LOWER ORD RIVER

FISH RESPONSE TO LOWERED ORD RIVER FLOW

TO

Water and Rivers Commission

PREPARED BY

Wetland Research & Management

DECEMBER 2002

Contents

Frontispiece: Freshwater crocodiles sitting on macrophyte beds exposed during the drawdown

1 Executive Summary

As part of developing a drought strategy for the Interim Allocation Plan for the Lower Ord River (LOR) (WRC, 2003), the Water & Rivers Commission initiated studies to test the effect of "drought" flows (approx $35m^3/s$) over a short period (normal dry season flows reduced for a three day period) on fish distributions in key areas of the lower river.

Replicate sampling of fish communities was undertaken in three habitats (pools, backwaters and macrophyte beds) before, during and after a period of reduced flows simulating anticipated drought flows. In association with fauna sampling, physico-chemical measurements of each habitat also were taken. This report details changes in physico-chemical conditions, and fish species composition, abundance and biomass in relation to flow periods, and assesses how fish communities and their habitats responded to low flows.

The trial detected large reductions in the areal extent of macrophyte beds and backwaters during the trial drought flows. Changes in water quality, such as elevated water temperatures, pH and dissolved oxygen within macrophyte beds, increased conductivity in pools and backwaters, and reduced turbidity and dissolved oxygen levels in pools were detected. Changes in the distribution and abundance of prawns and small bodied/juvenile fish species in backwaters and macrophyte beds also were recorded, but with minimal detectable effects on fish in pools. General observations on aquatic fauna (fish, crocodiles and waterbirds) suggested altered behaviour consistent with there being a reduced carrying capacity by the system, with likely increased predation pressure during the drawdown.

Data and observations from the trial drought strategy indicated that the lateral habitats of backwaters and macrophyte beds were particularly susceptibility to reduced water levels. Changes in fish catch were not always obvious, particularly in the pool habitat, however, it was considered that the short duration of the trial provided limited time for some expected responses to be manifest (i.e. changes in fish community structure due to increased predatory pressure and reduced carrying capacity may take weeks or months to occur).

From this short-term trial, the longer term implications of a sustained drought strategy (i.e. over a whole dry season) on the fish fauna of the LOR were predicted. It was considered that the carrying capacity of the system for some species (i.e. larger species in pools),

would be reduced from current levels but it was unlikely that these species would be lost from the system, although population sizes would be decreased.

The reduction in area of macrophyte and backwater habitat, and impacts upon species dependent on these habitats either directly (i.e. for residence), or indirectly (i.e. for providing a food source) was assessed as the area of greatest risk, with a drought flow significantly reducing their areal extent in the system. Because these habitats are unlikely to re-establish in the short term (i.e. macrophyte beds take at least a year to recolonize new areas, and backwaters appear to be structured by wet season flows), species dependent upon these areas may be placed at risk. The level of risk likely exists between population sizes being much reduced, to some species temporarily or permanently being lost from the system.

The current study saw a drawdown from a relatively high dry season flow of 80 m^3/sec. It is expected that under a revised allocation plan for the LOR, baseline dry season flows would be lower, at approximately 45/40 m^3/sec. Therefore, a drought strategy flow of 35 m^3/sec would likely see a proportionally lower reduction in water levels. As such, the effects observed during the current study will likely be smaller, but the actual extent will require accurate surveying and modelling of the distribution of habitats in the system once the lower dry season flows are established.

Conclusions reached from this study did not take into account any adverse effects that could occur from changes in water quality (i.e. excessive reductions in dissolved oxygen levels, or increases in nutrients, algal growth, conductivity, water temperature or irrigation-derived contaminants) which could not be predicted from the brief trial.

2 Introduction

Since the early 1960s the Ord River, in the far north of Western Australia has been impounded and regulated to provide water for irrigated agriculture on the Ord River floodplain and for hydroelectric power generation. Initially the river was regulated by the Kununurra Diversion Dam, built in 1962. This is a relatively small impoundment (2500 ha), constructed to form a hydraulic head to feed the Stage I irrigation area. In 1973 the scheme was expanded by construction of the Ord River Dam approx 50 km upstream, a major impoundment forming Lake Argyle (surface area of 74 000 ha at cessation of spillway flow, but > 100 000 ha after wet season flooding). The Ord Dam provided the irrigation area with greater protection from flooding and greater security of water supply in the dry season. In 1996 the Ord River Dam hydroelectric power station was completed. On average 1940 GL of water is released through the hydropower station to generate about 210 Giga watt-hours of electricity each year. Over 70% of the power is used by the Argyle Diamond mine and the remaining is fed into Western Power's East Kimberley regional electricity grid. Modification to the dam to provide a great hydraulic head for the hydroelectric scheme resulted in an effective 6 m increase in the height of the dam. Also, the flow regime of the Lower Ord River (LOR) was further modified whereby dry season flows were increased as a result of HEP releases.

Throughout these various phases no consideration had been given to the flows required to maintain the ecology and other water-dependent values of the LOR, with the Ord Irrigation Area essentially taking as much water as it required. Currently the area under irrigation is approximately 11780 ha utilising approximately 300GL year^{-1}. However, in recent years there has been pressure to increase significantly the area under irrigation. The current proposal (December 2002) would see an additional ~30 000 ha placed under irrigation, with an additional 855GL year^{-1} required.

In the period since Stage I was developed there has been an increased environmental awareness, including recognition of the need to maintain river flows to maintain water dependent ecological, cultural and social values. Therefore, as part of the proposed expansion, the Water & Rivers Commission (the Commission) was required to develop a water allocation plan for the LOR. Development of such as plan involves considerable scientific, technical and cultural investigation, detailed analysis, and extensive consultation before it can be finalised. As this takes considerable time the Commission prepared an interim allocation plan in 2002 to facilitate planning of the Stage 2 irrigation developments and, given current uncertainties, make initial provision for water dependant environments. The Interim Plan allowed for water to be allocated for ecological, cultural and social values before making decisions about the water available for the proposed expansions. Channel surveys were conducted and the wetted perimeter was used to estimate the effect of changed flow on habitat availability and key habitats for fish communities.

In developing the Water Allocation plan, the Commission considered the possibility of a drought period environmental water provision (EWP) in a restricted number of years. The drought period EWP would give greater security of supply to the irrigation scheme, but the reduced flows in the LOR would reduce wetted perimeter, and potentially increase the risk of oxygen depletion in the system and thereby risk to biota. Therefore the Commission initiated studies to test the effect of “drought” flows (approx $35m^3/s$) over a short period by examining oxygen dynamics and fish distribution in key areas of the lower river. Subsequently a model will be developed to evaluate oxygen depletion and risk in the longer term.

The current report details studies undertaken of fish communities of selected habitats on the LOR as part of the trial of drought flows describing how fish communities and their habitats respond to low flows. The main tasks were to:

- Undertake surveys of fish communities over nine days (before, during and after the low flow period);
- Sample fish fauna from three key habitats with four replicates of each per river stage;
- Undertake detailed description of habitat parameters;
- Determine fish species composition, population structure, abundance and biomass in relation to habitat and flow; and,
- Report on the effects of reduced flow on fish populations.

3 Methods

3.1 Flow modification

The aim of the drought trial was to reduce flows in the LOR from late dry season flows (approximately 80 m^3/s in October 2002) to the proposed drought flows of $35m^3/s$, and assess the effects, if any on water quality and selected key water-dependent values. To achieve the desired flows in the LOR it was necessary first to open the Kununurra Diversion Dam (KDD) to lower the level of Lake Kununurra and thereby increase storage. This initially increased flows in the LOR. The KDD then was shut down and discharge held back, allowing flows in the LOR to fall to the desired levels. Because it was not possible to shut-down the hydroelectric scheme due to energy demand from Kununurra and the Argyle Diamond Mine, releases from the Ord River Dam continued, and it was anticipated that Lake Kununurra would provide a storage for a maximum of three days (i.e. the drought flows in the LOR could be maintained for a maximum of three days). Therefore, the study design was to sample the LOR for three days prior to reducing flows ("Before")(i.e. whilst Lake Kununurra was being lowered), for three days whilst flows were reduced ("During")(whilst the KDD was closed), and then for three days following return of normal flows ("After"). Sampling would target the reach between Tarrara Bar and Carlton Crossing because modeling of different flow scenarios indicated the greatest change is wetted perimeter would occur in this section of the LOR. Given the distance downstream from the KDD (approx 50 km), it was anticipated there would be a lag in the response, taking at least 24 hrs for levels to fall in this section once the KDD was closed.

However, in practice, the lag in the system was much shorter than anticipated, with levels in the target reach falling to the desired drought stage within 12 hrs. This shorter lag was possibly due to 'simplification' of the channel following successive large wet season floods in 1999, 2000 and 2001. The floods reduced channel roughness, whereby silt deposits, macrophyte beds, riparian vegetation within the channel, sand bars and sand islands stabilized by riparian vegetation were washed from the system. As a result the "Before" period was reduced to two days, with the "During" and "After" periods still remaining at three days each, but brought forward by one day (Figure 1).

The Before period therefore was the 17th - 18th October 2002, the During period was the 19th – 21st October, and the After period was 22nd – 25th October 2002 incl.

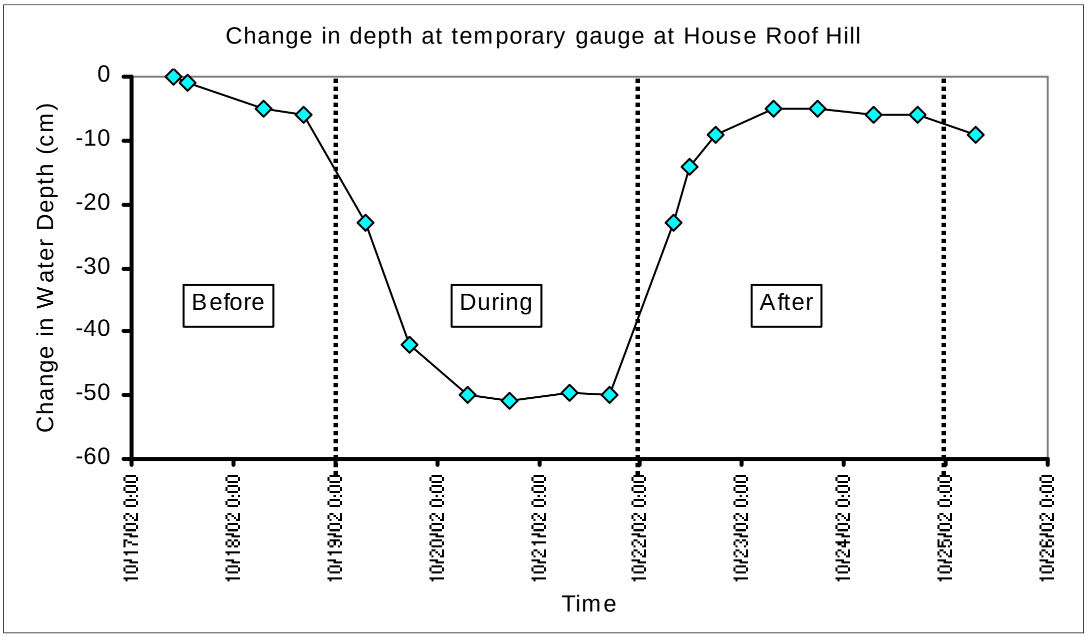

Figure 1. Changes in stage (cm) of the Lower Ord River as measured against a temporary gauge at House Roof Hill, indicating the "Before", "During" and "After" periods..

Water levels and flows during each period are indicated in Figure 2, with a drought flow of 35 m^3/s achieved for the three days, but with higher than normal flows occurring immediately before the shut down and after the KDD was reopened.

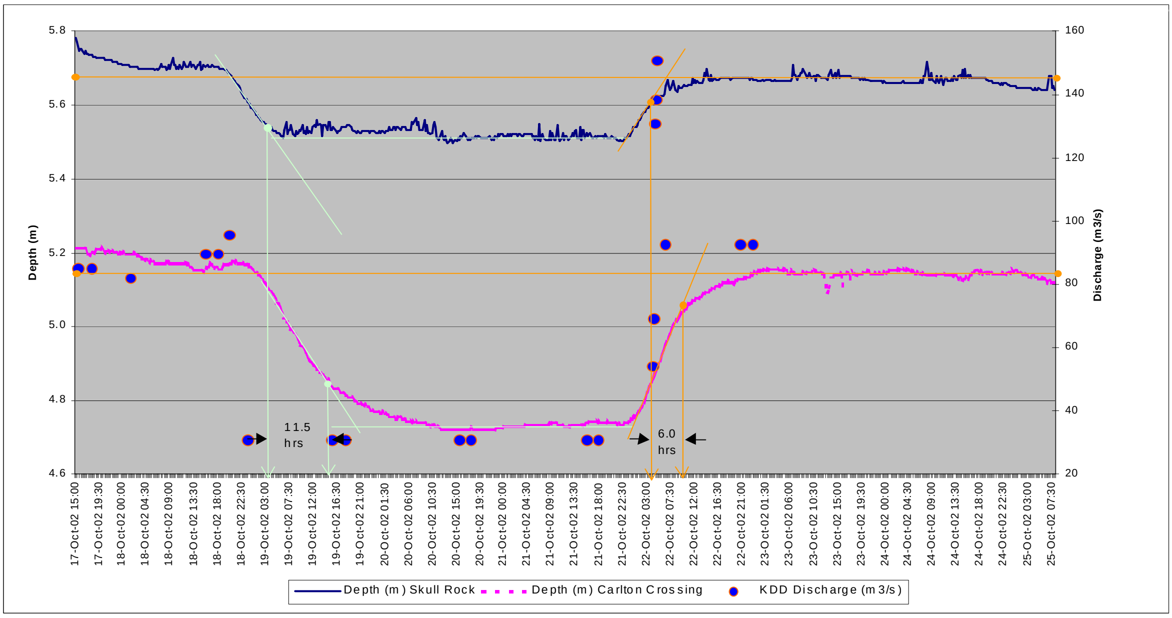

Figure 2. Changes in stage and discharge at various locations on the LOR during the drought trial, showing shutdown, decline in flows and levels and ensuing increases.

3.2 Habitat selection

To meet the objectives of this study, and given the time limitations, it was possible to undertake replicated sampling of three distinct habitat types. Habitats selected were those deemed most critical to fish populations (i.e. supported highest diversity and abundance) and which had the highest likelihood of being affected by changes in river flow/stage. The aim was to collect data that would detect any changes in the population structure of each fish species utilising each habitat and changes in the physical condition of these habitats under different river levels. From previous experience of the river system (A.W. Storey, unpub. dat.), ten dominant meso-habitats were identified:

- pools,
- gravel runs,
- turbulent rapids,
- shallow backwaters,
- deep backwaters,
- submerged macrophyte beds,
- emergent vegetation,
- snags/submerged woody debris
- flooded riparian vegetation and
- floodplain lagoons.

