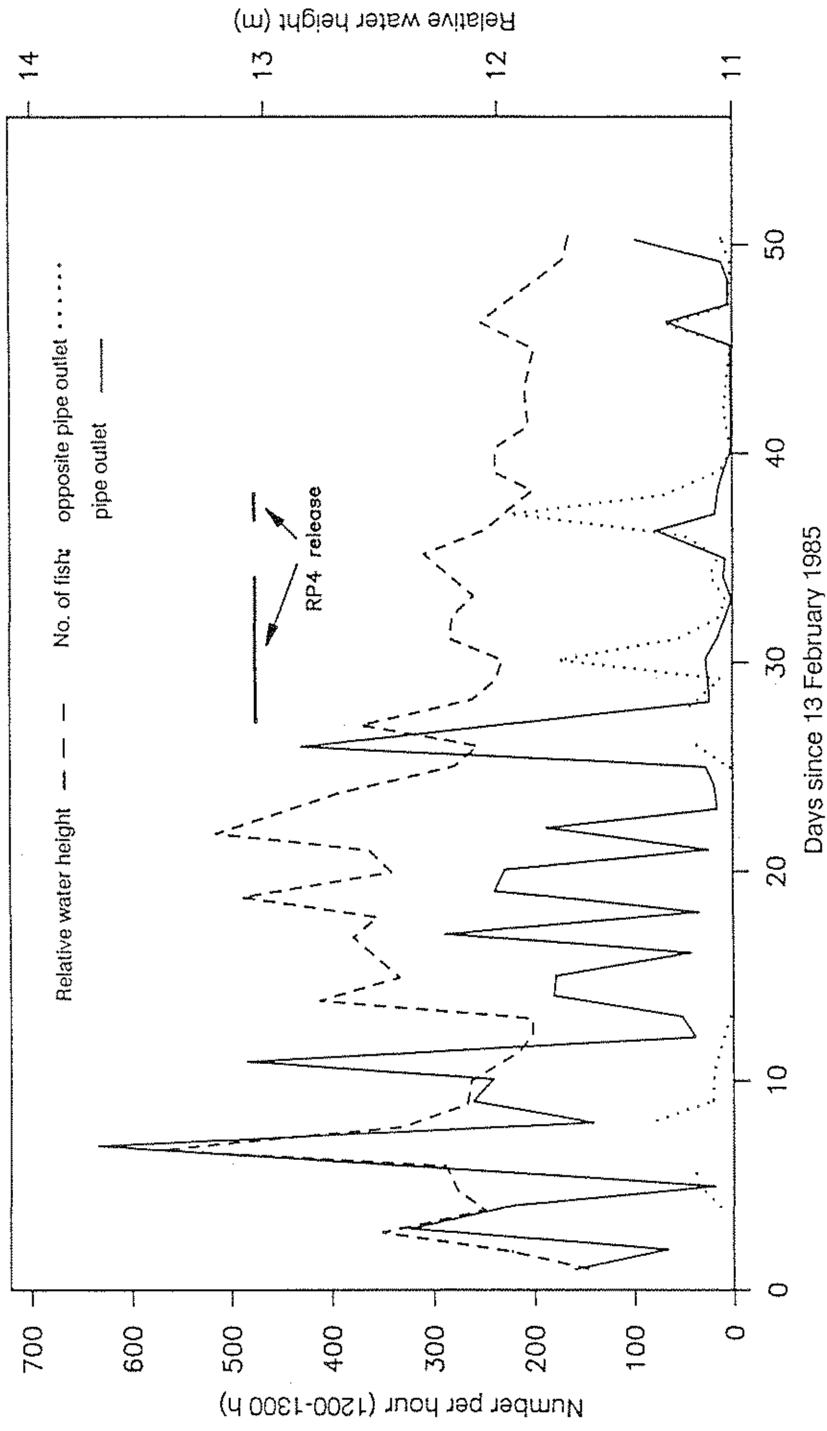
Length of newly-metamorphosed, juvenile mussels after 7 days in the creekside monitoring syst Magela Creek in relation to the size of mesh used to cover the holding container

| Mesh diameter | Mean total length ± SD (μm) ($n$ = 20) | Mortality ($n$ = 50) |
|---|---|---|
| *Creekside monitoring system* | | |
| 250 μm | 449 ± 21 | 5 |
| | 483 ± 41 | 0 |
| 500μm | 453 ± 39 | 5 |
| | 483 ± 40 | 10 |
| *Magela Creek* | | |
| 250 μm | 588 ± 38 | 2 |
| double layer | 606 ± 77 | 5 |
| 250 μm | 602 ± 28 | 3 |
| single layer | 634 ± 35 | 6 |
| 500 μm | 634 ± 33 | 3 |
| single layer | 636 ± 34 | 3 |

