PROCEEDINGS

FITZROY CATCHMENT SYMPOSIUM

12 - 13 NOVEMBER 1992

UNIVERSITY OF CENTRAL QUEENSLAND
ROCKHAMPTON, QUEENSLAND

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National Library of Australia Cataloguing

Fitzroy Catchment Symposium

ISBN O 908140 77 0

Editors: Duivenvoorden, L.J., Yule, D.F., Fairweather, L.E. and Lawrie, A.G.

Publishers: University of Central Queensland
Queensland Department of Primary Industries
Capricorn Conservation Council
United Graziers Association

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Dean of Applied Science
University of Applied Science
Rockhampton, Qld. 4702

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CLIMATE VARIABILITY IN THE FITZROY CATCHMENT

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INTRODUCTION

The most notable feature of climate in the Fitzroy Catchment is the variability, particularly rainfall variability. In the Fitzroy Catchment rainfall is usually the limiting climatic factor in pasture and crop growth, although temperature extremes are also important. However, evaporation, atmospheric moisture and temperature also affect plant growth which is important for crop management, forestry, and pasture production. Crop and pasture management affect soil conservation and runoff and therefore streamflow and water quality in the river system.

This paper begins with an explanation of the causes of central Queensland climate and its variability. Figure 1 is map of the Fitzroy Catchment with rainfall and climate stations marked. Rainfall, temperature, humidity and evaporation data are presented in tables and graphs and are discussed briefly. The main aim is to present climate data which can be used as a reference, since climate is so important for issues affecting the management of the Fitzroy Catchment, such as human and animal health, plant growth, transport, soil protection and streamflow. The stations are chosen for their length of record, and to offer a wide spread of information across the Catchment.

CONTROLLING INFLUENCES OF CLIMATE IN THE FITZROY CATCHMENT

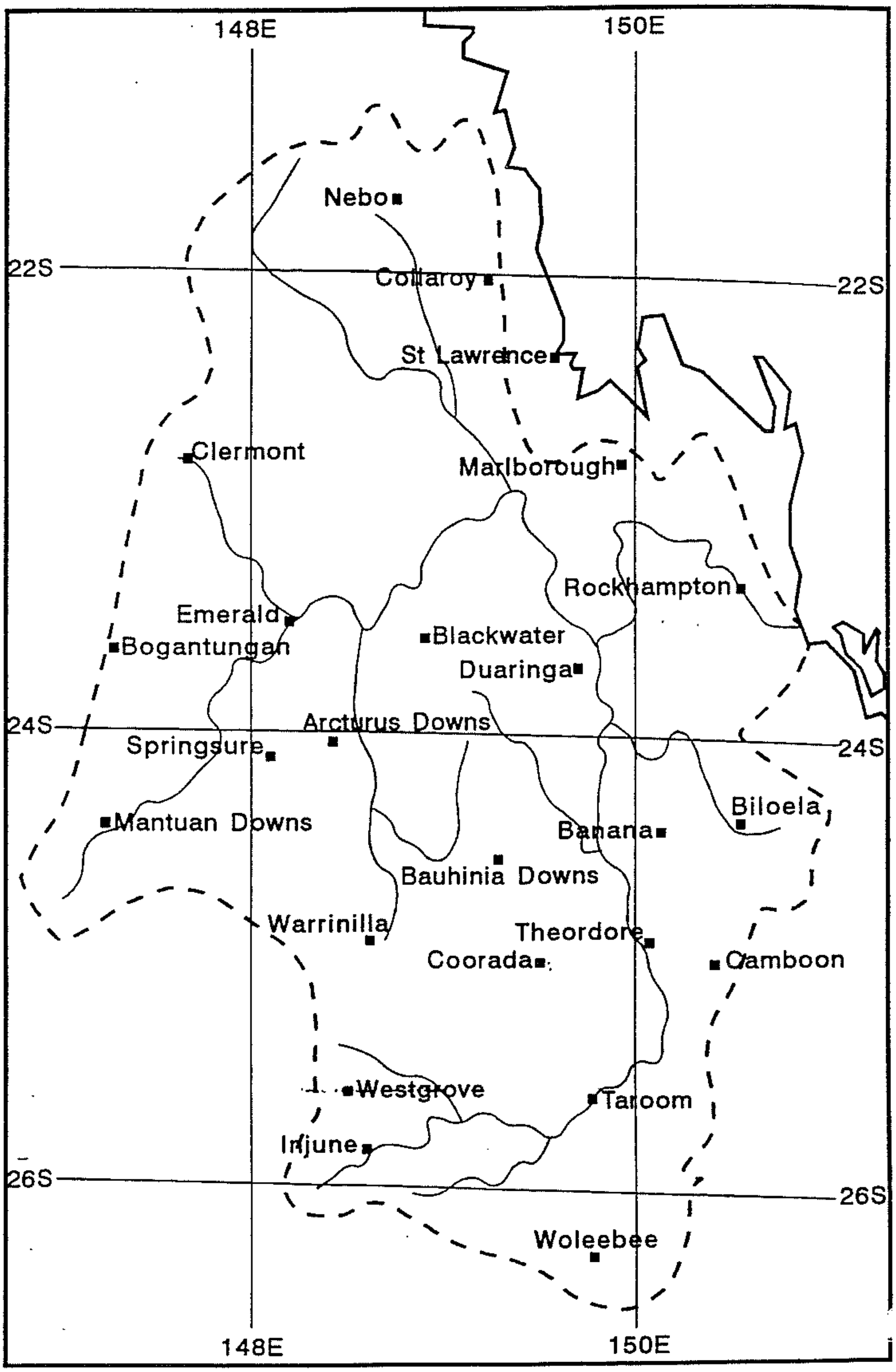
The climate of a place or region is the statistical description of meteorological elements such as temperature, pressure, relative humidity, evaporation and rainfall over a long period of time. Climate is not adequately described by averages and totals. Climate is better explained when a discussion of extremes, ranges, frequency distributions etc. are used to describe the variability of all weather elements.

Variation in the mean monthly values of the meteorological elements depends upon the locality's latitude, elevation and distance from the ocean in addition to the variable angle of elevation of the sun. The relative location of large bodies of water, barrier ranges, forests, grasslands and urban areas will also contribute to variations.

Once a description of a locality's climate is obtained, it may not necessarily hold for all time. For example, average summer rainfall does not mean the average values can be expected each year. Queensland summer rainfall varies greatly from year to year. Likewise, the range of values does not imply the limits. The range of a particular element that has occurred in the past 30 years may be quite

FITZROY CATCHMENT

Figure 1



different to the range of values in the next 30 years.

Climate trends over time may be identified in all meteorological variables. For example, annual rainfall at Clermont has gradually declined in the record of 1871 to 1991. However in the period 1871 to 1931, there is a marked decline in annual totals, which is followed by a marked increase in annual rainfall from the 1931 to 1991 (Davies 1991, Willcocks and Young 1991).

At the same time that Clermont rainfall records have shown an increase, there has been a decrease in daily maximum temperatures and an increase in daily minimum temperatures similar to the effects of a cloudy day. Davies (1991) suggests that these trends could be caused by increasing water vapour over the same period. He suggested that the Coral Sea is the major source of atmospheric moisture (water vapour) in the Clermont area. Davies (1991) then demonstrated that the increase in water vapour is most likely due to increasing sea surface temperatures in the Coral Sea. This is further discussed in the section, "The importance of the ocean".

Catchment location in relation to major pressure systems

The Fitzroy Catchment straddles the Tropic of Capricorn, and is located on the eastern edge of a very dry continent, but adjacent to a warm ocean. The catchment lies between two major pressure systems which affect the Australian climate. The catchment is south of the monsoon trough's usual January position, and north of the usual position of the sub-tropical ridge in July.

In summer, SE/NE winds blow across the warm Coral Sea (26°C in January) bringing moist air into the catchment. By winter the monsoon trough and the sub-tropical ridge have moved northward. Lighter SSW/SE winds bring much drier air into the catchment.

Short term variations to the usual seasonal circulations

The mean wind and moisture circulations described above are interrupted by incursions of moister or drier air into the catchment depending on the positions of the low pressure cells in the monsoon trough or the high pressure cells in the sub-tropical ridge.

Superimposed on these low-level systems are successions of developing and decaying upper troughs and ridges. The troughs act to destabilise the airmass (increased likelihood of rainfall) and the ridges tend to stabilise them. These systems are never static as they continually undergo change.

Occasionally tropical cyclones or a strong persistent northwest monsoon may bring very heavy rainfall during summer, as may a surface cold front and upper trough system in winter.

The importance of the ocean

The ocean has a heat storage capacity very much greater than the atmosphere (McEwan 1990) and greater than the land surface - atmosphere system. As a consequence, the oceans warm and cool very slowly and thereby play a major role in controlling pressure patterns and wind circulations over the oceans.

The oceans provide the water vapour essential for cloud formation and precipitation. Recent studies show there is a non-linear relationship between the ocean surface temperatures and the atmospheric moisture above (Liu *et al.* 1991, Stephens 1990). The warmer the ocean, the greater the evaporation rate from its surface and consequently the greater the atmospheric moisture above. Ocean temperatures adjacent to the Fitzroy Catchment vary between 26°C in January and 21°C in July. The mean mixing ratio (mass of water vapour in grams per kilogram of dry air) measured at 1500m above these waters in January and July varies respectively between 9 and 5.5 grams per kilogram. In other words there is about 65% more water vapour above the ocean at 26°C than one at 21°C.

Onshore winds in January bring this moisture over the Fitzroy Catchment. In July the winds carry in drier air from the interior of the continent, and the resulting July air mass has a mixing ratio of 3 grams per kilogram. Under normal circumstances, rainfall increases non-linearly as the water vapour content increases in an airmass (Davies 1980). This relationship readily explains the generally wet summers and drier winters that Queensland enjoys. Combined with the effects of a warmer ocean, it is not surprising then, that rainfall at Clermont and hence in the Fitzroy Catchment has slowly increased since the 1930's, as the temperature of the Coral Sea surface has gradually increased (Davies 1991).

Predictable variations in seasonal climate

The climate of the Fitzroy Catchment is affected by the El Nino / Southern Oscillation (ENSO) which is a global climate phenomenon (Partridge 1991). An ENSO event (La Nina or El Nino) is a change from the normal east-west circulation across the Pacific Ocean. There is a known relationship between ENSO and Australian rainfall and therefore generalised predictions can be made for a few months in advance (Nicholls 1985). To describe an ENSO event it is necessary to first describe the normal east-west circulation. The waters of the eastern equatorial Pacific are usually cold while to the west they are relatively warm. Southeast trades carry water vapour from over the warm Coral Sea to north-eastern Australia. In summer, the southeast trades converge with the northwest monsoon over northern Australia producing widespread uplift and rainfall. The strength of the southeast trades depends on the pressure gradient between the low pressure over northern Australia and the high pressure belt in the southeastern Pacific. The Southern Oscillation Index (SOI) is a measure of this pressure gradient. It is an index of the difference in air pressure between Tahiti and Darwin.

El Nino and La Nina are extreme variations from the normal circulation over the Pacific Ocean. El Nino is associated with negative phases of the SOI (when

Darwin pressure is above average and Tahiti pressure is below average). For northeastern Australia, including the Fitzroy Catchment, El Nino is usually accompanied by a cooling of the waters in the Coral Sea, a weakening of the southeast trades and the monsoonal trough, and a shift of the convectional activity from western Pacific to central Pacific. This causes a drier and more stable airmass over northeastern Australia, delays the onset of the northwest monsoon activities north of the catchment, fewer than average cyclones per season, and below average rainfall. La Nina conditions are the reverse, an enhancement of the normal temperature, pressure and rainfall patterns across the Pacific, and hence above average rainfall likely in the Fitzroy Catchment.

RAINFALL

Of the climate elements presented here, rainfall is the most variable in the Fitzroy Catchment, and has the biggest single influence on agricultural production, soil erosion and river flow. The Fitzroy Catchment has a summer dominant rainfall (Table 1). The deciles in Tables 1 and 2 give an indication of the variability that is not shown in a single "average" value. Deciles are calculated by listing the rainfall record from the lowest to the highest and splitting the record into 10 percentiles so that the deciles go from one to nine. Below the decile 1 value is the driest 10% of years and above the decile 9 value is the wettest 10% of years. Eighty percent of the rainfall records for a station fall between deciles one and nine. Thus for Nebo (Table 1), 80% of Summer rainfall recorded has been between 165 mm and 639 mm. Only 10% of years have had summer rainfall below 165 mm, and 10% were above 639 mm. Decile 5 is the median, the middle value. 50% of rainfall records are higher and 50% are lower than the median.

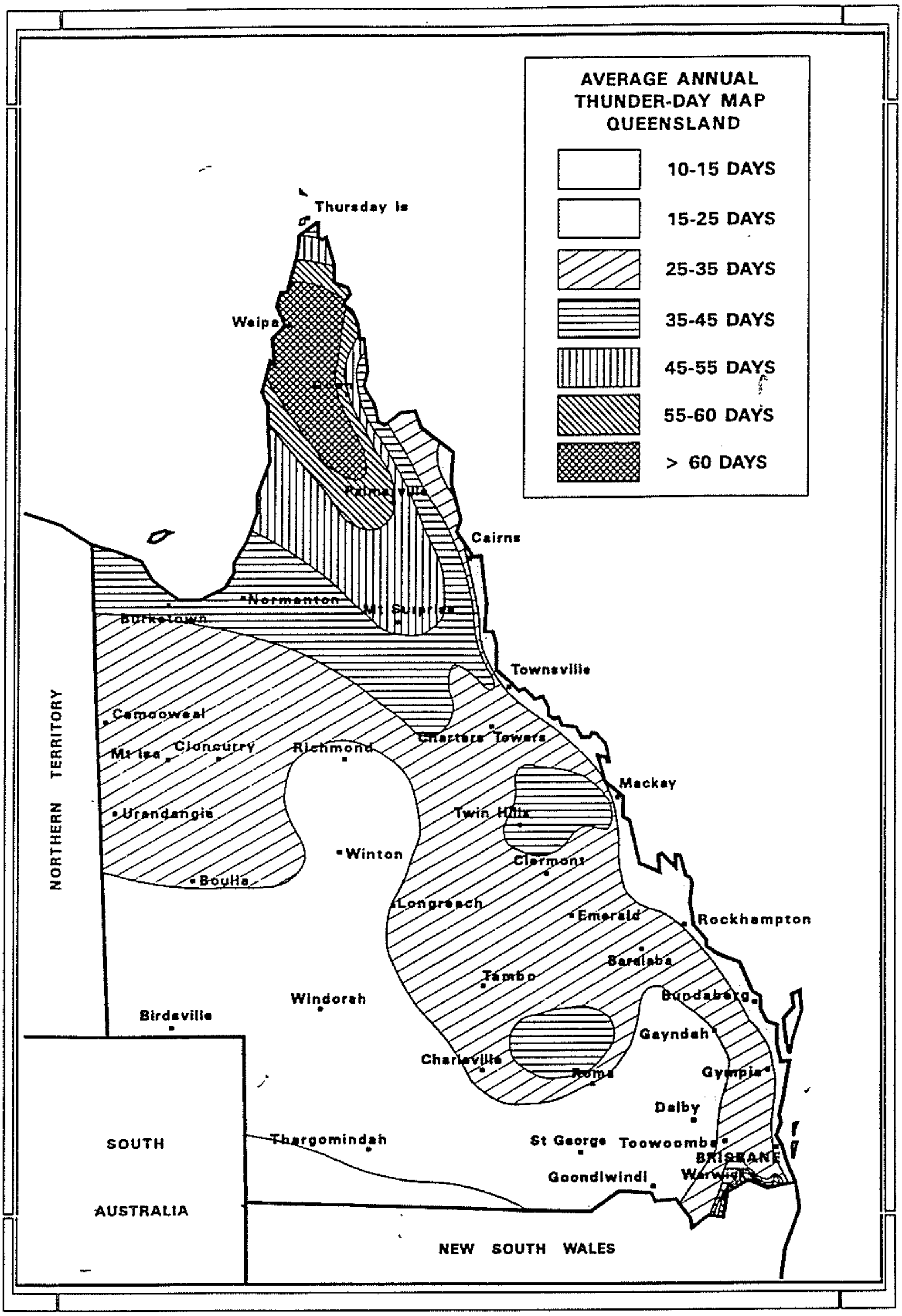
The median is a better indicator of "average" than the mean, since the extreme wet years increase the value of the mean. Table 3 shows that the highest monthly rainfall can be 3 to 11 times higher than the mean monthly rainfall. Comparing Tables 2 and 3, the means are higher than the medians. The means are usually closer to decile 6 than decile 5, giving a misleading impression of higher rainfall.

The highest daily rainfall in Table 3 is the highest recorded rainfall for any one day of the month. Those values are also much higher than the mean monthly values. Such high daily values of rainfall have implications for runoff and streamflow.

Thunderstorms contribute significantly to runoff and streamflow. Figure 2 gives the annual distribution of thunderstorm days in Queensland. In the coastal area of the Fitzroy Catchment, there are an average of 15-25 thunder days a year. Inland, the number of thunder days increases to 25-35, and north of Clermont it increases to 35-45 days per year.

TEMPERATURE

Temperatures are not as variable as rainfall, but the extremes are important in



AVERAGE ANNUAL THUNDER-DAY MAP OF QUEENSLAND

Figure 2

plant growth. Extreme heat and cold affect plant growth and can cause significant crop losses (Hammer and Rosenthal 1978). The Fitzroy Catchment experiences hot summers and often frost in winter, particularly in the southern area. The coastal towns have a smaller diurnal range of temperatures than the inland towns (Table 4) because of the modifying effect of the ocean. Elevation and latitude also affect temperature. The extreme maximums and extreme minimums in Table 4 are the highest and lowest monthly means recorded. Thus, Clermont's mean January maximum is 34.0°C, but the hottest January on record had an average daily maximum of 42.1°C. Likewise, at Taroom, the average July minimum is 4.8°C, but the coldest July on record averaged -5.6°C minimum (Table 4).

Table 5 provides the 86% and 14% percentiles of maximum and minimum temperatures for seven stations in the Fitzroy Catchment. These may be read as "one day in the week is above the 86% value and one day in the week is below the 14% value". Thus in any week of that month, one would expect 5 days to be between the 14% and 86% values.

The number of days in each month above 35°C or below 2.2°C are given in Table 6. The temperature 2.2°C is a measure of frost. At Injune, in April, there is a chance of frost and also a chance of temperatures over 35°C, but it is most unlikely to have these two events in the one day or on successive days. Likewise, there is a chance of frost as well as days over 35°C in September and October at Springsure, Injune, Taroom and Biloela (Table 6).

RELATIVE HUMIDITY

Relative humidity, dew point and dry bulb temperature are presented in Table 7. Relative humidity and dew point are measures of atmospheric moisture which affects heat stress in humans and animals and affects the efficiency of plant growth in relation to the amount of soil water used. Relative humidity is the ratio of atmospheric vapour pressure to saturation vapour pressure (moisture in the air compared with moisture the air can hold). Relative humidity is affected by current temperature and thus relative humidity decreases in the afternoon, as the temperature increases, and increases overnight as the temperature drops. The daily range of relative humidity at a locality increases as distance from the coast increases.

Dew point is the temperature at which saturation of the air occurs, and if pressure and vapour content are constant, dew point will remain the same when temperature changes. Therefore dew point does not change as much during the day as does relative humidity (compare relative humidity change and dew point change between the 9am and 3pm readings in Table 7). Humans and animals are most heat stressed when high temperatures and high atmospheric moisture occur together.

EVAPORATION

Evaporation is important in determining rainfall effectiveness. Pan evaporation values are presented in Table 8 together with rainfall and rain days. Pan evaporation is really a measure of potential evaporation. Evaporation is affected by rainfall, atmospheric moisture, temperature and humidity, so evaporation is likely to be higher inland than on the coast. Theodore has a higher evaporation than Rockhampton in summer (Table 8) but lower evaporation in winter, when it is cooler than at Rockhampton (compare Biloela and Rockhampton in Tables 4 and 5). Emerald has lower evaporation than Rockhampton, perhaps because the weather station sits in the middle of the Emerald Irrigation Area, which increases humidity.

Monthly evaporation is higher than the average monthly rainfall in each month indicating that the moisture is quickly lost, and fallowing to store soil moisture can be ineffective (Carroll *et al.* 1991). The values in Table 8 indicate the period of most stress to plants where the gap between evaporation and rainfall is highest. Spring and early summer is the time of year when there is the greatest deficit between rainfall and evaporation. At the same time dew points are low, (Table 7), indicating low atmospheric moisture, and solar insolation is high (values not shown), resulting in high evaporation, and less likelihood of rainfall. January to April is the time of smallest deficit, and thus least stress.

Dry periods are often accompanied by high evaporation (Table 9), low soil moisture, less cloud and often dry winds. The combination worsens the affects of dry spells. Table 9 provides examples from Theodore and Emerald of the low rainfall which is accompanied by high evaporation, and examples of low evaporation accompanied by high rainfall. Likewise, wet periods are accompanied by low evaporation and high cloud cover, slowing the drying process after floods.

CONCLUSIONS

Allowing for climate variation is very important in managing the Fitzroy Catchment. This paper has presented climate data that is most relevant to the management of the Fitzroy Catchment. It has shown that climate, especially rainfall is extremely variable in Central Queensland. The causes of climate and climate variability have been outlined. The climate in the Fitzroy Catchment is strongly influenced by the proximity of the warm Coral Sea which has a modifying affect on temperature and provides moisture which is brought over the catchment by prevailing winds. ENSO is a major contributor to the variation from the normal circulation and rainfall patterns.

The year to year variation in climate makes property management difficult. Early signs of long term change in production can be masked by yearly variation in production which is a result of climate variability (McKeon *et al.* 1990). Understanding climate variability is an essential part of addressing property management. Planning to accommodate this variability will improve the viability of a rural enterprise.

THEODORE EVAPORATION VARIABILITY

TABLE 9

HIGH MONTHLY EVAPORATION (mm) - LOW RAINFALL/RAINDAYS

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
YEAR	1969	1969	1985	1969	1973	1975	1970	1970	1980	1968	1968	1972
MONTHLY EVAP	336	289	268	206	153	129	130	186	236	259	310	309
MONTHLY RAINFALL	33	73	29	7	19	30	1	11	0	4	20	55
NO. OF RAINDAYS	3	2	4	1	3	1	1	2	0	1	3	5

LOW MONTHLY EVAPORATION (mm) - HIGH RAINFALL/RAINDAYS

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
YEAR	1974	1971	1989	1990	1989	1990	1989	1985	1978	1985	1989	1975
MONTHLY EVAP	163	129	143	109	93	73	56	84	118	144	156	183
MONTHLY RAINFALL	157	297	134	146	57	31	53	45	118	92	129	361
NO. OF RAINDAYS	14	17	8	13	10	5	4	3	9	9	10	9

THEODORE EVAPORATION VARIABILITY

TABLE 9

HIGH MONTHLY EVAPORATION (mm) - LOW RAINFALL/RAINDAYS

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
YEAR	1969	1969	1985	1969	1973	1975	1970	1970	1980	1968	1968	1972
MONTHLY EVAP	336	289	268	206	153	129	130	186	236	259	310	309
MONTHLY RAINFALL	33	73	29	7	19	30	1	11	0	4	20	55
NO. OF RAINDAYS	3	2	4	1	3	1	1	2	0	1	3	5

LOW MONTHLY EVAPORATION (mm) - HIGH RAINFALL/RAINDAYS

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
YEAR	1974	1971	1989	1990	1989	1990	1989	1985	1978	1985	1989	1975
MONTHLY EVAP	163	129	143	109	93	73	56	84	118	144	156	183
MONTHLY RAINFALL	157	297	134	146	57	31	53	45	118	92	129	361
NO. OF RAINDAYS	14	17	8	13	10	5	4	3	9	9	10	9

ROCKHAMPTON EVAPORATION VARIABILITY

TABLE 9 cont.

HIGH MONTHLY EVAPORATION (MM) - LOW RAINFALL/RAINDAYS

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
YEAR	1969	1969	1970	1967	1970	1970	1970	1970	1969	1971	1968	1979
MONTHLY EVAP	321	299	255	232	182	157	154	187	262	290	321	286
MONTHLY RAINFALL	15	54	14	11	*	9	2	20	3	17	45	15
NO. OF RAINDAYS	7	6	7	4	0	1	1	4	2	7	4	7

LOW MONTHLY EVAPORATION (MM) - HIGH RAINFALL/RAINDAYS

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
YEAR	1974	1971	1977	1990	1989	1990	1966	1966	1966	1986	1983	1965
MONTHLY EVAP	151	139	144	105	101	86	75	89	134	160	179	150
MONTHLY RAINFALL	660	446	248	199	304	34	28	60	78	61	112	195
NO. OF RAINDAYS	24	18	13	19	19	8	4	12	7	9	13	16

EMERALD EVAPORATION VARIABILITY

TABLE 9 cont.

HIGH MONTHLY EVAPORATION (mm) - LOW RAINFALL/RAINDAYS

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
YEAR	1985	1969	1985	1969	1969	1982	1969	1969	1969	1970	1982	1982
MONTHLY EVAP	282	253	236	219	146	120	157	180	259	265	344	362
MONTHLY RAINFALL	9	4	13	0	33	0	1	0	0	10	1	43
NO. OF RAINDAYS	5	2	7	0	3	0	1	0	0	2	1	3

LOW MONTHLY EVAPORATION (mm) - HIGH RAINFALL/RAINDAYS

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
YEAR	1974	1971	1977	1978	1983	1978	1973	1978	1978	1975	1973	1973
MONTHLY EVAP	118	147	116	125	92	67	82	114	133	176	206	191
MONTHLY RAINFALL	380	179	126	92	197	26	98	31	101	92	117	229
NO. OF RAINDAYS	24	11	10	3	14	9	9	5	8	9	10	12

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WATER RESOURCES OF THE FITZROY BASIN

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1.0 NATURAL WATER RESOURCES

1.1 SURFACE WATER

It is estimated that the mean annual discharge for the whole of the Fitzroy catchment is some 7 130 000 megalitres. Streams in the north-eastern corner of the Basin, where the rainfall is relatively higher, provide a disproportionately higher contribution to the total discharge. The Connors River, for example, which has a catchment area of 9 945 square kilometres or 7% of the total Basin area, provides, on average, 25% of the total annual discharge. Estimates of the mean annual discharge for major streams in the catchment are given in Table 1.1.

Streamflow records are available from 99 stream gauging stations, the locations of which are shown in Figure 1.1. Seventy of these gauging stations are still operating.

Streamflow, as with rainfall is seasonal with pronounced summer runoff. There is also considerable variation year to year. Monthly and annual streamflow statistics for selected gauging stations on the Dawson and Mackenzie Rivers and Funnel Creek are presented in Table 1.2. The variability in annual discharge is demonstrated in Figure 1.2 which shows records for a gauging station on the Dawson River at Theodore.

1.2 GROUNDWATER

Groundwater is obtained in this area from alluvial, sedimentary rock and fractured rock aquifers. The alluvial aquifers are associated with the surface water drainage of the area with extensive deposits occurring adjacent to the Nogoa, Comet, Mackenzie, Dawson, Isaac, Don, Dee and Fitzroy Rivers and Callide Creek. The sedimentary rock aquifers are confined almost entirely to the southern half of the Basin. The sedimentary aquifers in the Upper Dawson Valley are predominantly Hutton Sandstones and form the northern edge, at this location, of the Great Artesian Basin. Fractured rock aquifers provide groundwater supplies over the remainder of the catchment.

The location of the aquifers are shown in Figure 1.3.

The catchment exhibits a wide range of groundwater quality. Approximately half the area has access to groundwater with quality less than 3 000 milligrams per litre TDS.

Groundwater pumping rates are low for more than eighty percent of the area. The aquifers with high pumping rates are elements of the sedimentary rocks and some sections of the alluvium such as those associated with the Comet, Don and Fitzroy Rivers and Callide Creek.

Information on groundwater quality and pumping rates is given in Figure 1.4.

1.3 EXISTING WATER RESOURCES DEVELOPMENT

Major water conservation undertakings have been developed to provide water supplies for irrigation, industry and urban centres. Details of the storages are given in Table 1.3 and their locations are shown in Figure 1.5. Brief details of the major water conservation projects are given below.

Emerald Irrigation Area

Irrigation, urban, industrial and stock and domestic supplies are provided from a storage system comprising Fairbairn Dam, Selma and Town Weirs on the Nogoa River and Bedford, Bingegang and Tartrus Weirs on the Mackenzie River.

Water is diverted from Fairbairn Dam through 73 kilometres of channel on the left bank of the Nogoa River and 53 kilometres of channel on the right bank for irrigation farms. Irrigation supplies are also provided from the regulated sections and weirs of the Nogoa and Mackenzie Rivers from Fairbairn Dam to the Springton Creek junction which is some 90 kilometres downstream of Tartrus Weir.

Urban water supplies are obtained from Town, Bedford and Bingegang Weirs.

Water supplies for coal mines are obtained from Selma, Bedford and Bingegang Weirs.

Dawson Valley Irrigation Area

Irrigation urban, industrial and stock and domestic water supplies are provided from a system of weirs along some 310 kilometres of the Dawson River. The weirs in this system are Glebe, Gyranda, Orange Creek, Theodore, Moura and Neville Hewitt.

Irrigation supplies are provided from channel systems on the left and right banks of the Dawson River at Theodore. Supplies for these farms come from Theodore Weir. Water for irrigation is also obtained by private diversion from the regulated section of Dawson River from Glebe Weir downstream to the Central Queensland Railway Bridge near Boolburra.

Urban water supplies are provided from Orange Creek, Theodore, Moura and Neville Hewitt Weirs and the Dawson River.

Water for mining operations is obtained from Moura and Orange Creek Weirs.

Callide Valley

Irrigation, industrial, urban, stock and domestic supplies are provided within the Callide Valley from surface water storages and groundwater which is artificially recharged.

The major storage is Callide Dam which provides industrial water for Callide Power Station, urban water supplies for Biloela and irrigation, stock and domestic supplies by release into Callide Creek for extraction as surface water and groundwater following artificial recharge of the adjacent aquifer. Water supplies for the Power Station are augmented by water being diverted into Callide Dam from Awoonga Dam which is outside of the study area. Water is also diverted from Callide Dam for artificial recharge of the aquifers of Kroombit and Kariboe Creeks for irrigation, stock and domestic purposes.

Fitzroy Barrage

Urban and irrigation supplies are provided from the Fitzroy Barrage which is on the Fitzroy River at Rockhampton.

Water supplies for Stanwell Power Station, which is under construction, are to be taken via a pipeline from the Fitzroy Barrage. A weir, to be named Eden Bann, is to be constructed some 83 kilometres upstream of the Barrage to provide the additional supplies required for the power station.

TABLE 1.1

ESTIMATES OF MEAN ANNUAL DISCHARGE FOR MAJOR STREAMS

STREAM	CATCHMENT AREA (km^2)	MEAN ANNUAL DISCHARGE (ML)	MEAN ANNUAL RUNOFF (mm)
Nogoa R	27 895	880 000	32
Comet R	17 200	645 000	38
Mackenzie R (upstream of Isaac River junction)	52 335	1 730 000	33
Isaac R	22 470	2 229 000	99
Connors R	9 945	1 771 000	178
Mackenzie R (upstream of Dawson R junction)	69 920	4 139 000	59
Dawson R (at Theodore)	27 350	735 000	27
Dawson R	50 830	1 377 000	27
Don R	7 720	288 000	37
Fitzroy R	142 645	7 130 000	50

TABLE 1.2

STREAMFLOW STATISTICS FOR SELECTED STREAMS

Stream and AMTD Gauging Station Name and No. Period of Record	Dawson River at 230.1 km Theodore 130305 1929-1989			Funnel C at 74.4 km Main Road 130406 1966-1989			Mackenzie R at 585.8 Carnangarra 130103 1967-1989		
Month	Discharge (ML)			Discharge (ML)			Discharge (ML)		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum
JAN	758 549	71 781	0	737 069	98 020	0	1 959 969	270 030	1 341
FEB	2 651 382	206 536	0	564 801	124 641	5	2 048 936	368 432	5
MAR	1 337 774	73 574	0	472 247	112 461	272	1 066 761	117 448	0
APR	573 969	32 546	0	405 137	27 856	314	162 810	23 116	88
MAY	2 043 966	61 991	0	184 123	23 077	40	2 583 451	182 334	0
JUNE	741 357	40 740	0	48 404	7 430	4	587 357	44 091	0
JULY	871 888	28 630	0	65 067	5 810	0	90 781	13 041	0
AUG	293 540	17 494	0	16 420	1 954	0	112 471	9 130	0
SEP	162 647	4 617	0	5 279	1 033	0	116 050	7 332	0
OCT	346 474	21 177	0	7 152	1 316	0	100 864	7 187	0
NOV	298 969	22 222	0	24 920	4 229	0	72 764	11 317	0
DEC	990 074	87 493	0	302 575	30 351	0	1 503 667	139 293	4
Annual Discharge (ML)	4 790 820	678 883	0	1 486 658	419 980	8 554	4 946 831	1 225 359	3 834

TABLE 1.3

EXISTING STORAGES (1)

SUB-CATCHMENT AND STREAM NAME	STORAGE NAME	AMTD (km)	STORAGE CAPACITY (ML)	OWNER	MAJOR PURPOSE
FITZROY R					
Fitzroy R	Fitzroy Barrage	59.6	60 300	Rockhampton C.C.	Urban
U/T Maryvale C			2 500	Private	Irrigation
Eight Mile C	Bajool Weir	36.9	312	WRC	Urban
MACKENZIE R					
Mackenzie R	Tartrus Weir	429.5	12 000	WRC	Irrigation
Mackenzie R	Bingegang Weir	489.2	5 000	WRC	Industry
Mackenzie R	Bedford Weir	548.8	9 130	WRC	Industry
U/T Two Mile C			620	Private	Irrigation
Duck C			605	Private	Domestic
Columbia C	Columbia Ck Weir		99	Duaringa S.C.	Urban
German C	Bundoora Dam	27.4	14 000	Capcoal	Industry
German C			1 520	Capcoal	Flood Prevention
NOGOA R					
Nogoa R	Town Weir	663.5	487	Emerald S.C.	Urban
Nogoa R	Selma Weir	668.7	1 180	WRC	Industry
Nogoa R	Fairbairn Dam	685.6	1 440 000	WRC	Irrigation
Theresa C	Theresa Ck Dam	111.7	9 200	Belyando S.C.	Urban
Bath C			3 700	Blair Athol Coal	Industry
Washpool C			2 800	Blair Athol Coal	Flood Prevention
U/T Retro C			1 200	Private	Irrigation
U/T Centre C			891	Private	Irrigation
Sandy C	Sandy Ck Weir	63.3	360	Belyando S.C	Urban (Standby)
COMET R					
Comet R	Comet Weir	10.8	50	Emerald S.C	Urban
U/T Comet R			2 290	Private	Irrigation
Comet R Anabanch			700	Private	Irrigation
U/T Humboldt C			1 100	Private	Irrigation

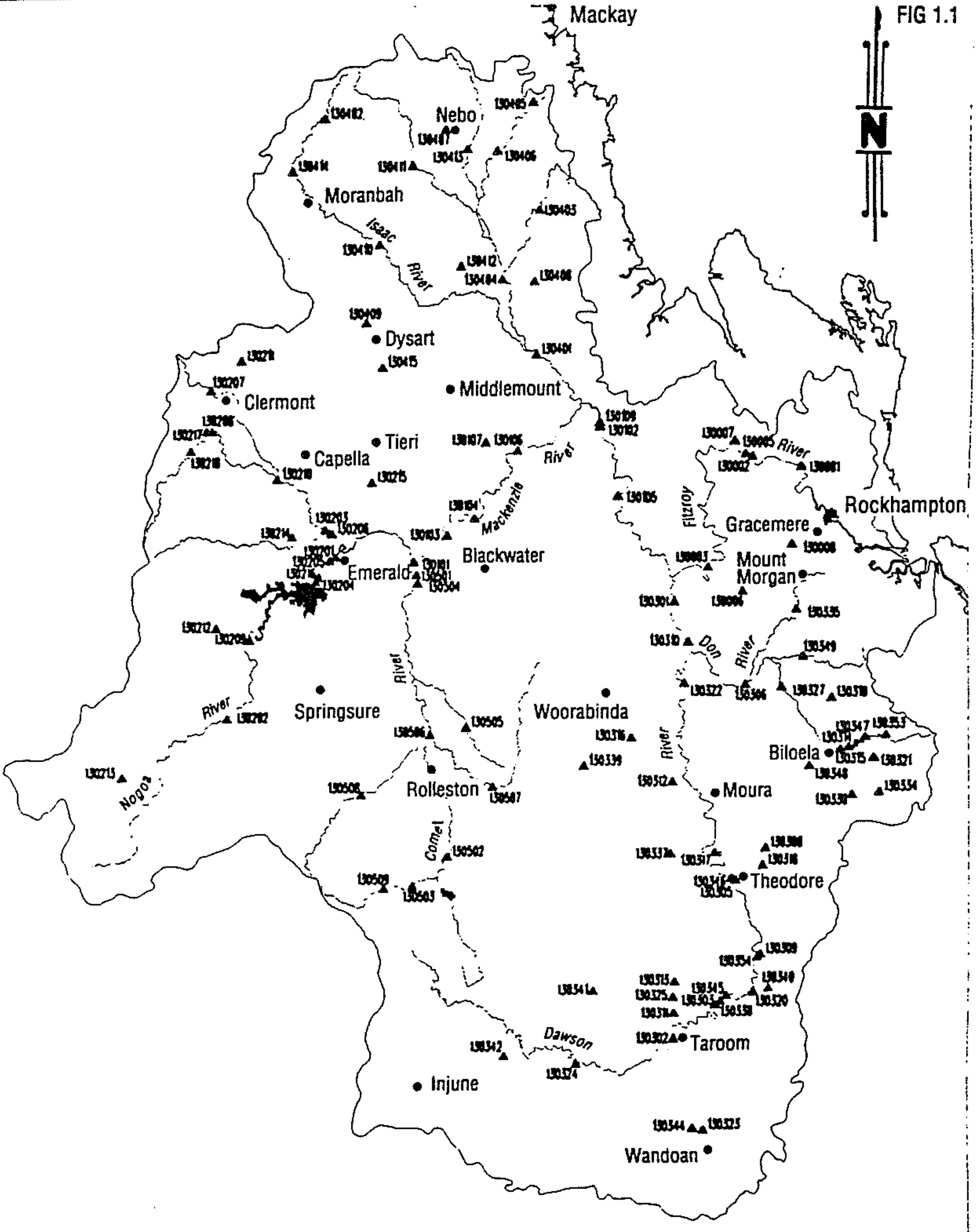
TABLE 1.3 (Continued)

SUB-CATCHMENT AND STREAM NAME	STORAGE NAME	AMTD (km)	STORAGE CAPACITY (ML)	OWNER	MAJOR PURPOSE
DAWSON R					
Dawson R	Neville Hewitt Weir	82.7	11 300	WRC	Irrigation
Dawson R	Moura Weir	150.2	7 250	WRC	Irrigation
Dawson R	Theodore Weir	228.5	4 760	WRC	Irrigation
Dawson R	Orange Creek Weir	270.7	8 780	WRC	Irrigation
Dawson R		284.5	14 700	WRC	Irrigation
Dawson R	Gyrandra Weir	326.2	17 300	WRC	Irrigation
U/T Dawson R	Glebe Weir		1 100	Private	Irrigation
U/T Dawson R			1 200	Private	Irrigation
DON R					
Callide C	Dakenba Weir	61.1	530	WRC	Regulation/ Groundwater Recharge
Callide C	Callide Dam	80.1	127 000	WRC	Industry
U/T Callide C			550	Callide Coalfields	Industry
Kroombit C	Kroombit Dam (3)	68.8	13 200	WRC	Groundwater Recharge
Back C			800	Private	Irrigation
Grevillea C	Grevillea Weir	18.0		WRC	Groundwater Recharge
Kariboe C	Thangool Weir	12.5		WRC	Groundwater Recharge
Kariboe C	Kariboe Ck Weir	16.4	155	WRC	Groundwater Recharge
Fletcher C	Fletcher Ck Weir	0.2	700 (2)	Mt Morgan S.C.	Urban
ISAAC R					
Blackburn C			1 000	Private	Irrigation
Ripstone C	Peak Downs Mine Dam		618	BHP-Utah	Industry
One Mile C	Saraji Mine Dam		400	BHP-Utah	Industry

Abbreviation U/T - unnamed tributary of.

Note: (1) This table does not include private farm dams with less than 500 ML capacity.
(2) Including groundwater storage.
(3) Under construction.

FIG 1.1



▲ Stream Guaging Stations

KILOMETRES

0 100 150

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FITZROY REGION
STREAM GAUGING STATIONS

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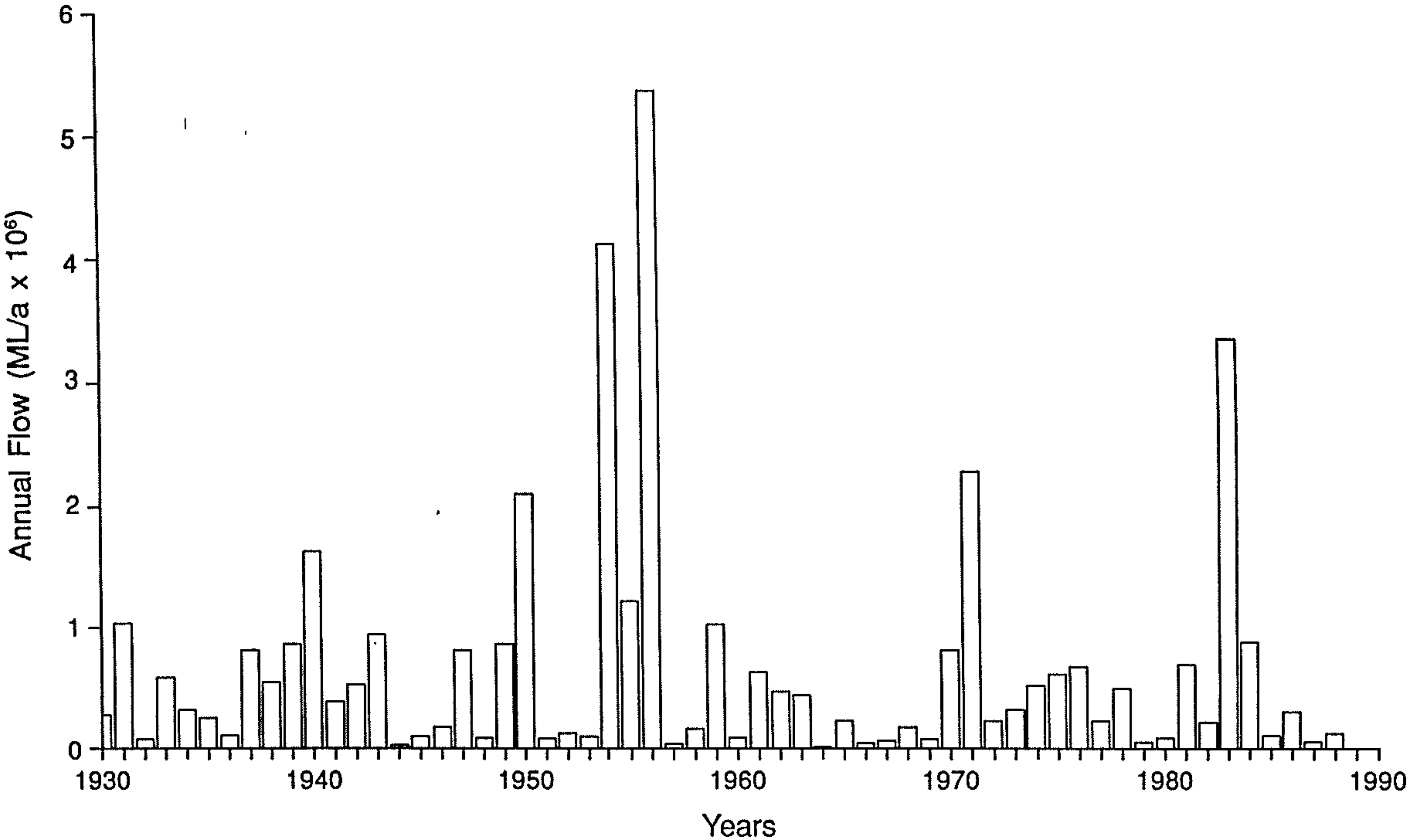
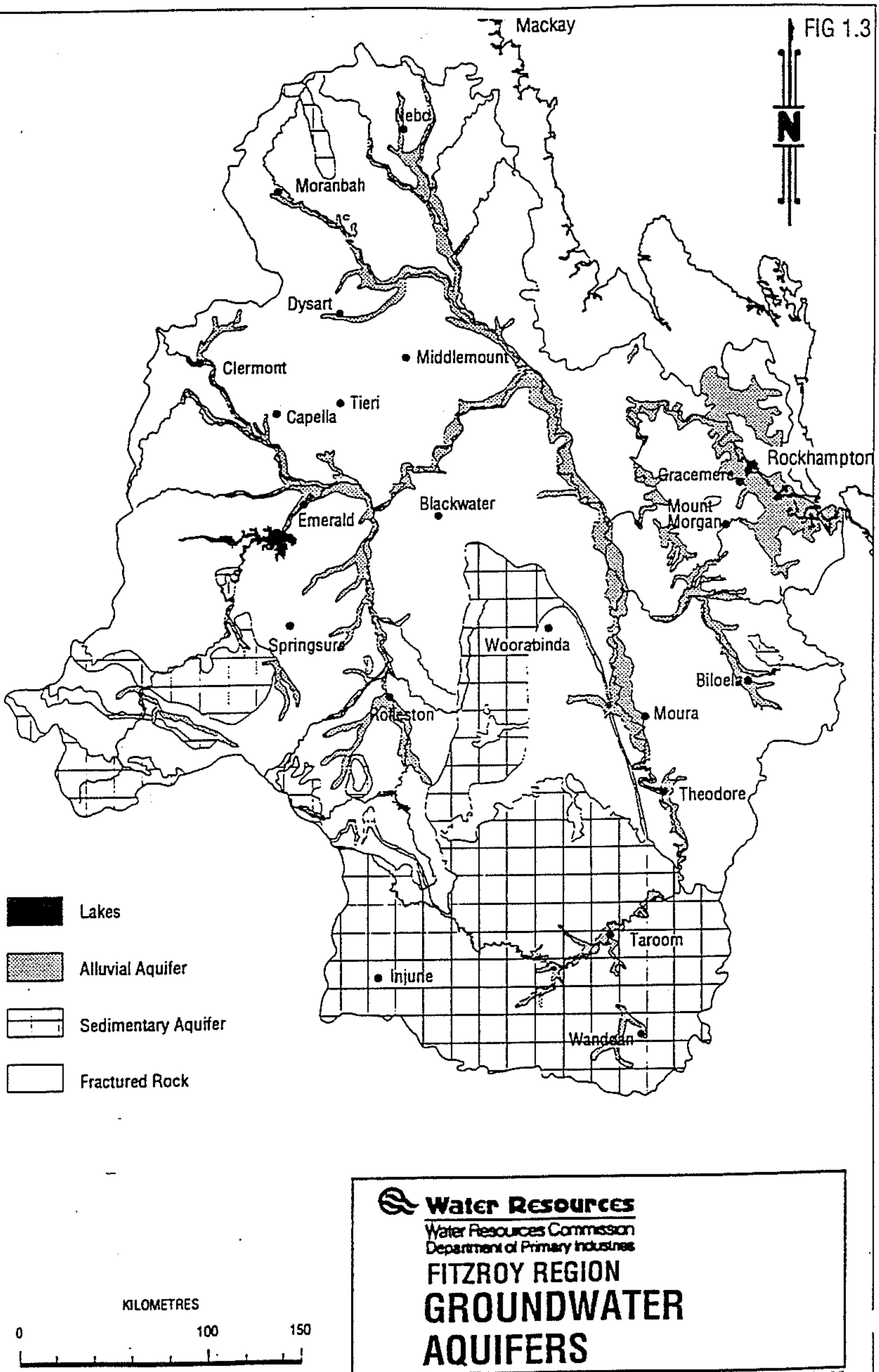


Figure 1.2 ANNUAL DISCHARGE GS130305 DAWSON RIVER AT THEODORE

FIG 1.3



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GROUNDWATER AQUIFERS

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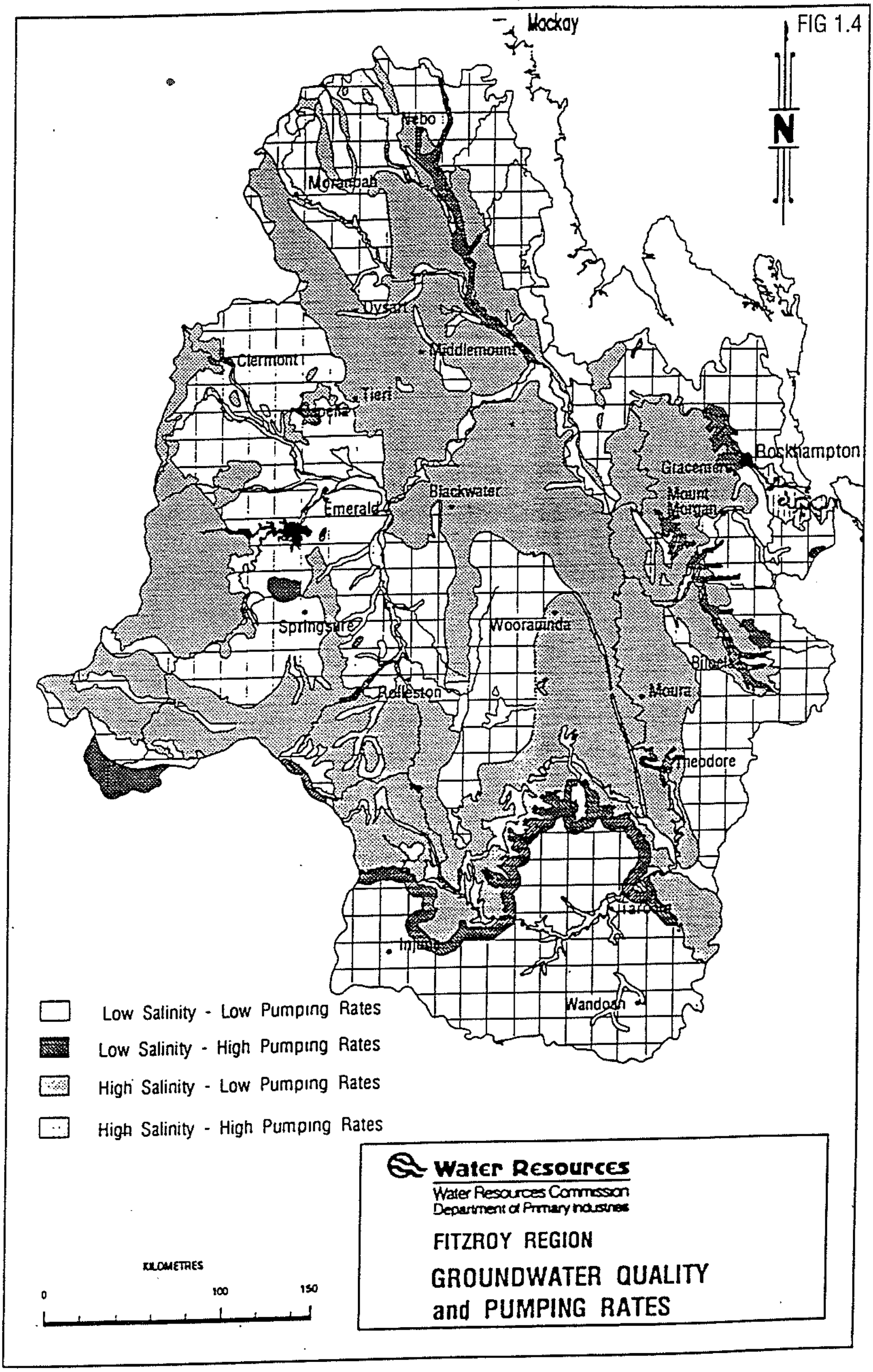

FIG 1.4

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FITZROY REGION
GROUNDWATER QUALITY and PUMPING RATES

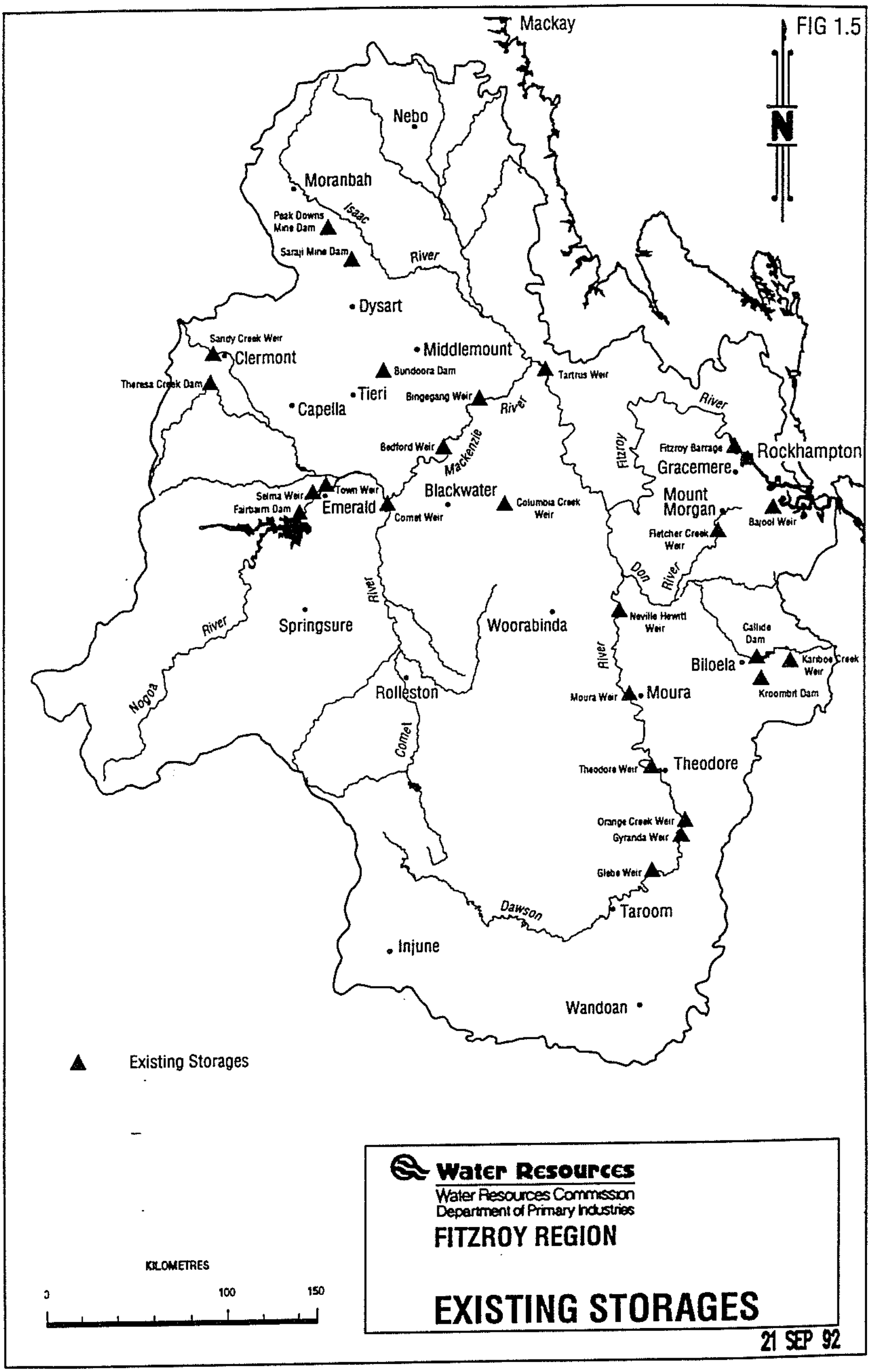
FIG 1.5
N
Mackay
Nebo
Moranbah
Isaac
River
Peak Downs Mine Dam
Saraji Mine Dam
Dysart
Sandy Creek Weir
Clermont
Middlemount
Theresa Creek Dam
Bundoora Dam
Tartrus Weir
Tieri
Capella
Bingegang Weir
River
Bedford Weir
Mackenzie
Fitzroy
River
Fitzroy Barrage
Rockhampton
Gracemere
Town Weir
Selma Weir
Fairbairn Dam
Emerald
Comet Weir
Blackwater
Columbia Creek Weir
Mount Morgan
Bajool Weir
Fletcher Creek Weir
Don
River
River
Springsure
River
Woorabinda
Neville Hewitt Weir
Callide Dam
Biloela
Kariboe Creek Weir
Kroombit Dam
Nogoa
River
Rolleston
River
Moura Weir
Moura
Comet
Theodore Weir
Theodore
Orange Creek Weir
Gyranda Weir
Glebe Weir
Dawson
Taroom
Injune
Wandoan
Existing Storages
KILOMETRES
0
100
150
Water Resources
Water Resources Commission
Department of Primary Industries
FITZROY REGION
EXISTING STORAGES
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2.0 AVAILABLE WATER SUPPLY

The existing available supply of good quality water from storages within the study area and groundwater aquifers is in excess of 1 200 000 ML/a. Groundwater supplies make up 934 000 ML/a or 78% of this total.

2.1 SURFACE WATER

The largest water supply system in the Fitzroy catchment is the Nogoa/Mackenzie Supply System. This system can provide some 154 000 megalitres of water per annum with a reliability of 100 percent. Relaxation of the reliability allows a larger supply to be provided. Under the presently adopted reliabilities, where urban and industrial supplies are assured and irrigation supplies are provided at 89 percent or 85 percent monthly reliability, the supply available is 218 000 megalitres per annum.

The assured supply available from the system of weirs along the Dawson River amounts to some 33 000 megalitres per annum. This system is currently operating at 75% annual reliability which provides a supply of 60 000 megalitres per annum.

Callide Dam provides on a safe yield basis some 4 800 megalitres per annum. Operated at 90% monthly reliability this supply increases to some 13 600 megalitres per annum. Additional supplies are also delivered into Callide Dam storage via a pipeline and natural stream channel from Awoonga High Dam which is outside the study area. These additional supplies are used in the Callide Power Station.

The Fitzroy Barrage has an annual supply of 40 000 megalitres per annum. this supply increases to 72 000 megalitres per annum with a monthly reliability of 99%.

Full details of the supplies available from the above surface water storages as well as other, smaller storages are presented in Table 2.1.

As well as supplies provided by storages located within the Fitzroy catchment, this area receives water imported from adjacent Basins. In addition to the Awoonga High Dam water mentioned above, water supplies are provided via pipeline from Eungella Dam for coal mining and associated urban needs in the Isaac River area. Eungella Dam is located on the Broken River, a tributary of the Burdekin River.

Water supplies (predominantly for irrigation) are also obtained from unregulated stream flow. However, it is very difficult to place a figure on the magnitude of the yield available from this resource because of the very high variability of stream flow from year to year and the limited coverage of stream flow data.

2.2 GROUNDWATER

Little is known of the groundwater in the study area with the exception of the alluvial aquifers associated with the Isaac River catchment, Don River, Dee river, Callide Creek and the Fitzroy River. An assessment of the groundwater yields for the remaining areas of the Basin has been made using geological interpretation. This assessment whilst only preliminary, provides an indication of the magnitude of the resource.

The preliminary assessment and the information from the better known areas indicate that the total groundwater yield available in the Fitzroy Basin is some 1 179 000 megalitres per annum. Almost 80% of this total yield is water of a quality that would make it suitable for irrigation, urban or industrial purposes.

Estimates of groundwater yields available for each aquifer type in each sub-catchment are given in Table 2.2.

2.3 SEWAGE EFFLUENT

There are a number of sewage treatment plants in the study area. These plants produce a significant amount of effluent and therefore provide a resource which could be used in the future.

Discharge from all sewage treatment plants amounts to more than 11 300 megalitres per annum. As would be expected the sewerage treatment plants at Rockhampton produce the largest volume of effluent in the Basin. In 1989/90 these plants discharged some 7 800 megalitres.

5.0 COMPARISON OF FUTURE DEMANDS AND AVAILABLE SUPPLIES

Because of the inability at this stage to quantify the available supplies from the unregulated stream flow, it will only be possible in this section to make quantitative comparisons for the regulated surface water and the groundwater.

The demands do not as yet include instream water requirements. Should an allowance be made for these in the future, the total water demand (the consumptive and instream requirements) will be significantly greater. This will result in an earlier date at which the available supply matches the demand.

5.1 REGULATED SURFACE WATER

Nogoa/Mackenzie Supply System

The total regulated supply available from the Nogoa/Mackenzie supply system ranges from some 154 000 ML/a at 100% reliability of supply to 218 000 ML/a under reliabilities of supply (monthly) from 85% to 100% at the various extraction points (see Case 2 Table 2.1). This supply compares with the estimated demands on the system of some 156 000 ML/a by 1995 and some 194 000 ML/a by the year 2010.

The supplies available from this system under the two cases of reliability presented in Table 3.1, together with the existing and estimated future demands that will be placed on the system, are shown in Figures 5.1 and 5.2.

As can be seen from Figure 5.2 it is predicted that the demand on the Nogoa R sub-catchment element of the system will exceed the supply available under the conditions of the Case 2 hydrologic study by some 8 000 ML/a by the year 2010. Case 2 represents the current allocation policy for supplies from the system. The forecast indicates that the demand should equal the supply available in this sub-catchment by about the year 2004.

On the assumption that the demand predictions are reasonable, whether or not there will be a real shortage in supply in this section by 2010 will depend on the reliabilities of supply demanded by the various users at that time and whether or not Fairbairn Dam and Selma Weir can provide the supplies in this section while still meeting the demands further downstream.

A close watch will have to be kept on the demands in this section of the supply system. Further hydrologic studies will need to be carried out if the demands and reliabilities requested by the users vary greatly from the Case 2 conditions.

Dawson River Supply System

The total supply available from the Dawson River supply system varies from 33 300 ML/a at 100% reliability to 64 400 ML/a at 70% reliability (annual) (see Table 2.1). This supply compares with the estimated demands on the system of some 33 000 ML/a by 1995 and some 49 000 ML/a by 2010.

