INLAND WATERS OF THE PILBARA WESTERN AUSTRALIA (PART 2)

Environmental Protection Authority
Perth, Western Australia
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"A contribution to the State Conservation Strategy"

INLAND WATERS OF THE PILBARA, WESTERN AUSTRALIA

PART 2

A REPORT OF A FIELD STUDY CARRIED OUT

IN OCTOBER-NOVEMBER, 1984

by

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Cover Photograph: Lower Carawine Pool on the Oakover River.

Back-Cover Photograph: Running Waters on the Davis River.

(Photographs by R J Masini)

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1. INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The Environmental Protection Authority has consistently emphasised the need to conserve wetland resources. While significant studies have been made in the south-west of Western Australia, little is known of the inland surface waters of the semi-arid areas of the state, notably the Pilbara region. For this reason, a study of inland waters of the Pilbara was initiated in 1983 with the following long-term objectives:

1. To produce an inventory of permanent and ephemeral inland surface waters which identifies and documents:

    (i) significant physical and biological characteristics;

    (ii) land tenure;

    (iii) amenity, conservation and recreational values;

    (iv) pressures arising from existing and potential land uses, human access and population centres.

2. To classify the waters, using significant physical and biological characteristics.

3. To establish priorities for management and/or reservation.

4. To develop guide-lines for appropriate conservation and management.

A first phase of the study began in March-April of 1983, and incorporated three main objectives:

1. To identify and document, as far as practicable, inland surface waters in the Fortescue and DeGrey river catchments in terms of their physical and biological characteristics.

2. To develop a preliminary classification system based on observations made in the field; and

3. To make recommendations for future phases of the study.

The study was interrupted during the latter stages by Tropical Cyclone Lena, which prevented access to the north-eastern Pilbara, effectively excluding this area from the survey. The recommendations for future phases of the study therefore included the survey of those surface waters which could not be documented in 1983. The results of the 1983 study have been published as 'Inland Waters of the Pilbara, Western Australia, Part 1' (Masini, 1988).

The present report concerns the results of a second study conducted during October-November 1984, with the following objectives:

1. To identify and document in terms of their important physical and biological characteristics, the wetlands of the Oakover-DeGrey catchments, with particular emphasis on Carawine Gorge, Skull Springs on the Davis River. Similarly, to survey wetlands along the Ashburton River and its catchment for inclusion in the data base for the Pilbara.

2. To review the wetland classification system devised during the 1983 study to encompass the whole Pilbara region, once adequate data have been obtained.

3. To carry out preliminary observations on the nutrient status of the wetlands of the Pilbara.

4. To make further recommendations for future phases of the study.

5. To make recommendations for the management of Pilbara wetlands.

This report should be read in conjunction with 'Inland Waters of the Pilbara, Western Australia, Part 1' (Masini, 1988). (IWP Part 1).

1.2 DEFINITIONS

The working definitions of the Pilbara and of Inland Surface Waters or Wetlands adopted previously have been adhered to for the purposes of this study (see Section 1.2, IWP Part 1).

1.3 CLIMATE AND RIVER GEOMORPHOLOGY

The Climate and River Geomorphology of the Pilbara region are described in detail in Sections 1.3 and 1.4, IWP Part 1.

The wetland classification system outlined in IWP Part 1 was based on a survey conducted during the latter half of the wet season (February-March 1983). Accessibility often limited site selection during the 1983 survey, and it was therefore decided to conduct the 1984 study in the late dry season (October-November), both to increase the likelihood of the Davis/Oakover region being accessible, and to observe the state of water bodies during the latter part of the 'dry' season.

This choice of season constrained the scope of the survey because, in general, only relatively permanent wetlands had surface water, as winter rainfall is uncommon especially in the north-eastern Pilbara (IWP Part 1). Additions to the data base used in formulating the classification system were therefore limited to wetlands with permanent/semi-permanent surface water. Nonetheless, many previously inaccessible wetlands could be visited during the 'dry' season, therefore substantially broadening the data set and coverage of the Pilbara region as a whole.

While a key objective of the surveys was to derive a classification of Pilbara wetlands, the collection of baseline data for wetland systems in this arid, sub-tropical region is essential for the purposes of future management, particularly as most current wetland management practices are derived from research and experience in temperate regions. In the course of the 1983 survey, data were collected on a range of parameters, including physical, physico-chemical and biological characteristics. The wetland classification system constructed following the 1983 survey did not utilise the full range of data collected, being based on physical parameters and, to a lesser extent, on floral indicator species. It was decided to continue to collect and extend the range of data in the 1984 survey in the interests of building up baseline data, even though not all of the data were used directly in the review of the classification system.

Nutrient cycling within arid ecosystems is poorly documented in general, and how these cycles operate within the Pilbara is unknown. In order to gain an understanding of some of the processes involved, preliminary work was carried out on the total nitrogen and phosphorus contents in major components of wetland areas. This was to provide background information about the relative levels and availability of these important nutrients within the wetland systems.

2. METHODS

2.1 FIELD WORK

Field work was carried out in October 1984, and involved travelling 5 000 kilometres within an area of 200 000 km^2. It included visits to the Ashburton and Davis/Oakover/DeGrey Rivers and to some wetlands of the Fortescue catchment formerly visited in the 'wet' season of 1983.

Appropriate licences to collect plants and animals were obtained from the Department of Fisheries and Wildlife and the National Parks Authority (now the Department of Conservation and Land Management).

Observations were made on a number of physical and biological characteristics of each wetland site visited. Field observations were recorded on a standardized proforma (IWP Part 1, Appendix 2). The methods used for measuring and observing individual parameters are outlined below.

Land tenure and usage were recorded as far as could be determined from cadastral maps and general observation.

2.2 PHYSICO-CHEMICAL CHARACTERISTICS

Water temperatures were measured with a Radio Spares Type 151-013 thermister, air temperature by field thermometer, and pH with an Orion RX combination pH electrode 91-56, calibrated in the field with standard buffers.

Conductivities were measured using a GK1 conductivity cell manufactured by TPS Pty. Ltd., and units expressed as mS/m , standardised to 25°C. pH and conductivity probes were operated through data loggers (Westlog, WA).

Total dissolved salts (TDS) were calculated from the conductivity data using the multiplication factors of 6.25, derived for the surface waters of the Harding River catchment (Snowy Mountains Engineering Corporation, 1982).

Total suspended solids (TSS), both organic and inorganic, were measured by filtering a known volume of water (usually 1 litre), through a preweighed, ashed 2.5 cm-diameter Whatman GF/C (glass-fibre) filter, and drying to constant weight at 70°C.

Unless stated otherwise, all measurements and determinations relate to surface water samples, ie 0-10 cm depth.

2.3 BIOLOGICAL CHARACTERISTICS

The dominant flora and fauna were examined to provide additional data for possible incorporation into and extension of the wetland classification system derived from the 1983 study.

i) *Fringing vegetation* - The fringing vegetation was sampled by documenting a transect from the land/water interface to a point designated as the limit of wetland influence (eg top of a levee bank). Plant specimens were collected and mounted on herbarium sheets, pressed and dried in the field for later identification.

Preliminary identifications were made by comparison with the 1983 collection with assistance from C. Nicholson of the Environmental Protection Authority. Specimens will be stored in the Pilbara Regional Herbarium, Karratha.

ii) *Emergent and submerged aquatic vegetation* - The emergent and submerged aquatic macrophytes were sampled and recorded. Specimens were collected and treated similarly to those of fringing vegetation apart from the more delicate submerged plants which were preserved in 10% formalin pending identification.

iii) *Phytoplankton* - Samples were taken to determine the concentration of phytoplankton and major genera present. For identification purposes a known quantity of water, up to 20 L was passed through a 20 µm mesh net, the retained material resuspended in filtrate, one half stored in 10% formalin and the remainder preserved with Lugol's solution. Larger filamentous and macroscopic algae were collected and preserved in 10% formalin.

A known volume of water, up to 2L, was filtered through a Whatman 4.5 cm diameter GF/C filter, frozen and analysed for chlorophyll a and phaeophytin in the laboratory according to the methods of Atkins *et al.* (1978), and the formulae of Strickland and Parsons (1972).

iv) *Benthic microalgae* - Three subsamples were taken from the frozen surface sediment (see section 2.4), extracted in 90% acetone, partitioned into hexane to remove chlorophyllides and analysed for chlorophyll a and phaeophytin according to the methods of Whitney and Darley (1979).

(v) *Fauna* - A limited faunal survey was performed by recording non-passerine birds, and fish.

2.4 NUTRIENT CHARACTERISTICS

Surface water samples were collected and stored in 150 mL sealable polyethylene bags (Nasco 6oz. 'Whirlpaks'). Subsamples were filtered through Whatman 4.5 cm diameter GF/C filters. The samples were stored unfrozen in the dark and analysed for total nitrogen (TN), total filtered nitrogen (TNF), total phosphorus (TP) and total filtered phosphorus (TPF) at the Nutrient Analysis Laboratory, Department of Botany, the University of Western Australia following the methods outlined in Atkins *et al.* (1978).

Sediment samples were collected from shallow areas (beneath water some 15 cm deep) using Duranol uc30 vials with holes drilled in the base to allow water to escape as the vial was pushed into the sediment. The vials, containing cores, were withdrawn from the sediment and capped. On return to camp they were allowed to slide from the vial and the top 5 mm of 6 replicate cores from each site bulked together, placed in a Whirlpak and frozen. These were later thawed, mixed thoroughly, subsampled, weighed and dried at 110°C to calculate wet to dry weight ratios, and analysed for TN and TP content using the Nutrient Analysis Laboratory, UWA standard methods.

3. RESULTS AND DISCUSSION

3.1 GENERAL

The location of surface waters visited, and a summary of their land status and usage is presented in Table 1. Figure 1 shows the locations of sampling sites visited during this survey. In comparing the data with those of the1983 survey, it is important to note that the time of year was different, this survey being conducted late during the dry season, the first survey late during the wet season.

3.2 AREA AND DEPTH

The area and depth of an inland water body at any given time depends on the nature of the substratum, gradient of the bed, water source and time elapsed since the last major rainfall event in the catchment. In the face of higher evaporation than precipitation (IWP, Part 1), permanent water bodies linked to an aquifer tend to exhibit less fluctuation in water depth, and may be deeper than water bodies that are totally dependent on runoff. In the dry season, the open water of spring systems occupies the greatest area compared with any other wetland type.

Flood levels in the Ashburton and Oakover/DeGrey River systems and catchments, as gauged by debris on the banks and caught in trees, were between 1.5-2.5m above dry season levels. This is comparable to previous observations (IWP Part 1).

3.3 PHYSICAL CLASSIFICATION OF SURFACE WATERS

The thirty-one sites surveyed during the 1984 field work were mainly permanent to semi-permanent wetlands in rivers, springs and gorges (Table 2) representing type 1 and type 2 wetland types (IWP, Part 1).

3.4 WATER QUALITY

Results of water quality sampling are presented in Table 3. Sampling sites are arranged in order of increasing distance upstream, either along the major river systems or within their associated catchments.

Table 1: Name, location and status of wetland sites studied in the survey, October-November 1984.