TABLE V

Environmental conditions in the ARR conducive to development of techniques suitable for lon; monitoring

| Environmental condition | Advantage for monitoring |
|---|---|
| Well-defined seasonality | • ecological processes are more easily identifie biological responses reflect well-defined environmental events<br>• biota are 'concentrated' as water levels fall, community/population characteristics at thi: may reflect the 'summation' of organism re. through the Wet season<br>• open and closed systems (i.e., the Wet and Dry) are available for study<br>• when making year-to-year comparisons, sea: effects can readily be removed, as points in relative to the seasons can easily be identifie<br>• the period when access is available to sampl sites is very predictable (e.g., installation an removal of passive sampling equipment) |
| Clarity of waters | • direct observations can be made on 'macro' This includes examination of biota occupyir particular areas, as well as those migrating particular points (in the case of fish, the narrowness of creek channels and the preser light-coloured substrates is a great advantag |
| Low variation in total annual discharge | • year-to-year variation in community/popula characteristics of the biota has the potential low |


Relative water height (m)
14
13
12
11
Relative water height
No. of fish: opposite pipe outlet
pipe outlet
RP4 release
0
10
20
30
40
50
Days since 13 February 1985
700
600
500
400
300
200
100
0
Number per hour (1200-1300 h)

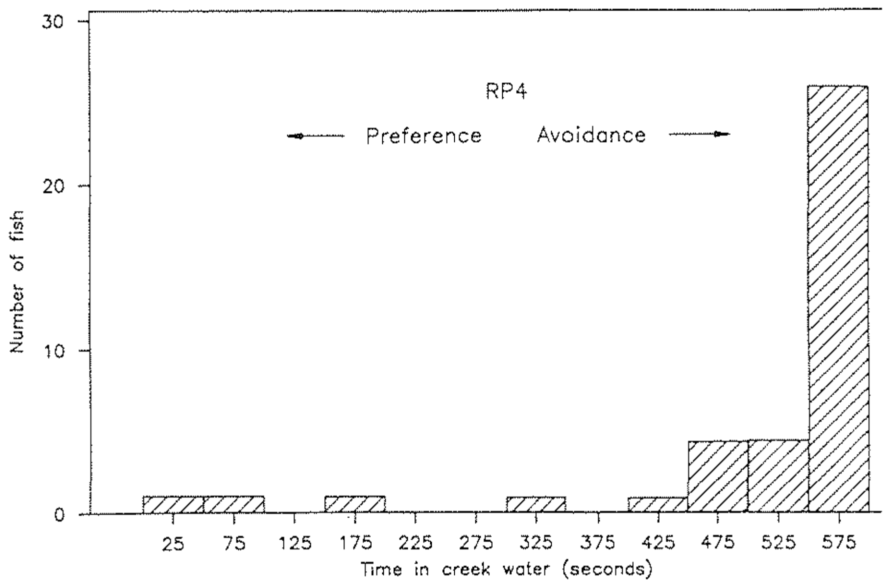



Fig. 10. Frequency distribution of time spent by chequered rainbowfish in creek water (versus u RP4 water) in forty 'choice' chamber trials each of 600 sec duration.

### *'Prompt' Detection*

An example of this approach occurred during the March 1985 RP4 releas assessment of the response of migrating fish to the plume of RP4 water in th is described in detail by Bishop (1987) and is summarised as follows. Daily of the bank-side migration of fishes were routinely made near the discharge between 1200 h and 1300 h and commenced on 13 February 1985, some 2 before the first of three operational discharges of RP4 water. Observations con until flow stopped in Magela Creek so that fish movement under natural con could be studied. During the first two discharges, observations were also m midday from a site on the side of the channel opposite the discharge point. (A flow rates, the increase in water depth did not always enable observations to b at these two sites.)

Fish of twenty-two species were observed moving during the March 1985 Analyses of the movement patterns of the five most abundant species indicat two species responded to the RP4 water plume. Chequered rainbowfish, *M taenia splendida inornata,* moved laterally away from the plume of RP4 w that at the sampling site opposite the discharge point, total and net (upstream downstream) migration rates were higher during the time of the discharge ure 9). In contrast, long toms, *Strongylura kreffti,* moved into the RP4 water

Subsequent laboratory tests with rainbowfish using RP4 water demonst statistically highly significant avoidance reaction (Figure 10), validating th observations, although a later, small 'trial' discharge of RP4 water into

Creek produced results that were not consistent with the field observ: attraction of long toms.

These types of observations can provide valuable early warning of possible effects (which may not be associated with toxicity but simply reflect an olfa some other response to the water). However, they can only be carried o discharge in Magela Creek does not exceed 20 cumecs, since at greater discha observational accuracy is unsatisfactory.

*Post-release Detection (2–5 Days After)*

Examination of the association between creek discharge and numbers of fis cularly chequered rainbowfish) passing the observation point (i.e. the Ran outlet – see above) per unit time indicates that the maximum rate of mo frequently occurred 3 to 5 days after a discharge peak. If this association is ( ed, then it might be developed into a method for detecting impaired res| migrating fishes. Under suitable conditions (i.e. where 'peaks' in creek d occur during waste-water releases, followed 2 or 3 days later by a period of less than 20 cumecs, which allow migration to be observed), the approac relatively rapid information of possible adverse effects when 'probable' m: migration rates fail to occur after an earlier creek spate. Thus, the metho provide a useful means of detecting migration changes resulting from was releases at times when creek flow is so high that observation of fish mov not possible.