The supplies from the Dawson River system, under the range of reliabilities shown in Table 2.1 together with the existing and forecast future demands, are shown in Figure 5.3.

The current policy regarding the allocation of supplies in this steam is that the supplies are provided with an annual reliability of 75%.

Under these conditions it is expected that the demands will not exceed the supplies available in this sub-catchment at least until the year 2010.

Since 1989 when the irrigators in the Dawson River accepted an annual reliability of 75% in return for increasing the supply from 43 700 ML/a to 60 000 ML/a, there has been two significantly dry periods that resulted in restrictions being placed on the allocations.

It is understood that the irrigators may seek to hold the total allocation at the present level of some 56 000 ML/a thus increasing the reliability from 75% to 80% annually. If this occurs and this level of reliability persists, then it is likely that the demand will equal the supply shortly after the turn of the century.

While the water supply is currently 93% allocated, it should be noted that there is substantial under utilisation of the resource. The demand in 1992 is running at some 31 000 ML/a.

The recently introduced capital charge for new allocations has resulted in very little, if any interest in taking up further supplies. While it is envisaged that in the long term additional irrigation allocations will be made, it is likely that the short term demands will be satisfied by a higher utilisation of the existing allocations.

Fitzroy Barrage

By the year 2010 the estimated demand on regulated surface water supplies in the Fitzroy R sub-catchment exceeds the existing supply available at 100% monthly reliability by some 18 000 ML/a. The existing supply is from the Fitzroy Barrage and the large increase in estimated demand is a result of the development of the Stanwell Power Station.

The shortfall in supply will not occur however, because a weir, to be named Eden Bann Weir, is being constructed on the Fitzroy River to meet the needs of the power station.

It is expected that the Barrage will be able to meet the urban and irrigation demands placed on the storage beyond the year 2010.

Callide Dam

It is not anticipated that there will be any shortfall in supply from Callide Dam by the year 2010.

Some 8 400 ML/a is diverted from Awoonga Dam, which is outside the Study Area into Callide Dam for use in the Callide Power Station. This amount has been included in this section.

Also, some 10 000 ML/a of the supply available from this storage is released downstream for groundwater recharge. This amount has not been considered in this section, but has been included in the following groundwater section.

5.2 GROUNDWATER

With the exception of the Callide Creek and Don River areas it is envisaged that the groundwater supplies will be able to meet the demands placed on them well beyond the year 2010.

While it is estimated that there will be no shortfall in total groundwater supplies within the catchment of the Don River at least until 2010, it is believed that the current demand equals the supply for the alluvial aquifers associated with the Don and Dee Rivers.

It is expected that the demand could exceed the supply in this area by some 2 500 ML/a by 1995 and approximately 7 000 ML/a by the year 2010.

Similarly, while it is unlikely that a shortfall in groundwater supplies in the Callide Creek catchment could occur before the year 1995, there is at present a significant shortfall in the supply available from the alluvial aquifer of this area. It is estimated that the present demand from the alluvium is some 37 000 ML/a which is 10 000 ML/a greater than the supply available from the aquifer even allowing for the supplies that are provided by Callide Dam and will be provided by Kroombit Dam.

It is predicted that the demand for water from the alluvial aquifer will continue to increase until by the year 2010, it is likely to be of the order of some 56 000 ML/a. Some 54 000 ML/a of this demand is expected to be for irrigation.

It is perceived that the demand could reach this magnitude because of the availability of good agricultural soil, the existence of appropriate infrastructure and the desire of the land owners to move from dryland to irrigated farming.

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Catchment Management for Marine Ecosystems
Where does the Fitzroy River System Finish ?

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Abstract

The discharge from the Fitzroy River enters the sea behind the northern end of Curtis Island, in the southern end of Keppel Bay. Wind and wave action in the area is minimised by the protective barrier of Curtis Island, and the consequent reduced movement of water causes deposition of suspended river sediment within the bay. Flood runoff from the Fitzroy River, and the associated sediment deposition, has recently had a major impact on the fringing reefs surrounding the continental islands within Keppel Bay.

Keppel Bay is an important commercial fishery supporting trawling for scallops and prawns, trolling for pelagic species, commercial aquarium fish and coral collection, oyster gathering and inshore gillnet enterprises. The bay also receives extensive tourist, commercial and recreational use.

Clearing of the Fitzroy River catchment for agricultural purposes, particularly in the last 30 years, has led to increased silt loads during flood events, exacerbating the high level of coral mortality experienced in the bay. The future management of catchment activities may significantly affect the viability of this important natural system.

It has been established that rivers along the Queensland coast provide the largest single source of nitrogen and phosphorous to close coastal waters. In the last 100 years the nature of river runoff from Queensland coastal catchments is believed to have changed markedly. Catchment modelling suggests there have been three to five fold increases, or more, in sediment and nutrient runoff.

The impact of these agriculturally derived materials on Keppel Bay are discussed in this paper and the significance of catchment management practices for the continued health of the Great Barrier Reef is considered.

The role of local government is addressed and recommendations for support mechanisms for these agencies are presented.

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Introduction

Many coral reefs around the world are now in a state of alarming decline, primarily due to terrestrial runoff of sediments and nutrients from adjacent catchments.

The impacts such contaminants have on coral reefs has been documented on a variety of scales (Byron, 1992; Brodie, 1991; Ward ,1990), however these impacts have rarely been addressed in the management of lands within a catchment, or indeed adjacent lands.

In certain situations, such as the Florida Keys in the United States of America, crisis point has been reached and coral reef ecosystem decline is occurring so rapidly, that recovery may not be possible . Even at this late stage coordinated efforts are not being made to redress this decline in the Keys. The situation has recently been described by users of the area as," like living with a terminally ill family member whose doctors argue over the symptoms while the patient silently slips away"(Ward, 1990).

To prevent similar situations occurring within the Great Barrier Reef, resources must be considered carefully and immediate action taken. Such action must be coordinated at the broad strategic level, but needs also to be focussed at the local level, to ensure recognition and management of particular problems. Local councils have a vital role to play here, and must be supported in their efforts to address the problems of integrated catchment management.

The Fitzroy Catchment

The Fitzroy basin covers an area of 140,000 square kilometres on the North East coast of Australia .The climate throughout the basin is distinctly seasonal, with heavy summer rainfall and protracted dry winter spells.

Most of the large volume flood flows in this basin are due to extremely high, short-term rainfall events, resulting from monsoonal or cyclonic synoptic activity. Widespread flooding is common throughout the gently undulating terrain and broad floodplains, with the subsequent runoff taking a considerable time to discharge into Keppel Bay through the Fitzroy River.

This runoff contains high sediment and nutrient loads and probably carries significant pesticide residues. Floods have the effect of flushing out pools and impoundments which have served as settling ponds for these contaminants.

The discharge from the Fitzroy River enters the sea 40 km south-east of Rockhampton behind the northern end of Curtis Island, in a low energy environment characterised by low mangrove islands, shallow re-entrants and straits. Wind and wave action in the area is minimised by the protective barrier of Curtis Island, and the consequent reduced movement of water causes deposition of suspended river sediment. Because of the constrictive nature of The Narrows to the south, most of the outflow from the river travels northwards, into Keppel Bay. This wide open bay extends another 50 kilometres northward along the coast, and contains more than 15 continental islands.

The seabed in the Keppel Bay area is composed almost entirely of terrigenous quartzose sands thought to be derived from the Fitzroy and the southern rivers of the Maryborough basin (Maxwell, 1968). These relatively mud-free deposits have been concentrated as a result of hydrodynamic factors related to the predominant south-easterly winds, and the unprotected nature of the coastline. Wave action generated by the strong south-easterly winds suspends the mud fraction, which is then largely removed by the strong tide-induced currents of the area (Beach Protection Authority, 1979).

The Keppel Islands are continental in origin, and support well developed fringing reefs, up to 200 metres wide. These generally occur as isolated reef patches adjacent to headlands, or on the protected south and western sides of the islands, and are dominated by *Acropora* spp.

Keppel Bay is an important commercial fishery supporting trawling for scallops and prawns, trolling for pelagic species, commercial aquarium fish and coral collection, oyster gathering and inshore gillnet enterprises. The bay also receives extensive tourist, commercial and recreational use.

There is an underwater observatory on Middle Island and tourist resorts on Great Keppel Island, Pumpkin Island and, up until recently, North Keppel Island. These developments have been located to take advantage of the adjacent coral reef communities with water based activities such as snorkelling, scuba diving and fishing, a focus of the activities offered.

Keppel Bay is mostly within the Great Barrier Reef Marine Park. The Bay is zoned and managed under the Great Barrier Reef Marine Park Act to accommodate a spectrum of commercial and recreational usage. Effective management of the area requires investigation and understanding of natural or anthropomorphic changes, to ensure adjustments to established management regimes are undertaken as required.

In January of 1991, extensive rainfall emanating from Tropical Cyclone Joy created widespread flooding within the Fitzroy River system. The floodwaters subsequently leaving the river, engulfed the islands within Keppel Bay. As mass mortality of corals resulting from freshwater innundation and associated sediment deposition had been reported previously (Squires,1962),(Banner, 1968),(Supriharyono, 1985), it was recognised that the magnitude of this event was likely to cause severe impacts throughout the fringing reefs of Keppel Bay. As expected this runoff and the associated sediment from these floodwaters had a major impact on the fringing reefs surrounding the continental islands within Keppel Bay. In fact, the shallow fringing reefs on the southern and western shores of Great Keppel, North Keppel, Middle and Miall Islands were devastated, with mortality of 90% reported over a wide area (Byron *et al*, 1992).

These impacts directly influenced use of the area, and created some difficulty for industries based on this resource.

Historic evidence suggests that the 1991 flood was simply another event in a long series of natural environmental perturbations. However, changes in the land use practices throughout the catchment (Johnson, 1985), which have significantly elevated sediment loads in the river, may be exacerbating the severity of the impact of these natural events. The cumulative effects of increasing silt deposition, combined with irregular massive freshwater immersion, may be reducing the viability and potential for re-establishment of the coral communities in certain locations throughout Keppel Bay.

Whilst it was not possible during the course of the 1991 flood event to establish overall sediment loads in the river, Department of Primary Industries officers reported that the flooding caused severe erosion and sedimentation in the river system. Soil loss estimates of 1300 tonnes per hectare were recorded in the cultivated areas of the floodplain, and in one instance 430,000 tonnes of alluvial soil was removed when a new channel was created (Chapman, 1992). As there were no records of massive soil deposition further downstream in the Fitzroy it is reasonable to assume that most of this displaced soil was relocated to the marine environs of Keppel Bay.

The development of the lands of the brigalow belt, (*Acacia harpophylla*), for agriculture in the mid 1960's to the early 1970's resulted in the clearing of several million hectares of central Queensland, primarily in the Fitzroy catchment (Webb, 1984). The soil erosion problems associated with this extensive clearing have not dissipated (Johnson, 1985). Whilst mud fractions are removed from Keppel Bay by strong northerly currents (Beach Protection Authority, 1979), large volumes of sediment from the brigalow lands are being deposited in Keppel Bay, during flood events.

This sediment causes ongoing stress of fringing reefs, as the waters of the bay are continually muddied by the resuspension of bottom sediment stirred up by winds, tides and currents.

Great Barrier Reef Region

This problem is not restricted to the Fitzroy River system. On a broader scale there is recognition that change in the quality and quantity of terrestrial runoff is potentially the most significant anthropogenic threat to the long-term conservation of the Great Barrier Reef (GBR) at all scales (Rasmussen and Cuff, 1990; Yellowlees, 1991; Bell, 1991).

Most river catchments in north and central Queensland, have been extensively modified since European settlement by forestry, urbanization and agriculture - particularly sugar cane cultivation and grazing. Scientific evidence of effects on the nutrient and sediment loads of the rivers is sparse but research effort is increasing as the potential problems are recognized. Scientific debate continues as to the severity of any resultant effect in the the GBR (Walker, 1991; Bell and Gabric, 1991; Kinsey, 1991), but there is general agreement of the need for clarification, through research, of the scale and the principle causes.

Recent studies using simple catchment models and existing data have quantified the principal sources of sediment and nutrients exported from the coastal catchments of Queensland (Moss *et al*, 1992). The report estimates that 15 million tonnes of sediment, 77 thousand tonnes of nitrogen, and 11 thousand tonnes of phosphorous, are exported annually to the coastal zone via river discharge. In central and northern Queensland, most of this load enters coastal waters of the GBR, the Fitzroy River being one of the three principal sources (Belperio and Searle, 1988). The study postulated that grazing is a bigger contributor of nutrients than sugar cane cultivation, and that sewage discharges are a minor component to the total flux. Sewage discharges can be significant at local scales, but contribute only a few percent of the terrestrial nutrient flux to the coastal waters of the GBR.

Most of the nutrients contained in river sediment washed from grazing lands are derived from the soil not from fertilizer. On the other hand, nitrogen and phosphorous in runoff from land cultivated for sugar cane comes from both soil loss and fertilizers. However, large increases in the use of fertilizers in the last thirty years have occurred (Pulsford, 1991) in coastal catchments. It has been suggested that significant amounts of this fertilizer is carried downstream in the river systems, eventually reappearing offshore as nutrient rich waters (Rasmussen and Cuff, 1990). As an example of changing fertilizer requirements, annual use in the Barron River area (Atherton Shire) rose from 144 tonnes in 1960 to about 3000 tonnes in 1988. However, usage in the Fitzroy catchment, without extensive sugar cane cultivation, has not increased as dramatically. Therefore, in the Fitzroy River catchment, land clearing and overgrazing are the primary contributors to excessive nutrient loads in adjacent marine areas.

Changes in some land management practices in recent years have the potential to reduce nutrient runoff. The most notable example is green cane harvesting and trash blanketting in sugar cane cultivation. The adoption of this practice has led to major reductions in soil erosion and hence phosphorous loss (Prove and Hicks, 1991). The national LANDCARE programs will hopefully lead to improved practices in other industries, reducing both soil and nutrient losses downstream. The present policy of the Great Barrier Reef Marine Park Authority regarding sewage discharges has led to some reduction in direct nutrient fluxes to the coastal zone (Brodie, 1991). This policy requires tertiary treatment (ie. nutrient removal) of sewage or land irrigation of sewage effluents, in the Great Barrier Reef Marine Park, and increasing use of land irrigation of effluents on the adjacent mainland.

Opinions as to how far terrestrial runoff moves across the continental shelf differ (Johns et al, 1988; Johnson and Carter, 1988; Gagan et al, 1987). Some studies suggest that terrigenous input reaches only halfway across the shelf while others have found terrigenous marker chemicals extending right to the edge of the shelf break. In general there does appear to be an inner reefal area dominated by terrestrial sediment and an outer area dominated by carbonate sediment, (Johnson and Carter, 1988; Wolanski and Van Senden, 1983).

King and Wolanski (1991) have shown, by modelling, that river plumes are normally constrained close to the coast by hydrodynamic conditions generated by the prevailing south-east wind regime. With variable wind conditions, river plumes can reach the outer reef as occurred with the Fitzroy River flood plume in January 1991, (Brodie and Mitchell, 1992, Prekker, 1992).

The effects of nutrient enhancement on coral reefs are well documented (Kinsey, 1991) with the largest 'natural experiment' having occurred in Kaneohe Bay, Hawaii. In this large partially enclosed bay, with an extensive barrier reef system, sewage effluents were discharged from after World War II until 1977. Extensive reef degradation occurred, with the areas nearest to the outfalls becoming dominated by filter feeding organisms. In areas some distance away coral was replaced by algal communities (Smith *et al*, 1981). Since removal of the discharges in 1977, the coral communities have made a slow recovery, although this is by no means complete. Corals in Kaneohe Bay are also episodically stressed by freshwater runoff from intense rainfall events. These events are exacerbated by land clearance for agricultural and urban development on adjacent catchments.

As noted previously, coral reefs can recover from freshwater kills, however the addition of a chronic stress, such as nutrient enhancement, may lead to failure to regenerate (Kinsey, 1991). Freshwater innundation, as occurred in 1991, combined with high sediment and nutrient loads, as previously discussed, may therefore pose a long-term threat to the reefs of Keppel Bay.

Management

In order to ensure the continued existence of the Great Barrier Reef, and the industries based on it's resource, it has become necessary to include catchment management activities in the overall management framework for the reef.

Even though the problem is widespread the focus of management activity to minimise these impacts must be at the local level. Therefore, Local Government Authorities have a primary role to play in this regard. In recognition of this crucial role the great Barrier Reef Marine Park Authority recently invited thirty nine councils to participate in the development of a twenty five year strategic plan for the Great Barrier Reef World Heritage Area.

The Great Barrier Reef Marine Park World Heritage Area is large with many neighbours. It can be adversely affected by outside influences. The development of the Strategic Plan is intended to ensure, that standards and guidelines for development, use, and conservation, result in a healthy, properly functioning Marine Park. The standards and guidelines must be co-ordinated across geographical boundaries and between stakeholder agencies.

This is achieved through the development of five year objectives, specifically, to establish a regionally based mechanism for integrating planning activities between the following:

- Integrated Catchment Management strategy;

- Coastal Protection strategy;

- public utilities, and

- Local Authorities

What this means in practice, is to establish agreed levels/standards for:

- fresh water quality;

- silt loads;

- nutrients;

- pesticides;

- herbicides, and

- other pollutants

In addition, it is necessary to make sure that appropriate testing, reporting, monitoring and reaction procedures are in place. Another five year objective of the plan is to have regional co-ordinated planning for local authorities influencing the area.

Of the twenty two councils represented there were few from inland shires. This suggests either a lack of concern, or a lack of understanding of the downstream impacts of catchment management.

Most participants, however, recognised the range of potential land-based impacts on the Great Barrier Reef, and the need for integrated planning processes. There was general consensus, that they should take active responsibility for land management and water quality issues.

The twenty five year objective and the five objectives have been accepted and it is encouraging to note that each of the regional local government groups would wherever possible integrate relevant objectives and strategies into their own corporate plans.

However, concern was expressed that these issues require substantial resources, which generally aren't available to Local Authorities. Shires on, or adjacent to, the coastal zone, also expressed concern that they were inheriting problems, particularly related to water quality , from shires upstream in the catchment. This problem is not unique, as landholders at the lower end of the Murray-Darling will tell you.

Conclusions and Recommendations

There are no discrete boundaries in natural processes. The fundamental ecological principle of interrelatedness explains why changes in one environment have flow-on or downstream effects in another. It must be recognised that the management of catchment activities significantly affects the viability of downstream ecosystems .

The development of catchments throughout Queensland has taken place in an *ad hoc* manner, with no real consideration of likely impacts, on downstream environments.

Some downstream effects of catchment disturbance have been identified, however these have yet to be evaluated.

The Integrated Catchment Management (ICM) initiative must address problems at a local level. It must provide appropriate consultative and planning processes with input from various levels. It must ensure appropriate coordination and management throughout all catchments that produce inputs to the GBR.

Support mechanisms, such as technical advisory services, need to be established which will enable managers to make appropriate land use decisions, based on the best available information.

The nature of catchment ecosystems is complex, and research to date has been limited. A program of inter-related research is necessary to address the significance of the various biological, physical and social parameters on the catchment as a whole. It is hoped that the collection of data to measure the impacts of catchment management practices is not postponed until crisis point but that a responsible and sensible program of research be developed prior to continued modification of existing lands.Though necessary, this research can not be achieved within a short time frame.

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VEGETATION OF THE FITZROY RIVER CATCHMENT

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INTRODUCTION

Some tens of millions of years ago the Fitzroy River basin had a level to gently undulating landscape interspersed with low hills. This landscape evolved under a protracted period of high and continuous rainfall through erosion, deposition and deep weathering. The more resistant rocks protruded as low hills and the weaker rocks and sediments became a deeply weathered peneplain with a sandy or loamy surface and a lateritic profile. Weathering was estimated to be up to 90m thick. The predominant vegetation was an evergreen forest.

A series of events took place since that time which had a profound effect in determining the current landscape, soils and vegetation of the Fitzroy River catchment. A change in climate, together with the rafting of the Australian continent into more tropical zones, resulted in alternating wet and dry periods. This together with uplifting and faulting in eastern parts led to accelerated erosion which removed much of the old Tertiary peneplain and exposed lower parts of the weathered profile and much older and unweathered beds of rocks and sediments and created extensive alluvial sheets.

This led Galloway (1967) to define 5 geomorphic categories to classify the current landscape which resulted from this long evolutionary history

1. Intact to moderately stripped Tertiary land surfaces

2. Erosional/depositional, mid-catenary surfaces within the Tertiary weathered zone

3. Erosional/depositional, lower catenary surfaces within the Tertiary weathered zone

4. Exposed surfaces below the Tertiary weathered zone

5. Post-Tertiary alluvial surfaces

The position in this catenary sequence, together with the nature of the underlying substrate, had an important influence on the physical and chemical features of the soil and the consequent vegetation.

The primary influence which determines the potential vegetation at any point in the region is climate. Decreasing rainfall from east to west is the dominant factor but the decrease in the winter component of the total rainfall and higher maximum and minimum temperatures from south to north also affects the composition of the vegetation communities. However within broad climatically defined zones, the vegetation type is under the control of the landscape, geology and soils. Recent history has also played a part. Grazing and fire can greatly modify the composition of the understorey in open forest and woodland communities. Clearing of the natural vegetation for agricultural and pastoral use has of course greatly changed the vegetation from that in existence at the time of white settlement.

VEGETATION TYPES

The following account of the vegetation of the catchment is a description of the major vegetation types that were presumed to be in existence at the time of white settlement. Gunn & Nix (1977) and Johnson (1984) have been used to prepare this account. These types still exist in the catchment though their extent has in some cases been greatly modified. It is convenient to classify vegetation on the nature and density of the canopy layer and such a structural classification is used below with further subdivision based on floristics.

Closed Forests

1. Semi-evergreen vine forests and thickets

These are mainly found on argillaceous sediments and basalts exposed following the removal of the Tertiary peneplain, usually on elevated and well-drained hilly to undulating terrain. Significant stands also occur on Tertiary weathered basalt. The soils are mainly brown and grey-brown loams and clays, occasionally texture contrast with a loamy surface and massive earths.

The canopy is dense and closed, usually 10-15m in height, comprising a number of co-dominant species often related to those occurring in coastal semi-evergreen vine forests and drier rainforests. Among the most common and widespread species in the canopy are *Geijera parviflora* (wilga - tree form), *Croton insularis*, *Canthium* spp., *Planchonella cotinifolia* var. *pubescens*, *Diospyros* spp., *Ehretia membranifolia* (peach bush), *Elattostachys xylocarpa*, *Excoecaria dallachyana* and *Atalaya salicifolia*. Emergents, up to 20m in height, are usually present and include *Brachychiton rupestris* (narrow-leaved bottle tree) and *B. australis* (broad-leaved bottle tree), *Acacia fasciculifera*, *A. harpophylla* (brigalow), *Casuarina cristata* (belah) and *Flindersia collina* (leopard ash). In southern areas, *Cadellia pentastylis* (ooline), and south-eastern areas, *Araucaria cunninghamii* (hoop pine), may be prominent while some *Eucalyptus* spp., such as *E. orgadophila*, may also be present. There is usually a moderately dense lower tree and shrub layer with *Acalypha eremorum* (turkey bush), *Carissa ovata* (currant bush), *Alectryon diversifolius* (scrub boonaree) and *Citriobatus spinescens* (wallaby apple). The ground layer is sparse with grasses, such as *Ancistrachne uncinulata* (hooky grass), *Oplismenus hirtellus* subsp. *imbecillis* and *Enteropogon unispiceus* and forbs, such as *Abutilon* spp. (flannel weeds), *Brunoniella australis, Deeringia amaranthoides, Pseuderanthemum variable* and *Cyperus gracilis* (whisker grass). Lianas are common and include *Parsonsia lanceolata, Cissus opaca* (native grape) and *Jasminum didymum* subsp. *racemosum.*

Macropteranthes leichhardtii (bonewood), and to a much lesser extent *Backhousia angustifolia* and *Croton insularis*, often dominates the canopy layer and the typical co-dominant canopy species become sparse.

2. Mangrove thickets

These occupy a small area at the mouth of the Fitzroy River on intertidal flats. *Rhizophora stylosa* (red mangrove), *Aegiceras corniculatum* (river mangrove), *Ceriops tagal* (yellow mangrove) and *Avicennia marina* (grey mangrove) are prominent.

Open Forests and Woodlands

1. *Acacia* open forests

These are common throughout the Fitzroy River catchment. Two distinct groups of communities occur, occupying distinct habitats and positions in the landscape and dominated by *Acacia* spp. in different Sections.

(a) *A. shirleyi* (lancewood) and related communities (*Acacia* spp. in Section Juliflorae) occurring on skeletal soils on breakaways and dissected scarps and earths usually in mid to upper and deeply weathered remnants of the Tertiary peneplain

(b) *A. harpophylla* (brigalow) and related communities (*Acacia* spp. in Section Plurinerves (Microneurae group)) occurring on clay and less commonly deep texture contrast soils usually in mid to lower and less weathered parts of the Tertiary peneplain and on exposed argillaceous sediments and basalts

<u>*A. shirleyi* and related open forests</u>

A. shirleyi (lancewood) open forests

They occur in hilly and mountainous terrain on skeletal soils developed on deeply weathered lateritised sandstones and are widespread throughout the region. The canopy is up to 15m in height, often unispecific, with occasional emergent *Eucalyptus* spp. such as *E. crebra* (narrow-leaved ironbark), *E. thozetiana* (yapunyah), *E. decorticans* (gum-topped ironbark), in southern areas, and *E. citriodora* (lemon-scented gum), in wetter central and northern regions. The understorey is usually sparse with *Acacia* spp., including

A. leiocalyx (black wattle), *Petalostigma pubescens* (quinine berry) and *Alphitonia excelsa* (red ash), on deeper soils. The ground layer is sparse with wiry grasses such as *Aristida* spp., including *A. caput-medusae, Ancistrachne uncinulata* (hooky grass), *Cleistochloa subjuncea, Paspalidium* spp. and *Calyptochloa gracillima* and ferns (*Cheilanthes* spp.)

A. catenulata (bendee) open forests

They are found on massive earths and shallower soils on gently undulating terrain on tablelands in upper parts of the deeply weathered Tertiary peneplain in central and northern areas. The canopy is usually 8-12m in height and is usually unispecific, though occasional *Eucalyptus* spp., such as *E. umbellata* may be present. The understorey is usually sparse with *Geijera parviflora* (wilga) and *Eremophila mitchellii* (sandalwood) prominent on deeper soils. *Lysicarpus angustifolius* (budgeroo) is frequently present with, in some situations, a low shrub layer of *Senna* spp. (cassias) and *Phebalium glandulosum*. The ground layer is sparse and similar to that occurring in the *A. shirleyi* open forests.

A. rhodoxylon (rosewood) open forests

They are found on usually coarse-grained sediments exposed following the removal of the Tertiary weathered profile. *A. rhodoxylon* forms a unispecific canopy up to 15m in height in central-eastern and south-eastern parts of the catchment but *Eucalyptus crebra*, on shallow sandy soils in hilly terrain, or *E. melanophloia*, on texture contrast soils in rolling terrain, may occur as emergents. In the former the understorey is usually moderately dense with *Acacia* spp., including *A. leiocalyx*, and *Petalostigma pubescens* while in the latter the understorey tends to be sparse with *Grewia retusifolia* and *Carissa ovata*.

A. harpophylla and related open forests

A. harpophylla (brigalow) open forests

These communities occupied almost 5 million ha. They vary both structurally and floristically and the following types can be recognised.

(a) *A. harpophylla* (brigalow) $\pm$ *Casuarina cristata* (belah) - *Geijera parviflora* (wilga) open forests

These communities are restricted to areas south of the Tropics where they are the most common type. They occur mainly on lateritised Tertiary sediments and transported Tertiary weathered zone material and basalts in the lower part of the Tertiary peneplain and on exposed argillaceous sediments. The soils are cracking clays and where the sediments are deep gilgai may be common.

The canopy is 10 -15 m in height with *C. cristata* a common associate. The relative abundance of the two canopy species can vary from pure *A. harpophylla* to almost pure *C. cristata*. In some areas *Cadellia pentastylis* (ooline) becomes prominent. The lower tree layer is usually well established with *Geijera parviflora* (shrub form) the most prominent species and *Eremophila mitchellii* (sandalwood), *Alectryon diversifolius* (scrub boonaree), *Myoporum deserti* (Ellangowan poison bush), *Apophyllum anomalum* (broom bush), *Ehretia membranifolia, Opuntia tomentosa* (velvety tree pear) and *Eremocitrus glauca* (limebush) usually present. *Rhagodia spinescens* (berry saltbush) and *Carissa ovata* are often present in a low shrub layer. Lianas are usually present and include *Cissus opaca, Jasminum didymum* subsp. *racemosum, Parsonsia lanceolata, Marsdenia leptophylla, Capparis lasiantha* (nipan) and *Sarcostemma viminale* subsp. *brunoniana* (caustic vine). *Paspalidium caespitosum* (brigalow grass) is invariably present in the ground layer with *P. gracile* (belah grass), *Enteropogon acicularis* (windmill grass), *Sporobolus scabridus* and *S. caroli* (fairy grass), *Leptochloa decipiens, Digitaria brownii* and *Cyperus gracilis. Cyperus bifax* and *Panicum subxerophilum* are common in gilgai. The forbs *Abutilon oxycarpum, Brunoniella australis, Enchylaena tomentosa* (berry cotton bush), *Sclerolaena tetracuspis* (brigalow burr) and *Einadia nutans* are usually present.

(b) *A. harpophylla* (brigalow) - *Terminalia oblongata* (yellowwood) open forests

In similar situations to the previous in areas north of the Tropics, *Terminalia oblongata* replaces *Geijera parviflora* in the lower tree layer. Otherwise they resemble the former communities structurally and floristically.

(c) *A. harpophylla* (brigalow) - *Eucalyptus cambageana* (Dawson gum) - *Eremophila mitchellii* (sandalwood) open forests

These communities are widespread throughout the catchment. They occur on lateritised sediments higher in the old weathered Tertiary landscape than the previous and occur on texture contrast soils. *Eucalyptus cambageana* is present as an emergent exceeding 20m in height over an *A. harpophylla* canopy which through burning often consists of a mosaic of suckers, whipstick brigalow and virgin trees. *Eremophila mitchellii* is the most prominent species in the lower tree layer with *Geijera parviflora*, in the south, and *Terminalia oblongata*, in the north, frequent but less abundant. *Canthium vacciniifolium* and *Flindersia dissosperma* become conspicuous in these communities. *Carissa ovata* usually forms a moderately dense low shrub layer. In addition to the grasses mentioned in the above communities, some species such as *Ancistrachne uncinulata, Cymbopogon refractus, Calyptochloa gracillima* and *Aristida ramosa* become prominent.

(d) *A. harpophylla* (brigalow) - *Eremophila mitchellii* (sandalwood) open forests

These communities are similar to the above without the emergent eucalypts. They are widespread but much less common.

(e) *A. harpophylla* (brigalow) - *Eucalyptus coolabah* (coolibah) open forests

These communities occur on more recent alluvial plains lining the major tributaries of the Fitzroy River. The soils are cracking clays and they are subject to intermittent flooding. *A. harpophylla* forms a tall canopy 10-18m in height with emergent *E. coolabah*, to 20m. *Lysiphyllum hookeri* is often present in the canopy. Except south of the Tropics, *Terminalia oblongata* is the most common species in the lower tree layer with characteristic species such as *Eremophila bignoniiflora*, *Alectryon oleifolius* (boonaree) and *Acacia oswaldii* (nelia tree). The low shrub layer is sparse to absent but the grassy ground layer is well developed with *Dichanthium sericeum* (blue grass), *Thellungia advena* (coolibah grass), *Sporobolus mitchellii* (rat's tail couch) prominent among the typical brigalow grasses. Forbs such as *Malvastrum americanum*, *Sida* spp. and *Alternanthera denticulata* are common.

(f) *A. harpophylla* (brigalow) - *Eucalyptus* spp. open forests

Some other species of *Eucalyptus* may become prominent as emergents in *A. harpophylla* communities. These include *E. thozetiana* (yapunyah) and *E. populnea* (poplar box). These communities usually represent transitional zones between the respective communities.

(g) *A. harpophylla* (brigalow) - *Dichanthium sericeum* (blue grass) mosaic

In southern parts of the region, *A. harpophylla* woodlands and *Dichanthium sericeum* grasslands form a mosaic known as patchy plain brigalow. They occur on gently undulating colluvial and erosional slopes on exposed argillaceous sediments. The soils are cracking clays, *A. harpophylla* patches often occupying the deeper soils. *Lysiphyllum carronii* is a common associate in the canopy. Smaller *A. harpophylla* patches often contain a sparse understorey of *Myoporum deserti* and *Alectryon diversifolius* but larger patches approach the structure of *A. harpophylla* - *Geijera parviflora* communities.

(h) *A. harpophylla* (brigalow) - semi-evergreen vine thicket (softwood) open forests

These occur along the eastern part of the catchment fringing the higher mountain ranges. They developed on brown and grey - brown clays and loams on exposed argillaceous sediments and basalts in undulating terrain. *A. harpophylla* forms a canopy to 18m in height with *Brachychiton rupestris* and *B. australis*, *Acacia fasciculifera* and *Casuarina cristata* over a dense semi-evergreen vine thicket understorey about 10m in height. *Acalypha eremorum*, *Citriobatus spinescens*, *Alectryon diversifolius* and *Carissa ovata* form a lower shrub layer. Vines and lianas are well developed with *Cissus opaca*, *Parsonsia* spp. and *Secamone elliptica* commonly occurring. The most common grass species are *Ancistrachne uncinulata*, *Oplismenus hirtellus* subsp. *imbecillis*, *Enteropogon unispiceus* and *Paspalidium* spp. while the forbs *Abutilon oxycarpum* forma *acutatum*, *Brunoniella australis*, *Cheilanthes distans*, *Solanum* spp. and *Cyperus gracilis* are usually present.

While most communities have a diverse understorey tree layer, significant areas are covered by stands with the vine thicket layer dominated by a single species. Three associations are recognised the first being by far the most extensive

A. harpophylla - *Macropteranthes leichhardtii* (bonewood)
A. harpophylla - *Backhousia angustifolia*
A. harpophylla - *Croton insularis*

Following disturbance such as severe fires, ringbarking and pulling all of the above *A. harpophylla* communities except the last, are often replaced by dense sucker growth. With time these sucker communities are replaced by stands of whipstick brigalow and ultimately mature layered open forests and woodlands.

A. argyrodendron (blackwood) open forests

These are best developed on lateritised sediments in the adjoining Belyando catchment in the overlap between the more mesic *A. harpophylla* communities and the more xeric *A. cambagei* (gidgee) communities. A few outliers occur in northern parts of the Fitzroy River catchment on cracking and non-cracking clays occasionally with gilgais. They are structurally and floristically similar to *A. harpophylla* communities.

Other *Acacia* open forests

A few related species of *Acacia* form similar unispecific canopies but they are relatively insignificant in extent. These include *A. tephrina* (boree), in north-western areas, and *A. melvillei* (yarran) and *A. pendula* (myall) in the south.

2. ***Eucalyptus* open-forests and woodlands**

They occupied about 9 million ha throughout the catchment, almost 75% of which were dominated by three species or species complexes - narrow-leaved ironbarks (*E. crebra/E.drepanophylla*), silver-leaved ironbark (*E. melanophloia*) and poplar box (*E. populnea/E. brownii*). Some other species form significant communities, either alone or as co-dominants. The most common *Eucalyptus* communities are

E. crebra/E. drepanophylla (narrow-leaved ironbarks) open-forests and woodlands

These species have been commonly confused in survey work and are treated here as a complex. They are widespread on gently undulating to hilly topography, usually in the upper deeply weathered Tertiary landscape and on older surfaces exposed following its removal. A number of variants do occur within the region depending on the situation

(a) On massive earths and deep texture contrast soils on deeply weathered remnants of the Tertiary peneplain. They occur on gently undulating terrain. *E. dolichocarpa* (long-fruited bloodwood) is often present in the canopy and small trees and shrubs such as *Petalostigma pubescens, Alphitonia excelsa, Acacia* spp. (wattles) and *Lysicarpus angustifolius* form a distinct layer.

(b) On deep sandy or skeletal soils developed on quartz sandstone. The terrain is usually hilly and dissected. *E. maculata* or *E. citriodora* may occur as co-dominants. *Callitris glaucophylla* (cypress pine), *Casuarina luehmannii* (bull oak) and *Acacia* spp. form an often conspicuous understorey tree layer. *Triodia* spp. (spinifex) may be present in the ground layer.

(c) On skeletal and shallow texture contrast soils developed on coarse sandstones and acid volcanic rocks, often with *E. maculata* (spotted gum) in southern areas and *E. citriodora* (lemon-scented gum) in central and northern regions. The terrain is hilly. The lower tree and shrub layer is sparse to moderately dense with *Acacia* spp., *Alphitonia excelsa, Petalostigma pubescens* and occasionally *Xanthorrhoea* (grass tree).

(d) On shallow loams on basalt in hilly terrain where it forms a grassy woodland.

The ground layer is usually sparse to moderate with *Aristida* spp. such as *A. caput-medusae* and *A. ramosa, Bothriochloa ewartiana* (desert blue grass) and *B. decipiens* (pitted blue grass), *Cymbopogon refractus* (lemon-scented barbwire grass), *Heteropogon contortus* (black spear grass) and particularly in basaltic areas, *Themeda triandra* (kangaroo grass) common.

E. melanophloia (silver-leaved ironbark) open-forests and woodlands

These communities are widespread throughout the region. A number of variations occur depending on the situation which influences the relative dominance of the woody understorey and grassy ground layers

(a) On undulating, occasionally hilly, terrain on soils derived from sandstones and shales and from igneous rocks mainly granites, acid volcanics and basalts, following removal of the weathered Tertiary land surface. The soils are usually texture contrast with a shallow sandy to loamy surface though on some lithic sandstones, shales and volcanics cracking clays have developed.

The communities are most commonly grassy woodlands. Associated canopy species include *E. erythrophloia* (gum-topped bloodwood), *E. crebra/E. drepanophylla, E. orgadophila* (mountain coolibah), except on granites and acid volcanics, and *E. papuana* (ghost gum). Understorey trees and shrubs are uncommon and include *Archidendropsis basaltica* (dead finish), *Eremophila mitchellii* and *Grewia* spp.. *Bothriochloa* spp. mainly *B. ewartiana, B. bladhii* (forest blue grass) and *B. decipiens, Themeda triandra* and *Heteropogon contortus* are the most abundant species with *Cymbopogon refractus* and *Aristida* spp. usually present. *Dichanthium sericeum* and associated species are prominent on cracking clays.

(b) On deep red and yellow earths on deeply weathered remnants of the Tertiary peneplain. The communities are usually layered. *E. dolichocarpa* and *E. papuana* are common associates in the canopy layer and small trees and shrubs such as *Petalostigma pubescens, Alphitonia excelsa, Acacia* spp., including *A. leiocalyx, Eremophila mitchellii* and *Lysicarpus angustifolius* form a distinct understorey layer. The grassy ground layer is sparse to moderate with *Aristida* spp., including *A. jerichoensis, Bothriochloa* spp., mainly *B. decipiens* and *B. ewartiana, Themeda triandra, Heteropogon contortus* and *Cymbopogon refractus*.

(c) On post-Tertiary alluvium. The structure and composition of the communities varies with the structure of the soil. On deep red and yellow earths the community is similar to that described under (b), except that *E. tereticornis* (Queensland blue gum), *E.tessellaris* (carbeen), *E. papuana* and *E. crebra* are the common canopy associates. On deep texture contrast soils *E. tereticornis, E. tessellaris* and *E. populnea* (poplar box) may occur in the canopy over a grassy ground layer.

E. populnea (poplar box) woodlands

These are widespread through out the region on undulating topography in the mid-catenary layers of the dissected Tertiary peneplain and on more recent alluvial plains, usually above average flood level. The soils are usually deep texture contrast and often solodic. *E. populnea* is the dominant canopy species but is replaced by *E. brownii* (Reid River box) in the extreme north of the area.

There is usually a sparse to well-developed low tree and shrub layer with *Eremophila mitchellii* the most characteristic species and *Geijera parviflora* a common associate with *Atalaya hemiglauca, Acacia excelsa* (ironwood), *Alectryon oleifolius* and the low shrub *Carissa ovata*. The ground layer is sparse to moderately dense with *Bothriochloa decipiens, Aristida* spp., including *A. ramosa* and *A. jerichoensis, Enteropogon acicularis, Eragrostis* spp. and *Enneapogon* spp.

E. populnea also forms large areas of grassy woodlands, in which *E. mitchellii* is uncommon, on similar soils and situations, and some may represent fire climaxes. On alluvial plains which are occasionally flooded, these communities are widespread. *E. mitchellii* can increase in density following disturbance and overgrazing.

E. coolabah (coolibah) woodlands

These are common on alluvial plains of the major tributaries of the Fitzroy River. They grow on alluvial clays, often cracking, in areas undergoing intermittent flooding. *E. coolabah* is the dominant canopy species but other eucalypts such as *E. tereticornis* and *E. tessellaris* or *E. populnea* may be present in transitional zones. Understorey trees where present include *Terminalia oblongata* in central and northern regions, *Acacia* spp. including *A. oswaldii* and *A. salicina, Eremophila bignoniiflora* and *Lysiphyllum hookeri*. The grassy ground layer is usually well developed with *Dichanthium sericeum, Paspalidium* spp., *Thellungia advena, Sporobolus mitchellii* and *Cyperus bifax* (downs nut grass) invariably common.

E. moluccana (gum-topped box) woodlands

These occur in south - eastern parts of the region on deep texture contrast soils on gently undulating terrain. *E. moluccana* is dominant in the canopy though *E. populnea* and *E. crebra/E. drepanophylla* may also be present. A sparse to moderately dense understorey of *Eremophila mitchellii* is usually present. A well developed grassy ground layer is common in many communities with *Themeda triandra, Heteropogon contortus* and *Bothriochloa* spp. the most common species.

E. orgadophila (mountain coolibah) woodlands

E. orgadophila forms grassy woodlands on crests of undulating basaltic country mainly in central parts of the region. The soils are usually cracking clays, often shallow, but communities can also occur on deeper cracking clays on weathered basalt and argillaceous sediments. The canopy is usually unispecific though *E. melanophloia* and *E. erythrophloia* may be present. Low trees and shrubs are sparse but the grassy ground layer with *Dichanthium sericeum* and associated grasses is well developed except where soils are very shallow when *Bothriochloa* spp., *Themeda triandra* and *Heteropogon contortus* are common.

E. thozetiana (yapunyah) woodlands

E. thozetiana forms woodlands often in mid to lower parts of the dissected and weathered Tertiary landscape on shallow texture contrast soils. They often merge with *Acacia catenulata* (bendee) and *A. shirleyi* (lancewood) in upper parts of the landscape and brigalow in lower parts. *Geijera parviflora, Eremophila mitchellii* and *Carissa ovata* may occur in the lower tree and shrub layer but they are less common where the soils are shallow.

E. tereticornis (Queensland blue gum) open-forests and woodlands

E. tereticornis lines the banks of the major rivers and streams. It also forms extensive communities on adjacent back plains and alluvial plains on deep texture contrast soils, cracking clays and clay loams, occasionally deep loamy sands, throughout the region. *E. tessellaris* is a common associate in better drained areas often with *E. dolichocarpa*. The understorey tree and shrub layer is usually very sparse though *Casuarina cunninghamiana* (river sheoak), *Callistemon viminalis* (bottle brush) and *Melaleuca bracteata* (black tea tree) are associates on river and creek banks. The ground layer is usually well developed with *Bothriochloa bladhii, B. decipiens, Dichanthium sericeum* and *Heteropogon contortus*.

In western parts of the catchment *E. camaldulensis* (river red gum) forms intergrades with *E. tereticornis* before replacing it in drier areas of the State, though the former is usually confined to riverbanks in the overlap area.

E. dolichocarpa (long-fruited bloodwood) - *E. tessellaris* (carbeen) - *E. papuana* (ghost gum) woodlands

These species form communities in central and northern parts of the region. They occur on deep sands and sandy earths on sandy aprons formed from lateritised sediments in upper parts of the Tertiary peneplain and on uniform sandy soils often deep on levees and plains. Understorey trees and shrubs are absent to sparse with *Melaleuca nervosa* occurring on earths and *Acacia leiocalyx* more common on sands. *Bothriochloa* spp., *Aristida* spp. and *Heteropogon contortus* are common in an often well developed ground layer.

E. maculata (spotted gum)/*E. citriodora* (lemon-scented gum) woodlands

E. maculata in southern areas and *E. citriodora* in central and northern areas are found throughout the region particularly in eastern parts. They occur mainly on shallow sandy and texture contrast soils in hilly terrain, particularly on lateritised coarse sediments and exposed quartz sandstone. They are usually associated with *E. crebra/E. drepanophylla*.

E. dolichocarpa is a common associate. There is usually a sparse to moderately dense woody understorey with *Alphitonia excelsa, Petalostigma pubescens, Acacia* spp., including *A. leiocalyx*, and *Callitris glaucophylla* and *Casuarina luehmannii* prominent in some areas.

The ground layer is sparse with *Cymbopogon refractus, Arundinella nepalensis* (reed grass), *Aristida* spp., *Eragrostis* spp., *Heteropogon contortus* and *Themeda triandra* usually present.

Mixed *Eucalyptus* shrubby woodland (sandstone form)

These are most common on steep rocky hills and plateaux on quartz sandstone especially in southern areas. They are best developed in the Carnarvon, Expedition and Lynd Ranges. The soils are sandy and skeletal. Stands are usually co-dominant with *E. watsoniana* (yellowjack) a characteristic species and *E. crebra/E. drepanophylla, E. decorticans, E. cloeziana* (Gympie messmate), *E. dolichocarpa, E. tenuipes* (narrow-leaved mahogany), *E. leichhardtii*(yellowjack) and *Angophora leiocarpa* (rusty gum) common associates. A sparse lower tree layer with *Callitris glaucophylla, Casuarina inophloia* (thready-bark oak), *Alphitonia excelsa, Acacia* spp., including *A. bancroftii, A. longispicata* and *A. neriifolia, Lysicarpus angustifolius* and *Petalostigma pubescens* overtops a dense and diverse shrub layer with *Acacia, Boronia, Xanthorrhoea, Dodonaea, Pultenaea, Leptospermum* and other genera. The ground layer is sparse with *Aristida* spp., *Entolasia stricta, Cleistochloa subjuncea* and *Eragrostis* spp.

Angophora leiocarpa (rusty gum) woodlands

In similar areas to the previous but restricted to southern parts of the region, *A. leiocarpa* forms open forests with *E. chloroclada, E. dolichocarpa* and *E. crebra.* They are found in more undulating terrain on deep texture contrast soils with a deep sandy surface over quartz sandstone. *Callitris glaucophylla* and *Casuarina inophloia* are prominent in the lower tree layer over a moderately dense layer of *Acacia* spp., including *A. leiocalyx, Petalostigma pubescens, Alphitonia excelsa* and *Dodonaea* spp. (hop bushes). The ground layer is sparse with *Aristida* spp. and *Panicum effusum*. *Triodia mitchellii* is common in some stands.

Other *Eucalyptus* woodlands

Some other *Eucalyptus* spp. become predominant in the canopy of minor communities in the Fitzroy River catchment. These include -

(a) *E. cambageana* (Dawson gum) - It usually occurs as an emergent in *A. harpophylla* communities but on rare occasions it does form woodland communities with *Eremophila mitchellii* and *Carissa ovata* prominent in the woody understorey

(b) *E. chloroclada* (tumble-down gum) - It forms grassy woodlands in deep uniform sandy soils on quartz sandstones in southern areas adjoining the Great Dividing Range

(c) *E. platyphylla* (poplar gum) - It forms grassy woodlands in north-eastern parts on deep texture contrast soils with a thick sandy surface on lateritised sandstones

(d) *E. acmenoides* (white mahogany) - It is prominent with other *Eucalyptus* spp. in the canopy of open forest communities in wetter parts of the region.

3. Other open forests and woodlands

Species of other genera form communities throughout the region though they are not extensive in area. The major types are

Callitris glaucophylla (cypress pine) open forests

They occur mainly on level to gently undulating terrain in southern parts of the catchment on deep texture contrast soils with a thick sandy surface and on uniform sands which have developed on lateritised sediments and quartz sandstones. *C. glaucophylla* forms a dense canopy layer of 10 -20m which often grades as an understorey into layered *Eucalyptus* woodlands with *E. populnea, E. crebra* or *E. melanophloia.* On shallower soils *E. chloroclada* and *Angophora leiocarpa* may be prominent. *Casuarina luehmannii* may be co-dominant in the canopy layer. A sparse low tree and shrub layer may be present with *Acacia* spp., such as *A. leiocalyx, Petalostigma pubescens, Alphitonia excelsa, Lysicarpus angustifolius* and *Dodonaea* spp.. The ground layer is usually sparse with *Aristida* spp., such as *A. caput-medusae* and *E. echinata, Eragrostis* spp., *Cymbopogon refractus, Enneapogon* spp., *Panicum effusum* and *Chrysopogon fallax.*

Casuarina spp. open forests and woodlands

Two species form minor communities in the catchment in very different habitats

(a) *Casuarina luehmannii* (bull-oak) open forests

C. *luehmannii* forms communities on deep texture contrast soils in similar situations to those described under *Callitris glaucophylla* open forests. These two communities are similar structurally and floristically and the often merge with each other.

(b) *Casuarina cristata* (belah) open forests and woodlands

C. cristata occasionally forms a unispecific canopy and though the communities are not extensive they are scattered throughout the catchment. They often occur in similar situations to *A. harpophylla* communities and resemble them structurally and floristically.

Tussock grasslands

Patches of grassland are scattered throughout the region on fresh basalt, argillaceous sediments and fine textured alluvium on level to undulating terrain. The soils are moderately deep to deep cracking, often self mulching, clays.

Dichanthium sericeum (blue grass) is the most common species with *Aristida leptopoda* (white spear grass) and *A. latifolia* (feather-top spear grass), *Bothriochloa erianthoides* (satin-top grass), *Panicum decompositum* (barley grass), *P. queenslandicum* (Yabila grass) and *Thellungia advena*. *Iseilema* spp. (Flinders grass) become important after summer rains while forbs such as *Rhynchosia minima, Polymeria longifolia, Calotis cuneata, Crotalaria dissitiflora* and *Malvastrum americanum* occur between the tussocks. In drier western areas *Astrebla* spp. (Mitchell grass) may become prominent.

Variations in substrate, soil and situation result in floristic variation, often associated with the presence of scattered trees. On fresh basalt *E. orgadophila, E. erythrophloia* and *E. melanophloia* may be present while on argillaceous sediments these grasslands may contain patches of *A. harpophylla* and *Lysiphyllum carronii*. On alluvial flood plains *E. coolabah, E. tereticornis, E. populnea* and *E. brownii* may be scattered throughout tussock grasslands.

Canopy/understorey relationships

The above classification is based on the floristic composition of the canopy layer. Yet throughout the region there is evidence of a certain independence in the canopy/understorey relationship. For example on the upper remnants of the Tertiary peneplain a characteristic shrubby understorey develops independently of the composition of the canopy layer. The *Geijera parviflora* understorey characteristic of *A. harpophylla* in subtropical areas in the catchment varies little in composition whether *A. harpophylla* or *Casuarina cristata* is dominant. On shallow clays on fresh basalt the grassy ground layer does not reflect variations in the canopy species. In many situations the composition of the understorey provides a better reflection of the inherent nature of the habitat than the canopy.

ENVIRONMENTAL CONTROLS ON DISTRIBUTION OF VEGETATION COMMUNITIES

As pointed out previously climate is the primary control over the distribution of species and vegetation types. Over the catchment climatic patterning is evident. Some of the most dramatic changes in Central Queensland linked to decreasing annual rainfall such as the replacement of *A. harpophylla* by *A. cambagei, Dichanthium sericeum* grasslands by *Astrebla* spp. and *Eucalyptus tereticornis* by *E. camaldulensis* occur slightly to the west of the catchment. With decreasing annual rainfall there is a shift from open forest to woodlands and the height of the canopy layer decreases. This rainfall gradient also influences the predominant habitat of *E. crebra/E. drepanophylla* open forests and woodlands which occur on massive earths on tablelands in the driest areas, on relatively deep texture contrast soils on moderate slopes in intermediate areas and on shallow and skeletal soils in hilly country in wetter coastal areas. However there are also significant changes from south to north. The understorey of the *A. harpophylla* open forests change dramatically about the Tropics with *Geijera parviflora* being replaced by *Terminalia oblongata*. Changes in emergent *Eucalyptus* spp. also occur within the catchment with *Eucalyptus maculata* being replaced by *E. citriodora* while a broad transition from *E. populnea* dominance to *E. brownii* dominance occurs in the very north of the catchment.

The position in the landscape and its relationship to the old weathered and dissected Tertiary peneplain has a strong controlling influence. This is clearly illustrated in Table 1. which shows a change in composition of the major formations along the catenary sequence from intact Tertiary land surfaces through the dissected weathered lateritic sediments to exposed surfaces below the weathered zone to post - Tertiary alluvial surfaces

Table 1. Percentage of major vegetation formations in five geomorphic categories

Geomorphic category	Plant Formation (%)							
	1	2	3	4	5	6	7	8
Intact or moderately stripped Tertiary land surface				20	71			9
Erosional/depositional mid-catenary surfaces in Tertiary weathered zone		33	20	26	10	6		5
Erosional/depositional lower-catenary surfaces in Tertiary weathered zone	5	86					3	6
Exposed surfaces below the Tertiary weathered zone	6	15			38	28	10	3
Post-Tertiary alluvial surfaces		18			44	32	3	3

Plant Formations:

1. Semi-evergreen vine thickets
2. *Acacia harpophylla* open forests
3. *A. shirleyi, A. catenulata* open forests
4. *Eucalyptus* woodlands (shrubby)
5. *Eucalyptus* open forests and woodlands (shrubs/grass)
6. *Eucalyptus* open forests and woodlands (grassy)
7. Grasslands
8. Other formations

Eucalyptus communities with a shrubby understorey dominate the intact Tertiary land surface with *Acacia shirleyi, A. catenulata* and *A. harpophylla* with *E. cambageana* and *Eremophila mitchellii* open forests prominent in the upper weathered layers. With reduced weathering and lateritic influence *A. harpophylla* communities are predominant. On exposed surfaces grassy *Eucalyptus* woodlands and grasslands become more common. The diversity of vegetation types on these exposed surfaces is related to the diversity of rock types as shown in Table 2.

Table 2. Relationship among vegetation types and geology on exposed surfaces.								
Rock Types	**Plant Formation (%)**							
	1	2	3	4	5	6	7	8
Quartz Sandstone					95	3		2
Acid Volcanics					66	34		
Mixed Sediments		13	2		45	38	2	
Argillaceous Sediments	23	53			12	3	9	
Basalt	9					40	51	

Layered *Eucalyptus* woodlands are the commonest formation on coarse grained acid and resistant rocks while *A. harpophylla* open forests and semi-evergreen vine thickets are the commonest types on the argillaceous sediments. Grasslands and grassy *Eucalyptus* woodlands are characteristic of basaltic areas.

Communities are not in a static state but change with changes in climatic trends. The grassy ground layer can vary in composition with short term fluctuations in climate. The woody understorey is more resistant but significant changes can occur naturally even within two decades. The canopy tree layer is much more resistant to change and may reflect past climatic conditions. Studies of community dynamics indicate there have been local shifts in community composition during the last few centuries, aside from the influence of man. Semi-evergreen vine thickets have expanded as an understorey layer into adjoining *A. harpophylla* communities and in turn *A. harpophylla* has moved into *Eucalyptus* woodlands where the habitat is suitable. There is historical evidence for the expansion of *A. harpophylla* onto *Dichanthium sericeum* grasslands. This indicates that we have been passing through a recent but long term wetter phase. These more recent changes must be viewed in the context of a much older arid phase when *A. harpophylla* open forests and semi-evergreen vine thickest were fragmented leaving refugial pockets on favourable sites.

The more recent patterning is however confounded by the impact of man through the introduction of a different grazing regime and fire pattern. The major dynamic changes have been induced by man and aside from the more rugged parts of the catchment, the current vegetation is a reflection of his activities.

IMPACT OF DEVELOPMENT ON THE VEGETATION PATTERN AND CONSERVATION STATUS OF SPECIES AND VEGETATION TYPES

Today much of the native vegetation has been modified and artificial grasslands and grassy woodlands have replaced the pre-settlement vegetation.

Pastoral and agricultural development has had by far the greatest impact. Early settlement involved the use of grasslands and grassy forests commonly associated with alluvial situations, as a source of native pasture for sheep and cattle. Particularly between the two World Wars ringbarking and felling were used to clear more fertile lands for crops and improved pastures but it was not until the Fitzroy Basin Brigalow Development Scheme commenced in the early 1960's that massive changes occurred. Heavy machinery which became available after World War II was used to clear *A. harpophylla* open forests initially in southern and eastern parts of the State. Pulling contractors moved gradually northwards and the period after 1960 saw most of the *A. harpophylla* and associated communities in the catchment converted into crop and pasture land. Chemical treatment of more fertile grassy *Eucalyptus* woodlands also produced major changes.

It is therefore timely to consider the impact of those changes to the vegetation and how well the diversity of vegetation types in the catchment has been conserved. Thirty nine conservation reserves exist in the catchment. Of these, fifteen are National Parks though six are small and aim to conserve particular mountain peaks. Of the remaining National Parks six are sited on predominantly dissected sandstone plateaux and the remaining three - Palmgrove, Dipperu and Nuga Nuga - in part or in whole conserve *A. harpophylla* open forests, semi-evergreen vine thickets and associated *Eucalyptus* open forests and woodlands. Dipperu is the only major National Park in the northern half of the catchment, though the Scientific Reserve at Taunton does make a significant contribution.

Numerous Environmental Parks have been gazetted, again mainly in the southern half of the catchment. Most are too small to play a major role in an overall conservation strategy for the catchment. There are three Environmental Parks that exceed 500ha - Mt Zamia which conserves a spectacular dissected tableland with shrubby *Eucalyptus* woodland, Mt Hopeful which conserves some semi-evergreen vine thicket and Princhester which conserves some coastal *Eucalyptus* open forests.

It can be seen that there is a lack of major conservation areas in northern parts. Many significant vegetation types are poorly or not conserved such as semi-evergreen vine thicket in certain areas, some *A. harpophylla* types (Sattler & Webster 1984), many of the *Eucalyptus* open forests and woodlands on surfaces exposed following the removal of the weathered Tertiary land surface and on post-Tertiary alluvial surfaces while substantial areas of grassland are not in any Reserves.

Considering the impact of development and the seemingly inadequate system of conservation reserves, it is interesting to study the number of rare and threatened species recorded for the catchment (Thomas & McDonald 1987). Details are provided in Table 3.

Table 3. Rare and Threatened Species in the Fitzroy River Catchment	
Category	No. of Species
Presumed Extinct Species	0
Endangered Species	0
Vulnerable Species, but not currently endangered	16
Rare Species, but not currently vulnerable	35
Poorly Known Species	7

It is surprising that there are no endangered species on the list. This is largely due to the fact that rare and vulnerable species are mainly restricted to the dissected sandstone areas - Carnarvon Range, Isla Gorge and Blackdown Tableland - where endemism is relatively high, which were unsuitable for agricultural and pastoral development and, largely due to scenic beauty, are well conserved. The *A. harpophylla* open forests and *Eucalyptus* open forests and woodlands on the more fertile soils show little local endemism.

CONCLUSION

The Fitzroy River catchment at the time of settlement was dominated by *Eucalyptus* open forests and woodlands and *Acacia* open forests. The distribution of vegetation types is broadly controlled by climate but, within the catchment, position in the much dissected weathered Tertiary landscape and the nature of the underlying rock largely determined the local vegetation pattern. Since settlement the major change to the vegetation pattern resulted from the clearing of *Acacia harpophylla* (brigalow) open forests and ringbarking and chemical treatment of more fertile grassy *Eucalyptus* woodlands. Currently no species are known to be endangered but this is largely due to the high degree of rarity among species in the *Eucalyptus* open forests and woodlands which cover the infertile and agriculturally and pastorally unproductive dissected and relatively well conserved sandstone tablelands. Many communities within the catchment are not conserved in any sizeable reserves and there is a lack of substantial National Parks in the northern half of the catchment.

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Title: **Aquatic Macropytes of the Fitzroy River Catchment**

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INTRODUCTION:

Aquatic and semi-aquatic plants are an important component of the bank-side vegetation which links the terrestrial and aquatic systems of a river basin. As such they have many important roles relevant to the management of river catchments. They reduce the erosion of streams, banks and lake shorelines by slowing water currents and by binding the sediments with their roots. They create habitats essential to the survival of a host of other aquatic organisms, such as aquatic insects, snails, shrimps, fish and many types of birds. Many of these animals graze on the microscopic organisms that grow on the plants, or the plants themselves may be an important food source. Terrestrial animals graze on these plants and may depend on them in times of drought. Aquatic plants also filter the water of suspended solids and nutrients, thereby acting as a natural purification system. They therefore play a crucial role in the nutrient cycles that link aquatic and terrestrial environments.

Little information has been published about the aquatic plants in the Fitzroy River Catchment. Some information is available on the distribution and heavy metal content of aquatic plants in the Dee and Don Rivers (Duivenvoorden, 1988, 1989; Mackey, 1988) and on the species of plants present in Yeppen Yeppen Lagoon (Mackey, 1991), but these studies tell us little about the relative importance of aquatic plants in the Fitzroy Catchment as a whole. From the catchment management point of view, more information about aquatic macrophytes is required on:

1. their potential to control bank-side erosion in different parts of the catchment
2. their ability to remove nutrients from surface run-off such that the frequency of algal blooms is reduced, and
3. their distribution and diversity within the catchment in relation to sites which may have special significance as habitats for wildlife preservation.

As one of the first steps to gaining this information, this paper reports on some of the results of a study designed to gather base-line information about the distribution, species richness and dynamics of aquatic macrophytes in the Fitzroy River Catchment.