Site No	Name	Map Number and Name 1:100,000 Series	Map Coordinates E	N	Land Use	Station Name	Lease	Reserves
1.	Nanutarra Crossing	1952:Uaroo	052	457	Pastoral	Nanutarra	3114 1096	Stopping place for travellers and stock 1114(Watering stock)
2.	Wagoon Pool	2251: Capricorn			Pastoral	Kooline	3114 705	
3.	Ashburton River Pool	2251:	1:100,000 Maps Not Available		Pastoral	Ashburton Downs	3114 1132	
4.	Ashburton Claypan	2251:			Pastoral	Kooline	3114 705	
5.	Hamersley Gorge	2453: McRae	016	382				
6.	Yampire Gorge 1	2553: Wittenoom	498	234				
7.	Yampire Gorge 2	2553: Wittenoom	515	255				
8.	Above Fortescue Falls	2653: Mt George	593	134	HAMERSLEY RANGE NATIONAL PARK			
9.	Below Fortescue Falls	2653: Mt George	592	134				
10.	Dales Gorge	2653: Mt George	607	130				
11.	Circular Pool	2653: Mt George	606	134				
12.	Hooley Creek	2454: Mount Bilroth	030	795	Pastoral	Mt Florance	3114 465	5155 (Water) 259ha
13.	Coondiner Pool	2852: Roy Hill	729	842	Pastoral	Marillana	3114 984	
14.	Yandearra Pool	2555: Satirist	461	522				
15.	Yanrey Road Crossing	2555: Satirist	428	472				
16.	Warden Pool	2555: Satirist	367	445	RESERVE 31427. USE AND BENEFIT OF ABORIGINALS			
17.	Friendly Creek Dam	2555: Satirist	380	498				
18.	Red Rock Creek	2756: Carlindi	165	220	Pastoral	Carlindie	3114 638	
19.	Nullagine River Pool	2954: Nullagine	300	024				

Table 1: Name, location and status of wetland sites studied in the survey, October-November 1984 (Cont).

Site No	Name	Map Number and Name 1:100,000 Series	Map Coordinates E	N	Land Use	Station Name	Lease		Reserves
20.	Cooke Creek	3054: Eastern Creek	438	014					
21.	Coppin Gap	2956: Muccan	000	878	Pastoral	Yarrie	398	723	Preservation of natural formation(259 ha)
22.	Moolyella Mines 1	2855: Marble Bar	009	601	Mining	Reserve 7080:Stopping place for travellers and stock.			
23.	Moolyella Mines 2	2855: Marble Bar	008	605	Mining	Reserve 28380: Native ceremonial ground			
24.	Marble Bar Dredge	2855: Marble Bar	999	567	Mining				
25.	Lower Carawine Pool	3155: Braeside	955	230	Pastoral		398	653	
26.	Upper Carawine Pool	3154: Pearana	020	158	Pastoral				
27.	Running Waters	3154: Pearana	065	014	Pastoral				On stock route
28.	Yownama Creek	3155: Braeside	080	426	Pastoral	Warrawagine	3114	1094	
29.	Skull Springs 1		940	804					
30.	Skull Springs 2	3154: Pearana	940	806	Pastoral	Wandanya	3114	979	
31.	Skull Springs 3		940	807					

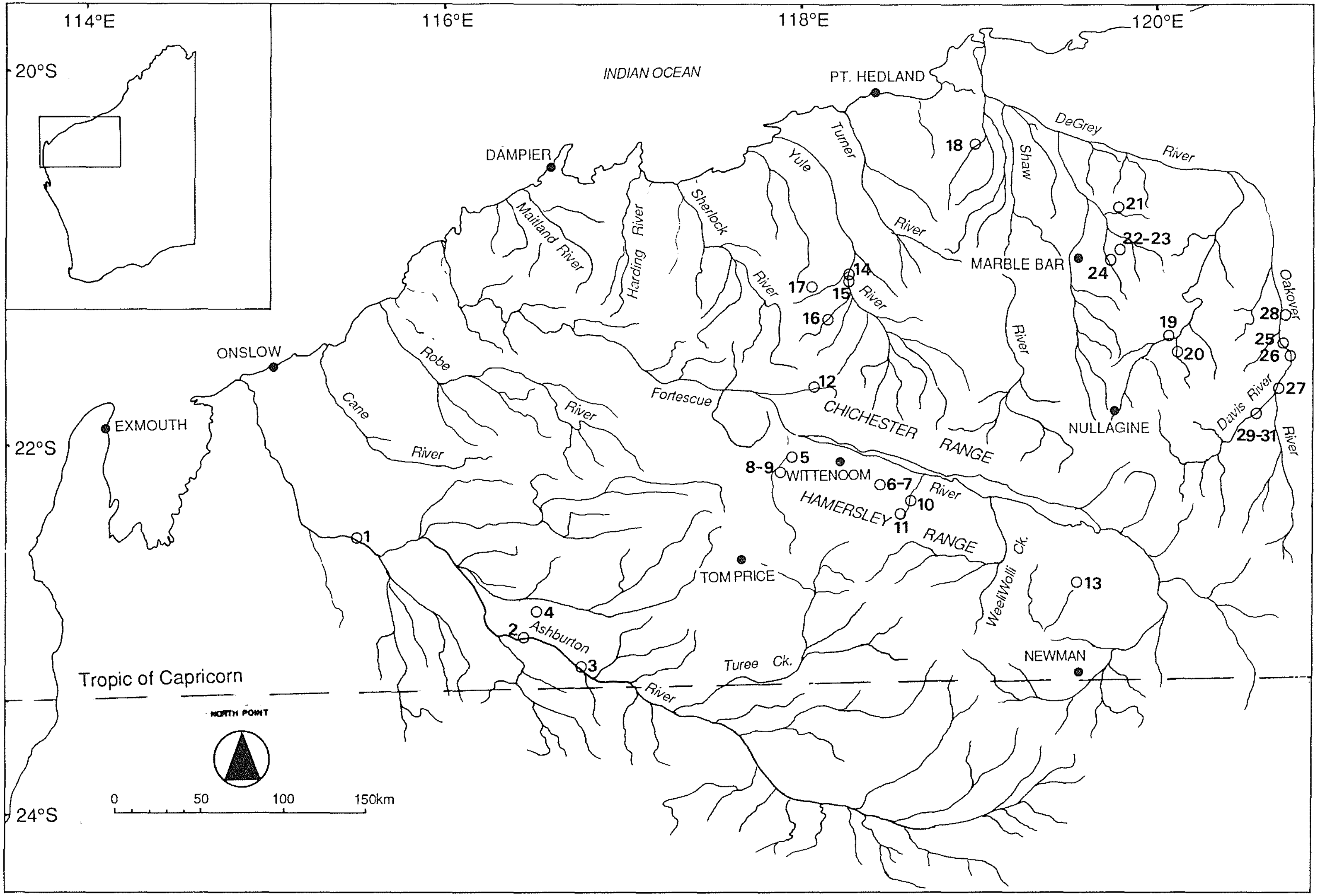

Figure 1. Map of the Pilbara region showing the location of sampling sites visited during October-November, 1984.

Table 2: Wetland sites of the Pilbara (sampled in October-November 1984) classified according to characteristic water source, relationship to groundwater, persistence, gradient of bed and predominant substrate.

Wetland Type and Number	Water Source *	Relationship to Groundwater	Persistence	Gradient of Bed	Predominant Substrate Type	 Permeability	Site Name and Number
1. SPRING	Aquifer	Water table at surface	Permanent	Steep - medium	Shallow bedrock Unsorted alluvium	Very low High	Hamersley Range National Park (5-11) Running Waters(27) Skull Springs (29-31)
2. PRIMARY RIVER POOL	Residue from river flow, bank storage Occasionally maintained by groundwater	Water table often shallow- ie .less than 2m for most of the year	Permanent- semi-perm.	Low	Variable: upper catchment bed-rock and fine to medium alluvium; lower catchment fine -grained alluviums	Mixed-low	Nanutarra Crossing (1) Wagoon Pool (2)) Ashburton River Pool (3) Hooley Creek (12) Yandearra Pool (14) Yanrey Road Crossing (15) Warden Pool (16) Nullagine River Pool (19) Cooke Creek (20) Coppin Gap (21) Lower Carawine Pool (25) Upper Carawine Pool (26) Yownama Creek (28)
3. HEADWATER STREAM OR DRAINAGE CHANNEL	Runoff from catchment after rain	Ill-defined perched water-table, shallow	Ephemeral intermittent	Steep - medium	Coarse, unsorted alluvium over bedrock	High Very low	
4. PRIMARY RIVER CHANNEL	Rainfall in catchment via stream flow	Watertable greater than 2m in depth	Ephemeral	Medium-low	Thin layer of fine colloidal material (cracks on drying) over-lying medium coarse-grained alluviums	Clay-low	

Table 2: Wetland sites of the Pilbara (sampled in October-November 1984) classified according to characteristic water source, relationship to groundwater, persistence, gradient of bed and predominant substrate. (Cont.)

Wetland Type and Number	Water Source *	Relationship to Groundwater	Persistence	Gradient of Bed	Predominant Substrate		Site Name and Number
					Type	Permeability	
5. ADJOINING POOL	Stream over-flow (outside true drainage channel)	Unknown	Ephemeral-intermittent	Effect-ively nil	Fine-grained alluvium	Low	Red Rock Creek (18)
6. EPHEMERAL CLAYPAN	Local runoff via sheet flow or seepage	Variable- unknown	Ephemeral-intermittent	Effect-ively nil	Fine-grained alluviums	Low	Ashburton Claypan (4)
7. SEMI-PERMANENT CLAYPAN	On slight drainage line local runoff & catchment	Unknown	Semi-permanent	Effect-ively nil	Medium to Fine-grained alluviums	Low	Coondiner Pool (13)
8. TIDAL REACH	Ocean via tide	Often below watertable	Permanent	Effect-ively nil	Fine -grained alluvium	Low	
9. ARTIFICIAL WETLAND	Variable-often altered drainage line	Unknown	Variable	Effect-ively nil	Variable	Usually low	Friendly Creek Dam (17) Moolyella Mines (22-23) Marble Bar Dredge (24)

* Water source in addition to direct input from rainfall and local runoff.

Table 3: Physico-chemical properties (air temperature, water temperature, pH, conductivity, total dissolved salts and turbidity) of inland waters of the Pilbara, October-November 1984.

	Site Number	Temp °C Air	Water	pH	COND. @25°C	TDS mg/L	TSS ppm
Ashburton River System							
Nanutarra Crossing	1.	35.5	29.1	8.71	128.1	801	5.97
Wagoon Pool	2.	34.5	27.2	8.64	84.8	530	40.82
Ashburton River Pool	3.	29.3	21.2	8.37	15.5	97	7.93
Fortescue River Catchment							
Hamersley Gorge	5.	30.5	23.4	8.36	66.5	416	0.90
Yampire Gorge 1	6.	29.9	25.2	8.07	20.7	129	18.00
Yampire Gorge 2	7.	29.9	25.0	8.51	164.0	1025	-
Above Fortescue Falls	8.	30.9	26.0	8.44	47.0	294	0.87
Below Fortescue Falls	9.	30.6	25.2	8.33	48.2	301	1.30
Dales Gorge	10.	30.6	27.3	9.54	27.5	172	18.95
Circular Pool	11.	27.8	20.5	8.35	30.9	193	0.50
Hooley Creek	12.	23.9	21.1	8.63	128.1	801	2.42
Coondiner Pool	13.	23.4	11.8	8.61	9.6	60	25.33
Yule River System							
Yandearra Pool	14.	33.3	27.4	9.14	45.8	286	-
Yule River Catchment							
Yanrey Road Crossing	15.	32.9	26.8	9.17	125.2	783	3.10
Warden Pool	16.	27.9	26.4	9.38	116.1	726	2.60
Friendly Creek Dam	17.	37.3	27.4	10.24	30.9	193	2.77
DeGrey River Catchment							
Nullagine River Pool	19.	24.0	22.0	7.97	40.9	256	1.55
Cooke Creek	20.	34.5	17.5	8.28	38.6	241	2.60
Coppins Gap	21.	39.2	23.9	8.41	217.5	1357	31.93
Moolyella Mines 1	22.	36.3	24.9	8.59	40.8	255	117.63
Moolyella Mines 2	23.	41.4	30.0	9.27	273.2	1708	22.00
Marble Bar Dredge	24.	41.3	31.3	9.20	338.4	2155	8.80
Oakover River System							
Lower Carawine Pool	25.						
	Surface	35.0	25.9	8.59	91.9	574	-
	1.0m	35.0	25.6	8.59	93.3	583	-
	2.0m	35.0	25.0	8.58	93.1	582	-
	3.0m	35.0	22.8	-	-	-	-
	3.5m	35.0	22.4	7.95	95.7	598	-
	5.0m	35.0	21.4	7.80	99.1	619	-
	8.0m	35.0	19.8	8.10	110.0	688	-
Upper Carawine Pool	26.	27.8	24.3	8.87	142.7	892	3.43
Running Waters	27.	41.6	32.4	8.51	121.0	756	4.60
Oakover River Catchment							
Yownama Creek	28.	27.1	22.9	9.53	115.6	723	161.00
Skull Springs 1	29.	39.5	28.5	8.02	42.2	264	-
Skull Springs 2	30.	39.5	28.3	8.16	47.0	294	2.60
Skull Springs 3	31.	39.5	28.4	7.50	62.1	388	4.94