## 2.3. Delayed detection of short-term effects

### 2.3.1. *Structure of Benthic Macroinvertebrate Communities*

Sampling of benthic macroinvertebrates colonising natural and artifical su is being used to obtain baseline information in the seasonal reach of Mage from upstream of the Ranger release-pipe outlet downstream to Mudginbe bong. This information will be used as a basis for detecting effects of wast and determination of the extent of this impact in both the short-term and (t extent) longer-term. Changes in community structure will be used to mor assess impacts, although in the future, it is envisaged that functional measu trophic relations) of environmental impact will possibly be incorporated to ment this information. Studies were instigated in the 1987-88 Wet season to and assess the merits of artificial and natural substrates for providing inf about short-term and longer-term impacts (ARRRI, 1988).

The most successful form of artificial substrate sampling devices so far in Magela Creek consist of gravel-filled, plastic-mesh cylinders that are tet the submerged roots of clumps of *Pandanus* located in mid-stream. Sam natural substrates (with a Surber sampler) has been confined to that creel consisting of the sloping stream bed between the unconsolidated sand bed water's edge. Substrates here comprise mostly fine sands containing organi with considerable macrophyte growth (mostly *Eriocaulon setaceum*). No applic has yet been made of variations in macroinvertebrate community structur monitoring and assessing mine waste-water releases to Magela Creek.

For detection of short-term effects, it is desirable that information be ava at least during the particular Wet season involved, if not during the release technique of using artificial substrates to sample macroinvertebrate communi the obvious choice in providing such information because (a) they are colonis a diverse fauna and abundant numbers, (b) involve the least time in processin sorting of samples and (c) represent the least sampling effort which provides a dance estimates with acceptable errors (ARRRI, 1988).

For detection of longer-term effects, information related to natural event which might contribute to a long-term baseline (years) is necessary. Because sub tial differences have been found between the structure of macroinvertebrate cor nities of artificial substrates and those of natural substrates (ARRRI, 1988), i evident that artificial substrates cannot be considered a substitute here for st of the natural substrate fauna in the study of longer-term effects. It is consi therefore that a cost effective approach might be to sample natural substrates only during any particular Wet season, doing so at the Wet/Dry transition p when major flow has subsided. This timing has the two-fold advantage that (i) sp diversity is generally highest at this phase of the hydrological cycle in Magela C and (ii) for legal, as well as practical reasons, any controlled releases of waste-waters would have been completed by this time. The information coll about the diversity of the fauna in Magela Creek at this time would, therefore, a suitable and integrated measure of community response to waste-water rele

### 2.3.2. *Fish Migration – Seasonal Detection*

Data on the numbers of fish migrating up Magela Creek (as used in the early-detection studies of migration described above) are being analysed to eva their possible use in indicating overall seasonal effects.

Preliminary examination of the association between the number of days on w Wet season creek discharge was 'high' (see Figure 11) and the number of days ' numbers' of fish were observed moving upstream during the Wet season, rev that for several of the smaller-growing species the relationship was a negative (An example of such a relationship for the chequered rainbowfish is shown in Fi 11.) If upon further analysis this or similar associations can be shown t predictable, then such an approach might be capable of detecting short-term longer-term mining-induced responses of both fish already migrating and t normally expected to commence migration (using a similar rationale to that desc for the latter 'early-detection' approach – Section 2.2.2). Thus, a measure o frequency of occurrence of movement of large numbers of fish over a standar observation period might be derivable after each Wet season that could serve a integrated index of any short-term or longer-term acute or chronic effects that occurred in areas downstream of Ranger during the Wet season. In particular