METHODS:

To gather information from most parts of the catchment, sites were selected from each of the major sub-catchments (Figure 1). Of the 101 sites surveyed, most were located at

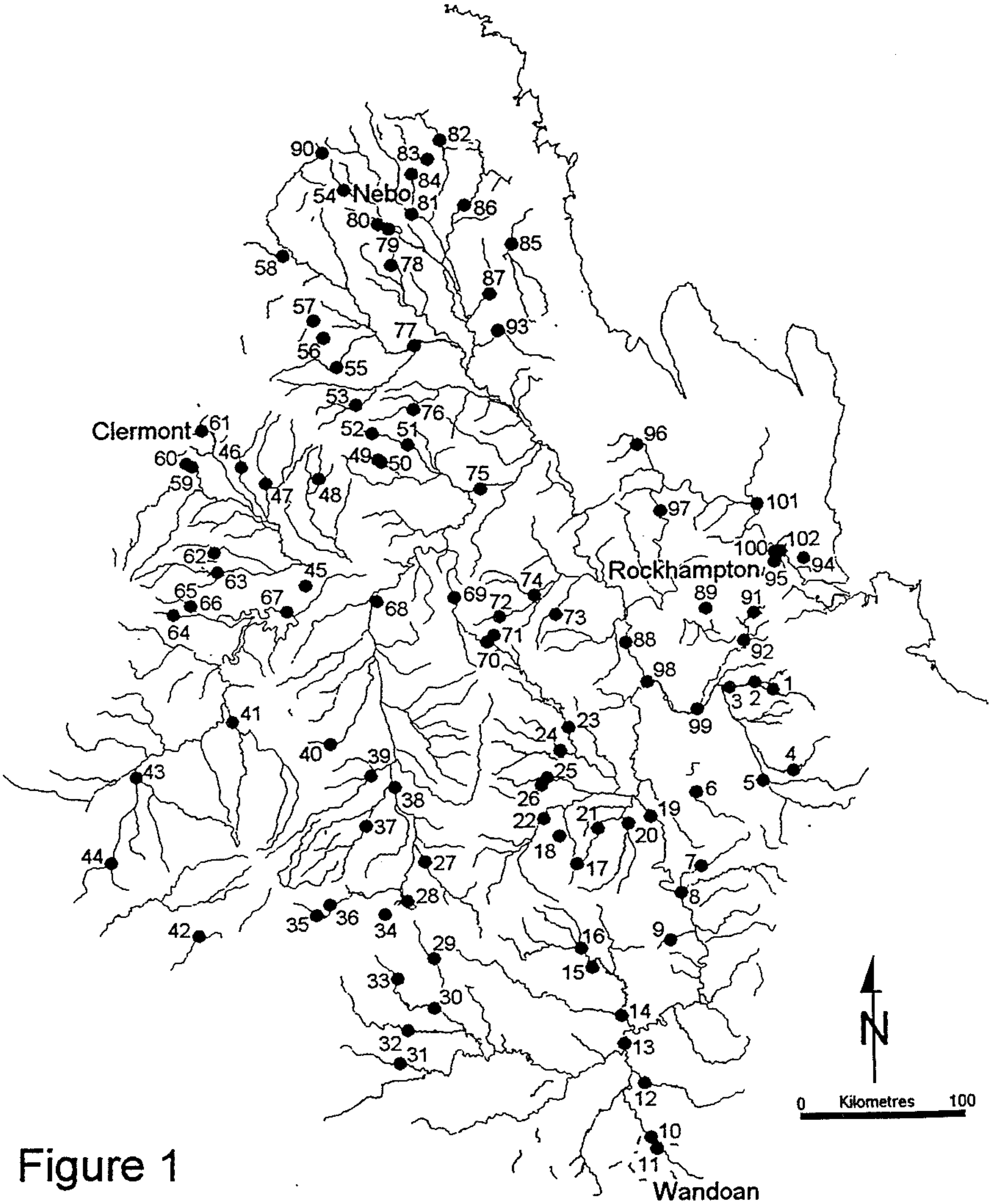

Figure 1

Fitzroy River Catchment
Macrophyte Sampling Sites

the intersection of streams and roads, but 14 lakes, dams and marshy wetlands were also studied. Each stream site covered an area no more than 50 metres upstream of the intersection with a road, while sites at dams or lakes extended for approximately 50m along a shoreline. The general features of each site were recorded, including details such as the width of the stream bed, the percentage of the site shaded, the slope of the banks, the amount of water present and the pH and conductivity of the water.

The presence of all herbaceous aquatic and semi-aquatic macrophyte species was recorded at each site. Most of these species were closely associated with the waterways studied. Where necessary, specimens were collected and pressed for later identification. Specimens collected are stored at the Biology Department of the University of Central Queensland.

The first survey of the catchment was completed in 1989 and was repeated in 1990 to study the dynamics of the species in relation to the wet season floods. The record floods in January 1991, followed by the drought of the same year, presented the opportunity of determining the effect of these environmental extremes on aquatic plant distribution, and so the catchment was again surveyed towards the end of 1991 just prior to the 1991/92 wet season floods.

RESULTS:

Over the 1989-91 period, 105 aquatic and semi-aquatic macrophyte species were recorded from the Fitzroy catchment. The most common plant genera were *Persicaria* (6 species); *Cyperus* (17 species); *Juncus* (6 species) and *Potamogeton* (5 species). Species of *Persicaria* were the most widely distributed, occurring for example at 56% of sites surveyed in 1989.

A large proportion of the sites had very few species. In 1989, 43% of sites had two or less species. The corresponding figures for 1990 and 1991 are 28% and 46% respectively. The plants present at these sites were usually species of *Cyperus*, *Juncus* or *Lomandra*. These are often well adapted to withstand prolonged dry periods, commonly encountered in Central Queensland.

Ten of the 101 sites surveyed had relatively high numbers of aquatic plant species (>15) and half of these ten were lakes or dams (Table 1). Species commonly found in lakes and dams included *Nymphaea gigantea*, *Nymphoides indica*, *Azolla pinnata*, *Potamogeton crispus*, *Hydrilla verticillata*, *Myriophyllum verrucosum*, *Vallisneria gigantea*, *Ludwigia peploides* and *Polygonum attenuatum*.

On average, most sites surveyed had between two to five species of aquatic plants at any one time (Figure 2).

The Don and lower Fitzroy River sub-catchments had the highest mean number of species per site. For each sub-catchment, the average total number of species found per site

Table 1. Sites in the Fitzroy Catchment at which more than 15 species were documented in the period 1989 to 1991.

Site No.	Name	Sub-catchment	Total No. of species (1989-1991)
1	Don River, Lancefield	Don	15
91	Dee River (upstream of mine site)	Don	20
14	Lake; opposite Palm Tree Creek, near Taroom	Dawson	15
45	Nogoa River, Emerald	Nogoa	15
60	Theresa Creek Dam	Nogoa	16
78	dam/marsh; Swampy Creek (SE of Dipperu Nat. Park)	Isaac	15
94	Nankin Creek, Thompson's Point Road	Fitzroy	17
95	Yeppen Yeppen Lagoon	Fitzroy	16
97	Fitzroy River at Glenroy Crossing	Fitzroy	15
100	Fitzroy River, just above barrage	Fitzroy	18

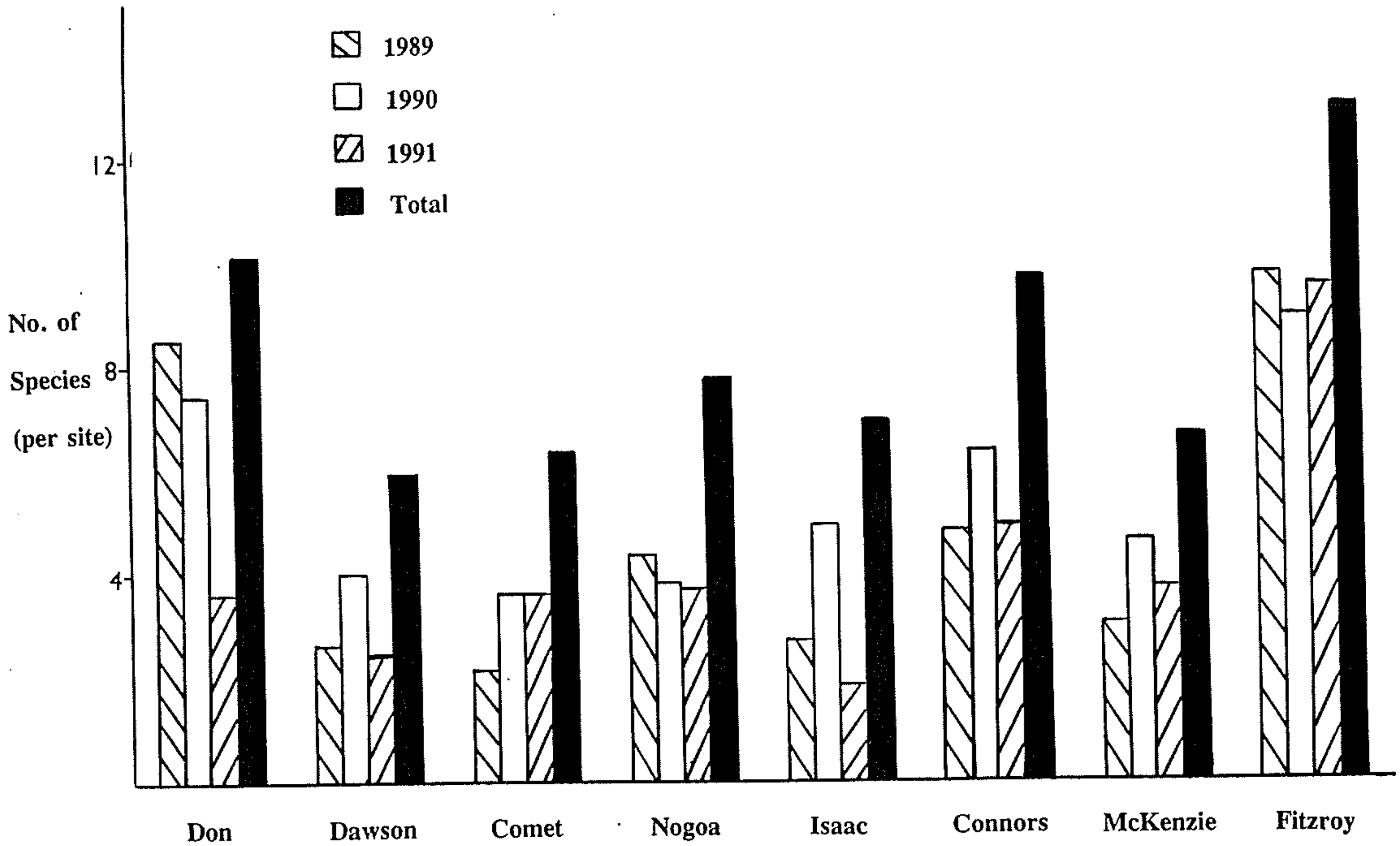

Figure 2. Mean numbers of aquatic macrophyte species recorded in subcatchments of the Fitzroy River basin in 1989, 1990 and 1991. Total mean numbers refer to all species recorded over the three year study period at each site.

over the three-year sampling period was generally much higher than the mean number found in any one year. This indicates that the species profile at any one site changes from year to year, with some species being lost and new ones being introduced.

Large reductions in the number of aquatic plant species were recorded at many sites following the January 1991 flood and subsequent drought (Table 2). These data further illustrate the dynamic nature of the number of aquatic plant species at a site. The aquatic plants surviving the flood and drought extremes were most often species of *Cyperus* and *Juncus*. Species of *Persicaria*, though normally having a widespread distribution, were often lost from sites following the flood and drought.

DISCUSSION:

The paucity of aquatic macrophyte species at many sites within the Fitzroy Catchment is not surprising, given the generally dry climate of the area. Some sites however, had relatively high numbers of species. At most of these sites surface water was present at all times of the year.

The information obtained in this study can be used in making decisions about the management of the catchment. As regards bank-side erosion, a large proportion of the sites studied had two or less species of macrophytes, and in these largely drier areas aquatic plants make up a relatively small proportion of the bank-side vegetation. They therefore probably only have a limited role in preventing bank-side erosion in these areas, though species of *Cyperus*, *Juncus* and *Lomandra* could be seeded in these areas at an appropriate time of year so that their growth may help to prevent bank-side erosion. *Cyperus rotundus* may be a particularly good species to use since it produces an extensive rhizome system which helps to bind the soil. Its root tubers allow the plant to regenerate following floods and prolonged dry periods. Species of *Juncus* and *Lomandra* have the advantage that they are resistant to grazing by herbivorous animals.

In less drier areas within the catchment, species which could be used for erosion control include *Phragmites australis*, *Typha* sp. *Schoenoplectus litoralis* and some species of *Eleocharis*. *Schoenoplectus validus* and *Phragmites australis* have been successfully used to control erosion in water treatment ponds in Victoria (Hutchinson and Locke, 1992). In New South Wales, a Commonwealth funded project is studying bank-side vegetation with the aim of stabilising banks and creating buffer zones which will filter out nutrients before they reach the stream. This project involves the N. S. W. Water Resources, Total Catchment Management committees, Landcare and environmental groups.

Table 2. Sites in the Fitzroy Catchment at which more than 15 aquatic macrophyte species were lost between 1990 and 1991.

Site No.	Name	Sub-catchment	No. of Species 1989	1990	1991
1	Don River, Lancefield	Don	13	14	0
3	Don River, Burnette Highway	Don	5	9	1
99	Don River, Rannes	Don	9	11	1
15	Gwenbegawine Creek	Dawson	9	14	5
31	Hutton Creek	Dawson	3	9	2
56	Hughes Creek	Isaac	4	5	0
57	Boomerang Creek	Isaac	-	5	0
77	Isaac River, Fitzroy Development Road	Isaac	6	7	2
78	dam/marsh; Swampy Creek	Isaac	4	14	2
85	Connors River, near Girnwood	Connors	8	10	3
87	Connors River, Marlbor-ough - Sarina Road	Connors	8	11	2
90	Lake Elphinstone	Connors	-	10	5
49	German Creek Dam	McKenzie	8	13	6

In relation to the use of aquatic bank-side vegetation for the removal of nutrients entering waterways in Central Queensland, more needs to be known about the sources of significant nutrient inputs and the dimensions of the zone of aquatic/bank-side vegetation required to remove a large proportion of these nutrients. This is one of the points discussed by Fabbro and Duivenvoorden (1992) in relation to blue-green algae problems in the Fitzroy. Aquatic macrophytes which may be useful to compete for the algae for the nutrients as they enter the river system are *Phragmites australis*, *Hydrilla verticillata*, *Typha* sp., *Schoenoplectus litoralis* and *Ceratophyllum demersum*.

One of the more important findings of this study is the dynamic nature of the species profile at sites within the catchment. Since many of the species do not have subterranean organs from which they can regenerate, the continual replacement of some species by others must depend on seeds being washed downstream. Should this supply of seeds be reduced, fewer plants may germinate and grow on the banks of streams. This may result in increased bank-side erosion when the streams next flood. It therefore appears to be important to protect the sources of seeds of aquatic bank-side vegetation. One important source is likely to be the wetlands associated with the river systems. These contain the same species of aquatic plants as found in the streams, in addition to many others. The location of some of these wetlands rich in aquatic macrophyte species have been identified in this study. They include the wetland opposite Palm Tree Creek near Taroom (site 14) and the marshy area southeast of Dipperu National Park (site 78, Table 2). The high species richness of the latter site is surprising given its location in a very dry area of the Isaac River sub-catchment.

The value of sites rich in aquatic macrophyte species extends beyond their aesthetic value. Their role as seed banks for recolonisation of stream bank-side vegetation has been discussed. The diverse range of plant species is usually highly correlated with high diversities of other aquatic organisms such as snails, aquatic insects, fish and aquatic birds. More information is needed about the role of these habitats in the life cycles of many of these biota - for example the importance of these areas as fish nurseries, as sources of seeds distributed by water fowl or fish and as feeding grounds for migratory birds. Only with this type of information can we make the appropriate decisions about the management of wetlands within the catchment.

ACKNOWLEDGEMENTS:

I would like to thank Peter Rey for all the trouble he went through to produce the map of the catchment, Donna Duivenvoorden for preparing the graph and Maxy Barron for typing the manuscript. Financial support for the study was supplied by the Biology Department and the University of Central Queensland Grants scheme.

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M A N G R O V E S

WITH SPECIAL REFERENCE TO SOME LOCAL SPECIES & SITUATIONS

by

MOLLY CRAWFORD

MANGROVES
WITH SPECIAL REFERENCE TO SOME LOCAL SPECIES & SITUATIONS

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INTRODUCTION

Mangroves are vascular plants that have successfully colonised the intertidal zone. Characteristically they are found growing in sheltered bays and estuaries of tropical regions, though a few species are able to extend along more temperate coastlines. World-wide there are at least ninety species; here in Australia over thirty species in fifteen families.

The Port Curtis District Flora which covers our local area lists twenty species, to which I have added one more recently, Schyphiphora hydrophylacea - the Yamstick Mangrove, with previous southern limit to Townsville.

Much has still to be learnt about the morphology, distribution and speciation of mangroves. Temperature appears to be a limiting factor to distribution, in particular the lower threshold. Failure to adapt to frost may be a key factor. It is interesting to note that Avicennia marina, the Grey Mangrove, that can grow at the southernmost limit of mangroves anywhere in the world, tolerates a high salt concentration in the cell sap, which could account for some frost resistance.

ADAPTATIONS

Salinity

Adaptations in mangroves to their saline environment take different forms in different species.

*Salt secretion, or extrusion, by salt glands in leaves occurs in Aegiceras, Aegialitis, Avicennia species and others.

*Salt accumulation where salt is deposition in older leaves prior to leaf fall, is found in Excoecaria, Lumnitzera and Xylocarpus species.

*Succulence, found in many mangrove leaves may help to reduce salt concentration.

*Salt can be filtered out at root level. Salt excluders include all the members of the Rhizophoraceae family.

Soil Interaction

In addition to salinity, the soils in which mangroves grow lack oxygen necessary for root respiration, and have a semi-fluid nature.

Specialised rooting systems enable mangroves to adapt to these conditions, and take a variety of forms.

Though rooting systems are shallow, the ratio of below/above ground bio-mass is often higher in mangroves than for other vegetation. This characteristic, along with the intricate spread of long horizontal roots with smaller vertical anchoring and breathing roots, enables the plants to resist the twice daily ebb and flow of the tide, and to maintain their establishment in the unstable substratum. All the surface roots are well supplied with lenticels, small pores, that allow aeration down to submerged roots.

Reproduction - Vivipary

A third adaptation to their environment found in many, though not all mangroves, is that of vivipary. This could be likened to the development of placental mammals in the animal kingdom, for seeds develop into seedlings while still attached to, and receiving nourishment from the parent tree.

Of the twelve species of the Rhizophorazeae family in Australia, all except one are mangroves, and these are all viviparous.

In the three mangrove genera of this family, Rhizophora, Bruguiera and Ceriops, seedling stem, or hypocotyls, grow out from the apex of the fruit. Propagules, when shed, are bottom heavy, so that on a high tide they float away almost upright. When, and if, a favourable site is reached, they root easily and soon become established, but many end up along the drift lines on beaches. Propagules shed at low tide, spear into the ground below the parent and can develop if light and space allow.

In the Grey Mangrove a viviparous seedling is shed from the tree complete with a yellow-green pericarp. When this splits, two large bright-green cotyledons are revealed. The seedlings are buoyant prior to the shedding of the pericarp.

This adaptation of vivipary may mean that the large developed seedling that leaves the parent plant is less likely to be damaged by water movement. Vivipary may also assist rapid root attachment.

However, other successful species are non-viviparous. One such is the Milky Mangrove, growing on the landward side of the mangrove community, and so less likely to shed seeds into tidal water. This is an interesting mangrove having male and female flowers on separate trees. Male trees are often completely deciduous prior to flowering. Male flowers hang like catkins and visiting insects pollinate the smaller female flowers. These produce three chambered capsules. Seeds are dispersed when the capsules burst open violently.

ZONATION

Zonation in mangroves appears to come about in response to climate, surface form and elevation above mean sea level. Locally there are few clearly defined parameters. However, the Grey Mangrove dominates in the seaward pioneer zone, with the Stilted Mangrove just behind. This species also fringes creeks and estuaries, interspersed with the smaller River Mangrove. The Yellow Mangrove copes well with high salinity areas bordering salt pans. Tall Bruguieras usually grow in firm elevated positions. The Milky Mangrove can flourish away from the tidal influence on the landward side, along with the small Holly-leaved Mangrove.

FAUNA

Arthropods, especially crustaceans are always well represented, also molluscs, insects and spiders.

Of the vertebrates, at least seventy species of fish spend part of their life cycle in the mangrove ecosystem. One fish, the fascinating mud-skipper, is found almost nowhere else. Many small fish become important prey species for the larger commercially important fish such as Giant Perch and Barramundi. Reptiles such as crocodiles and turtles are often seen feeding in mangroves; also a number of snakes and lizards.

A rich bird fauna is associated with mangroves, some 250 species, of which fourteen are said to be obligate mangrove species.

In our locality these include the Mangrove Gerygone, Mangrove Honeyeater, the Collared Kingfisher and the Straited Herron.

Fruit Bats are the only mammal in Australia frequenting mangroves in numbers.

CONCLUSION

This fascinating ecosytem of mangroves where large flowering plants associate intimately with the sea is now being recognised as a valuable resource. The nutrient rich soils formed from the decomposition of fallen mangrove leaves support a wide variety of marine life, which in turn sustains coastal fisheries.

In addition it is thought that the mangrove forest protects the coast from erosion, caused either by heavy rainfall on the landward side, or by onslaughts from the sea.

Now the mangroves themselves need protection, protection from land-use practices such as clearing and filling of coastal wetlands, and perhaps the establishment of ponded pastures, protection from mosquito control measures and from coastal development.

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TERRESTRIAL FAUNA OF THE FITZROY CATCHMENT

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Introduction

There is little detailed documentation of the fauna occurring in this region at the time of first settlement (Gordon 1984). John Gilbert made fauna collections and other observations in 1844-45 during the Leichhardt expedition. Gilbert's party passed through the middle of the Fitzroy catchment, crossing the Dawson in the south and moving north to the Comet/Mackenzie system and then on to the Isaac and the Peak Range and north to the Burdekin catchment. Chisholm (1944, 1945) discusses the bird records from Gilbert's diaries. Gilbert remarked on the numbers of kangaroos. On the 30th Dec 1844, he saw one kangaroo near the Comet River (Gilbert 1844-45). On 1st January 1845 while on the Comet River, he comments on the difficulty of obtaining kangaroos due to their lack of hunting dogs, "although daily attempts are made to shoot" kangaroos and "even in the scrubs ... wallaby's seem to be very few, more especially in the scrub country we have passed over since leaving the Expedition Range" . On 14th January, 1845 , camped on the McKenzie River below its junction with the Comet, he stated that "we have ... met with ... very few of Kangaroo and other animals". His comments suggest that large macropods were usually scarcer than they are today. (Thirty years later in the late 1870's pastoralists were complaining about plagues of kangaroos in the same district, and bounties were established in an attempt to control them (Wright 1981).) On the 15th January, Gilbert collected the first central Queensland specimen of the bridled nailtail wallaby *Onychogalea fraenata*, further along the McKenzie River.

Carl Lumholtz collected in central Queensland from 1880-84 (Collett 1887, Lumholtz 1889). Dr Lumholtz was based at Gracemere near Rockhampton with the Archer family, who had connections with Norway. One of the new species that he discovered in north Queensland, the green ringtail possum *Pseudocheirus archeri*, was named after the Archers. He travelled on collecting expeditions as far west as the Diamantina River and north to the Cardwell district. Other sites he visited included Peak Downs, Minnie Downs, Coomooboolaroo, Manaroo, Winton and Mackay. Lumholtz recorded 33 mammal species from the Fitzroy Catchment including some important historical records (western quoll *Dasyurus geoffroyi* - possibly the only Queensland record of this species, brush-tailed phascogale *Phascogale tapoatafa*, northern bettong *Bettongia penicillata tropica*, spectacled hare-wallaby *Lagorchestes conspicillatus* and bridled nailtail wallaby). Lumholtz (1884, 1885) published two papers on echidna *Tachyglossus aculeatus* taxonomy based on his central Queensland collections. Coomooboolaroo, near Duaringa, was an important collecting site for Lumholtz who was primarily interested in collecting bird specimens for the museums of the University of Christiania in Norway. Subsequent records by Barnard (1925) of the avifauna of Coomooboolaroo add to the historical value of this property.

Wright (1981) discusses environmental changes in the region of Nulalbin, south of Coomooboolaroo, based on historical research. In the 1880's, wattle scrubs were expanding in area in sandstone country and brigalow was spreading in the river valleys, apparently due to the abandonment of firing; speargrass, bulloak, lancewood and rosewood were all increasing in area, and the original pastures were diminishing (Wright 1981, pp. 240-42, p. 251). Water turbidity has also greatly increased. Even at the height of flood in the 1890's the Dawson still ran with clear water rather than silt laden floodwater as occurs today (Wright 1981, p. 13). The severe drought at the turn of the century accentuated such changes, leading to a permanent decrease in carrying capacity for stock (Wright 1981 p. 272). In 1905 and 1906 prickly pear was expanding greatly in this region (Wright 1981 p. 275).

Charles Barnard (1925) reviewed changes in the avifauna of Coomooboolaroo over the period from 1873-1925. His brother H. Greensill Barnard (1934) provided further comment on the birds of central Queensland. Coomooboolaroo was first settled in the late 1850's and acquired by the Barnard's in 1873. The Barnard brothers were subsequently responsible for the discovery of the central Queensland population of the northern hairy-nosed wombat *Lasiorhinus krefftii* at Epping Forest near Clermont (Longman 1939). The Barnards describe environmental change on the property and change in the abundance of birds on Coomooboolaroo while they were there. Striking changes occurred to the watercourses early after settlement, including extensive loss of fringing lagoons and associated vegetation and silting up of formerly permanent waterholes. One of the major changes was loss of low vegetation along creeks, an important resource for some fauna species, due to grazing and trampling by cattle. Le Souef (1891) provides further faunal records for Coomooboolaroo, gathered while visiting the Barnards.

In 1928-29, the well-known South Australian zoologist Hedley Finlayson spent three months collecting mammals on the Dawson and Fitzroy Rivers, ranging from Taroom in the south to Mt Hedlow in the north and including Coomooboolaroo (Finlayson 1931, 1934). He provides ecological notes on the species he observed and information on historical changes in the status of species such as the bridled nailtail wallaby, the western quoll and the tiger quoll *Dasyurus maculatus*. He records the time of the first sightings of the fox *Vulpes vulpes* on the Fitzroy as 1917 on Rio Station by H. Barnard and 1924 at Mt Hedlow by R. Vallis (Finlayson 1934). Finlayson also published a paper on rodent taxonomy as a result of his work in this area (Finlayson 1942).

More recent faunal work in the catchment has also been carried out. Staff from the CSIRO and the Queensland Forestry Department surveyed the Pluto Timber Reserve near the head of the Nogoa River in 1970, recording 26 reptiles, 122 birds and 37 mammals (Anon. 1972). Crossman and Reimer (1986) surveyed the terrestrial vertebrates of Taroom Shire between 1977-1979. From 1973-1977, Gordon and Lawrie (unpublished) surveyed the terrestrial vertebrates of the Emerald region. Gordon and Lawrie (1980) also surveyed the distribution of the bridled nailtail wallaby in the Dingo area. Further research on this species has included a study of its habitat and ecology (Tierney 1985)

Fauna habitat

The Fitzroy Catchment contains a number of distinctive vegetation types and land forms which determine the nature of faunal habitats in the area. Eucalypt communities include tall open forest (wet sclerophyll forest), open forest and large areas of woodland. Distinct riverine communities also occur here, with forest red gum, coolabah and brigalow vegetation. "Scrub" vegetation includes particularly associations of brigalow, lancewood, belah, cypress and yellowwood. Vine thickets (softwood scrubs) formerly occupied sufficiently large areas to form important fauna habitat. In the Central Highlands, volcanic activity gave rise to basalt soils supporting large areas of natural grassland, the blue grass downs. Large wetlands occur near Rockhampton and smaller water bodies occur throughout the region. Large artificial water bodies also present in the area, such as Lake Maraboon near Emerald, provide habitat for waterbirds. The extensive sandstone ranges of the Central Highlands add greatly to the floristic and habitat diversity of the area. Rocky hills and mountains scattered throughout the region are utilised by a small component of rock-haunting species. The only well developed caves occur on or near Mt Etna north of Rockhampton, but smaller caves and crevices in other ranges are important for some species. Two montane areas, the Blackdown and Consuelo Tablelands, have sufficient altitude and moisture to influence the faunal composition.

Adaptive associations and biogeographic composition

Most mammals of the Fitzroy Catchment tend to have relatively broad habitat utilisation, occurring across a range of broad vegetation types (Gordon 1984). The mammal fauna is dominated by species of the eucalypt forests and woodlands. Many mammals show a general affinity for eucalypt communities. These include arboreal folivores such as the greater glider *Petauroides volans* and the koala *Phascolarctos cinereus*, tree denning species such as brushtail possums *Trichosurus vulpecula* and gliders, and blossom feeding species such as fruit bats. Many others, such as various ground dwelling mammals, are species of forest and woodland in general. Riverine forests, primarily communities of *Eucalyptus tereticornis* or *E. microtheca*, enable some mainly coastal species to range further inland, or occur at greater abundance in the inland, than would otherwise be possible. These include the koala, the short nosed bandicoot *Isoodon macrourus*, the sugar glider *Petaurus breviceps* and the greater glider. Some of these species may also be found in forest in mountain ranges in the more inland parts of the catchment, which includes extensive areas of rugged country, the sandstone ranges of the Central Highlands. The open forests and woodlands associated with these ranges enable some other species of humid coastal areas to extend farther inland in the region such as the ringtail possum *Pseudocheirus peregrinus*, the whiptail wallaby *Macropus parryi*, the yellow-bellied glider *Petaurus australis* and the mosaic-tailed-rat *Melomys cervinipes* (Gordon 1984).

The mammal fauna of vine thickets is depauperate and derived from that of eucalypt communities or rainforest, including species such as the long nosed bandicoot *Perameles nasuta* and the mosaic-tailed rat (Gordon 1984). Other mammals occurring in this community include the echidna, brushtail possum, swamp wallaby *Wallabia bicolor* and black-striped wallaby *Macropus dorsalis*

(Gordon 1984). In the Burdekin catchment to the north, two lizards have been recorded in vine thickets that are thought to be endemic to these communities (Kahn and Lawrie 1987), indicating that it is possible that some endemism may be found also in the Fitzroy/Dawson fauna among the lower vertebrates and invertebrates.

Mammals occurring in brigalow and other sclerophyllous scrubs are derived from the mammals of the eucalypt communities (Gordon 1984). However, there is a minor association of the mammals with scrub vegetation. The bridled nailtail wallaby has an association with edge conditions of scrubs including brigalow communities (Gordon and Lawrie 1980). Finlayson (1931) comments on the association of the wallaroo *Macropus robustus* with scrub vegetation (cypress and rosewood) and this is borne out by observations of the author. At some sites, scrub vegetation in lowland country appears to serve as alternative to rugged areas as a shelter site for this species. The black-striped wallaby has a strong preference for denser vegetation including *Acacia* scrubs, vine thickets and shrubby eucalypt communities.

There is some indication of the presence of a grasslands fauna in the area, which is partly derived from a more widely spread grassland/shrubland fauna of arid and semi-arid zones (Gordon 1984). The earless dragon *Tympanocritis lineata* occurs in the blue grass downs of the Central Highlands. The recently discovered *Rattus* species in the Central Highlands also appears to be part of a grasslands fauna.

The fauna includes rock-haunting mammals, the rock-wallabies *Petrogale penicillata* and *P. inornata* and the northern quoll *Dasyurus hallucatus*. These may be found in many of the more rugged or rocky ranges in the catchment. Cave faunas include the bats of the limestone cave complexes on and near Mt Etna and bats in smaller caves further inland (Jolly 1990). The presence of the ghost bat *Macroderma gigas*, a vulnerable species in Queensland and Australia's only carnivorous bat, is particularly significant. This is one of the largest known colonies and one of the few sites for this species in Queensland. Mt Etna includes a major nursery cave for the little bent-winged bat *Miniopterus australis*.

Stream fauna includes the Fitzroy River tortoise *Rheodytes leukops*, endemic to the catchment and listed as Vulnerable by the Australian and New Zealand Environment and Conservation Council.

The fauna of the catchment is derived primarily from the eastern Australian open forest/woodland fauna with some closed forest elements (Gordon 1984). Small groups from other faunas are also present including species of the arid/semi-arid zones (eg., red kangaroo *Macropus rufus*, desert mouse *Pseudomys desertor*), the tropics and semi-arid tropics (eg., northern quoll, spectacled hare-wallaby *Lagorchestes conspicillatus*) and ubiquitous Australia wide species (eg., echidna, western quoll) (Gordon 1984). The brigalow belt, which includes most of the catchment, appears to form a minor centre of distribution for vertebrates (eg., the black-striped wallaby) (Gordon 1984).

The Fitzroy Catchment has a rich and diverse terrestrial fauna. If we take the mammals as an example, the 58 native mammals known to have occurred there (Collett 1887; Finlayson 1931, 1934; Crossman and Reimer 1986; Gordon and

Lawrie, unpublished data) include 12 macropods, 9 dasyurids and 8 rodents. This compares well with other areas of comparable size. Four of these are now thought to be extinct in the catchment.

The fauna forms a transition along two gradients (Johnson and Gordon 1981). Along an east-west gradient, species of more arid areas gradually replace the species of coastal humid habitats. And along a north-south gradient, the fauna forms a mixture of tropical and south-eastern (Bassian) species. Some southern and northern species reach their limits in the region.

Montane fauna

The fauna of Blackdown Tableland and Consuelo Tableland include geographic isolates and even endemic species. Consuelo Tableland, lying on the south-western boundary of the catchment, has the northernmost occurrence of the tiger snake *Notechis scutatus*, otherwise occurring in south-eastern Queensland (Porter and Gordon 1985). Other species include Cunningham's skink *Egernia cunninghamii*, the yellow-footed marsupial mouse *Antechinus flavipes*, the bush rat *Rattus fuscipes* and the mosaic-tailed rat. The uncommon eastern chestnut mouse *Pseudomys gracilicaudatus* also occurs here. The fauna of Blackdown Tableland includes the yellow-footed marsupial mouse, the mosaic-tailed rat and the eastern chestnut mouse. It may also have been the collecting site for the northern bettong, now thought to be extinct in central Queensland. The location of the only specimen, collected by Lumholtz in 1884, is given as Coomooboolaroo, a nearby property (Collett 1887). This species now survives only in a restricted area of tall open forest on the Atherton Tableland in North Queensland.

An endemic Orthopteran *Cooloola dingo* has been described for the Blackdown Tableland (Rentz 1986). The invertebrates of Consuelo and Blackdown tablelands also include a number of geographic isolates (Atkins 1974; Carne 1981; Lambkin 1988; Monteith and Yeates 1988).

Changes in the faunal community

Changes to the faunal community are described by Johnson and Gordon (1981). Initial settlement resulted in severe declines and extinctions on a selective basis, affecting a relatively small number species that were particularly sensitive to the disturbance associated with settlement. These declines were gradual for some species, extending through to relatively recent times in some cases. Barnard (1925) reported seeing the last paradise parrot *Psephotus pulcherrimus* in 1902. One of the quolls (the western quoll?) apparently disappeared about the same time (Barnard 1934). The remnants of the bridled nailtail wallaby and northern hairy-nosed wombat populations lasted through to recent times when active management halted their decline. The wombat has not been definitely recorded in the catchment, but it occurred to the north and south of the Fitzroy and there are uncertain reports of it on the upper Dawson. Other species that have disappeared include the northern bettong, the tiger quoll and the brush-tailed phascogale. Many of these declines may be attributed to an effect of the pastoral industry on these species. Barnard (1925) and Barnard (1934) attributed some of the declines among birds to the direct impact of severe drought in a landscape which had been so modified by grazing that secure habitat was no longer present. Two of the larger mammals, the nailtail wallaby and the wombat, may be directly affected by competition with stock for food as both have relatively narrow habitat preferences in landforms that are heavily frequented by stock (Gordon and Lawrie 1980; Gordon *et al.* 1985; Johnson 1991). Both have expanded in numbers following removal of grazing. Small mammals may also have suffered some decline as most species are either uncommon or rare in grazed country in this region (Johnson and Gordon 1981).

Population expansion occurred among some species such as the large macropods (Wright 1981) and the koala (Johnson and Gordon 1981) which subsequently may have declined to a lower abundance.

More recently, since the 1950's, broad scale clearing of scrub and eucalypt woodland vegetation has been taking place. The final impact of this on the fauna has yet to be realised, but it is likely to be much greater than the effect of earlier disturbance.

Of the introduced mammals that are commonly thought to affect native fauna, the fox and the rabbit *Oryctolagus cuniculus* are uncommon in most parts of the catchment. Feral cats *Felis catus*, however are widespread and common. Their impact on the native fauna can only be conjectural. As habitat destruction (the modification of the ground layer by grazing and cultivation and the clearing of timber) is widespread and severe, it is more likely that this is the prime cause of extinctions and declines. The positive response of the bridled nailtail wallaby and the northern hairy-nosed wombat to the removal of stock grazing tends to support this. We may speculate that cats have however affected the native carnivores that have declined through direct competition for food.

Fauna conservation

There are a number of significant fauna conservation issues in the catchment, some of which have been discussed above,

- Species that have become extinct or probably extinct in the area include the paradise parrot, black-breasted button-quail *Turnix melanogaster*, western quoll, tiger quoll, brush-tailed phascogale, northern bettong.

- The catchment includes populations of species that are currently classified by the Australian and New Zealand Environment and Conservation Council as Endangered (bridled nailtail wallaby) and Vulnerable (Fitzroy River tortoise, , ghost bat) on an Australia wide basis. In addition, some other species from the catchment are considered to be of poor status in Queensland: spectacled hare-wallaby (Vulnerable), ornamental snake *Denisonia maculata* (Vulnerable), Dunmall's snake *Glyphodon dunmalli* (Vulnerable).

- Garnett (1992) lists four birds occurring in or near the catchment as Endangered or Vulnerable: red goshawk *Erythrotriorchis radiatus*, V; squatter pigeon *Geophaps scripta scripta* (southern subspecies) V; star finch

Neochmia ruficauda ruficauda (eastern subspecies) E; and black-throated finch *Poephila cincta cincta* (southern subspecies) V).

- Conservation of the bridled nailtail wallaby.

- Conservation of the montane fauna of the Blackdown and Consuelo Tablelands.

- Conservation of the bat fauna of the Mt Etna region including the ghost bat and the little bent-winged bat nursery.

- Conservation of the spectacled hare-wallaby, a small wallaby of the eucalypt woodlands that appears to have undergone a decline in the region and is now rare in most areas or entirely absent.

- Reservation and conservation of areas of the blue grass downs of the Central Highlands and its associated fauna. Because of its economic value this community is poorly conserved.

- Conservation of the recently discovered species of *Rattus* from the Central Highlands.

- Conservation of the small and medium sized mammal fauna of the grazing lands. Fauna surveys indicate that these species generally occur at very low density and have probably undergone a decline. They include rodents, small dasyurids and bandicoots. The desert mouse and the new *Rattus* species are particularly rare in the catchment. Long-nosed bandicoots have become rare in inland areas due to clearing of vine thickets and may now be rare in the entire catchment.

- Clearing of brigalow and vine thicket communities. The faunal communities of these vegetation communities have undergone severe disturbance. Vine thickets in particular are inadequately conserved.

- The upsurge in the development and clearing of eucalypt woodlands and its probable severe impact on the status of many animal species. The survival of much of the fauna of the area has been due in part to the survival of the eucalypt woodlands and open forests throughout much of the catchment, despite the loss of the brigalow and vine thicket communities. Future broad scale development and clearing of the eucalypt woodlands will lead to many more local declines and extinctions among the fauna.

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The Impacts of Catchment Development on the Fish Fauna of the Fitzroy River System.

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Abstract

The Fitzroy River exhibits a unique fish faunal assemblage with at least two species known only from this drainage system.

The species present in the river are a combination of representative species from both the East Coast and Murray-Darling drainages systems, and include a number of introduced species.

Extensive clearing of the catchment and the installation of more than 30 impoundments throughout the drainage basin has modified habitat conditions and ecosystem health of the river.

This paper examines the habitat requirements, migratory patterns, and introductions of fish species in the Fitzroy River, discusses the impacts of catchment management and flow control practices on these species and highlights the need for much greater understanding of our existing ecosystems and their management regimes.

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Introduction

The Fitzroy basin is the second largest catchment in Australia covering an area of 140,000 square kilometres on the North East coast of Australia .

The climate throughout the basin is distinctly seasonal, with heavy summer rainfall and protracted dry winter spells.

The river flow reflects this pattern with minimal streamflow in the June to November period, and elevated flows in response to seasonal rainfall usually emanating from easterly trough lows, (Figure 1).

Most of the large volume flood flows in this basin are due to extremely high, short-term rainfall, resulting from monsoonal or cyclonic synoptic activity. Widespread flooding is common throughout the gently undulating terrain and broad floodplains, with the subsequent runoff taking a considerable time to discharge into Keppel Bay through the Fitzroy River.

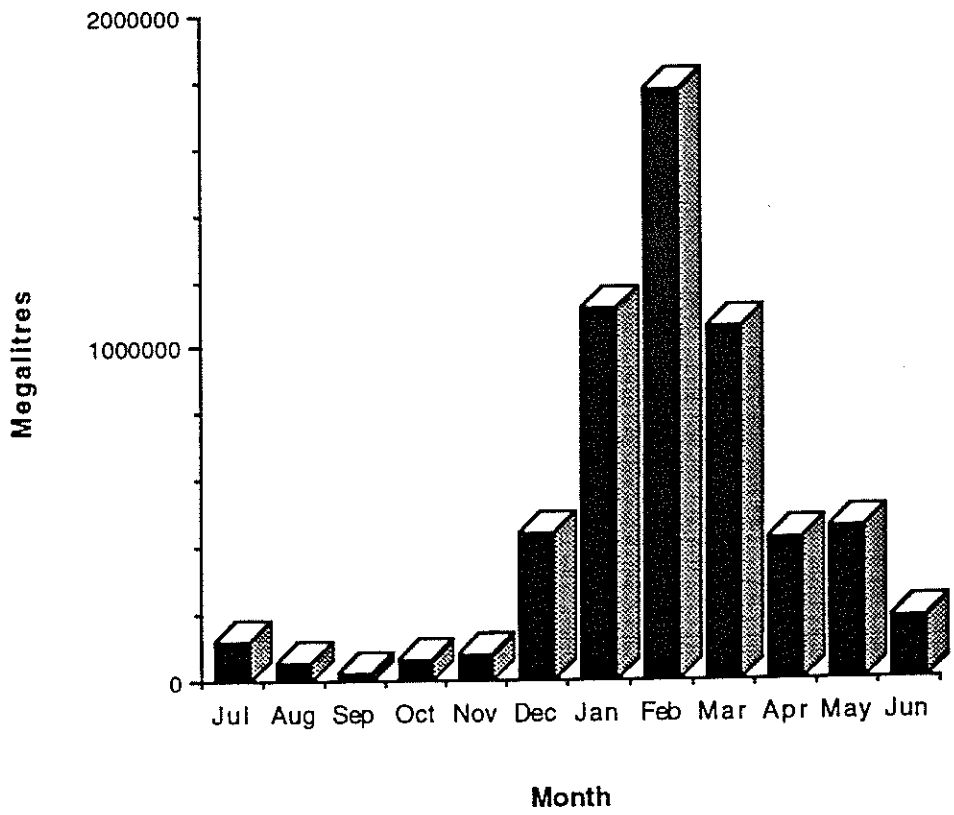


Figure 1. Mean Monthly Streamflow Values for the Fitzroy River (1914 - 1991)

This river system exhibits a unique freshwater fish assemblage with at least two species, the Saratoga *(Scleropages leichhardti)* and the Leathery grunter *(Scortum hillii)*, only known from this drainage system. It also represents for a number of species the limit of their geographic range.

The species present in the river are likely to be remnants of what formerly existed, with a few additions, such as the murray cod *(Maccullochella peeli)* and silver perch *(Bidyanus bidyanus)*, that have been stocked for recreational angling purposes . This stocking program was initiated by the Department of Primary Industries in 1987 to promote and encourage inland recreational angling via the creation and enhancement of impoundment fisheries throughout the state. To date ten public impoundments have been stocked in the Fitzroy basin at a cost in excess of $300 000,(refer Appendix 1).

It should, therefore, be recognised that the existing fish fauna are not the naturally occurring species, and may not be the preferred species assemblage.

The two factors that are essential for the continued species existence in any aquatic system are habitat availability and food supply.

In the last thirty years increased silt loads derived from clearing of adjacent lands and the installation of impoundments on this river system have created a situation which has modified the instream habitat to such an extent that many species are either eliminated or enhanced throughout the basin. Unfortunately those species that have been eliminated are considered to be the desirable species and those enhanced are considered of little value.

We have obviously got the balance wrong.

The following comments will, in the first instance, discuss the habitat requirements of the fish. They will then proceed to indicate how the existing catchment management practices have interfered in this natural system. Finally, we offer some recommendations to managers to address these problems.

Habitat Requirements

It is important to realise that in terms of our understanding of habitat dynamics there is limited information on fish habitat generally, but more specifically, there has been very little research undertaken on aquatic river systems in tropical Australia. Most of the principles of temperate aquatic ecology have been applied, and for management purposes it has been assumed that they are equally appropriate for tropical ecosystems.

Little is known about the innate response of aquatic organisms to environmental messages, such as increased flow rate, temperature variances, reduced oxygen levels etc. Organism activity is generally discussed as a response to change and is always described in anthropocentric terms. However, there is limited, if any, understanding of the actual mechanisms and instinctive processes taking place which determine activity in these animals.

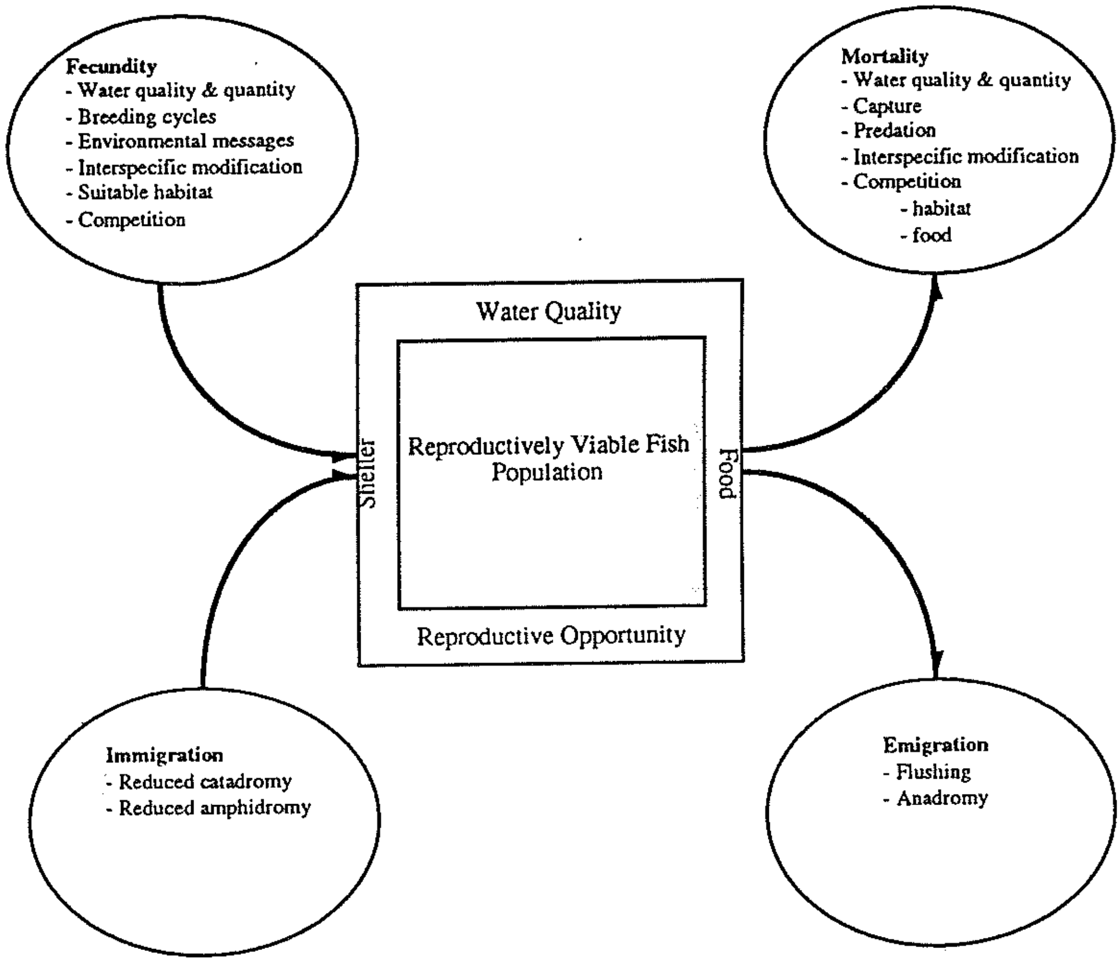
There are a number of basic requirements for a population to exist in the long-term, they are food, shelter, appropriate water quality and reproductive opportunity. Factors such as fecundity and mortality rates and emigration and immigration will also operate to determine overall population size, (Figure 2).

In the river situation habitat is basically made up of substrate, instream cover and water depth and quality.

Food supply is, for most species of fish, a result of the habitat availability for their prey or fodder species.

Consequently the protection of suitable habitat and appropriate food supplies will ensure that instream biological values are maintained in the long term.

Figure 2. Factors Affecting Population Survival



Habitat availability varies considerably with flow levels. For example whenever flow exceeds the capacity of the banks it opens up many new feeding grounds and shelter sites.

It is uncertain what the effect of a low flow season has on many of these species.

In natural flooding episodes the rise and fall of water level is a gradual process. Flooding provides the stimulus for major events, such as breeding and migration.

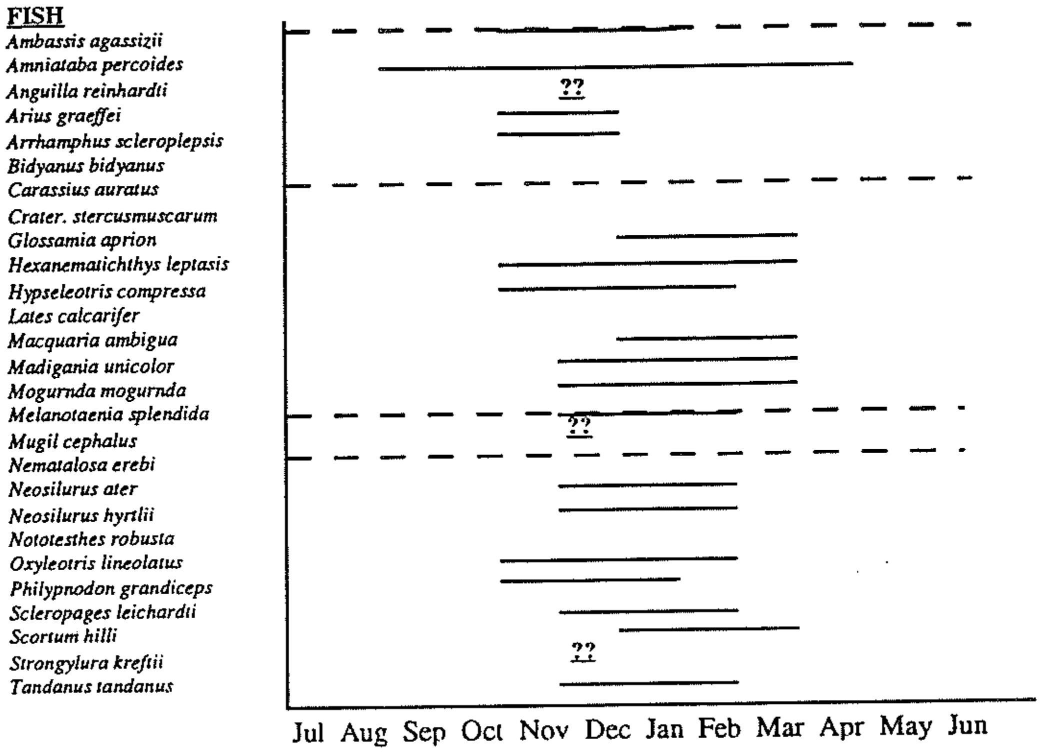
Fish, in particular, initiate breeding cycles in response to rising water levels. Lawrence, (1989), Many species have a period of up to seven days from the initial fertilization of eggs through larval stage to free-swimming juveniles.

During flooding events the grassy banks of the floodplains provide prime feeding grounds for many species, particularly the carnivores with soil fauna becoming available.

The large floodplain areas of the Fitzroy River, generally take a long time to subside and therefore maximise the potential of the species that take advantage of the changed conditions and the survival of juvenile fish in particular.

The following table (Table 1), records the seasonal breeding cycles for the species of fauna known to occur in the Fitzroy River. There is seemingly a correlation between the commencement of breeding cycles and the onset of the wet season.

Table 1. Seasonal Breeding Cycles for Fish Species Known to Occur in the Fitzroy River System.



--- Indicates year round breeding possible
__ Time of breeding

Reproductive strategies for many of these species are based on an immediate response to the first seasonal falls with short timeframes of development from egg to larvae. Within seven to ten days most species have progeny through to free-swimming larval stage.

This period would seem to be critical for the continued survival of these species in a local context. Once the progeny have reached larval stage they are more able to respond to fluctuations in habitat availability.

During this period the conditions generally become most favourable for the continued survival of young because floodplains become accessible, water quality improves with the flushing of anoxic pools and both vegetation and invertebrate lifeforms grow in abundance. This growth provides food supplies for the young and ensures an elevated chance of survival to maturity.

Bearing in mind that many of these species have few breeding cycles in a lifetime, each season is important in maintaining the species existence in an already degraded environment.

Existing Management

Due to the limited nature of available water in Australia the major emphasis of managers has been to develop operational procedures which maximise water availability and optimise use.

This type of management has been evident in the United States of America, Canada and New Zealand. However, in these instances the management has been directed at maximising instream components of the environment to directly benefit a single species, usually of economic value and has not truly been for the environment as an entity.

In reality, therefore, actual consideration of the natural environment has been almost non-existent.

More recently consideration has been given by managers to responsible environmental management of riverine ecosystems.

Several methodologies have been developed for assessing the environmental water requirements of rivers, such as the Instream Flow Incremental Methodology (IFIM) developed in the United States and the RHYBABSIM program utilised in New Zealand. However, as Arthington et. al. (1991) indicate these existing methodologies cannot be adopted simplistically in the highly variable and hydrologically unpredictable environments of most Australian rivers.

In Australia there have been a number of approaches to determining appropriate water management practices to satisfy instream requirements. However it was not until the mid 1980's that water allocation strategies acknowledged the needs of natural systems. In 1991 the Centre for Water Policy Research, at the University of New England, hosted an international seminar entitled, "Water Allocation for the Environment". The proceedings from this seminar attempted to consolidate existing knowledge on this topic.

Out of this seminar came a variety of alternative allocation strategies. As recorded in the proceedings, Arthington et.al.(1991) recommended an approach which defined the environmental conditions that have maintained the river in its characteristic form and then, based on the natural hydrological regime of the river, utilised these conditions as the fundamental guide to water allocation strategies.

This approach has many positive aspects not the least of which is that it accepts that there is a legitimate right to maintain the desired natural riverine community. Whilst the sentiment of such a strategy is considered appropriate it may be too limiting given the scope of the problem. Many riverine ecosystems are already so severely degraded that managers should be adopting a pro-active approach by setting their management objective not to maintain situations where they are already degraded, rather trying to improve ecosystem health, stability and variation.

Of course there would be a need for much greater understanding of our existing ecosystems and their existing management regimes.

The LANDCARE program which is currently being developed throughout Australia has focussed primarily on the management of lands for sustainable use. This program if successful should have flow-on effects that provide substantial improvement of instream values.

Indeed there would be some value in extending the concept of LANDCARE to incorporate the connections between terrestrial and aquatic management. In New South Wales recently there has been the suggestion of a RIVERCARE program to operate concurrently with LANDCARE. It is an important initiative towards a coordinated approach to catchment management.

The Queensland Government has gone a little further with the establishment of the principle of Integrated Catchment Management (ICM).

Integrated Catchment Management suggests that the management of land and water resources is most effective when based on the river catchments. It recognises that most of our problems affecting our land and water resources are interrelated and cannot effectively be solved individually.

A number of the issues to be addressed in developing a successful ICM program for the Fitzroy .

Catchment clearing

The development of the lands of the brigalow belt, (*Acacia harpophylla*), for agriculture in the mid 1960's to the early 1970's resulted in the clearing of several million hectares of Central Queensland, primarily in the Fitzroy catchment (Webb, 1984). The two major problems of soil erosion and soil salinity that were associated with this extensive clearing have not dissipated, (Johnson, 1985).

These problems manifest themselves in the aquatic environment as physico-chemical changes to the water. Elevated silt loads and chemical loading of nutrients and pesticides are likely to be major problems within the Fitzroy. These changes are compounded because of the settling effect of impoundments.

The stream substrate in the Fitzroy River is a combination of sand, silt and stone. In the wider sections of slow-flowing river, coarse sands constitute the majority of the substrate. In the areas adjacent to the rocky bars the substrate is composed primarily of pebble and stones.

Studies in the temperate regions, (Jowett,1991), have shown that changes in the streambed substrate are likely to cause significant changes in the invertebrate fauna of the river, which are a primary food source of many fish. However not enough is known of the invertebrate fauna of this area to adequately predict the extent of changes or the flow-on impacts of these changes.

Silt and nutrient loads in the Fitzroy River will of course flush in event of major flooding, however this will probably send a pulse of both sediment and nutrients in to the receiving waters of the lower Fitzroy and Keppel Bay with ensuing problems for the aquatic fauna in those locations, (Byron, 1992).

During the 1991 flood large quantities of silt were contained within the floodwaters. Whilst it was not possible during the course of this flood event to establish overall sediment loads in the river, Department of Primary Industries officers reported that the flooding caused severe erosion and sedimentation in the river system. Soil loss estimates of 1300 tonnes per hectare were recorded in the cultivated areas of the floodplain, and in one instance 430,000 tonnes of alluvial soil was removed when a new channel was created (Chapman, 1992).

Besides floods the first major flows of the season provide a flushing effect on ponded areas and provide renewed levels of dissolved oxygen, nutrients and particulate food matter. In addition it may flush out stagnating pondages, remove excessive silt, trim back encroaching vegetation, and stimulate breeding or migratory cycles (Arthington, 1991). These naturally high flow levels are necessary to revitalise ecosystem processes.

Impoundments

There are in excess of 30 impoundments on the Fitzroy River system all of which may pre-determine habitat conditions and ecosystem health of this section of the River.

The construction of weirs and impoundments may affect the physical and chemical environment for the biota. Some of the changes are immediate and obvious (eg. reduced flow, regulated flow). Other changes may only become obvious in the longer term, such as reduced populations or localised extinction of particular species.

When flow is reduced there are also a number of changes to both the quality of the water and the substrate. The water loses oxygen and particulate matter such as silt settles out. This silt covers the substrate making it largely unsuitable for many species of invertebrate fauna and creates a smothering effect on eggs that may have been deposited on the substrate by fish or other instream fauna.

Water quality changes caused by impoundments may create subtler barriers to fish migration, (Harris, 1984), however limited information is available on the water chemistry of this river, or its effects on various species.

Water quality and quantity become critical when it affects the individual ability of a species to successfully recruit new individuals to the population.

Various habitat types support differing faunal groups. Water flow and consequent water levels downstream determine the extent of the various habitat types. Therefore the focus of operational guidelines should be to minimise impacts on these characteristics of the habitat types.

The construction of impoundments will innundate some areas which were previously shallow riffle areas. These riffle habitats support a variety of fauna. Areas covered by fine silt, such as backwaters, and to a lesser degree the open river, rarely support large populations of stream dwelling insects which are a fodder species for small fish. Sand and gravel substrate provides more suitable habitat for species of instream fauna. Some species, such as caddis, may be more commonly associated with larger more stable substrate and some, such as chironomids and worms are also abundant in fine substrate.Sand and gravel substrates are also ideal breeding locations for certain species of fish, (eg. *Tandanus tandanus*).

To a lesser degree impacts are likely immediately downstream due to modified flow regimes .

This is the section of the river where the change is most apparent because at this site the flow is usually reduced to a controlled outlet, (eg. the outfall of a fishway), and when flow is released its velocity is greatest at the source of the outlet. It is also the place where the water level will more abruptly change with commencement and cessation of release. The water is not as likely to backup in this area as it is further downstream. Also further downstream other influences, such as inflow from feeder creeks, are likely to reduce impacts.

The abrupt cessation of flow during construction of the Tallowa Dam on the Shoalhaven River in New South Wales reportedly resulted in a high mortality of fish immediately below the dam wall as the fish became stranded, (Bishop and Bell, 1978).

Reductions in flow tend to narrow stream channels and alter patterns of sedimentation and bank erosion.

Under certain seasonal conditions sections of the Fitzroy stop flowing. However at these times in many areas there is still a sub-surface flow of water through the highly porous streambed.

Access to the adjacent floodplain is provided by the numerous feeder creeks. If there is a decrease in flow and the feeder streams are not able to access the adjacent floodplain systems , recruitment processes will be limited.

If the release of waters from the impoundment was of short duration breeding may be artificially initiated with limited potential for successful recruitment. If this was then followed up by natural flooding episodes these animals would not necessarily be capable of repeating breeding activity and the opportunity for recruitment may have been lost to the population.

For this reason abrupt releases of significant volumes of stored water should be avoided.

Releases of water will need to be continual or sustained, with no intermittent or slug flows, to ensure that critical levels are maintained downstream.

Large instantaneous releases may also create a flushing effect on many species of fauna. Under natural flow conditions water level rise is a gradual process allowing time for species to adjust or relocate to avoid the high velocity flows.

Sudden releases of water could also impact on the nature of the stream. It may exacerbate existing streambank erosion and reduce the habitat availability for species which rely on the vegetation of the stream banks for food or shelter.

Large floods and floods that occur when impoundments are close to full in most instances will still be passed downstream. The peaks of these events may be mitigated by the volume of water absorbed by the impoundment, however, generally this would be an insignificant component of the event. Regardless, it should be noted that as the peak level determines the extent of floodplain innundation, any reduction of the flood flow will result in some loss of floodplain innundation.