3.4.1 WATER TEMPERATURE

The temperature of water bodies varies both seasonally and diurnally (Bayly and Williams, 1977). Diurnal variations are greatest in shallow, unshaded surface waters where water temperatures follow those of air (Williams, 1983) as seen at Coondiner Pool (site 13) where a temperature of 11.8°C was recorded in the early hours of the morning, indicating pronounced night-time heat loss in this large, shallow, unshaded semi-permanent claypan. Deep pools are more buffered to temperature change due to their small surface area to volume ratios reducing heat exchange capacity (Williams, 1983). Vertical temperature stratification was evident in relatively deep waters such as Lower Carawine Pool, site 25 (Figure 2).

Deep stratified water bodies, with greater thermal stability than shallow exposed areas should have a broader range of stable thermal niches and hence potential for greater aquatic species richness.

3.4.2 pH

pH values ranged from 7.50 at Skull Springs (site 31) to 10.24 at Friendly Creek Dam (site 17) with most water bodies having a pH between 8 and 9. The pH of artificial systems was shown to be significantly higher (0.05 confidence limit) than the natural systems examined, using the non-parametric U- test of Mann-Whitney (Snedecor and Cochran, 1979).

pH is usually not well buffered in freshwater systems because of low concentrations of dissolved ions. Catchment soil and sediment types influence surface water pH, but during the dry season with little or no runoff, it is likely that pH will be controlled by carbon fixation and utilization rates. The progressive removal of carbon dioxide from freshwater via photosynthetic fixation increases pH, while respiration and the subsequent release of CO_2 decreases pH. For example, the Moolyella mine sites with medium to high relative phytoplankton levels (sites 23 and 24), had high pH levels during the day, indicative of higher rates of photosynthesis than at site 22 which had little phytoplankton and no submerged or emergent macrophytes. Furthermore, a vertical profile through the water column at Lower Carawine Pool (site 25), showed a high pH in the mixed layer which is indicative of higher primary productivity (Figure 2).

The relationship between free CO_2 and pH may be determined at known temperature, conductivity and alkalinity. The interrelationship between physical and biological parameters in the water column is elaborated on further in section 3.5.2

3.4.3 CONDUCTIVITY

Conductivities ranged from 9.6 mS/m at Coondiner Pool (site 13) to 338.4 mS/m at site 24, an artificial wetland near Marble Bar. Most waters showed conductivities between 50 and 150 mS/m. Conductivity is directly related to water density, and in deep waters such as Lower Carawine Pool, site 25, conductivity was lowest in the surface layers and increased with increasing water depth (Figure 2).

Using the relationship between conductivity and total dissolved salts as outlined in the methods, most waters had TDS loads of between 300 and 1000 mg/l, and were therefore 'fresh' as defined by Bayly and Williams, (1977).

3.4.4 TOTAL SUSPENDED SOLIDS (TSS)

TSS varied markedly over the range of wetlands surveyed, ranging from 0.5 ppm at Circular Pool (site 11) to 161 ppm at Yownama Creek (site 28), with most waters being less than 5 ppm. Waters are generally more turbid during the wet season when fine colloidal particles are brought into suspension after rain or water flow. During the dry season most waters are standing, suspended material settles and turbidities are low (Williams, 1983). The average turbidity of waters sampled during the wet season in 1983 was 79.6 ppm (IWP 1983) in contrast to an average turbidity of 19.6 ppm measured in this survey in the dry season.

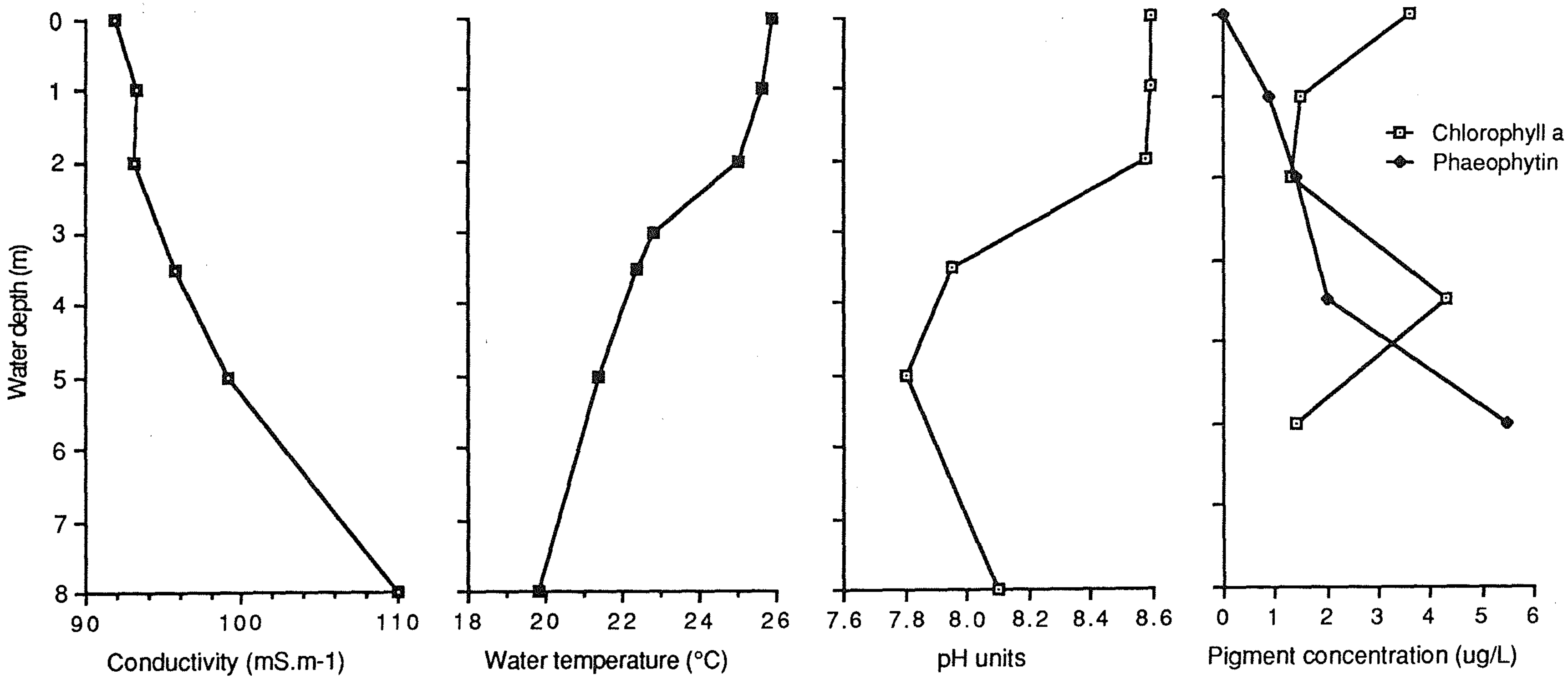

Figure 2. Vertical water column profile of Lower Carawine Pool (site 25) sampled during the course of the survey, October-November 1984 showing vertical conductivity, temperature, pH, chlorophyll a and phaeophytin stratification.

The degree to which suspended particles settle may depend on a number of factors. Water column total phosphorus concentrations (See Section 3.7 and Table 10) were significantly correlated with TSS (r = 0.98). However, much of the total phosphorus was not removed by filtration (Table 10), and so the phosphorus may not for the most part be bound to the suspended solids. Perhaps high amounts of suspended material reduced light penetration through the water column to levels which limited aquatic plant growth and so phosphorus assimilation. Turbidity may also be related to the salt concentration of a water body due to the salting out of non-electrolytes (ie faster flocculation rate) (Kolthoff *et al.* 1969). As pools evaporate during the dry season, the level of total dissolved salts increases. The lower turbidities recorded in this survey may be due in part to the slightly higher conductivities recorded in 1984 (average of 91.9 mS/m) in contrast to 1983 (average of 73.1 mS/m, excluding the sites under tidal influence).

3.5. FLORA

3.5.1 MACROPHYTES

More than 200 plant species were collected from the wetlands surveyed during 1984 (Appendix 1). When incorporated with the 1983 collection, the total number of species collected is over 300.

Identification to species and in some cases generic level proved difficult, in many cases due to a lack of flowering or fruiting material. The species lists for each site are representative of the areas surveyed and for the season at which the material was collected, although the number of species would undoubtedly increase if collections were made at different times of the year.

Floral species richness is a measure of the total number of different flowering plant species within a defined area and can be useful for comparative purposes, such as in this case where it is used to compare different wetland types. The sampling methods used in 1983 and in this study were identical, and so for this analysis the data sets were pooled.

The species richness data (Figure 3) shows headwater streams (mean=32.5, n=2) and adjoining pools (mean=28.7, n=3)to be the most diverse of the wetland types considered, but the low number of sites in each of these groups should be noted. Of the three data sets available for adjoining pools, one is for Red Rock Creek during the wet season of 1983 when 49 species were collected, and another is for the same site sampled in the dry of 1984, when only 9 species were collected; many wetland plant species are ephemeral, responding to the presence of water and not persisting in dry conditions.

The low species richness of tidal areas (wetland class 8) was calculated from data collected in 1983 from only three sites, and may therefore be atypical. Detailed work on these complex interfaces between land and sea was beyond the scope of this study, but nonetheless these areas are important and require further attention (Gordon, 1986).

A 1-way analysis of variance was performed on the data to determine if there were any significant differences in species richness between the wetland classes (Figure 4). Wetland types 3, 5 and 8 were excluded from the analysis because of their small sample sizes. Two groups emerged as being significantly different from each other; wetland classes 1G ('gorge' springs), 1R ('river' springs) and 2 (primary river pools) in one group, and classes 4 (primary river channels), 6 (ephemeral claypans), 7 (semi-permanent claypans) and 9 (artificial wetlands) in the other. Although springs were divided into two sub-classes on the basis of their association with either gorge or river systems (1G and 1R respectively) (see section 4), this result showed that both types had remarkably similar plant diversities, not justifying their subdivision on this criterion alone.

The affinities in species richness of the artificial wetlands studied to that of ephemeral and semi-permanent claypans reflects their structure as depressions along slight drainage lines of low relief where water collects after rain. This suggests that their role and function, analogous to naturally occurring claypans, has been primarily dictated by their geomorphology.