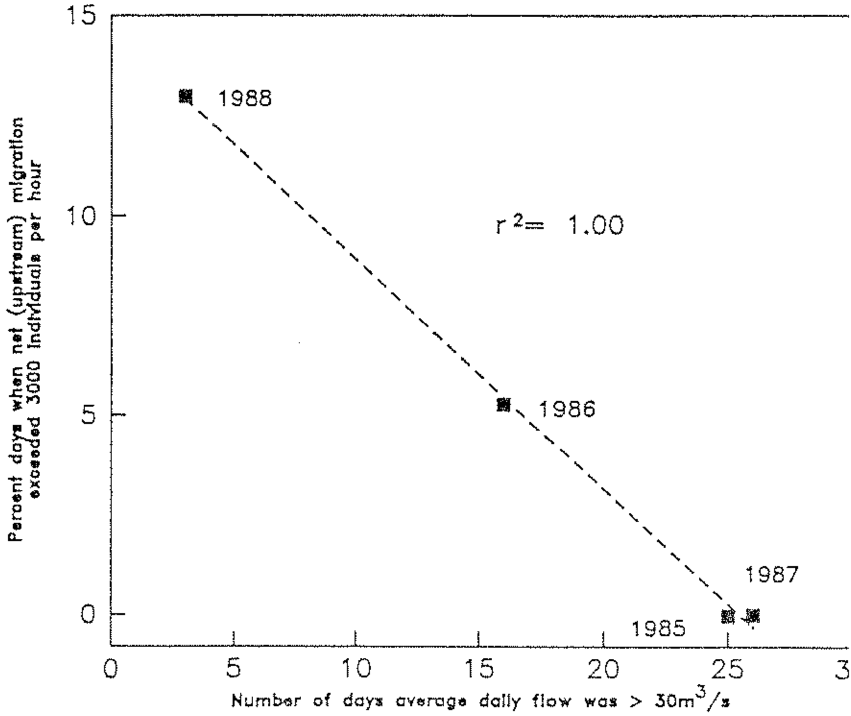



Fig. 11. Relationship between characteristics of Wet season hydrology and the migration patter chequered rainbowfish, 1985-1988.

index would be a measure of both the success of Wet season recruitment of i these downstream sites and of subsequent upstream migration.

## 2.4. Detection of longer-term effects

Ultimate assurance that waste-water has been released in an environmentally sa tory manner will rely chiefly on the evidence that post-release biological data c differ significantly from those of historical baselines. Because such baseline d this type inevitably show fluctuations and temporal trends, the considerable tinued commitment by the ARRRI to the collection of biological (including future, biochemical) information on Magela Creek is necessary to obtain re estimates on which such decisions can be based. The studies described ('Delayed detection of short-term effects') will in most cases contribute to bas useful for detecting any longer-term effects caused by the release of waste-w Other studies described below, however, are designed specifically to detect e that may only appear over the long-term.

### 2.4.1. *Benthic Macroinvertebrate Communities and Populations*

Study of the macroinvertebrate communities from natural substrates of the channel of Magela Creek (as described above) will continue at sites upstrear downstream of the Ranger release point in order to evaluate and assess the long-te effects of mine waste-water releases. Both Marchant (1982) and Outridge (19 1988) provided useful information on seasonal and spatial variations in littoral a benthic macroinvertebrate communities of several Magela Creek billabongs. B studies, however, were of short duration (12 months) and until this information b is expanded, neither is sufficient to design monitoring programs.

Other than the studies in which particular attributes of the physiology of freshw er mussels (*Velesunio angasi*) were indicated as being suitable for monitoring a assessment of short-term effects of waste-water releases (see Section 2.2.1), these a other biological attributes will also have considerable potential in the assessment long-term mining impact. For example, in a study of the biology and ecology freshwater mussels in Magela Creek waterbodies, Humphrey and Simpson (19 found moderate to high correlation between a number of biological measures (e mussel abundance, population structure, maximum ages, growth and reproducti and various environmental factors (chiefly water temperature, dissolved oxy concentrations, Wet season discharge patterns and/or phytoplankton conc trations). Such information provides a valuable basis against which to 'correct f natural events and detect, quantify and assess long-term effects associated with m waste-water releases to Magela Creek.

### 2.4.2. *Structure of Fish Communities*

#### *'Backflow' Billabongs*

The structures of fish communities in eight backflow billabongs, selected on the ba of their geographical (and hydrological) relationship to the Ranger mine site, h been surveyed with the use of multiple-mesh sized gillnets from 1978 to 1987. Det of the methodology and results are given by Bishop (1987). Major features of th results as they relate to monitoring of fish community structure within backfl billabongs in the future, are summarised below.

Associated with the progressive increase in the abundance of aquatic vegetati a result of the removal of water buffalo from Kakadu National Park, there have b distinct changes in fish species composition in the majority of billabongs samp over the surveillance period. The most common compositional change has bee decrease in the proportion of large-growing fish species (i.e., as adults) in catch The basis of this change is assumed to be simply that the larger fish are physica unable to utilise the more heavily-vegetated areas than are small-growing speci

It is notable that the compositional structure of late-Wet season fish samples fr one billabong (Indium Billabong) in which there has not been a great proliferat of aquatic vegetation, was 'persistent' (*sensu* Grossman, 1982) over a period of years when habitat changes were occurring in other billabongs. This was shown a statistically highly significant concordance between abundance ranks from yea year with $p = 0.003$ ('$p$' is the probability generated by Kendall's coefficient concordance (Kendall's W) that abundance ranks were not correlated amor years). As would be expected, concordance was not significant in billabong large changes in vegetation had occurred (e.g., $p = 0.375$ and 0.125 for Coc and Georgetown Billabongs respectively).