The quantity and distribution of these habitats changes seasonally. During late dry season, when the drought was to be trialed, the naturally lower river levels resulted in there being no deep backwaters and the riparian vegetation and floodplain lagoons were dry. Of the remaining habitats, gravel runs and rapids were likely to be affected by changes in flow, however, these habitats were more important for aquatic invertebrates and did not appear to be critical to fish populations (i.e. support low diversity and abundance, with resident species likely represented in other habitats; AW Storey, in prep). Snags, emergent vegetation, pools, shallow backwaters and submerged vegetation were regarded as critical habitats. The snags and emergent vegetation support similar fish to those found in pools, but were considered logistically more difficult to sample effectively. Therefore, pools, shallow backwaters and submerged macrophyte habitats were selected for sampling in this study. Pools comprised the slow-flowing, non-turbulent, deeper (> 2 m) reaches of the river and shallow backwaters consisted of small embayments and side channels off the main channel that were shallow (> 1 m), with low to zero flow (< 5 cm/sec). Submerged macrophyte habitat consisted of submerged beds of rooted, aquatic plants that were totally submerged. The dominant submerged macrophyte species was Ribbon weed, *Vallisnaria americanum*. Although other species of submerged macrophyte were present in small quantities, to standardise sampling of this habitat, only totally submerged weed beds of V. *americanum* were sampled.

3.3 Site selection

The initial design was to collect four replicate samples from each habitat before, during and after the reduction in flows, providing a balanced design with a total of 36 samples. Subsequently, the sampling method was modified so that additional replicates could be collected, with the aim of optimising the statistical power of the design. This would have provided 12 replicates of pool habitats and six replicates each of backwaters and macrophyte beds to be collected in each period (n = 72). However, the reduction in the length of the Before period resulted in an unbalanced design with 64 replicate samples collected (Table 1). Study sites were selected based on prior knowledge of the reach gained from previous studies of habitat use by fish in the LOR (AW Storey, unpub. dat.). The same pools were re-sampled in each period, however, because of the physical disturbance to macrophyte beds and shallow backwaters when sampled, which would likely affect the fish populations of these locations to such an extent that populations would not have recovered between flow periods, new, independent representative of these habitats were sampled on each occasion. The location of each site was recorded by GPS to allow accurate mapping. The location of replicate backwater, macrophyte and pool samples for each sampling period are indicated in Figures 3 – 5 respectively.

Table 1. Level of replication achieved within each habitat for the study of fish response to lowered Ord River flows

Reach	Pools	Submerged Macrophytes	Shallow Backwaters	**Total per regime**
Before flow reduction	8	4	3	**15**
During flow reduction	12	6	7	**25**
After flow reduction	12	6	6	**24**
Total per habitat	**32**	**16**	**16**	**64**

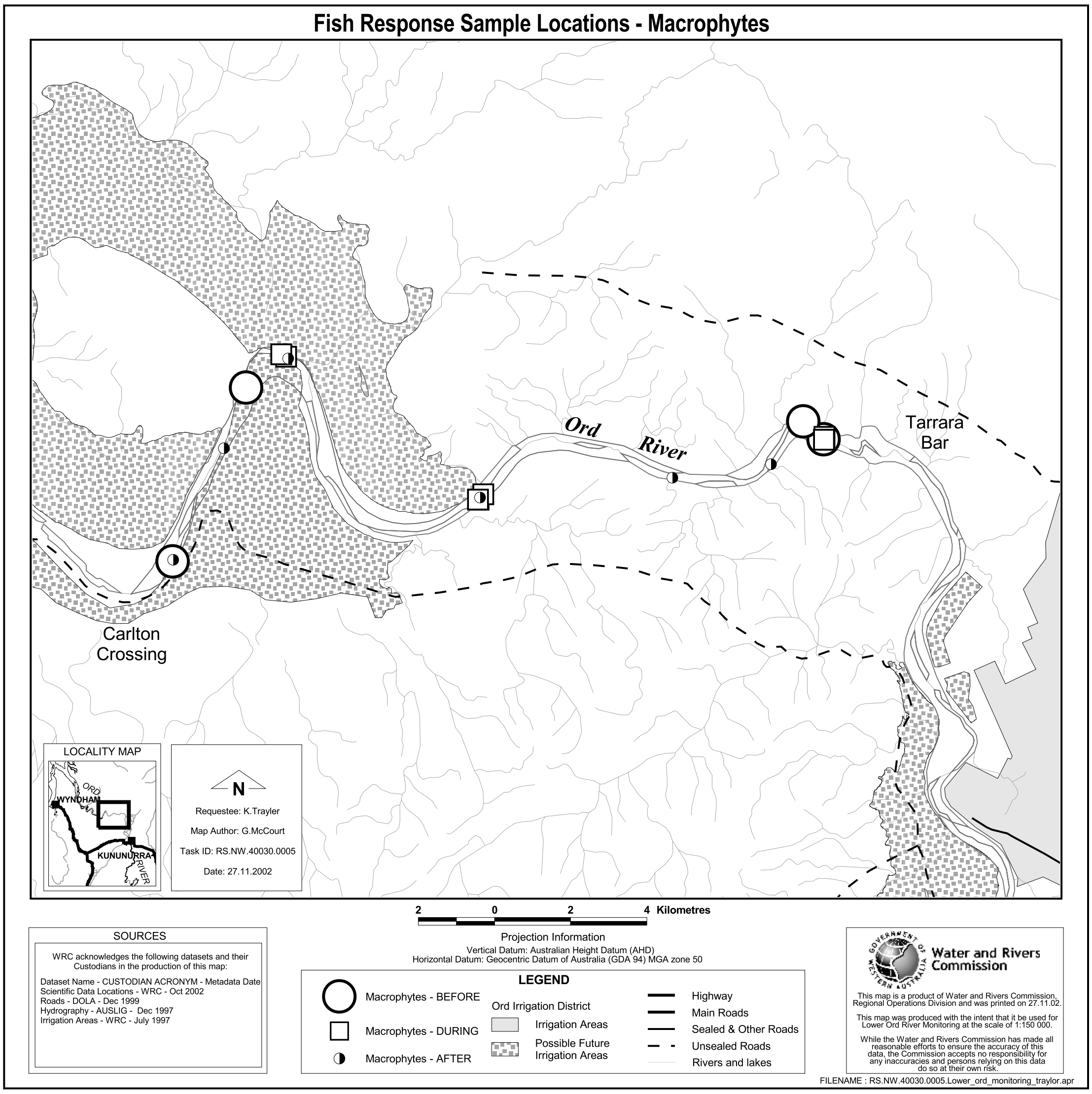

Figure 3. Location of macrophyte sites sampled before, during and after the drawdown trial

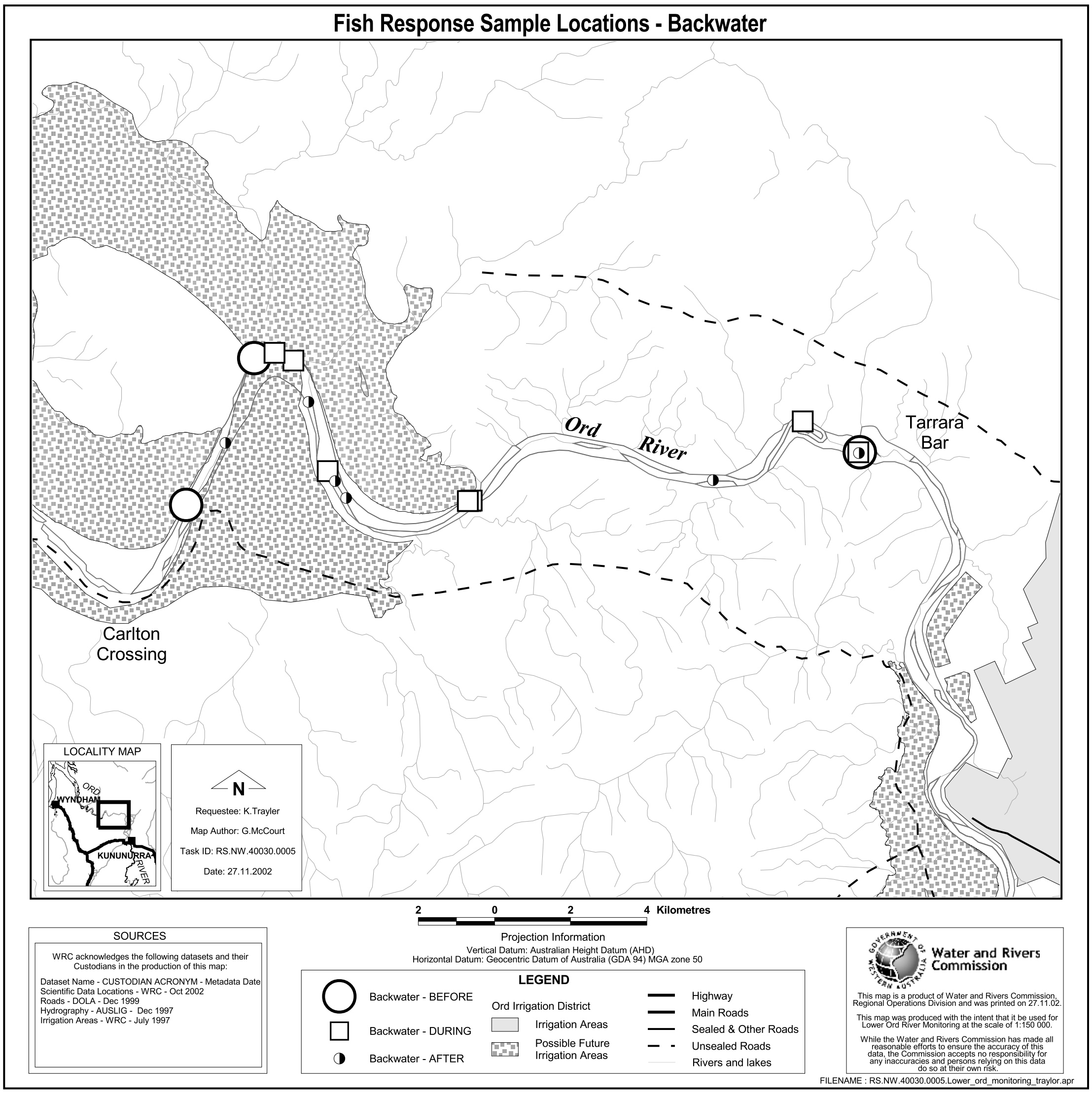

Figure 4. Location of backwater macrophyte sites sampled before, during and after the drawdown trial

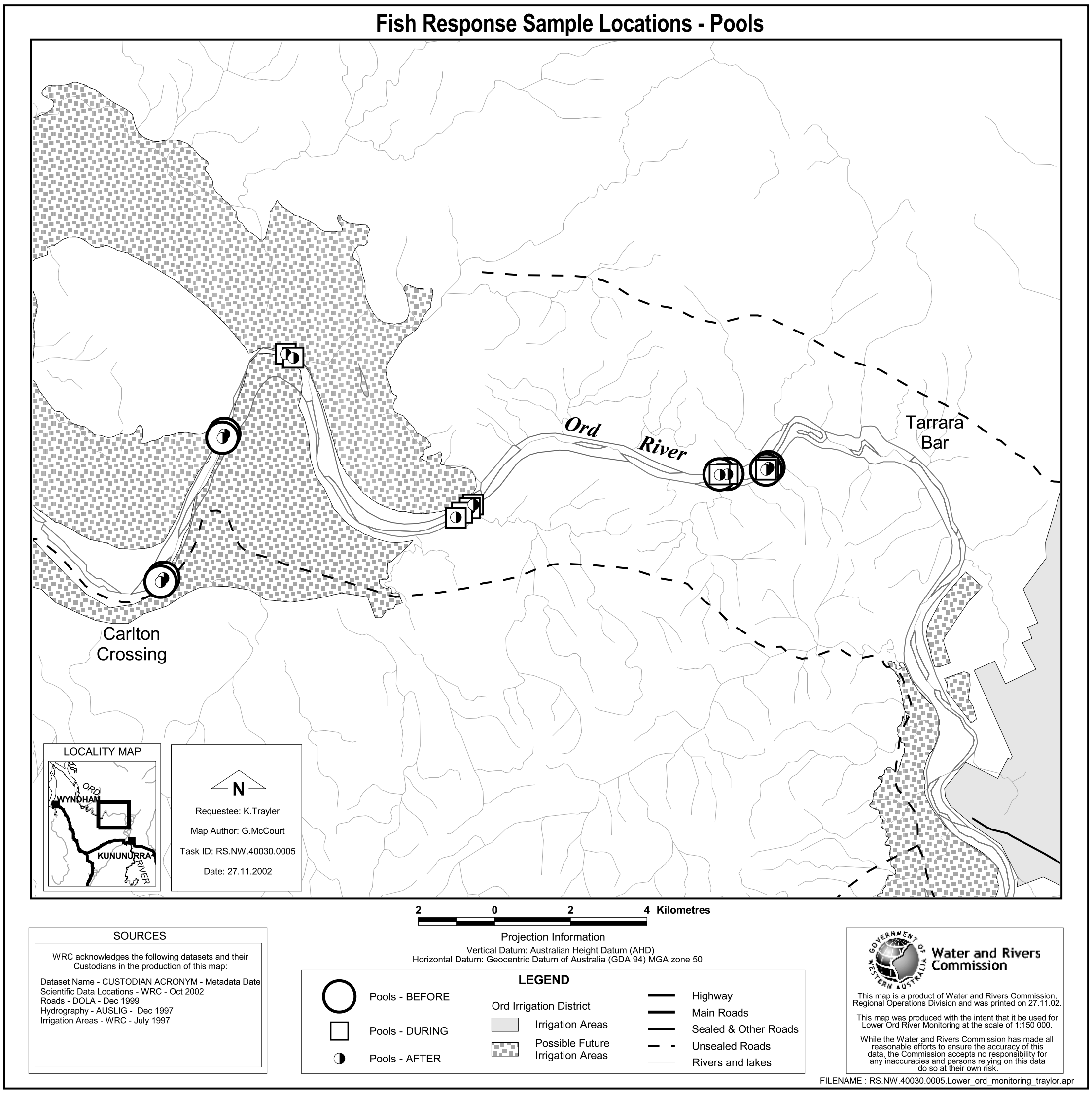

Figure 5. Location of pool sites sampled before, during and after the drawdown trial

3.4 Fish Fauna

Pool habitats were sampled using multi-panel gill nets (30 m nets consisting of six panels each of 5 m length, of increasing mesh size from 1" to 6" stretched mesh size), with total catch from a net treated as an individual replicate. Previous use of this technique has proven it effective in providing standard catch per unit effort (CPUE) data from a range of habitats in the Ord and adjacent rivers (Pentecost, Dunham and Keep; A.W. Storey, in prep.). The data provide standardised measures of species richness, abundance and biomass, from which community composition and population structure are easily derived.

Gill nets were set in pools (water depth > 2 m) for 3 hrs, with net sets commencing either in the morning (approx 0630 hrs) or from mid-day. At each site nets were set at 30 – 45 degree from the bank (depending upon strength of flow), with the smallest mesh size nearest the shore.

The shallow backwater habitat was sampled with a 20 m long x 1.5 m deep beach seine constructed from10 mm diamond mesh. The aim at each site was to deploy the net across the mouth of the backwater and draw the seine through the water body retaining all fish and prawns present. Macrophyte beds were sampled with a smaller beach seine (10 m long x 1 m deep, with 6 mm diamond mesh). In each instance, a macrophyte bed of approximately 3 x 3 m in area was selected and the small seine drawn through the bed and onto the adjacent shore and all fish and prawns retained.

All fish caught from each habitat were identified to species, weighed and standard length recorded before being released. Where large numbers of small species were taken, a random subsample of at least 10 specimens were individually weighed and measured, and the remainder counted and a total weight recorded.