Similarly when the first major rainfalls occur within the catchment and elevated water levels begin to occur within the impoundment it is imperative that a substantial percentage of this flow is passed downstream to allow breeding cycles to commence.

For the manager these flows would probably replenish a supply which has diminished over the preceding dry season and the temptation to capture all of the first flows, in case the wet season doesn't eventuate, will appear paramount. However, if the fish don't receive the flows or if the wet season is too late many species will either not breed that year or will attempt to breed in poor conditions and suffer a high larval mortality.

As far as possible there should be an attempt to mimic natural events. If there is a rainfall event in the catchment, then some of the ensuing flow should be passed downstream. This is particularly important in the late spring-summer period when many species are gravid and prepared for breeding.

On a more positive note, in the future when our biological understanding of these species becomes more complete it should be possible to induce breeding in many of these species. For example, if the season has been particularly dry and the impoundments had sufficient stored capacity to allow a gradual release, then providing elevated water levels for approximately seven to ten days may allow successful breeding and recruitment of juveniles for some species.

The other area of concern is the restriction of movement for species that occur, or are likely to occur, within the river.

To minimise impacts of impoundments on the fish in the Fitzroy the manager must aim to provide suitable upstream and downstream access for populations of the species concerned. The following example highlights the need for a better understanding of the dynamics of our aquatic ecosystems.

Given that there are in excess of thirty impoundments on this system most species are already extremely restricted from their former range. The barrage has reportedly been the major obstacle for many species of fish migrating within the Fitzroy River.

Example - Fitzroy River Barrage

In response to public concern over the efficiency of the fish ladder on the Barrage the Rockhampton City Council in 1991 requested the Department of Environment and Heritage to undertake an independent study of the effectiveness of this ladder. Trials were commenced in February 1992 and will continue for twelve months.

The preliminary results from this study show that most species, including barramundi (*Lates calcarifer*), are capable of passing through the barrage fish ladder. However, results have confirmed a general reluctance of fish, in particular barramundi, to use this ladder for upstream access. Whilst these studies are only at an early stage and not yet able to quantify the proportion of animals successfully completing this passage, it is evident that the ladder acts as a species filter with only a few species completing passage. Unfortunately the 'desirable' species are not amongst those utilising the ladder successfully.

Initial indications from this study, are:

1) That the headwater within the fishway is of significance in determining success of passage; and

2) That during the winter months fish generally do not enter the fishway.

3) The design of the fishway does not extend to low water so that fish are only able to access the ladder at high tide.

4) A right angle bend in the centre produces a confused eddy system which may disorient fish and limit passage.

Based on these preliminary results it would seem essential to maintain sufficient headwater, in the fishways, at times of the year when the fish are attempting to move upstream.

Additionally it may be practical to close the outfall from the Barrage fishway during these months of inactivity thereby maintaining storage in the barrage impoundment. This option, however shouldn't be considered until the results of the current study are finalised. Further advice should then be canvassed from relevant sources (eg. DPI Fisheries).

Recommendations

Most of the problems affecting our land and water resources are interrelated and cannot effectively be solved individually.

There is a definite need to develop a holistic approach to the management of the Fitzroy River Catchment.

The Integrated Catchment Management plan for the Fitzroy must incorporate a pro-active approach to conservation The plan should have the management objective of improving ecosystem health, stability and variation, not to maintain situations which they are already degraded

The management of impoundment outflows will have a significant effect on the continued existence of many species in this river system. The following comments provide some guidance on these matters

- As far as possible there should be an attempt to mimic natural events.
- Abrupt releases of significant volumes of stored water should be avoided.
- Releases of water will need to be continual or sustained, with no intermittent or slug flows, to ensure that critical levels are maintained downstream.
- It is essential to develop fishways that allow the passage upstream of native fish
- Sufficient headwater must be maintained in those fishways, at times of the year when the fish are attempting to move upstream.

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Fitzroy River Barrage

Impoundment Specifications
River: Fitzroy
Nearest City: Rockhampton
Impoundment Owner: Rockhampton City Council
Recreation Facilities: Boat ramps, picnic shelters, toilets
Recreation Use: Water skiing, sailing, picnicking angling, no camping
Stocking Group Name: Fitzroy River Fish Management Group

Stocking Summary		Total Cost	
Golden Perch	180 310	Government	$52 579
Barramundi	51 132	Group	$22 620
Sleep Cod	5 900		
Saratoga	30		

Mount Morgan No.7 Dam

Impoundment Specifications
River: Dee
Nearest Town: Mount Morgan
Impoundment Owner: Mount Morgan Shire Council
Hall Height: 9.4 metres
Recreation Facilities: Boat ramp, picnic shelters, toilets
Recreation Use: Water skiing, picnicking, angling, no camping
Stocking Group Name: Mount Morgan Big Dam Fish Restocking Committee

Stocking Summary		Total Cost	
Golden Perch	12 000	Government	$3 500
Silver Perch	7 600	Group	$2 400
Sleepy Cod	4 000		

Callide Dam

Impoundment Specifications
River: Callide Creek
Nearest City: Biloela
Impoundment Owner: Queensland Water Resources Commission
Recreational Facilities: Boat ramps, picnic area, shelter sheds, toilets, BBQ
Recreational Use: Skiing, sailing, picnicking, swimming, angling, no camping
Group Name: Callide Valley Native Fish Stocking Association

Stocking Summary		**Total Cost**	
Golden Perch	100 948	Government	$42 918
Silver Perch	91 456	Group	$8 800
Sleepy Cod	1 000	Dr R. Tan	Not recorded
Saratoga (yearling and adult fish)	122		

Glebe Weir

Impoundment Specifications
River: Dawson
Nearest Town: Taroom
Impoundment Owner: Queensland Water Resources Commission
Wall Height: 10.3 metres
Recreational Facilities: Boat ramp, picnic shelters, BBQ's, toilets, powered sites
Recreational Use: Skiing, angling, camping and picnicking
Stocking Group Name: Taroom Fishing and Restocking Club

Stocking Summary		**Total Cost**	
Silver Perch	72 612	Government	$21 734
Golden Perch	31 000	Group	$4 350
Sleepy Cod	3 430		

Theodore Weir

Impoundment Specifications
River: Dawson
Nearest Town: Theodore
Impoundment Owner: Queensland Water Resources Commission
Wall Height: 7 metres
Recreation Facilities: Boat ramp, BBQ's, picnic shelters, toilets
Recreation Use: Skiing, picnicking, angling and no camping
Stocking Group Name: Theodore Weir Fish Stocking Group

Stocking Summary		Total Cost	
Silver Perch	14 500	Government	$2 750
Golden Perch	7 000	Group	$5 200
Sleepy Cod	6 500		

Moura Weir

Impoundment Specifications
River: Dawson
Nearest Town: Moura
Impoundment Owner: Queensland Water Resources Commission
Recreation Facilities: Boat ramp, picnic shelters, toilets
Recreation Use: Skiing, picnicking, angling and no camping
Stocking Group Name: Theodore Fish Stocking Association

Stocking Summary		Total Cost	
Silver Perch	24 704	Government	$6 404
Golden Perch	4 348		

Neville Hewitt Weir

Impoundment Specifications
River: Dawson
Nearest Town: Baralaba
Impoundment Owner: Queensland Water Resources Commission
Recreational Facilities: Boat ramp, toilets, picnic shelters and BBQ's
Recreational Use: Skiing, picnicking, angling and camping
Stocking Group Name: Baralaba Recreation and Fish Stocking Group

Stocking Summary		Total Cost	
Golden Perch	35 524	Government	$9 375
Silver Perch	8 670	Group	$150

Fairbairn Dam

Impoundment Specifications
River: Nogoa
Nearest Town: Emerald
Impoundment Owner: Queensland Water Resources Commission
Recreational Facilities: Boat ramp, picnic shelter sheds, BBQ's, toilets, ski club, sailing club, Water Safety Council Centre and commercial camping and caravan park
Recreational Use: Skiing, sailing, swimming, angling, picnicking and camping
Stocking Group Name: Fairbairn Dam Fish Stocking Group

Stocking Summary		Total Cost	
Silver Perch	161 210	Government	$48 200
Murray Cod	80 500	Group	$50 650
Saratoga	100		

Bundoora Dam

Impoundment Specifications
River: German Creek
Nearest Town: Middlemount
Impounded Owner: Capricorn Coal
Recreation Facilities: Boat ramp, BBQ's, picnic shelter sheds, toilets
Recreation Use: Skiing, sailing, picnicking, angling and camping
Stocking Group Name: Bundoora Recreational Fish Restocking Association

Stocking Summary		Total Cost	
Silver Perch	25 295	Government	$15 109
Golden Perch	19 625	Group	$1 000
Sleepy Cod	1 000		
Saratoga	20		

Theresa Creek Dam

Impoundment Specifications
River: Theresa Creek
Nearest Town: Clermont
Impoundment Owner: Belyando Shire Council
Recreational Facilities: Boat ramp, picnic shelter sheds, BBQ's, ski club and toilets
Recreational Use: Skiing, sailing, angling and no camping
Stocking Group Name: Theresa Creek Dam Fish Management Committee

Stocking Summary		**Total Cost**	
Silver Perch	36 242	Government	$13 783
Golden Perch	17 688	Shire Council	$2 000
Tandanus	1 000		
Saratoga	20		

Succession of assemblages of intertidal invertebrates following the January, 1991 Fitzroy River Flood

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Abstract

During January, 1991 a rain depression in the aftermath of Tropical Cyclone Joy caused a record flooding of the Fitzroy River. Southeasterly winds drove the freshwater plume inshore and northward into Keppel Bay. Very low surface water salinities (between 5 and 12 ppk) were recorded at mainland stations during the period 7 to 19 January. The layer of low salinity water was at least 2 m in depth (O'Neill _et al._, 1992; Brodie and Mitchell, 1992). Mortality of sessile intertidal invertebrates was primarily a function of the duration of exposure to the low salinity layer. Within the tidal height interval between Mean Low Water Springs and Mean High Water Neaps 95% of sessile invertebrates (barnacles and oysters) were killed. Gastropods varied in their ability to survive the low salinity water. Permanent quadrats were established on natural substrate at 4 mainland sites and 1 island site to study the succession of sessile animals on substrate cleared by the flood. At all sites opportunistic green algae first recolonized the substrate. This gave way to dense covers of newly recruited barnacles and oysters. The first sessile invertebrates to recolonize the quadrats were "early successional" forms with generally high recruitment and short life spans. Thereafter succession progressed differently at different sites. After 19 months the invertebrate assemblages of some sites had returned to their previous states in which "late successional" species predominated. However, at other sites new assemblages, consisting of early successional species and species formerly not present at the sites, have persisted. The unpredictability of succession in natural environments is of relevance to natural resource management.

Introduction

On 26 December, 1990 Tropical Cyclone Joy crossed the Queensland coast near Ayr. The resultant heavy rainfall in the northern parts of the Fitzroy catchment caused record flooding of the Fitzroy River (Baddily, 1992). Primarily southeasterly winds during the period from 28 December to 18 January caused the freshwater plume exiting from the mouth of the Fitzroy to spread mainly inshore and northward into the Keppel Bay area (O'Neill, _et al._, 1992). The resultant dilution of the surface waters of

Keppel Bay was expected to have devastating effects on benthic intertidal organisms in this area.

Previous to the flood I had carried out surveys of the intertidal at 5 sites in Keppel Bay. These data were compared with those from surveys of the same sites following the flood. Further, sets of permanent quadrats had been established at each of the sites previous to the flood. Periodic observations of these, and of the wider habitat in which they were located, were made during the period of greatest freshwater dilution.

The study of succession after a disturbance is important from both practical and theoretical standpoints. Succession is being monitored at 5 sites within Keppel Bay and addresses questions relevant to the local environment such as: what is the nature of succession in these communities; will recovery be complete, in the sense that the communities will come back to what they were before the flood; and what is the time course of succession? All of these questions require long term monitoring and only partial answers can be given at this stage, but it appears that complete recovery will require many years, even in the absence of any further wide spread disturbance.

The ecological theory of succession, is an area of active research (see Connell and Slatyer, 1977; and more recently Farrell, 1991 and Caswell and Cohen, 1991 for reviews and models). Early successional species are defined as having the following characteristics: short lived, short generation time, rapid and dense recruitment, and low growth to propagule production ratio. Characteristics of late successional species are: long lived, long generation time, sparse recruitment and high growth to propagule production ratio. Connell and Slatyer (1977) proposed that succession can occur according to one of three models: facilitation, inhibition or tolerance. In facilitation early successional species alter the environment so that it becomes more favourable for late successional species which then replace the early species. In inhibition the early successional species inhibit the establishment of late successional species and the result can either be no replacement, or replacement, of early by late successional species, depending on the relative rates of recruitment and survival of early and late species. In tolerance the early successional species has no effect on the colonization of the late successional species and the late successional species eventually replaces the early one because it is more tolerant of the reduction of resources accompanying colonization.

The investigations I have carried out indicate that species fitting the characteristics of both early and late successional species occur in the intertidal assemblages in Keppel Bay and that inhibition is the predominant model of succession. However the outcome of succession at different sites, even when the same species were involved, was not predictable in the short term (19 months).

In this paper I have limited discussion mainly to the sessile species of the intertidal habitat. These species occupy the surface and determine the general character of the assemblage or community.

Methods

Study sites

The locations of the study sites are shown in Fig. 1. All sites were located within the intertidal on rocky substrate. All sites faced in a northeasterly direction and thus are classified as open, rather than sheltered coast.

Observations during the flood

Prior to the flood (8/2/90, 20/7/90 and 20/7/90, respectively) 4 0.04 m^2 permanent quadrats at each site were established at Wave Point, Emu Point and Rocky Point in order to study long term changes in the intertidal communities. The corners of the quadrats were marked with screws driven into the rock. The quadrats were established within a zone dominated by the barnacle Tetraclita squamosa, which occurred between about 0.5 to 3 m above MLWS (mean low water springs). Permanent quadrats were spaced at a horizontal distance of 4 m.

Between 7/1/91 and 17/2/91 there occurred a continuous freshwater dilution of the surface waters of Keppel Bay (Coates, unpublished obs.). During this period the numbers of macroinvertebrates, and estimates of percent cover of algae and sessile macroinvertebrates (using clear plastic overlays with 100 regularly spaced dots), within permanent quadrats were made at each site at approximately weekly intervals. Observations of the wider habitat of each site were also made during each visit.

Surveys before and after the flood

Four of the sites; Pleasant Island, Waterpark Point, Wave Point and Wreck Point were surveyed by vertical transects, during spring low tides, before and after the January, 1991 Fitzroy River flood. The survey dates were: 6/90 and 3/91, 2/90 and 3/91, 8/89 and 4/91 and 9/90 and 5/91, respectively. On each date 4 vertical transects (6 at Wreck Point) were set 4 (2 at Wreck Point) metres apart and 0.04 m_2 quadrats were placed at 1 metre intervals along each transect. The bottom quadrat of each transect was placed at the water's edge and the time noted so that the estimated height of the first quadrat above MLWS could be calculated using the Queensland Official Tide Tables, with Gladstone as the standard port and Rosslyn Bay as the secondary place. The height of each subsequent quadrat above the previous one was estimated using a measuring stick and level. All macroinvertebrates within each quadrat, except those deep within crevices, were counted in the field or from photographs. Percen. cover of the categories algae, barnacles and oysters were estimated using clear plastic overlays with 100 regularly spaced dots. The data from each survey were pooled within 0.5 m tidal height intervals relative to MLWS.

At the sites Wave Point, Emu Point and Rocky Point numbers of the barnacle _Tetraclita squamosa_, were estimated from 50 0.04 m^2 quadrats placed randomly within the _T. squamosa_ zone before and after the flood (Table 1).

Succession in permanent quadrats

At Wave Point, Emu Point and Rocky Point on 13/3/91, 14/3/91 and 14/3/91 respectively, cleared quadrats of the same size were established next to each original uncleared permanent quadrat and marked as before. Within the cleared quadrats all organisms were removed by scraping followed by scrubbing with a wire brush. In all cases no further manipulation of any of the quadrats occurred.

At Pleasant Island and Waterpark Point, previous to the flood, there were distinct zones of the barnacles _Tesseropora rosea_ and _Tetraclita squamosa_, with the _T. squamosa_ zone being above the _T rosea_ zone at Pleasant Island and below it at Waterpark Point. On 27/3/91 and 11/5/91, respectively, four cleared quadrats, with adjacent uncleared control quadrats, were established within each zone at each site. The pairs of cleared and uncleared quadrats were set 4 m apart horizontally. No further manipulation of any of the quadrats was carried out.

At various times the sites were revisited and all macroinvertebrates counted and the percent cover of algae and sessile invertebrates within quadrats estimated as above.

Results

Observations during the flood

On 10/1/91 50 - 60 % of barnacles and 20 - 70 % of oysters living within the permanent quadrats previous to the flood at Wave Point, Emu Point and Rocky Point had died. By 20/1/91 90 -100 % of the original barnacles and oysters within permanent quadrats were dead. During this period it was observed that barnacles and oysters lower on the shore, or within tide pools, died before those higher on the shore or not in tide pools. Also during this period species of gastropods which occur in the low to m intertidal region (approximately 0 - 2.5 m above MLWS) such as: _Siphonaria spp._, _Chiazacmea spp._, _Pateloida spp._, _Planaxis sulcatus_, _Thais kieneri_, _Morula marginalba_ and chitons were observed dead or in a weakened state, whereas high intertidal (approximately 2.5 - 6 m above MLWS) species such as

Nodilittorina millegrana and N. pyramidalis were not effected (Coates, unpublished obs.).

Surveys before and after the flood

Figures 2 - 4 show the percent cover of the most common barnacle species at different tidal height intervals relative to MLWS, before and after the flood at 3 sites.

The before and after patterns for Wave Point (Fig. 2A and B) were typical for the mainland/intermediate wave exposure sites (Wave Point and Wreck Point) with heavy mortality of barnacles occurring between 0 to 2.5 m above MLWS. The loss of the barnacle Chthamalus sp. from the high intertidal interval, 5 to 5.5 m above MLWS, was probably not a result of flooding as barnacles at this level were observed to be unaffected during the period of greatest freshwater dilution.

The loss of T. squamosa from 3 mainland/intermediate wave exposure sites was further documented by measurements of abundance in 50 random quadrats within the T. squamosa zone before and after the flood (Table 1).

A striking feature of Figs. 3A and B (Pleasant Island) is the high % cover of Tesseropora rosea post flood in the tidal height interval of about .5 to 3 m above MLWS. This is due to heavy recruitment of this species at these heights during April/May (Coates, pers. obs.). Although not shown in Fig. 3, considerable mortality of larger, presumably older, T. rosea had occurred at this site, as evidenced by the number of empty tests observed during the post flood survey. Mortality of Tetraclita squamosa had occurred in the tidal height interval from about 2 to 3 m above MLWS. There was little apparent mortality of T. squamosa between above 3 m MLWS.

Comparison of Figs. 4A and B (Waterpark Point) shows a great mortality of T. squamosa between about -.5 to 3.5 m above MLWS. There was a decrease in T. rosea coverage in all tidal height intervals where they occurred previous to the flood.

Succession in permanent quadrats

Figure 5A, B and C shows succession in cleared quadrats at 3 mainland/intermediate wave exposure sites. At all sites green algae, primarily Ulva sp., colonized the bare substrate shortly after clearing, reaching a total coverage of about 16 - 25%, and persisted for about 3 - 4 months. Following this succession proceeded differently at the three sites.

At Wave Point there was a brief recruitment by the barnacle Hexaminius popeiana, which soon disappeared. Oysters, both Crassostrea amasa and C. echinata, built up to about 25% coverage of the substrate but were virtually all eliminated by the time of the last observation (9/7/92), and judging by their small size, apparently never achieved sexual maturity. During the first months of 1992 Ulva again occupied from about 10 to 18 percent of the substrate, on average, but had disappeared by the time of the last observation. During all of this time there was a slow accumulation of the Tetraclita squamosa, which by the time of the last observation at this site occupied about 3 percent of the substrate with few other sessile species evident (Fig. 5A). Chthamalus sp., although present at this site, never occupied more than 1 to 2 % of the substrate during this study.

At Emu Point after an initial colonization and decline of Ulva sp. there was some minor, temporary recruitment of H. popeiana and eventually a massive colonization by the barnacle Chthamalus sp., which by the last observation at this site (1/7/92) occupied about 90% of the substrate (Fig. 5B).

At Rocky Point there was a temporary colonization by H. popeiana, which overlapped with the initial built up Ulva sp.. H. popeiana reached about 30% cover and persisted through the winter of 1991; but by the summer of 1992 it had virtually disappeared from this site. Chthamalus sp. and another barnacle, not previously seen at this site, Tesseropora rosea, began recruiting into the quadrats in late winter of 1991. By the time of the last observation at this site (1/7/92) Chthamalus sp. occupied about 60% of the substrate, T. rosea about 16% and algae about 6% (Fig 5C).

In the quadrats established within the T. squamosa zone at Pleasant Island there was an initial recruitment of Tesseropora rosea; however, this species did not survive in this area and coverage by T. squamosa was gradually increasing at the time of the last observation (30/4/92) (Fig. 6A).

Within the T. rosea zone at Pleasant Island T. rosea coverage had rapidly increased up to 75% by 6/11/91. At 30/4/92 coverage by living T. rosea had decreased to about 38%. However, the tests of dead animals occupied another 32% so the available bare substrate was only about 30%. Almost no recruitment of Tetraclita squamosa was observed in this area (Fig. 6B).

At Water Park Point T. rosea had colonized up to 41.5 and 48% of the substrate in the T. squamosa and T. rosea zones, respectively, by the time of the last observation on 29/8/92 (Fig. 7A and B). Available bare substrate in the T. squamosa and T. rosea zones was about 46 and 35%, respectively, at the last observation. Recruitment of T. squamosa was very sparse in both zones at this site.

Discussion

Effects of the January, 1991 Fitzroy river flood

The fresh water plume issuing from the mouth of the Fitzroy river spread into Keppel Bay as a layer of at least 2 m in depth (Brodie and Mitchell, 1992). From the Official Queensland tide tables it was calculated that during the 312 hour period from 7/1/91 to 19/1/91, when the salinity of shoreline surface waters ranged from 9 to 12 ppk, tidal heights between -1.0 to 2.5 m relative to MLWS, experienced the most prolonged exposure to low salinity water, with the peak exposure at about 0.5 m relative to MLWS (Coates, unpublished obs.)

Prior to the flood the midshore areas (1 to 3.5 m above MLWS) of the mainland/intermediate wave exposure sites Wave Point, Wreck Point, Emu Point and Rocky Point, were characterized by stands of the barnacle Tetraclita squamosa with patches of the barnacle H. popeiana and a few rock oysters scattered amongst them. As a result of the flood these stands of T. squamosa, as well as H. popeiana and other sessile species, were virtually eliminated from between 0 to 2.5 m above MLWS leaving a landscape of bare substrate, with a few scattered T. squamosa surviving in the midshore region. Above this tidal level survival of sessile species was not affected by the flood.

At the high wave exposure sites, Pleasant Island and Waterpark Point, by both Tesseropora rosea and Tetraclita squamosa suffered heavy mortality in the tidal height interval between 0 to 3 m above MLWS. Mortality probably extended higher in the intertidal at higher wave exposure sites due to the increase in effective tidal height, during the period of freshwater dilution, caused by southeasterly wind driven waves.

At the time of the postflood survey of Pleasant Island, T. squamosa had not recovered, but heavy recruitment of T. rosea had resulted in coverage of the substrate by this species equal to that before the flood.

At the mainland/exposed site, Waterpark Point, at the time of the post flood survey neither species had shown much recovery.

Succession in permanent quadrats

Previous to the flood the sites Wave Point, Emu Point and Rocky Point were classified as the same habitat type on the basis of both physical characteristics, such as wave force and location, and assemblages of species (Coates, unpublished obs.). At these sites the facies of the zone between 0 to 2.5 m above MLWS was determined by the barnacle Tetraclita squamosa.

T. squamosa is a classic late successional species, with long life span, rapid growth to a large size, low and patchy recruitment and high survival rate (Hines, 1979). Chthamalus sp., Hexaminius popeiana and Tesseropora rosea all have the characteristics of early successional species with short life spans, relatively slow growth (although T. rosea has an intermediate growth rate), abundant recruitment and relatively low survival.

It was expected that succession would result in the reestablishment of a *T. squamosa* zone at all three sites. It may do so in the long term. However, after 19 months Wave Point is the only site showing any tendency for this to occur. At this site the recruitment and survival of other sessile species has been poor and *T. squamosa* is gradually accumulating, although at last observation had reached only 10% of its original level of coverage.

At Emu Point and Rocky Point recruitment and survival of early successional species has been high and it appears that recruitment by *T. squamosa* has been inhibited by lack of bare substrate. It is interesting that although observed only rarely at this site previous to the flood, *T. rosea* had recruited substantially at Rocky Point.

Previous to the flood the Pleasant Island and Waterpark Point sites were classified as belonging to the same, high wave exposure, habitat type. Both had distinct zones of *T. squamosa* and *T. rosea*. A likely prediction was that succession would result in the reestablishment of both zones in their original tidal intervals. At Pleasant Island this indeed appears to be happening. Although there was some early recruitment of *T. rosea* in the original *T. squamosa* zone, survival of *T. rosea* has been poor and *T. squamosa* is recolonizing the quadrats. Within the original *T. rosea* zone recruitment of *T. rosea* has been very heavy and although considerable mortality of this species occurred during the summer months, little bare substrate was available due to the accumulation of the tests of dead *T. rosea*.

At Waterpark Point, however, *T. rosea* has recruited and survived well in both the original *T. squamosa* and *T. rosea* zones. Recruitment of *T. squamosa* has been very sparse in both zones.

The data from the succession studies are consistent with the inhibition model of succession, with varying levels of recruitment and/or survival of early successional species amongst sites and levels on the shore. Experimental manipulations, such as selective removal of early successional species, are required to confirm this preliminary conclusion.

An interesting result of the succession studies is that succession has progressed differently within different sites, even though these sites are of the same habitat type and have the same suite of species. This emphasizes that although a common model of succession may be in operation, the result of succession remains unpredictable due to site specific variations in the recruitment and/or survival of either early or late successional species. The general relevance of this finding is that habitats do not automatically recover, or "come back", to their original state following the cessation of disturbance. This is an important realization for managers of natural resources.

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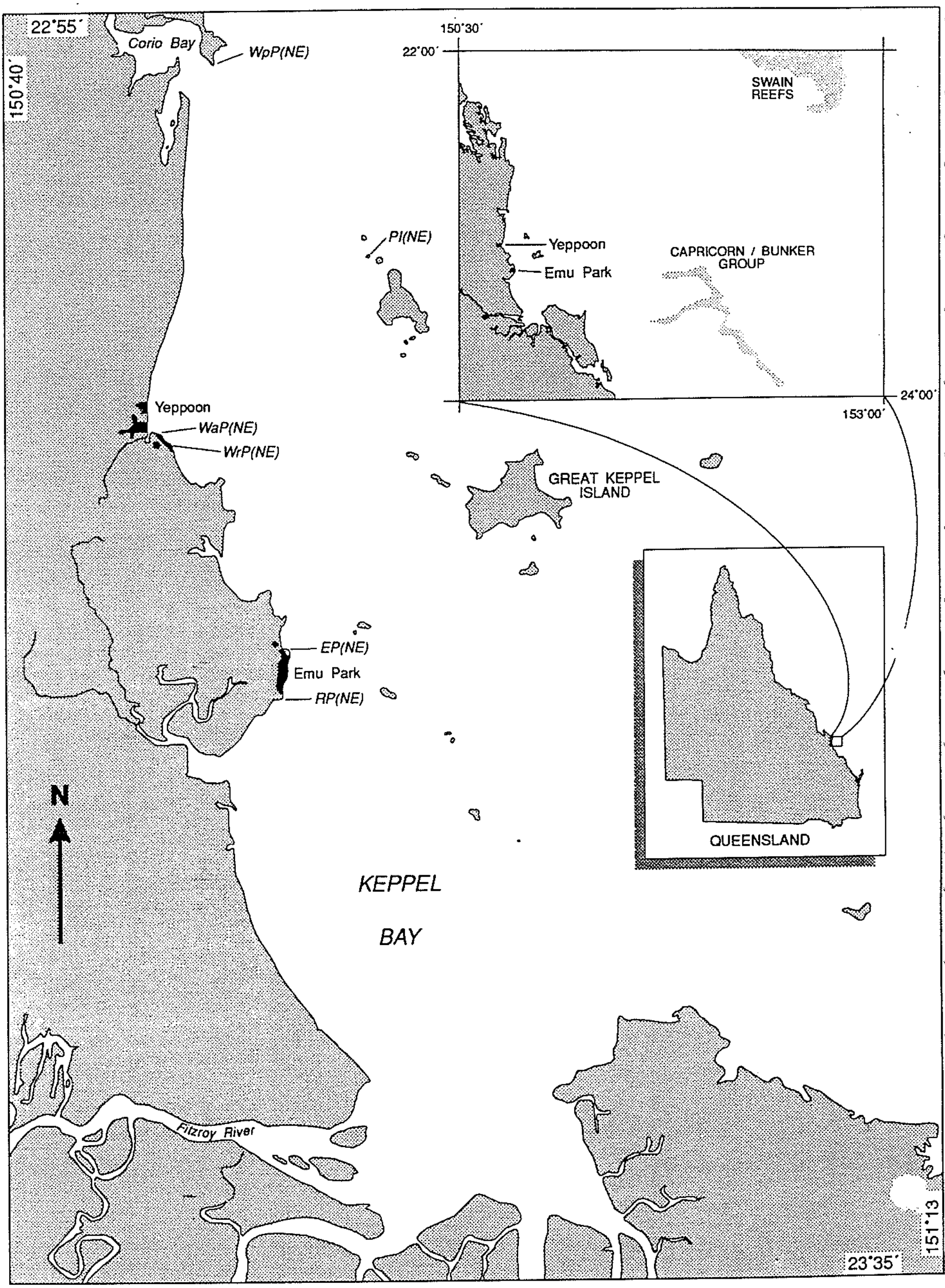


Figure 1. Study sites within Keppel Bay. PI(NE) = Pleasant Island; WpP(NE) = Waterpark Point; WaP(NE) = Wave Point; WrP(NE) = Wreck Point; EP(NE) = Emu Point; RP(NE) = Rocky Point.

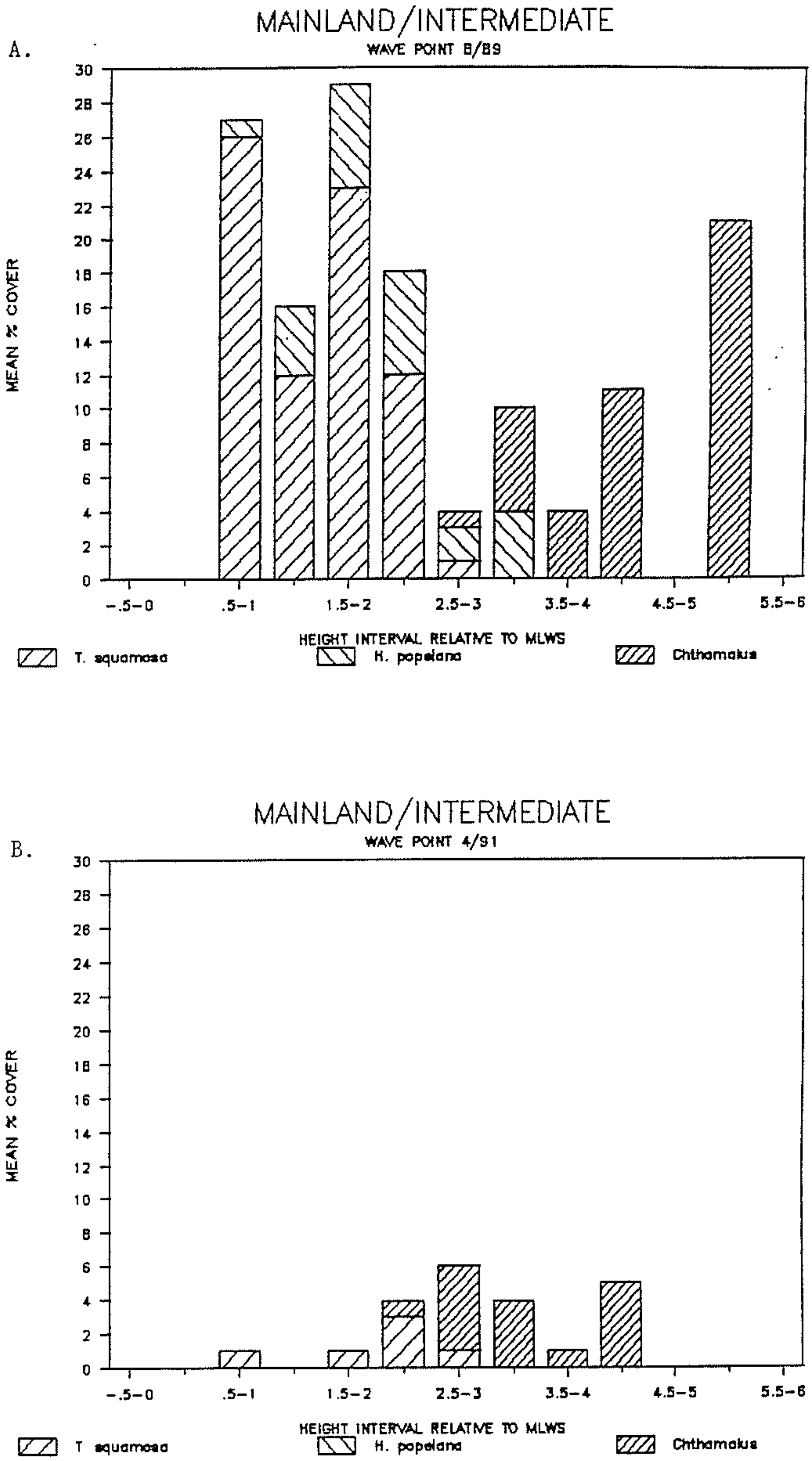
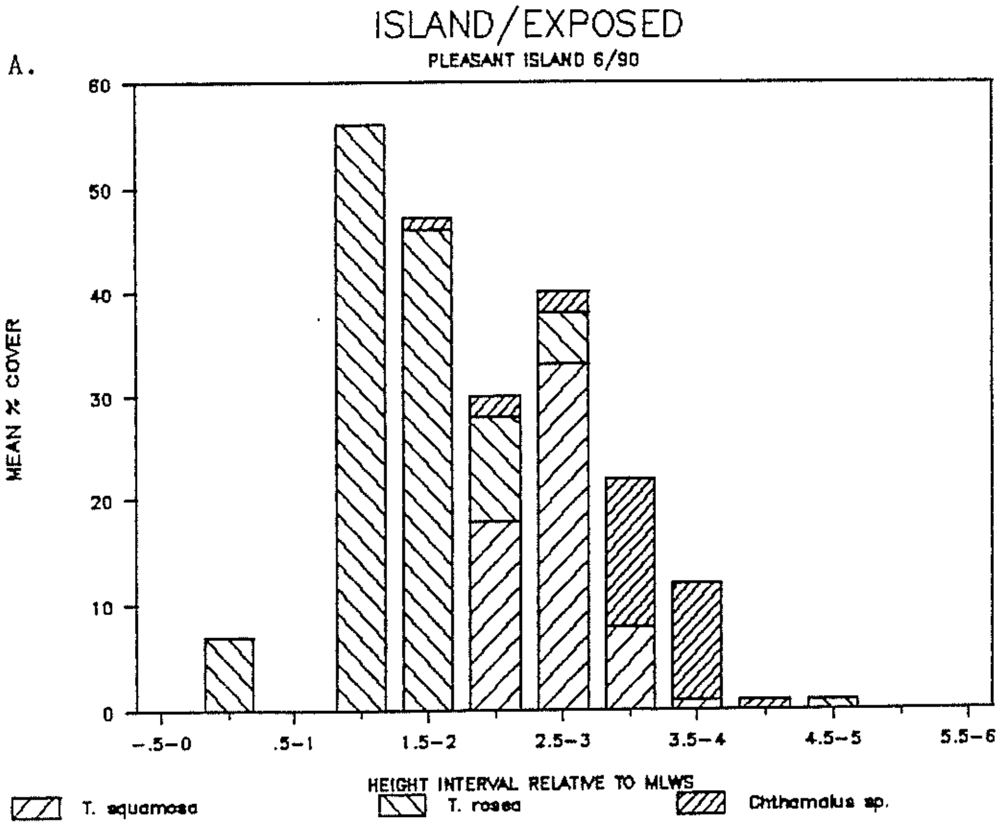


Figure 2. Mean % cover of most common barnacle species at Wave Point.
A. before January, 1991 Fitzroy River flood; B. after flood.

A.



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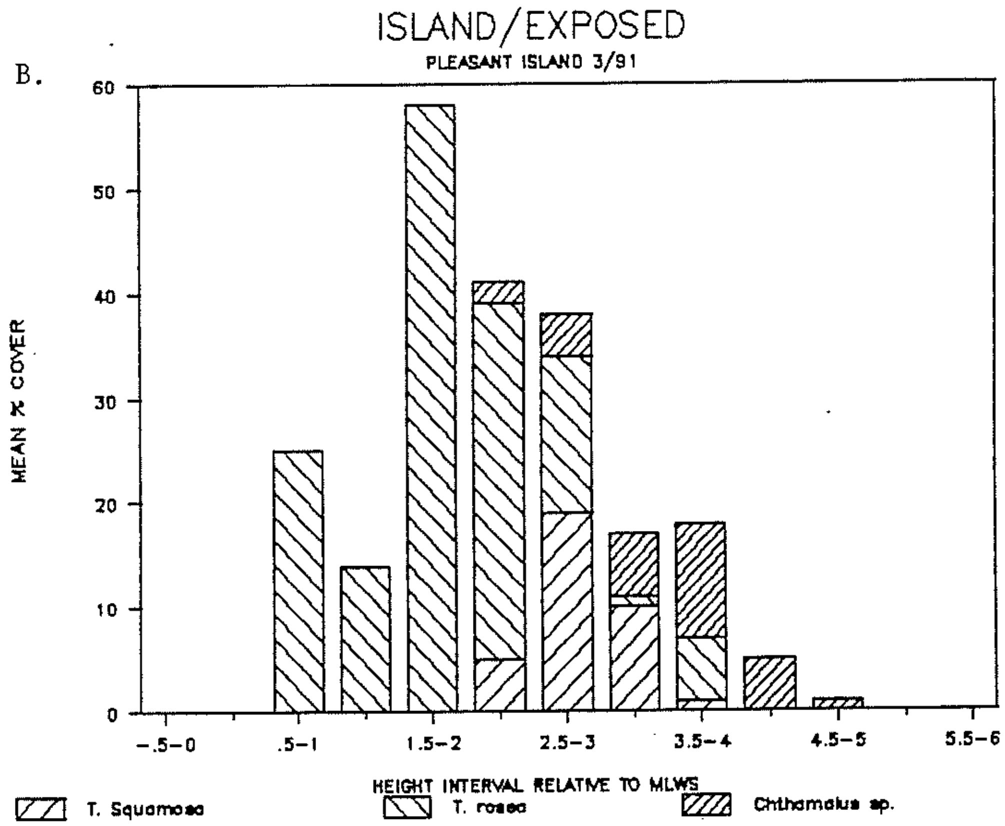
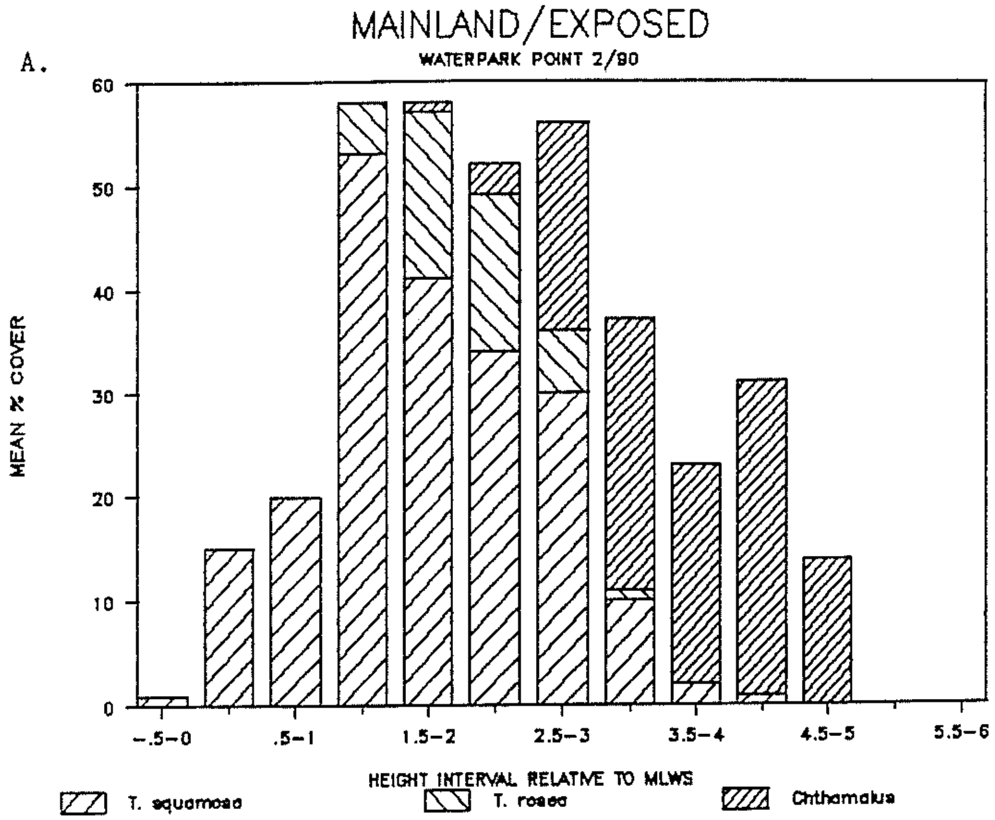


Figure 3. Mean % cover of most common barnacle species at Pleasant Island. A. before January, 1991 Fitzroy River flood; B. after flood.

A.



B.

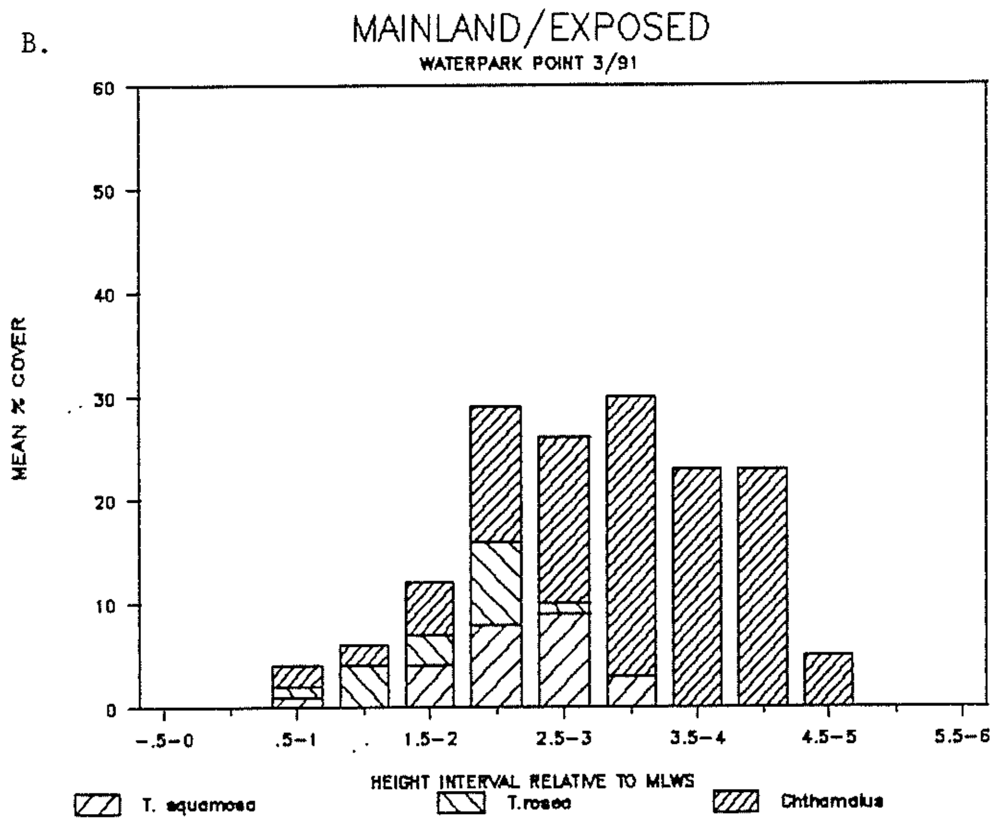
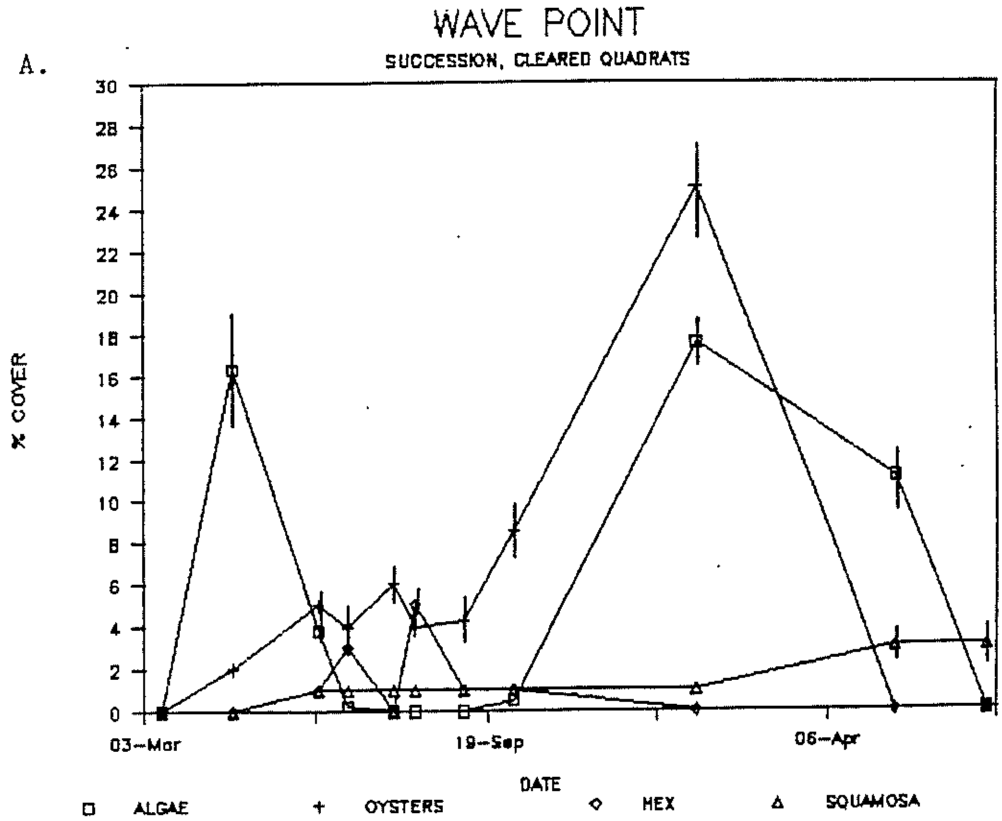
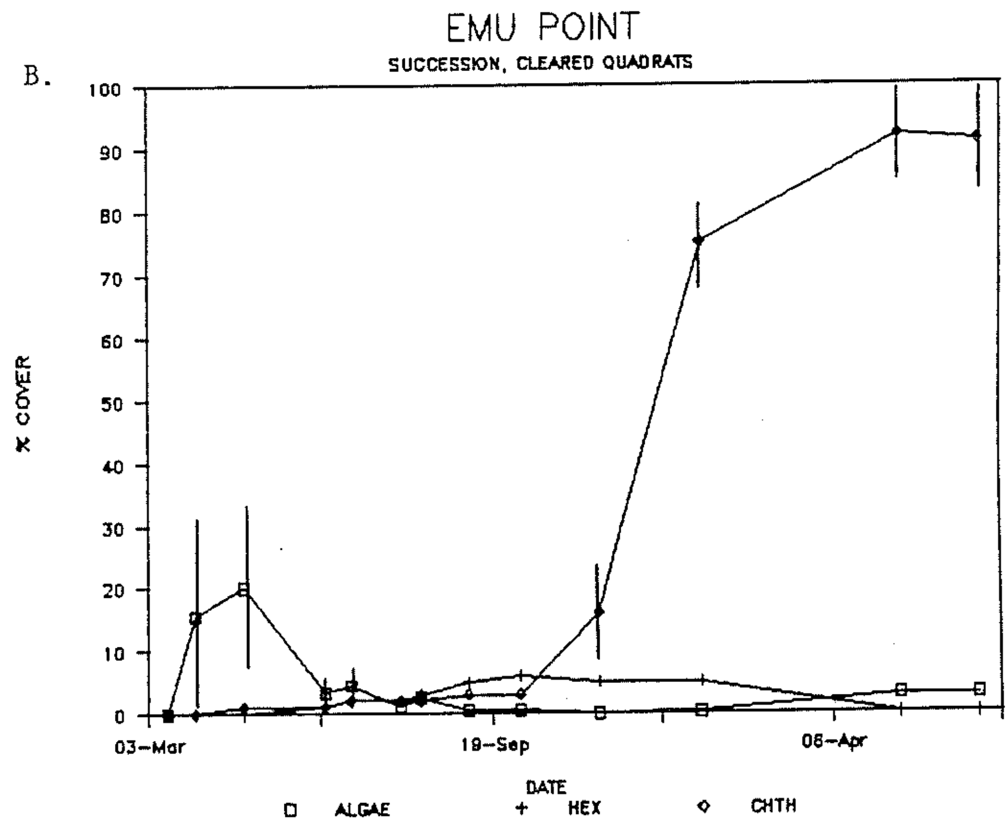


Figure 4. Mean % cover of most common barnacle species at Waterpark Point.
A. before January, 1991 Fitzroy river flood; B. after flood.

A.


WAVE POINT
SUCCESSION, CLEARED QUADRATS
% COVER
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
03-Mar
19-Sep
06-Apr
DATE
ALGAE
OYSTERS
HEX
SQUAMOSA

B.


EMU POINT
SUCCESSION, CLEARED QUADRATS
% COVER
100
90
80
70
60
50
40
30
20
10
0
03-Mar
19-Sep
06-Apr
DATE
ALGAE
HEX
CHTH

C.

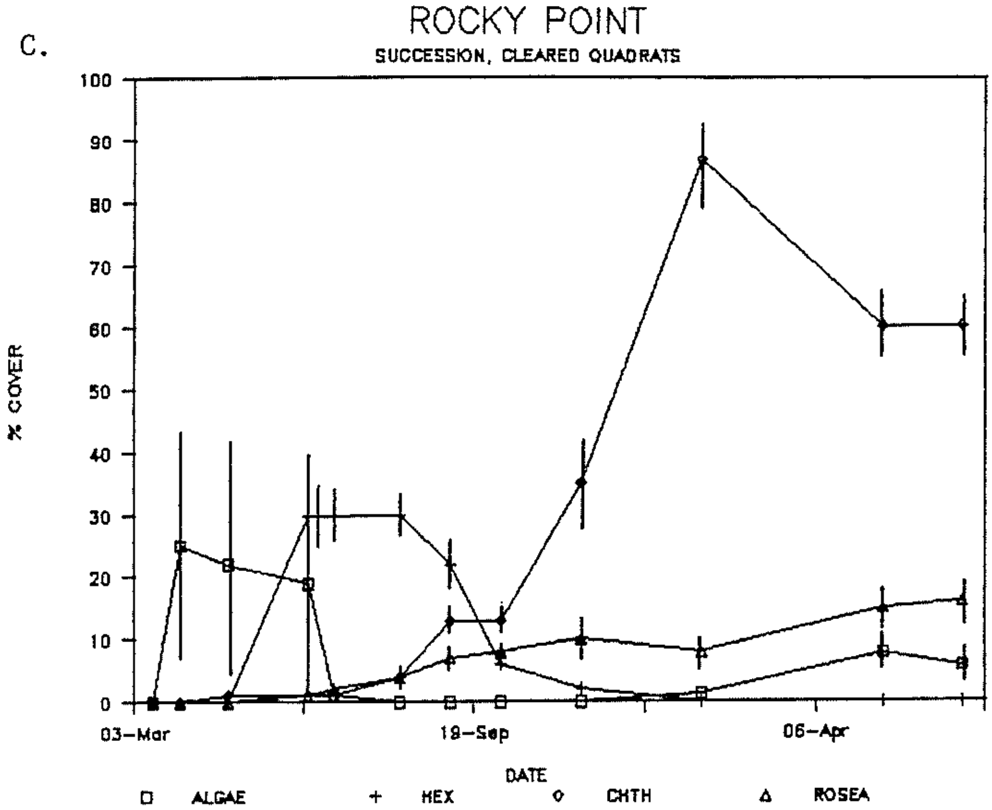
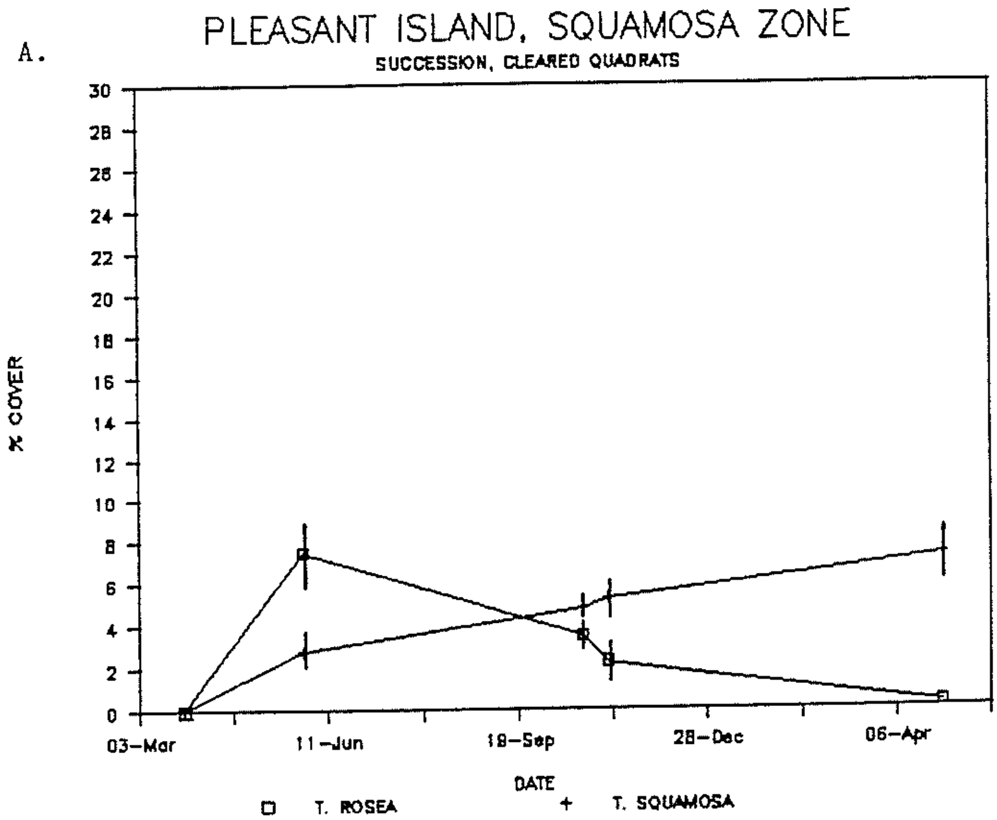


Figure 5. Succession in cleared quadrats at three mainland/intermediate wave exposure sites following the January, 1991 Fitzroy River flood. HEX = Hexaminius popeiana; SQUAMOSA = Tetraclita squamosa; CHTH = Chthamalus sp.; ROSEA = Tesseropora rosea. %cover means and standard errors from 4 quadrats are shown.

A.



B.

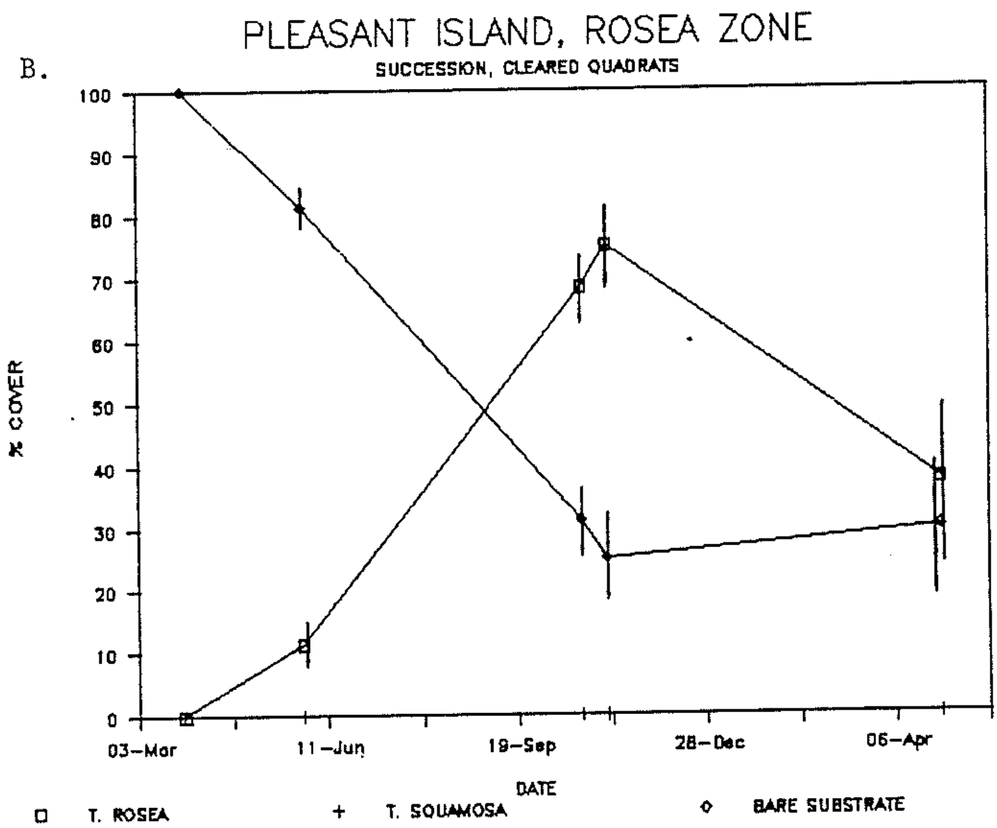
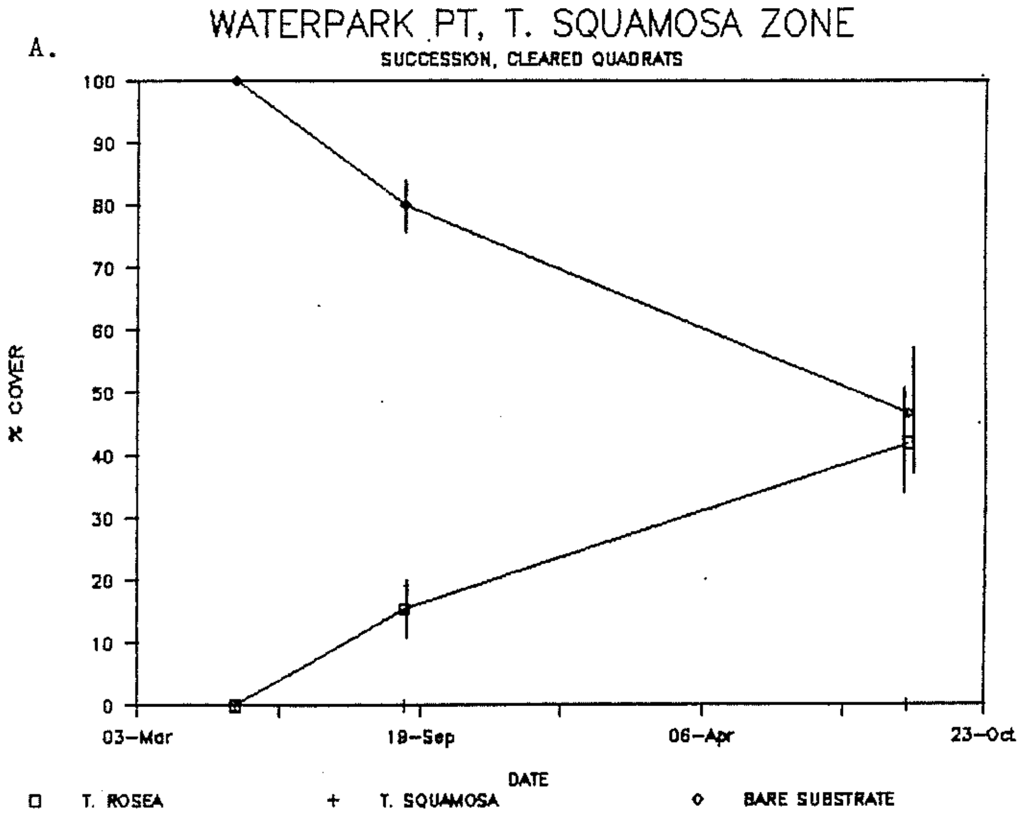


Figure 6. Succession in cleared quadrats within the T. squamosa and T. rosea zones at Pleasant Island following the January, 1991 Fitzroy River flood. % cover mens and standard errors from 4 quadrats are shown.

A.



B.