The occurrence of such year-to-year changes does not necessarily preclude of the data obtained in distinguishing 'natural' community responses from induced responses provided that control sites are sampled. Nevertheless, the distinguishing these responses is complicated by such changes; less reliance : placed on temporal controls and difficulties of interpretation may occur if th and nature of year-to-year changes varies between control and 'exposed' s

However, the overriding consideration now is the fact that it is impossib. gillnets within most of the billabongs because of the high density of vegetation. Accordingly, the baseline of community data gathered so far ca expanded, nor will it have sufficient value for monitoring whilst the de vegetation remains high or increases further. (In order to obtain a pertinent b efforts are being made to devise standardised methods for sampling fish in ar high densities of vegetation. One method which shows promise in this rega which will be further investigated, is a 2 × 2 m lift trap used in conjunctior jet of water, the latter serving to attract fish into a trapping area.)

*Gulungul Creek, a Tributary Downstream of Ranger*

Community data from this study span the period 1980-88 and arise from r counts of fish at ten sites along Gulungul Creek (see ARRRI (1987a) for a des of the rationale and approach of the study). The underwater counting technic in this study is very effective because of the constant high clarity of waters its proximity to the escarpment.

The original aims of this study were (a) to provide baseline data on the f creek which flows close to the Ranger Tailings Dam, and (b) to develop an tanding of processes which influence migration patterns of fishes within th With respect to the latter aim, Gulungul Creek (Figure 5) was chosen becaus considered to be a suitable replica for Magela Creek, in that the knowle understanding of processes influencing events in Gulungul Creek could be to the more geographically extensive and hydrologically complex Magela Knowledge of such processes in Magela Creek was (and still is) considered d in order that 'natural' responses of migrating fish can be distinguishe mining-induced responses (i.e., those caused by the release of waste-water

As the community data from the project accrued, it became apparent t baseline information could also be used directly for monitoring in the follow ways: i) data on those species which it appears do not migrate out of the san habitat of Gulungul Creek, may be used as a spatial control for migrati gathered in Magela Creek (see 'Fish migration' studies above); and ii) data c on species which appear to be recruited into the creek from Gulungul Bil located in the lower reaches of Gulungul Creek, may be used as a temporal for community information gathered from the billabong (see above: Structur communities in backflow billabongs). The results of studies made in the 19[illegible] Wet season to validate assumptions vital to these two monitoring applic[illegible] confirmed earlier views (above) concerning fish migration paths and recru[illegible] sources.

Apart from the fact that relationships are becoming discernible between y[illegible] year patterns in community structure and stream hydrology, a notable f[illegible] emerging from this study is the extremely high level of persistence of the compo[illegible] al structure of communities in refuge pools in the upper reaches of the creek. [illegible] eight-year comparison of mid-Wet season data gathered in one particular p[illegible] was calculated (Kendall's W) that a probability of less than 1 in 200 000 existe[illegible] abundance ranks were not correlated amongst years. Such a high level of c[illegible] sitional persistence in freshwater fish communities has not been documente[illegible] where in the world. Apart from the high level of persistence found in the comp[illegible] of fish from Indium Billabong (probability of 1 in 330), the community dat[illegible] the next highest level of persistence (probably of 1 in 25) is that collected by [illegible] and Vondracek (1985) in an examination of fish communities over a five year [illegible] in Martis Creek, a seasonally-flooding, small stream in California, U.S.A.

### 2.4.3. *Chemical Monitoring of Biota*

Metals constitute the major known components of possible concern in the F[illegible] mine waste-waters and once discharged these substances (in contrast to any d[illegible] able organic compounds which might be present) are always potentially availa[illegible] accumulation by the biota of the region. (All organisms reflect the abunda[illegible] available substances in their environment to some degree and the biota const[illegible] distinct biogeochemical province whose chemical composition should be ascer[illegible] whenever this aspect of an ecosystem is of concern.)

While certain substances discharged in the mine wastes will be channel[illegible] solution through most of the permanent waterbodies downstream of the R[illegible] mine, waterbodies beyond Mudginberri Billabong lie in the zone of major floo[illegible] deposition of water-borne materials (ARRRI, 1985) and these areas ma[illegible] constitute sedimentary 'sinks' (i.e., sites of enrichment) of the discharged m[illegible] They may then subsequently be remobilized, by either biotic agents (benthic ma[illegible] vertebrates) or chemical processes (or both) and become available at enh[illegible] concentrations to organisms at higher trophic levels.

Because significant increases in concentrations of metals in organs of anim[illegible] regarded as harmful, until proven otherwise (a tenet of toxicology [Brown [illegible] there is a need to identify whether this is occurring in this region and if so to [illegible] the risk (e.g., by histological examination, laboratory experimentation) th[illegible] given resulting concentrations represent. Examination should also be ma[illegible] essential metal concentrations because concomitant with increase in one meta[illegible] may be significant decreases in concentration of an essential element. (The l[illegible] calcium where cadmium accumulation is occurring is one of the best k[illegible] examples, demonstrated in 'itai-itai' disease (Tsuchiya *et al.*, 1978).)