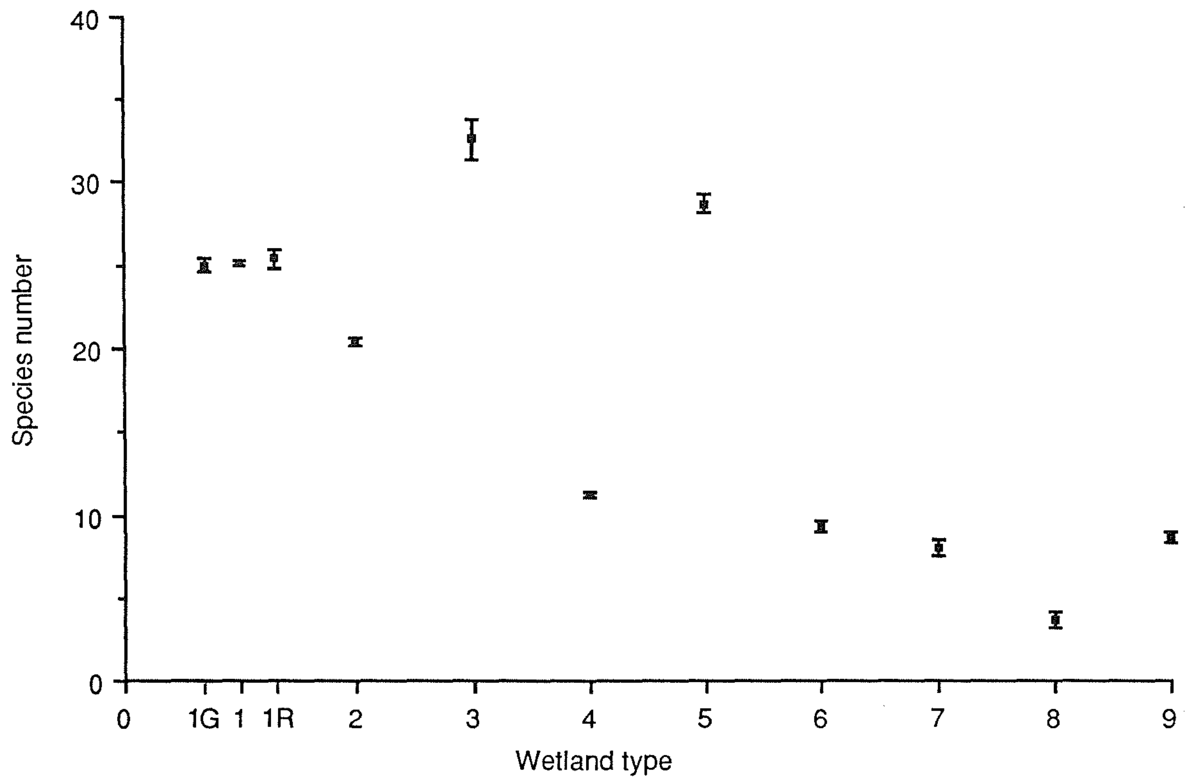

Figure 3. Floral species richness data (1983 and 1984) for wetland classes 1-9.

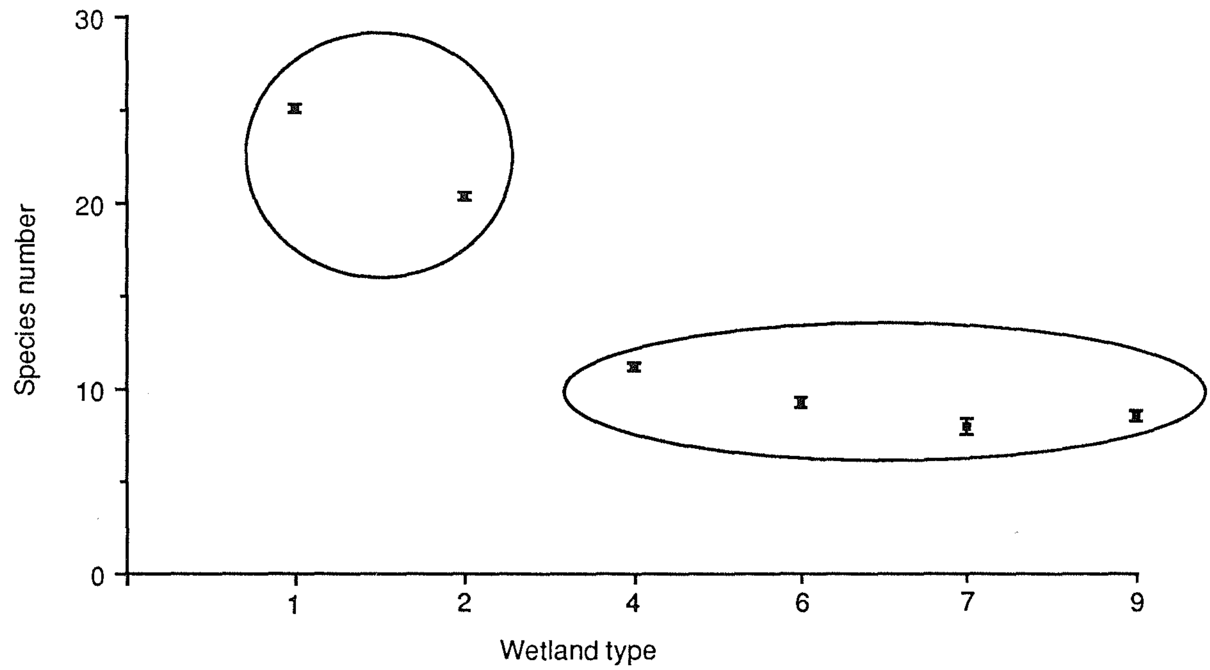

Figure 4. Analysis of variance for floral species richness for selected wetland class groups.

The analyses of the species richness data reinforces the earlier physical classification. The major physical difference between the above groups is water persistence which reflects its availability to dependent biota. Wetland classes 1G, 1R and 2 have permanent/semi-permanent water supplies compared with the remainder (classes 4,6,7 and 9) which range from semi-permanent to intermittent (see Table 2).

3.5.2 PHYTOPLANKTON

Phytoplankton genera collected are listed in Table 4. Chlorophyta, Cyanophyta and Chrysophyta (Diatomaceae) all appear in 89% of the waters sampled. Although the dominance of different algal genera may be indicative of different ecological conditions, and while many generalisations may be made (eg the presence of the Charales as an indicator of relatively alkaline conditions, Prescott 1966), marked fluctuations over time in numbers (biomass), species composition and photosynthetic activity are typical features of phytoplankton populations. Long term investigations, incorporating both diurnal and seasonal measurements, would be necessary before the composition of phytoplankton populations could become a significant component of a classification system.

Chlorophyll a concentrations are a readily measured and reasonably accurate measure of phytoplankton biomass. Most water column chlorophyll a concentrations were below 5 µg/L and were higher than the concentration of the degradation product, phaeophytin (Table 5). The vertical chlorophyll profile in the water column was examined for Lower Carawine Pool (site 25) in association with physico-chemical parameters (Figure 2). The data for temperature and pH show that this water body was stratified, with a diurnally mixed layer 2-3 m deep. Chlorophyll a concentrations showed two peaks, one at the surface, the other under the mixed layer at 3.5m. As there is effectively no water movement between this layer and the surface, it is unlikely that the population at 3.5 m is a result of sedimentation of cells from above, but suggests that it is a discrete population.

3.5.3 BENTHIC MICROALGAE

The role of benthic microalgae in aquatic ecosystems is poorly understood, but recent work, particularly in estuarine systems has shown this component of the aquatic flora to be important in the total primary production (Admiraal, 1980; Masini, 1986).

The best estimate of benthic algal biomass is achieved by measuring chlorophyll a concentrations and expressing these on a dry weight or unit area basis (Table 5). This method has disadvantages because it does not differentiate between chlorophyll a of the benthic microalgae and that derived from other sources such as phytoplankton that has sedimented out of the water column, aquatic or terrestrial higher plant material. The method does however measure functional chlorophyll a and hence is directly relevant to photosynthetic potential.

Although the role of these primary producers in the food chain of inland surface waters in the Pilbara is still to be determined, it is likely they provide a food source for benthic fauna and hence indirectly for organisms at higher trophic levels. In shallow clear water, typical of the water bodies surveyed during the dry season, the photosynthetic potential of benthic microalgae is quite high. Most waters were less than 1m deep when surveyed, but assuming an average water depth of 1m to estimate chlorophyll a in the water column on an areal basis, averages of 11.34 mg chl a/m^2 and 35.6 mg chl a/m^2 were obtained for phytoplankton and benthic microalgae respectively. Because the data set is limited (one season and seventeen sites), it is difficult to compare these values with published values for other water bodies. However, the phytoplankton chlorophyll a falls within the range 0-15 mg/m^3 of values obtained for Lake Hume 1974-1976, (Walker and Hillman, 1977).

The community structure and species diversity of benthic microalgae and phytoplankton have been used as indicators of environmental perturbation (Stevenson, 1984) and the trophic level of lakes (Brugum, 1983). Knowledge of changes in species composition may prove useful in the management of the wetland resources of the Pilbara.

Table 4: Phytoplankton collected from Pilbara inland waters, October-November 1984.

	Site Number																										
	1	2	3	5	6	7	8	10	11	12	13	14	15	16	17	19	20	21	22	23	24	25	26	27	28	29	31
CHLOROPHYTA																											
Ankistrodesmus sp.			+									+					+	+									
Characium sp.			+																								
Chlorella sp.																+	+										
Chlorococcum sp.								+																			
Cladophora sp.																						+					
Closterium sp.													+														
Cosmarium sp.										+			+	+	+	+	+								+		+
Desmidium sp.				+								+															
Dictyosphaerium sp.			+																								
Eudorina sp.			+																								
Franceia sp.			+																								
Golenkina sp.			+																								
Mougeotia sp.										+								+									
Pediastrum sp.			+						+					+		+	+	+									
Planktosphaera sp.																								+			
Pleurodinium sp			+																								
Pleurotium sp.											+		+														
Oedogonium sp.	+		+					+	+	+	+	+	+	+		+		+					+				
Ulothrix sp.																											
Scenedesmus sp.			+									+	+	+		+	+	+			+			+	+		
Spirogyra sp.			+			+			+								+	+		+			+				+
Staurastrum sp.			+							+		+	+	+	+		+										
Tetraedron sp.										+																	
Zygnema sp			+	+	+		+										+										
EUGLENOPHYTA																											
Phacus sp.																											
Trachelomonas sp.													+														

Table 4: Phytoplankton collected from Pilbara inland surface waters, October-November 1984 (Cont).

	Site Number																										
	1	2	3	5	6	7	8	10	11	12	13	14	15	16	17	19	20	21	22	23	24	25	26	27	28	29	31
CYANOPHYTA																											
Anabaena sp.										+	+	+	+	+	+	+	+				+	+			+		
Anacystis sp.			+	+																				+			
Aphanocapsa sp.			+																								
Chroococcus sp.			+	+			+	+		+		+	+	+	+		+							+			
Elaktothrix sp.												+															
Elormogones sp.												+															
Geminella sp.																							+				
Gomphoshaeria sp.																											+
Lyngbya sp.																		+									
Merismopedia sp.	+		+							+			+	+	+		+						+				
Nostoc sp.					+																						
Oscillatoria sp.	+	+	+		+		+	+	+			+	+	+		+	+	+	+		+			+	+	+	+
Phormidium sp.																				+							
Pleurotanium sp.																											
Rhizoclonium sp.																	+										
Rhizoclavium sp.																											
Scytonema sp.												+				+											
Spirulina sp.	+																	+							+		
PYRRHOPHYTA																											
Glenodinium sp.														+			+										
Peridinium sp.			+											+			+	+									
XANTHOPHYTA																											
Vaucheria sp.																		+									
DIATOMACEAE	+		+	+	+	+	+	+	+	+		+	+	+		+	+	+	+	+	+	+	+	+	+	+	+
CHARALES	+	+									+	+		+				+				+		+			+

Table 5: Chlorophyll a, phaeophytin of inland waters and chlorophyll a, phaeophytin and wet/dry weight ratios of wetland sediments of the Pilbara, October-November 1984.