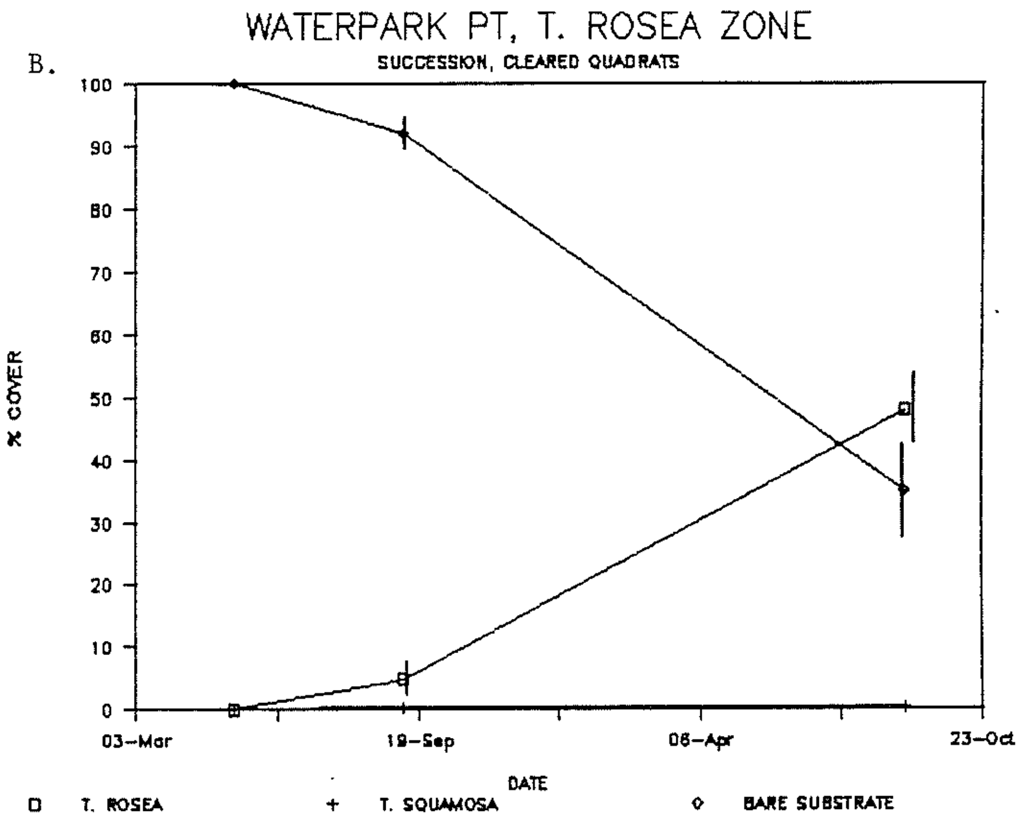


Figure 7. Succession in cleared quadrats within the *T. squamosa* and *T. rosea* zones at Waterpark Point following the January, 1991 Fitzroy River flood. % cover means and standard errors from 4 quadrats are shown.

SETTLEMENT AND DEVELOPMENT OF THE FITZROY REGION

INTRODUCTION

The lands of the Fitzroy region provided sustenance and, at times, plenteous food for the Aboriginal people for about 40,000 years. While they were true conservationists, taking only what they needed for each day, they also brought changes to the land through the use of the firestick. The arrival and settlement of Europeans in the 1850s and 1860s 'speeded up' this process. Land use in the 130 years since then has gone through many changes. Initially the region's wealth came from wool and gold, but within a decade beef cattle had replaced sheep in coastal areas. A century was to pass, however, before coal supplanted gold as the region's richest mineral.

After briefly outlining the origins of settlement and the significance of the Fitzroy River in the lives of the pioneers, an assessment is made of the most significant Land Acts 1860s-1960s in relation to the Fitzroy region.

Lorna McDonald

Historian

In May 1992 I stood on the north-eastern escarpment of the Razorback Range overlooking the wide Fitzroy River Valley and its river winding through the marine plains to Keppel Bay. This was almost the same scene that met the astonished gaze of Charles and William Archer on 4 May 1853 when they became the European discoverers of the Fitzroy River. Even today one's eyes are drawn to the river, the broad valley with its scattered lagoons and lush marine plains with the Berserker Range as backdrop. The man-made roads and distant provincial city appear insignificant. The Archers, loyal citizens of their adopted colony, followed tradition in naming the river to honour the Governor of NSW, but pleased themselves in bestowing the names of a legendary Norse hero on Mt Berserker and that of Charles Archer's favourite stallion on Mt Sleipner. This was a just reward for the steed which had carried Charles from the Burnett to the Fitzroy.

The first white men to travel through western parts of the Fitzroy catchment were the two exploration parties led by Ludwig Leichhardt. On his first expedtion, 1844-45, Leichhardt named the Dawson, Comet,Mackenzie and Isaac rivers as well an several creeks and the Peak Range. On his second abortive expedition in 1846-47, his party camped at the junction of the Comet and Mackenzie for about six weeks, suffering from what he called 'fever and ague'. As it was a very wet summer, it was undoubtedly a mosquito-borne disease such as Dengue fever or Ross (Comet) River fever! Sir Thomas Mitchell also entered the region briefly, giving the Nogoa its Aboriginal name in August 1846.

It was Leichhardt who told his friends the Archer brothers about the inland streams which he believed must form one large river to 'disembogue' in Keppel Bay. On that May day in 1853 they confirmed the accuracy of Leichhardt's assumption, but by that time the Fitzroy region's most famous explorer was lost somewhere in the inland with his party, never to be heard of again.

On their second expedtion to the Fitzroy in July-August 1853, Charles and Colin Archer followed the river to its junction with the Mackenzie and then detoured to Broadsound. It was Charles' description of the Fitzroy Valley, and Colin Archer's sketch map, in addition to Leichhardt's Journal, which persuaded the NSW government to open the region to pastoral settlement on 10 January 1854. The official map was based on Colin's sketch. The coastal country became the Port Curtis Pastoral District and the catchment areas the Leichhardt Pastoral District.

According to law, the two pastoral districts were proclaimed as unoccupied crown lands, even though thousands of Aborigines in half a dozen tribal groups had occupied the country for countless years. Each clan or family group claimed a particular area and there were clearly defined tribal limits. Because they frequently moved camp to take advantage of seasonal bounties or to avoid deficiencies, they were less affected by drought than the settlers 'fixed' in one location.

A steady stream of pastoralists trickled northwards through the Dawson Valley in the wake of the Archers. Numbers increased from 1858 when a gold rush to Canoona brought thousands of would-be diggers to the muddy banks of the Fitzroy at Rockhampton - a 'township' consisting of a store and a shanty pub. Merchants and tradesmen were hot on the heels of the diggers, also government officials to bring law and civilisation to the frontier. While the gold rush was dismissed as a 'duffer', it gave Rockhampton instant population which would otherwise have taken years to achieve.

The Fitzroy in 1858 also attracted more pastoralist explorers who rode westward to mark out crown leases for hopeful squatters. P.F. MacDonald was one young adventurer who almost lost his life in 1858-59 to take up crown leases in the Fitzroy basin - one or two for his own use, the rest as speculation. In the Springsure area he retained Fernlees for himself, but in 1861 sold Cullin-la-ringo to H.S. Wills of Victoria. Two weeks after Wills arrived with his large party, nineteen white men, women and children were brutally murdered within a few minutes. In the following weeks countless numbers of Aborigines were shot to give this tragic happening the dubious distinction of the worst of its kind in Australian history. The innocent, both black and white, suffered for the sins of district squatters who had driven the Aborigines from their clan lands and hunting grounds.

Despite the tragedy of racial conflict, there were also positive results from exploration and early settlement in the region. Without government assistance, graziers found routes across ranges, rivers and downs which in time became roads. Townships were established, especially along the railway that inched its way from Rockhampton to Emerald 1867-79, with branches to Clermont and Springsure in the 1880s.

In Rockhampton itself, firmly planted on both banks of the Fitzroy, the river was the artery which kept its heart beating from 1855 to 1903, when the railway from Brisbane reached the town. The river provided the only means of overseas, interstate and intrastate communication. Overseas passengers and goods were off-loaded in Keppel Bay on to river lighters which brought them to the town wharves on Quay Street. Wool from the inland was exported via the river, also gold in small quantities from 1858 and in massive amounts after the opening of the Mt Morgan Mine in 1882. Copper was added at the turn of the century.

It was black gold (coal) which attracted American and Japanese attention towards the region from the late 1950s. Coal was not a late discovery. Leichhardt observed it in the Mackenzie River in 1845 and a geological survey of the Fitzroy River in 1855 (from the river mouth to above Yaamba) reported good prospects for 'coal measures.' 'A considerable quantity' of coal was located near the Mackenzie River in 1868 (Blackwater) and a decade later at Tolmies. Blair Athol coal was pronounced 'the best in the world' and used by the railways in 1890, but only briefly. It was cheaper (they said) to bring it from Newcastle. Donald Fraser, a Rockhampton man, founded the Mammoth Coal Co. in 1911 and mined in the Blackwater area until the 1920s, but was unable to interest the railways. Mount Morgan Mine used Baralaba coal in the 1920s, but all the region's mines suffered the same fate until after the Second World War.

Thiess Bros. Pty Ltd began drilling at Blackwater in 1957, the beginning of the modern industry. While that company moved to Moura, the Utah Mining Company officially opened the Blackwater Mine, 11 May 1968. The dramatic developments since those small beginnings in the mighty Bowen Basin are part of contemporary history. Within a few years new towns su ch as Moranbah, Middlemount, Dysart and Tieri sprang up in the bush where for a century only cattle had roamed, and before that Aborigines and native fauna.

It took 300 million years for the growing plants of Gondwana Land to become the massive coal beds of the Bowen Basin. But in three short decades millions of tonnes of coal have been exported to feed industrial plants in Japan and other countries. Leichhardt would be astonished that his sighting of Mackenzie River coal could lead to such great economic, environmental and social changes within the Fitzroy River catchment.

While coal mining has brought the most dramatic changes to the region, more subtle changes came with land settlement. Despite man's moon walk and current space exploration which may land him on Mars, the collective feet of the human race are still frimly planted on the earth's surface. The earth provides our food, natural fibre clothing and most of the building materials for our housing. It has been said that:

> ...taking man's essential egotism into consideration, it is inevitable that land should assume an immense economic and political significance, becoming an eternal object of contention. (1)

This is certainly true of land legislation in Queensland, with almost every Land Act from the first in 1860 to recent times proving contentious.

When the first Queensland parliament sat in 1860, legislators were determined to avoid the earlier bitterness in southern colonies. The Unoccupied Crown Lands Act of 1860 (ignoring the indigenous people) did not please most squatters. The first applicant who provided details of location and boundaries (marked trees, physical features) received a licence to occupy blocks of not less than 25 square miles (6,475.5 hectares) and not more than 100 square miles. Each block had to be identified by name. Some of these were later adopted for townships, for example, Springsure, Emerald, Capella, Comet and Moranbah. Application for a 14 year lease could be made eighteen months later, provided each block was stocked to one-quarter of its capacity. This clause was supposed to deter speculators, but in fact merely obliged them to sell before licences expired. P.F. MacDonald with more than 40 blocks in the Leichhardt District, most on the Nogoa and Mackenzie, which had to be sold before their licences expired wrote to his brother in 1862:

> The late Land Bill compels us to stock every Run without delay and as you are perhaps aware I have still a few unstocked which I must make an effort to secure.... (2)

Unlike the southern colonies, the 1860 legislation allowed for 'agricultural reserves' in the vicinity of towns. An aspiring farmer could select from 40 to 320 acres (16.9 to 123.2 hectares) at the upset price of $2 an acre (.405 ha.). Even so, the minimum of 40 pounds ($80) was beyond the resources of many immigrants. Several years later they were encouraged to migrate from Britain through the issue of 'Land Orders' which assisted many to obtain their own selection. Beverley Kingston maintains that agricultural reserves were 'invented in a spirit of cautious compromise... typical of all land legislation in Queensland.' (3) This appears to be confirmed by the many Amendment Acts, 1860s-1960s.

The spirit of 'cautious compromise' certainly failed to impress a group of Central Queenslanders who in 1865 founded the Land League, to argue the case for lower fees. In the following year it published the

Land League Papers in an attempt to have freehold land made available to both farmers and graziers for 25 cents an acre. (The average weekly wage was then about $5 a week.) Archibald Archer, a member of the Land League, became Member for Rockhampton and one of the chief 'architects' of the Crown Lands Alienation Act of 1868. This gave the Crown the right to resume approximately half of each leasehold, but with compensating pre-emptive rights for the lessee. While most squatters deplored these resumptions which applied to the Port Curtis Pastoral District, the 1868 Act was a major piece of legislation which led to an 'explosion' in closer settlement. Some of today's leading cattlemen in the Fitzroy region are descended from dairy-farming selectors of the 1870s.

The twelve Land Acts of the 1860s, followed by ten more in the 1870s demonstrate the spirit of compromise, but it was the Crown Lands Act of 1884 which Bernays described in 1919 as 'perhaps the most important milestone' in land legislation to that time. (4) C.B. Dutton. an unusually liberal minded squatter from the Rolleston area of CQ, was instrumental in bringing radical change to the land laws. The Act of 1884 established a Land Board to administer the laws, resumed half of each surrendered crown lease and divided it into 'agricultural farms' and 'grazing farms.' Agricultural farms had a 50 year lease and the right to convert to freehold after ten years (later reduced to five). Small farms could be freeholded for 25 cents per acre (.404 ha.). Grazing farm leases were fixed at 30 years, subject ot periodical reassessment. Originally they were limited to 20,000 acres (809.372 ha.), later raised to 60,000 acres (2,428.116 ha.). Both types were required to be fenced or otherwise improved.

Legislators in the early 1900s demonstrated their readiness to meet specific needs. Three of those Acts had great relevance to the Fitzroy region. The Prickly Pear Selections Act of 1901 almost gave land to graziers in return for clearing the noxious cacti which by then choked the scrubs and even over-ran some roads. In the end it was eradicated, not by man's puny efforts, but ecological means - the cochineal insect and the cactoblastis. A laboratory set up at Gogango in 1925 bred and distributed eggs for attaching to the pear. A.G. Laurie of Westwood played an important role in that most successful experiment.

Again in 1902 another Crown Lands Act was introduced to assist landholders cope with the most disastrous drought in the history of eastern Australia. It killed 75 per cent of Queensland's cattle herd and up to 90 per cent in the Fitzroy region. Because of these great losses, all leases were extended - some up to 42 years.

The Lands Amendment Act of 1908 provided perpetual lease selections similar to agricultural farms, but with even lower rents. It was this or other acts of the Kidston government in those years which opened up the scrublands in the Fitzroy Valley to disadvantaged European migrants - mainly German. Rich scrublands in The Caves and Milman areas became a food bowl for Central Queensland.

The Disadvantaged Soldiers' Settlement Act of 1917, erected with the best of intentions, failed miserably in providing adequate living areas for returned servicemen in the Fitzroy region as throughout Australia. But later legislators did learn from the history of heartbreak and failure that land quality, climate and other environmental factors should dictate the extent of 'a living area.' Even so, it was not until the Brigalow and Other Lands Development Act of 1962 that a combination of scientific and economic research resulted in a realistic Act regarding living areas.

It seems that all eyes were turned towards Central Queensland following a report on post-war prospects for land utilisation. The initial outcome was the establishment of the Queensland British Food Corporation (1948) which commenced broad-acre grain production in the central highlands between Clermont and Springsure. It acquired 199,655 hectares, including the historic Peak Downs and Cullin-la-ringo stations. Although the Daniels family had grown wheat at Gindie as early as 1896, it was not a viable operation. Likewise dryland cotton crops in the Capella-Emerald areas failed miserably in the 1920s. While the QBF Corporation also failed after several years, the cause was a combination of poor seasons and bad management. Significantly, the scheme proved that wheat and oilseeds could be grown successfully on a broad scale in those rich cracking-clays. Land hungry farmers, mainly from the southern states, created a land-rush.

The attention focussed on ther Fitzroy catchment was not confined to the downs country. At the Queensland sitting of the federal government's Royal Commission on Pastoral Lands Settlement (1950) Colin Clark quoted Premier Hanlon: '... if we do not quickly settle all the available land in Queensland to its fullest capacity somebody else will come and do it for us.' (5) Clark believed the 'somebody' would be Asian. P.J. Skerman in his presidential address to the Queensland Branch, Australian Institute of Agricultural Scientists on 11 March 1953, estimated that two-thirds of the 9.3 million hectares in the brigalow belt remained 'untouched.' Hand clearing ventures during the 1930s when men were so desperate that they would wield the axe from daybreak to dark for not much more than 'tucker', made little impression on the scrub. It was the wartime introduction of the bulldozer which revolutionised scrub clearing. Some people saw it as equal in significance to the invention of the wheel.

The Queensland government,after a preliminary investigation of brigalow lands in the Fitzroy Basin proved positive, invited the Bureau of Agricultural Economics to assess the 3.8 million hectares in 1961-62. The Bureau's economic advice was so encouraging that the Brigalow and Other Lands Development Act (1962) followed immediately. This gave birth to the Fitzroy Basin Brigalow Land Devlopment Scheme. The region was initially divided into three zones identified as: Area I Dawson River west to Expedition Range; Area II Expedition Range west to Comet River; Area III Capricorn Highway north to Nebo. In 1965 the scheme was extended southwards to Wandoan and Injune and identified as Area IA. (6)

The Department of Lands showed great wisdom in appraising the carrying capacity of the Fitzroy Basin brigalow lands and then establishing adequate living areas for lessees. The blocks ranged from a minimum of 3.276 thousand hectares in Areas I, IA and II, to 12.141 thousand hectares in Area III. Approximately 2 million hectares south of the Capricorn Highway were within the scheme by 1965 and 2.4 million hectares north of the highway by 1968. Ballots for the first blocks in Area I were held in April and May 1963 and by September 1968 of the 142 blocks occupied, 103 were allotted by ballot and 37 sold at auction. The same pattern emerged north of the highway 1968-74.

While all brigalow settlers were faced with a variety of problems such as tin-shed dwellings, brigalow regrowth and, in 1974, the collapse of the beef cattle market, they were generally positive about its success. Beef cattle numbers increased from approximately 295,000 in 1962 to 750,000 vastly superior animals by 1979. As well as this huge increase in beef production, the scheme brought roads, schools, telephones and electricity to formerly sparsely populated,isolated areas. The Brigalow and Other Lands Act of 1962 reveals a rare example of statesmanship. The legislators looked ahead to the next generation instead of the next election.

Two great post-war developments, the production of environmentally adapted beef cattle and the Brigalow Scheme have combined to make Rockhampton on the Fitzroy River the beef capital of Australia. The Brigalow and Other Lands Act of 1962 might be ranked with the Land Acts of 1868 and 1884 as the most significant land legislation in Queensland, 1860s-1960s. In each of these Acts selectors were given a chance to become independent and, with hard work, produce food for domestic and overseas markets. Some of the region's most successful cattlemen are descended from 'struggling selectors' of the 1870s who began as dairy farmers and later converted to beef cattle. Some third generation Central Queenslanders drew blocks through the Fitzroy Basin Brigalow Land Development Scheme.

A century of land legislation and its application within the Fitzroy River catchment has shown land use change from mainly grazing to a more diverse pattern. Broadacre grain production and, since the Fairbairn Dam came into operation, irrigated cotton production in the Emerald district. In recent years a 'downside' has emerged: over-clearing of land has led to rising salt in some areas, erosion in others, and in brigalow soils in particular, a decline in soil fertility. As one landholder in Area IA commented:

> ... it is essentially country that grew brigalow in its natural state and if you remove it entirely you remove something that has been adding to the fertility of the soil over many, many generations.... (7)

Land Care groups are now tackling these and other problems caused by 130 years of land settlement in the Fitzroy region. This positive approach is to be commended, but past generations (including legislators) should not be castigated on the standards of the 1990s. We have the advantage of hindsight.

Land legislation will never please everyone. I believe that the conclusion reached in 1919 by parliamentary historian, C.A. Bernays, is as true today as it was then:

> Much has been done in our short history towards solving the problems of ideal land settlement. It is needless to say that much remains to be done, and that with the ever-changing conditions of the people, and the periodical seasonal trials that spring up, our land legislation must of necessity ever remain in a tentative condition. New conditions have constantly to be met; new difficulties have to be overcome, and not until the millennium arrives can the ideal be attained. (8)

Lorna McDonald.

ENDNOTES

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2. P.F. MacDonald to A.L. MacDonald, 4 Sep. 1862.
3. B.R. Kingston, 'The Search for and Alternative to Free Settlement in Queensland, 1859-66.' (Extract article from Queensland Heritage,nd.)
4. C.A. Bernays, Queensland Politics During Sixty (1859-1919) Years. Brisbane, 1919. p. 321.
5. Colin Clark, 'Land Settlement in Queensland'. Economic News, Vol. XIX, 1950, p.l.
6. Lorna McDonald, Cattle Country, Brisbane, Boolarong Press, 1988. pp. 160-70.
7. Bernays, op. cit., p.343.
8. Cattle Country, p. 181.

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An Overview of Nature Conservation in the Fitzroy Catchment - Protected Areas, Management Principles and Rare and Threatened Plants.

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Abstract

Nature is conserved on a series on National Park estates in the Fitzroy Catchment, and although these represent the 'jewels in the crown', there remains a community responsibility to ensure that the catchment's life support systems remain viable through the adoption of sustainable land-use practises off-estate. The new Nature Conservation Act provides the opportunity for land-holders to protect and retain areas of high conservation value through a system of nature refuges. Summaries of the existing protected areas and rare and threatened plant species are presented.

Introduction

Management of natural systems is based upon the premise that active management of those systems is firstly necessary and secondly practicable. Management in this context consists of action taken in the belief that they will contribute to the retention of whole or designated biota (Main 1987). A distinction therefore needs to be drawn between active management and simple protection.

This distinction was reinforced in the article by Chase (1987) entitled 'How to save our National Parks'. It refers to the US Parks Service whose recent management has apparently been based upon a protectionist philosophy. The article says in part; *'even though this protectionist philosophy - as an incarnation of the wilderness vision - receives strong support from conservationist public-interest groups, it alone is an inappropriate model for managing our national parks. Never complete ecosystems, these places have been radically altered by civilisation and are now tiny islands surrounded by a technological society. The eviction of Indians, the elimination of predators, the introduction of exotic plants and animals, and a century of fire control have thrown even the 'wildest' parks into ecological disequilibrium. And once a system has been truncated and thrown out of balance, it no longer has the capacity to restore itself...'*

A policy of protection therefore, will neither arrest further change nor ensure that all that happens is 'natural'. Rather, over time it will produce historically unprecedented conditions - an entirely new regime of fauna and flora - which we have not anticipated and which we will probably not like!

Nature Conservation in Queensland

New nature conservation legislation, *Nature Conservation Act 1992* (Qld. Gov. 1992), has been introduced into Queensland that sets out to provide a framework for the comprehensive conservation of nature rather than being strategy specific such as relating to the establishment and management of parks and protected areas. The act provides for eleven (11) classes of protected areas with specific management principles (see Table 1) allowing for more flexibility in their management.

The current extent, class, location and local authority of protected area estate in the Fitzroy River Catchment is listed in Table 2.

Much of the recent conflict on National Parks in Queensland has concerned, not so much the management of existing parks, as the establishment of new ones. Although it is now recognised that the often quoted figure of 4% of the State's landscape is being devoted to National Park is a rather arbitrary target, the demand for national park is likely to grow.

As argued by Fisher, Krutilla and Chicchetti (1972) and independently by Tisdell (1972), the value of natural areas is likely to rise faster than the value of the resources in alternative use. However, the basis for Queensland doubling its national park estate is maximising representation of the state's biodiversity. Significantly, the new act defines biodiversity in a comprehensive manner including recognition of ecosystem, landscape, species and genetic diversity.

Implementation of this program involving the acquisition of more than 3.6 M ha of land is being planned within a regional biogeographic framework.

Regional Biogeography

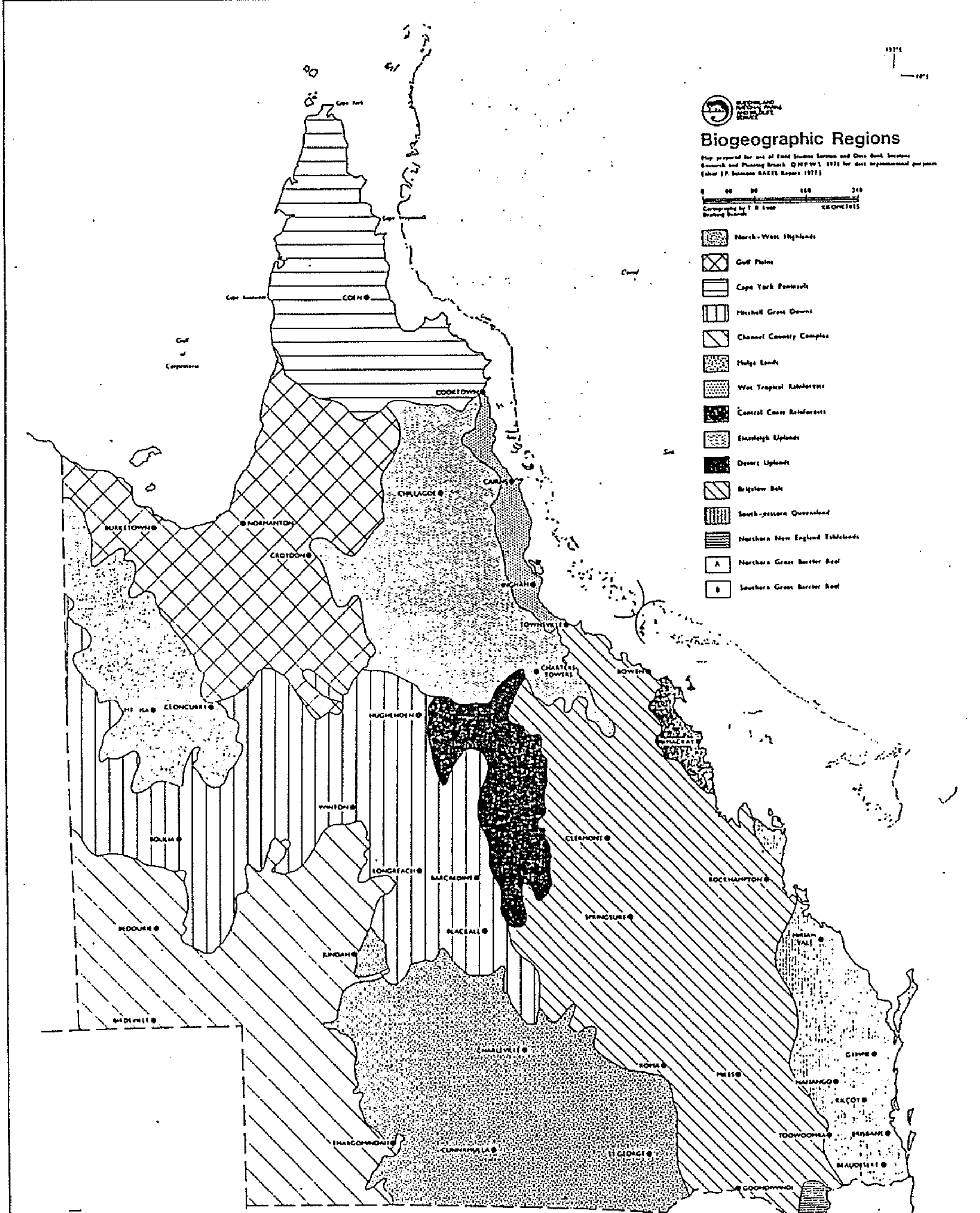
The first level is recognising Queensland biodiversity is the 13 terrestrial biogeographic regions shown in Map 1 (Stanton and Morgan 1977). The Fitzroy Catchment is almost totally contained within the Central Section of the Brigalow Belt. Areas of key conservation value within the Brigalow belt were delineated by Stanton and Morgan (Map 2; 1977). More detailed conservation planning by Morgan (1989) involving subdivision of the Central Brigalow Area into sub-regional provinces (Map 3) on the primary basis on geology, and then upon other natural patterns such as landform, soils, vegetation and fauna. This sub-regional planning framework was the lowest practical level and each province generally included several land systems previously used in land-use planning. Morgan also provided standardisation (for conservation purposes) across land systems and hence define the level of representation. Recent Thematic mapping was used to define existing and key conservation areas within each province.

Table 1 Management Principles for Classes of Protected Areas

Protected Area	Management Principles
National Parks (Scientific)	Protect the areas's exceptional scientific values and, in particular - ensure that the processes of nature continue unaffected in the area; and protect the area's biological diversity to the greatest possible extent; and allow controlled scientific study and nomitoring of the area's natural resources.
National Parks	Provide for the permanent preservation of the area's natural condition to the greatest possible extent; and protect and present the area's cultural and natural resources and their values; and ensure that the only use of the area is nature-based and ecologically sustainable.
N P (Aboriginal Land)	Manage as a National Park, as far as practicable, in a way that is consistent with any Aboriginal tradition applicable to the area.
N P (Torres Strait Islander Land)	Manage as a National Park, as far as practicable, in a way that is consistent with any Island custom applicable to the area.
Conservation Parks	Conserve the area's cultural and natural resources and their values; and provide for the permanent conservation of the area's natural condition to thegreatest possible extent; and ensure that any commercial use of the area's natural resources, including fishing and grazing, is ecological sustainable.
Resources Reserves	Recognise and, if appropriate, protect the area's cultural and natural resources; and provide for the controlled use of the area's cultural and natural resources; and ensure that the area is maintained predominately in its natural condition. Commercial forestry operations must not be conducted in Resources Reserves.
Nature Refuges	Conserve the area's significant natural resources; and provide for controlled use of the area's natural resources; and provide for the interests of the land-holders to be taken into account.
Coordinated Conservation Areas	Conserve the area's natural and cultural values by coordinated management involving the area's various land-holders; and take account of the area's values, including its recreational, educational and commercial values; and provide for the interests of the various land-holders to be maintained.
Wilderness Area	Protect or restore the wilderness values, and the cultural and natural resources, of the area to the greatest possible extent; and maintain the area to preserve its capacity to evolve in the absence of significant human interference; and provide opportunities for solitude and appropriate self-reliant recreational and spiritual activities.
World Heritage Management Area	Meet international obligations in relations to the area. Protect the area's internationally outstanding cultural and natural resources and its biological diversity; and transmit the area's world heritage values to future generations.
International Agreement Area	Maintain the area's importance to the conservation of nature that is subject of international concern; and conserve the area's native wildlife habitat as far as practicable; and provide for the interests of land-holders to be taken into account.

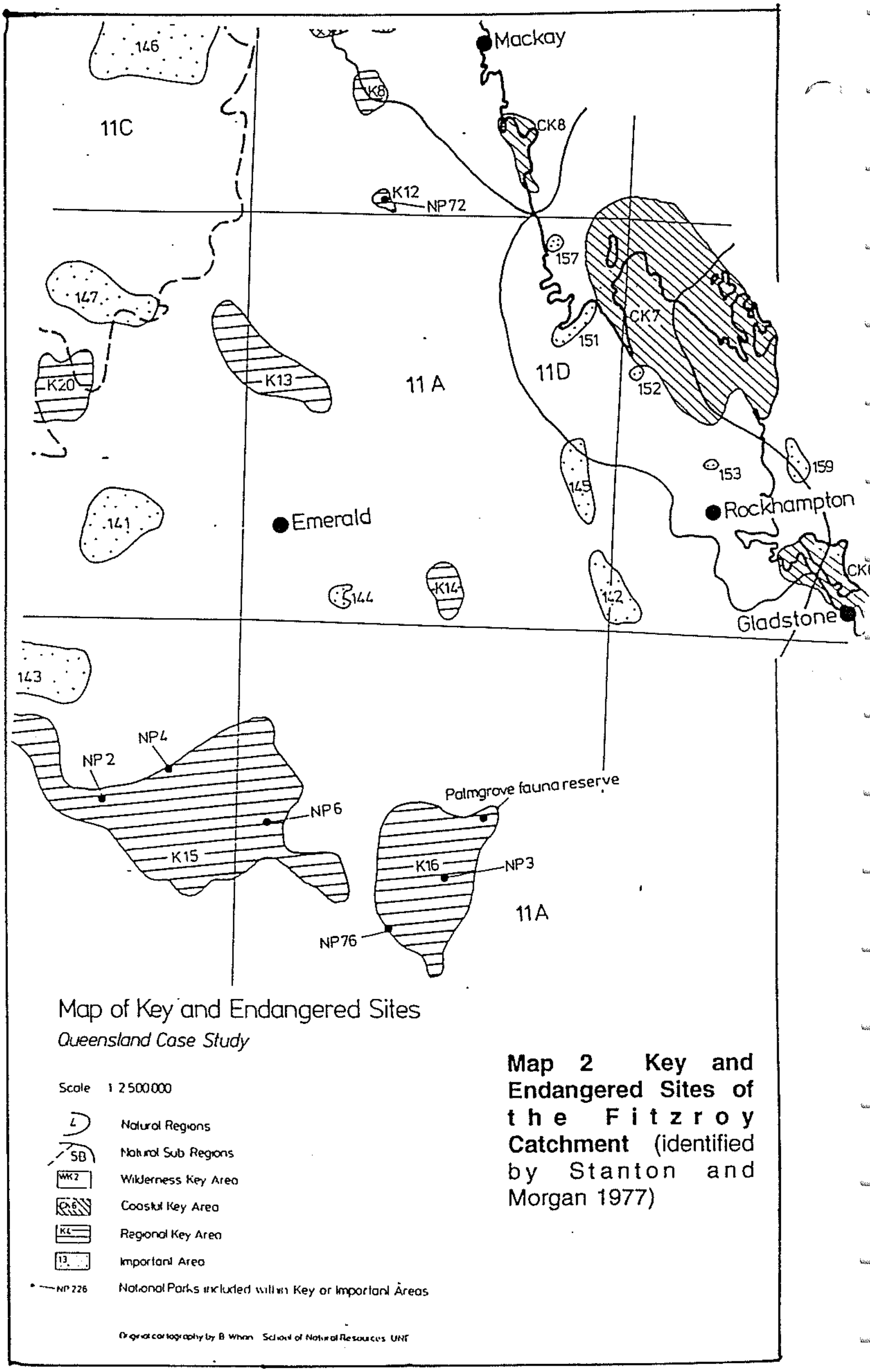
Table 2 National Parks and other Reserves in the Fitzroy Catchment

Park Name	Area (ha)	Reserve No.	Initial Gazettal	Lat	Long	Local Authority
Scientific Reserves						
Taunton	11626.0	184	Mar-79	23 20	149 13	Duaringa
National Parks						
Blackdown Tableland	23800.0	181	Jan-80	23 43	149 05	Duaringa
Carnarvon (in total)	251000.0	236	Apr-32	25 00	148 00	Bauhinia (and others)
Expedition	104000.0	76	Jun-69	25 16	149 09	Bauhinia, Bungil, Taroom
Isla Gorge	7830.0	30	Jun-64	25 11	149 58	Banana, Taroom
Kroombit Creek	7460.0	435	Jul-92	24 22	150 50	Banana
Mt Etna Caves	391.0	846	Apr-74	23 09	150 28	Livingstone
Mt Jim Crow	144.0	893	Oct-77	23 13	150 38	Livingstone
Nuga Nuga	2550.0	56	Apr-91	24 58	148 40	Bauhinia
Palmgrove	25600.0	64	Jun-91	24 58	149 23	Duaringa
Peak Range	761.0	202	Apr-90	22 40	148 01	Belyando, Broadsound, Peak Downs
Peak Range	784.1	108	Sep-83	22 46	148 08	Broadsound
Precipice	9830.0	59	Oct-89	25 19	150 05	Taroom
Rundle Range	2170.0	176	Apr-90	23 39	150 59	Calliope
Snake Range	1210.0	68	Sep-72	24 03	147 36	Emerald
Wolfgang Peak	172.4	189	Apr-84	22 33	147 50	Belyando
Environmental Parks						
Alma Creek	1.7	328	Sep-74	23 54	150 17	Banana
Bell Creek	93.3	380	Nov-86	24 10	150 23	Banana
Blackwater	35.1	140	Feb-74	23 35	148 48	Duaringa
Carraba	44.5	163	Nov-79	25 47	149 41	Taroom
Dawson River	12.9	42	Oct-74	24 33	149 52	Banana
Dawson River	40.9	129	Oct-74	24 32	149 52	Banana
Highworth Bend	51.6	40	Jul-74	24 50	149 54	Banana
Limestone Creek	19.8	968	Jan-83	23 18	150 31	Rockhampton
Long Island Bend	25.7	845	May-75	23 14	150 25	Livingstone
Mackenzie Creek	29.4	24	Feb-85	23 04	149 04	Duaringa
Mt Archer	2270.0	1050	Mar-87	23 20	150 30	Rockhampton
Mt Hopeful	554.4	415	Jul-89	23 48	150 26	Mount Morgan
Mt Leura	196.5	191	Jul-88	23 24	147 33	Emerald
Mt Scoria	21.7	67	Sep-77	24 32	150 36	Banana
Mt Zamia	1140.0	229	Aug-78	24 05	148 04	Bauhinia
Princhester	721.8	803	Jul-91	23 00	150 00	Livingstone
Roundstone	198.0	41	Sep-74	24 38	149 45	Banana
Vandyke Creek	215.8	7	May-80	24 10	147 47	Bauhinia
Wallaroo	428.0	87	Nov-81	25 16	148 48	Bauhinia
Zamia Creek	38.9	32	Jan-78	24 37	149 23	Duaringa
Resources Reserves						
Boggomoss	400.0	60	Dec-87	25 23	150 10	Taroom
Bouldercombe Gorge	334.0	1130	May-92	23 36	150 30	Livingstone
Broadmount	614.0	1009	Feb-85	23 28	150 46	Livingstone
Expedition	2930.0	63	Mar-92	25 40	149 08	Bungil
Flat Top Range	1950.0	1036	May-86	23 24	150 43	Livingstone
Lake Murphy	550.6	53	Jun-86	25 29	149 40	Taroom
Stones Country	259.7	661	Feb-90	26 23	149 53	Taroom

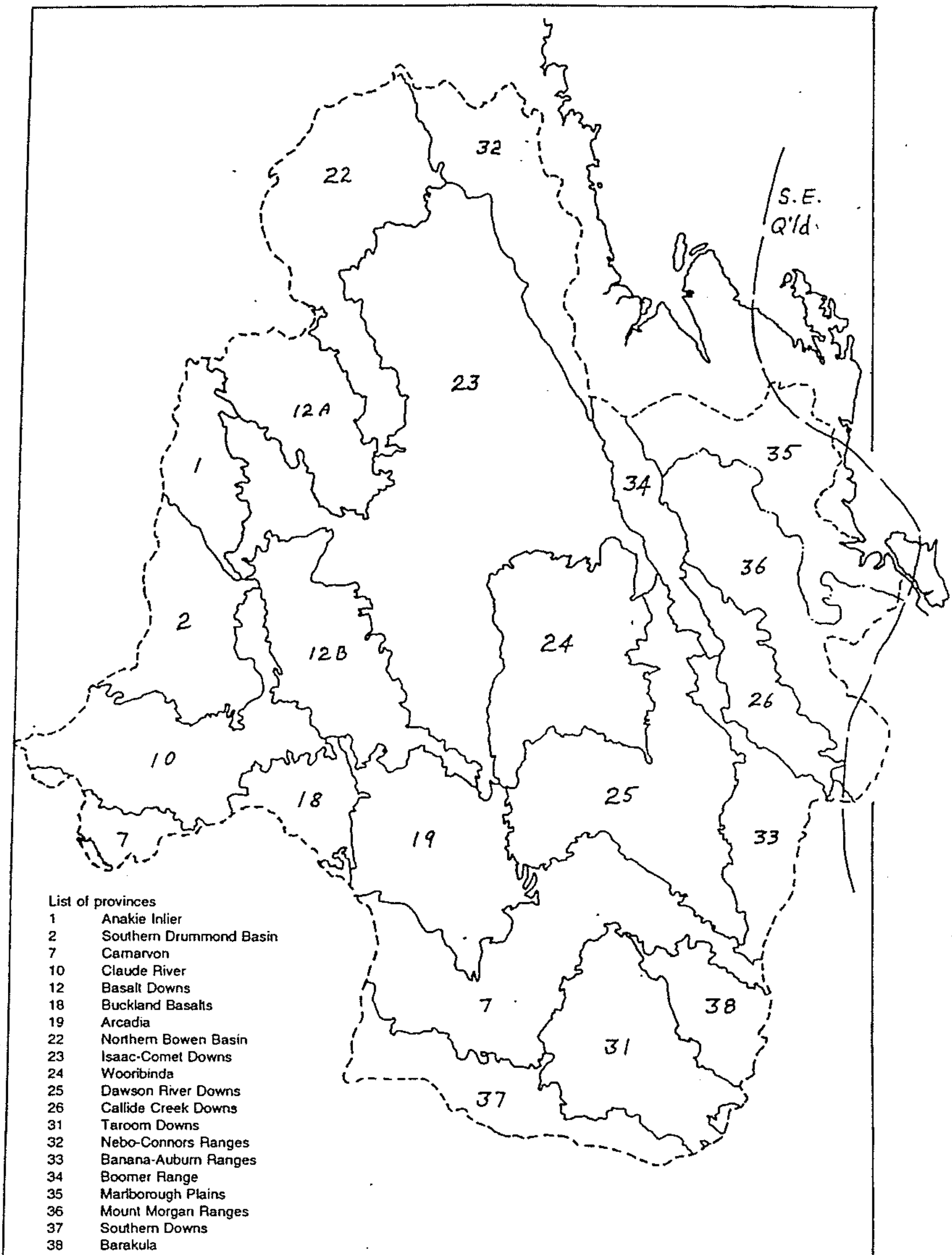


Map 1 Natural Provinces of the Central Section of the Brigalow Belt Biogeographic Region within the Fitzroy Catchment

Source: Province information from Morgan (1988)



Map 2 Key and Endangered Sites of the Fitzroy Catchment (identified by Stanton and Morgan 1977)



Map 3 Natural Provinces of the Central Section of the Brigalow Belt Biogeographic Region within the Fitzroy Catchment
Source: Province information from Morgan (1989)

Planning for Conservation

The key area analysis has identified the obvious difficulties of obtaining representation in the catchment, dominated by brigalow (*Acacia harpophylla*) communities, chiefly on the fertile plains and interspersed with by eucalypt dominated ranges and other acacia associations, much of which has been extensively modified. 'Successful' conservation of the nature of the catchment required a network, of which a limited amount is actually in reserved estates. Property planning techniques based on province management strategies may provide connection of remnants across the landscape. As conservation is not the primary purpose of most non-estate land-use, community nature conservation may be the key to raising the representation of those feature identified by the provincial framework.

The Nature Conservation Act (1992) provides for a range of non-estate measures. Rare and threatened species of flora and fauna will be studied to prepare recovery plans. A list of the rare and threatened plant species based on an unpublished revision (1991) of Thomas and McDonald (1989) has been prepared for the catchment (Table 3 & Appendices 1 & 2). Their conservation status and various related information on distribution and habitat allows more detailed assessment of the probability of their occurrence in a particular plant community. It must be stressed that the database is far from complete in representation. Currently more than half the species are in protected areas of greater than 1000 ha.

Catchment as Management Units

Because environmental variation occurs on many geographical scales, systems of regions have been developed that can be modified to fit any scale. One of the most versatile regional units has been the watershed, or catchment area of a stream. Watershed form a convenient management unit because they can be simply and unambiguously defined from a topographic map. They are independent of scale, in that, large river systems like the Fitzroy can be broken into hierarchic system of smaller basins. Watersheds also have other advantages as basis for regional divisions. Soil related changes in vegetation reflect location within the watershed, since the physical features of a basic directly affect the hydrologic characteristics of the streams draining. Thus discrete conservation assets such as riparian lands can be identified and collated.

Normally, land use maps, and even planning proposals, show broad categories of uses and assets. Rather than poster type maps, mosaics are required for good reason. They result from asking the land to display discrete attributes which, when superimposed reveal great complexity. But this is the real complexity of opportunity and constraint. Yet it may appear anarchic, but only because we have become accustomed to the dreary consistency of zoning, because we are unused to perceiving the real variabilities in the environment, and responding to this in our planning and management.

Management of protected areas as key assets requires

Table 3 Rare and Threatened Plants of the Fitzroy Catchment

Based on on the 1991unpublished revision of McDonald and Thomas (1989)

Family	Species name	Distrib. & Cons. Status	Pastoral District/ State	One degree grid cell	Habitat & cultivated status	Conserved in listed reserve
E (endangered)						
ASPIDIACEAE	Tectaria devexa (C. Chr.) Copel	2E+	Pc	N13	AH	
EUPHORBIACEA	Neoroepera buxifolia Muell. Arg. & f. Muell.	2E	Pc	N13,M12	MK	
POACEAE	Homopholis belsonii C.E.Hubb.	3E	Dd,NSW	Q12,Q13,R14	FF,FD,MC	
V (Vulnerable)						
POACEAE	Paspalidium scabrifolium S.T. Blake	1V	Pc	N13	FA	
APOCYNACEAE	Neisosperma kilneri (F. Muell.) Fosberg & Sachet	2VC	Nk,Sk	K11,L12	AA,AC,G	Mt Dryander
ASTERACEAE	Helichrysum eriocephalum J.H. Willis	2VC	Sk	L11		Eungella
CAPPARACEAE	Capparis thozetiana (F. Muell.) F. Muell.	2V	Pc	N13		
EPACRIDACEAE	Leucopogon cuspidatus R. Br.	2V	Pc	M12,N13		
FABACEAE	Pultenaea setulosa Benth.	2V	Pc	M12		
LOGANIACEAE	Logania diffusa R. Henderson	2VC	Le	N12	FF	Blackdown Tableland
MIMOSACEAE	Acacia calantha Pedley	2V	Le	P13	FA,FB	
MYRTACEAE	Calytrix gurulmundensis Craven	2V	Dd	Q12,Q13		
	Eucalyptus argophloia Blakely	2V	Dd	Q13,Q14	MC,C	
	Eucalyptus beaniana L. Johnson & Hill	2VC	Le	P12	WA	Isla Gorge
	Eucalyptus pachycalyx ssp. waajensis L. Johnson & Hill	2V	Dd,Le	P13,Q13	FA	
	Eucalyptus scabrida Brooker & A. Bean	2V	Le	O10,O11	WA	
	Eucalyptus xanthope A. Bean & Brooker	2V	Pc	M12	FA	
POACEAE	Aristida annua B. Simon	2V	Le	N11,O11		
POLYGALACEAE	Comesperma oblongatum (R.Bt. ex Benth.) Pedley	2V	Pc	M13	HH,LL,YG,ED	
ACANTHACEAE	Graptophyllum excelsum (F.Muell.) Druce	3VC	Co,Pc,Nk,Sk	H7,J9,K11,N13,N14	AH,G,C	Royal Archway Cave
AIZOACEAE	Macarthuria ephedroides C. White	3VC	Le,Ml,Wb	N12,O8,O10,P12,P13,Q16	FA	BlackdownT'land, Carnarvon (Salvator Rosa), Cooloola
ASCLEPIADACEAE	Gymnema brevifolium Benth.	3V	Le,Nk,Pc	I9,J9,M13,N13,O11	WA	
EPACRIDACEAE	Leucopogon blakei Pedley	3VC	Dd,Le	O11,P11,Q12,Q13	WA	Carnarvon
EUPHORBIACEAE	Bertya opponens (F. Muell. ex Benth.) Guymer	3VC	Le,Pc	N11,O12,O14	FA	Castletower
	Bertya sharpeana Guymer	3VC	Le,Mo	K11,L11,Q16	EM	Eungella,Mt Coolum
FABACEAE	Daviesia discolor Pedley	3VC	Le,Bn	N12,P15	FA	Blackdown Tableland
HALORAGACEAE	Myriophyllum implicatum Orch.	3V	Dd,Mo,Wb	R15,R16,Q13,P16	FF,YR	
HERNANDIACEAE	Hernandia bivalvis Benth.	3VC	Pc,Mo,Wb	K11,N13,O13,P14-15,Q15,R15	AA,AH,G,C	Q.NPWS Moggill
MIMOSACEAE	Acacia curranii Maiden	3V	Dd,NSW	Q12	AH,CA	
MYRTACEAE	Darwinia decumbens Byrnes	3VC	Dd,Le	N12,Q13	SS	Blackdown Tableland
	Eucalyptus raveretiana F. Muell	3VC	Nk,Sk,Le,Pc	J9,J10,K9,K10,K11,L11,N13	AG,MK	Dipperu
	Melaleuca groveana Cheel & C. White	3VC	Le,Bn,Dd,Mo,NSW	N12,P11,Q13,Q14,Q15,S15	AH,FA,HH	Beerwah, Blackdown Tableland, Mt French,
POACEAE	Dichanthium setosum S.T. Blake	3VC	Le,Mo,NSW	O11,R15	FA,OD,ZZ	Carnarvon
PROTEACEAE	Hakea trineura F. Muell.	3VC	Pc,NSW	M12,N13	FA,YC,G,C	Not conserved in Queensland
RHAMNACEAE	Trymalium minutiflorum E.Ross	3V	Bn,Pc	O13,Q14	FA	
SANTALACEAE	Thesium australe R.Br.	3VC+	Dd,Le,Mo, NSW, Vic, Tas.	P11,Q14,R14,R15,R16	FA,ZZ	Mt Greville
SAPINDACEAE	Cossinia australiana S. Reyn.	3V	Pc,Wb	N13,O13,O14,P15,Q15	AH	
SIMAROUBACEAE	Cadellia pentastylis F. Muell.	3VC	Dd,Ma,Le,Bn,Pc,NSW	O13,P11-12,Q10,R12-13,S13-14	AH	Sundown

Table 3 (continued) Rare and Threatened Plants of the Fitzroy Catchment

Family	Species name	Distrib. & Cons. Status	Pastoral District/ State	One degree grid cell	Habitat & cultivated status	Conserved in listed reserve
STACKHOUSIACEAE	Stackhousia tryonii F. Bailey	3VC	Pc	N13,L13,M12,M13	OD,ZZ	South Percy Island
R Rare						
ARECACEAE	Livistona sp. 'Blackdown Tableland' R.J. Henderson 1180	2RC	Le	N12	FA,G,C	Blackdown Tableland
	Livistona sp. 'Carnarvon & Taroom' R.W. Johnson 2764	2RC	Le	P11,P12	OF,G	Carnarvon
DILLENIACEAE	Hibbertia hendersonii S. Reyn	2RC	Le	N12		
EPACRIDACEAE	Leucopogon grandiflorus Pedley	2RC	Le	P11		Carnarvon
EUPHORBIACEAE	Beyeria sp. 'Bull Ck Gorge' (B. O'Keeffe 573)	2RC	Le	O9,O10	PI	Carnarvon (Salvator Rosa)
MIMOSACEAE	Acacia gittinsii Pedley	2RC	Le	N12,P12	FA,FI,PI,C	Blackdown Tableland .
	Acacia islana Pedley	2RC	Le	P12,P13	FF,MM	Isla Gorge
	Acacia storyi Tind.	2RC	Le	N11,N12	FI,OD,OF	Blackdown Tableland
	Acacia sp. 'Biloela' (F. Ford s.n. May 1987)	2R	Pc	O13	FA	
MYRTACEAE	Calytrix islensis Craven	2RC	Le	P12		Isla Gorge
	Eucalyptus disclusa L. Johnson & Blaxell	2RC	Le	N12	WA	Blackdown Tableland
	Eucalyptus mensalis L. Johnson & Hill	2RC	Le	N12	WA	Blackdown Tableland
	Eucalyptus sicilifolia L. Johnson & Hill	2RC	Le	O11	WA	Mt Zamia EP
	Eucalyptus sphaerocarpa L. Johnson & Blaxell	2RC	Le	N12	FI,FJ	Blackdown Tableland
	Homaranthus decasetus Byrnes	2RC	Le	P11,P12	WA	Isla Gorge
ORCHIDACEAE	Genoplesium pedersonii D. Jones	2RC	Le	N12		Blackdown Tableland
	Genoplesium validum D. Jones	2RC	Le	N12		
RUTACEAE	Boronia eriantha Lindley	2RC	Le	O9,O10,P10	FA	Carnarvon (Salvator Rosa)
THYMELAEACEAE	Pimelea leptospermoides F. Muell.	2R	Pc	M12,M13,N13		
XANTHORRHOEACEAE	Lomandra teres T. Macfarlane	2RC	Le	O10		Carnarvon (Salvator Rosa)
ZAMIACEAE	Macrozamia platyrhachis F. Bailey	2RC	Le	N12	FA,G	Blackdown Tableland
ASCLEPIADACEAE	Tylophora calcarata Benth.	3R+	Pc,Co,NT	A5,C4,C6,I9,N13	AA	
BLECHNACEAE	Blechnum ambiguum	3RC	Le,NSW	N12	FI	Blackdown Tableland
CAMPANULACEAE	Wahlenbergia sp. 'Isla Gorge' S.L. Everist 8069	3RC	Le,Ma	P10,P11,P12		Isla Gorge, Carnarvon
COMBRETACEAE	Macropteranthes fitzalanii F. Muell.	3RC	Bn,Nk,Pc	J9,K11,N13,O14,P14	AH	Mt Dryander, Conway, Whitsunday Island
EHRETIACEAE	Ehretia sp. 'Isaac River' E.R. Anderson 2875	3R	Le,Nk,Pc	J9,L11,L13,M12,N14	AH,MC	
EUPHORBIACEAE	Bertya pedicellata F. Muell.	3RC	Bn,Le	O9,O10,P14	FA	Carnarvon (Salvator Rosa)
FABACEAE	Leptosema chapmanii Crisp	3R	Le,Ml,Nk	K8,N8,O11,P11	HH	
GLEICHENIACEAE	Diplopterygium longissimum (Blume) Nakai	3RC+	Co,Sk,Nk	H8,I8,L11	AA	Bellenden Ker, Eungella
LOGANIACEAE	Logania cordifolia Hook.	3RC	Le	O10,P11,P12	FI	Carnarvon, Expedition
LORANTHACEAE	Lysiana filifolia Barlow	3RC	Nk,Le	N12,H8		Blackdown Tableland,
	Muellerina myrtifolia	3RC	Dd,Pc,Bn,Mo,NSW	O13,P14,S15	AC,AH,FF	Coalstoun Lakes, Main Range
MIMOSACEAE	Acacia gnidium Benth.	3RC	Bn,Le,Nk,Ml,Sk	K8,M11,N9,O9,O10,P13,P14	SS	Isla Gorge
	Acacia hockingsii Pedley	3RC	Bn,Le	P12,Q14	FF,FA,MM	Isla Gorge
	Acacia holotricha Pedley	3R	Le,Pc,Bn	N12,P12,P14	FF,FA	
	Acacia pubicosta C. White	3RC	Le,Pc,Ma,Wb	N12,N13,O13,P10,P15	FF,FI,OD,WB	Mt Walsh, Blackdown Tableland, Carnarvon
	Acacia spania Pedley	3R	Le,Ml,Wa	N11,O6,O9,P7	SA	
MYRTACEAE	Callistemon pearsonii Spencer & Lumley	3RC	Le,Sk	L11,N12	LL,C	Blackdown Tableland

Table 3 (continued) Rare and Threatened Plants of the Fitzroy Catchment

Based on on the 1991unpublished revision of McDonald and Thomas (1989)

Family	Species name	Distrib. & Cons. Status	Pastoral District/ State	One degree grid cell	Habitat & cultivated status	Conserved in listed reserve
	Darwinia thomasii (F. Muell.) Benth.	3RC	Le,Bk,Ml,Nk,Sk	K7,K8,L9,O10	WW	Carnarvon (Salvator Rosa, Kaka Mundi)
	Eucalyptus curtisii Blakely & C. White	3RC	Dd,Mo,Le	P12,Q12,Q13,Q15,R13,R15,R16	FA,NN,WA,CL,G,C	Isla Gorge,Expedition
	Eucalyptus melanoleuca S.T. Blake	3RC	Mo,Le,Bn,Pc	N12,O13,Q14	FA	Blackdown Tableland
	Eucalyptus rubiginosa Brooker	3RC	Le,Dd,Bn	P12,P13,Q13	FA	Isla Gorge
OLEACEAE	Notelaea pungens Guymer	3R	Bn,Dd,Le	P13,Q13	WA	
ORCHIDACEAE	Pterostylis woolsii Fitzg.	3RC	Dd,Le,NSW,VIC	N12,S14		Girraween, Blackdown Tableland
PROTEACEAE	Grevillea cyranostigma McGillvray	3RC	Le	O10,P11	FA	Carnarvon (Salvator Rosa)
	Grevillea singuliflora F. Muell	3RC	Dd,Le,Bn,Mo	N12,P14,Q13,R12,R15	FI, G	Blackdown Tableland
	Persoonia amalieae Domin	3RC	Bn,Le,Pc,Sk,Wb	L11,O14,P15		Castletower, Eungella, Mt Walsh
RUTACEAE	Bosistoa medicinalis (F. Muell.) T. Hartley	3R	Pc,Nk	K11,N13,N14	AA,AH	
SAPINDACEAE	Atalaya calcicola S. Reyn.	3R	Co,Pc	H7,N13	AA,AH	
	Dodonaea macrossahii F. Muell. & Scortechini	3R	Dd,NSW	Q13,R12,S14	FC,WA,CL,YC	
VERBENACEAE	Callicarpa thozetii Munir	3R	Pc	L12,N13	FA	
K (Poorly Known)						
CELASTRACEAE	Apatophyllum sp. 'Bull Creek' (A.R. Bean 2225)	1K	Le	O9	PI	
FABACEAE	Zornia pedunculata S.Reyn & Holland	1K	Pc	O13	FI	
MYRTACEAE	Baeckea sp. 'Mt Minda' (M.B. Thomas 257)	1KC	Le	O10		Carnarvon (Salvator Rosa)
CAPPARACEAE	Capparis humistrata (F. Muell.) F. Muell.	2K	Pc	N13		
LILIACEAE	Dianella fruticans R. Henderson	2KC	Ma,Le	O10	WA	Carnarvon (Mt Moffatt, Kaka Mundi)
MIMOSACEAE	Acacia sp. 'Roper Peak' (A. Bean 630)	2K	Le	M11	LL	
MYRTACEAE	Decaspermum sp. 'Mt Morgan' D. Hoy 71	2K	Pc	N13	AH	
ORCHIDACEAE	Gastrodia crebriflora D. Jones	2K	Le	N12	FF	
	Prasophyllum incompositum D. Jones	2KC	Le	O10	WA	Carnarvon
PITTOSPORACEAE	Bursaria sp. 'Glen Geddes' (P.Forster 3400)	2K	Pc	N13	FA	
ACANTHACEAE	Rhaphidospora cavernarum (F. Muell.) R.M. Barker	3K	Pc,Co	N13		
ASTERACEAE	Stemmacantha (Leuzea) australis Gaudich.	3K	Mo,Bn,Dd,Pc, NSW,Vic	O13,O14,P14,Q11,R14,R15,S14		
CELASTRACEAE	Apatophyllum sp. 'Expedition Range' (E.J. Thompson s.n. Mar 1984)	3KC	Le	O12,P11	WA	Lonesome
DROSERACEAE	Aldrovanda vesiculosa L.	3K+	Pc,Wb,NSW,NT	N13,O15		
FABACEAE	Desmodium macrocarpum Domin	3K	Bn,Le,Ml,Nk	I7,K8,N9,N11,N12,P14	OD	
	Zornia pallida Mohl.	3K	Bn,Dd,Ma	P14,Q11,S14		
HALORAGACEAE	Myriophyllum muricatum Orch.	3K	Co,Pc,NT	H8,M13	EL	
LAMIACEAE	Prostanthera odoratissima Benth.	3K	Dd,Le	N12,O11,R13	FA	
ORCHIDACEAE	Pterostylis sp.'Coomera Valley' (J.Roberts s.n. Sept 1986)	3K	Dd,Mo	Q13,R16		
PROTEACEAE	Grevillea sp. 'Coominglah' (A. Bean 236)	3K	Bn,Pc	O13,N13		
RHAMNACEAE	Cryptandra sp. 'Barakula' V. Hando 151	3K	Dd,Le	P13,Q12,Q13	WW	
TILIACEAE	Corchorus hygrophilus Cunn.	3KC	Le,Bn,Nk	J9,P11,P14	FA	Carnarvon

ranking natural and cultural assets depending on significance and susceptibility to change. One problem has been in areas when assets are unevenly distributed resulting in collating for a geographical or political region with ranking at an administrative level. Clearly defining the spatial limits simplifies data collection and management.

By definition, protected areas can be viewed as remnants in a catchment hierarchy. Little practical value to land managers as resulted from research into fragmented ecosystems. Rather such research has concentrated on the 'biogeographic' consequences with little regard to changes in the physical environment. Saunders, Hobbs and Margules (1991) argue *'that the dynamics of remnant areas are predominantly driven by factors arising in the surrounding landscape. Management of, and research on fragmented ecosystems should be directed at understanding and controlling these external influences as much as at the biota of the remnants themselves. There is a strong need to develop an integrated approach to landscape management that places conservation reserves in the contact in the context of the over all landscape.'*

Future focus for Nature Conservation Planning

In the future, development of Integrated Regional Nature Conservation Strategies should be based on the following objectives:

a) complement representation of biodiversity in protected areas.

b) maintenance of biodiversity throughout the landscape.

and c) contribute to sustainable land use and management.

Development of a simple, clear and practicable basis to focus policy, research, planning and management needs is the key strategy.

Implications to the above objectives are:

a) Representation: National Park estate is projected to represent 80% of regional biodiversity (plant communities) and greater rare and threatened fauna and flora representation.
- establish need
- listing of rare and threatened species not or only poorly represented for each biogeographic region.
- identification of critical habitats and/or landscapes (including catchments) needing protection

b) Maintenance of biodiversity throughout the landscape: That is, the natural range of species. This will require focusing on key components.
  - restricted habitat types
  - riparian lands
    - major rivers, creeks, lakes, and shoreline communities
  - others such as mountain tops and plateaux.

c) Sustainable land use:
   - identify threats and management issues e.g. degradation, land-type, property size, total herbivore grazing pressures, attitudes etc.
   - bench mark monitoring
     - landscape health and change
     - management of protected areas.

Key Tasks for Nature Conservation

The key tasks for nature conservation are:

1 Development of biogeographically based nature conservation audits, baseline monitoring and documentation of significant issues

2 Contribution of nature conservation considerations to the Department of Local Government State Planning Policies

3 Development of guidelines for Department of Environment and Heritage response for nature conservation input into Town Planning Schemes and Development Control Plans

4 Development of policies and guidelines on nature conservation in relation to applications for tenure conversion, and

5 Development of policies and guidelines on nature conservation in relation to the clearing of leasehold lands.

Conclusion

Nature conservation in the catchment aims to obtain maximum representation of key natural areas in a minimum of land area, namely efficient land-use for conservation. Two of the problems that are faced are: the level of disturbance that characterises many (but not all) of the provinces and the historic concentration of the acquisition process on those areas of mainly scenic value. Despite this narrow criteria, significant representation of floristic types has been achieved, however in other types, original communities are reduced to unviable remnants, the survival of which is a challenge to sympathetic community nature conservation.