Two major practical problems exist, however, with regard to monitoring ARR, and that is the great extent of the area to be examined (the Magela Cre its associated floodplain covering, for example, at least 200 km$^2$ during th season) and difficulty of access and sampling during the Wet season. As a quence, extensive detailed monitoring, e.g., using community structu organisms, and assessment (along with associated research) of the possible of released mine wastes on the aquatic biota of all of the large, remote, and cc bodies of surface waters downstream of Mudginberri Billabong are beyo resources of the ARRRI. Furthermore, in view of the distance of such water the Ranger site, the degree of hazard existing there may be small, so that in monitoring may be unnecessary. The absence of a need for some form of mon anywhere downstream of a waste discharge, however, cannot be assumed where the environmental fate of all constituents of the waste is known and ir the limit of any hazard.

It is considered that the largest potential 'far-field' hazard to aquatic biota resulting from the accumulation of metals, particularly in depositional area in order to circumvent the physical and logistic difficulties of sampling such fishes, which themselves constitute mobile environmental sampling 'agent being sampled and may be more easily studied than community structure o nisms from Mudginberri Billabong and billabongs downstream of this. The p of this approach is to determine the essentially 'long-term' (i.e., equilibrium) b concentrations of chemical elements in particular body organs of fish so that concentrations might be compared, and, should increases have occurred, to potential risks by appropriate laboratory experiments.

In addition to the use of organisms at the top of the truly aquatic food we which therefore can reflect accumulation via the food web as well as accumu direct from the ambient water, studies have also already been made of the c trations of stable and radioactive metals in the soft parts of the mussel, *Vel angasi*, from Magela Creek billabongs (Allison and Simpson, 1983; Jeffr Simpson, 1984, 1986; ARRRI, 1984, 1985, 1987a, 1987b). These long-lived nisms, being sedentary, can be used to assess 'overall' long-term water quality particular part of the creek system in which they are found but, in contrast to fishes, can also be utilized in 'short-term' monitoring, the concentration organism of substances of short biological half-life being very much influen the recency of exposure. Evidence of exposure to such substances is rapidly although this does not mean that such exposure might not have had some a metabolic or physiological impact.

## 3. Baseline Studies in the Upper South Alligator River

### 3.1. Background

Biological studies on the aquatic environments of the Conservation Zone are cu ly directed towards the gathering of baseline data from the upper South Al

River (SAR). The data include the identity and abundance of organisms maki communities in the aquatic environments so that the information obtained m used as a basis for detecting and assessing any future environmental imp exploration, mining or ore processing at Coronation Hill. Much of the backg knowledge gained in studies on the biology of aquatic organisms in the Magela is directly applicable to mining elsewhere in the Region, and this has as considerably in data gathering in the SAR. Emphasis in the studies near Coror Hill has been placed on the development of biological monitoring procedure strategies using macroinvertebrate and fish communities.

The sampling strategy in the SAR consists of systematic seasonal collecti information from a number of similar sites upstream and downstream c proposed mine site. Data gathered on aquatic organisms will be used to in whether mining activities are, or are not, having adverse effects, from comp of community structure below mine sites (past and future) with that of commu at control sites upstream (or elsewhere). In addition, data from current sa (which may or may not reflect influences from abandoned mines – see belov be used to identify significant relationships between the fauna, water chemistr physical habitat structure, associations which might be used to detect future a impacts.

Until very recently, both the upper and lower reaches of the SAR were witl active pastoral lease (either Goodparla or Gimbat). As a consequence, in se of the river around Coronation Hill, there is abundant evidence of buffalo d to riparian vegetation (and subsequent erosion); buffalo eradication prograr now underway in the Conservation Zone and Kakadu Stage 3. Further, a nu of small abandoned mines are located along the northern escarpment-face abo river in its upper reaches. Small-scale exploration and mining for silver, lead and copper occurred in the late 1930s, and uranium was mined underground a open cut from at least 12 discrete deposits (including Coronation Hill) for mor a decade over the 1950s and 1960s. At least one small SAR tributary (Rockhole Creek) located downstream of Coronation Hill is polluted for much of its len acid water draining from an adit of an abandoned and unrehabilitated, ur mine. Nevertheless, the river water, in terms of its chemistry and biota, wo described as of good quality. Baseline studies in the SAR prior to new r operations in the Conservation Zone are essential to identify and describe no naturally-occurring variation in the faunal composition but also to help disti the present impacts from buffalo and past mining disturbances, from any mining impacts. Such information will also provide a basis for detectin measuring any improvement in water quality following buffalo remova any effects of rehabilitation of old mine workings that occurs in the future. interim, prospective studies on any mine-polluted stream in the upper SAR ment might provide useful information on the relative sensitivity of particula cies, something that might usefully be applied in assessment of future mini pact in the SAR.

## 3.2. CURRENT PROGRAM

### *Macroinvertebrates*

In order to develop suitable strategies by which to assess the application of m vertebrate communities in detecting biological impact caused by mining acti Coronation Hill, a routine baseline program began in the Dry season of 1

(1) describe spatial and seasonal patterns in macroinvertebrate communit ture; and

(2) identify those major environmental factors affecting patterns of com structure that need to be taken into account in the development of a tec suitable for monitoring environmental change.