	Site Number	Water Column chl a µg/L	Water Column phaeo µg/L	Sediments chl a µg/gdwt	Sediments phaeo µg/gdwt	Sediments chl a mg/m	Sediments phaeo mg/m	Sediments wet/dry wt.ratio
Ashburton River System								
Nanutarra Crossing	1.	1.7	0.7	2.6	4.1	14.6	22.6	1.7
Wagoon Pool	2.	10.0	3.9	4.6	8.4	11.1	20.5	2.8
Ashburton River Pool	3.	4.1	1.3	1.8	2.1	13.9	16.0	1.4
Fortescue River Catchment								
Hamersley Gorge	5.	1.7	1.3	-	-	-	-	-
Yampire Gorge 1	6.	0.8	0	-	-	-	-	-
Yampire Gorge 2	7.	-	-	-	-	-	-	-
Above Fortescue Falls	8.	0.6	0	-	-	-	-	-
Below Fortescue Falls	9.	0.3	0	-	-	-	-	-
Dales Gorge	10.	-	-	-	-	-	-	-
Circular Pool	11.	1.1	0.2	-	-	-	-	-
Hooley Creek	12.	1.7	0.2	7.5	12.1	43.8	70.0	1.6
Coondiner Pool	13.	6.1	5.2	1.3	3.0	6.3	14.3	1.8
Yule River System								
Yandearra Pool	14.	4.8	3.5	14.7	3.1	28.7	19.0	1.6
Yule River Catchment								
Yanrey Road Crossing	15.	5.3	1.6	4.1	4.8	16.8	19.7	1.9
Warden Pool	16.	8.1	0.9	2.1	2.1	12.7	12.3	1.5
Friendly Creek Dam	17.	3.0	0.6	-	-	-	-	-
DeGrey River Catchment								
Nullagine River Pool	19.	4.8	3.5	14.7	3.1	28.7	19.0	1.6
Cooke Creek	20.	5.1	2.2	-	-	-	-	-
Coppins Gap	21.	2.0	0.9	2.3	2.7	15.7	18.1	1.4
Moolyella Mines 1	22.	5.0	2.5	1.6	2.6	9.5	15.5	1.5
Moolyella Mines 2	23.	8.5	0	3.9	2.3	25.5	15.3	1.8
Marble Bar Dredge	24.	4.3	1.0	46.5	95.6	53.4	109.8	4.2
Oakover River System								
Lower Carawine Pool	25.			0.5	2.9	3.7	20.6	1.5
	Surface	3.6	0	-	-	-	-	-
	1.0m	1.5	0.9	-	-	-	-	-
	2.0m	1.3	1.4	-	-	-	-	-
	3.5m	4.3	2.0	-	-	-	-	-
	5.0m	1.4	5.5	-	-	-	-	-
Upper Carawine Pool	26.	0.9	0.4	-	-	-	-	-
Running Waters	27.	0.8	0.6	86.0	106.6	85.9	106.5	6.5
Oakover River Catchment								
Yownama Creek	28.	85.4	27.8	24.5	41.4	70.8	119.5	2.1
Skull Springs 1	29.	0.6	0.8					
Skull Springs 2	30.	44.7	2.8	41.4	54.6	179.7	237.3	2.0
Skull Springs 3	31.	0.9	0.4					
	Mean(x)	8.1	2.6	14.2	20.2	34.9	50.1	2.1
	S.D.	17.6	5.6	22.6	32.8	43.0	59.2	1.3
	n	27	28	18	18	18	18	18

3.6. FAUNA

3.6.1 AQUATIC MACROFAUNA

Table 6, produced from data collected in 1983 and 1984, shows clearly the diversity of fish occurring in spring systems. Although not evident from Table 7, it was noted that highland spring systems with pools separated by physical barriers such as waterfalls did not show the diversity characteristic of lowland spring systems. Being physically isolated from other permanent water bodies, highland springs have lower seasonal recruitment capabilities than springs along river systems, which often have interconnections through intermittent river flow. For example, anecdotal evidence suggests the presence of barramundi (*Lates calcarifer*) at Lower Carawine Pool (site 25). It is likely that primary river pools (wetland class 2) will, at certain times of the year, contain most of the fish species recorded for springs, as well as more estuarine species when closer to the coast.

3.6.2 BIRDS

During the course of field work in 1984, 33 species of birds were observed in association with the Pilbara wetlands (Table 7); 17 of these species were also observed in the 1983 survey.

It should be noted that this is not an exhaustive species list as, in line with IWP part 1, only the larger, more obvious species were recorded.

A summary of the total number of bird species observed at the 9 wetland classes over both studies (1983 and 1984) is presented in Table 8. Springs (wetland class 1), primary river pools (wetland class 2) and semi-permanent claypans (wetland class 7) had the greatest diversity of birds associated with them, but there was no significant difference in the number of bird species per sampling site between any wetland types (Table 9).

Table 9: Mean number of birds species observed during the classification of inland waters of the Pilbara,over both periods of the study, March-April 1983 and October-November, 1984.

wetland class	n	mean	± s.e.
1	9	6.89	1.18
3	12	6.17	1.08
4	4	3.00	0.81
7	6	6.33	1.91
9	3	6.33	1.47

From these data it appears that areas of permanent to semi-permanent surface water exhibit greater bird species diversity than less permanent water bodies. It is likely that during the wet season, when ephemeral water bodies form, birds range more widely than in the dry season. As these ephemeral water bodies dry, birds dependent on water will either contract their range locally to more permanent water bodies, or migrate to other regions.

During wet seasons which have below-average rainfall and during subsequent dry seasons, areas of permanent and semi-permanent water will come under increased use from water birds and other water-dependent fauna.

Table 6. Summary of aquatic macrofauna observed at the 9 wetland classes identified during the classification of the inland waters of the Pilbara, over both periods of the study. March-April 1983 and October-November 1984.

	WETLAND TYPE							
Fish Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**
Western Rainbow Fish *Melanataenia splendida australis* (Castelnau)	+	+	+	+			+	+
Barred Grunter *Amniataba percoides* (Gunther)	+	+	+	+			+	
Spangled Perch *Leiopotherapon unicolor* (Gunther)	+							+
Fortescue Grunter *Leiopotherapon aheneus* (Mees)	+		+					
Fork-tailed Catfish *Arius australis* (Gunther)	+							
Eel-tail Catfish *Neosilurus hyrtlii* (Steindachner)	+					+		
Freshwater Mullet	+							
Freshwater Herring *Nematalosa erebi* (Gunther)	+		+	+				
Tadpoles					+			
Molluscs	+		+			+		
Crustacea				+	+			

Table 7. Bird species observed at 19 Pilbara wetland sites. October-November 1984.

Common Name	Scientific Name	Site number 1	2	3	4	12	13	14	15	16	17	19	20	21	23	25	26	27	28	30
Australian Little Grebe	*Podiceps novaehollandiae*								+											
Australian Pelican	*Pelicanus conspicillatus*							+		+									+	
Cormorant	*Phalacrocorax sp.*					+		+		+	+	+			+	+	+	+		+
White-necked Heron	*Ardea pacifica*	+	+					+			+					+	+			+
White -faced Heron	*Ardea novaehollandiae*									+			+	+	+	+		+		
White Egret	*Egretta alba*										+									
Jabiru Stork	*Xenorhynchus asiaticus*														+					
Straw -necked Ibis	*Threskiornis spinicollis*						+													
Black Swan	*Cygnus atratus*										+									
Black Duck	*Anas superciliosa*	+				+	+			+	+	+			+		+			+
Grey Teal	*Anas gibberifrons*								+											
Eagle		+	+						+											

Table 7. Bird species observed at 19 Pilbara wetland sites. October-November 1984 (Cont).

Common Name	Scientific Name	Site number 1	2	3	4	12	13	14	15	16	17	19	20	21	23	25	26	27	28	30
Black-tailed Native hen	*Gallinula tenebrosa*	+					+													
Black -fronted Dotterel	*Charadrius melanops*					+	+			+	+			+	+					
Sandpiper																				+
Black -winged Stilt	*Himantopus himantopus*														+					
Peaceful Dove	*Geopelia placida*		+																	
Red-plumed Pigeon	*Lophophaps plumifera ferruginea*		+	+													+		+	
Little Corella	*Cacatua sanguinea*	+	+	+		+	+	+		+		+			+	+	+	+	+	+
Galah	*Eolophus roseicapillus*	+	+	+			+					+					+			
Cockatiel	*Nymphicus hollandicus*			+																
Port Lincoln Parrot	*Barnardius zonarius*																+			

Table 7. Bird species observed at 19 Pilbara wetland sites. October-November 1984 (Cont).

Common Name	Scientific Name	1	2	3	4	12	13	14	15	16	17	19	20	21	23	25	26	27	28	30
		Site number																		
Budgerigar	*Melopsittacus undulatus*	+		+		+														
Blue-winged Kookaburra	*Dacelo leachii*													+			+			+
Sacred Kingfisher	*Halycon sancta*			+		+	+	+	+	+										+
Rainbow Bee-eater	*Merops ornatus*							+						+						+
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*																			+
Butcherbird	*Cracticus sp.*		+									+					+			
Finch		+			+														+	+
Welcome Swallow	*Hirundo neoxena*		+	+		+														
Willie Wagtail	*Rhipidura leucophrys*													+						
Crow	*Corvus sp.*	+		+				+		+	+								+	+
Magpie -lark	*Grallina cyanoleuca*	+	+	+		+		+		+	+								+	+

* Identifications were made using: Slater, P. (1970). A Field Guide to Australian Birds. Vols 1 and 2. Rigby Limited.

Table 8. Summary of avifauna observed at the 9 wetland classes identified during the classification of the inland waters of the Pilbara, over both periods of the study. March-April 1983 and October-November 1984.

Common Name	Scientific Name	Wetland Class 1	2	3	4	5	6	7	8	9
Emu	*Dromaius novaehollandiae*	+								
Australian Little Grebe	*Podiceps novaehollandiae*	+	+							
Australian Pelican	*Pelicanus conspicullata*	+	+		+					
Cormorant	*Phalacrocorax sp.*	+	+				+	+		+
White -necked Heron	*Ardea pacifica*	+						+		+
White -faced Heron	*Ardea novaehollandiae*	+	+	+			+	+	+	+
White Egret	*Egretta alba*									+
Black Bittern	*Dupetor flavicollis*							+		
Jabiru Stork	*Xenorhynchus asiaticus*		+							+
Straw -necked Ibis	*Threskiornis spinicollis*							+		
Yellow-billed Spoonbill	*Platalea flavipes*							+		
Black Swan	*Cygnus atratus*									+
Black Duck	*Anas superciliosa*	+	+		+		+	+		+
Grey Teal	*Anas gibberifrons*		+							
Pink-eared Duck	*Malacorhynchus membranaceus*				+					
Eagle					+					
Black-tailed Native Hen	*Tribonyx ventralis*		+					+		
Coot	*Fulica atra*		+		+					
Australian Bustard	*Eupodotis australis*								+	
Snipe	*Gallinago sp.*							+		
Black -fronted Dotterel	*Charadrius melanops*	+	+		+		+	+		+
Sandpiper								+		

Table 8. Summary of avifauna observed at the 9 wetland classes identified during the classification of the inland waters of the Pilbara, over both periods of the study. March-April 1983 and October-November 1984. (contd)

Common Name	Scientific Name	Wetland Class 1	2	3	4	5	6	7	8	9
Sandpiper		+								
Black -winged Stilt	*Himantopus himantopus*						+	+		+
Tern (Oceanic)	*Sterna sp.*								+	
Tern (Marsh)	*Chlidonias sp.*				+					
Peaceful Dove	*Geopelia striata*		+							
Red-plumed Pigeon	*Lophophaps plumifera ferruginea*	+	+					+		
Little Corella	*Cacatua sanguinea*	+	+	+	+			+		+
Galah	*Eolophus roseicapillus*	+	+					+	+	
Cockatiel	*Nymphicus hollandicus*		+							
Port Lincoln Parrot	*Barnardius zonarius*	+						+		
Budgerigar	*Melopsittacus undulatus*		+					+		
Cuckoo sp.	*Chrysococcyx sp.*	+								
Blue-winged Kookaburra	*Dacelo leachii*	+	+							
Sacred Kingfisher	*Halycon sancta*	+	+	+	+			+		+
Rainbow Bee-eater	*Merops ornatus*	+								
Welcome Swallow	*Hirundo neoxena*		+		+			+		
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	+								
Australian Crow	*Corvus orru*	+	+					+		
Butcherbird	*Cracticus sp.*	+	+							
Painted Finch	*Emblema picta*	+								
Finch		+	+							
Magpie -lark	*Grallina cyanoleuca*	+	+		+			+		+
Willie Wagtail	*Rhipidura leucophrys*	+	+					+		

* Identifications were made using: Slater, P. (1970). A Field Guide to Australian Birds. Vols 1 and 2. Rigby Limited.