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Appendix 1. Status Codes for Table 3 - Rare and Threatened Plants

Distribution

1 Species known only from the type collection.

2 Species with a very restricted distribution in Australia and a maximim geographic distribution of less than 100 km.

3 Species with a range greater than 100 km in Australia but occurring in small populations which are mainly restricted to highly specific habitats.

Conservation status

X Species presumed extinct.

E Endangered species at serious risk of disappearing from the wild state in 10-20 years if present land use and other causal factors continue to operate.

V Vulnerable species not presently endangered but at risk over a longer term due to continued depletion or likely loss of habitat.

R Species which are rare in Australia, but not currently considered endangered or vulnerable (e.g. relatively large population in a restricted area or smaller populations spread over a wider range).

K Poorly known species that are suspected to belong to any of the above categories.

Supplementary codes

C Species known to be represented, but not necessarily conserved, within a national park or other proclaimed reserve.

+ Species with a distribution extending beyond the Australian continent.

Distribution

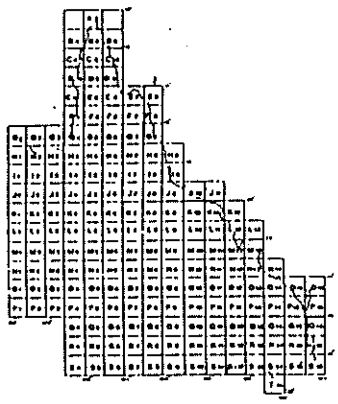
Distribution is listed according to the pastoral districts of Queensland and the various states of Australia:

Queensland

Bk	Burke
Le	Leichhardt
NK	North Kennedy
NG	North Gregory
Mi	Mitchell
SG	South Gregory
SK	South Kennedy
Wa	Warrego

Other States

NSW	New South Wales
NT	Northern Territory
SA	South Australia
WA	Western Australia
Vic	Victoria
Tas	Tasmania



Additional data

Habitat status (e.g. AH)
The habitat codes correspond to information stored on the Queensland Herbarium computerised records in HERBRECS. This information is in an incomplete form. A list of the various habitat codes is shown in Appendix 2.
Cultivated status
G Growing in a botanic garden or arboretum
C commercially available from nurseries

APPENDIX 2 HABITAT CODES

Rainforest (A) (projective foliage cover of trees > 70%; height > 5m)

AA	Closed forest/rainforest - not otherwise specified
AC	Subtropical closed forest/rainforest - includes complex notophyll and mixed notophyll vine forests (=emergent *Agathis* spp. *Araucaria* spp.)
AG	Fringing closed forest/rainforest, gallery rainforest - includes *Castanospermum australe, Waterhousea floribunda* and other riparian communities
Ah	Strongly seasonal, dry closed forest/rainforest (softwood scrub, monsoon scrub/forest, hoop pine scrub, 'turkey scrub', etc.) - includes deciduous vine thicket, low microphyll vine forest/thicket, semi-evergreen vine thicker, araucarian microphyll vine forest/thicket.

Scrubs and heaths (C, H) (projective foliage cover of shrubs > 30%; height < 8m)

CA	*Acacia* spp. scrubs - not otherwise specified
CL	Mallee (*Eucalyptus* spp.) scrubs
HH	Closed or open health - not otherwise specified

Open forests and woodlands (F, M, N, O, P, T, W) (projective foliage cover of trees < 70%; height > 5m)

FA	*Eucalyptus* spp. open forest or woodland - not otherwise specified
FB	*Acacia* spp. open forest or woodland - not otherwise specified
FC	*Callitris* spp. open forest or woodland - not otherwise specified
FD	*Casuarina* spp. open forest or woodland - not otherwise specified
FF	Open forest or woodland - not otherwise specified
FI	*Eucalyptus* spp. open forest - not otherwise specified
FJ	*Eucalyptus* spp. tall open forest - not otherwise specified
MC	*Acacia harpophylla* (brigalow) mid height open forest
MK	Fringing mid height open forest (along watercourses)
MM	Mid height open forest - not otherwise specified
MN	Low open forest - not otherwise specified
OD	*Eucalyptus* spp. open forest - ironbark
OF	*Eucalyptus* spp. open forest - smooth bark
PI	*Eucalyptus* spp. & *Acacia* spp. woodland or open woodland
WA	*Eucalyptus* spp. woodland or open woodland - not otherwise specified
WB	*Eucalyptus* spp. woodland or open woodland - bloodwood
WW	Woodland or open woodland - not otherwise specified

Shrublands (L, S) (projective foliage cover of shrubs < 30%; height < 8m)

LL	Low or low open shrubland - not otherwise specified
SS	Tall shrubland or tall open shrubland - not otherwise specified

Grasslands, herblands and sedgelands (Y, Z)

YC	*Triodia* spp. hummock grassland
YG	Littoral strand grassland - not otherwise specified
YR	Sedgeland - not otherwise specified
ZZ	Grassland - not otherwise specified

Miscellaneous communities (E)

ED	Wallum (coastal lowland) communities - not otherwise specified
EL	Aquatic communities - not otherwise specified
EM	Montane scrubs and heaths - not otherwise specified

USAGE OF FITZROY RIVER WATER BY THE STANWELL POWER STATION

R.A. Evans

Queensland Electricity Commission, Stanwell Power Station

ABSTRACT

The latest 1400 MW coal fired power station for the Queensland Electricity Commission is under construction at Stanwell, 30 km west of Rockhampton. The two main requirements of the station will be coal, supplied from the Curragh mine and water from the Fitzroy River. The station water supply includes a weir located 96 km upstream of the Rockhampton Barrage, designed and built by the Water Resources Commission. A barrage off-take structure with pumping station and pipeline to the site has been built by the Water Resources Commission. Water will be used for makeup to the cooling towers, boiler makeup, domestic supply, and general site use. The estimated average water usage is about 21 000 ML/year. On site water management aims to reuse water where possible to minimise the quantity discharged. Discharge of water commences in October 1992, to the Neerkol Creek system which flows to the Fitzroy River flood plain to the south-west of Rockhampton.

INTRODUCTION

The Queensland Electricity Commission is responsible for planning, construction and operation of power stations in Queensland. In October 1981, the State Government approved the siting of Stanwell Power Station, about 30 km by road, south-west of Rockhampton. It was considered to be the most suitable after nine months of studies and economic assessment of possible sites in Central Queensland. Figure 1 shows the location of Stanwell Power Station.

Construction was started in 1984 and is continuing with commercial load of Unit 1 planned for March 1993. Subsequent units will be commissioned at yearly intervals. The station will have four, 350 MW coal fired boiler and turbo-generator units, similar to Tarong Power Station. The station's power output will be fed into the state distribution grid and can be used outside of the Central Queensland area.

Stanwell Power Station requires two major inputs to operate, coal and water. Coal is supplied from the Curragh Open Cut Mine by rail to the station. The station will burn about four million tonnes per year. The supply of water, its on site usage and waste water discharge is discussed in this paper.

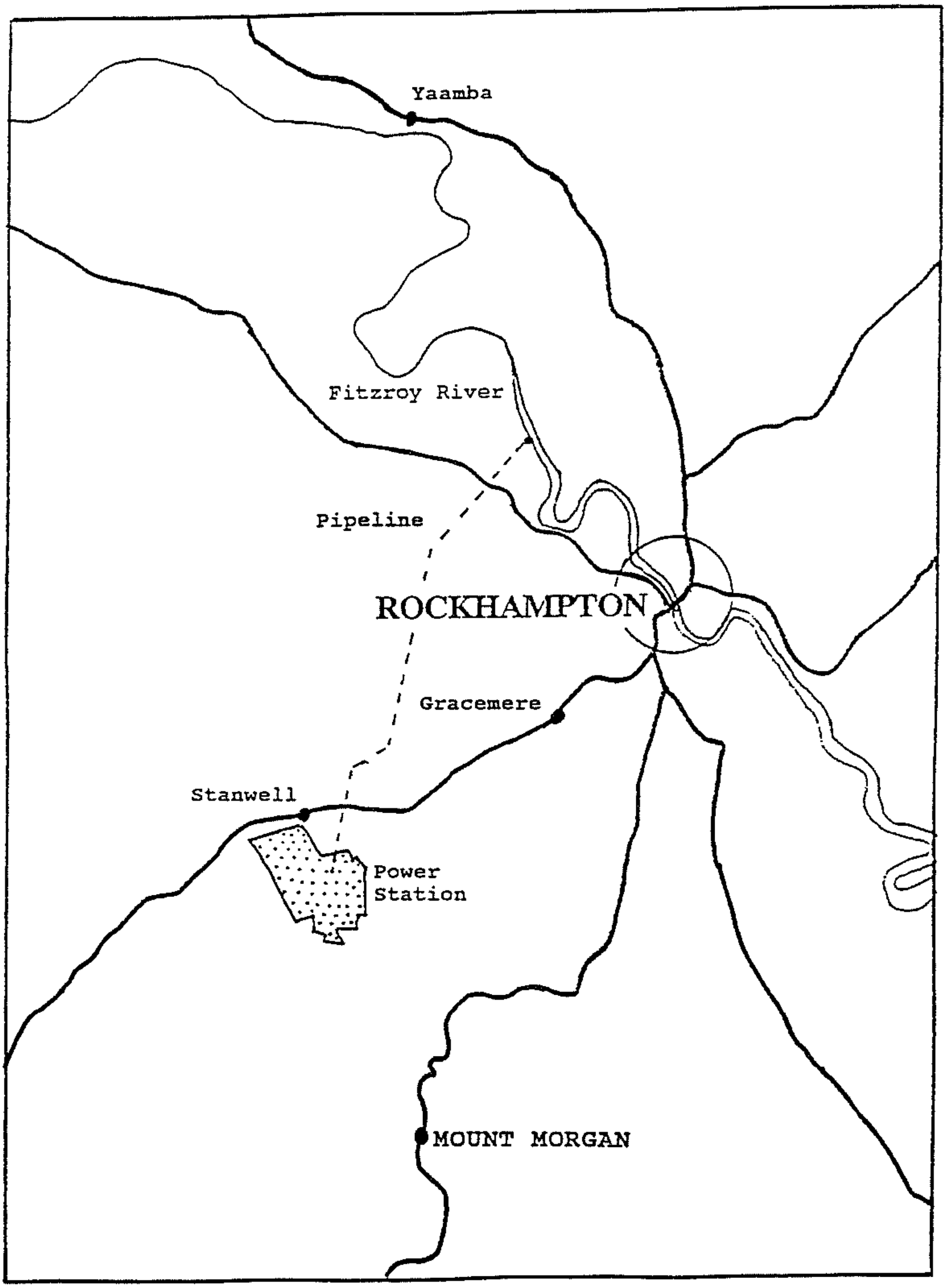


Figure 1: Locality map showing Stanwell Power Station and the water supply pipeline.

SUPPLY OF WATER

Water is supplied to the station from the Fitzroy River Barrage by the Water Resources Commission. The Water Resources Commission has built a pump station about 15 km upstream of the barrage with two, 100% pumps. Each pump has a pumping capacity of about 1000 L/s. A 30 km pipeline transports the water to a 1900 ML dam at the station. Several land holders have licences to draw water from the pipeline for stock watering.

To augment the barrage storage, the Water Resources Commission will build a weir on the river about 35 km west-north-west of Yaamba. This weir will store about 42 500 ML of water. The station will use on average 21 000 ML per year, depending upon the Fitzroy River (raw water) quality and station operation. The on site dam provides storage to allow maintenance of the pipeline and pumps and will gravity feed the station.

SITE WATER MANAGEMENT

Stanwell Power Station will not be a zero discharge station like Callide 'B'. The station will discharge waste water under a Department of Environment and Heritage license.

As all water has to be pumped to the station, a number of steps have been taken to ensure efficient raw water use and minimise station discharge quantity. These include;

- *development of a water management strategy*
- *modified operating methods*
- *dense slurry ashing system*
- *an overall water system approach which allows for interconnection of sub-systems.*

The water management philosophy is to make efficient use of raw water; minimise off site discharge quantity (suitable quality water only); recycle water where possible; and contain water unsuitable for discharge on site.

On site dams and ponds are shown in figure 2. The features to note are;

- *Water Supply Dam*
- *Stormwater Holding Dams - Coal Stockpile Runoff Ponds*
  - Effluent and Reclaim Dams
- *Ash Disposal Area*
- *Northern Stormwater Dam - Station Discharge Point*

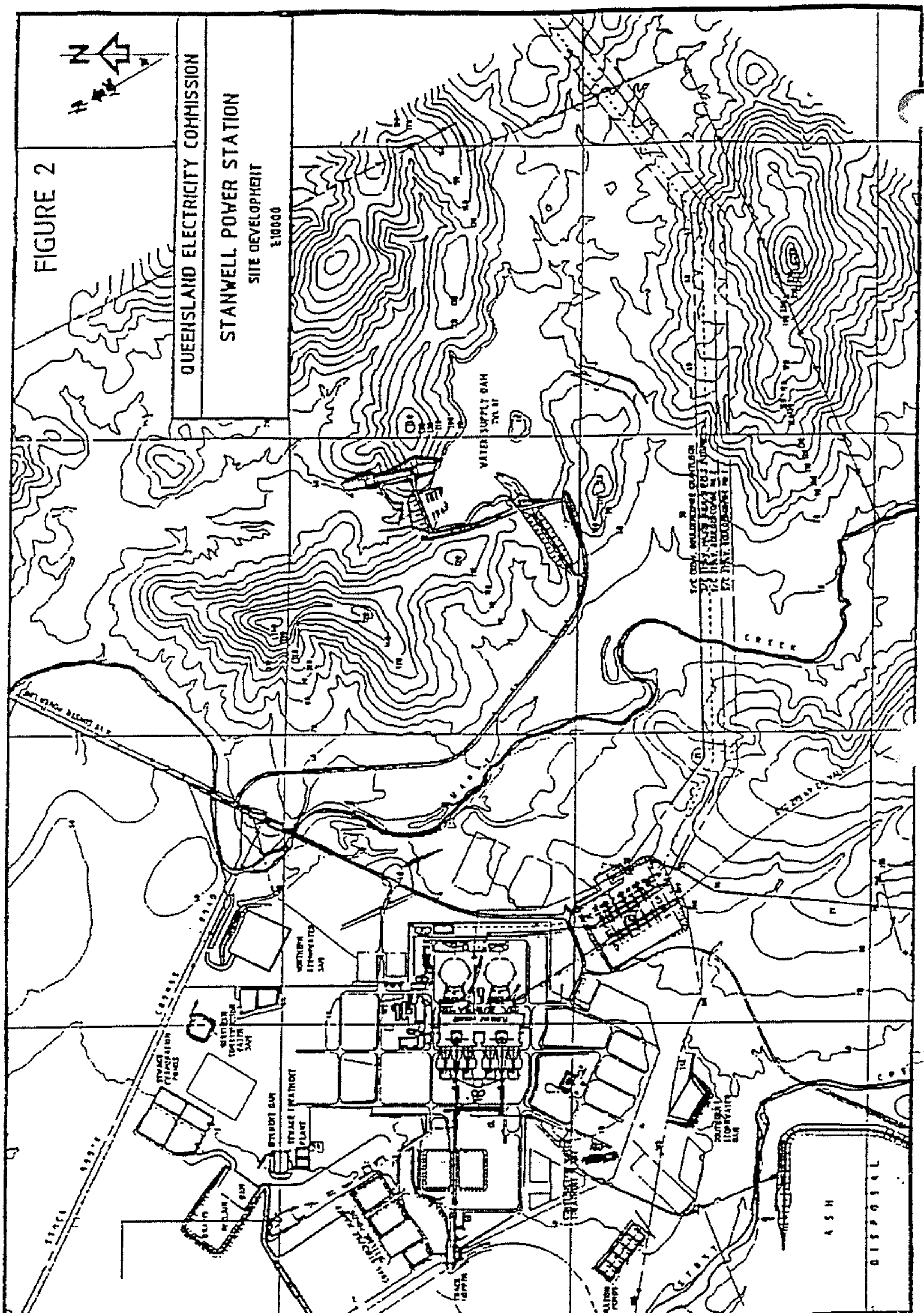


FIGURE 2
QUEENSLAND ELECTRICITY COMMISSION
STANWELL POWER STATION
SITE DEVELOPMENT
1:10000
WATER SUPPLY DAM
CREEK
ASH
DISPOSAL

Management of these dams is important for station operation and the objectives of minimising discharge quantity and environmental effects. A site water management strategy has been developed, the main points of which are;

> *Ensure the Water Supply Dam water quality is suitable for station use. This includes catchment land use, destratification, and monitoring of water quality and algal populations.*
>
> *Stormwater dam levels will be kept low to have the maximum runoff holding capacity to avoid unlicensed discharges. The Effluent and Drains Reclaim Dams are used for water recycling and will be discussed later.*
>
> *All non-dischargeable chemical wastes from the water treatment plants will be blended with ash and disposed of on site.*
>
> *Ash Disposal Area Runoff Ponds will not be allowed to discharge to the environment. Water can be pumped to the station for reuse or allowed to evaporate.*
>
> *Oil spill containment and retrieval equipment will be used to prevent off site discharge.*

Figure 3 illustrates the major water flow paths in the station. It can be seen that the cooling towers are the biggest users of raw water and that most of the water is lost through tower evaporation and drift.

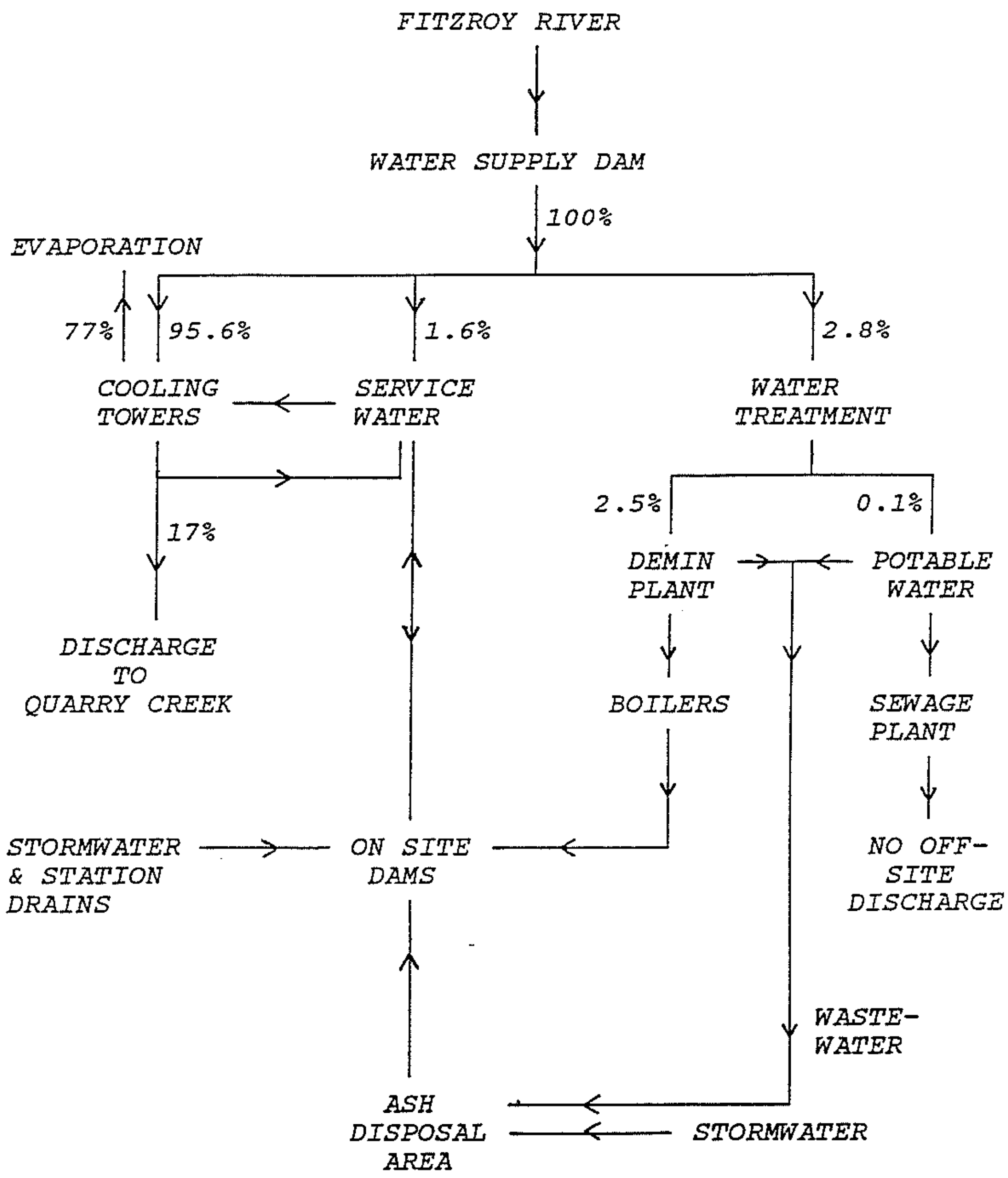
Cooling Towers

The water in the towers is used as coolant for the condensers and auxiliary heat exchangers. Sulphuric acid and chlorine is added to the water to control scaling and bio-fouling.

The large amount of evaporation causes an increase in the concentration of chemicals and hence scaling conditions in the water. About 300 L/s will be lost per tower this way. In normal operation it is expected that the raw water will be concentrated about six times on average.

To avoid scaling of the heat exchanger tubes, water referred to as blow-down, is continuously released from the tower. The blow-down is treated to remove suspended solids and then released to Quarry Creek in compliance with a Department of Environment and Heritage license.

Water loss from the towers is usually made up with raw water.



(Concentration Cycles = 5, Capacity Factor 82%)
Flows shown as % of annual use of 21 043 ML

Figure 3: Stanwell Power Station simplified water flow paths.

Service Water

Service water is used for general hosing and irrigation, drag-link conveyor cooling, fire-fighting, makeup water for the ash slurry plants and cooling tower makeup water when there is excess stormwater on site.

It will consist mainly of recycled water from the following sources;

* *stormwater*
* *draglink conveyor cooling pond overflow*
* *boiler blowdown*
* *station dirty drains.*

Water is reclaimed from the Drains Reclaim Dam for use as Service Water. Total dissolved solids content of the Service Water will be controlled to not exceed 1000 mg/L. This is done by blending cooling tower blow-down and raw water with Drains Reclaim Dam water.

Normal runoff quantities into the Drains Reclaim Dam, will be used as Cooling Tower makeup to prevent any unlicensed discharge. Overflow of this dam will only occur after heavy rainfall. Dilution of the effluent by runnoff is expected to minimise environmental effects.

Water Treatment

The Fitzroy River water is only used in it's raw form for cooling purposes. For other uses it is treated in some way. About three percent of the water is treated by clarification to produce filtered water. A small amount of this is chlorinated to produce potable water. The rest of the filtered water is put through a demineralisation plant to produce boiler feedwater.

Effluent produced by the water treatment plants is not discharged off site. It is all used for ash disposal to a non-discharge area. Sewage is treated on site and evaporation ponds are used to ensure effluent is not discharged from the site.

DISCHARGE

The station will be continuously discharging, on average about 120 L/s of Cooling Tower blow-down with four units operating. Discharge limits have been set for the following parameters;

* *total dissolved solids*
* *chloride*
* *total suspended solids*
* *total residual chlorine*
* *temperature*
* *dissolved oxygen*
* *turbidity*
* *quantity*
* *pH*

Water will be discharged via the Northern Stormwater Dam to Quarry Creek. This flows into Neerkol Creek which flows eastwards to Gracemere, where it's name changes to Scrubby Creek. Scrubby Creek flows into a series of lagoons and drainage lines on the Fitzroy River flood plain.

As part of obtaining the discharge license all available surface and groundwater quality data of the Neerkol Creek system was collated. The Queensland Electricity Commission has carried out baseline water sampling for a number of years.

Surface water quality of Neerkol Creek was monitored between 1982 and 1990. Neerkol Creek discharge volumes have also been recorded near Stanwell since early 1987. Similarly the groundwater quality in the Stanwell, Gracemere and Fitzroy River flood-plain areas were monitored from 1982 to 1990. Groundwater levels have been measured over the same period. Some bores have been monitored by the Water Resources Commission for the last 40 years. This data was used to form a descriptive model of surface and groundwater behaviour in the catchment.

Consideration has been given to the effects of the station discharge on downstream Protected Environmental Values or beneficial uses. The Protected Environmental Values used are defined in the ANZEC 'Draft National Water Quality Guidelines', 1990. A number of these were not relevant to this catchment. These were industrial water supply, hydro-electric power generation, navigation and shipping, recreation, edible fish and crustacea production, shellfish culture and harvesting and scientific and educational purposes.

The Protected Environmental Values relevant to the catchment are;

* *Potable Water*
* *Agricultural Water Supply*
* *Protection of Aquatic Water Systems*
* *Maintenance of Water Associated Wildlife*
* *Recharging of Aquifers*
* *Aesthetic Enjoyment.*

A full discussion of the findings is beyond this paper.

Through discussions with the Department of Environment and Heritage on site and off site surface and groundwater monitoring programs will be carried out to monitor effects of the station discharge.

SUMMARY

The Stanwell Power Station will be a large user of Fitzroy River water and will discharge cooling water blow-down into a creek which flows to the Fitzroy River flood plain near Rockhampton.

To minimise the amount of raw water used, the station will manage water use on site and reuse water where possible.

Station water discharge is licensed by the Department of Environment and Heritage. Water unsuitable for discharge will not be released from site. Effects of the discharge will be assessed by conducting surface and ground water monitoring.

ACKNOWLEDGMENTS

I would like to acknowledge the following people for providing information to prepare this paper. Mr D Buchbach of Generation Technology, Queensland Electricity Commission. Mr P Smith, Managing Director of Waste Solutions Australia Pty Ltd. Thanks to Mr R Robinson of Stanwell Power Station, Queensland Electricity Commission for advice and assistance with editing.

Sediment storage in headwater catchments in the Fitzroy Basin: Implications for integrated catchment management.

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Introduction

The principle of integrated catchment management, also referred to as total catchment management, is based on the premise that the river basin or catchment is the most appropriate administrative unit for water management. While the logic of this is obvious, the establishment of catchment based planning and administrative units is developing only slowly in Australia. Historical inertia and vested interests are powerful forces retaining pre-existing boundaries in place and ensuring their continued use for new purposes. The issues here are invariably complicated by the division of responsibility for aspects of water management between the different tiers of government (local, state and federal) and between different agencies of the same tier.

The obvious logic of integrated catchment management as an administrative and planning device is based on the functional unity of the drainage basin. A vast body of scientific literature exists which enunciates and demonstrates the principles of the organisation of the drainage basin. In process terms, water carrying sediment and solutes runs off from hillslopes into first order tributaries which join into a regular network, ultimately feeding the main stream which discharges into the sea or an enclosed basin. One of the early analysts of the drainage basin, R.E. Horton (1945), was also responsible for a conceptual model of runoff generation (Horton, 1933) in which rainfall in excess of the infiltration capacity over the whole basin becomes runoff into the stream network. This is known as Hortonian overland flow and forms the basis of most rainfall/runoff and sediment production models in common use. The conceptual approaches to the drainage basin engendered by the Horton model provide the basis for assumptions that there is a direct and immediate connection between events (runoff, erosion, pollution) on the valley side slopes of tributary streams and impacts in the main streams of the catchment.

This conceptual approach is flawed in two ways. Firstly, despite the widespread acceptance of the Hortonian model of runoff generation and its use in most process models, Hortonian runoff is in fact the exception rather than the rule and probably only occurs in certain specialised environments. The partial contributing area model (Hewlett and Hibbert, 1967; Dunne, 1978) provides a more accurate representation of the way overland flow is actually generated and it shows that only a relatively small part of the catchment produces surface runoff during storms and that these partial contributing areas are usually in or close to drainage lines.

Secondly, the assumption that the material entrained by the runoff will be transported quickly and efficiently through the drainage network requires considerable qualification. Material transported in ionic solution (eg salt) will be transported by the flow to its ultimate destination; soluble materials which become adsorbed onto solid particles (eg P and N) will follow the pathways of the particles; very fine particles (clay) will be retained in the flow until chemical conditions cause flocculation, as in an estuary; coarser particles will be redeposited usually after transport for only a short distance. Meade (1988) has provided a comprehensive review of the literature on sediment transport and storage in river systems which shows that for coarse sediment transport, slope-channel coupling is generally poor so that sediment eroded from slopes is usually stored for long periods on the slopes before finding its way into channels, and that the movement of coarse sediment down the channel network is episodic with storage delay times commonly in the order of hundreds, thousands or tens of thousands of years.

The administrative elegance of integrated catchment management is only reflected in some of the processes operating in the catchment at the time scale which is relevant to decision making. In this paper data are presented from two upstream tributaries of the Fitzroy system, the Brown River and the upper Nogoa River, which illustrate ways in which sediment is stored within the catchment and give some indication of the storage delay times involved in sediment movement through catchments. The implications of this for effective use of resources in catchment management are discussed.

The Upper Nogoa River

The Nogoa River has its headwaters west of Springsure in the hills on the outcrop of Lower Jurassic sandstones (the Precipice, Hutton and Boxvale Sandstones), part of the sedimentary sequence of the Great Artesian Basin (Mollan, 1967). Within the steep valleys cut in the sandstones the drainage net is reasonably well integrated but downstream, to the north, the sandstone has been stripped by erosion to reveal the softer mudstones and siltstones of the Triassic Moolayember Formation. Here the landscape is more subdued and alluvial fans form where streams debauch from the sandstone valleys onto the plains. The drainage network of the Nogoa system is not completely integrated as the channels disappear on the alluvial fans at the break in slope.

These alluvial fans are sediment stores which are periodically incised by gullies. Schumm (1977) has described a process by which this occurs. As sediment accumulates, the slope of the fan steepens until a threshold slope at which erosion occurs is reached and the fan is incised by a gully. The head of incision works upstream across the fan while the sediment is deposited downstream to form a new fan. Prosser (1991) has described an alternative mechanism whereby gullies develop along lines of preferred flow. In either case, this alternation of phases of incision and deposition can be explained entirely in terms of intrinsic relationships in the system. External stimuli, such as climate changes, are not necessary prerequisites.

The main Nogoa channel between Cungelella homestead and the sandstone escarpment is itself a low angled alluvial fan which has been incised in the period since 1846 when it was first mapped by Mitchell (1848). The Nogoa previously crossed this fan as a series of anastomosing channels but now all of the flow is contained in a single large channel incised about 5 metres into the fan surface. Alluvial sediments exposed in the walls of this channel contain dateable wood and charcoal which indicate a consistent deposition rate of about 1m per thousand years over the past 3,500 years. The last stripping phase on this main channel would appear to have been at least 3,500 years BP.

Further upstream the channel of Louisa Creek, a tributary of the Nogoa, contains peat and interlayered sand lenses, which are now being stripped. Dating of the peat suggests that stripping phases have also occurred at ca 1,000 and 500 years BP (Bell et al., 1989). Analyses of pollen in the peat, reported by the same authors, indicates that no major environmental changes can be detected in the vegetation composition over this period.

Ciesiolka (1987) has reported on measurements of slope and gully erosion in a nearby part of the Nogoa catchment and has dated some alluvial fan deposits. Ciesiolka's dates and those reported above indicate that erosion events prior to European colonisation have not been synchronous. He reports that survey records indicate gully erosion throughout the area shortly after the arrival of the Europeans (and their livestock). Severe gully erosion is currently widespread throughout the catchment (Skinner et al., 1972) and both the main Nogoa channel and Louisa Creek are now in an erosional phase. Despite this widespread erosion, much of the sediment, especially the coarser fraction, is being redeposited within the catchment system. The modern erosion is unusual in the historical context because of its synchronisation across the catchment; in other ways the system remains the same with sediment being transported only short distances and redeposited.

The Brown River

The Brown River drains the Arcadia Valley southeast of Rolleston and is another upstream tributary of the Fitzroy system. Below its junction with Moolayember Creek the Brown River is known as the Comet. Geologically and topographically the catchment of the Brown is similar to that of the Nogoa and the channel network also is not well integrated with many streams spreading onto alluvial fans as they enter the valley.

The channel of Moolayember Creek is flanked by sand levees where it joins the Brown River. This sand deposition by Moolayember Creek has effectively blocked the valley of the Brown River impounding Lake Nuga Nuga. Moolayember Creek is perched above the general level of the valley floor between natural levees. Some of the flow in this creek breaks out to the south through crevasses in the levees and flows up-valley into Lake Nuga Nuga.

The channel of the Brown River terminates in a bird's foot delta where it enters Lake Nuga Nuga. On the first map of this area drawn by surveyor Vernon Brown in 1866, this delta is shown and he has noted on the map that "the river here spreads out over large flats and cannot be traced". Much of what is now Lake Nuga Nuga is described on the map as "swamps", "open flooded box flats", "oak scrub" and "open brigalow scrub". The lake was mapped and named but it was small with an area of only about 0.5 km^2. The present lake covers an area of some 17 km^2.

The trees which Brown noted on his map are all now dead and many can be seen still standing on the bed of Lake Nuga Nuga. The historical records do not give the date of the expansion of the lake to drown the trees but local anecdotal evidence suggests that it may have been around 1880. The lake expands and contracts over short time scales in response to seasonal and annual variations in rainfall but it also fluctuates over longer time spans, sufficient for mature trees to grow on its bed. These longer term fluctuations appear to be in response to the behaviour of the levees of Moolayember Creek which impound the lake, suggesting that periodic sediment accumulation and stripping is occurring there.

The present water level control on Lake Nuga Nuga is a debris dam consisting of timber ranging in size from small sticks to large tree trunks. The longer term fluctuations in the size of Lake Nuga Nuga may be related in part to the formation and destruction of these debris dams. Another contributing factor to this behaviour could be the occurrence of large floods in either the Brown River or Moolayember Creek. A large flood in Moolayember Creek but not in the Brown River could result in deposition at the junction which blocks off the Brown; when the Brown River floods it could erode a channel through the Moolayember Creek deposits.

For the Brown River, the sediment being transported into the delta is fine sand and silt, coarser material being stored on the alluvial fans further up the valley. This is in contrast to Moolayember Creek which is transporting and depositing coarse sand at this site. Only clays in suspension now pass downstream from the Brown River system beyond Lake Nuga Nuga and the geomorphology of the site suggests that no coarse sediment from the catchment of the Brown River has passed downstream beyond the lake for a considerable time, perhaps thousands of years. No formal analyses have yet been carried out of the hydrology, sedimentology or geomorphology of this area.

Discussion

This brief description of two tributaries of the Fitzroy system indicates that storage delay times for sediment are quite long, certainly in the order of thousands of years. It also reveals that the knowledge base is limited and that there is considerable scope for further work. In considering the need for expansion of the knowledge base (as distinct from the data base) it is worth noting that there are a number of significant differences between Australia in general (and the Fitzroy Basin in particular) and the humid temperate zone of the northern hemisphere where much of the literature originates, which limit the transferability of conceptual approaches developed there. Geological erosion rates in Australia are significantly lower than in North America and Europe, largely because of the tectonic stability and low relief of the Australian continent (Lambeck and Stephenson, 1986).

The hydrology of Australia is also significantly different to all other continents except southern Africa. Australian rivers have annual flows two to three times more variable than those of comparable rivers in other continents. More importantly in terms of erosion and river channel behaviour, the floods of Australian rivers show more extreme behaviour than those of comparable rivers in other continents. The ratio of the once in 100 year flood to the mean annual flood is a useful measure of flood variability. The mean value for the rivers of the world is 3.67, for Australian rivers it is 5.08 (McMahon et al., 1992) while for the Nogoa at Emerald it is 7.50.

Data presently available for the Nogoa suggest that while in the past erosion events have not been synchronous across the catchment, widespread gully erosion followed European settlement. This modern synchronised erosion phase may have been triggered by disturbance, perhaps by the introduction of cattle which naturally congregate in the moister valley bottoms of this otherwise dry environment.

Skinner et al. (1972) considered that the present widespread erosion was a response to grazing pressure and recommended that action be taken to reduce the erosion so as to control sediment yield to protect the Fairbairn Dam. The evidence presented here for the Nogoa and the Brown catchments indicates that sediment storage times are very long and that therefore any action taken to reduce erosion in the catchment would be unlikely to have any discernible effect on rates of sediment accumulation in the Fairbairn Dam within the management time frame.

The ideas of integrated catchment management have often been used to justify carrying out soil stabilisation works on catchment slopes to protect downstream areas. In the early 1960s, soil conservation measures were carried out in the catchment of the Eppalock Dam in central Victoria to prevent the dam from being infilled with sediment. No follow up analyses of the effectiveness of this work has ever been carried out and it simply assumed by the responsible government agencies, without testing, that they have been effective.

More recently, pressure from the Snowy River Improvement Trust in East Gippsland caused the Victorian Department of Water Resources to investigate the possibility that agricultural soil erosion in the Monaro area of New South Wales was causing accelerated modern deposition in the channel and on the floodplain of the Snowy River at its downstream end. Studies on the history (Finlayson and Bird, 1989), geomorphology (Brizga and Finlayson, 1992) and sedimentology (Caitcheon et al., 1991) of this system have shown that much of the sediment mobilised by accelerated soil erosion in the upstream catchment has been redeposited there. The Snowy catchment is much steeper than the Fitzroy, it is in a more humid and less variable climatic environment and its drainage network is well integrated, yet here too the erosion of the upstream catchment is not apparent in sediment movement on the main river system.

Although few formal data are available, it appears from anecdotal information supplied by reservoir managers that large dams in Australia are not seriously affected by high rates of sediment input despite the widespread accelerated soil erosion associated with the introduction of European farming practices in Australia. Similarly there appears to be no evidence that accelerated soil erosion in Australian catchments has led to any increase in the rate of sediment delivery to coastal systems (Bird, 1983). The same is not true of smaller dams or on-farm dams high up in the catchment network or on valley side slopes (see, for example, Moore, 1990). Sedimentation rates in these dams are commonly high since they generally lie within the slope system where the mobilisation and redeposition of sediment is taking place.

Where problems of erosion and sedimentation have developed in Australian streams in the post European settlement period, the cause can often be traced to some impact on the stream channel rather than on the catchment. This has been demonstrated quite conclusively for rivers in Victoria by Bird (1980, 1982) and Brizga (1990). Nevertheless, the perception persists among river managers that catchment impacts such as forest clearing and bushfires are a major cause of alluvial river channel instability (Ministry of Conservation, Victoria, 1983).

Conclusions

"......very little direct linkage is visible between the erosion of uplands and the discharge of sediment at the mouths of large rivers. ....the time lags between erosion and sediment transport are such that the sediments being carried by large rivers today may represent episodes of erosion that occurred decades, centuries, or even millenia ago." Meade (1988, p171) wrote this largely on the basis of experience of rivers in the United States. Similar time lags can be expected in Australian rivers.

The data presented here suggest that sediment storage times in the Fitzroy basin are long (thousands of years) and this is important in planning the use of resources in catchment management. Money spent on ameliorating agricultural soil erosion is unlikely to have any impact on sediment movement in major rivers and must therefore be justified largely in terms of on-site benefits. More appropriate targets are the sources of turbidity in rivers and bank erosion on the main river channels.

The fully integrated channel network of the textbooks does not exist throughout the Fitzroy Basin. Local topography and dry conditions determine that the network becomes completely connected only occasionally. This, combined with very high levels of variability of annual flows and floods, even by Australian standards, suggests that there is a need to carry out fundamental research to provide a better understanding of the Fitzroy and similar systems as a basis for effective and cost efficient catchment management. Integrated catchment management is the most appropriate administrative framework within which to pursue these matters.

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PAPER PREPARED FOR THE "FITZROY CATCHMENT SYMPOSIUM"

Held 12-13 November 1992, at the University of Central Queensland.

TITLE: BARRAMUNDI IN THE FITZROY RIVER

AUTHORS: **Kim Martin & Bill Sawynok**

Because the Barramundi requires a habitat that provides access to both salt and fresh water at various stages of its maturity and to ensure successful procreation of the species, the Fitzroy River system with its extensive delta area coupled with its enormous freshwater catchment area is an ideal habitat for this famous fish.

Sexually mature adult fish breed in tidal areas in or adjacent to estuaries in the period between September and February each year. The fingerlings remain in the relative protection afforded by the mangrove areas of the estuary until summer monsoon rains come. When and if these heavy rains arrive causing minor to heavy flooding, the juvenile fish respond by heading upstream in search of lagoons and creeks where they can take up residence.

The small barra remain in this freshwater environment, feeding off the abundant food supply and growing rapidly. In this habitat, the barra quickly assumes the role of the chief predator apart from the crocodile of course.

Depending upon the size of the body of water the barra finds himself in, fish may grow to well over twenty kilograms and choose to remain in the area for a number of years. But as indicated earlier, all mature fish following the breeding urge, must return to the salt water to complete the cycle.

Since settlement in the area by white people last century, the Fitzroy River has been recognized for its barramundi. Commercial fishermen have been harvesting the river's barra since the early 1900's with recreational fishermen only really having an impact since the invention of suitable fishing reels some years later.

Following World War 2, records show that there were over 100 registered members of the Rockhampton branch of the Queensland Commercial Fishermen's Organisation as it is now known, seeking a living from the Fitzroy River and adjacent coastal strip. This figure has presently dropped to less than half that of the post war years.

Until fairly recent history, both commercial, and for that matter, recreational netting was allowed in freshwater environs. Commercial netters regularly worked the waters of the Fitzroy upstream of Rockhampton, possibly up as far as the Dawson and Mackenzie Rivers and every land owner adjacent to the river would set nets quite regularly to obtain fish for

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the family table. The area proved to be the ideal habitat for the barramundi's freshwater phase and anecdotal records and photographs exist showing the large catches made in the upper reaches of the river over half a century ago.

Even though the numbers of commercial fishermen working the river have decreased, technology has meant that the efficiency of their methods has improved greatly. This, coupled with the increase in pressure being applied by the recreational fishing sector compared to that a few decades ago, has probably at the very least, maintained the total removal pressure being applied to the resource.

However, by far the most serious blow imparted to the river's barramundi population was the construction of the barrage across the river at Rockhampton in the late 1960's.

Within a few short years of the barrage's completion, the population of barramundi in waters upstream of the structure had dwindled to almost zero. The barrage had proved to be an impenetrable barrier to the barra's normal migration pattern upstream each year, so that as the fish matured and travelled downstream to find the salt water, no small fish were making it upstream to take their place.

Literally hundreds of kilometres of prime barramundi river habitat was denuded of this majestic fish, a situation which sadly remains to this very day.

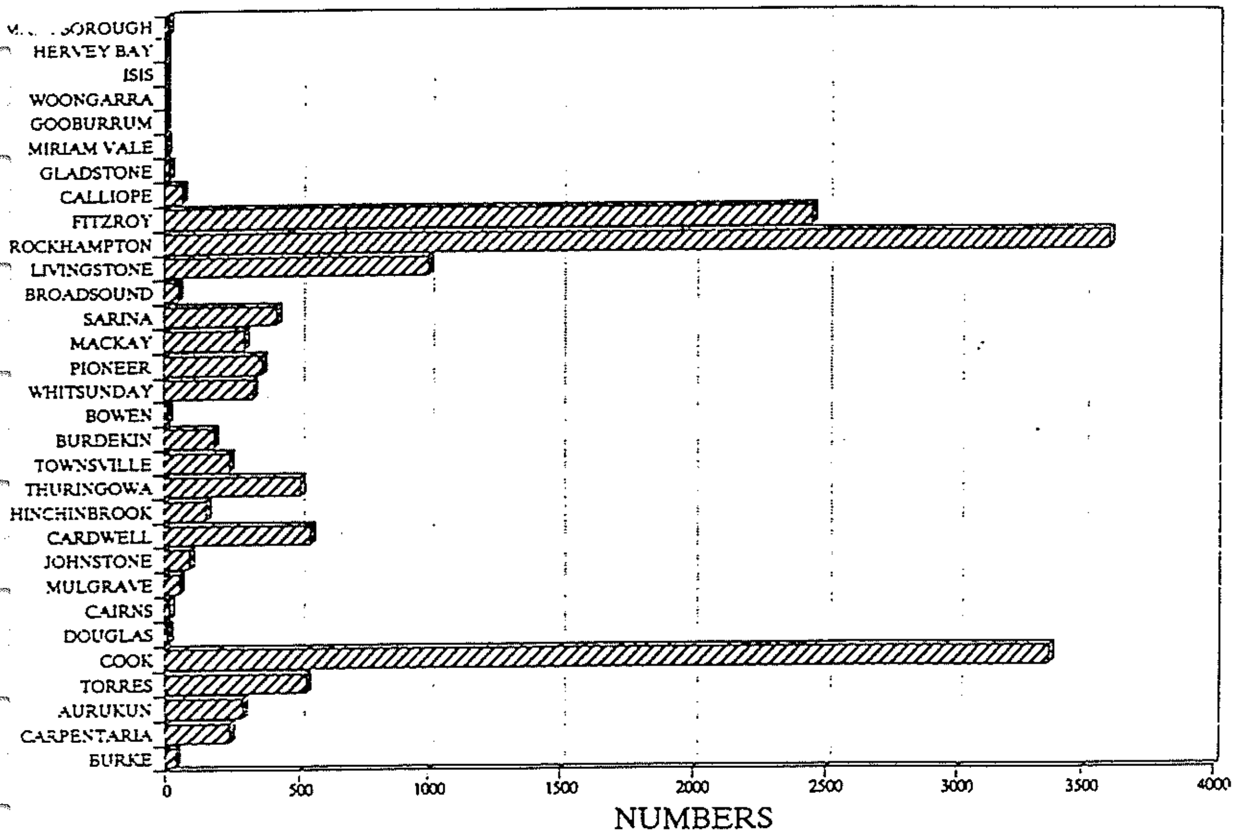
One of the best ways to obtain data and in fact monitor the status of a fish population is through a tagging program. The State Government through the Department of Primary Industries Fisheries Division working cooperatively with the state branch of the Australian National Sportfishing Association (ANSA), have in operation the "Sportfish Tagging Program". This program has been running continuously throughout Queensland for a number of years, but has, during the last four years in particular, really blossomed into significance.

Barramundi have been the most tagged of all eligible species under the program, with a total of 15,000 fish being tagged across the state up to the end of June 1992. Local Central Queensland based club, CAPTAG, has been heavily involved in the tagging of barra in the Fitzroy River in particular.

Under a special permit from the Department of Primary Industries, Captag members have been allowed to tag barramundi within the otherwise "closed to fishing zone" adjacent to the Fitzroy River Barrage. This has resulted in far greater numbers of barra being tagged in the system with the resulting data obtained building up a very comprehensive picture of the current status of the barramundi population in the Fitzroy River.

In fact, somewhere around 7000 barramundi have been tagged in Central Queensland to date(see Appendix 1), most of which have been tagged in the Fitzroy River, its tributaries or freshwater feeder systems.The following graph shows the numbers of Barramundi tagged in the state by Local Authority areas. (Note numbers in Livingstone, Rockhampton and Fitzroy Shires)

TAGGED BARRAMUNDI BY LOCAL AUTHORITY
SPORTFISH TAGGING 1985/92



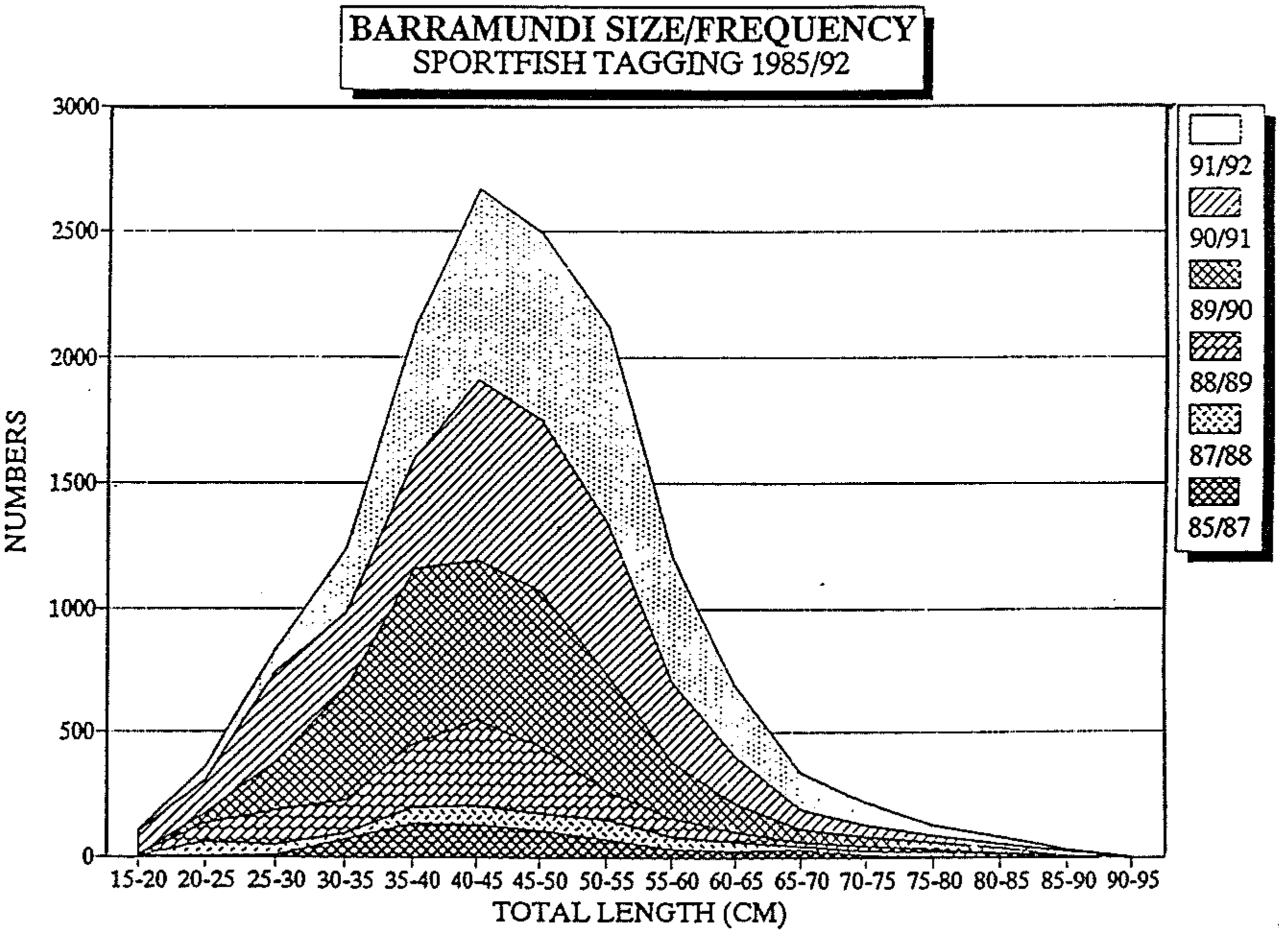
Statewide, there has been a tag return rate of approximately 10.8% for Barramundi, but the return rate in Central Queensland is significantly higher. This is due to a combination of factors, namely the relatively high pressure being applied to the barra population over a geographically limited area by both commercial and recreational fishermen and the fairly high profile of the importance of tagging being maintained by local club Captag.

There have been a number of very successful campaigns run to encourage fishermen to return tag information, with rewards for information being offered in the form of T-shirts and caps from the DPI, and even fishing equipment courtesy of local tackle dealers. Also a number of individual commercial fishermen have cooperated by returning tag information from fish they have caught, as well as one local Seafood wholesaler who advises details of any tagged fish which pass through his establishment.

Unfortunately, it is well known that there still exists a sizable illegal net fishery for barramundi in Central Queensland. This sector obviously catches tagged fish, but naturally will not supply details of these captures. There is no way of knowing exactly how many tagged fish are removed from the fishery by these illegal operators, however, net seizures by officers of the Boating and Fisheries Patrol often contain tagged barramundi. It is therefore reasonable to assume that the percentage of unreported tag returns from illegal netting activities is significant.

Because barramundi below the legal length (now 580mm) are particularly susceptible to being caught on lines, it is quite likely that a considerable number are being removed from the fishery by line fishermen ignorant of the impact their activities may be having on the resource. This is another source of unreported tag returns. Again, these fish will never be reported because of the illegal circumstances surrounding their extraction from the fishery.

The following graph depicting lengths of barra caught and tagged under the Sportfish Tagging Program gives credence to the above assertion that a large number of undersized barra are being caught by line fishermen and subsequently removed from the fishery. It is clear from the graph that the majority of fish being caught by line fishermen are below the legal limit. The assumption that a percentage of these are being kept instead of returned to the water is based upon anecdotal evidence from observations made by fishermen involved in the tagging program who regularly report instances of undersized fish being kept by other fishermen frequenting the same fishing locations as themselves.



So, whilst the official tag return rate for barramundi in the Fitzroy system is a staggering 18.2%, when the potential for non-reported tag returns is taken into account, the real return rate is most likely anywhere in the region of 25% to 30%. A return rate of this proportion should sound alarm bells within fish management circles because such a sustained pressure will surely have a destructive effect on the fishery.

Growth rates of barramundi have been studied for some time now and data gained through the tagging program has verified the results obtained through these studies. As a generalisation, it would appear that barra within the Fitzroy system achieve a growth rate of approximately 1mm per day up to a length of 600mm. Once fish reach this length, they deepen and increase their weight more so than the rapid overall length gains previously achieved.

There have been some quite long term barra tag returns notified through the program, the longest of which was a fish at large for a period 1610 days!

One example of the growth rate of barra within the Fitzroy system was a fish of 330mm originally tagged in the freshwater section of Gavial Creek in February 1989, recaptured by a commercial fisherman in the Fitzroy River downstream of Rockhampton City in April 1992. When recaptured, it had increased its overall length to 860mm. In weight terms, this was an increase from less than a kilogram to a strapping 7.3 kg. in a little over three years.

Just as a matter of interest, and to highlight the susceptibility to capture of barramundi, the shortest recorded period for a tag return was an incredible 10 seconds! The fish was tagged and released by one angler, and immediately attacked the lure of his fishing companion casting nearby and was captured again. In fact it has not been uncommon at all to have barra recaptured again on the same day that they were tagged.

One of the more important aspects of useful information retrieved from the tagging of barramundi in the Fitzroy system has been the movement patterns of the fish. As discussed earlier in this paper, barra move freely between fresh and salt water. Following summer floods, taggers in Central Queensland frequent the many freshwater lagoons and creeks associated with the Fitzroy system, in particular the area known as the Twelve Mile near Marmor, and the lagoon system just south-west of Rockhampton city.

Large numbers of small barramundi enter these areas during the floods and are easy targets for line fishermen. Almost all these fish are well below the legal limit though and therefore should be returned following capture. These fish offer an excellent opportunity for tagging, as they will only remain in the freshwater for a season or two before returning to the salt water. Countless small barra tagged in these freshwater areas have been recaptured at a later date in the Fitzroy River or associated salt water streams.

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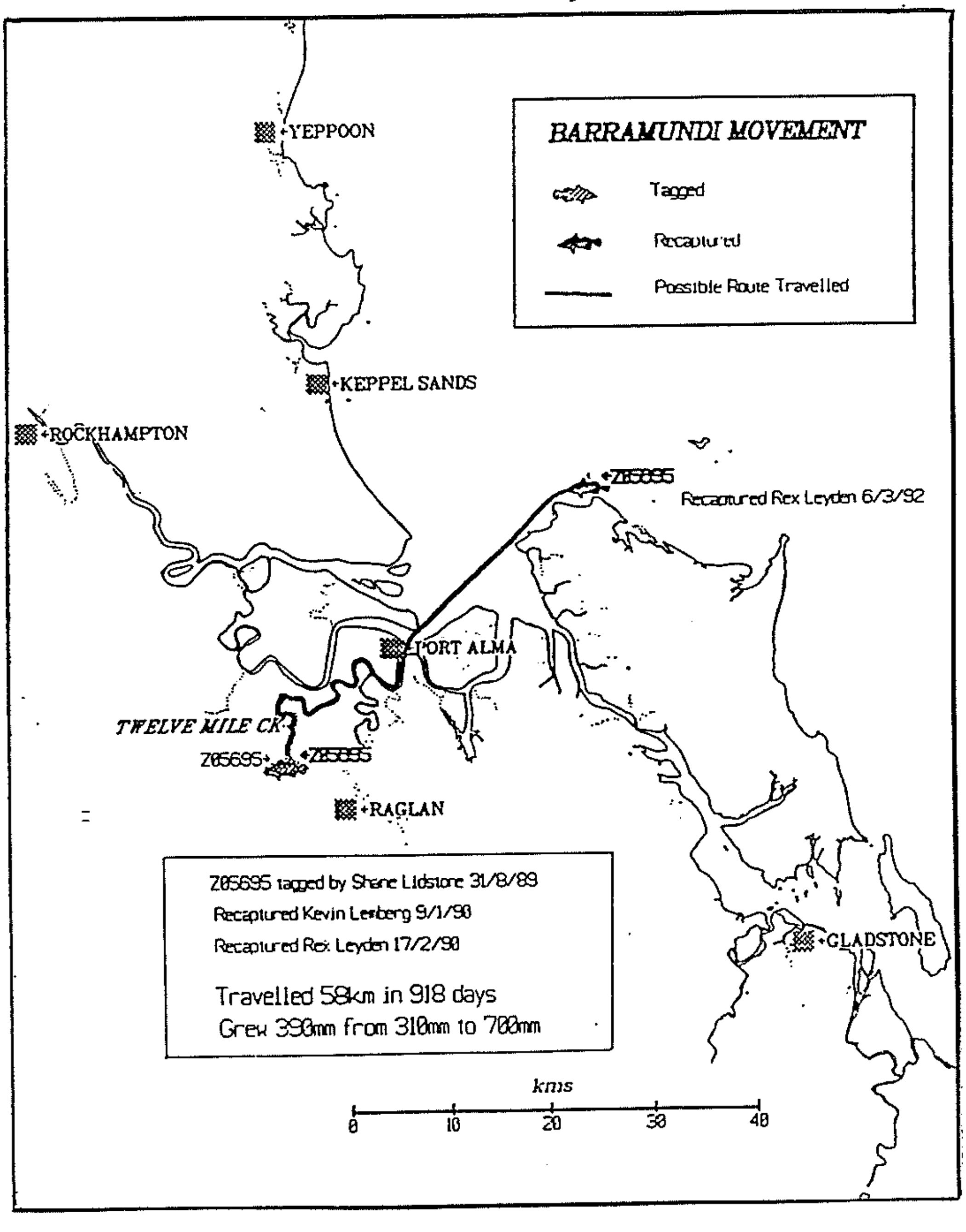
Tag return data seems to indicate that the barramundi usually remain in the same system or river for at least the first few years of life, as only a very small percentage of reported tag returns come from fish which have travelled between systems. For reasons unknown, there is a definite trend for those fish which do move, to move in a southerly direction. A small number of fish tagged in the Fitzroy system have been recaptured in the Gladstone area and further south, but no reports have been received of tagged barra travelling north from the Fitzroy River to Corio Bay, which would seem an obvious alternative.

The following map shows the movement of one quite "famous" barra. This fish was captured on no less than FOUR separate occasions over a period of two and a half years, incredibly, by the same person twice, twelve months apart. It moved from the freshwater in the Twelve Mile Creek, out to sea to Station Point on the northern side of Curtis Island, a distance of about 58 kilometres. During its two and a half years of freedom, the fish grew from 310mm to 700mm.



The tagging program in the Fitzroy River is providing comprehensive, reliable data which will be invaluable in the future to persons and agencies charged with the responsibility of developing management principles and strategies aimed at sustaining a viable barramundi population in the system for generations to come.

MANAGEMENT ISSUES

The following management issues are those which we see as being paramount to the survival of the barramundi within the Fitzroy River system.

1. **PROVISION OF A FISHWAY/TRANSFER DEVICE AT THE FITZROY BARRAGE IN ROCKHAMPTON WHICH WILL BE USED BY BARRAMUNDI TO GAIN ACCESS TO THE FRESHWATER SECTION OF THE SYSTEM.**

If some form of fishway can be devised that barramundi will use, within a very short time the upper freshwater reaches of the Fitzroy River will again become the domain of this mighty fish. If such natural restocking were to occur, there is no reason why a flourishing tourist industry based upon barramundi fishing could not be established in Central Queensland. Currently, fishermen from all over the country pay large amounts of money to travel to the Northern Territory and far north Queensland specifically to catch a Barramundi. If they could be assured of catching their prize in Central Queensland, at a greatly reduced travel cost, there is little doubt that many anglers would prefer to fish in our waters.

While it could be argued that there still exists a reasonable barramundi population in the lower Fitzroy despite the barrage, it should be remembered that there have been a succession of significant floods in recent times which have allowed some barra to make their way upstream via an alternative route through the lagoon system to the south and west of Rockhampton.

If we were to see an extended period during which time no large flooding occurred, it is quite possible that the barramundi population could be seriously depleted and it is debateable whether the population could recover and reestablish itself again.

Whilst the following management issues are also of importance to the future of the barramundi in the Fitzroy system, we believe that the provision of a successful fishway should be viewed as the most urgent and receive priority status.

2. **LIMITING OF THE TOTAL REMOVAL PRESSURE BEING APPLIED TO THE RESOURCE.**

In recent years, fish management authorities have recognized the need to implement strategies aimed at providing a measure of protection to the Barramundi in Queensland. These include bag limits for recreational anglers, estuarine closures to commercial netting and a closed season during the recognized breeding time.

All of these measures should be applauded and must have a positive effect in terms of affording protection to the resource. However, no investigation has been done with regard to the total removal pressure being applied to the barramundi fishery. In fact, it is not known exactly how large the resource actually is.

It is a basic principle that to sustain a renewable resource of any kind indefinitely, the removal rate must be significantly less than the replacement rate. This is particularly true of a fishery, where climatic and other environmental influences have an impact on the resource as well.

The tag return rate for barramundi in the Fitzroy River system as stated previously in this paper, is cause for very serious concern in terms of the removal rate. It should be stated that a number of tagged fish recaptured by recreational fishermen are below the legal length and returned to the water, so that the 18.2% return rate referred to is not necessarily an accurate representation of the real removal rate. However, when unreported tag returns are taken into account, the real removal rate for barramundi in the Fitzroy system is probably in the vicinity of 20% or more.