Samples have been collected at two-monthly intervals since October 1987 sampling sites were selected in a portion of the SAR extending some 5 km up of Coronation Hill (2 control sites) and approximately 20 km downstream (6 Sites physically similar to one another, and within riffle areas, were chosen fo On each sampling occasion and at each site, an area of 0.25 $m^2$ of substr sampled to a depth of ~ 10 cm using a Surber sampler. Associated environ data have been collected with each sample for use in description of the p structure of the habitat and physico-chemistry of the water.

The macroinvertebrate fauna of the SAR is a diverse one and is domin Ephemeroptera (Leptophlebiidae, Caenidae, Baetidae), Trichoptera (main dropsychidae, Hydroptilidae, Philopotamidae), Diptera (Chironomidae, Sim and Coleoptera (Elmidae). Generally, increases in abundance of organisms c have occurred over the Dry season (May-November), while declines have o over the Wet season months (December-April) a result presumably, of river-s over this period (ARRRI, 1988).

### *Fish*

Methods of standardising data collected by underwater observation on num fish present in communities within permanent pools of the SAR and some tributaries are being examined. For spatial controls, a number of sites ar studied either in the SAR itself, upstream of the Coronation Hill project a in major tributaries such as Dinner, Fisher or Koolpin Creeks, areas which expected to be affected by mining activities. Twenty-six fish species hav observed in the South Alligator near Coronation Hill.

Studies of the fish communities in the small tributary of the SAR drain proposed tailings dam area and overburden stockpiles of the Coronation Hill could be the basis for early warning of adverse effects from seepage fro structures. Consequently, between the late-Wet and early-Dry seasons, t communities at a number of sites both in this creek and at similar site second-order tributary further downstream, i.e. a control stream, are include monitoring scheme.

## 4. Problems and Prospects in Biological Monitoring in the ARR

### 4.1. Monitoring and Assessment of Short-Term Effects

Problems of management of excess mine waste-waters in the ARR will b pressing in years where there has been exceptionally high rainfall, and it is a times that discharge to streams is likely to be sought. Authorisation for rel Ranger's RRZ water to Magela Creek will be given (if at all) only when flow creek reaches or exceeds 20 cumecs (a specific legal requirement). This fact raise a number of problems in relation to monitoring short-term effects up aquatic biota whilst release is occurring. *In situ* monitoring will be virtually ir ble under conditions of high creek flow because the test organisms are likel inaccessible. It will also not be possible to make accurate observations o movements; and the creek waters themselves may be naturally of a highly st quality so that useful organism responses (e.g., reproductive activity of fres mussels, mortality of larvae of particular fish species) cannot necessarily b

Thus, it will be necessary for some time to continue to search, and d techniques and methods for providing early warning of adverse changes conditions of high creek flow. In this regard 'creekside' monitoring offers th promise so far, although it will be necessary to identify the most useful org to hold in this system (i.e., ones that can both tolerate the poorer water associated with periods of high discharge and yet provide sensitive responses t waste-waters). The monitoring and assessment of short-term effects will assisted by 'delayed-detection' techniques, i.e. the detection of anomalies migration patterns, breeding responses of freshwater mussels or the com structure of macroinvertebrates colonising artificial substrates, when high dis subside during the Wet season.

It is likely that similar problems and solutions will arise in the upper Alligator River in future, should early detection of adverse effects arising fro of mine waste-waters to the river, ever be required. Such circumstances will als in wet years, and thus at high river flows. Under such conditions, it will be v impossible to sample or make observations upon fish communities and while difficulties will be encountered with the sampling of macroinvertebrate comm an additional problem will be that abundances of these organisms will be v as a result of river scouring.

In order to help deal with such situations, suitable 'back-up' techniqu procedures have been, and are being, developed to monitor and assess the Wet season impact of waste-water discharges upon the aquatic ecosystem of th from evidence obtained at the end of the Wet season. At this time sa difficulties are reduced (e.g., water clarity is high, sites become accessib organism abundances and species richness of the aquatic fauna are generally l Irrespective of the fact that it is essential, when and where possible, to quantify and assess waste impacts as early as possible (preferably *during* r the monitoring and assessment undertaken at the end of the Wet season su the response of the biota and so provide the best evidence that no adverse i have occurred. Such assurance will be provided by comparisons of post· information with that of pre-mining, biological baselines.

## 4.2. Monitoring and assessment of longer-term effects

As discussed earlier (Section 1.3), it is widely believed that high enviror variability and consequent high biotic variability (a result of the Wet-Dry ‹ cycle) would impose considerable difficulties upon the development of moı systems capable of detecting longer-term, mining related effects in the AF perience to date, however, indicates that, on the contrary, biotic variability very low, thus reducing problems in the design of particular monitoring systeı example, as described above (Section 2.4.2), the compositional structure of so communities in Magela Creek catchment showed a very high level of year- 'persistence'. For macroinvertebrate communities, relatively low seasonal vɛ in the biota has been reported in channel billabongs of Magela Creek (e.g., M berri) (Marchant, 1982; Outridge, 1988) whilst Outridge (1988) commented ge on the high degree of similarity between his (1981-82) study and that cor earlier (1979-80) by Marchant (1982) in a number of Magela Creek water indicating a strong annual recurrence of seasonal trends in the faunas. Huı and Simpson (1985) similarly found least biological variability in freshwater populations of the channel billabongs whilst stable populations with regular y year recruitment occurred in all waterbodies where there was an absence of s dissolved oxygen depletions. It is concluded that examples such as these coincident patterns in stream hydrology, namely high definition in seasons ɛ annual variation in discharge.