3.5 Physico-chemical parameters

Physico-chemical parameters most likely to show a response to a change in flow regime were measured for each replicate sample (Table 2). Because individual backwaters and macrophyte beds were not re-sampled, a random selection of each was made and additional measurements taken before, during and after to record changes in the same waterbody across flow regimes. Within the shallow backwaters, fixed transects were pegged across the waterbody and depth recorded at regular intervals (every 0.5 m across small backwaters and 1.0 m in large backwaters) along the transect before, during and after the drawdown. These data were used to calculate percent change in wetted cross-sectional area in backwaters.

Prior to lowering water levels, all macrophyte beds were totally submerged (i.e. strands of the Ribbon weed were all underwater and did not break the surface). However, during the drawdown, the reduced water levels resulted in areas of ribbon weed beds either coming in contact with the surface (i.e. were still inundated, but in shallow water to the extent that the weed was in contact wit the surface) or were totally dry. To quantify this effect, previously totally submerged beds were selected and the aerial percentage of beds that were submerged, floating or totally exposed were recorded. In addition, water temperature, dissolved oxygen and pH were recorded from within submerged and floating parts of these beds to compare water quality between submerged and floating parts of the beds during the drawdown.

Table 2. Physico-chemical parameters measured for each replicate sample, giving names, abbreviations and units of measurement.

Parameter	Abbreviation	Unit
pH	pH	#
Conductivity	conductivity	us/cm
Salinity	salinity	mg/l
Turbidity	Turb	ntu
Temperature	temp	^{0}C
Mean velocity	veloM	cm/sec
Mean depth	depthM	m
Dissolved Oxygen	DO%	%
Oxygen Concentration	DOmg	mg/l

3.6 Analyses

All data, including taxonomic lists, physico-chemical measurements and GPS locations were entered onto Excel spreadsheet and archived for future reference.

One-way analysis of variance (ANOVA) was used to test the significance of changes in species richness, abundance and biomass of fish populations, and associated physico-chemical parameters between flow regimes. One-way ANOVA was also used by habitat type to test for differences in the abundance of each species between flow periods. Prior to analyses, normality and equality of sample variances were tested and appropriate transformations applied where necessary. Tukeys HSD multiple comparison test was then used a *posteriori* to locate between-regime differences where a significant main effect was observed.

The CSIRO Pattern Analysis Package PATN (Belbin, 1995) was used to investigate changes in species composition within each habitat over time. All replicate samples were ordinated using **S**emi-**S**trong **H**ybrid **M**ulti**d**imensional **S**caling (SSH MDS) to produce an n-dimensional scatter plot for each habitat. For each analysis, similarity between samples was determined using the Bray-Curtis association measure. *A priori* groupings (Before, During and After) were superimposed on the ordination plots to assess the distinctiveness of the separation of samples into flow regimes. To test the significance of the separation of samples grouped by flow regime in ordination space, the **An**alysis **o**f **Sim**ilarity ANOSIM option in PATN (Belbin, 1995) was used.

The wetted cross-sectional area of the selected backwaters was calculated for each flow period and the percent change from Before to During (i.e. loss in area), and from During to After (i.e. recovery in area) calculated. Changes in the degree of exposure of macrophyte beds was estimated (i.e. submerged, versus floating versus exposed), and finally, the significance of differences in water quality parameters between deep and shallow sections of macrophyte beds were tested using one-way ANOVA.

All analyses were supported by visual observations of the response of fish and other aquatic life to changes in flow regime in the selected habitats, and in other habitats within the river system but not selected for sampling under this study.

4 Results

4.1 Water Quality

The study was conducted under fine and hot conditions. Maximum daily air temperatures ranged from 40 – 44 ^{o}C, there was negligible cloud cover, light winds and no rainfall during the 10 day period. Within the water quality parameters, there were few significant differences between flow periods in backwaters, macrophyte beds or pools (Tables 3 – 5 respectively). Within backwaters there was a small but significant change in conductivity, with the After period (303 µs/cm) higher than the Before period (279 µs/cm)(Table 3).

Within macrophyte beds there were significant changes in turbidity and velocity over time (Table 4), with significantly higher levels of both before the shutdown than during or after. Although water levels (and velocities) were equivalent to or greater than pre-drawdown levels once the KDD was opened, the significantly lower velocities in the After period probably reflected the sampling regime, whereby post drawdown sampling targeted areas of macrophyte beds that had been exposed, and so were nearer the shore and so in lower velocity areas.

Table 3. Summary of one-way ANOVAs on physico-chemical parameters measured in backwaters in each flow period (Before, During & After). Tukeys HSD multiple comparison test was used to locate between-level differences for a significant main effect. A common line joins levels not significantly different at $p < 0.05$ and effects are in descending order. Arithmetic mean values are in parentheses.

Effect	df	F	p	Tukeys (HSD) Range Test		
Backwater Water Quality						
pH	2,13	0.06	ns	After (8.89)	During (8.85)	Before (8.78)
Conductivity (µs/cm)	2,13	4.11	0.0415	After (302.5)	During (292.9)	Before (278.7)
Turbidity (NTU)	2,13	1.27	ns	Before (24.6)	During (16.8)	After (12.8)
Temperature (^oC)	2,13	1.69	ns	After (31.9)	During (30.1)	Before (30.0)
Salinity (ppt)	2,13	1.22	ns	During (0.456)	Before (0.447)	After (0.445)
Velocity (cm/sec)	2,13	1.11	ns	Before (1.33)	After (0.85)	During (0.00)
DO (% saturation)	2,13	1.89	ns	Before (151.4)	During (128.0)	After (119.7)
DO (conc., mg/l)	2,13	3.18	ns	Before (7.1)	During (4.9)	After (4.4)

Table 4. Summary of one-way ANOVAs on physico-chemical parameters measured in macrophyte beds in each flow period (Before, During & After). Tukeys HSD multiple comparison test was used to locate between-level differences for a significant main effect. A common line joins levels not significantly different at $p < 0.05$ and effects are in descending order. Arithmetic mean values are in parentheses.

Effect	df	F	p	Tukeys (HSD) Range Test		
Macrophyte Bed Water Quality						
pH	2,13	0.89	ns	During (8.98)	Before (8.78)	After (8.75)
Conductivity (µs/cm)	2,13	2.24	ns	After (297.2)	During (293.7)	Before (286.8)
Turbidity (NTU)	2,13	8.06	0.0053	Before (30.8)	During (19.7)	After (15.5)
Temperature (^oC)	2,13	1.15	ns	During (31.2)	After (31.1)	Before (29.7)
Salinity (ppt)	2,13	0.76	ns	Before (0.453)	After (0.450)	During (0.443)
Velocity (cm/sec)	2,13	11.40	0.0005	Before (17.13)	After (1.42)	During (0.42)
DO (% saturation)	2,13	1.14	ns	During (137.0)	Before (126.1)	After (123.8)
DO (conc., mg/l)	2,13	1.54	ns	During (5.1)	Before (4.9)	After (4.6)

Within pools there were significant changes in conductivity, turbidity and dissolved oxygen (% saturation and concentration) (Table 5). As for backwaters, conductivity in pools showed a small but significant increase over time, with the before period lower than the after and during periods. Turbidity was again higher before than during or after the drawndown. This may reflect the flushing and re-suspension of fine particulates during the higher flows which occurred when Lake Kununurra was lowered. Dissolved oxygen levels showed a small, but significant trend of higher levels before than after the drawdown, with intermediate levels during the reduced flows. Mean levels ranged between 117% to 111%.

Table 5. Summary of one-way ANOVAs on physico-chemical parameters measured in pool in each flow period (Before, During & After). Tukeys HSD multiple comparison test was used to locate between-level differences for a significant main effect. A common line joins levels not significantly different at $p < 0.05$ and effects are in descending order. Arithmetic mean values are in parentheses.

Effect	df	F	p	Tukeys (HSD) Range Test		
Pool Water Quality						
pH	2,29	0.89	ns	Before (8.75)	After (8.73)	During (8.57)
Conductivity (µs/cm)	2,29	5.13	0.0124	After (299.3)	During (299.1)	Before (289.0)
Turbidity (NTU)	2,29	4.09	0.0274	Before (35.9)	After (16.7)	During (16.5)
Temperature (^{o}C)	2,29	1.07	ns	After (29.6)	During (29.2)	Before (29.1)
Salinity (ppt)	2,29	1.19	ns	During (0.460)	After (0.456)	Before (0.455)
Depth (m)	2,29	0.01	ns	During (3.14)	After (3.11)	Before (3.09)
Velocity (cm/sec)	2,29	0.47	ns	Before (17.33)	After (16.42)	During (14.03)
DO (% saturation)	2,29	3.65	0.0387	Before (117.2)	During (115.3)	After (110.9)
DO (conc., mg/l)	2,29	6.47	0.0047	Before (4.55)	During (4.47)	After (4.28)
Secchi (cms)	2,27	0.57	ns	After (188.9)	Before (177.9)	During (168.2)

4.2 Habitat Effects

4.2.1 Macrophyte beds

The drawdown had a pronounced effect on the condition of the submerged macrophyte beds in the river. Prior to the drawdown the macrophyte beds were all totally submerged, and there were only a few areas where there was strands of macrophyte in contact with the water surface. However, during the drawdown there were large areas of the macrophyte beds that became totally exposed (approx 37 %) (Plates 1 & 2), with approx 50% of the macrophyte beds left in shallow water where the macrophyte strands were floating, in contact with the water surface. This left approx 13% of the macrophyte beds still totally submerged, compared with 100% submerged before the drawdown (Figure 6).

Plates 1 & 2. Areas of previously submerged macrophyte bed left exposed or floating during the drawdown

Following the large changes in the state of previously submerged macrophyte beds, physico-chemical measurements were made in remaining submerged areas, as well as those areas now in shallow water and floating on the surface. Exposed sections of macrophyte beds dried-out very rapidly in the hot conditions, leaving a mat of dry, crisp macrophyte leaf material (Plates 3 & 4). Comparison of water quality in submerged areas and areas now floating detected significantly higher ($p < 0.05$) water temperature (34 ^{o}C versus 31 ^{o}C), pH (9.9 versus 9.2) and dissolved oxygen levels (186 % versus 150 % saturation) in the floating than the submerged area (Table 6 & Figure 7). These differences reflect the shallow and still nature of the water around the floating sections compared with the areas remaining submerged, where water was deeper and still flowing. This indicates a significant biological change in the condition of the macrophyte habitat with respect to areal extent and water quality. After water levels returned, macrophyte beds were re-inundated, but there were now large dead sections along the margins, indicating where the beds were exposed and had become desiccated (Plate 5).

Plate 3. A bed of *Vallisnaria americanum* during the drawdown, showing exposed (left), floating (central) and submerged (right) sections.

Plate 4. Healthy strands of ribbon weed, *Vallisnaria americanum* (top) compared with decaying macrophyte that was exposed for three days and then re-inundated (bottom)

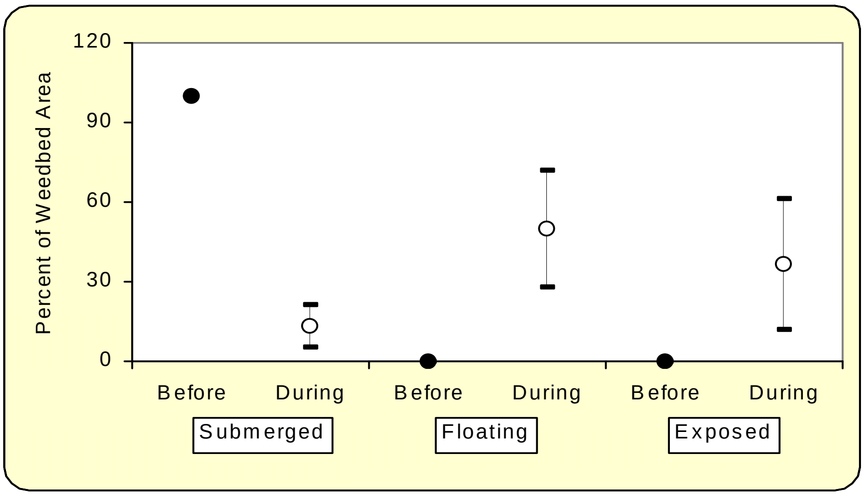

Figure 6. Changes in the state of macrophyte beds before and during drawdown, indicating mean (± 95% CI) area of each bed submerged, floating on the surface or totally exposed.

Table 6. Summary of one-way ANOVAs on physico-chemical parameters measured in submerged and floating regions of macrophyte beds during the drawdown. Tukeys HSD multiple comparison test was used to locate between-level differences for a significant main effect. Levels are in descending order and arithmetic mean values for each level are in parentheses.

Effect	df	F	p	Tukeys (HSD) Range Test		
Macrophyte Beds						
Water Temperature	1,4	8.92	0.0405	Floating (33.7)	>	Submerged (30.7)
pH	1,4	12.93	0.0228	Floating (9.86)	>	Submerged (9.19)
DO (% saturation)	1,4	9.26	0.0383	Floating (186.2)	>	Submerged (149.8)
DO (conc. mg/l)	1,4	4.19	ns	Floating (6.67)	=	Submerged (5.67)

Plate 5. A bed of *Vallisnaria americanum* that was re-inundated after the drawdown, showing the previously exposed area that has died off (right), and surviving, but stressed leaf material (left)

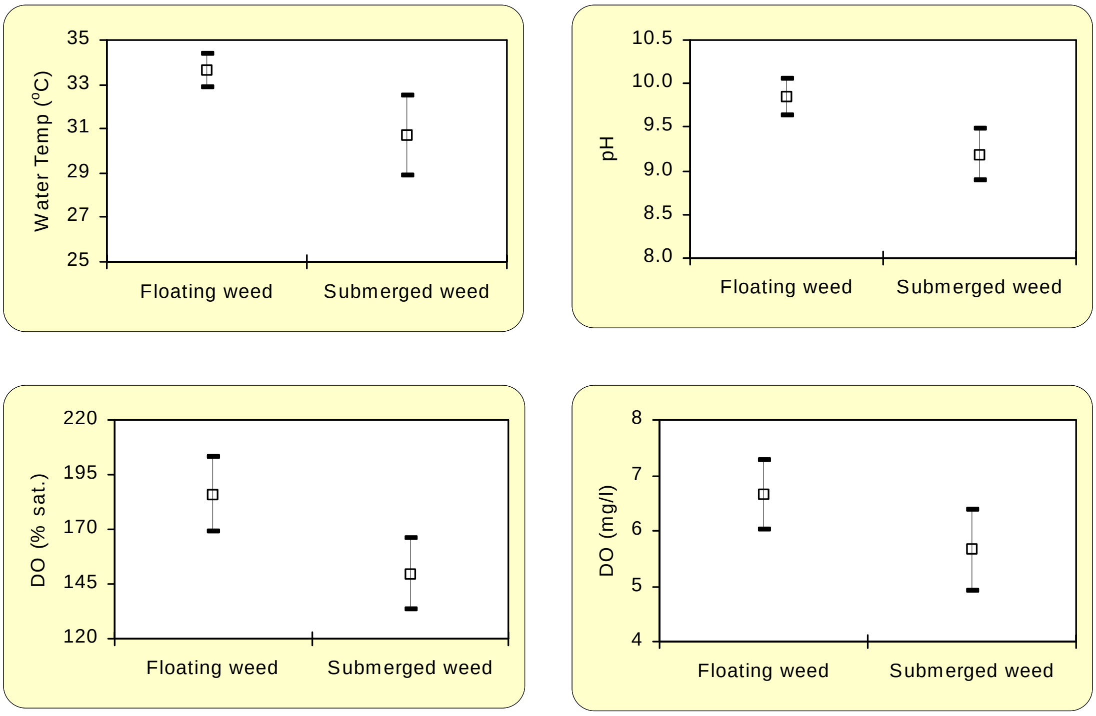

Figure 7. Differences in water quality between submerged and floating areas of macrophyte beds measured during the period of reduced water levels

4.2.2 Backwaters

Surveys of water depths along transects in backwaters indicated an 80% reduction in mean cross-sectional wetted area during the drawdown (Table 7, Figure 8), with some backwaters drying-out totally (i.e. Backwater # 1 – downstream end) (Plates 6 & 7), or being reduced to a very shallow water body, much reduced in area (i.e. Backwater #1 –

upstream, Backwater #2 – upstream) (Figure 8) (Plates 8 & 9). Following return of water levels, the areal extent of the backwaters being monitored had returned to levels observed before the drawdown. These analyses indicated a large effect on the functional status of backwaters in the reach surveyed.