Such a high figure is disturbing without even knowing what the size of the total resource is. We contend therefore, that some means of limiting the known removal rate be investigated. The existing bag limit of five fish in possession for recreational anglers should be sufficient to limit the numbers being removed by this sector, however apart from log book returns from commercial operators, which often lack accuracy, it is difficult to ascertain the extraction rate attributable to commercial fishermen.

Limiting of commercial fishermen's barramundi catches is almost impossible and even unfair, but there is a strong argument for limiting the number of commercial operators licensed to fish in a given area. In terms of the Fitzroy River, a maximum number of licensed operators able to fish the river and associated environs could be decided upon, which would enable a more accurate account of fish being removed to be kept, and it would also allow these individual operators to reap a better living than many are probably currently doing.

At least a more accurate picture of the pressure on the fishery could be maintained and if deemed necessary, catch limitations could be invoked in poor seasons as a means of protecting the existing breeding stock until a favourable wet season eventuated. Inherent in this philosophy is a significant degree of local involvement in management guideline formulation.

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3. BARRAMUNDI FOODCHAIN PROTECTION

The extensive area of estuarine environment around the Fitzroy River delta is extremely important to the life cycle of the barramundi. In particular the prawn population in the area is a primary food source for the juvenile barramundi as well as a food source for other small fish which in turn become the food of the adult barramundi.

The danger to this invaluable food resource comes from the commercial trawlers fishing the area. While there is little argument that the prawn population is of sufficient size to sustain a reasonable level of commercial effort, it is becoming alarmingly apparent that increasing numbers of such trawlers and the vastly improved apparatus being used by them in this area have the potential to significantly deplete the prawn resource in a very short period.

Such a depletion would certainly impact heavily on the barramundi and could cause a drastic reduction in numbers throughout the entire system. Again a solution might be to impose limitations on the numbers of trawlers licensed to operate in the area, with further limitations on the minimum size of the prawn being targeted so as to protect the resource from overexploitation at an immature stage, which is unfortunately happening at present.

4. HABITAT PROTECTION

Too often, habitat protection is thought of in terms of "destruction" only. Protection of a habitat should begin long before the "destruction phase" has been reached. The construction of the Fitzroy River barrage is a prime example of how a habitat can be adversely affected with minimal actual "change" to its physical appearance.

Barramundi habitat requirements are very diverse as previously detailed, and small changes in one area, may result in catastrophic consequences for the whole future of the population.

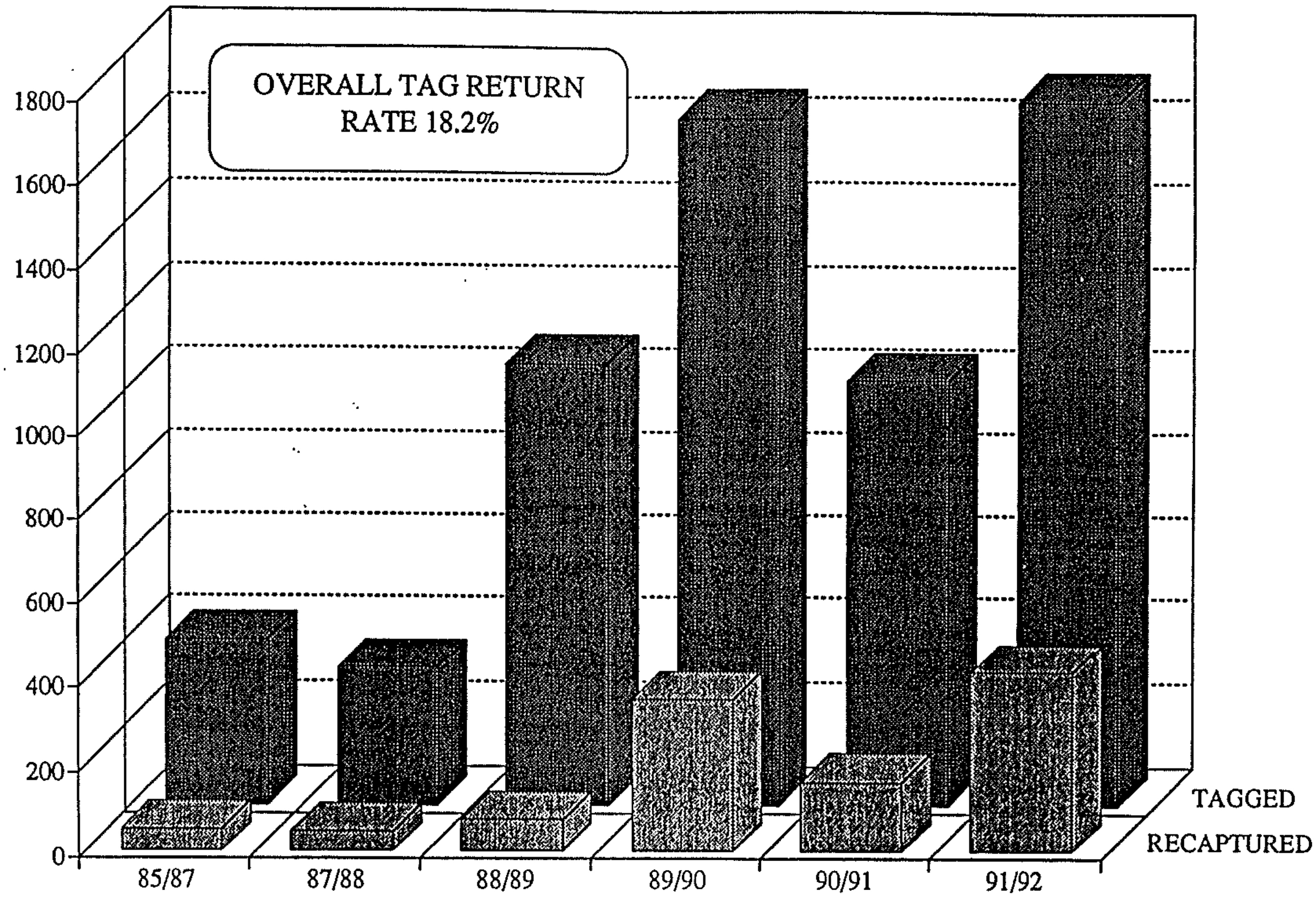
Weirs and dams of course are of major concern, but the reckless establishment of ponded pastures in tidal and associated coastal wetland can be very damaging also. Mangrove stands are important both in terms of cover for the juvenile fish as well as a feeding ground for barramundi of all sizes.

Even upstream in the freshwater, the quality of the water in terms of insecticide and fertilizer residue must be closely monitored. Also in the same freshwater environment, it is important to leave sufficient natural cover along the edge of the waterway, such as fallen trees, for the barramundi to use as an ambush point and cover. Even waterlevel variations caused by weirs may adversely change the habitat, making the water too deep and dark for efficient sight feeding, as is the nature of the barramundi in this regard.

The barramundi has always been synonymous with the Fitzroy River, and with thoughtful management, will remain so into the future.

APPENDIX 1

BARRAMUNDI TAGGED/RECAPTURED
FITZROY RIVER SYSTEM



SOIL EROSION AND ITS MANAGEMENT IN THE CROPPING LANDS OF THE FITZROY RIVER CATCHMENT

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1.0 Introduction

Soil erosion by water in the extensive cropping lands of the Fitzroy River catchment is a serious problem threatening the long term productivity of the area.

The rapid development of new cropland in the early 1980's resulted in the area of unprotected cropland increasing at a rate of about 50000 hectares per annum.

The annual cropping of erodible soils combined with high intensity but variable rainfall has resulted in the Fitzroy catchment croplands having one of the highest erosion risks in eastern Australia.

This paper describes the nature and extent of the soil erosion hazard in the Fitzroy catchment and outlines some land use and land management options needed to minimise the problem.

2.0 Climatic influences on Land Use and Erosion Hazard

Rainfall in the Fitzroy Catchment is characterised by a marked summer dominance, extreme variability and high intensity. Throughout the area, mean annual rainfall varies from 500 - 700mm with approximately three quarters falling in the summer months. Winter rainfall is generally low and extremely variable. High intensity storms or short term droughts can occur during any month of the year. In summer, storms with rainfall intensities of 80mm/hour are not uncommon.

Heat waves or periods of high temperatures restrict the early planting of summer crops. Late planted summer crops or early planted winter crops are susceptible to frost damage.

3.0 Land type influences on cropping and soil erosion

Currently, about 700000 hectares are cultivated in the Fitzroy River catchment. The majority of the cultivated area is restricted to the clay soils of the Open Downs and Brigalow land types because of their higher moisture holding capacities. The open downs cracking clay soils are more prone to rill and gully erosion than the brigalow clays where sheet and rill erosion are the more common forms of erosion. Gully formation often restricts the workability of cropping areas whereas sheet erosion, whilst not as obviously can remove fertile topsoil

The dryland cropping soils are moderately fertile but deficiencies in nitrogen and phosphorous are common after years of continuous cropping. The open downs clay soils are generally less than 90cms to bedrock and the brigalow clay soils have increasing salinity levels below 45cms.

Due to the shallow nature of most of the cropping soils, plant available water is the most limiting factor for crop production. Consequently, loss of soil depth due to erosion has very severe consequences on plant available water.

Land slopes for the open downs and brigalow clays range from 0.5% to 3%. Slope lengths vary, however slopes up to 1.5 kilometres long are common in the open downs land types.

4.0 Effects of cropping systems on soil erosion

Summer cropping increases the erosion hazard as summer plantings occur when most of the erosion rainfall occurs. Soils are exposed when the land is being prepared for planting or early crop growth provides insufficient cover to minimise erosion.

Winter cropping offers the opportunity to retain suitable cover through the period of high rainfall erosity. This applies particularly to wheat where dense cover levels can be maintained by appropriate management practices.

The choice of crop type has a major effect on erosion risk. Sunflower produces its maximum canopy cover in April/May, well after the period of high erosive rainfall. Following harvest, very little stubble cover remains to protect the soil.

Sorghum provides much more cover following harvest and unlike sunflower, the fibrous root system helps to bind the soil close to the surface. Wheat stubble provides the best post harvest soil protection.

The area planted to various crops in the catchment fluctuates significantly with rainfall patterns. However Table 1 provides a comparison of the area planted to the three major dryland crops grown in the catchment.

Table 1: Five year area mean for major dryland crops for years 1981 - 1985 and 1986 - 1990

CROP TYPE	AREA MEAN 1981 - 1985 Ha	AREA MEAN 1986 - 1990 Ha
Sorghum	232500	204000
Sunflower	103000	80000
Wheat	144000	191000

Source: Australian Bureau of Statistics

6.2 Crop Rotations

Sorghum is generally planted into a fallow in which soil moisture has accumulated. This fallow usually follows a sorghum or sunflower crop but occasionally may follow wheat grown either three or fifteen months previously. It is highly desirable to include wheat as part of any crop rotation because of its high stubble levels. Another important strategy is to plant sunflowers into wheat stubble because soil moisture can be accumulated between a wheat harvest in October and a sunflower planting in February and the stubble provides adequate ground cover for erosion control during the sunflower cropping period.

This wheat/sunflower rotation has become widely accepted in the Central Region and many sunflower growers claim that their best crops have been those double cropped following wheat.

The inclusion of a pasture, preferably legume based, for a number of years in any cropping system is highly desirable. Soil structure and soil nitrogen can be improved and the erosion risk reduced.

6.3 Opportunity Cropping

Every opportunity must be taken to plant a crop when soil moisture is adequate. Over 90% of summer rainfall can be lost from the fallow by evaporation. Therefore, soil water is best utilised by a growing crop rather than be lost through evaporation or runoff when high rainfall occurs. However, farmers planting crops on an opportunity basis, away from normal planting periods, must consider the risk of crop damage due to frosts or heat waves during critical flowering periods.

Cropping opportunities can be increased by maintaining stubble levels through the fallow. High stubble levels, particularly late in the fallow, improve water infiltration and increase planting opportunities.

6.4 Fallow Management Practices

Stubble cover is the single most important factor to minimise erosion. Stubble levels can be maintained throughout the fallow by reducing tillage. Different tillage implements vary in the degree of stubble incorporate. Blade ploughs have least effect with only about 10% of the stubble incorporated. Chisel ploughs and scarifiers incorporate 25% to 30% whereas one way disc ploughs incorporate at least 50% of the stubble in each operation.

Herbicide usage for weed control is increasing in the Central Region. Substituting herbicides for tillage operations prolongs the life of the stubble through the fallow. Where is necessary to reduce stubble levels to avoid blockage with planting machinery, stubble reduction is best carried out late in the fallow.

Where stubble levels are low, some form of tillage may be needed to increase surface roughness to slow down runoff. Cultivating to produce coarse, cloddy tilth increases surface detention and slows sheet flow.

5.0 Extent of Soil Erosion in the Catchment

Currently, some 563000 hectares of the 690000 hectares of cultivation in the Fitzroy catchment are prone to soil erosion. The following table illustrate the extent of erosion prone land on a Shire basis in the catchment.

Table 2: Extent of Erosion Prone Cropland as at May 1992

Shire	Area of Cultivation Ha	Area of erosion prone cultivation Ha
Banana	170000	137000
Duaringa	92000	80000
Bauhinia	144000	115200
Emerald	90000	72000
Peak Downs	124000	99200
Belyando (part)	23000	21000
Broadsound	30000	25000
Livingstone	6700	5200
Fitzroy	10500	8200
TOTAL	690200	562800

Source - Land Conservation QDPI statistics 1992

6.0 Land Use and Land Management options to minimise the problem

6.1 Choosing Suitable Crops and Crop Rotations

At least 30% surface cover is needed to reduce soil losses to acceptable levels and even higher levels of cover are required to substantially reduce water runoff.

The type of crop grown and the fallow management practices that are applied have a major effect on surface cover as shown in Table 3

Table 3: Change in crop stubble cover over the fallow period.

Tillage method	Stubble cover percent at the end of the fallow		
	Wheat	Sorghum	Sunflower
Zero tillage	86	48	35
Reduced tillage	50	30	17
Conventional tillage	26	20	5

Source. Carroll and Fossett, 1988

Other benefits of conservation tillage are reduced farm machinery and labour costs. Spraying for weed control can be carried out in a fraction of the time taken to cultivate, leaving labour available for other tasks. Tractors and tillage machinery last longer and depreciation costs are lower than that with conventional tillage.

6.5 Control of Surface Runoff

Runoff control structures such as contour banks and waterways are effective in reducing rill and gully erosion. However, unacceptable soil loss still occurs between the contour banks when the soil is bare, for example Sallaway *et al.* (1983) have shown that an accumulated seasonal soil loss of over 13 tonnes per hectare was lost in runoff from bare contour bays. Contour banks are placed strategically down the slope to segment the length of slope and control runoff. Spacings range between 80 and 120 metres depending on the degree of land slope. A slight gradient along the bank ensure that runoff is safely conveyed to water disposal areas.

Costs to construct contour banks vary from $ 80 to $ 100 per hectare depending on spacing and construction machinery used. Annual maintenance costs average $ 8 to $ 10 per hectare. Runoff control structures have been readily accepted by landholders. Table 4 shows the implementation rate of contour banks in the cropping lands of the Fitzroy catchment from 1980 to 1992.

Table 4: Implementation of soil conservation structures in the Fitzroy catchment 1980 - 1992

Year	Area of cropland requiring protection Ha	Area of cropland protected with structures Ha	% of erosion prone to cropland protected
1980	294000	131600	45
1984	440500	242900	55
1988	535000	297900	56
1992	562800	344700	61

Source. Land Conservation, QDPI Statistics

7.0 Conclusions

Soil erosion is a major threat to long term productivity of the croplands of the Fitzroy River catchment. However, with current trends in the adoption of land management measures by rural landholders, soil loss rates are being significantly reduced. A combination of land management works and practices is needed to reduce soil losses to acceptable levels. The following land use and land management practices should be integrated into farming systems:

- crops should be planted whenever soil moisture is adequate;

- high stubble wheat crops must be used in rotation with low stubble crops such as sunflower

- stubble cover must be maintained at high levels using appropriate fallow management practices and

- runoff control structures such as contour banks need to be constructed on all sloping land.

8.0 References

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ECOLOGICAL BASIS FOR INTEGRATED CATCHMENT AND RIVER MANAGEMENT: ESSENTIAL RESEARCH IN THE FITZROY RIVER CATCHMENT

by

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FITZROY CATCHMENT SYMPOSIUM

November 1992

ABSTRACT

The management of a large river system such as the Fitzroy River in a sustainable state requires a sound knowledge of ecological linkages between the catchment and its watercourses, and of the processes which determine the water quality, physical condition and ecological "health" of the river and its tributary streams. When these linkages and processes are understood in quantitative terms, it is possible to develop predictive models which can be used to establish management guidelines for catchment land use, riparian vegetation protection, flow regulation and so on, to meet environmental and water quality objectives. Predictive models are also required to underpin the development of practices which will improve the condition of degraded rivers and streams so that their biota are retained or rehabilitated. CCISR (the Centre for Catchment and in-stream Research) is presently developing the second stage of a long-term research program designed to provide a sound ecological basis for the integrated management of Queensland rivers. This paper outlines the new research program in general terms, showing how it will assist in the management of catchments and rivers in an integrated framework. The studies outlined are expected to assist in the further development of a classification scheme for Queensland rivers. The Fitzroy catchment will be one of the major study areas for the program, and a major objective of the study will be to determine how similar or different it is to the Burdekin River and other rivers studied to date.

1.0 INTRODUCTION

The management of a large river system such as the Fitzroy in a sustainable state requires a sound knowledge of catchment and river linkages, and of the processes which govern the water quality, physical condition and ecological "health" of the river and its tributary streams. When these linkages and processes are understood in quantitative terms, it should be possible to develop predictive models which can be used to establish management guidelines for catchment land use, riparian vegetation protection, flow regulation and so on, to meet environmental and water quality objectives. Predictive models are also required to underpin the development of practices which will improve the condition of degraded rivers and streams so that their biota are retained or rehabilitated. We have a limited but growing knowledge of the ecology of Queensland rivers, especially in relation to the distribution and habitat requirements of fish and aquatic invertebrates, but there are no quantitative models of the type required for integrated catchment and river management.

CCISR (the Centre for Catchment and in-stream Research) is presently developing the second stage of a long-term research program designed to provide a sound ecological basis for the integrated management of Queensland rivers. Initially this program will focus on the maintenance of diverse and healthy fish communities, building upon research already undertaken during a prior project called the "The Ten-rivers Study". From this basis, and as time and resources permit, our research group proposes to address additional issues, particularly the influence of riparian vegetation on river ecology and water quality, and the most appropriate and robust methods for monitoring river 'health'.

The objective of this paper is to outline the research program in general terms, showing how it will assist in the management of catchments and rivers in an integrated framework. The Fitzroy catchment will be one of the major study catchments for the research program.

2.0 RELATIONSHIP OF RESEARCH PROGRAM TO ICM AND RIVER MANAGEMENT

2.1 Integrated Catchment Management

The Queensland ICM initiative, and Total Catchment Management in other states, provide a rational framework for the sustainable use and management of natural resources. Knowledge of these natural resources is increasing but most land use decisions have been made without any capacity to predict their effect on adjacent and more distant components of the landscape. As a result, the physical condition of many rivers and streams is degraded, water quality problems are increasing, the biological resources of rivers are threatened and the amenity value of many rivers is reduced.

As part of the Queensland ICM initiative, the Water Resources Commission is developing a methodology for assessing the physical characteristics and environmental condition of streams and rivers. When implemented on a catchment by catchment basis, it will ultimately produce a regional and state-wide classification of rivers, based on the climatic, geomorphological and topographic variables that determine valley and channel morphology, the flow regime and the physical habitat characteristics of streams.

The crucial next step is to establish relationships between these physical descriptors of catchments and streams, and the biological communities they support. The great value of a classification of river and stream types is that once critical biophysical relationships (models) are established for selected rivers within each regional type, the biological properties of other rivers of the same type can be predicted from the model. Management practices can then be developed which will, within certain margins, be applicable in all rivers of a regional river type.

The development of comprehensive biophysical models for Queensland rivers of each regional type would be an enormous task, and the best way to proceed rapidly is to focus on one major component of the aquatic ecosystem, such as the fish community. The advantages of working with fish are that there is already solid information on their distribution in many Queensland rivers, they are generally not difficult to survey and identify, and public action groups such as LandCare and ICM committees can assist with activities directed towards protection of fish, especially rare species and those of significance for recreational fishing. By protecting the fish fauna of rivers, many other biological components (e.g. invertebrates) and important ecological processes (e.g. energy flow through food chains) will also be protected. Over time, information about other biotic groups can be incorporated into models concerned initially with the fish fauna, and this is our long-term objective.

Research by our group (CCISR) on the flow regimes, physical habitat structure and fish communities of 10 Queensland rivers ("The Ten-rivers Study"; Pusey, Arthington and Read), extending from the Albert and Mary in S. E. Queensland to the Pascoe on Cape York Peninsula, has tentatively established that these rivers can be grouped into three, possibly four, biophysical regional types: Type (1) S. E. Qld rivers (e.g. the Albert and Mary); Type (2) Central Qld rivers (e.g. the Burdekin and Fitzroy system); and Type (3) Wet Tropics rivers (e.g. the Mulgrave, Russel and Sth Johnstone rivers). Cape York rivers (e.g. the Normanby) have some physical and biological features consistent with the Burdekin system, but their position in this regional classification remains to be determined.

Within each regional river type, the influences of the flow regime and in-stream habitat diversity on fish diversity and community structure have been partially established, but there are many unresolved issues and gaps in the knowledge base. In the Mary (Pusey et al. in press) and Albert rivers, S. E. Qld, fish community structure can be predicted accurately (80-92% successful) from variables describing habitat structure (substrate, depth, water velocity, and cover, such as aquatic plants, litter and snags). The Burdekin River and several Cape York rivers show a different set of relationships. In the Burdekin, because of the monotonous nature of the habitat over much of its length, fish diversity is relatively low and fish community structure is only weakly predictable from habitat structure. The variability of recruitment success with varying wet season flows and flooding appears to be much more important in determining fish community structure (Read et al. 1992).

In some Cape York rivers, habitat structure and the presence of predators are the probable determinants of fish diversity and density. The significance of these factors in turn depends on the morphology of the river valley and the extent of wet season flooding. Within floodplain lagoons, both predators and habitat complexity (particularly the presence of cover and refuges from predation) combine to determine which species survive to recolonise the main stream channel upon resumption of the wet season (Kennard, pers. comm.). Finally, in rivers of the wet tropics (Mulgrave and Sth Johnstone), stream gradients, habitat structure and biological interactions (competition for food, predation) appear to determine fish diversity and community structure but there are unresolved influences of flow variability.

In summary, we have regional river models which, with various levels of confidence, enable us to predict fish community diversity and structure from physical habitat structure, which in turn is related to the flow regime and channel morphology. To capitalise on this research and apply the findings to ICM, these models must be extended in several ways.

Firstly, we need to establish the relationships of geographical catchment characteristics, channel morphology, the flow regime, and habitat structure within each system. This research will answer such questions as: What is the dominant discharge responsible for maintaining stream channel morphology and what is its frequency? Are there geographical differences in stream morphology within and between river regions and how do these difference compare with patterns observed elsewhere in Australia and overseas? What is the time-scale of change to channel morphology following perturbation of the catchment and is this the time scale that management practices for rivers in general are aimed at? Are geographical differences in catchment and channel morphology reflected in differences in stream habitat for fishes and in habitat at various longitudinal positions within the river?

Secondly, the models developed to date to predict fish community structure from physical habitat structure are based on a small selection of rivers and physical conditions. They must be extended to assess how habitat requirements vary in various Queensland river types and in order to incorporate seasonal variations in habitat requirements and preferences. This information will provide a basis from which to design management practices that consider the relationships between stream channel morphology, discharge, in-stream habitat and the needs of the biota. Data on the habitat requirements of fish can also be used to design methods of habitat rehabilitation, restoration or the construction of special types of habitat for biological purposes (e.g. spawning habitat). Two components of the research program are designed to address these issues.

2.2 In-stream Flow Requirements of Rivers

The management of river flows, and of catchment land-use practices which modify the flow regime, must be incorporated into the broad agenda of catchment management, as envisaged in the Queensland ICM initiative and Total Catchment Management in NSW. Research which addresses in-stream flow management should also be framed in this broader context. There are many difficulties and knowledge gaps hindering the development of strategies for river flow management in Queensland and elsewhere in Australia, and new approaches are clearly needed based on a sound knowledge of Australian rivers.

The recent International Conference on Water Allocation for the Environment (Pigram and Hooper 1992) concluded that an holistic approach is required to assess the water requirements of the entire riverine ecosystem (see Arthington et al. 1992a; King et al. in press). This approach maintains that if the essential features of the natural flow regime can be identified and adequately incorporated into a modified flow regime, then, all other things being equal, the extant biota and the structural and functional integrity of the riverine ecosystem should be maintained. Milner and Knights (1989) outlined a similar approach to assessing wetland water requirements in NSW.

Features of the hydrologic regime which are perceived to be important for maintenance of riverine ecosystems are: seasonal and inter-annual patterns of flow (Arthington et al. 1992b), variability and predictability of flow within seasons and from year to year (Poff and Ward 1989; Bunn and Boughton 1991), the timing, quantity and duration of low flows (Stalnaker 1981), flood flows of different magnitudes, duration and recurrence intervals (Reiser et al. 1989), and the consequent variability and predictability of water levels and habitat within river channels.

For many Australian rivers there are good long-term records of unregulated river flows from which the characteristics of natural flow regimes can be determined. For some systems, there are also catchment/river hydrological models which can be used to predict the flow regime under various scenarios of rainfall, natural recharge, water availability under storage and off-stream uses. However, there is very little quantitative information on the ecological significance of most attributes of natural flow regimes, and hence it is very difficult to predict the effects of modified flow regimes with any degree of confidence. Studies such as the Barker-Barambah project (Arthington et al. 1992b) are providing valuable data on the short-term effects of flow regulation (i.e. several years after the construction of an impoundment) but there is very little ecological information on the long-term effects of natural and modified flows for Queensland rivers.

Critical gaps in knowledge include: the flows that maintain channel morpholog, in-stream cover and therefore invertebrate and fish habitat; flood flows that maintain water quality and substrate diversity; flow events that govern fish and invertebrate breeding cycles and levels of recruitment, and the ecological effects of flooding after prolonged periods of low flow (as have occurred in the Mary River), as well as the effects of low flows on systems that have experienced prolonged or intermittent flooding (i.e. the effects of various sequences of flooding and drought).

Whilst these key ecological responses to the flow regime remain unknown, ecologists can only provide very general guidelines on river flow requirements, e.g. monthly percentile values based on the natural flow regime (e.g. Hall 1991; Arthington et al. 1992b) and these may well demand more water for stream channel and ecosystem maintenance than is actually necessary, as well as lacking precision. Research focused on the ecological definition of significant flow events and flow sequences is urgently required.

The models of habitat structure vs fish community structure developed from CCISR's Ten-river Study are based on the condition of river habitats during periods characterised by relatively low flows, or in some rivers, before and after one or two floods. The long-term ecological significance of sequences of high and low flow events, and their interaction with other driving variables (e.g. channel morphology, habitat structure, competition between fish species and the effects of predation) have not been fully elucidated. This has been due to the relatively short-term nature of these studies (1-4 years) and the erratic occurrence of floods during the study period to date. Furthermore, it has not been possible to examine the effects of such flow variations on fish recruitment in such a short time-frame.

The third component of the new research program is designed to provide essential information about the effects of long-term variations in river discharge on in-stream habitat structure, fish diversity, community structure and patterns of recruitment.

2.3 Experimental Studies on the Stability of Fish Community Structure

The three-part research program described above will determine how various physical factors influence the diversity and structure of river fish communities in space and time. To develop practical guidelines for river management agencies and ICM groups, it is essential that the roles of all physical and biological factors which may influence fish community structure are firstly described, and then shown experimentally to have a significant effect. An experimental program will be established in selected rivers with the following objectives: (i) to examine the stability of fish communities under various conditions of habitat manipulation (e.g. presence, absence and density of snags, and other components of physical habitat); and, (ii) to determine how biological processes such as competition or predation influence the stability of fish communities under different physical conditions.

Research to date on the Mulgrave and South Johnstone rivers suggests that both competition and predation may have a significant effect on the fish community. The Sooty Grunter and Freshwater Catfish are two large and numerically important species in these rivers and we hypothesise that their presence influences fish assemblage structure in a manner not directly related to habitat structure or discharge pattern. Of course, the presence of either of these species may in itself be a function of the discharge regime or of habitat structure. Other fish species may be included in the experiments, dependi upon evidence of their impact gathered from the descriptive field studies.

3.0 STUDY AREAS

The research program will include major rivers of each hypothetical 'regional river type', particularly rivers where ICM initiatives are being established and where information is needed on habitat protection, flow management and the ecology of river fishes. The following rivers are proposed as our major study sites at this stage.

Type (1): S. E. Qld rivers: e.g. the Albert and Mary rivers. Both are likely to be affected by population growth and catchment development, and they may be impounded in the near future. The Albert has a similar fish fauna to the Tweed River, NSW, and its investigation may provide guidelines for other northern NSW rivers. The Mary supports two significant fish species (Mary River Cod and Queensland Lungfish), which must be protected. The Mary river is the focus of several community action groups (LandCare and ICM) and QDPI studies. Further investigation of the Mary river and comparisons with the Burnett will provide a test of variation within rivers of this regional type. The inclusion of Barker-Barambah Creek for some aspects of the research is a possibility, since it would provide information on the short to medium-term effects of impoundment on the fish community, fish recruitment, the population densities of dominant species and their biological condition.

Type (2): Central Queensland rivers: e.g. the Burdekin and Fitzroy rivers. These rivers are already affected by urban and agricultural development, as well as by the construction of impoundments and by flow regulation. Both river systems support species of significance for recreational fishing (Barramundi, Sooty Grunter, Freshwater Catfish, Green-hide Jacks). Research on these rivers will assist in the development of regional natural resource management plans and strategies for ICM. They may have features in common, or being so large and diverse, and probably have many differences requiring full investigation.

Type (3: Wet Tropics rivers: The Mulgrave and Sth Johnstone rivers have very high fish species diversity, supporting over 35 species of which up to four are undescribed and thought to be new to science. Investigation of these rainforest rivers will guide future management of other tropical rivers, such as the Russell, Barron, Daintree, Tully and Herbert rivers, and will contribute to the conservation of World Heritage values. The Sth Johnston should be compared with the Nth Johnstone, to extend the work already underway there under programs for ICM and assessing the downstream effects of agriculture. The Mulgrave river is being used by QDPI as a test case for restocking barramundi and the effects of stocking would be examined as part of Program 4, above. The flow regime of the Tully River may be altered by future hydroelectric power development, with unknown impacts on the Sooty Grunter recreational fishery and the Jungle Perch, as well as other native species.

Type (4): Cape York rivers: The Normanby, Pascoe and Stuart rivers should be studied to determine the significance of flooding patterns in regulating fish community structure within main river channels and floodplain lagoons, and the importance of flows which sustain an interchange of fauna between these habitats. There has been virtually no research on the ecology and management of floodplain rivers in northern Australia. Research on Cape York rivers will complement the faunal surveys and biogeographic assessments being undertaken by CYPLUS (Cape York Peninsula Land Use Study) and could be integrated with this program. The research proposed here will assess temporal variation in fish community structure, as well as producing ecological guidelines on flow management issues in floodplain rivers.

4.0 MAJOR OUTCOMES OF RESEARCH PROGRAM

This research program will provide original information and detailed, predictive understanding which we consider are essential for the sound management of catchments and their waterways. The following major outcomes are anticipated:

1. Understanding of how geology, valley and channel morphology, surface runoff and river flow regimes influence the distribution, abundance, diversity and communit structure of the freshwater fish fauna of Queensland east coast rivers.

2. A detailed manual on the biology and habitat requirements of many fish species common to Queensland and New South Wales rivers including information on complex habitats such as floodplain river channels and lateral billabongs.

3. Predictive models of fish community structure based on the physical characteristics of river habitats in major rivers of Queensland, and a basis for testing these predictive models in other rivers in each region.

4. Predictive models to assess the ecological impact of catchment landuse practices which modify runoff and flow (such as forestry, agriculture, riparian clearing, impoundment and hydropower generation), as well as the impact of any regional climatic change.

5. More precise ecological criteria and management guidelines for environmental water allocation for rivers, with an initial emphasis on protection of the fish fauna.

6. Models to predict changes in habitat structure and fish communities in systems for which there are catchment/river hydrologic models.

7. Better understanding of the factors influencing fish reproduction and recruitment, and hence improved capacity to conserve rare and endangered species, and to manage species that are important for recreational fishing and species performing important ecological roles.

8. An understanding of the relative importance of physical vs biological processes in structuring river fish communities, and hence a comprehensive model of the factors which must be managed to protect river fish communities.

9. Ecological guidelines to underpin the overall management of streams and rivers, the development of mitigation practices, and habitat restoration techniques.

10. A package of methods, experimental approaches and predictive models which could be applied and tested anywhere in Australia, with appropriate modification to suit local conditions.

5.0 PROGRAM MANAGEMENT AND RESOURCES

The research program outlined in this paper is intended to have an initial life of five years and the restrictions on resources will require that study sites and catchments are limited. Careful choices of field sites will be essential at the outset. The selection of study sites will be guided by the knowledge we already have for some rivers, and the need to include other rivers as tests of our regional models; we also propose to work where there are urgent demands for information to assist in river management. The Fitzroy is a very large river system, and we will be seeking advice and input from other research groups, the Water Resources Commission and QDPI, ICM committees and local land owners, to establish the optimum research strategy for the Fitzroy catchment.

At regular intervals, it is proposed that a newsletter will be produced to inform all groups with an interest in the study about its progress and findings as they become available. It is probable that seminars will be given from time to time, and field days a also a possibility. We also intend to conduct interviews amongst the community to determine as much as possible about the history of the river and its fish communities.

During the life of the research program, we will be seeking opportunities to broaden the scope of the research by undertaking specific local studies such as additional work on the influence of riparian vegetation, or the ecological significance of important habitats (e.g. snags, aquatic macrophytes). Post-graduate students are likely to become involved in these more focused studies. Community involvement and support will also be most important and will be actively encouraged. Interested persons are invited to contact the authors with ideas and comment on the research we have outlined.

6.0 CONCLUSIONS

Integrated Catchment Management and the maintenance of healthy river ecosystems both require a sound understanding of ecological processes and critical linkages between catchments and the waterbodies they support. Whilst our knowledge of Queensland rivers is steadily increasing, there remain many critical gaps in understanding, especially in relation to the effects of the flow regime on river communities. This paper has shown how such issues will be examined in a long-term research program which will include the Fitzroy River catchment as one of its major study areas.

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IMPACT OF AGRICULTURAL LAND USE ON INPUTS TO THE FITZROY RIVER SYSTEM

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INTRODUCTION

The Fitzroy Basin is one of the richest economic regions in Queensland. The estimated value of dryland and irrigated cropping is $215 M, the cattle industry $250M and open-cut and underground coalmining $6.8 Billion. Each industry is linked by their dependence on the land, water and associated biological resources within the Fitzroy catchment. Therefore, there is a need to consider an integrated approach to the management of the physical resource so that development and conservation can be sustained.

The QDPI Natural Resource Management unit has established and maintained a number of small catchment studies in the Fitzroy Basin to investigate the relationship between land management, surface runoff and soil erosion. This paper provides an overview of the outcomes from these experiments and contributes to the resource base of the catchment and its physical condition.

DESCRIPTION OF CATCHMENT STUDIES

Four catchment studies have been established in Central Queensland to address land management issues for the cleared Open Downs, Eucalypt Woodland and Brigalow lands (Figure 1). These sites are at Capella, Emerald Irrigation Area (EIA), and Springvale in the Mackenzie River System and the Brigalow Catchment Study in the Dawson River System. A summary of the treatments and data collected at each site are given in Table 1.

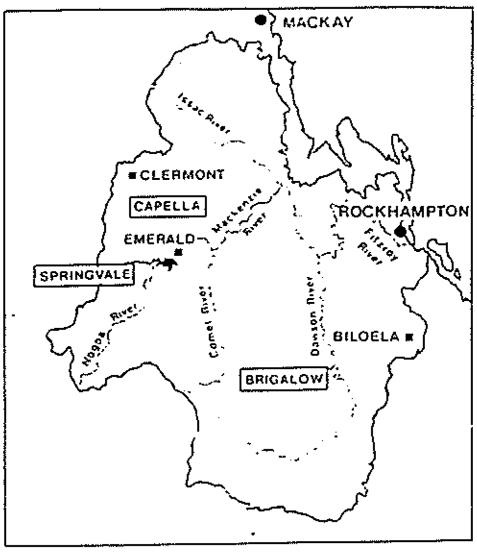

Figure 1 Location of QDPI Catchment Studies

Table 1. QDPI Catchment Studies in Fitzroy River Basin.

Site	Duration	Catchment Areas	Treatments	Data Collected
Capella	1982-92	9 Catchments Ave. 13 ha	Sorghum, Sunflower, Wheat x zero, reduced, conventional tillage	Rainfall, runoff, sediment, evapotranspiration, fallow soil water, crop yield
Brigalow	1965-82 Calibration 1983-Land Use Change	3 Catchment 12-17 ha	Brigalow forest, crop (wheat), pasture	Rainfall, runoff, sediment, soil water, EC, pH, P_B, N,P,K,S,Cl, organic carbon, yield, pasture production, cattle liveweight
Springvale	1979-80 grazed 1982-Cattle excluded	10 ha	Grazed and ungrazed	Rainfall, runoff, sediments from hillslope and catchment.
EIA	1986/87 1990/91		Slope length comparison under cotton	Rainfall, irrigation, runoff, sediment, nutrient NO_3N, P

The rainfall in central Queensland is extremely variable (Table 2). For example, annual rainfall for Emerald can range from 200 to 1400 mm. Such season-to-season variability complicates the development and testing of farming and land management systems. A way to overcome this problem is to use models along with field experiments to simulate the climate-water-soil-plant and farm management interactions.

Table 2. Mean, Maximum, Minimum and Percentage Summer Rainfall for Stations in Central Queensland.

	Period (Years)	Mean (mm)	Maximum (mm)	Minimum (mm)	Oct-Nov %
Capella	91	591	1102	190	74
Emerald	107	639	1407	206	72
Bogantungan	100	695	1836	178	73
Banana	110	674	1217	271	71

MODELLING APPROACH

The PERFECT model (Productivity, Erosion and Runoff Functions to Evaluate Conservation Techniques) (Littleboy et al. 1989) has been developed by QDPI to simulate the major effects of management and climate on: runoff, soil erosion, soil water, drainage, crop growth and yield. Daily climatic data is used as a basic input. The Capella and Brigalow catchments along with other QDPI studies have been used to develop and validate the PERFECT model.

The LAMSAT project (Land Management Strategies for the Semi-Arid Tropics) (Hairsine et al. 1991) will use data from the Springvale study to improve and parameterise runoff/water balance and soil loss components for grazing system models.

OUTCOMES FROM QDPI CATCHMENT STUDIES

The Capella Study

The project has studied wheat, sorghum and sunflower cropping with fallow management using conventional, reduced or zero tillage on a self-mulching black earth (vertisol). Soil loss, runoff, soil water, cover and yeilds are measured in nine contour bays (average area 13.5 ha).

Crops were monocultured until 1986 when an opportunity cropping approach was adopted. Tillage practices have been continuously maintained over the experimental period.

Cropping, fallow management and soil erosion

Sunflowers produce the highest soil erosion on the central Highlands (Table 3). There are two reasons. Firstly, the crop produces low stubble cover and secondly, the fallow and seedbed preparation coincides with the regions summer rainstorm period.

Table 3 Predicted runoff and soil loss for three crops grown as monoculture compared to opportunity cropping. PERFECT simulations were for 85 years of Central Highlands rainfall. (Reduced tillage farm practice).

Crop	No. Crops Grown	Runoff mm^{-1} yr^{-1}	Soil loss t ha^{-1} yr^{-1}
Sunflower	53	150	26
Wheat	57	144	15
Sorghum	58	116	10
Opportunity	87	91	6

Previous soil erosion research have shown that farm management practices that maintain high stubble cover can reduce rain drop impact, sediment detachment and transport, runoff and soil loss (Freebairn and Wockner, 1986a, 1986b).

Stubble cover can have a dominant effect on soil erosion and runoff for individual storms (Figure 2). Typical stubble cover after harvest for wheat, sorghum and sunflower is 90, 60, and 40% respectively. The amount of stubble retention during a fallow is determined by the tillage practice. For example, a primary tillage with a disc plough can reduce wheat stubble cover by 65%. In contrast, the use of a chisel or a blade plough would cause a 25% and a 12 % reduction in stubble respectively.

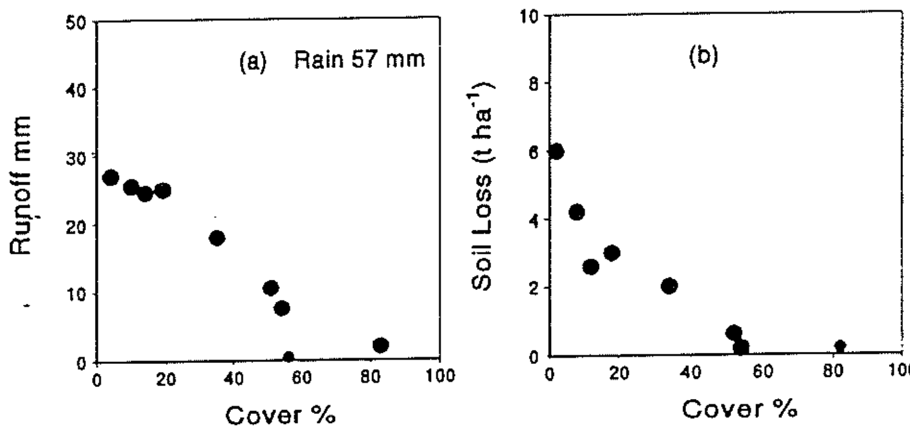

Figure 2 **The effect of soil cover on runoff and soil loss for a storm at the Capella study.**

Long-term simulations using PERFECT (Carroll et al. 1992) have shown that opportunity cropping will increase the number of crops grown in the region and also reduce the risk of soil erosion (Table 3). The simulations compared opportunity cropping to monoculture cropping using reduce tillage fallow management (reduce tillage is the practice used by most farmers in the region).

In the monoculture comparison sorghum had the least soil erosion because it has the benefit of the first planting option in summer. More sorghum crops were also grown. Consequently, there was more vegative cover and crop water use during the summer rainstorm period and less runoff and soil loss than monoculture sunflower and wheat. Zero tillage wheat has had the least soil erosion (2 t/ha) during both the trial period and from long-term simulations.

Water balance

Soil evaporation dominates most fallow water balances and in one nine month fallow, total soil evaporation was 343 mm or 92% of rainfall. The Capella study has found fallow effeciencies are generally less than 20%.

Long-term simulations have also shown that even with opportunity cropping soil evaporation is very large (55% of the water balance). This reflects the large amount of ineffectual rainfall that occurs in the region. Over 60% of the regions daily rainfall occurs in amounts less than 10 mm. In the central

Highlands pan evaporation rates average 4 mm/day in winter and 8 mm/day in summmer. So, such small falls of rain are soon evaporated.

Soil water content is the most important factor that determines whether rainfall will produce runoff on a black earth and many other soil types. The PERFECT simulations show that the sequence and the number of crops grown will have a major effect on the soil water content and hence runoff (Figures 3).

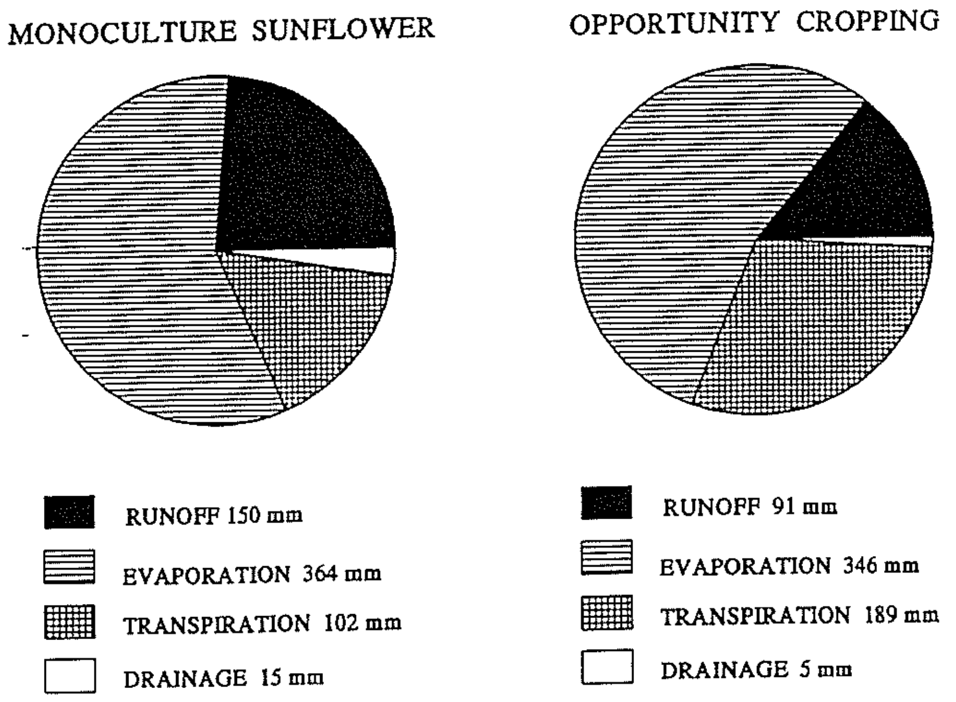

Figure 3. **A comparison of the water balance between monoculture sunflowers and an opportunity cropping farming system. PERFECT simulation were for 85 years of Central Highland rainfall.**

However, even with opportunity cropping, crop water use was only 29% of the water balance. A relatively small proportion of the long-term rainfall. Interestingly, runoff was equivalent to 50% of the crop water use and highlights crop use and soil water storage are often exceeded in very high rainfall periods.

The Brigalow Study

Brigalow (Acacia harpophylla) and associated woodland communities occupied approximately 275 of the Fitzroy Basin (Nix 1977). Under the Fitzroy Basin (Brigalow) Land Development Scheme, an estimated 6 million hectares of native vegetation was pulled and burnt and developed for pasture and cropping.

The Brigalow Catchment Study was initiated to investigate the impact of land clearing on hydrology, groundwater, soil salinity, soil erosion, soil fertility and productivity. The study commenced in 1965 when rainfall and runoff were measured from three brigalow catchments. Then in 1982 two catchments were cleared and developed for pasture and wheat cropping. The Brigalow catchments have uniform, dark non-cracking clays and dark duplex soils.

Groundwater Recharge

Clearing of native forests has been given as a reason for: an increase in groundwater recharge, a rise in watertables and dryland salinity. However, the Brigalow study has found that brigalow lands developed and managed conservatively have a low salinity risk.

Normally, trees transpire throughout the year and extract water from a greater depth and create a larger soil water deficit than pasture or crops. In contrast, the Brigalow study has found soil water deficits are similar in the Brigalow forest, pasture and cropping catchments. Deficits are similar because Brigalow is shallow rooted (0.8 cm) and adapts to the semi-arid environment by regulating transpiration during dry periods.

The study found recharge was substantially effected (7-70 mm/yr) when the catchments were initailly cleared in 1981 to 1983. This was caused by record high rainfall (450 mm in April/May 1983) during a time when the crop and pasture catchments were bare and grass partially established. However, once the wheat crop and pasture were established after 1983 there was little recharge (Figure 4).

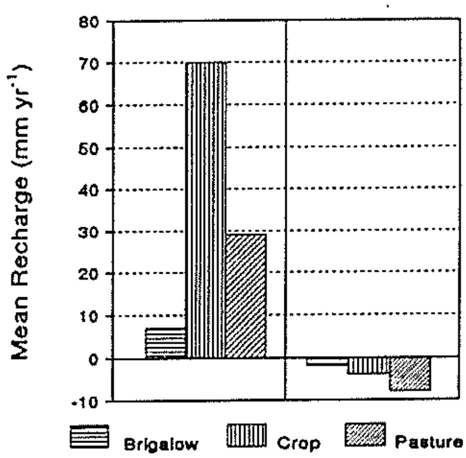

Figure 4 **Mean recharge rate for brigalow forest, crop and pasture. Immediately after clearing (1981-83) and after establishment of land use (1983-87)**

The Brigalow study has found that climate variability can have as great an impact on groundwater recharge as land use or soil type once agricultural land use has been established. Groundwater recharge is sporadic because of the variable rainfall and high evaporation rates in the region (potential evaporation exceeds average rainfall in every month of the year).

Most drainage occurs during the summer when the wheat is in fallow and transpiration is low. Whereas, there is less drainage in buffel pasture because the transpiration rate is high during the summer rainfall season.

Soil Fertility

An increase in soil nutrient was short lived after clearing and burning the brigalow forest. Three years after burning and pasture establishment, available nitrogen and phosphorus was reduced from 59 and 37 mg/kg to 5.3 and 22 mg/kg respectively (Lawrence and Cowie, 1992).

A pasture/grazing enterprise will be less exploitive of soil nitrogen than cropping. The study found after three years cropping, 69 kg N/ha/yr had been removed in grain compared to 3 kg N/ha/yr in animal weight. It is also likely less nitrogen will be lost by runoff and erosion from pasture than from cropping.

Annual Water Balance

Evapotranspiration is the dominant component of the annual water balance, consuming in excess of 87% of average annual rainfall (Figure 5). Long-term simulations show that most of the rainfall is used as transpiration under Brigalow and pasture land use. However, like the Capella study under cropping, approximately 63% of rainfall is lost by soil evaporation and can rise to 80% when bare fallowed.

Surface runoff is a small component of the annual water balance for brigalow forest. Runoff from brigalow forest represented 6% of the average annual rainfall (Figure 5). Runoff increased after clearing and establishing wheat (12%) and pasture (9%). However, average annual drainage only increased from 0 to 3 mm/yr after conversion from brigalow to wheat cropping and was unaltered by conversion to pasture.

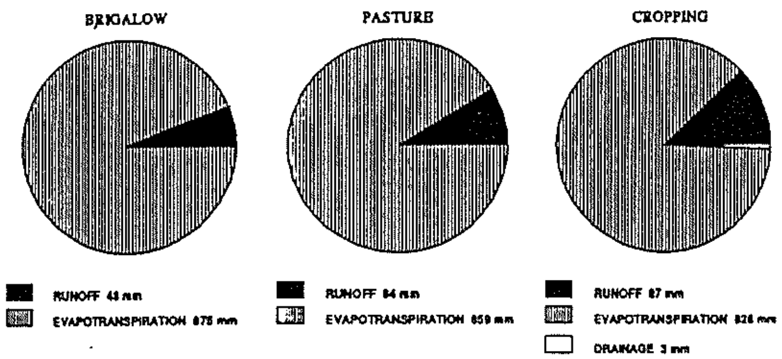

Figure 5. **Average annual water balance for brigalow forest, buffel pasture and wheat cropping**

The Springvale Study

The Nogoa River drains the basalt and sandstone landscapes of the Buckland Tablelands in central Queensland. The major water storage on the Nogoa is the Fairbairn dam, built in 1972 upstream from the Emerald township. The dam provides water for the Emerald Irrigation Area (EIA) and several coalmines.

The Nogoa catchment is considered to be one of the worst eroded areas in the 600 to 700 mm rainfall belt of tropical Australia (Skinner et al. 1972). The most severe soil degradation is associated with texture contrast soils with highly dispersible subsoils, developed from flaggy sandstone and mudstone. Thirty percent of the Nogoa catchment has texture contrast soils.

Grazing settlement commenced during the 1860's, with almost all the holdings being devoted to sheep. This practice continued until the mid 1950's when properties began to convert to cattle grazing. Practically no sheep are now grazed in the catchment. It is felt that stocking with sheep from 1860's to the 1950's has been a major factor contributing to soil degradation (Skinner et al. 1972).

Ciesolka (1987) concluded that gully erosion took place in the catchment prior to European settlement. However, overgrazing has exacerbated natural erosion rates on preferentially grazed areas i.e. mudstone derived soils supporting false sandelwood and desert blue grass.

Soil erosion, runoff

The Springvale catchment was grazed up until 1982 when cattle were excluded from the trial area. Table 4 shows there was a 50% reduction in runoff at the catchment study between 1979/80 and 1983/84. During this period pasture and litter cover increased from 34 to 47%.

Table 4 Annual rainfall, runoff and soil loss from Spring Vale catchment (1970/80 to 1983/84).

Year	Rainfall (mm)	Runoff (mm)	Runoff (%)	Cover %	Soil Loss t ha^{-1}
1979/80	740	233	31	34	9
1980/81	532	137	26	36	3.7
1981/82	368	81	22	30	4
1982/83	1216	429	35	45	14
1983/84	782	116	15	47	1.6

Soil cover can decrease annual runoff (Figure 6). In 1986/87 370 to 470 mm of annual rainfall (50 to 60% of the 790 mm rainfall) was lost as runoff from areas with surface cover levels less than 10%. Therefore, effective rainfall for grass growth and evaporation was only 320 to 420 mm, creating an artificial drought in a year of slightly above average rainfall. The bare areas include 'scalds' that have remained bare despite exclusion of cattle for 8 years and areas that are subjected to heavy grazing pressure.

Soil erosion was also reduced by 82% between 1979/80 and 1983/84. On hillslopes areas total soil loss (bedload plus suspended load) was also high and negatively related to total projected cover (Figure 6).

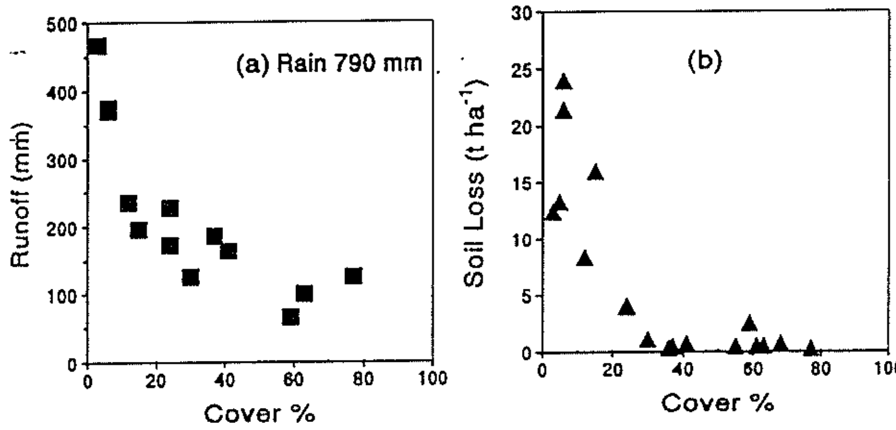

Figure 6 **Annual runoff and soil loss (bedland plus suspended load) versus total projected cover, on hill slopes at the Springvale study**

Soil loss declined from 20-25 t/ha to 1 t/ha for cover levels between <5 and 30%. Soil loss from bare soil areas are equivalent to 1.5 and 2.5 mm soil depth eroded in one year. This is excessive soil loss, considering the soils are shallow (<50 cm) and have a shallow nutrient profile (Ciesolka,1987).

The Emerald Irrigation Area Study

Cotton is the predominant crop grown in the irrigation area (10 000 out of 12 000 ha). The crop is usually planted in October and harvested in March. Cotton growing has important implications on soil erosion, runoff and potentially chemical transport with fallowing, fertilising, planting, irrigation and insecticide application all coinciding with the regions summer rainstorm period.

A project was established in 1986-87 to study: the effect of furrow length on soil erosion, and to quantified the degree of erosion from rainfall and irrigation. Two experimental sites were established at the properties of S.Denaro and G.Roberts; both were on a black earth soil with slopes of 1.0 and 1.3 %.

At both sites a short furrow length (SFL) and a long furrow length (LFL) were compared. In the paper Denaro's furrow length comparison are shown (SFL 240m and LFL 480m). Runoff and soil loss were measured from six furrows for the length comparisons.

Comparison of rainfall and irrigation induced erosion

Table 5 shows that the SFL reduced soil loss from rainfall by approximately 25%. Under irrigation soil erosion was slightly higher from the SFL because there tended to be higher runoff from the SFL. The amount of soil loss from an irrigation is determined by total runoff and duration. Consequently, eliminating unnecessay runoff from irrigations will minimise soil movement into taildrains and from farm properties.

Table 5 **Summary of soil loss and runoff for 1986/87 cotton season at the Denaro site. Irrigation runoff and soil loss after three hours duration**

Event	Units	Furrow length (m) 240 SLF		Furrow length (m) 480 LFL
Rainfall				
Rainfall	mm		242	
Runoff	mm	77		88
Soil loss	t ha^{-1}	2.9		3.9
Irrigation				
Runoff	mm	23		16
Soil loss	t ha^{-1}	0.6		0.5

Rainfall contributed the highest soil erosion from the EIA. In 1986/87 at the Denaro site 75% of the seasons' soil loss occurred from rainfall and 25% from irrigation. The soil loss pattern from rainfall differed sharply from that of irrigation. Irrigations were characterised by low sediment concentrations and runoff rates when compared to rainfall events.

Sediment concentration declined for both rainfall and irrigation through the cotton growing season. There was a 90 to 96% reduction in sediment concentration between the first and final irrigation. The decline coincided with the termination of cultivation and the increase in crop canopy cover.

Critical soil erosion period in the EIA

The critical soil erosion period when growing cotton is between pre-plant irrigation and crop canopy development; 85% of the total soil loss caused by rainfall occurred before canopy closure (Carroll et al. 1991).

However, runoff and soil loss can be high during a cotton crop. This is caused by high antecedent soil moisture conditions caused by regular irrigations during the maturing cotton crop.

For example, cyclone Joy in 1990/91 produced 321 mm rainfall and 190 mm of runoff (60% of the rainfall). The large amount of runoff was due to rainfall occurring after an irrigation had just been completed.

Though sediment concentration was relatively low, total soil loss was high (8 t/ha) due to the large amount of runoff. The rainfall from cyclone Joy occurred when the cotton crop was almost closed.

Nutrient and Pesticide Movement from EIA

In 1990/91 nitrogen and phosphorus concentrations in runoff and sediment were measured from a farm property. The measurements showed elevated levels of both nutrients in runoff and sediment from both irrigation and rainstorm (Table 6). Inorganic phosphorus has been associated with an increase in blue green algae growth in NSW river systems. Oliver and Boon (1992) have found that a sizeable fraction of inorganic phosphorus adsorbed to suspended clay can be used by algae.

Table 6 Nutrient analysis on runoff and sediment from agricultural catchment in EIA (1990/91).

Sample Taken	Runoff	Sediment						
	NO_3N	NO_3N	BicarbP	Cl	Cu	Zn	Mn	Fe
	mg l^{-1}	mg kg^{-1}						
Irrigation 1	0.91	2	29	15	1.1	4.6	6	8
Irrigation 2	14.37	3	23	6	1.6	1.3	3	7
Rainstorm	13.0	4	33	45	1.0	1.0	3	7

Endosulfan levels of 0.57 mg/kg were found on the sediment transported in runoff. This is expected since endosulfan is quickly adsorbed onto sediment. Levels in runoff are complicated by a delay between sampling and analysis and are not presented. Hydrolysis reactions are relatively rapid consequently samples should be extracted as soon as possible (Peterson and Batley, 1991).

FUTURE PROJECTS

Monitoring of soil erosion and water quality from Open-Cut Coalmining

The project involves the collaboration of the: Coalmining Industry, Department Agriculture and of Mining and Metallurgical Engineering at the Univesity of Queensland, Natural Resource Management of QDPI, Department of Civil Engineering and Surveying at the University of Newcastle, and the Surface management Group of the Australian Coal Industry Research Laboratories Ltd.

The project will determine the critical topographic parameters (degree and length of slope) and vegetative cover (pasture and trees) for acceptable erosion control on a spectrum of spoil/soil material.

The major objective of the project is to recommend stable post-mining landscapes to achieve feasible and acceptable standards of landscape stability.

CONCLUSIONS

The four QDPI catchment studies have shown that farm practices that maintain soil surface cover levels between 30 and 40% can reduce both soil erosion and runoff.

Factors that effect the amount of surface cover in dryland cropping are: crop type, cropping intensity and tillage practice. Simulation from the PERFECT model show that opportunity cropping can increase cropping intensity and crop water use. Thereby reducing soil erosion, runoff and evaporation and drainage.

Maintaining good pasture condition, particularly during the summer rainstorm period can also minimise soil erosion and runoff. A well managed pasture will not deplete soil nitrogen as much as cropping and will also have a low salinity hazard.

Catchments studies need to run for a least 10 to 15 years to reliably sample the variable rainfall environment of Central Queensland. The Capella, Springvale and Brigalow catchments have been established for 10, 12 and 27 years respectively. The catchments are valuable resources for monitoring further land use issues. One such issue is the impact of primary production on water quality. Little information has been collected from the catchments on nutritient and pesticide transport. The future mining project will address this issue with concern to open-cut coalmining. The QDPI catchments are ideally suited to address the same issue for dryland, grazing and irrigation agricultural industries.

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FLUVIAL PROCESSES IN THE LOWER FITZROY RIVER

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1.0 INTRODUCTION

The Fitzroy River near Pink Lily Bend is a major source of high grade sand for the Rockhampton District. However, there has been substantial bank erosion upstream of the extraction area, which has been occurring well before extraction operations commenced. Recent river cross-sections have revealed that there has been significant bed erosion downstream of the extraction operation.

As there has been increasing interest in extracting sand and gravel from other reaches of the Fitzroy River, the Water Resources Commission, who has the responsibility for these operations in the non-tidal section of the river, realised that a management plan was needed to promote the most beneficial use of the resource consistent with the protection of the stream environment and community expectations.

The Water Resources Commission initiated a study to review the existing information to improve the understanding of the sediment transport processes in the Fitzroy River and the management of existing and future extractions. The results of the study are presented in this paper. The study area which extends from the Fitzroy Barrage (AMTD 60.5 km) to upstream of Yaamba (AMTD 125 km) is shown in Figure 1.

2.0 SEDIMENT TRANSPORT PROCESSES IN THE LOWER FITZROY RIVER

The sediment transport processes believed to be occurring in the Fitzroy River are described below with particular attention to the Pink Lily Bend reach and downstream to the barrage where there is the most information. Before dealing with the sediment transport processes, it is necessary to review the hydrology of the system as the streamflow is the driving force behind the fluvial processes.