Whilst it is true that some waterbodies in the ARR have in recent years l less useful for monitoring due to progressive environmental change (e.g., 'ba‹ billabongs of Magela Creek, Section 2.4.2), other sites have remained v unchanged in terms of habitat-structure (e.g., the channels of Magela Cre‹ Ranger, SAR near Coronation Hill) or have always maintained a seasoı year-to-year limnological stability (e.g., channel billabongs of Magela Creek stability will facilitate considerably the development of monitoring and asse programs.

Other than avoiding sampling locations which are subject to high enviror variability, and consequently high biological variability, there are a nuı strategies available in the ARR which will also facilitate further developn monitoring programs.

One significant feature of the ARR monitoring studies is the high level of ‹ ecological information available on processes governing the dynamics of ɪ the aquatic organisms. When applied to the design of monitoring systems the analysis of monitoring data, such information increases the likeliho‹ monitoring results are well-focussed and conclusive. There are two 'areas' wh type of information is being used:

*Accounting for natural variability.* A number of intensive and extensive s (e.g. on freshwater fish (Bishop *et al.*, 1986) and freshwater mussels (Humphre Simpson, 1985) have been carried out under OSS research consultancies, and have provided information about relationships between biotic and non-biotic en mental variables. This is a particularly important requirement for the long monitoring of environmental change in Magela Creek where spatial controls a always available and where there is therefore, a need for much reliance 'temporal' controls. Examples of such information, including facets of fresh mussel ecology (Section 2.4.1) and the developing understanding of relatio between fish migration counts and Wet season hydrology (Section 2.3.2), hav previously discussed. For fish populations and communities in particular, collection over a number of years will be required to identify and establish rel ships between the fauna and environment. A valuable feature of the fish-moni programs undertaken at ARRRI therefore, has been the acquisition of an ext base of information gathered from long-running studies in order to develop su monitoring techniques.

*Dealing with characteristics of biota which may be disadvantageous in monit* This problem area is most relevant to the use of fish in monitoring, and in part to aspects associated with their mobility (as a consequence of which it can ne assumed that changes [or lack thereof] in their population or community cha ristics at a given point in a stream reflects long-term conditions prevailing a point). Because of the marked yearly expansion and contraction in area of the aquatic environments, fish movement (migration) is extensive and approp timed, habitat exploitation being a vitally important survival strategy. Studies c aspect of the dynamics of freshwater fish communities have indicated a num ways of dealing with possible movement-related problems in monitoring. The simple of these is that of taking advantage of the Region's particular rainfall pa examining communities only when site-to-site movement is impossible, i.e. c the Dry season when waterbodies are 'closed'. For example, by examining the r and extent of community changes occurring through the Dry season in the is billabongs in relation to different 'exposures' to mine waste-waters during th season, it is believed a means of detecting longer-term mining-induced effects be developed. An alternative approach is to actually take advantage of mobil particular, regular and defineable migratory behaviour. This approach is depe greatly on a detailed knowledge of migration characteristics (e.g., the locality of where migrations commence and the nature of the route taken). In the ARR is now a considerable body of such information for fish, and accordingly, op nities are available to develop means of detecting longer-term mining-induced e on migrations.

There are a number of other features of ARR monitoring studies which set apart from those undertaken elsewhere. Most of these features relate to the en mental conditions characteristic of the ARR, these being conducive to the ef collection of comprehensive biological data. Many of these have been touched within this paper, and are summarised in Table V. There are two remaining f not referred to in this table which are worthy of comment. The first is the lo of water-associated health risks (apart from crocodiles) faced by aquatic rese in the ARR. While this is not an unusual feature within most of Australia, it be considered rare and advantageous by researchers working on tropical fres environments in highly populated parts of the world. The second feature cc the benefits to the ARR researchers which flow-on from the placement o research base (the ARRRI within the Ranger Project Area) within their researc In this respect, the ARR researchers are in a unique and opportune situation the majority of their sampling sites on Magela Creek are within fifteen n travelling-time from both their laboratory base and their residences. This prc not only reduces research costs, but also maximises opportunities to respond c and to obtain high quality information on sudden or critical biological events would otherwise be lost in the time gaps of sampling regimes that are based on field trips to the research area.

## Acknowledgments

The contribution to the program discussed in this paper of Peter Dostine, Walden and Catriona Turley, all of the Biological Monitoring Section of A is gratefully acknowledged. We also thank Glen Riley for valuable comments earlier draft.

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