Table 7. Mean (+ 1 SE) percentage change ("-" = decrease, "+" = increase) in wetted cross-sectional area of backwaters from the before to the during period, and the during to the after period.

	Before compared with During	During compared with After
Mean	- 78.5 %	+ 78.5 %
1 SE	5.5	6.2
No.	8	8

Plates 6 & 7. A shallow backwater (Site # 1 in Figure 8) before (left) and during (right) the drawdown showing extent of drying-out

Plates 8 & 9. A medium-depth backwater (Site # 3 in Figure 8) before (left) and during (right) the drawdown showing extent of drying-out.

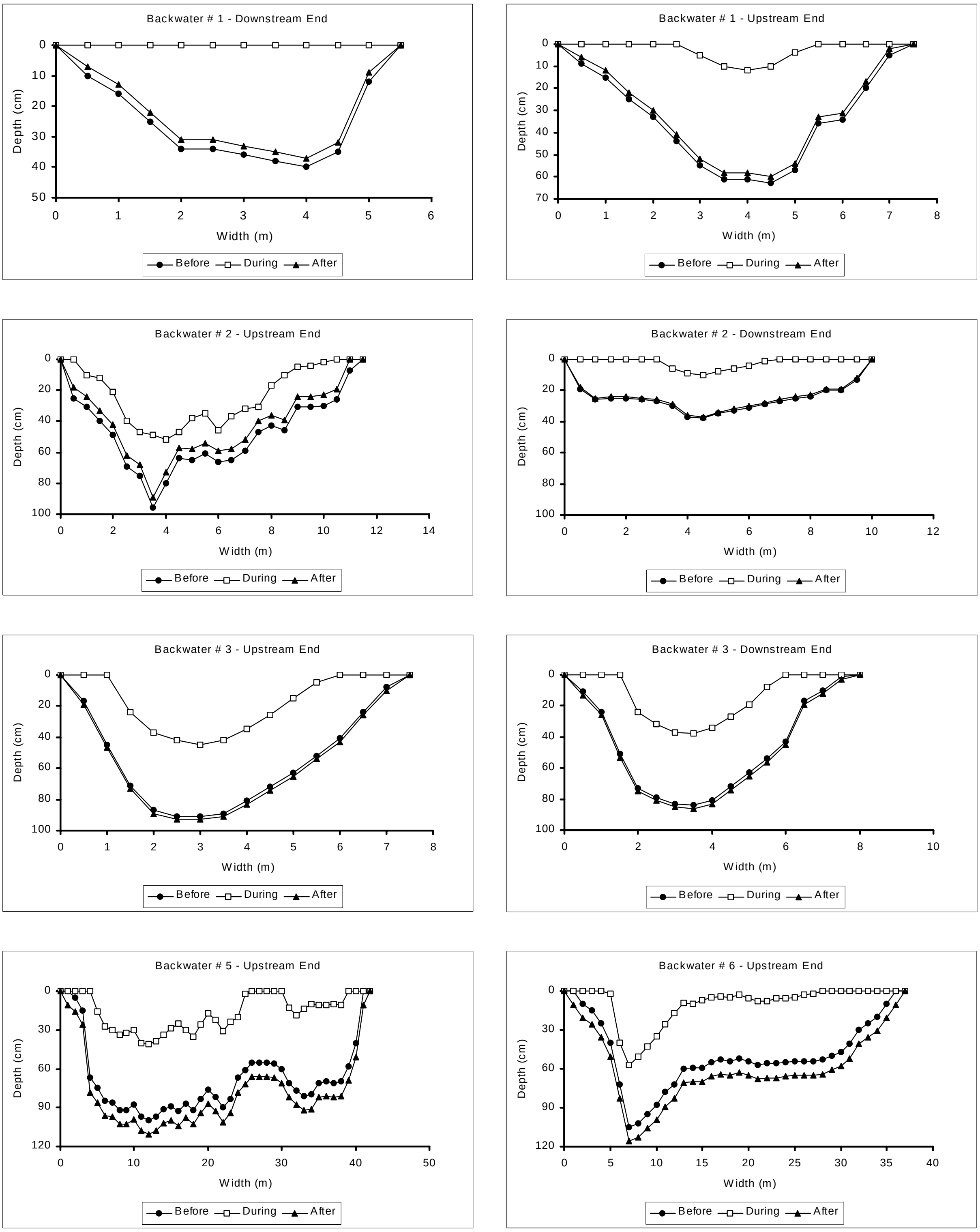

Figure 8. Water depths (cms) along transects across randomly selected backwaters before, during and after the drawdown, as a basis for calculating changes in wetted cross-sectional areas.

4.3 Fauna Effects

4.3.1 Macrobrachium prawns

The number and weight of *Macrobrachium* prawns caught in seine net samples from macrophyte beds and backwaters were recorded. For the purposes of this study the two commonly encountered species of *Macrobrachium* prawn that occur in the system (*M. rosenbergii* & *M. bullatum*) were combined due to the labour intensive nature of separating to species level.

Within macrophyte beds there was a very significant effect of the drawdown on abundance and biomass of prawns. Significantly higher numbers were recorded in beds before (mean = 65) and during (mean = 25) the drawdown than after (mean = 2), and greatest biomass was recorded from macrophyte beds before the drawdown (mean = 21 g), with significantly lower biomass recorded during (mean = 5 g) and after (mean = 1 g) the drawdown (Table 8, Figure 9). Within backwaters there were no significant effects of the drawdown on abundance or biomass of prawns, with few prawns taken from this habitat (Table 8).

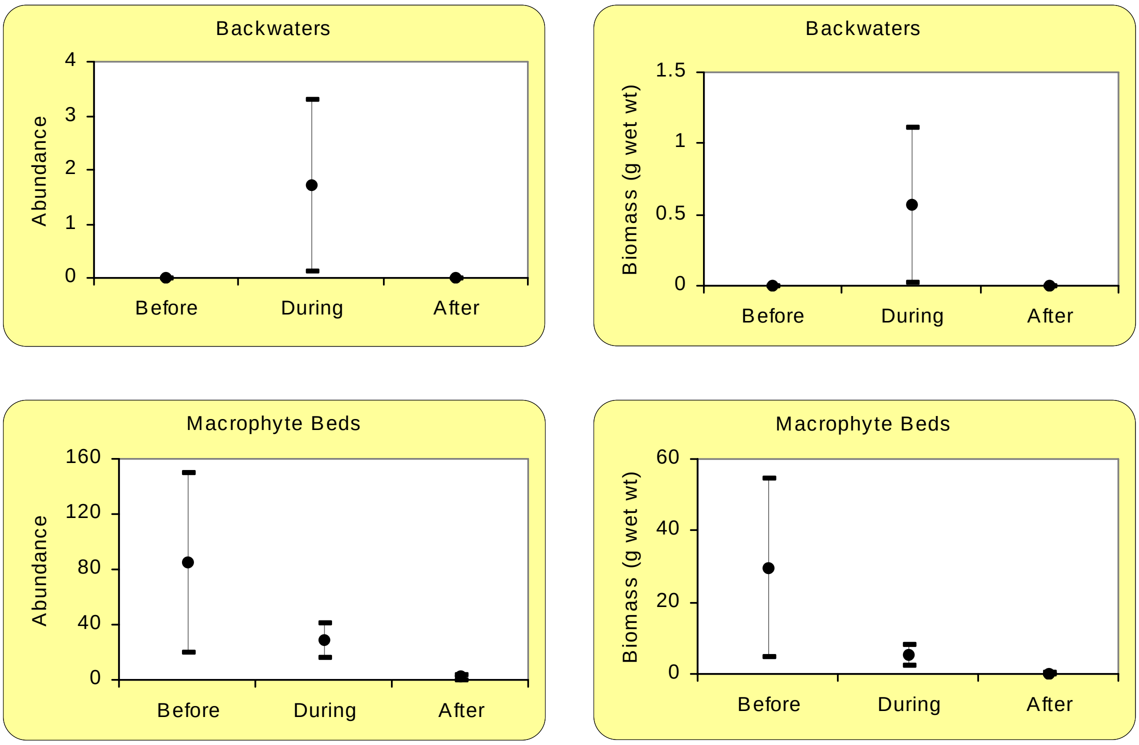

Figure 9. Changes in mean (± 95% CI) abundance and biomass of *Macrobrachium* prawns in macrophyte beds and backwaters before, during and after changes in water levels

Table 8. Summary of one-way ANOVAs on abundance and biomass (g) of *Macrobrachium* prawns sampled from macrophyte beds and from backwaters before, during and after the drawdown. Tukeys HSD multiple comparison test was used to locate between-level differences for a significant main effect. Levels are in descending order and arithmetic mean values for each level are in parentheses (geometric means for transformed data).

Effect	df	F	p	Tukeys (HSD) Range Test		
Macrophyte Beds						
Abundance (log10)	2,13	23.77	<0.0001	Before (64.6)	During (25.1)	After (2.3)
Biomass (log10) (g)	2,13	22.36	<0.0001	Before (20.9)	During (5.3)	After (1.1)
Backwaters						
Abundance	2,13	2.74	ns	During (1.71)	Before (0.00)	After (0.00)
Biomass	2,13	2.60	ns	During (0.57)	Before (0.00)	After (0.00)

4.3.2 Fish fauna

Analysis of fish community descriptors by habitat type detected only one significant effect from the drawdown, with species richness in macrophyte beds higher during the drawdown (mean = 3.8) than after (mean = 1.7), with intermediate levels before the drawdown (mean = 2.3) (Table 9; Figure 10). Catches tended to be variable which precluded some apparent trends from being significant (i.e. abundance and biomass in macrophyte beds, abundance and biomass in pools; Table 9, Figure 10).

Table 9. Summary of one-way ANOVAs on fish community descriptors (abundance, biomass and species richness) for macrophyte beds, backwaters and pool habitats before, during and after the drawdown. Tukeys HSD multiple comparison test was used to locate between-level differences for a significant main effect. Levels are in descending order and arithmetic mean values for each level are in parentheses.

Effect	df	F	p	Tukeys (HSD) Range Test		
Macrophyte Beds						
Abundance	2,13	2.50	ns	During (84.2)	After (32.2)	Before (16.0)
Biomass (g)	2,13	1.69	ns	Before (112.9)	During (26.7)	After (8.8)
Richness	2,13	5.70	0.0167	During (3.8)	Before (2.3)	After (1.7)
Backwaters						
Abundance	2,13	0.02	ns	Before (50.3)	During (47.6)	After (44.2)
Biomass (g)	2,13	3.35	ns	Before (404.7)	After (89.9)	During (80.0)
Richness	2,13	0.16	ns	During (4.5)	Before (4.0)	After (4.0)
Pools						
Abundance	2,29	1.01	ns	Before (18.6)	After (15.8)	During (13.3)
Biomass (g)	2,29	0.51	ns	Before (7765)	After (7370)	During (5867)
Richness	2,29	2.47	ns	During (4.8)	Before (4.6)	After (3.3)

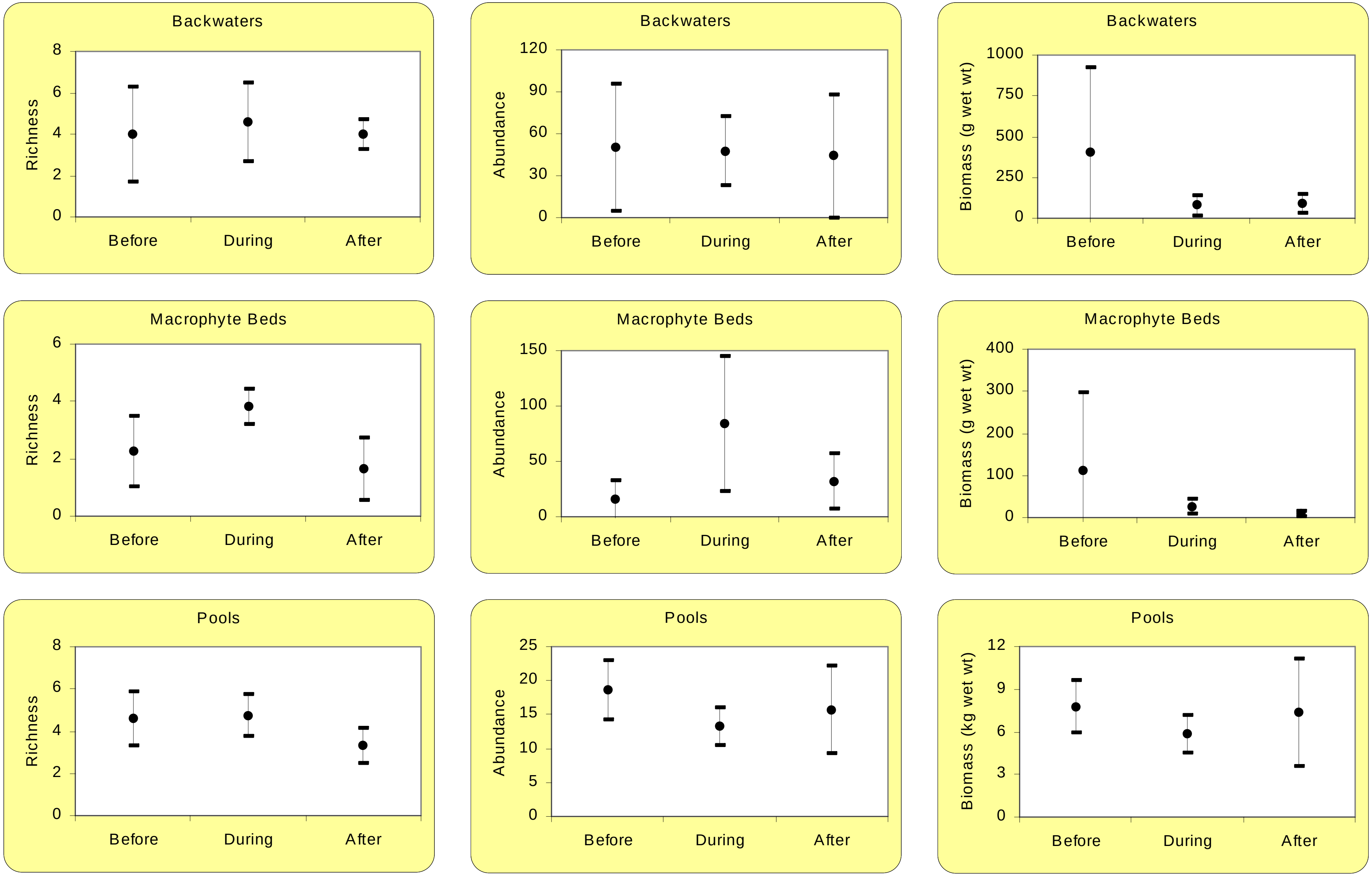

Figure 10. Changes in mean (± 95% CI) richness, abundance and biomass of fish in macrophyte beds, backwaters and pools before, during and after changes in water level.