3.6.3 TERRESTRIAL MACROFAUNA

Although not examined in detail during this study, the use of wetlands by macrofauna is by no means insignificant. As well as the ever-present cattle, many mammals, reptiles and insects were observed around the wetlands during field work. Native macropods such as the red kangaroo (*Megaleia rufa*) and the euro (*Macropus robustus*) were commonly observed using the gallery forests around wetlands as shelter during the day, as well as using the wetlands as water sources in early mornings and evenings. Bats were commonly seen and heard hunting insects after dark. Olive pythons commonly occur near water and a large specimen over 3 m long was observed during sampling of the Weeli-Wolli spring system in 1983. The feral donkey (*Equus asinus*) was prevalent in the Oakover/Davis River region. Feral cats (*Felis catus*) were observed at a number of locations and are known to be damaging to small native marsupial populations (Davies and Prentice, 1980), and to birds such as the rainbow bee-eater (*Merops ornatus*) which commonly nests in burrows along river banks.

Terrestrial macrofauna, although they may range widely, are very dependent on the life supporting habitat offered by wetlands, particularly permanent and semi-permanent water bodies.

3.7 NUTRIENTS

An understanding of the main processes controlling nutrient pools in aquatic and terrestrial ecosystems is a useful and often necessary prerequisite for developing efficient conservation and management strategies. Knowledge of the nutrient levels of pristine waters allows the early detection of disturbance and potential eutrophication. In terms of aquatic river systems, nutrient spiralling (Williams, 1983) involves the concept that each part of the system is dependent upon nutrient energy leaked from upstream by 'inefficient' processes of energy collection, use and storage. The first step in gaining an understanding of this flow involves the measurement of the levels of the major nutrients nitrogen and phosphorus. Nitrogen is an important constituent of a wide variety of organic compounds and is especially important in the structure of proteins. Phosphorus is commonly regarded as being more important in determining the amount of living matter in a water body than any other single factor (Bayly and Williams, 1977).

Due to the episodic nature of the rainfall in the Pilbara region and hence the discontinuous mechanism for input of nutrients into the aquatic system, seasonal, and more intensive measurements during runoff events would be necessary for complete evaluation of the nutrient gradient. The measurements presented here (Table 10) are a first step towards this end.

3.7.1 WATER COLUMN NUTRIENTS

Mean total nitrogen (TN) concentrations for the water column were 1126 ± 198 µg/L. Levels of less than 1000 µg/L are considered to be indicative of a pristine, non-eutrophic water body (Williams, 1983). The mean total phosphorus (TP) concentration of 73 ± 29 µg/L, however, falls above the range considered to be normal for natural waters (0-40 µg/L). Calculated from the means of the TN and TP data, before and after filtration, 24% of the TN and 32% of the TP in the water column was associated with particulate matter. The mean and standard error of the TN:TP ratios for the water bodies examined were 17.7 ± 2.0.

3.7.2 SEDIMENT NUTRIENTS

Sediment TN and TP concentrations were 991 ± 297 and 152 ± 22 µg/g d wt.respectively. The mean of the TN:TP ratios of the sediments was 6.2 ± 2.0.

3.7.3 NUTRIENT INTER-RELATIONSHIPS

Given optimum environmental conditions for plant growth, high nutrient concentrations generally result in high plant biomass. The maximum biomass attainable is then controlled by the nutrient in lowest relative concentration.

Table 10. Total filtered and unfiltered nitrogen and phosphorous; total nitrogen to phosphorus ratios of inland waters and sediments of the Pilbara, October-November 1984.

	Site Number	Water column				Sediment		Water	Sed
		TN µg/L	TNF µg/L	TP µg/L	TPF µg/L	TN µg/gdwt	TP µg/gdwt	TN:TP	TN:TP
<u>Ashburton River System</u>									
Nanutarra Crossing	1.	1031	904	42	38	235	182	24.5	1.3
Wagoon Pool	2.	2508	2062	91	63	985	184	27.6	5.4
Ashburton River Pool	3.	776	700	51	38	106	140	15.2	0.8
<u>Asburton River Catchment</u>									
Ashburton Claypan	4.	-	-	-	-	107	168	-	0.6
<u>Fortescue River Catchment</u>									
Hamersley Gorge	5.	178	751	30	32	-	-	5.9	-
Yampire Gorge 1	6.	407	331	45	30	-	-	9.0	-
Yampire Gorge 2	7.	535	395	97	34	-	-	5.5	-
Above Fortescue Falls	8.	298	382	29	39	-	-	10.1	-
Below Fortescue Falls	9.	216	305	24	30	-	-	9.0	-
Dales Gorge	10.	458	407	52	27	-	-	8.8	-
Circular Pool	11.	598	726	58	36	-	-	10.3	-
Hooley Creek	12.	1464	1107	36	52	504	145	40.7	3.5
Coondiner Pool	13.	598	776	103	118	415	457	5.8	0.9
<u>Yule River System</u>									
Yandearra Pool	14.	726	636	40	40	236	82	18.2	2.9
<u>Yule River Catchment</u>									
Yanrey Road Crossing	15.	1438	1400	43	32	239	48	33.4	5.0
Warden Pool	16.	1871	1578	56	31	197	78	33.4	2.5
Friendly Creek Dam	17.	878	522	39	27	-	-	22.5	-
<u>DeGrey River Catchment</u>									
Red Rock Creek	18.	-	-	-	-	235	73	-	3.2
Nullagine River Pool	19.	625	318	34	29	237	58	19.9	4.1
Cooke Creek	20.	687	407	39	37	-	-	17.6	-
Coppins Gap	21.	675	636	69	48	195	74	9.8	2.6
Moolyella Mines 1	22.	1171	1489	349	218	106	85	3.4	1.2
Moolyella Mines 2	23.	2330	764	109	52	106	121	21.4	0.9
Marble Bar Dredge	24.	2317	1820	90	78	3573	103	25.7	34.7
<u>Oakover River System</u>									
Lower Carawine Pool	25.					195	130	-	1.5
	Surface	585	420	45	38	-	-	13.0	-
	1.0m	624	636	30	35	-	-	-	-
	2.0m	611	458	38	16	-	-	-	-
	3.0m	649	509	38	20	-	-	-	-
	5.0m	636	395	41	36	-	-	-	-

Table 10. Total filtered and unfiltered nitrogen and phosphorous; total nitrogen to phosphorous ratios of inland waters and sediments of the Pilbara, October-November 1984. (contd)

	Site Number	Water column				Sediment		Water	Sed
		TN µg/L	TNF µg/L	TP µg/L	TPF µg/L	TN µg/gdwt	TP µg/gdwt	TN:TP	TN:TP
Oakover River System (Cont.)									
Upper Carawine Pool	26.	1107	713	29	33	-	-	38.2	-
Running Waters	27.	1833	878	52	21	4474	170	35.3	26.3
Oakover River Catchment									
Yownama Creek	28.	5385	3221	474	149	2777	239	11.4	11.6
Skull Springs 1	29.	385	484	37	38	-	-	10.7	-
Skull Springs 2	30.	649	458	42	24	1463	199	15.5	7.4
Skull Springs 3	31.	420	254	31	26	1794	249	13.5	7.2
	Mean(x)	1126	857	73	50	991	152	17.1	6.2
	S.D.	1068	658	93	43	1327	97	10.8	8.9
	n	29	29	29	29	20	20	29	20

In general, high standing crops of primary producers were associated with high nitrogen concentrations. There was a strong positive correlation ($p \leq 0.05$) between sediment TN and both sediment chlorophyll a ($r=0.895$) and sediment phaeophytin ($r=0.939$). Similar correlations were evident between sediment TN:TP ratio and both sediment chlorophyll a ($r=0.837$) and sediment phaeophytin ($r=0.938$). On the other hand there was no significant correlation between TP and sediment total pigment. It was noted that sites with 80% or more cover of submerged aquatics had exceptionally high sediment, and to a lesser extent high water column, N:P ratios (eg sites 2,15,24,27-31), suggesting phosphorus limitation.

According to limnological classification (eg Wetzel, 1975), all but two of the sites sampled in 1984 were meso to hyper-eutrophic when the total phosphorus values are used, or oligo/meso-trophic if the total nitrogen values are used.

Site 23 (Moolyella Mines 2), a turbid artificial wetland with minimal aquatic or fringing vegetation, exhibited a high TP concentration within the water column. In this situation it is suggested that something other than phosphorus is limiting primary production (eg light penetration of the water column). Site 28 (Yownama Creek) with a dense phytoplankton population had the highest TP concentration measured, a large percentage of which was particulate (deduced from the TPF (total phosphate filtered) data). There were many bird droppings on rocks surrounding this small pool, suggesting that a high phosphorus load may have triggered the algal bloom. This observation, as well as the high TN:TP ratios measured overall in the water column, suggests that Pilbara wetland systems are in general phosphorus limited.

An ecosystem in equilibrium with its environment would be expected to show a nutrient balance in which, on average, loading of nutrients in short supply approximately balances losses. In the wetlands of the Pilbara it appears that phosphorus is conservative and predominantly trapped in the form of plant material. Nitrogen on the other hand appears to be available in excess compared with phosphorus, and not all bound in plant material.

The high nitrogen content of legumes in general (eg mulga and other acacias), their ability to fix atmospheric N and their common occurrence on the periphery of wetlands suggests they may constitute an important nitrogen source for the wetlands. The input of nutrients, mainly nitrogenous compounds, by cattle and sheep may also be substantial, especially in the smaller surface water bodies.

As it appears that most Pilbara surface water bodies have relatively low nutrient levels, any potential activity which may cause an increased loading of nutrients into wetland systems should be carefully scrutinized before being allowed to proceed.

3.8 LAND USE

Pastoral activities, mining, recreation and tourism are the dominant forms of land use in the area, and have marked effects on Pilbara wetlands. Recent years have seen increased access and development throughout the Pilbara region.

3.8.1 PASTORALISM

With the trend in recent years for pastoralists to opt for cattle rather than sheep as stock, there has been increased usage of naturally occurring wetlands as sources of feed and water. *Cenchrus ciliaris* (buffel grass) and other non-endemic species have been introduced to improve feed quality and availability and are now widespread, especially along water courses.

During medium to good seasons, food and water are generally available for both native wildlife and stock, but during poor seasons and even in good seasons when poor management such as overstocking and lack of stock control is practiced by pastoralists, there is competition for these essential but limited resources.