Within each habitat type, one-way ANOVA was used to test for significant changes in the abundance of each species of fish between the different flow regimes. A total of 13, 11 and 13 species of fish were recorded from backwaters, macrophyte beds and pool habitats respectively (Table 10).

Table 10. Mean abundance of each species of fish in each habitat, giving total number of species taken from each habitat.

SPECIES	Backwaters	Macrophyte bed	Pools
Ambassis spp	35.1	6.0	0
Amniataba percoides	7.5	4.6	1.7
Arius graeffei	0	0	3.4
Arius midgleyi	0	0	1.9
Craterocephalus stramineus	8.0	1.0	1.0
Glossamia aprion	2.8	3.7	0
Glossogobius giuris	3.2	2.5	0
Hephaestus jenkinsi	2.0	0	1.5
Hypseleotris compressa	17.3	65.9	0
Lates calcarifer	0	0	1.5
Leiognathus equulus	7.5	3.0	1.0
Leiopotherapon unicolor	1.5	0	0
Liza alata	4.0	0	8.0
Megalops cyprinoides	0	0	1.3
Melanotaenia splendida australis	10.3	4.5	0
Nematalosa erebi	2.0	40.0	3.5
Neosilurus hyrtlii	0	1.0	0
Scatophagus argus	0	0	1.0
Strongylura krefftii	1.3	1.0	1.0
Syncomistes butleri	0	0	2.0
Number species per habitat	13	11	13

In backwater habitat there were no significant differences in the abundance of any species across flow regimes (Table 11.). In macrophyte beds there were significant differences in the abundance of Barred grunter, Mouth almighty and Empire gudgeon across flow periods. For the Barred grunter there were higher densities during the drawdown (mean = 5.2) than after (mean = 0.6), with intermediate levels before the drawdown (mean = 1.6). For the Mouth almighty there were higher densities during the drawdown (mean = 2.0) than before (mean = 0), with intermediate levels after the drawdown (mean = 0.2)(Table 11). Similarly, the Empire gudgeon had higher densities during the drawdown (mean = 38.2) than before (mean = 0), with intermediate levels after the drawdown (mean = 9.5)(Table 11). In pools the Bony bream was the only species to show a significant difference in abundance across flow regimes, with higher densities before (mean = 4.4) than during the drawdown (mean = 1.3), with intermediate levels after the drawdown (mean = 2.0)(Table 11).

Table 11. Summary of one-way ANOVAs on changes in abundance of individual fish species in each habitat (macrophyte beds, backwaters and pool habitats) before, during and after the drawdown. Only species that showed a significant effect are listed. Data were $\log_{10}(x+1)$ transformed prior to analysis. Tukeys HSD multiple comparison test was used to locate between-level differences for a significant main effect. Levels are in descending order and geometric mean values for each level are in parentheses.

Effect	df	F	p	Tukeys (HSD) Range Test		
Macrophyte Beds						
Amniataba percoides (Barred grunter)	2,12	5.47	0.0205	During (5.2)	Before (1.6)	After (0.6)
Glossamia aprion (Mouth almighty)	2,12	4.42	0.0364	During (2.0)	After (0.2)	Before (0.0)
Hypseleotris compressa (Empire gudgeon)	2,12	7.11	0.0092	During (38.2)	After (9.5)	Before (0.0)
Pools						
Nematalosa erebi (bony bream)	2,28	4.53	0.0198	Before (4.4)	After (2.0)	During (1.3)

Changes in fish community structure within each habitat were assessed by the ordination of fish abundance data for all samples using Multi-Dimensional Scaling, grouping samples into flow periods and then testing for significant separation of groupings in ordination space using ANOSIM.

Ordination of samples from backwaters had an optimum solution with two dimensions and a stress of 0.136 (NB stress < 0.15 is considered acceptable; Belbin, 1995), however, there was no separation of flow periods in ordination space (ANOSIM > 0.05; Figure 10). Ordination of samples from macrophyte beds (optimum solution with two dimensions and a stress of 0.059) showed a significant separation of flow periods in ordination space (ANOSIM, p < 0.0001), with the After period separating from the Before and During periods, with the latter periods overlapping (Figure 11).

Ordination of samples from pool habitat (optimum solution with three dimensions and a stress of 0.135) failed to show any separation of flow periods in ordination space (ANOSIM > 0.05) (Figure 12).

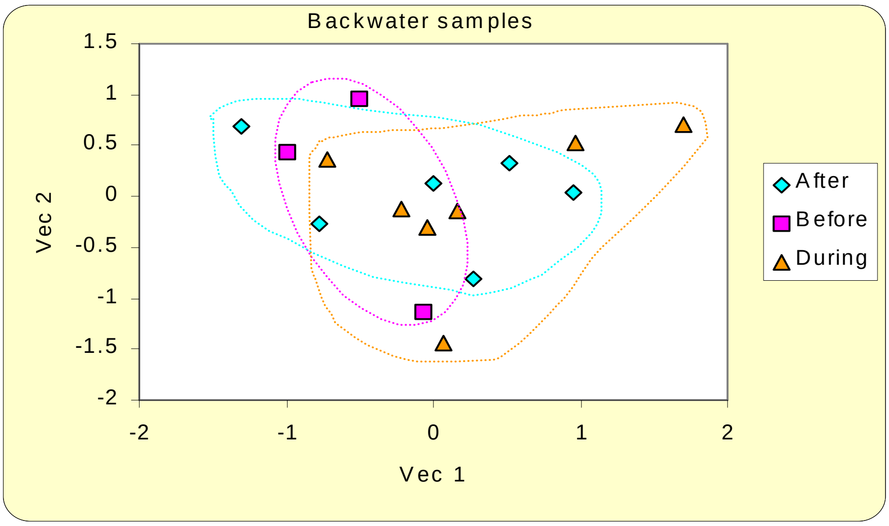

Figure 10. Multidimensional scaling of fish community data for macrophyte habitat, grouping sites by flow periods (Before, During and After drawdown)

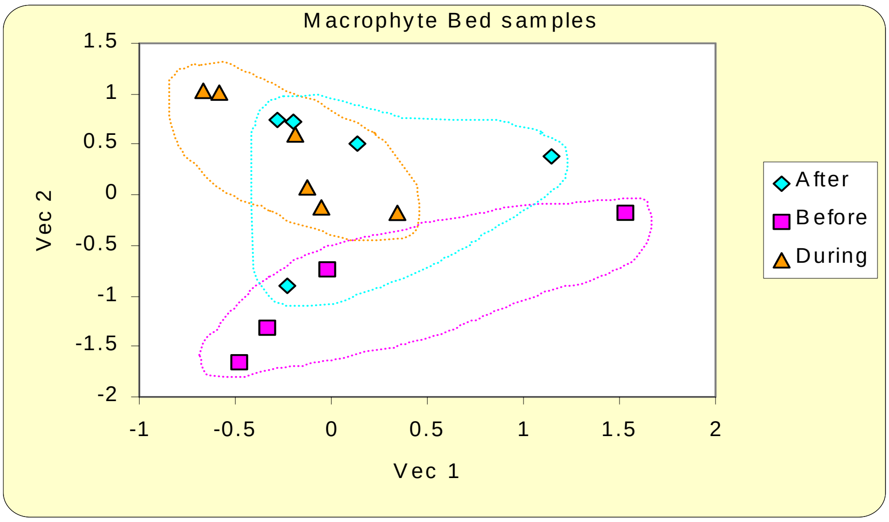

Figure 11. Multidimensional scaling of fish community data for backwater habitat, grouping sites by flow periods (Before, During and After drawdown)

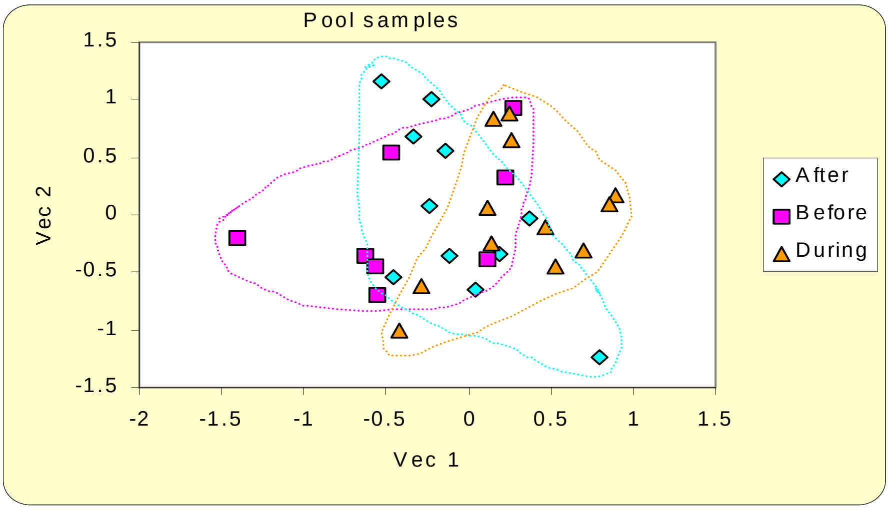

Figure 12. Multidimensional scaling of fish community data for pool habitat, grouping sites by flow periods (Before, During and After drawdown)

5 Discussion

5.1 Macrophyte Beds

During the drawdown period, the greatest changes in water quality were measured within macrophyte beds, where temperature, pH and dissolved oxygen (%) levels were significantly higher in previously submerged but now floating compared with areas still submerged. The effect reflects the shallow, low velocity nature of the water within the floating sections and indicates a significant change in the condition of this part of the previously submerged macrophyte habitat. The long term response/survival of these floating sections of the previously submerged macrophyte beds is not know. It is possible that these sections will die-off because of the higher water temperatures and direct exposure to the sun (i.e. leaf material floating on the water surface); after only three days exposure, the floating strands appeared in poorer condition than areas remaining submerged. Similarly, the suitability of these ‘hotter’ areas of macrophyte bed for aquatic fauna (fish and invertebrates) is not known as the tolerances and responses of fauna to the altered physico-chemistry is unknown.

Studies on habitat preferences of aquatic macroinvertebrates and fish in the LOR (Storey, 2002, in prep) have indicated that macrophyte beds are the preferred habitats for several small species of fish (i.e. Mouth almighty and Empire gudgeon) and for immature and smaller species of *Macrobrachium* prawns (Storey, in prep). Prior to the first recent big wet season flows in 1999, there were extensive macrophyte beds along much of the lower Ord River (AW Storey, pers obs), and these beds likely supported a large biomass of fish and prawns. Oral accounts from local fisherpersons confirmed that these areas supported large populations of “bait fish” and also that the narrow channels between the macrophyte beds were a good location to catch barramundi with rod and line. It was reported that the barramundi, which tend to be ambush predators would sit in the channels between macrophyte beds in wait of prey drifting between macrophyte beds.

During the first sizeable flood in the lower Ord River in approx 20 yrs, in March 2000, nearly all macrophyte beds (and the fine silt accumulations, which tend to support the macrophyte beds) were washed from the system, dramatically reducing the area of this habitat. Local accounts, supported by personal observations (AW Storey) suggest that whilst macrophyte beds were lost, there was an increase in the quantity and quality of snag habitat (inundated large woody debris), with new snags entering the system from bank slumping and old snags being uncovered as silt was removed. Snags are a good habitat for barramundi, and after the loss of macrophyte beds, the snags became the preferred location for catching barramundi with rod and line.

Throughout 2000, 2001 and early 2002 there was little macrophyte present in the system, with successive large wet season flows in early 2001 and early 2002 appearing to restrict recolonisation. It was not until late 2002 that extensive areas of ribbon weed (*Vallisnaria americanum*) started to re-establish. This temporal sequence indicates that macrophyte beds, once removed may take several seasons to regrow. Although barramundi had an alternative habitat (snags), there did not seem to be an alternative habitat for small prey fish species (AWS, pers obs.). Anecdotal evidence from 2002 suggests there was a reduction in the availability of “bait fish” in the lower Ord, which would support the contention that there was a reduced carrying capacity for small fish species in the system.

During the three days of the drawdown, the exposed portions of macrophyte beds rapidly dehydrated and leaf mass died off. Within three days of re-inundation, the dead leaf material had started to rot and disintegrate, however green shoots were evident, coming through the decomposing weed mats. Presumably the roots of the ribbon weed had managed to stay damp and survive the three days exposure and it is likely the plants subsequently recovered. An actual drought would likely last for weeks to months, and it may be assumed that root material would not survive such an extended period out of water. Therefore, an extended drought flow would likely lead to a substantial reduction in the area of macrophyte beds. The lag in the recovery of macrophyte beds following the March 2000 floods indicates that a similar lag may occur following an extended (weeks to months) drought flow, whereby large areas of macrophyte beds are lost, with recovery taking at least until the next dry season.

The current study implemented a drawdown from a relatively high dry season flow of approx. 80 m^3/sec to the trial drought flow of 35 m^3/sec. In reality, it is anticipated that under a Stage II development, a revised flow regime for the LOR would see a lower baseline dry season flow of 45/40m^3/s. Therefore, a drought strategy flow of 35 m^3/sec would likely see a proportionally lower reduction in water levels. This in turn would likely have a lower impact on area of macrophyte and the changes observed during the current study are likely greater than would be anticipated.

As stated above, the macrophyte beds are a dominant habitat for prawns, which likely form a sign component of the diet of many fish and likely are an important component of the food web. Prawns are used as bait by recreational fisherpersons on the LOR to catch barramundi, and *Macrobrachium* prawns were shown to be extremely important in the diet of comparable species of fish in the Fly River in Papua New Guinea (i.e. Ariid catfish, grunters and barramundi, Storey *et al.* 2001).

Data suggest that the drawdown affected the abundance and biomass of prawns in macrophyte beds. From observations it appeared that prawns preferred macrophyte beds in deeper, higher velocity water. The reduction in flows likely pushed prawns into macrophyte beds in previously deeper parts of the system (and which were more difficult to sample). Following the resumption of flows, there was no recolonisation of the impacted macrophyte beds along the margins presumably because the suitability of this habitat was affected by the reduced flow period.

This infers that the system had a reduced carrying capacity for prawns assuming numbers before the shutdown were at equilibrium between habitat availability and predatory pressure. Any initial increase in density in deeper areas would be counter-balanced by greater predation over time, and overall, there would likely be a reduction in population size of prawns.

Fish communities of macrophyte beds probably responded similarly, as indicated by a significant reduction in species richness after the drawdown compared with before and during. Sampling of macrophyte beds by necessity targeted those beds along the shallow margins (i.e. < 1 m deep), as these areas could be sampled effectively given the threat from crocodile attack and the difficulty of pulling a fine mesh seine through dense macrophyte beds in deep water. Therefore, after the drawdown, sampling was again limited to the margins, but which now were significantly modified and which supported fewer species. The Mouth almighty and Empire gudgeon previously were common in healthy macrophyte beds along the margins. During the drawdown the abundance of these species actually increased, most likely due to concentration effects as much of the macrophyte beds were exposed. But after the drawdown these species were not present in the modified areas of macrophyte beds. Logic assumes that the abundance of these species would increase in the remaining healthy portions of macrophyte beds (as observed during the drawdown), but predatory pressure would reduce numbers back to pre-drawdown densities, thereby resulting in a reduced overall population size (*viz*. reduced system carrying capacity for the affected species).

Therefore, an extended drought flow would likely lead to a reduction in area of macrophyte beds, with a concomitant reduction in abundance/biomass of prawns and small fish species. The implications for the overall fishery are hard to predict, but a reduction in habitat area and prey abundance will likely flow-on to manifest as a reduction in top predators at some point in the future.

5.2 Backwaters

Within backwaters there was a significant trend of increasing conductivity with time. This may reflect evapoconcentration during the low flow period within this habitat, which typically has low water velocity, and is shallow with a large surface area to volume ratio. The effect may have been accentuated by the high ambient air temperatures at the time (40 – 44 ^{o}C). Although statistically significant, the change was minor and probably would have little biological significance. However, given that this response occurred quite rapidly (i.e. within three days), a continued drought flow throughout the dry season could cause continued evapoconcentration, and biologically significant changes in conductivity.

Data and observations from this study indicated a large reduction in the size of the backwaters monitored, with approximately an 80% loss in wetted cross-sectional area. These estimates were based on the comparison of cross-sectional area before versus during the drawdown. On one hand, the estimates could be regarded as slightly high since river levels prior to the drawdown were higher than “normal” late dry season flows due to the water level in Lake Kununurra being lowered. However, on the other hand, the ecological effect of the change was probably greater as many backwaters were reduced in depth to such an extent (i.e. large areas < 20 cms deep), that functionally they would have been of little value as habitat to fish during the draw down.

As discussed above, the dry season flows during a revised allocation plan for the LOR (45/40 m^3/sec) would be lower, and therefore, the proportional loss in area of backwater habitats likely would be less if a drought flow of 35 m^3/sec were implemented (i.e. a decline of ~ 5 – 10 m^3/sec compared with the 45 m^3/sec decline observed in the current study). However, at this stage it is not know how the backwater habitat would be distributed under the lower dry season flow of 45/40 m^3/sec, and therefore it is not possible to accurately predict the effects of a drought flow on this habitat.

Although it was anticipated that the reduction in water levels would result in the loss of those backwaters which were functional before water levels were reduced, it was anticipated that this loss would be compensated by the formation of new backwater habitat at the lower stage. However, surprisingly this did not occur, with few new backwaters appearing under the lowered flows. Although not quantified, overall there appeared to be a large and significant reduction in the total area of functional backwaters under the reduced flow regime. The loss of backwaters was also accompanied by a loss of connectivity between the main channel and tributaries. Although none of the tributaries were flowing, their mouths effectively acted as long, shallow backwaters, with water from the main channel penetrating tens to hundreds of metres up the mouth of the tributaries. However, during the drought flow, all tributaries that had been connected became cut-off by sand bars across the channel mouth (Plates 10 – 13). Although water bodies remained behind the sandbars, these were small, shallow, probably had deteriorating water quality, would have been susceptible to heavy predator pressure (i.e. from herons/egrets and freshwater crocodiles), and likely would dry out over an extended period. The loss of backwater and side channel habitat at the same critical river height suggests that these habitats were formed as a result of hydrogeomorphological processes that occur at specific discharges. For instance, the AHD of the bed of the tributaries as they enter the main channel (i.e. the elevation of the thalweg of the tributaries) likely indicates a balance between late wet season flows in the main channel and the sediment transport / erosional ability of late wet season flows down the tributaries, with the mouth of most tributaries being at the same elevation. Whatever the hydrogeomorphological process responsible, it was apparent that the reduction in water levels had a very large effect on the area of this habitat.

Plates 10 – 13. The mouth of two creeks before (top, left & right) and during (bottom left & right) the drawdown, showing loss of connectivity with the main channel.

A study of habitat preferences of fish in the LOR (Storey in prep) has indicated that the shallow backwater habitats (including the mouths of tributaries) are the preferred habitats for many small bodied species of fish (i.e. Glassfish, Rainbow fish) and for juvenile stages of larger species (i.e. Bony bream, Mullet), providing shallow habitat where they can avoid larger, deeper-bodied predators. The loss of this habitat will likely result in increased predatory pressure on individuals displaced into deeper water, with likely flow-on effects to the population size of small-bodied species and cohort strength of young-of-the-year juveniles. Loss of young-of-the-year for a species will flow on to a decline in population size as this cohort reaches maturity.

5.3 Pools

Conductivity in pool habitat exhibited a response similar to that observed in backwaters, and the same mechanism and argument apply. Turbidity also showed a response in pools, most likely reflecting changes in discharge between flow periods, with higher flows leading to re-suspension of fine particulate matter and so increasing turbidity. Dissolved oxygen levels also showed a significant trend of higher levels before than after the drawdown. There is no definitive explanation for this trend, but it could indicate minor depletion of oxygen levels during the drawdown (i.e. stratification of pools), followed by a flushing of this "depleted" water once flows resumed. The reduction in the areal extent of submerged macrophyte beds during and after the drawdown (at least 37 % reduction in area of macrophyte beds, with a greater area exhibiting stress), would undoubtedly reduce the photosynthetic contribution to the reach and this also could account for a minor reduction in daytime spot measurements in oxygen levels. The observed depletion was minor, with mean levels ranging between 117% and 111%, however, given that this response occurred quite rapidly (i.e. was apparent over a three day reduction in flow), a continued drought flow throughout the dry season could lead to greater depletion, possibly resulting in biologically significant changes in dissolved oxygen.

Within the pool habitats, apart from the changes to water quality mentioned above, there were few obvious physical changes evident. This probably relates to the large areal extent of pools and their inherent variability in size and depth. On theoretical grounds the approx. 50 cm reduction in water levels across all pool habitat would have reduced their depth and, by inference, their carrying capacity for fish. The change in depth would also have increased predatory pressure on resident species, increasing densities and forcing species preferring deeper water into shallower areas.

However, there were no detectable changes in richness, abundance or biomass of fish between flow periods, with the only statistical effect being a reduction in numbers of Bony bream caught during the drawdown period. The absence of significant effects partly reflects the variable nature of fish catches, but also the short exposure period for the trial, with little time for communities to respond. For instance, it would be unlikely to observe a change in species richness over a three day period, as you are unlikely to loose species from the whole system. It may be hypothesised that reduced depths would concentrate fish and therefore increases in abundance and biomass could be expected during the drawdown. However, this assumes that a.) fish behaviour was not altered, and b.) the effect was sufficiently great as to be detected statistically.

Little is known of the response of fish species inhabiting the LOR to a reduction in flows/depth, but a possible response is that fish will actually reduce their mobility/swimming activity to minimise the potential to be predated. Since the gill netting method is a passive sampling technique, relying on fish actively swimming into the nets, any reduction in fish activity could actually reduce catches, counter-acting any increase in catches due to increased fish density. Similarly, the size of the anticipated change (the effect size) in biomass or abundance, combined with the inherent variability in the data and the level of replication that was logistically possible will determine the ability for the sampling program to detect an effect. Power analysis using catch data from the before period indicated that a 40% change in biomass or abundance and a 50% change in species richness would need to occur before a significant effect would be detected statistically. Obviously any effects that may have occurred during the drawdown were smaller than these, and so were not detectable statistically.

5.4 General observations

The above interpretations based on empirical data were also supported by general observations made before, during and after the drawdown. The observations suggested that fish and water dependent vertebrate species were affected by the change in water level. In particular, it was apparent that components of the fauna was exposed to increased predatory pressure. At the edges of pools and in the broad, open shallow margins, fish and crocodiles (large and small freshwater crocodiles and small estuarine crocodiles) were much more obvious during the drawdown. Schools of large and small fish and small to medium crocodiles were very obvious in shallows during the drawdown, moving in fast and erratic fashion, generally indicative of being stressed and trying to avoid real or perceived threats. It could be argued that fish always move in this fashion, but were now visible because of the lower water levels, however, the increased visibility of the fish and small crocodiles indicates potential for greater predation by freshwater and estuarine crocodiles and various piscivores (i.e. sharks, barramundi, herons/egrets etc).

As well as increased predatory pressure on fish within the open water column, those small fish species remaining in the shallows, or stranded in isolated pools were subjected to immense predatory pressure from piscivorous waterbirds. During the drawdown the shallow margins, isolated pools and exposed macrophyte beds attracted large numbers of piscivorous birds such as egrets, herons, brolgas, and black-necked storks actively feeding on the stranded and concentrated smaller fish and other aquatic life (Plate 14).

Plate 14. Waterbirds congregating on exposed and floating macrophyte beds to feed on small fish, aquatic insects and prawns concentrated in the shallows

Plate 15. Two freshwater crocodiles sitting on exposed macrophyte beds during the drawdown.

A change in crocodile behaviour also was apparent during the drawdown, with many animals sitting in exposed areas in shallows or on exposed macrophyte beds (Plates 15), or atypically, in shallow, fast-flowing rapids. Smaller individuals of both species of crocodiles are predated upon by larger estuarine crocodiles. Because the large estuarine crocodiles are territorial and likely occupy most of the deeper pools, the smaller individuals probably faced the choice of leaving the exposed shallows to enter the previously deeper areas, but at risk from predation by mature animals, or trying to survive in less preferred and exposed habitats. Over the longer timescale, predation by raptors, piscivorous birds (herons, egrets, brolgas, storks), large piscivorous fish (barramundi) and crocodiles (freshwater & estuarine) would reduce fish and crocodile populations to a new, lower equilibrium.

5.5 Conclusions

As part of the process for developing the Interim Allocation Plan for the Ord River, Storey (2000) undertook a comprehensive literature review of the impacts of changed river flows on fish habitat availability and utilisation. This was done in an attempt to further understand the relationship between water levels and fish habitat requirements. The aim of the literature review was to document the impacts of reducing or increasing flows on fish habitat availability and, subsequently, the impacts on species and populations, specifically reviewing the effects of changes in water depth.

The review documented a very strong and scientifically accepted relationship between fish species diversity and habitat diversity, with parameters most often used to measure habitat diversity being water depth, water velocity, aspects of substrate composition (i.e.

particle heterogeneity) and extent of cover (i.e. riparian and instream vegetation, bank morphology and amount of woody debris).

The review determined that a change in discharge resulted in changes in depth, velocity, substrate structure and degree of cover, and that changes in these parameters inferred a concomitant reduction in habitat availability/suitability, with an associated decline in abundance, biomass and/or diversity of species. In most instances, water depth was seen as the key parameter influencing fish diversity, with decreases in species diversity occurring in association with reduced habitat diversity.

Specifically, it was noted that water depth influenced a.) the amount of a particular habitat (e.g. woody debris) available in the water column, b.) the vertical space in the water column available to mid-water schooling species and c.) the ability to avoid terrestrial predators. Depth can provide relatively stable, sheltered areas whereas shallow areas are particularly sensitive to reductions in water level, and with increasing depth, light penetration decreases and hence visibility is reduced, again providing protection from predators.

The review listed numerous authors (i.e. Sheldon, 1968; Mendelson, 1975; Baker & Ross, 1981; Moyle & Senanayake, 1984; Moyle & Vondracek, 1985, Gorman & Karr, 1978; Grossman et al., 1987 a & b; Welcomme, 1985) who have reported that fish species occupy different mesohabitats, with species separated vertically, based on morphology and feeding habit. It was noted that a reduction in depth ultimately forced species to alter their optimum habitat utilisation, and forced together species normally segregated.

Predatory pressure was also an important factor, whereby small fish and young of large species are found in shallow areas. Power *et al*. (1985), Schlosser (1987a) Schlosser (1982a, b), Finger (1982), Moyle & Baltz (1985) and Bain *et al*. (1988) all reported that large piscivorous fish force small fish into shallow refugia, and that shallow and slow-flowing areas were used by small, young fish of several species, and deep areas were primarily inhabited by larger, older fish.

The review listed studies which observed changes in fish assemblages due to changes in depth. For example, Mann (1988) reported that reduced water levels resulted in low flows and shallow water which in turn led to the formation of dense populations of the small cyprinid *Phoxinus phoxinus* in place of larger cyprinids, trout, pike and perch. Newcombe (1981) and Orth & Maughan (1982) noted that usable habitat declined markedly when flows were reduced below base levels, and Bain *et al*. (1988) noted that decreases in flow displaced the shallow shoreline zone, forcing fish restricted to these areas to relocate, exposing the shallow and slow-water fishes to increased predatory pressure. Cowx & Welcomme (1998) noted that lateral habitat, often characterized by low-velocity areas (< 4 cm sec-1) at the margins of the stream channel are important for young-of-the-year fish. An increase in area of lateral habitat resulted in major improvement in the density of age-0 fish, with flow-on effects to population size. Conversely, reduction in lateral habitat correlated with elimination of young-of-the-year fish. Depending upon channel shape, small increases or decreases in depth may substantially alter the area of lateral habitat.

The review concluded that with respect to the LOR, the generalities of the relationships between fish species diversity, habitat diversity and the parameters used to characterise habitat diversity, in particular water depth would apply. The review also concluded that without empirical relationships for habitat requirements of fish species in the LOR, it must be considered that a reduction in water depth would likely result in a reduction in habitat availability/suitability, which would likely result in a loss in species diversity.

Data and observations from the trial drought strategy support the general conclusions from the literature review. In particular, the susceptibility to changes in water level of the lateral habitats of backwaters and macrophyte beds in the LOR, which showed large physical changes accompanied with significant biotic changes. Although changes in fish catch were not always obvious, particularly in the pool habitat, the short duration of the trial provided only limited time for a response to be manifest (i.e. changes in fish community structure due to increased predatory pressure and reduced carrying capacity may take weeks or months to occur).

The long term implications of a sustained drought strategy (i.e. lasting for a whole dry season) to the fish fauna of the LOR are difficult to predict. In essence, dry season river levels would be reduced to levels that occurred prior to 1996 (i.e. prior to increased dry season flows as a result of releases from the hydroelectric scheme). Therefore, although carrying capacity for different species would be reduced from current levels (i.e. of larger species in pools), it is unlikely species would be lost from the system, although population sizes would be decreased. One of the greatest risks would be the reduction in area of macrophyte and backwater habitat, and impacts upon species dependent on this habitat either directly (i.e. for residence), or indirectly (i.e. for providing a food source).

It would appear that the current distribution of these habitats in the channel relates to the current dry season low flow depths/levels which are higher than the proposed non-drought period dry season flow rate of 45/40m^3/sec in the revised Interim Water Allocation Plan (WRC, 2003). Under the revised flow regime, the distribution of macrophytes in the channel would be different, with plants re-establishing to the lower flows. At this stage it is not possible to predict the areal extent of macrophyte beds under the 45/40 m^3/sec. However, a further reduction in flow during drought periods would draw down water levels away from these habitats, and likely significantly reduce their areal extent in the channel. Because these habitats are unlikely to re-establish in the short term (i.e. macrophyte beds take at least a year to recolonize new areas, and backwaters appear to be structured by wet season flows), species dependent upon these areas may be placed at risk. Possible effects range from population sizes being much reduced, to species temporarily or permanently being lost from the system.

Conclusions reached from this study did not take into account any adverse effects that could occur from changes in water quality (i.e. excessive reductions in dissolved oxygen levels, or increases in nutrients, algal growth, conductivity, water temperature or irrigation-derived contaminants) which could not be predicted from the brief trial.