Native fauna cause minimal erosion of banks during watering and feeding, but this cannot be said of cattle which cause bank erosion, trample and eat vegetation and resuspend silt while walking along banks and in the shallows. Increased nutrient loading in the vicinity of water bodies may also lead to deterioration of water quality (see Section 3.7.6). In the more isolated areas, wild donkeys and possibly camels add to the problem.

Excessive grazing of native ephemeral plants, small shrubs and even trees leads to soil instability, creating dust which blows or washes into the water bodies. Over long periods it is conceivable these water bodies may show significant silt accumulation, reducing their water holding capacity and hence altering the physical properties of the water body, imparting stress on parts of the dependent biota.

3.8.2 MINING

Mining companies have opened up much of the Pilbara through exploration and by building and maintaining roads, new towns and stable communities. Mining generally exploits a particular mineral resource, but also uses large amounts of water, often from highly localised areas, and causes other modifications to the natural environment.

The artificial wetlands associated with mining near Marble Bar (sites 22, 23 and 24) provide areas of surface water for a variety of organisms. It appears these areas are not formed by the alteration of natural surface water bodies, but are open pits which act as dams, trapping water after rain. Mining, in this area at least, has resulted in the formation of semi-permanent water bodies in areas where surface water is scarce.

Sites 22, 23 and 24 appear to show stages in the maturation of this type of artificial wetland. The physical data and observations made for these sites (Table 11) seem to indicate changes that occur as the systems stabilize. Light penetration increases as turbidity decreases, allowing benthic micro-algae and possibly other submerged aquatic plants to grow. Changes in the oxygen status of the sediment are apparent, with the development of a distinct anaerobic zone. This is concurrent with the establishment of submerged and emergent aquatic vegetation. It would be of interest to monitor these sites regularly, either on a seasonal or annual basis.

Table 11: Selected physical data and observations of artificial wetlands near Marble Bar, October-November, 1984.

Site No.	Cond mS/m	pH	TSS mg/l	Oxic zone cm	Benthic chl a mg/m^2	Submerged aquatics	*Typha*
22	40.8	8.59	117.63	>10 cm	9	absent	absent
23	273.2	9.27	22.00	to 4cm depth	25	trace *Najas*	clumps
24	338.4	9.20	8.80	to 1cm depth	53	dense *Najas*	dense

It is possible that with maturation these water bodies can support and provide refuge for quite diverse communities of flora and fauna. If this end result is considered during the construction stage, it may be possible to model the areas to resemble naturally-occurring wetlands with a similar geomorphology (eg Coondiner pool, site 13, a semi-permanent claypan). The banks could be stabilized by planting suitable trees and shrubs and the areas managed as useful resources for wetland biota.

3.8.3 RECREATION AND TOURISM

The influx into the Pilbara of increasing numbers of people for work and tourism, the mobility of 4-wheel drive vehicles and the amenity provided by wetlands has resulted in surface water bodies being the focal point of recreational activities, especially during the drier months.

From observations made during the field work, it is apparent that isolation is the best protection an area can have from degradation. Easily accessible areas are favoured by tourists and have the greatest litter problems: for example poorly-degradable products such as plastic food packaging and disposable nappies were more noticeable in 1984 than during the1983 survey, and there is increasing cause for concern about the prevalence of this type of litter for both public health and aesthetic reasons.

4. OVERVIEW OF THE CLASSIFICATION SYSTEM

The classification system proposed in IWP 1983 was found to be valid when applied to the Ashburton and Oakover/DeGrey river systems surveyed in this study. The broadness of the different wetland categories is useful for classifying wetlands over such a wide area, but for the purposes of management, the spring classification could be usefully subdivided into "river springs" (wetland type 1R) and "gorge springs" (wetland type 1G) on the basis of their geomorphology. "Gorge springs" such as those of the Hamersley Ranges (sites 5-11), Lower Carawine Gorge (site 25) and Eera Barana (sites 54-64, 1983), offer a degree of micro-climatic stability due to shading from associated rock faces, but often have few trees associated with them, because of limited soil. Broad "river springs", such as those along the Davis and Oakover Rivers (Running Waters, site 27, Skull Springs, sites 29-31) and Weeli Wolli Springs (sites 26-32, 1983), have dense, broad gallery forests offering shade and a range of habitat types. Highland "gorge springs" are relatively isolated having only downstream water flow while lowland "river springs" are much less isolated due to links both upstream and downstream via river channels during wet periods. The subdivision is not warranted on the basis of other criteria (eg high species richness (Section 3.5.1), nutrient levels (Table 10), etc). As with the other categories within the classification, further subdivision is possible and would be useful and desirable should specific regions be examined or compared. The level of the classification sub-units is ultimately dependent upon the purpose for which they are to be used.

5. MANAGEMENT CONSIDERATIONS

The wetland classification system is primarily based on surface water permanence and geomorphology. Within the wetland classification system, two major groups can be discerned: those of a permanent to semi-permanent nature, and those ranging from semi-permanent to intermittent.

Primary river channels and headwater streams occupy relatively large areas but hold water for only a short period after rain. Ephemeral claypans and adjoining pools also hold water at this time. Therefore for short periods during the wet season, surface water is relatively widespread, with all wetland types holding water if sufficient rain has fallen in their catchments.

At these times of year, overland travel is difficult in the Pilbara, and tourist use is reduced. Water and feed are in good supply, diffusing the pressure of stock. As a result of widespread water availability overall pressure on individual wetlands is lowered. As the dry season progresses, the ephemeral and intermittent water bodies dry, and pressure is focused on the more durable surface water bodies, notably springs, primary river pools and semi-permanent claypans.

As conditions become more favourable for travel in the region, tourist use is increased. Spring systems and, to a lesser extent, primary river pools, are perhaps the most aesthetically appealing to humans. The areas with waterfalls, rock pools, and gallery forests provide notable contrast to the surrounding arid landscape. The visitor has a great diversity of vegetation and animal life to observe in natural surroundings, and the opportunity is often taken to obtain relief from the heat by swimming or by resting in the shade provided by surrounding trees or gorge faces. These features are generally restricted to areas of permanent/semi-permanent water. For the water-dependent biota of the

Pilbara which cannot migrate or withstand desiccation, these areas provide the last regional refuge in dry seasons and hence are necessary for those species to survive in the area.

It is important to bear in mind the effects of previous and existing land use in the region to understand the current status of the Pilbara wetlands. The effects of the pastoral industry have been so pervasive that it is now not possible to obtain baseline information from wetlands in pristine condition and to recognise all the changes that have occurred. It is possible that some of the introduced plant species have out-competed native species for the limited resources available. Some exotics, especially grasses (eg *Cenchrus ciliaris*) are now an integral part of the wetland systems and it would be difficult to eradicate these exotics from all but selected areas, and impractical in the absence of suitable native species to fill the vacated niches.

There are constructive measures that could be taken however, such as limiting grazing by stock and hence the associated trampling of vegetation, effectively reducing bank erosion and silting of water bodies. Preventing the access of cattle to important pools during the dry season while at the same time providing them with water which is pumped into troughs, has been an effective compromise in certain areas of the Kimberley region.

Some of the wetland systems examined are reserved for various purposes (see Table 1) and may be managed accordingly. The Hamersley Range National Park is policed to an extent by rangers from the Department of Conservation and Land Management. The area is highly promoted as a regional scenic attraction and sees increasing tourist use each year. Most wetlands in the Pilbara are unmanaged and other areas (such as Hooley Creek) were set aside many years ago for the purposes of watering stock and as resting places for travellers. It appears that little thought was put into their selection as reserves other than convenience, and the fact that they are crown reserves is all but forgotten.

Isolated, relatively unknown areas were found in this survey to be the closest to pristine condition and the wildlife there were least perturbed by the human presence. It was noted that many rockholes, springs and pools annotated on older maps are not being marked on more recent maps produced by the Department of Land Administration. By not advertising their presence, tourist pressure is relieved to a degree.

The large distances between the major springs and river pools would make it difficult to service these areas if they were designated as reserves. The building and maintenance of amenities such as ablution blocks would be both difficult and expensive, and would probably be regarded as undesirable by those who genuinely wish to visit these areas and see them in their natural state. Of the services that could potentially be provided, facilities for litter disposal would be the most desirable, and the most efficient to maintain. Newmont Mining Company, Telfer, currently provides a rubbish collection service in some areas frequented by its employees. It may be possible for the Department of Conservation and Land Management to liaise with large organisations employing people in the area, to provide and extend this type of service.

The effective management of a wetland will take into account all major forms of land use, be they conservation, pastoralism, tourism or mining. These different land uses are not necessarily mutually exclusive, as the maintenance of healthy wetland systems is beneficial for all forms of land use. For example, the location of mining towns depends largely on the availability of a reliable potable water supply and the quality of life of the inhabitants of these towns is greatly enhanced by the recreational potential of healthy wetlands in the vicinity. Tourism in the arid Pilbara also benefits from the added attraction of healthy wetlands and their associated biota. In the case of pastoralism, a deterioration in water quality will adversly affect the carrying capacity of an area for cattle and sheep.

Land use decisions must take into account the long-term impact of particular uses: for example, while some may disturb an area in the short-term, the use of correct rehabilitation procedures may neutralise this effect in the long-term. Other forms of disturbance may irreparably damage an ecosystem and require different considerations. In areas of high conservation value such as National Parks, areas of outstanding beauty or in important habitats including those of relatively permanent water in an arid environment, the economic advantages of tourism become increasingly important. Decisions based on short-term economic gain may prove to be costly in the long-term.

6. RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

i) A more complete understanding of nutrient relations, especially after episodic events, would increase knowledge of wetland processes for better-informed management.

ii) Knowledge of changes in species composition of wetland biota may prove useful in the management of wetland resources of the Pilbara by providing indicators of system perturbation.

iii) Some artificial wetlands should be monitored on a regular basis to increase understanding of the changes that occur as systems stabilise, with a view to designing artificial water bodies in such a way that stabilisation is promoted and enhanced.

iv) Methods of litter management should be investigated.

v) A review of the status, purpose and vesting of existing reserves should be undertaken with a view to updating these so that they are relevant to the current land use of the region.

7. RECOMMENDATIONS FOR MANAGEMENT

i) A preliminary investigation of the nutrient status of Pilbara wetlands suggested that they were phosphorus-limited at the time of the study. This observation suggests that attention should be given to the location of potential sources of phosphorus-eg septic tanks, effluent disposal sites adjacent to important wetlands. The effects of additional phosphorus would be to alter the nutrient balance of the area, thereby affecting the wide range of organisms which depend upon that wetland. It could contribute to a deterioration of the water quality resulting in increased algal growth and hence increased decay and odours, alteration of habitat, decreased availability of water for the dependent biota and a rapid deterioration of aesthetic appeal.

ii) As more details of the structure and functioning of Pilbara wetlands come to light, it is clear that informed and effectual management requires a different set of considerations to those identified as important in temperate ecosystem wetlands, on which most management criteria are founded. Special attention should be directed to the extreme seasonality of the Pilbara region and to the magnitude of natural changes in the environment and biota that occur with time.

iii) Management plans should take account of the major components of wetland ecosystems, including the protection of the water regime (maintenance of natural inputs and outflows), water quality, fringing and submerged vegetation, and associated fauna.

iv) Attention should be given to methods of limiting the disturbance of the wetland ecosystems by a) introduced species, particularly sheep and cattle and b) humans.

v) In the face of increased access and tourist use, consideration should be given to creating a reserve encompassing a representative, self-sustaining portion of the Davis/Oakover River spring systems before this area becomes excessively degraded. In addition to providing some protection for the biota of this unique area, a reserve in the vicinity of Running Waters (site 27) could be jointly managed as a buffer zone to prevent the southward spread of bovine carried diseases such as tuberculosis.

vi) The importance of litter management should be given increasing consideration.

vii) The importance of the wetland areas to Aboriginal usage was not examined during the course of both surveys due to lack of expertise in this field by the authors. Future management should consider the traditional methods of management of these areas, the current usage of these areas by the Aboriginal people and the archaeological importance of specific sites.