6 Acknowledgements

Wetland Research & Management is again indebted to Steve McIntosh for his invaluable assistance and continued enthusiasm in the field. Rebecca Dobbs is thanked for data entry. Staff of the Water & Rivers Commission, Kununurra office are thanked for their continuing support with logistics and for the loan of field equipment. Kerry Trayler, Water & Rivers Commission, Perth is thanked for her constructive input, for contract management, and for organising the drafting of location maps. This project was funded by the Water & Rivers Commission (through the Office of Major Projects) as part of their ongoing investigations to develop an allocation plan for the Ord River.

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8 Appendices

8.1 Appendix 1. Physico-chemical data

Appendix 1. Locations and physico-chemical data for each replicate sample by habitat and flow period.

HABITAT	REGIME	REPLICATE	DATE	TIME	LATITUDE	LONGITUDE	PH	CONDUCTIVITY	TURBIDITY	TEMPERATURE	SALINITY	SECCHI DEPTH	WATER DEPTH	VELOCITY	DISSOLVED OXYGEN	DISSOLVED OXYGEN
					Geodata 66	Geodata 66	#	(us/cm)	(ntuS)	(^{0}c)	(mg/l)	(cm)	(m)	(cm/sec)	(% SAT)	(mg/l)
Backwater	Before	BW1	17/10/02	1130	15 32.414	128 31.382	8.88	284	52.8	30.53	0.45	-	-	1.0	141.4	5.4
Backwater	Before	BW2	17/10/02	1610	15 34.510	128 30.373	9.24	266	9.4	31.16	0.43	-	-	0.0	199.2	11.3
Backwater	Before	BW3	18/10/02	945	15 33.777	128 40.288	8.21	286	11.7	28.31	0.46	-	-	3.0	113.7	4.5
Backwater	During	BW1	20/10/02	1010	15 33.779	128 40.263	8.73	305	15.0	28.82	0.47	-	-	0.0	118.1	4.6
Backwater	During	BW2	20/10/02	1115	15 33.333	128 39.448	9.02	302	22.1	30.59	0.46	-	-	0.0	138.5	5.2
Backwater	During	BW3	21/10/02	930	15 34.454	128 34.578	8.55	306	16.7	30.34	0.46	-	-	0.0	120.2	4.6
Backwater	During	BW4	21/10/02	1415	15 32.343	128 31.683	9.33	295	14.7	31.80	0.44	-	-	0.0	146.7	5.4
Backwater	During	BW4-a	19/10/02	845	15 34.464	128 34.556	8.72	288	15.6	28.93	0.46	-	-	0.0	112.8	4.4
Backwater	During	BW5-a	19/10/02	1200	15 34.030	128 32.456	8.92	286	18.0	30.20	0.46	-	-	0.0	132.1	5.0
Backwater	During	BW6-a	19/10/02	-	15 32.452	128 31.958	8.69	282	15.6	30.16	0.44	-	-	0.0	127.3	4.9
Backwater	After	BW1	22/10/02	830	15 33.624	128 30.953	8.72	313	15.2	30.10	0.46	-	-	0.0	103.2	3.9
Backwater	After	BW2	23/10/02	915	15 33.785	128 40.271	8.46	295	12.8	29.08	0.45	-	-	5.1	111.8	4.3
Backwater	After	BW3	23/10/02	1315	15 34.164	128 38.122	10.17	289	5.4	36.32	0.42	-	-	0.0	162.5	5.6
Backwater	After	BW4	24/10/02	920	15 34.168	128 32.563	8.84	310	11.3	32.81	0.45	-	-	0.0	111.3	4.1
Backwater	After	BW5	24/10/02	940	16 34.408	129 32.726	8.70	321	8.5	32.91	0.45	-	-	0.0	106.4	3.9
Backwater	After	BW6	24/10/02	1210	15 33.038	128 32.175	8.47	287	23.7	30.05	0.44	-	-	0.0	123.2	4.7
Macrophyte	Before	MB1	17/10/02	1200	15 32.839	128 31.258	8.78	287	40.3	29.96	0.46	-	-	30.6	129.5	5.0
Macrophyte	Before	MB2	17/10/02	-	15 35.313	128 30.177	8.54	293	24.5	30.62	0.45	-	-	10.0	124.6	4.7
Macrophyte	Before	MB3	18/10/02	1045	15 33.587	128 39.755	8.91	283	31.5	28.76	0.45	-	-	19.3	122.5	4.8
Macrophyte	Before	MB4	18/10/02	1440	15 33.333	128 39.456	8.88	284	27.0	29.34	0.45	-	-	8.6	127.9	4.9
Macrophyte	During	MB1	20/10/02	1030	15 33.554	128 39.765	9.10	295	22.6	30.83	0.45	-	-	0.0	136.2	5.1
Macrophyte	During	MB2	20/10/02	1430	15 33.595	128 39.759	9.30	296	17.5	33.50	0.43	-	-	0.0	148.8	5.4
Macrophyte	During	MB3	21/10/02	955	15 34.444	128 34.673	8.94	297	24.6	32.52	0.44	-	-	1.5	142.6	5.2

HABITAT	REGIME	REPLICATE	DATE	TIME	LATITUDE	LONGITUDE	PH	CONDUCTIVITY	TURBIDITY	TEMPERATURE	SALINITY	SECCHI DEPTH	WATER DEPTH	VELOCITY	DISSOLVED OXYGEN	DISSOLVED OXYGEN
Macrophyte	During	MB4	20/10/02	1520	15 32.363	128 31.781	9.23	300	20.3	30.87	0.45	-	-	1.0	129.5	4.9
Macrophyte	During	MB5-a	19/10/02	940	15 34.444	128 34.673	8.86	288	15.4	29.19	0.45	-	-	0.0	126.6	4.9
Macrophyte	During	MB6-a	19/10/02	1440	15 32.399	128 31.853	8.43	286	18.0	30.18	0.44	-	-	0.0	138.3	5.3
Macrophyte	After	MB1	22/10/02	900	15 33.694	128 30.929	8.68	311	16.0	29.92	0.46	-	-	0.0	106.4	4.1
Macrophyte	After	MB2	22/10/02	1320	15 35.285	128 30.182	8.76	307	29.4	32.25	0.46	-	-	1.0	119.6	4.4
Macrophyte	After	MB3	23/10/02	840	15 33.943	128 38.982	8.13	300	12.3	29.11	0.47	-	-	0.0	110.7	4.3
Macrophyte	After	MB4	23/10/02	1400	15 34.132	128 37.525	9.29	287	15.0	34.50	0.42	-	-	0.0	170.0	6.1
Macrophyte	After	MB5	24/10/02	815	15 34.411	128 34.700	8.71	292	9.7	29.12	0.45	-	-	7.5	106.8	4.1
Macrophyte	After	MB6	24/10/02	1440	15 32.417	128 31.881	8.92	286	10.4	31.74	0.44	-	-	0.0	129.2	4.8
Pool	Before	GN1	17/10/02	-	15 33.495	128 30.936	8.30	291	73.2	29.24	0.45	145.00	2.33	27.6	116.9	4.5
Pool	Before	GN2	17/10/02	1015	15 33.555	128 30.913	8.30	291	73.2	29.24	0.45	145.00	2.17	21.4	116.9	4.5
Pool	Before	GN3	17/10/02	1400	15 35.548	128 30.037	8.94	292	24.1	30.20	0.46	126.00	2.40	13.6	120.1	4.6
Pool	Before	GN4	17/10/02	1410	15 35.605	128 29.994	8.77	292	15.2	30.19	0.46	134.00	2.03	27.3	118.9	4.5
Pool	Before	GN5	18/10/02	830	15 33.986	128 38.943	8.84	289	9.9	27.82	0.46	232.00	3.64	5.1	109.9	4.4
Pool	Before	GN6	18/10/02	830	15 34.026	128 38.905	8.88	289	9.4	27.84	0.46	230.00	4.55	18.0	111.8	4.4
Pool	Before	GN7	18/10/02	1200	15 34.087	128 38.340	9.00	286	23.0	28.95	0.45	210.00	3.48	17.3	120.9	4.7
Pool	Before	GN8	18/10/02	1200	15 34.090	128 38.228	8.95	282	59.2	29.01	0.45	201.00	4.18	8.3	122.5	4.8
Pool	During	GN10	21/10/02	845	15 34.563	128 34.545	8.62	310	12.1	29.68	0.46	158.00	2.96	20.8	114.9	4.4
Pool	During	GN10-a	19/10/02	800	15 34.563	128 34.545	8.98	289	8.8	27.92	0.46	-	3.36	11.0	108.9	4.3
Pool	During	GN11	21/10/02	1245	15 32.353	128 31.842	8.38	301	48.3	30.08	0.46	150.00	2.82	19.4	118.9	4.5
Pool	During	GN11-a	19/10/02	1400	15 32.353	128 31.842	8.89	289	15.8	29.50	0.45	142.00	2.86	23.2	117.6	4.5
Pool	During	GN12	21/10/02	1245	15 32.413	128 31.956	7.95	298	18.0	30.10	0.46	150.00	2.73	12.0	117.7	4.5
Pool	During	GN12-a	19/10/02	1400	15 32.413	128 31.956	8.94	289	27.5	29.51	0.45	144.00	2.75	17.5	120.3	4.6
Pool	During	GN5	20/10/02	850	15 33.986	128 38.943	7.91	303	10.2	28.22	0.48	218.00	3.41	7.0	109.5	4.3
Pool	During	GN6	20/10/02	850	15 34.026	128 38.905	8.01	303	10.5	28.15	0.46	225.00	3.90	5.0	107.5	4.3
Pool	During	GN7	20/10/02	?	15 34.087	128 38.340	8.87	304	13.3	29.64	0.46	174.00	3.49	6.5	123.5	4.8
Pool	During	GN8	20/10/02	?	15 34.090	128 38.228	8.75	304	11.6	29.52	0.46	156.00	3.68	4.8	123.0	4.8
Pool	During	GN9	21/10/02	845	15 34.513	128 34.599	8.37	307	12.8	29.70	0.46	165.00	2.71	24.9	114.7	4.4
Pool	During	GN9-a	19/10/02	800	15 34.513	128 34.599	9.18	292	8.9	27.92	0.46	-	3.05	16.2	107.0	4.2
Pool	After	GN1	22/10/02	800	15 33.495	128 30.936	9.07	314	15.4	29.50	0.46	112.00	2.06	14.2	106.0	4.1
Pool	After	GN10	24/10/02	745	15 34.563	128 34.545	8.67	291	8.7	28.71	0.46	218.00	3.61	23.0	105.3	4.1
Pool	After	GN11	24/10/02	1230	15 32.353	128 31.842	8.65	287	13.1	29.97	0.44	179.00	3.28	32.4	114.4	4.4

HABITAT	REGIME	REPLICATE	DATE	TIME	LATITUDE	LONGITUDE	PH	CONDUCTIVITY	TURBIDITY	TEMPERATURE	SALINITY	SECCHI DEPTH	WATER DEPTH	VELOCITY	DISSOLVED OXYGEN	DISSOLVED OXYGEN
Pool	After	GN12	24/10/02	1230	15 32.413	128 31.956	8.55	287	16.4	30.01	0.44	182.00	3.31	21.6	114.2	4.4
Pool	After	GN2	22/10/02	800	15 33.555	128 30.913	9.20	314	14.9	29.47	0.47	137.00	1.95	15.2	104.0	4.0
Pool	After	GN3	22/10/02	1245	15 35.548	128 30.037	8.66	306	43.4	31.31	0.45	135.00	2.26	21.6	119.7	4.5
Pool	After	GN4	22/10/02	1245	15 35.605	128 29.994	8.72	310	18.9	31.15	0.45	135.00	1.96	25.8	116.8	4.4
Pool	After	GN5	23/10/02	800	15 33.986	128 38.943	8.87	300	8.3	28.63	0.46	268.00	3.64	2.1	106.8	4.2
Pool	After	GN6	22/10/02	800	15 34.026	128 38.905	8.69	301	8.5	28.57	0.46	268.00	4.27	9.7	105.9	4.2
Pool	After	GN7	23/10/02	1140	15 34.087	128 38.340	8.42	295	27.5	29.53	0.45	161.00	3.44	10.7	116.9	4.5
Pool	After	GN8	23/10/02	1140	15 34.090	128 38.228	8.41	296	16.4	29.43	0.47	218.00	4.16	5.7	114.5	4.4
Pool	After	GN9	24/10/02	745	15 34.513	128 34.599	8.79	291	8.5	28.76	0.46	254.00	3.45	15.0	106.5	4.2
						Average	8.77	294.38	20.92	30.13	0.45	172.50	3.13	7.61	124.21	4.80
						Minimum	7.91	266.00	5.40	27.82	0.42	126.00	2.03	0.00	103.20	3.90
						Maximum	10.17	321.00	73.20	36.32	0.48	232.00	4.55	30.60	199.20	11.30

8.2 Appendix 2. Fish catch data

Appendix 2. Abundance and biomass of each species of fish in each replicate sample by habitat and flow regime.

HABITAT	REGIME	REPLICATE	SPECIES	NUMBER	BIOMASS (g)
Backwater	Before	BW1	*Ambassis* spp	88	68.0
Backwater	Before	BW1	*Melanotaenia splendida australis*	8	4.5
Backwater	Before	BW2	*Ambassis spp*	17	9.5
Backwater	Before	BW2	*Glossamia aprion*	1	2.0
Backwater	Before	BW2	*Hypseleotris compressa*	3	3.0
Backwater	Before	BW2	*Liza alata*	1	915.0
Backwater	Before	BW3	*Amniataba percoides*	3	7.0
Backwater	Before	BW3	*Craterocephalus stramineus*	23	10.0
Backwater	Before	BW3	*Glossogobius giuris*	1	4.0
Backwater	Before	BW3	*Hephaestus jenkinsi*	2	186.0
Backwater	Before	BW3	*Hypseleotris compressa*	1	1.0
Backwater	Before	BW3	*Melanotaenia splendida australis*	3	4.0
Backwater	During	BW1	*Amniataba percoides*	2	20.0
Backwater	During	BW1	*Craterocephalus stramineus*	17	10.0
Backwater	During	BW1	*Strongylura krefftii*	1	5.0
Backwater	During	BW2	*Ambassis* spp	3	2.1
Backwater	During	BW2	*Hypseleotris compressa*	68	17.0
Backwater	During	BW2	*Melanotaenia splendida australis*	9	6.0
Backwater	During	BW3	*Ambassis* spp	1	1.0
Backwater	During	BW3	*Amniataba percoides*	7	16.5
Backwater	During	BW3	*Glossogobius giuris*	5	6.0
Backwater	During	BW3	*Leiopotherapon unicolor*	1	11.0
Backwater	During	BW3	*Melanotaenia splendida australis*	8	24.0
Backwater	During	BW4	*Ambassis* spp	62	79.0
Backwater	During	BW4	*Amniataba percoides*	11	17.3
Backwater	During	BW4	*Melanotaenia splendida australis*	22	37.0
Backwater	During	BW4-a	*Ambassis* spp	1	1.0
Backwater	During	BW4-a	*Amniataba percoides*	15	82.0
Backwater	During	BW4-a	*Craterocephalus stramineus*	1	0.5
Backwater	During	BW4-a	*Glossamia aprion*	8	24.0
Backwater	During	BW4-a	*Glossogobius giuris*	5	4.5
Backwater	During	BW4-a	*Hypseleotris compressa*	36	12.0
Backwater	During	BW4-a	*Leiognathus equulus*	1	24.0
Backwater	During	BW4-a	*Leiopotherapon unicolor*	2	42.0
Backwater	During	BW4-a	*Liza alata*	1	0.5
Backwater	During	BW4-a	*Strongylura krefftii*	1	50.0
Backwater	During	BW5-a	*Amniataba percoides*	5	14.0
Backwater	During	BW5-a	*Craterocephalus stramineus*	1	0.5
Backwater	During	BW5-a	*Melanotaenia splendida australis*	9	6.0
Backwater	During	BW6-a	*Ambassis* spp	1	1.0
Backwater	During	BW6-a	*Amniataba percoides*	5	25.0
Backwater	During	BW6-a	*Liza alata*	14	9.0
Backwater	During	BW6-a	*Melanotaenia splendida australis*	9	11.0
Backwater	During	BW6-a	*Nematalosa erebi*	1	1.0
Backwater	After	BW1	*Ambassis* spp	133	134.0
Backwater	After	BW1	*Amniataba percoides*	3	21.0
Backwater	After	BW1	*Hypseleotris compressa*	3	4.5
Backwater	After	BW1	*Leiognathus equulus*	14	27.1
Backwater	After	BW1	*Liza alata*	3	17.0
Backwater	After	BW2	*Craterocephalus stramineus*	3	2.5
Backwater	After	BW2	*Glossogobius giuris*	4	13.0
Backwater	After	BW2	*Melanotaenia splendida australis*	4	1.6

HABITAT	REGIME	REPLICATE	SPECIES	NUMBER	BIOMASS (g)
Backwater	After	BW2	*Strongylura krefftii*	2	105.0
Backwater	After	BW3	*Ambassis* spp	10	8.0
Backwater	After	BW3	*Amniataba percoides*	12	91.5
Backwater	After	BW3	*Craterocephalus stramineus*	3	1.5
Backwater	After	BW3	*Melanotaenia splendida australis*	7	5.0
Backwater	After	BW4	*Amniataba percoides*	14	36.0
Backwater	After	BW4	*Glossamia aprion*	1	4.0
Backwater	After	BW4	*Glossogobius giuris*	3	10.0
Backwater	After	BW5	*Amniataba percoides*	6	7.0
Backwater	After	BW5	*Glossamia aprion*	1	5.0
Backwater	After	BW5	*Glossogobius giuris*	1	0.5
Backwater	After	BW5	*Hypseleotris compressa*	9	13.0
Backwater	After	BW5	*Nematalosa erebi*	3	14.0
Backwater	After	BW6	*Hypseleotris compressa*	1	0.5
Backwater	After	BW6	*Liza alata*	1	1.0
Backwater	After	BW6	*Melanotaenia splendida australis*	24	17.0
Macrophyte bed	Before	MB1	*Amniataba percoides*	7	29.5
Macrophyte bed	Before	MB1	*Craterocephalus stramineus*	1	0.5
Macrophyte bed	Before	MB1	*Leiognathus equulus*	3	17.0
Macrophyte bed	Before	MB1	*Neosilurus hyrtlii*	1	346.0
Macrophyte bed	Before	MB2	*Ambassis* spp	5	4.0
Macrophyte bed	Before	MB2	*Melanotaenia splendida australis*	4	14.0
Macrophyte bed	Before	MB3	*Amniataba percoides*	1	3.0
Macrophyte bed	Before	MB3	*Nematalosa erebi*	40	30.0
Macrophyte bed	Before	MB4	*Amniataba percoides*	2	7.5
Macrophyte bed	During	MB1	*Amniataba percoides*	3	2.0
Macrophyte bed	During	MB1	*Glossamia aprion*	4	0.4
Macrophyte bed	During	MB1	*Hypseleotris compressa*	190	60.0
Macrophyte bed	During	MB1	*Melanotaenia splendida australis*	2	8.0
Macrophyte bed	During	MB2	*Amniataba percoides*	2	1.0
Macrophyte bed	During	MB2	*Glossamia aprion*	1	0.5
Macrophyte bed	During	MB2	*Hypseleotris compressa*	157	31.0
Macrophyte bed	During	MB3	*Ambassis* spp	1	0.1
Macrophyte bed	During	MB3	*Amniataba percoides*	11	2.0
Macrophyte bed	During	MB3	*Glossamia aprion*	12	1.0
Macrophyte bed	During	MB3	*Hypseleotris compressa*	12	5.0
Macrophyte bed	During	MB4	*Amniataba percoides*	4	0.4
Macrophyte bed	During	MB4	*Glossamia aprion*	2	0.2
Macrophyte bed	During	MB4	*Hypseleotris compressa*	54	16.0
Macrophyte bed	During	MB5-a	*Amniataba percoides*	9	2.0
Macrophyte bed	During	MB5-a	*Glossogobius giuris*	1	10.0
Macrophyte bed	During	MB5-a	*Hypseleotris compressa*	7	3.5
Macrophyte bed	During	MB5-a	*Melanotaenia splendida australis*	3	3.0
Macrophyte bed	During	MB5-a	*Strongylura krefftii*	1	1.0
Macrophyte bed	During	MB6-a	*Amniataba percoides*	7	3.5
Macrophyte bed	During	MB6-a	*Glossamia aprion*	1	0.5
Macrophyte bed	During	MB6-a	*Hypseleotris compressa*	20	8.0
Macrophyte bed	During	MB6-a	*Melanotaenia splendida australis*	1	1.0
Macrophyte bed	After	MB1	*Hypseleotris compressa*	61	7.0
Macrophyte bed	After	MB2	*Ambassis* spp	12	12.0
Macrophyte bed	After	MB2	*Hypseleotris compressa*	60	7.0
Macrophyte bed	After	MB3	*Amniataba percoides*	1	0.1
Macrophyte bed	After	MB3	*Glossamia aprion*	2	0.2
Macrophyte bed	After	MB3	*Hypseleotris compressa*	32	8.0
Macrophyte bed	After	MB3	*Melanotaenia splendida australis*	10	11.0
Macrophyte bed	After	MB4	*Glossogobius giuris*	4	3.0
Macrophyte bed	After	MB4	*Melanotaenia splendida australis*	7	3.0

HABITAT	REGIME	REPLICATE	SPECIES	NUMBER	BIOMASS (g)
Macrophyte bed	After	MB5	*Amniataba percoides*	4	1.6
Macrophyte bed	After	MB6	No spp	1	1.0
Pool	Before	GN1	*Arius graeffei*	2	1022.0
Pool	Before	GN1	*Liza alata*	8	6551.0
Pool	Before	GN1	*Nematalosa erebi*	2	1082.0
Pool	Before	GN2	*Arius graeffei*	3	744.0
Pool	Before	GN2	*Arius midgleyi*	1	118.0
Pool	Before	GN2	*Lates calcarifer*	2	825.0
Pool	Before	GN2	*Liza alata*	14	8396.0
Pool	Before	GN3	*Arius graeffei*	4	1610.0
Pool	Before	GN3	*Liza alata*	2	1707.0
Pool	Before	GN3	*Megalops cyprinoides*	1	98.0
Pool	Before	GN3	*Nematalosa erebi*	5	1389.0
Pool	Before	GN4	*Amniataba percoides*	2	23.0
Pool	Before	GN4	*Arius graeffei*	5	1504.0
Pool	Before	GN4	*Lates calcarifer*	1	1370.0
Pool	Before	GN4	*Liza alata*	5	2029.0
Pool	Before	GN4	*Nematalosa erebi*	4	1737.0
Pool	Before	GN4	*Scatophagus argus*	1	262.0
Pool	Before	GN4	*Syncomistes butleri*	4	1043.0
Pool	Before	GN5	*Arius graeffei*	1	209.0
Pool	Before	GN5	*Arius midgleyi*	2	439.0
Pool	Before	GN5	*Liza alata*	3	1070.0
Pool	Before	GN5	*Nematalosa erebi*	19	5185.0
Pool	Before	GN6	*Amniataba percoides*	2	12.0
Pool	Before	GN6	*Arius graeffei*	1	656.0
Pool	Before	GN6	*Arius midgleyi*	6	2474.0
Pool	Before	GN6	*Hephaestus jenkinsi*	2	298.0
Pool	Before	GN6	*Lates calcarifer*	2	2256.0
Pool	Before	GN6	*Liza alata*	9	5488.0
Pool	Before	GN6	*Nematalosa erebi*	5	1135.0
Pool	Before	GN6	*Syncomistes butleri*	2	317.0
Pool	Before	GN7	*Arius graeffei*	2	1187.0
Pool	Before	GN7	*Liza alata*	4	2314.0
Pool	Before	GN7	*Nematalosa erebi*	8	2701.0
Pool	Before	GN8	*Amniataba percoides*	1	4.0
Pool	Before	GN8	*Arius graeffei*	4	1798.0
Pool	Before	GN8	*Liza alata*	3	1616.0
Pool	Before	GN8	*Nematalosa erebi*	7	1453.0
Pool	During	GN10	*Amniataba percoides*	4	23.0
Pool	During	GN10	*Arius graeffei*	3	1343.0
Pool	During	GN10	*Liza alata*	14	5885.0
Pool	During	GN10	*Nematalosa erebi*	1	254.0
Pool	During	GN10-a	*Arius graeffei*	5	940.0
Pool	During	GN10-a	*Lates calcarifer*	2	1992.0
Pool	During	GN10-a	*Liza alata*	4	1896.0
Pool	During	GN11	*Arius graeffei*	3	1155.0
Pool	During	GN11	*Liza alata*	1	569.0
Pool	During	GN11	*Nematalosa erebi*	5	1823.0
Pool	During	GN11	*Strongylura krefftii*	1	478.0
Pool	During	GN11	*Syncomistes butleri*	2	727.0
Pool	During	GN11-a	*Arius graeffei*	7	3264.0
Pool	During	GN11-a	*Arius midgleyi*	1	157.0
Pool	During	GN12	*Amniataba percoides*	3	26.0
Pool	During	GN12	*Arius graeffei*	2	292.0
Pool	During	GN12	*Leiognathus equulus*	1	5.0
Pool	During	GN12	*Liza alata*	5	2924.0

HABITAT	REGIME	REPLICATE	SPECIES	NUMBER	BIOMASS (g)
Pool	During	GN12	*Megalops cyprinoides*	2	1613.0
Pool	During	GN12	*Nematalosa erebi*	3	618.0
Pool	During	GN12	*Syncomistes butleri*	1	173.0
Pool	During	GN12-a	*Amniataba percoides*	1	7.0
Pool	During	GN12-a	*Arius graeffei*	2	558.0
Pool	During	GN12-a	*Arius midgleyi*	2	297.0
Pool	During	GN12-a	*Craterocephalus stramineus*	1	250.0
Pool	During	GN12-a	*Liza alata*	4	2756.0
Pool	During	GN12-a	*Nematalosa erebi*	1	305.0
Pool	During	GN12-a	*Syncomistes butleri*	2	583.0
Pool	During	GN5	*Amniataba percoides*	1	5.0
Pool	During	GN5	*Liza alata*	5	2824.0
Pool	During	GN5	*Nematalosa erebi*	1	645.0
Pool	During	GN6	*Amniataba percoides*	1	5.0
Pool	During	GN6	*Lates calcarifer*	1	1316.0
Pool	During	GN6	*Liza alata*	5	3357.0
Pool	During	GN6	*Nematalosa erebi*	1	616.0
Pool	During	GN6	*Syncomistes butleri*	1	591.0
Pool	During	GN7	*Amniataba percoides*	1	18.0
Pool	During	GN7	*Arius graeffei*	1	603.0
Pool	During	GN7	*Arius midgleyi*	2	1584.0
Pool	During	GN7	*Lates calcarifer*	1	1107.0
Pool	During	GN7	*Liza alata*	10	7927.0
Pool	During	GN7	*Nematalosa erebi*	2	173.0
Pool	During	GN7	*Syncomistes butleri*	1	145.0
Pool	During	GN8	*Amniataba percoides*	1	9.0
Pool	During	GN8	*Arius graeffei*	2	281.0
Pool	During	GN8	*Arius midgleyi*	1	110.0
Pool	During	GN8	*Liza alata*	15	8034.0
Pool	During	GN8	*Nematalosa erebi*	1	466.0
Pool	During	GN9	*Arius graeffei*	1	168.0
Pool	During	GN9	*Liza alata*	6	4104.0
Pool	During	GN9	*Nematalosa erebi*	3	406.0
Pool	During	GN9-a	*Arius graeffei*	4	1219.0
Pool	During	GN9-a	*Arius midgleyi*	1	358.0
Pool	During	GN9-a	*Liza alata*	4	2741.0
Pool	During	GN9-a	*Nematalosa erebi*	1	116.0
Pool	During	GN9-a	*Strongylura krefftii*	1	33.0
Pool	During	GN9-a	*Syncomistes butleri*	2	531.0
Pool	After	GN1	*Arius graeffei*	7	1064.0
Pool	After	GN1	*Liza alata*	19	14727.0
Pool	After	GN1	*Nematalosa erebi*	3	989.0
Pool	After	GN10	*Amniataba percoides*	1	5.0
Pool	After	GN10	*Arius graeffei*	8	1926.0
Pool	After	GN10	*Liza alata*	2	1075.0
Pool	After	GN10	*Megalops cyprinoides*	1	930.0
Pool	After	GN10	*Nematalosa erebi*	1	590.0
Pool	After	GN11	*Arius graeffei*	1	450.0
Pool	After	GN11	*Nematalosa erebi*	1	778.0
Pool	After	GN11	*Syncomistes butleri*	1	403.0
Pool	After	GN12	*Amniataba percoides*	1	8.0
Pool	After	GN12	*Arius graeffei*	8	1381.0
Pool	After	GN12	*Hephaestus jenkinsi*	1	103.0
Pool	After	GN12	*Liza alata*	4	2661.0
Pool	After	GN12	*Nematalosa erebi*	1	232.0
Pool	After	GN2	*Arius graeffei*	6	1085.0
Pool	After	GN2	*Liza alata*	25	16399.0

HABITAT	REGIME	REPLICATE	SPECIES	NUMBER	BIOMASS (g)
Pool	After	GN3	*Arius graeffei*	1	124.0
Pool	After	GN3	*Arius midgleyi*	1	390.0
Pool	After	GN3	*Liza alata*	26	15643.0
Pool	After	GN3	*Nematalosa erebi*	4	1787.0
Pool	After	GN3	*Syncomistes butleri*	4	1195.0
Pool	After	GN4	*Arius graeffei*	3	1174.0
Pool	After	GN4	*Liza alata*	4	1943.0
Pool	After	GN4	*Nematalosa erebi*	3	669.0
Pool	After	GN5	*Amniataba percoides*	2	17.0
Pool	After	GN5	*Arius graeffei*	2	618.0
Pool	After	GN5	*Liza alata*	7	3439.0
Pool	After	GN5	*Nematalosa erebi*	5	1518.0
Pool	After	GN6	*Arius graeffei*	5	1037.0
Pool	After	GN6	*Liza alata*	6	5102.0
Pool	After	GN6	*Nematalosa erebi*	1	340.0
Pool	After	GN6	*Strongylura krefftii*	1	126.0
Pool	After	GN7	No spp	1	1.0
Pool	After	GN8	*Amniataba percoides*	2	19.0
Pool	After	GN8	*Arius graeffei*	1	100.0
Pool	After	GN8	*Liza alata*	11	6368.0
Pool	After	GN8	*Nematalosa erebi*	4	1592.0
Pool	After	GN9	*Amniataba percoides*	2	11.0
Pool	After	GN9	*Nematalosa erebi*	3	422.0
			Total no. / wt (kg) fish	**2011**	**223.9**