8. SUMMARY AND CONCLUSIONS

Areas in the Davis/Oakover River and Ashburton River regions which were inaccessable during stage one of the study were surveyed and the data proved readily referable to the classification system proposed earlier in Inland Waters of the Pilbara, Part One (Masini, 1988).

A preliminary investigation of the nutrient status of Pilbara wetlands showed them to be phosphorus limited at the time of study. The importance of surface water bodies in the Pilbara to both wildlife and man is stressed.

Recommendations for sound management of the Pilbara wetlands include;

- limitation of disturbance
- protection of the water regime (maintenance of natural inputs and outflows)
- protection of the wetland vegetation
- limitation of nutrient enrichment
- litter management
- consideration of Aboriginal usage

Just as management plans are being developed for our coastal areas, it is essential that action be taken to realize the importance of inland water resources of the arid regions of Western Australia, and that sound management strategies recognise as far as possible the important components of the wetland ecosystem: water supply and quality, terrestrial, fringing and submerged vegetation, phytoplankton, microbenthos and fauna, the seasonality of the region and the importance of the nutrient balance. These strategies should be developed and implemented to promote, preserve or enhance the qualities of an important resource at this critical stage in the economic development of the region.

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APPENDIX

Key
* Wetland type (see Table 2)
** Site numbers (see Table 1)

PLANT SPECIES COLLECTED AT WETLAND SITES IN *	1										2													5	6	7	9			
THE PILBARA, OCTOBER-NOVEMBER 1984 **	5	6	7	8	9	11	27	29	30	31	1	2	3	12	14	15	16	19	20	21	25	26	28	18	4	13	17	22	23	24
PTERIDOPHYTA																														
Marsileaceae																														
Marsilea sp																										0				
Fern spA						0																								
Fern spB						0																								
Fern spC																			0											
ANGIOSPERMAE																														
Monocotyledonae																														
Cyperaceae																														
Cyperus conicus (R. Br.) Boeck.																								0						
Cyperus difformis L.														0																
Cyperus vaginatus R. Br.		0	0	0	0	0		0				0	0		0	0	0		0		0	0	0							
Cyperus sp1														0																
Cyperus sp2																										0				
Cyperus sp3																						0								
Cyperus sp4											0				0							0	0							
Cyperus sp5																					0									
Cyperus sp6							0																							
Cyperus sp7																		0												
Cyperus sp8																				0										
Cyperus sp9																				0										
Cyperus sp10											0																			
Schoenoplectus litoralis (Shrader) Palla# (*Scirpus litoralis* Schrad.=*Schoenoplectus*)					0	0	0	0			0									0		0	0							
Juncaceae																														
Juncus sp						0																								
Poaceae																														
Cenchrus ciliaris L.														0			0	0			0									
Cenchrus sp																		0												
Cooch																					0									
Eragrostis australasica (Steud.) C.E. Hubbard				0	0																									
Eragrostis sp1	0			0	0	0										0				0				0				0	0	
Eragrostis sp2															0								0					0	0	0

	5	6	7	8	9	11	27	29	30	31	1	2	3	12	14	15	16	19	20	21	25	26	28	18	4	13	17	22	23	24
Eriachne sp1																										0				
Eriachne sp2																			0											
Setaria sp1												0																		
Setaria sp2												0																		
Sporobolis sp											0								0					0						
Themeda australis (R. Br.) Stapf																			0											
Typhaceae																														
Typha domenginses Pers.																			0										0	0
DICOTYLEDONAE																														
Amaranthaceae																														
Aerva javanica (Burm f.) Juss. ex Schult															0		0				0	0		0						
Alternanthera nodiflora R. Br												0				0		0	0					0		0		0		
Amaranthus pallidiflorus F. Muell																					0		0							
Ptilotus exaltatus Nees																														
Ptilotus sp				0																										
Apiaceae																														
Trachymene sp			0										0																	
Apocynaceae																														
Carissa lanceolata R. Br.																			0											
Asteraceae																														
Centipeda sp1											0			0				0	0							0	0			
Centipeda sp2																														
Centipeda sp3							0										0													
Pluchea rubelliflora (F. Muell.) B.L. Robinson														0					0											
Pluchea sp1			0				0				0		0	0	0	0	0	0		0							0	0	0	0
Pluchea sp2																										0				
Pluchea sp3																		0												
Boraginaceae																														
Trichodesma zeylanicum (F. Muell.) R. Br				0	0																									
Caesalpineaceae																														
Cassia notabilis F. Muell.																0														
Cassia venusta F. Muell.																								0						
Cassia sp1							0												0											
Cassia sp2																		0												
Petalostylis labicheoides R. Br.					0			0										0			0									
Capperaceae																														
Capparis spinosa L.								0														0								

	5	6	7	8	9	11	27	29	30	31	1	2	3	12	14	15	16	19	20	21	25	26	28	18	4	13	17	22	23	24
Cleome viscosa L.								0				0			0			0			0									
Casuarinaceae																														
Casuarina sp				0																										
Chenopodiacea																														
Atriplex cinerea subsp *rhagodioides* (F. Muell.) Aellen=*Atriplex rhagodioides* F. Muell				0																										
Atriplex sp																						0								
Dysphania rhadinostachya (F. Muell.) A.J. Scott											0				0							0					0			
Holosarcia sp																									0					
Compositae																														
Flaveria australasica Hook.														0																
Helipterum sp				0																										
Pterocaulon sp																		0												
Senecio sp						0																								
Convolvulaceae																														
Bonamia rosea (F. Muell.) Hall. f.																		0					0							
Bonamia sp														0																
Ipomea muellerii Benth.							0	0			0				0		0	0			0	0	0							
Curcubitaceae																														
Mukia maderaspatana (L.) M.J. Roem.																					0	0								
Elatinaceae																														
Bergia sp																										0				
Euphorbiaceae																														
Adriana hookeri (F. Muell.) Muell.-Arg.																						0								
Adriana tomentosa Gaudich											0																			
Euphorbia australis Boiss.							0	0							0	0	0	0		0	0	0	0				0			
Euphorbia coghlanii F.M. Bail.								0							0		0	0			0									
Goodeniaceae																														
Dampiera sp														0	0															
Goodenia sp1							0																				0			
Goodenia sp2				0																										
Goodenia sp3				0																										
Goodenia sp4																		0												
Lauraceae																														
Cassytha filiformus L.															0															
Lobeliaceae																														
Lobelia quadrangularis R. Br.#						0	0	0																						

	5	6	7	8	9	11	27	29	30	31	1	2	3	12	14	15	16	19	20	21	25	26	28	18	4	13	17	22	23	24
Lythraceae																														
Ammannia sp							0																							
Malvaceae																														
Abutilon sp																					0									
Abutilon sp2																					0									
Gossypium robinsonii F. Muell.#								0																						
Hibiscus panduriformis Burm. f.																														
Sida sp1								0																						
Sida sp2																		0			0	0								
Sida sp3																					0									
Mimosaceae																														
Acacia ampliceps Maslin							0															0	0						0	
Acacia aneura F. Muell. ex Benth.																									0					
Acacia arida Benth.#																					0									
Acacia citrinoviridis Tind. & Maslin#	0																													
Acacia coriaceae DC.								0			0				0	0	0	0	0		0	0								
Acacia farnesiana (L.) Willd.		0												0																
Acacia maitlandii F. Muell.																									0					
Acacia pyrifolia DC.					0													0	0		0						0			
Acacia victoriae Benth.																														
Acacia sp1																														
Acacia sp2						0													0											
Acacia sp3		0		0	0																									
Acacia sp4																										0				
Acacia sp5								0																						
Acacia sp6								0				0							0											
Acacia sp7																						0								
Acacia sp8																							0							
Acacia sp9							0																							
Acacia sp10															0			0	0					0			0			
Acacia sp11																											0			
Acacia sp12																								0						
Acacia sp13																								0						
Acacia sp14											0																			
Acacia sp15																									0					
Moraceae																														
Ficus platypoda (Miq.) A. Cunn. ex Miq.																					0									

	5	6	7	8	9	11	27	29	30	31	1	2	3	12	14	15	16	19	20	21	25	26	28	18	4	13	17	22	23	24
Myrtaceae																														
Eucalyptus camaldulensis Dehnh.	0	0					0			0	0			0	0	0	0			0	0									
Eucalyptus coolabah Blakely & Jacobs																						0				0	0			
Eucalyptus sp1			0										0																	
Eucalyptus sp2								0																						
Eucalyptus sp3																					0									
Eucalyptus sp4							0																							
Eucalyptus sp5																			0											
Eucalyptus sp6												0																		
Melaleuca bracteata F. Muell.	0		0		0								0																	
Melaleuca glomerata F. Muell.							0	0			0						0	0		0			0	0						
Melaleuca leucadendran (L.) L.#			0		0	0	0	0	0	0	0		0		0			0	0	0	0	0								
Melaleuca linophylla F. Muell.				0		0																								
Melaleuca sp1					0																									
Melaleuca sp2																						0								
Melaleuca sp3																0	0													
Papaveraceae																														
Argemone mexicana L. var *ochroleuca* (Sweet) Lindl.								0							0		0					0					0			
Papilionaceae																														
Aeschynomene indica L.																										0				
Crotalaria cunninghamii R. Br.																						0								
Crotalaria trifoliastrum Willd.#		0																	0											
Indigofera monophylla DC.															0			0												
Indigofera sp		0																												
Psoralea patens Lindl.							0	0													0		0							
Psoralea sp																		0												
Rhynchosia minima (L.) DC.												0		0		0														
Sesbania cannabina (Retz.) Poir.														0									0					0	0	
Sesbania formosa (F. Muell.) N.T. Burbidge								0														0								
Swainsona maccullochiana F. Muell.												0																		
Tephrosea rosea (F. Muell.) ex Benth.								0											0											
Vigna lanceolata Benth							0	0						0				0				0								
Polygonaceae																														
Meuhlenbeckia cunninghamii (Meisn.) F. Muell.								0																		0				
Proteaceae																														
Hakea suberea S. Moore																							0							

	5	6	7	8	9	11	27	29	30	31	1	2	3	12	14	15	16	19	20	21	25	26	28	18	4	13	17	22	23	24
Sapindaceae																														
Atalaya hemiglauca (F. Muell.) F. Muell. ex Benth.								0						0			0			0		0								
Dodonea viscosa Jacq. var spatulata (Sm.) Benth.		0																												
Scrophulariaceae																														
Stemodia grossa Benth.#		0	0			0	0	0			0		0	0				0	0	0			0					0	0	
Stemodia viscosa Roxb.		0				0																								
Solanaceae																														
Solanum diversiflorum F. Muell.																			0											
Solanum lasiophyllum Dun.				0													0													
Nicotinia sp				0																										
Sterculiaceae																														
Brachychiton sp																		0												
Stylidiaceae																														
Stylidium sp						0																								
Tiliaceae																														
Corchrus sp1				0																										
Corchrus sp2								0																						
Corchrus sp3																						0								
Corchrus sp4																				0										
Corchrus sp5																				0										
Corchrus sp6																	0	0												
Corchrus sp7											0																			

All identifications were made using-
Jessop, J (editor in chief) (1985). FLORA OF CENTRAL AUSTRALIA, Australian Systematic Botany Society.
except
#Green, J.W. (1985). CENSUS OF THE VASCULAR PLANTS OF WESTERN AUSTRALIA, W.A. Herbarium, Department of Agriculture, Perth. 2nd edition.

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