2.1 <u>Fitzroy River Hydrology</u>

Only a brief summary is given here as the hydrology of the Lower Fitzroy River has been reviewed in detail by CMPS&F (1992). The Fitzroy River has a catchment of approximately 144 000 km^2 in Central Queensland. The flows in the Lower Fitzroy River are recorded at Gauging Station 130005 located near The Gap. The most important feature of the flows in the Fitzroy River from the point of view of the fluvial processes is the variability which can be seen in Figure 2 which shows the annual flows recorded at the gauging station for the period from 1922 to 1990 when complete years of record were available. A measure of this variability is the coefficient of variation which is the ratio of the standard deviation of the flows to the mean annual flow. For this station the coefficient of variation is 1.1, which means that the standard deviation is slightly more than the mean annual flow of 5.5 million ML.

An important feature of the flooding of the Lower Fitzroy River is the breakout at Pink Lily Bend which inundates the floodplain to the south of Rockhampton and effectively isolates the town. This breakout is viewed as a sort of relief valve diverting flow around Rockhampton rather than through the middle of town. Any changes to the height of the natural levee on the outside of the bend has the potential to alter the flow distribution between the main channel and the floodplain.

According to the CMPS&F study, the threshold of breakout flow at Pink Lily currently occurs at a flow of 7,500 to 8,000 cumecs which corresponds to a level of 9.3 metres AHD at Pink Lily. An examination of the streamflow record identified 13 floods when major breakouts would have occurred. The average period between exceedence was 6 years.

2.2 Pink Lily Bend Erosion

The Rockhampton City Council has been monitoring the erosion of the outside of the bend at Pink Lily since 1948. The results of the survey are shown on Figure 3. The first survey of the bend was carried out in 1865 for the first cadastral survey. The property boundaries on both sides of the river are still based on this survey. The rate of bank recession is highest in the zone where the breakout first occurs.

The average rate of bank recession in the zone of maximum erosion was estimated using the two lines shown. The bank recession derived from these two lines are shown in Figure 4, where the slope of the lines represents the rate of bank recession. Prior to the construction of the barrage in 1971, the average rate of recession is 3 metres per year at both lines. After 1971, the rate of recession has decreased to 1.4 metres per year at line 1 and 2.8 metres per year at line 2. The difference is caused by the large section of bank collapse in line 2 in the 1991 flood. From 1971 to 1989, the rate of bank recession was 1.1 metres per year at both sections.

While there are a number of processes contributing to the bank failure at the bend (see Cameron McNamara,1981), piping/sapping [Hagerty (1991a & b)] is the predominant cause of the rapid rate of bank recession. The soil profile at the bend consists of 3 metres of silty clay on top of a fine uncemented sand layer which extends below the water line. During the recession of major floods, as the flood level drops, water infiltrates into the sand layer near the full supply level of the barrage. As this water seeps back into the river, it washes away this layer destabilising the thick alluvial layer on top of the sand layer. During the 1991 flood, sections of bank up to 30 metres wide slumped into the river.

The main contribution of the stream velocities at the outside of the bend is to remove the material sloughing into the river. The stream gauging exercise carried out by the Water Resources Commission (Voltz, 1991) measured an average stream velocity of 0.77 ms^{-1} and a maximum of 1.42 ms^{-1} when the flood was at the bank-full level. These velocities are much lower than the velocities in the town reaches further downstream. Surface velocities of 3.8 ms^{-1} were estimated in the town reaches during the 1918 flood (CMPS&F, 1992).

As the main driving force behind the bank erosion is fluctuating water levels, the apparent decrease in the rate of bank failure since the construction of the tidal barrage is probably caused by the stabilisation of water levels. Prior to 1971, this reach of the river was tidal with the water level varying over a range of 3.1 metres during a Spring Tide (Cameron McNamara, 1981). This variation of water level in the sandy layer of the bank would probably have led to a faster rate of removal of material from the sandy layer leading to the faster rate of bank failure. With the construction of the barrage, the erosion would be mainly caused by flooding. However, large slumps can still occur during major flooding events such as the January 1991 event.

During the 1950's bank stabilisation works were undertaken. However, these works failed during the large floods experienced during that decade. Photographs of the area show the same failure mechanism was active during this period. The dramatic failure of these works show that any future works should take account of the failure mechanism.

2.3 Stream Channel Changes

Several cross-sections between Pink Lily Bend and the Barrage have been surveyed at different times since 1950. Unfortunately, the dates of the surveys varies from section to section and there is some uncertainty as to the datum and the location of some of the 1950 cross-sections. The cross-sections were reviewed for evidence of upstream and downstream scour which could be associated with the sand extraction operations.

The review of the surveys of sections upstream of the extraction zone showed no conclusive evidence of upstream degradation caused by the extraction operation. There was considerable change in the location of the left bank at AMTD 69.4 km caused by bank erosion. However, the changes in the surveys could be explained by natural processes.

Downstream of the extraction zone, there was a consistent long-term trend of scour in the main channel despite some uncertainties in the location of the surveys. Normally it would be expected that there would be a tendency for deposition in the backwater of the barrage. As the trapping efficiency of a storage depends on the ratio of the capacity of the storage to the volume of the flood, the trapping efficiency of the barrage during a major flood event such as the 1991 flood would be very small. Therefore, the expected deposition would be small. The observed scour must be caused by some process, either man-made or natural, that has reversed the expected behaviour.

As there are no surveys from the early 1970's to separate the scour in the period prior to the sand and gravel extraction from the present, it is not possible to confirm that the scour has been caused by the sand extraction from an analysis of the survey data.

Walsh (1988) used a mathematical model to simulate the sediment transport rates in the Lower Fitzroy River. While the model gave the correct trend of erosion and deposition along the stream, it tended to underpredict the magnitude of the changes. Because the model was set up prior to 1987, it is probably based on the old 1950 cross-sections. The model would have to be recalibrated against more recent survey information before it could be used to estimate the impact of the dredging.

2.4 Past and Future Changes

Cameron McNamara (1981) predicted the future behaviour of the Fitzroy River in the vicinity of Rockhampton based on the expected behaviour of a meander and the known past behaviour of the river. An examination of aerial photographs of the floodplain near Rockhampton shows the courses of the river during the past. The river once meandered to the south of the present location of Rockhampton through the area where the Pink Lily breakout flows now go. Cameron McNamara state that the stream was diverted from its old course about 8000 years ago when there was a drop in the sea level and predict that in about 500 years with the continuing erosion of the Pink Lily Bend, the river could switch back to its old course to the south of Rockhampton.

The past behaviour shows that the river has meandered over the flood plain in times past and will probably continue to do so if left to its own devices. The sediment transport processes caused by this meandering could account for the scour now occurring in the section downstream of Pink Lily. However, a comparison of the present stream course with the old course shows that there has been a considerable shortening of the stream. When a stream has been straightened, either naturally or by flood mitigation works, the increase in slope causes an increase in stream velocities and sediment transport rates. 8000 years is not a long time in the geological life of a stream such as the Fitzroy and it is possible that the stream is still adjusting to the changed watercourse, thus explaining the high potential scour predicted by the mathematical model for the town reaches. While the dredging of the river bed continues, it is not possible to test this hypothesis.

2.5 Sediment Inflow

Observations of the sand bars deposited at different locations in the section downstream of Yaamba suggest that the sediment load is quite high. The dirty colour of the water also suggests a high wash load. The wash load consists of the finest material which is transported in suspension. The bed material load consist of bed material which can move in suspension or in contact with the bed.

Suspended sediment measurements were made by the Water Resources Commission at The Gap during the March 1988 flood (Kelly, 1988). Walsh (1988) also estimated the wash load by collecting two samples from the town reaches at the peak of 1988 flood. The concentration of the surface samples were 658 mg/L and 584 mg/L. Using the peak discharge from the mathematical model simulation of the flood, the wash load was estimated to be 5431 kg/s and 5507 kg/s (ie. between 470,000 and 480,000 tonnes/day). These estimates are consistent with the measurements at The Gap.

The suspended sediment sampling only measures the suspended component of the bed material load. The total bed material load was estimated at The Gap using the particle size distribution of samples collected in the Fitzroy River at Pink Lily as samples were not available from further upstream. There is a rocky control at The Gap so it has been assumed that material is available from further upstream.

The supply of bed material to the Lower Fitzroy River was estimated using the daily streamflow recorded at the stream gauge 130005 and a sediment rating curve using the programs developed by Poplawski (1987). The programs require the cross-section parameters and velocity for a series of discharges. Hydraulic variables were estimated using the cross-section and flow measured at the gauging station cross-section at The Gap. The sediment rating curve was then derived using the most commonly used formulae for sandy bedded streams, namely the formulae derived by Engelund & Hansen (1967), Ackers & White (1973) and van Rijn (1984a,b and c). After comparing the estimates of the formulae with the measurements, the Ackers & White formula was used.

The mean annual bed material load in the Fitzroy River was estimated to be 270,000 tonnes. The estimated annual bed material load is quite variable (Figure 5) ranging from 400 tonnes during a very dry year to 4,000,000 tonnes during 1954. Because the annual load is dominated by the large floods it is better to use the median bed material load for guidance when regulating sand and gravel extraction. The median load which is exceeded in 50 % of years was estimated to be 73,000 tonnes. Walsh (1988) estimated the bulk density of the sediment collected downstream of the Pink Lily Bend to be 1.56 tonnes/m^3 so that median annual sediment supply (excluding the wash load) is 47,000 m^3. The bed material loads for the 1918 and 1991 floods were estimated to be 3.8 and 2.2 million tonnes respectively.

It should be noted that this value is an estimate of the bed material supply to the Lower Fitzroy River downstream of The Gap. Between The Gap and Pink Lily there are several locations where there has been deposition during flood events. Therefore, it would be expected that the rate of supply upstream of Pink Lily would be much lower than the estimate at The Gap. The bed material load was estimated at the Pink Lily bend using the stream gauging data from Voltz (1991) and the Ackers & White formula was only 4,300 tonnes/day for a discharge of 5,000 cumecs. This value is about 10 % of the bed material load estimated at The Gap for the same discharge. The other sediment transport formulae gave a similar reduction in the bed material load.

3.0 CONCLUSIONS

The annual supply of bed material to the Lower Fitzroy River was estimated to vary from 400 tonnes to 4,000,000 tonnes depending upon the streamflow. The mean annual sediment supply was estimated to be 270,000 tonnes while the median annual supply was only 73,000 tonnes. Significant deposition occurs in and along the river from The Gap to Pink Lily and it is estimated that only 10 % of the material reaches Pink Lily.

The bank erosion on the outside of the bend at Pink Lily is caused by piping/sapping failure and is probably not significantly affected by the dredging. The construction of the Barrage has slowed the rate of bank recession at Pink Lily from 3 metres per year to about 1 metre per year. However, large sections of bank (up to 30 metres wide) can still fail during a major flood such as the 1991 event.

There does not appear to have been significant bed erosion upstream of the extraction area during the 1991 flood. However, there was some scour recorded at the cross-sections downstream of the Pink Lily Bend. A monitoring programme has been proposed which will identify the cause of this scour.

4.0 ACKNOWLEDGMENTS

The author wishes to thank the Commissioner of Water Resources for permission to publish this work. Opinions and conclusions expressed in this paper are those of the author and are not necessarily those of the Water Resources Commission.

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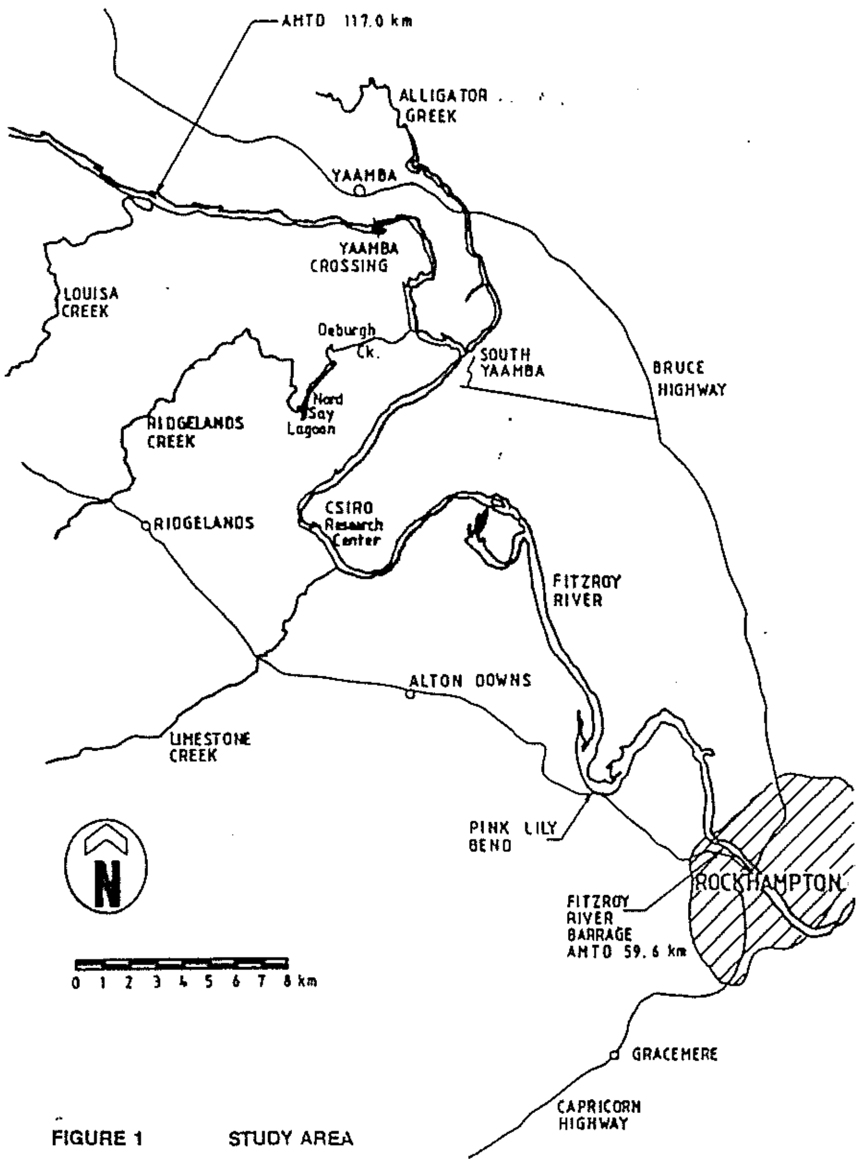

FIGURE 1 STUDY AREA

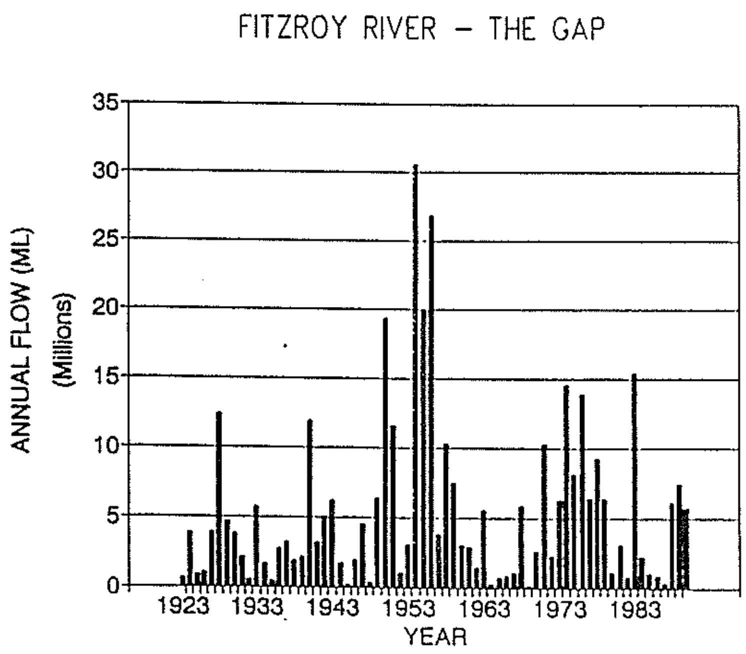

FIGURE 2 ANNUAL STREAM FLOW, FITZROY RIVER AT THE GAP

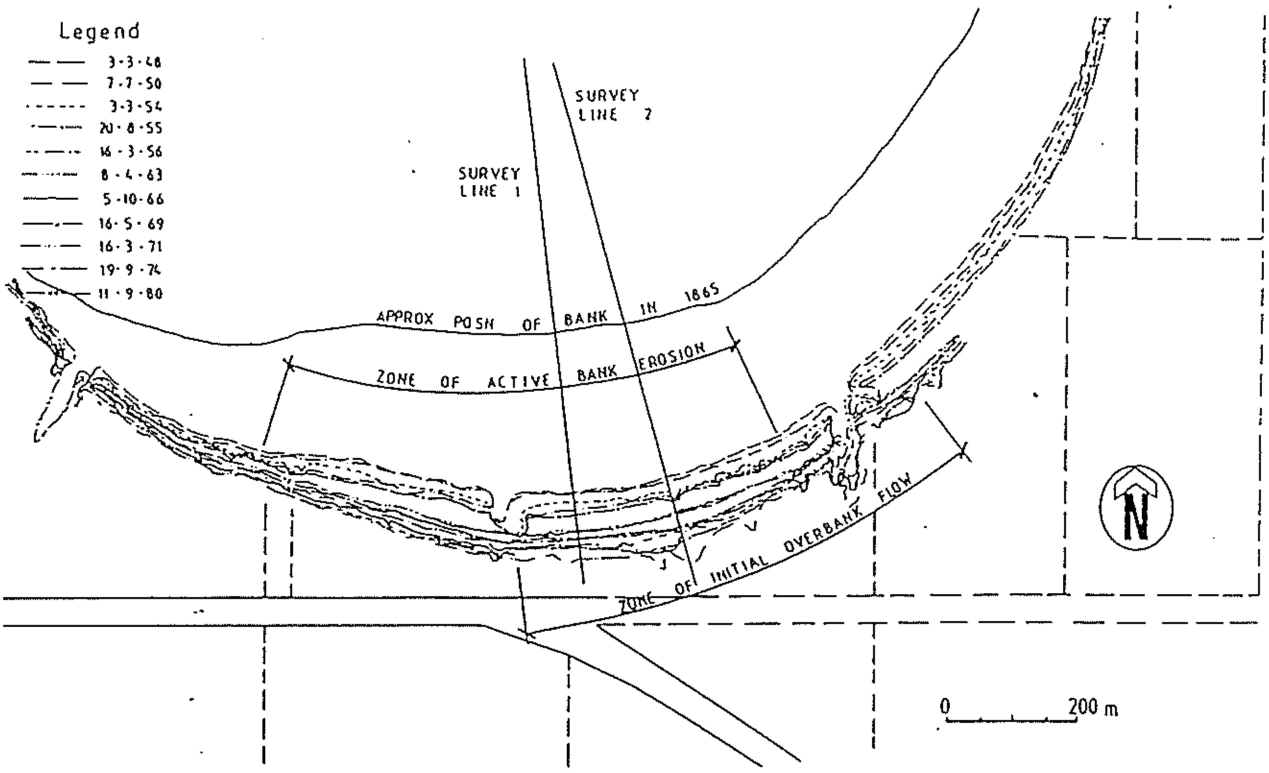

FIGURE 3 PINK LILY BEND BANK LOCATION

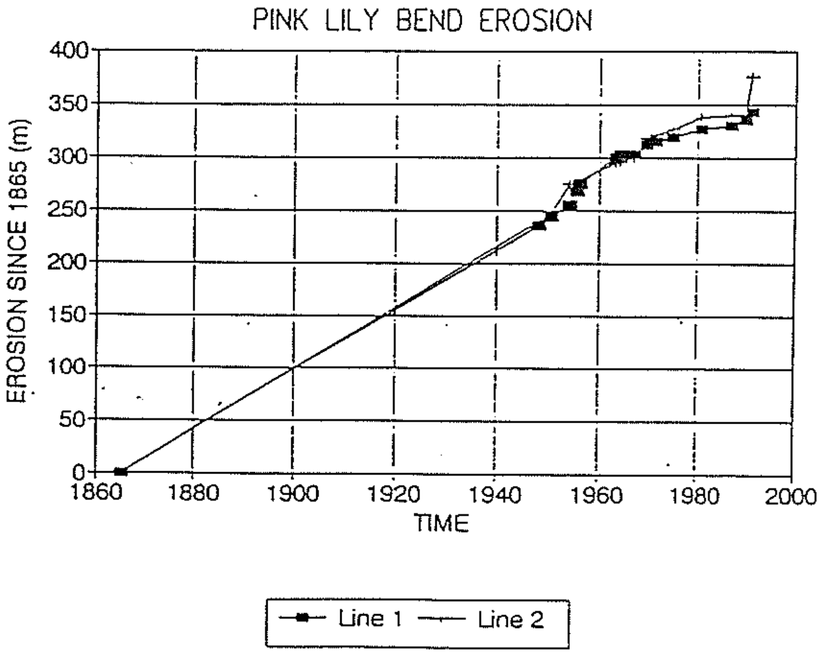

FIGURE 4 PINK LILY BEND BANK EROSION

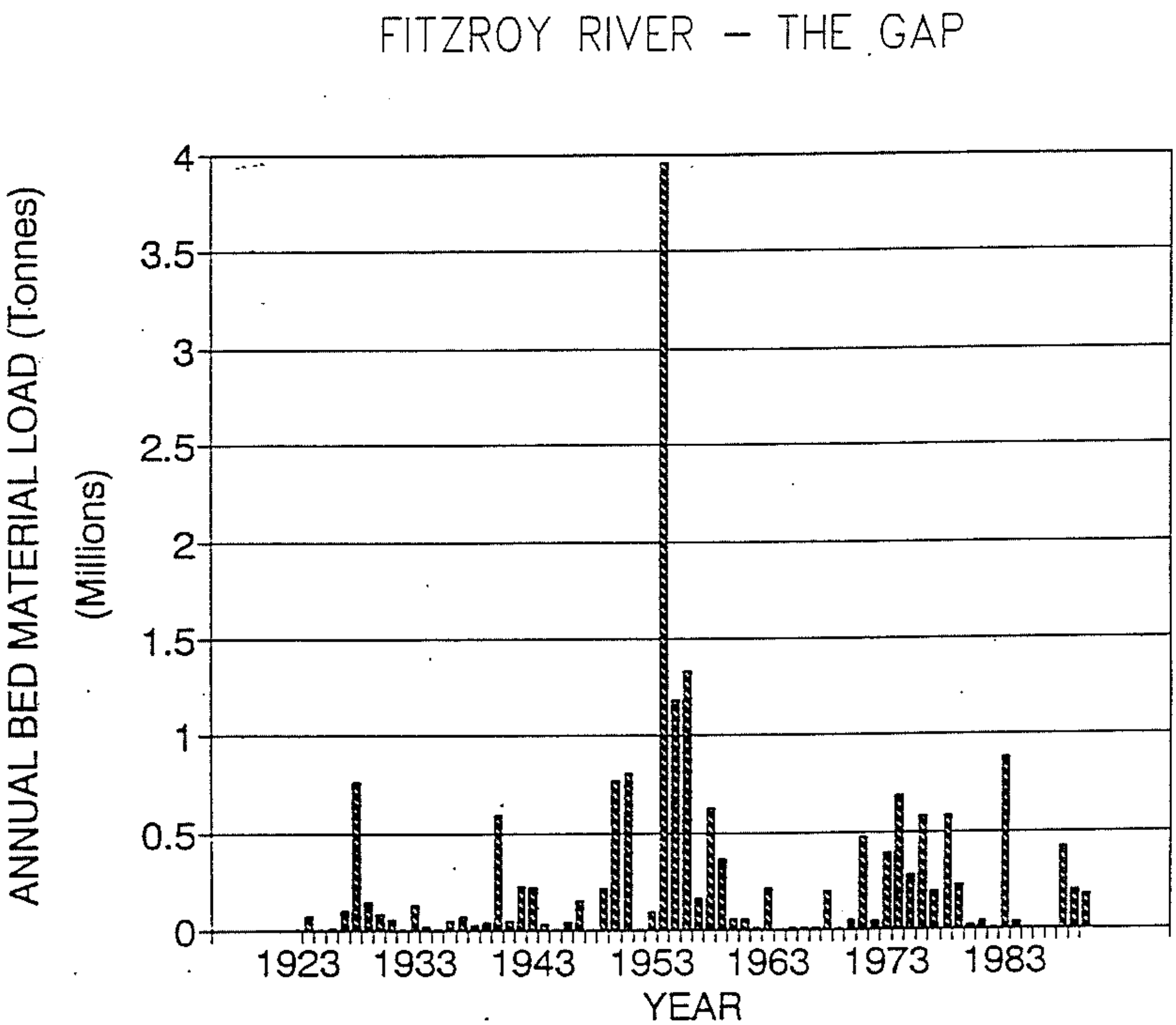

FIGURE 5 **ANNUAL BED MATERIAL LOAD, FITZROY RIVER AT THE GAP**

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Fisheries Overview Dawson River Sub-Basin

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Abstract

This paper provides a fisheries perspective on some aspects of the Dawson sub-basin, areas covered include: development, land use, impoundments, stream flow, recreational fish stocking and selected fish species. Land use practices, impoundments and introduced fish species have modified both habitat and the fish population.

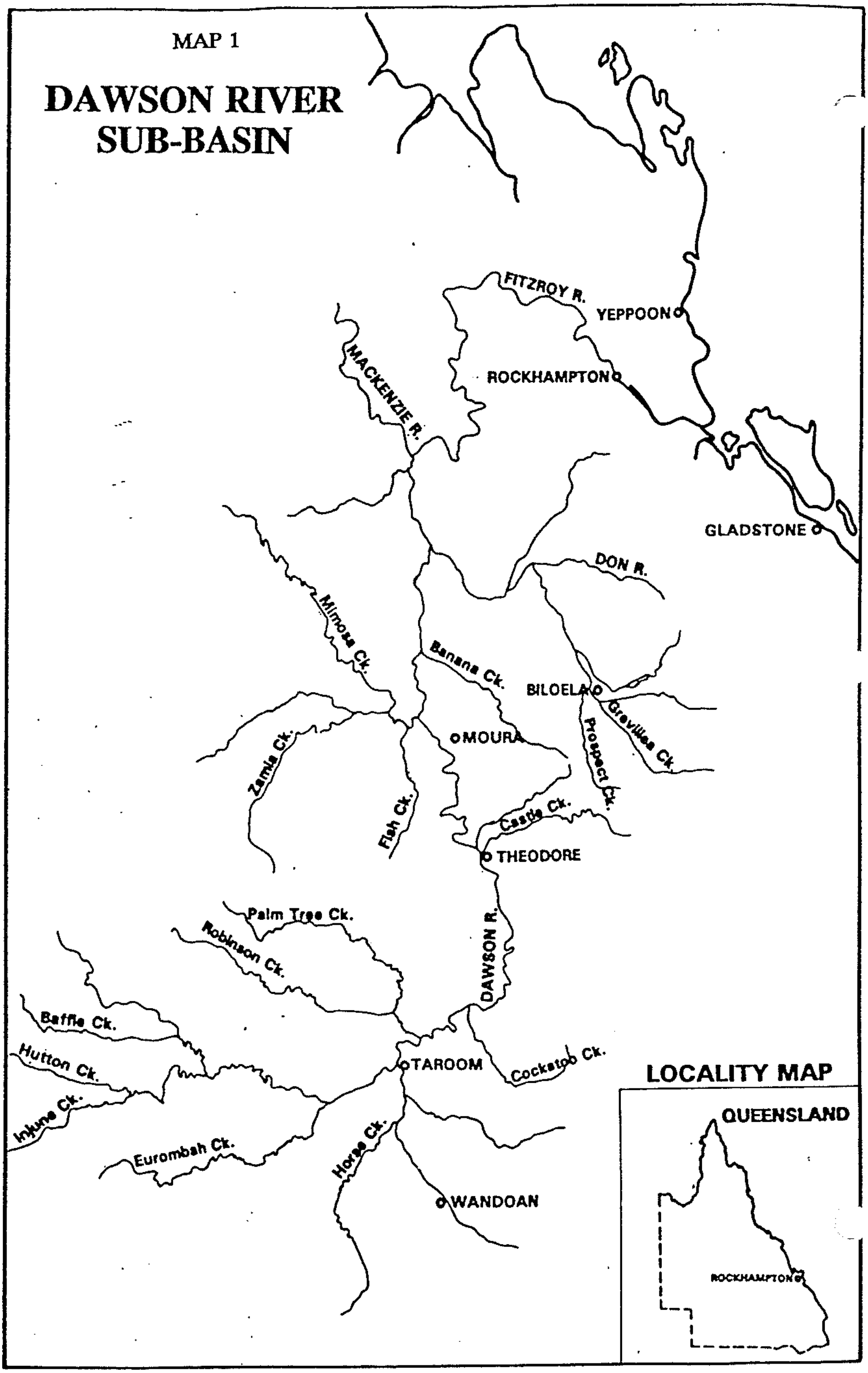
There is a need for current information on the ecology and assessment of streams in Queensland. The Dawson River (sub-basin) is a warmwater stream and maintains a large fish community with the generally complex species habitat relationships.

Introduction

Many factors affect distribution of Australian freshwater fish species - instream habitat, water quality, riparian vegetation, stream gradient, climate and the most important, geographical barriers. Australia's freshwaters can be divided into twelve drainage divisions of which the Dawson sub-basin is part of the northeast division (Merrick & Schmida 1984). It covers an area of 50 000km^2 in central Queensland and with the Nogoa, Comet, Mackenzie, Issacc-Connors and Fitzroy Rivers combining to form the largest basin along the east coast of Australia.

The Dawson River rises west of Injune in the Carnarvon Ranges and to the south in the Wandoan area travelling through the Taroom, Theodore, Moura and Baralaba districts. Major tributaries are the Don and Dee Rivers which join the Dawson near Rannes. The Dawson joins the Mackenzie (23° 37'S, 149° 36'E) to form the Fitzroy River near Duaringa. The Dawson sub-basin falls between longitude 148° 00'E and 151° 00'E and latitude 23° 37'S and 26° 30'S. The Dawson sub-basin is regarded as a sub-tropical system (Map 1). It can be classified as a long indirect coastal stream, with long winding upper and middle reaches caused by very low gradients (300 metres in 550kms) [Map 2].

Natural resource agencies such as Land Use and Fisheries, QDPI need state-of-the-art knowledge on (1) warmwater stream ecology, emphasising fish/habitat relationships, and (2) methods for assessing river condition and factors impacting on this condition. Ultimately the environmental variables that are predictive of fish community structure need to be determined and the quantitative relationships between the variables and catchment activities must be established. Two goals of the Land Use and Fisheries Group Business Plan are management and development of the States' fisheries resources and protection and management of ecosystems on which fish depend.


MAP 1
DAWSON RIVER SUB-BASIN
FITZROY R.
YEPPOON
ROCKHAMPTON
MACKENZIE R.
GLADSTONE
DON R.
Mimosa Ck.
Banana Ck.
BILOELA
Grevillea Ck.
Prospect Ck.
MOURA
Zamia Ck.
Fish Ck.
Castle Ck.
THEODORE
Palm Tree Ck.
Robinson Ck.
DAWSON R.
Baffle Ck.
Hutton Ck.
Injune Ck.
TAROOM
Cockatoo Ck.
Eurombah Ck.
Horse Ck.
WANDOAN
LOCALITY MAP
QUEENSLAND
ROCKHAMPTON

Weir Details of Dawson River

WEIR	A.M.T.D.	CAPACITY	LENGTH STORAGE	SURFACE AREA	RELEASE LOCATION	DATE CONSTRUCTED
Glebe	326.2km	17540ML	30km	530ha	Bottom	1972
Gyranda	284.5km	14700ML	36km	610ha	Top Mid Bottom	1987
Orange Creek	270.7km	6780ML	14km	170ha	Top Bottom	1932
Theodore	228.5km	4760ML	15km	99ha	Middle Top	1925
Moura	150.2km	7246ML	32km	32ha	Middle Top	1946
Neville Hewitt	82.7km	11300ML	31km	295ha	Bottom	1976

Season Stream Flows

The Dawson catchment is subject to a highly seasonal rainfall. Maximum stream flows (Figure 1) generally occur during summer with January averaging the highest mean rainfall (Figure 2). Thus physiochemical composition of the Dawson fluctuates widely throughout the year. By spring, flow is greatly reduced and early summer may bring periods of no flow in sections of the sub-basin. This effect has been compounded, by water harvesting from both river and the underground aquifers for use on extensive tracts of irrigated crops.

During times of minimal or no flow, dramatic changes occur in stream water quality. Organic matter accumulates quickly in still ponds, which under flow conditions would be removed. With increased decomposition of debris, dissolved oxygen levels are lowered and ph values change. Whilst aquatic organisms have evolved in the fluctuating conditions these changes have been accentuated by catchment activities and in some cases, eg. flow rates, normal seasonal patterns of runability have been altered.

Fish spawnings are associated with flooding, in the majority of species, when the abundance of living space and food provides the best conditions for the survival and growth of the young fish. Such is the influence of these factors that in years of more intense flooding, survival and growth are so improved that the total biomass of the fish community rises and a strong year class is produced for transmission on to other years. Because the fish community can vary in abundance with the fluctuations in flood strength, catches of angling species are often correlated with years, following periods of good flooding (Welcomme 1985).

Compared with the general world trend, Australian rivers have low mean annual discharges and a high variability of flow. This variability increases as the catchments and rivers get smaller. The mean peak annual floods are an order of magnitude greater and more variable than they are for world average streams (McMahon 1982). This variability in flow makes management of Australian rivers and their catchments more difficult than elsewhere and means that ecological principles established for Northern Hemisphere streams cannot be extrapolated to Australian situations. This difficulty it seems is only now being realised.

Spawning Activity

Fish have been adversely affected by regulation of river flow (page 4) and floodplain alienation. Reduced fish numbers have often been attributed to reduced spawning due to loss of spawning cues, restriction of upstream migration, loss of access to spawning sites, or to reduced larval and juvenile survival. The more obvious changes to the river environment have been caused by flow regulation and the construction of weirs. This has reduced the frequency, size and duration of floods, the seasonality of peak water flows (delayed effect), water temperature and oxygen levels. Certain sections of the Dawson River have prolonged flows associated with riparian release. Associated with flow regulation are problems of bank erosion and siltation compounded by riparian land-clearing and agriculture. Flooding provides a spawning cue for many species and rising waters take eggs and larvae onto the floodplain. For species in which spawning is not flood cued, a change in flood timing may adversely affect recruitment as when floods are not matched to the breeding season, there will be no floodplain habitat for the larval and juvenile fish (Rohan 1988). The warm, shallow waters of the floodplain are intrinsic to the feed, shelter and growth of larval and juvenile fish.

Organisms have adapted to seasonal cycles in streams and maintaining these cycles will be necessary to preserve natural ecosystem processes. Early life stages are critical in determining adult recruitment as fish mortality is usually greatest during these stages.

Riparian Vegetation

Extensive land clearing has been undertaken in the Dawson sub-basin since the 1920's, in places the river banks have been cleared to the water's edge resulting in greatly increased siltation.

Recently it has become clear that the riparian zone is a critical component in the linkage between streams and their catchments (Cummins 1986). This zone may shade streams, lowering primary production and decreasing temperature fluctuations. It may also stabilise the stream channel and its banks, contribute organic matter vital to the functioning of the detritivore communities, moderate sediment, nutrient and water inputs and contribute large woody debris to the stream (Lowrance *et al.* 1984; Barton *et al.* 1985; Cummins 1986; Fitzpatrick 1986; Petersen *et al.* 1987). Riparian vegetation harbours arthropods some of which fall into the stream and may be consumed. These provide an important food source for Saratoga and other species.

Queensland Government Freshwater Recreation Enhancement Program

In 1986 a Queensland wide program to enhance the recreational angling in freshwater commenced. To date over 60 impoundments have been stocked with fish fingerlings (generally 50mm total length) and in excess of 50 fish stocking groups have been formed statewide. The program has had varying degrees of success. Six stocking groups were formed and operate in the Dawson River sub-basin.

KOALA HABITAT IN CENTRAL QUEENSLAND: implications for management

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Introduction

The single greatest threat to the koala *Phascolarctos cinereus* in Queensland is habitat destruction (Phillips 1990) and the simplest solution to the conservation of the koala is habitat retention. The problem has always been how to develop land for agriculture, industry, urban development and tourism and conserve koala habitat at the same time. In many places koalas coexist with human activity. For example, koalas live within the urban environment of south-east Queensland (McDonnell 1986) and have recolonised parts of urban Ballarat, Victoria (Chuck pers. comm.). They live with cattle grazing across Queensland (Melzer pers. obs.) and with jet aircraft at the Amberley airforce base near Ipswich (Carrick pers. comm.). In all these cases the coexistence has been accidental. The correct habitat remained or, in the case of Ballarat, was created by a recent gardening trend for native trees within the city limits. However, the presence of trees alone does not result in the presence of koalas. There are many parts of eastern Australia where, for no obvious reason, there are no koalas. Despite encountering many other arboreal marsupials, Braithwaite *et al.* (1983) failed to find any koalas while monitoring clear felling of forest in south-east New South Wales. At Stanwell, near Rockhampton, koalas were absent from the upper reaches of Quarry Creek despite an apparently acceptable eucalypt community and the existence of koala populations within a 25 km radius (Melzer 1991).

Koala distribution in Central Queensland

Koalas are widely distributed across central Queensland, extending from the coast to the semi-arid environment west of Longreach (Fig. 1). The distribution is patchy however, with extensive areas in which koalas are extremely rare or absent (Phillips 1990). The apparent patchiness in koala distribution across the region reflects natural variation in the population density in differing vegetation types (Melzer unpublished data) and extensive clearing for grazing and agriculture. More than 50% of all the tree communities, other than those on hills and mountains have been cleared (Shields pers. comm.) and this clearing has fragmented the distribution of the koala. For example, extensive, low density koala populations occurred in brigalow (*Acacia harpophylla*) communities wherever eucalypts occurred. Most of these brigalow forests have been cleared (Sattler and Webster

1984), commonly along with the scattered eucalypt component, and replaced with expansive grasslands and low shrublands. This clearing probably explains the very few recent records of koalas to come from the Isaac and Mackenzie River drainage areas and much of the Comet River valley. The loss of koalas from the Rockhampton region and areas north towards Mackay has been attributed to clearing associated with the development of the beef industry since the 1950's (Wood pers. comm.).

Many of the remaining populations of koalas in the Fitzroy catchment are associated with the largely uncleared hills and mountains. It is in these areas that an understanding of relatively undisturbed koala / habitat interactions can be observed. We have recently completed a study of a koala population centred on such an area. The study examined the characteristics of habitats supporting a range of koala population densities. An analysis of species composition, plant community structure, foliar nutrition and soil characteristics was related to koala population density. The utilisation of one habitat type by koalas was monitored and the patterns of movement and the use of tree species and community analysed. A range of clearing regimes on this site allowed an examination of the possible impacts of tree management programs on a koala population. The results of this study provide a regional context for the development of some land management practices compatable with the conservation of koalas in the Fitzroy River catchment.

Habitat and koala population density

At Springsure, 70 km south of Emerald in central Queensland, basalt from tertiary volcanic activity once formed thick beds over much older sedimentary rocks. Subsequent erosion has, in places, uncovered these older sediments producing a complex landscape of rugged volcanic mountains and hills and low but equally rugged sandstone ridges interspersed with plains of rich volcanic clays and poor sandy loams. A complex mosaic of open forest, woodland and downs reflects the mosaic of soils and topography. Much of the brigalow associated forests and adjacent woodlands to the east of the Springsure region and encompassing the Comet River have been cleared. However, most of the region immediately surrounding Springsure remains largely uncleared. Streams rise in the volcanic mountains, the Minerva Hills, flow west to the Nogoa River and east to the Comet River (Fig. 2).

Koala populations of different densities occurred throughout the region. Five sites with koala population densities ranging from less than one koala per square kilometre to forty koalas per square kilometre were studied. It was found that the highest population densities occurred on the more fertile, basaltic clays while the lowest densities occurred on the least fertile, sandy soils. These high density sites were more open and had lower overstorey cover than the low density sites (Table 1). After analysing the floristic and structural composition of the sites it was found that koala population density increased with an increasing contribution of most preferred food species to the tree communities on the site (Fig 3a). In contrast, population density declined with the increasing contribution of less preferred and non - fodder species to the tree communities (Fig. 3b).

This is a significant observation as the tree communities on the fertile soils are generally the most likely to be cleared (Reed *et al.* 1990). The flood plains around Rockhampton are an example of this pattern.

Utilisation of habitat by koalas

At one of the study sites, 16 female and 18 male koalas were fitted with radio transmitting collars and the koala's use of topography, tree communities and tree species was monitored over a period of 27 months. This site was located on Norwood Creek, 5 km west of Springsure. Within the site, the creek flowed through a narrow valley bounded by ridges, mesas and volcanic mountains rising some 200 metres above the valley floor. Five eucalypt communities occurred on the site. Of these, the *E. citriodora, E. crebra*, and *E. orgadophylla* communities were located on the surrounding ridges and hills. The *Eucalyptus tereticornis* and *E. melanophloia* communities occurred on the valley floor. The *E. tereticornis* community fringed the streamlines. This stream fringing community accounted for nearly 47% of koala sightings while 36% of sightings were in the *E. crebra* community. The remaining 17% of sightings were associated with the other communities. On 57% of sightings koalas were associated with the valley floor adjacent to drainage lines. However, 43% of sightings were in the surrounding ridges and hills (Melzer and Lamb 1992).

Koalas were found to use 17 species of trees, although 69% of sightings were in *E. tereticornis* and *E. crebra* (Table 2). They have been observed to eat *E. tereticornis, E. crebra, E. melanophloia, E. orgadophylla* and *E. exerta* and are probably eating other species to a lesser extent.

This is a more complex pattern than the local view that the "river gums" were most important to koalas. This view may well be a self fulfilling attitude as the stream fringing community is commonly the only significant vegetation left intact after "tree treatment". Koalas which survive the process of tree clearing or poisoning would, in the short term at least, congregate in the remaining stream fringing community.

A variety of clearing regimes were present along Norwood Creek. These regimes ranged from total clearing of all but some of the stream fringing *E. tereticornis* community to selected thinning of specific eucalypt communities. Although koalas traversed totally cleared paddocks, using scattered remnant trees as day time refuges, these paddocks were not included in any permanent ranges. The remnant trees used by the traversing koalas were between 300 and 500 metrès apart. In contrast a permanent population of koalas used paddocks where the clearing amounted to thinning but not removal of tree communities (Melzer and Lamb 1992). Clearly, the pattern of "tree treatment" determines the chances of koalas remaining within any region.

Long distance dispersal and long term survival

During the survey on Norwood Creek, two female koalas undertook directed, long distance movements and one male koala, a young adult, crossed the study area before establishing a range. One female was tracked to a point some 22 km west of the site before being lost. The second female was located 19 km south of the study area. The young male wandered over 7 km before establishing a range area. All three animals moved across a variety of environments including poisoned woodlands and cleared paddocks. While crossing the cleared paddocks the koalas took refuge in remnant trees and dead trees were used for temporary refuge in poisoned woodlands.

These relatively long distance dispersals suggest that, in the Springsure region at least, koala populations should be considered as a single widespread population rather than a series of distinct colonies. An analysis of genetic diversity in Queensland koalas suggests that they have been subject to occasional, severe population declines and that the ability to expand rapidly from these catastrophic events may ensure the long term viability of the species (Worthington Wilmer *et al.* 1992).

The dispersing koalas did not follow drainage lines or obvious vegetation corridors but rather, moved straight across the landscape, in places relying on remnant trees as day refuges. This pattern of movement places an unexpected significance on the retention of trees across the entire landscape as a dispersal environment for koalas.

The willingness of koalas to venture into open country should not be seen as a vindication for broad scale clearing. Large areas of open country would be an effective barrier to koala dispersal. Moving long distances without appropriate fodder and the associated leaf water would subject the koalas to considerable stress. During summer, shade is essential for the regulation of body temperature (Carrick pers. comm.) while koalas on the ground, without access to trees, are vulnerable to predation (Melzer pers. obs.). Koalas probably need to have day refuge trees about 500 metres apart and stands of fodder trees at about a kilometre spacing. For example, the young male koala discussed earlier, moved about 700 metres through a poisoned forest and took refuge in a dead tree 600 metres from healthy forest.

Land management and koala conservation

If the aim for conservation of the koala is the maintenance of the natural distribution of the species then National parks or reserves can only protect single populations of koalas and will do little to ensure the continued existence of the animal across the region. Conservation measures must enable the coexistence of the koala and people. The Springsure koala study has provided some information which may facilitate this coexistence.

At Springsure, koalas were found at higher densities in habitat consisting of open woodland with a low density of eucalypts, but where the most preferred fodder species were most abundant, relatively dense and occurred more frequently than other possible fodder species. At these higher density sites the most preferred fodder species tended to have larger girths than preferred fodder species at other sites. Koala densities also tended to be higher on more fertile soils.

These observations are consistent with findings from other states (Hindell 1984, Reed *et al.* 1990, Phillips 1990) and provide guidelines for the management and conservation of koalas.

It is difficult to provide specific recommendations as these are inherently site specific. However, generalised policy guidelines can be provided. There are four aspects which need to be considered:-

1) Clearing regimes
2) Siting habitat re-creation and rehabilitation programs
3) Selection of tree species for rehabilitation
4) Planting design

1) Clearing regimes

High density koala populations are rare in the Fitzroy catchment. No clearing should occur where such populations exist. High density populations should be studied to determine their extent, conservation status and regional significance. Although clearing should be avoided, there is no suggestion that grazing or other activities should be stopped unless there is a clear threat to the koalas or their habitat.

If any koala habitat is to be cleared, careful planning of the operation would minimise the impact of the disturbance to the koala population. Utilisation of a specific habitat by koalas involves a complex selection of a wide range of tree species within a number of plant communities. At Springsure, the stream fringing community was most used, although koalas used communities on adjacent ridges to a significant extent. Where possible, existing plant communities should be retained intact. Thinning appears to be less disruptive than total clearing. The most preferred fodder species should be retained and plant communities on the ridges should be linked to the stream fringing communities.

Koalas were observed to move quite long distances, at times across open paddocks where they relied on remnant vegetation for day refuges. Dispersing koalas did not use vegetation corridors but were found to take the direct route rather than following stream or vegetation lines. Scattered trees across the landscape, 300 to 500 metres apart, would provide a dispersal environment even though the indications are that koalas would not settle in such a sparcely treed environment.

Their ability to undertake long distance dispersal may be an important mechanism in avoiding the deleterious effects of longterm inbreeding. The land management practices within the Fitzroy catchment have probably alienated areas formally capable of supporting high density koala populations and fragmented the widespread, low density, koala populations of the region. Although koalas may be genetically adapted to survival as small, isolated populations for a period of time (Worthington Willmer *et al.* 1992) the process of fragmentation must result in the ongoing loss of populations to the catastrophy of habitat destruction, disease, drought or fire.

2) Siting habitat re-creation and rehabilitation programs

Rehabilitation of koala habitat should follow two strategies. One strategy should concentrate on the conservation of fragmented populations through habitat extension and the development of dispersal environments to adjacent potentially suitable habitat. The second strategy should locate sites which used to support, or have the potential to support, high densities of koalas. These sites appear to be those which are well watered, on fertile soils and capable of supporting highly preferred fodder species.

3) Selection of tree species for rehabilitation

Koala population density in the Springsure region appears to be related to the presence of most preferred fodder species in each particular habitat. The fodder species most preferred by koalas are known but the appropriate mix of species varies from region to region. In all koala populations examined, a range of less preferred fodder species were exploited to some extent while some non-eucalypt species were exploited, probably as shelter trees. The species selected should be predominately prime fodder species but should include some less preferred species and possibly non-fodder species to reflect the known choices of koalas in the region.

4) Planting designs

The preference of koalas for relatively open habitat (for example 15 - 23 trees/ ha at Springsure), allows a degree of flexability in the planting design for rehabilitation programs. Plantings could be arranged around buildings or smaller paddocks, as a series of clumps across open country or as scattered trees. The distance between trees or clumps should not be so great as to deter the easy movement of koalas. Although koalas were observed to move 300 to 500 metres between trees in cleared country, they never established permanent ranges in those areas. Distances of about 100 metres are probably more appropriate. Carefully designed planting should allow the development of koala habitat around existing agricultural, industrial or urban activity.

Considered and conservative tree management on properties, involving planned clearing and structured replanting, would ensure the retention, and possibly, the expansion of koalas across the Fitzroy catchment.

Acknowledgements

This study was funded by the Australian Koala Foundation. Additional funding was provided by BHP - UTAH, while Hastings Deering (Qld) provided a vehicle. The support of the Rockhampton City Council and Blair Athol Coal is acknowledged. Property owners, Paul and Jessica Lawless - Pyne, Mick and Pat Mayne, Ken Perrett, Tim and Lyn Sypher, Ray and Betty Thomson, Brian Milner, Ken and Beverly O'Keeffe, Rodney Heath, Auban Woolcock, the Bauhinia Shire Council and the Department of Environment and Heritage kindly permitted access to their properties. The volunteers who assisted with the koala capture and habitat surveys are also acknowledged.

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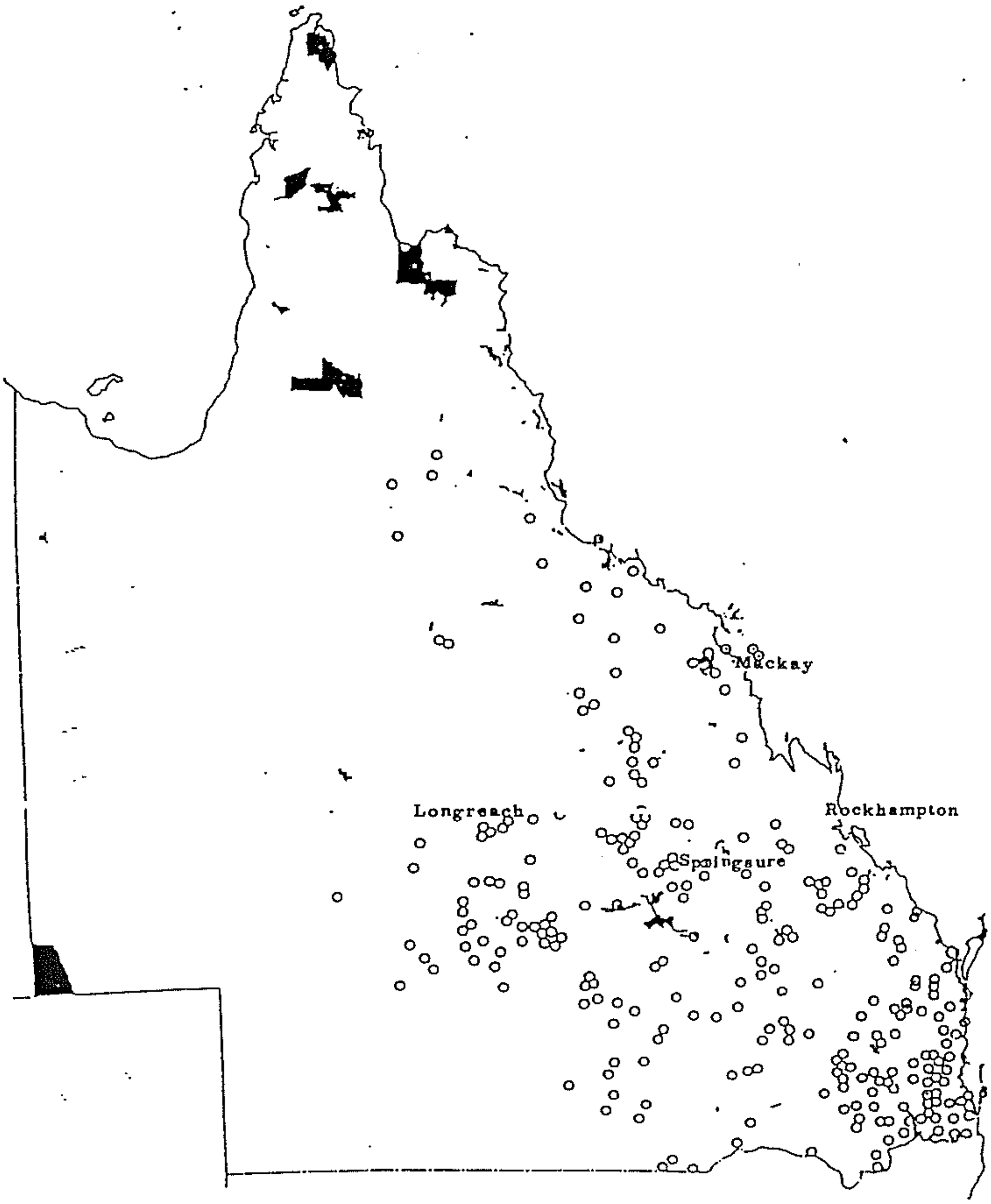

Fig. 1 Distribution of koala sightings in Queensland. (Source: The Queensland Dept. of Environment and Heritage.)

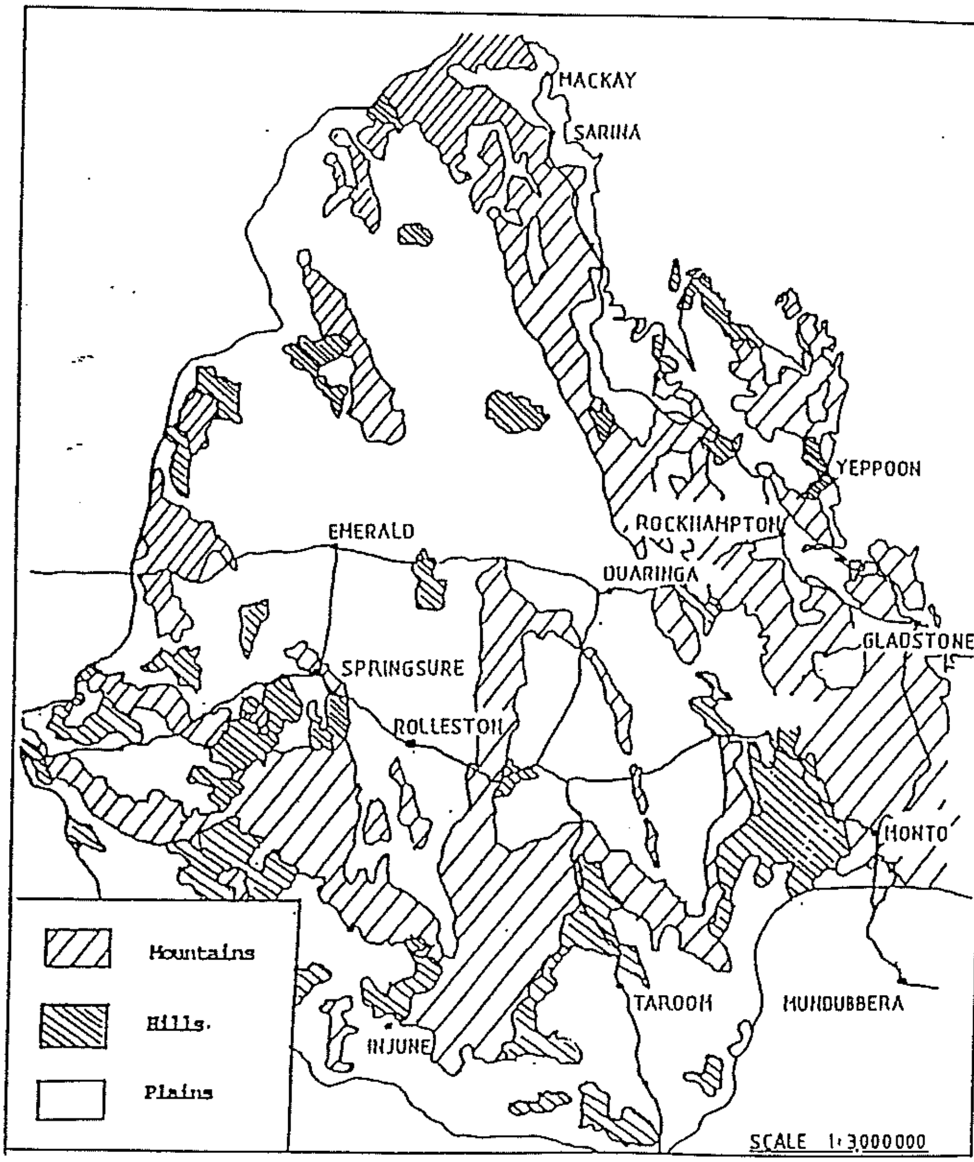

Fig. 2 Terrain types of the Fitzroy catchment. (Source: Galloway *et al.* (1966))

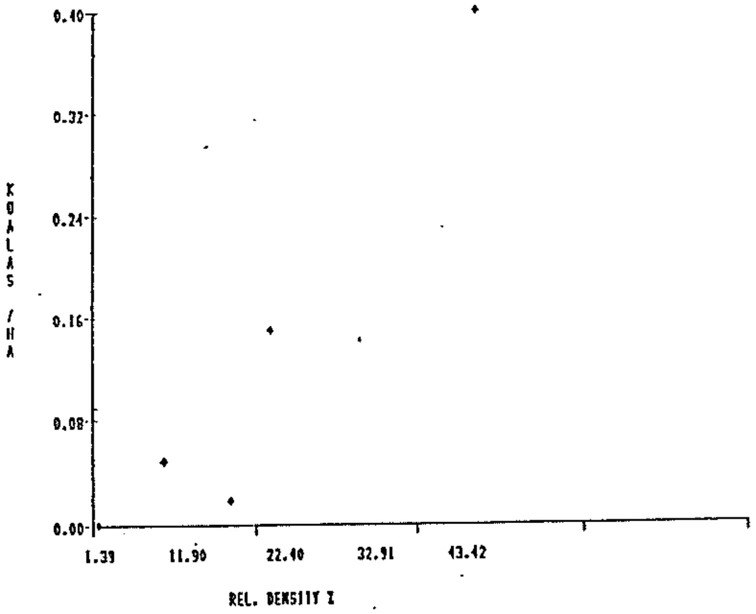

Fig. 3a At Springsure, koala population density increased with increasing relative density of most preferred fodder species. A similar pattern was evident in a comparison of koala density with the frequency, relative frequency, relative dominance and importance of most preferred fodder species.

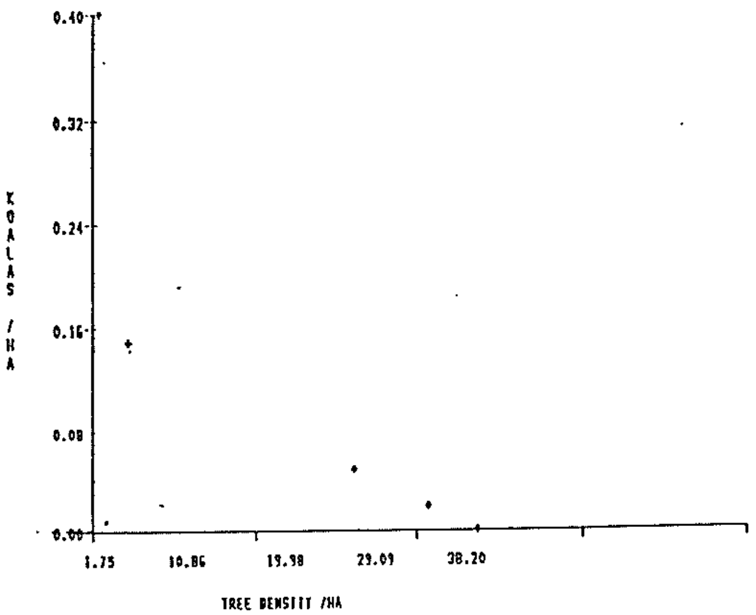

Fig. 3b Koala population density declined with increasing stem density of least preferred fodder species. Similar patterns were evident when koala density was compared with the dominance and importance of the least preferred fodder species.

SITE	KOALAS /ha.	COMMUNITY STRUCTURE	TOTAL COVER %	FOLIAGE PROJECTIVE COVER %	STEM DENSITY /ha.	BASAL AREA sq.M.	SPECIES DIVERS.
Wallalee	0.40	woodland	17.0	10.8	14.8	0.28	12
Koala Ck	0.15	woodland	17.8	11.8	22.7	0.51	18
Pinnacle	0.05	open forest	40.5	28.5	222.8	0.01	18
Norwood Ck	0.02	open forest	48.8	30.7	120.8	0.03	15
Riverstone	< 0.01	open forest	48.3	31.1	148.7	0.79	20

Table 1 Structural characteristics of five koala population sites at Springsure.
(Classification after Specht 1970).

Table 2 Queensland - based koala fodder species. (From Kelly 1992).

SPECIES	1	2	3	4	5	6	7	8
Angophora subvellutina		*						
Eucalyptus acmenoides					*			
E. amplifolia	*							
E. camaldulensis	*	*	*	*	*			
E. camphora	*				*			
E. campageana	*				*			
E. cinerea	*							
E. citriodora	*				*	*	*	?
E. crebra	*	*	*		*	*	*	*
E. drepanophylla	*	*		*	*			
E. exserta						*		*
E. fibrosa						*		
E. grandis		*		*				
E. haemastoma	*			*				
E. intermedia					*			
E. longirostrata		*						
E. maculata	*	*	*	*	*			
E. melanophloia							*	*
E. melliodora	*				*			
E. microcorys		*		*				
E. moluccana		*			*	*		?
E. nicholii	*							
E. ochrophloia		*						
E. orgadophila		*					*	
E. pilularis		*		*				
E. populnea	*	*	*		*	*		*
E. propinqua	*	*	*	*	*			
E. punctata	*				*			
E. raveretiana						*		*
E. resinifera		*						
E. robusta	*	*		*	*			
E. saligna		*		*				
E. seeana		*			*			
E. siderophloia		*						
E. sideroxylon		*						
E. signata		*			*			
E. tereticornis	*	*	*	*	*	*	*	*
E. tessellaris					*		*	*
E. thozetiana	*							
Lophostemon (Tristania) conferta		*		*		*		?
Melaleuca nervosa						*		*

List of Species supplied by:

(1) Australian Koala Foundation (AKF).
(2) Queensland Forest Service (QFS).
(3) National Koala Survey (Phillips 1990).
(4) Queensland Wildlife Preservation Society Koala Survey (Campbell *et al* 1979).
(5) Koala Summit, Sydney (*In* Koala Management: Proc. AKF Conf., 1986).
(6) Bill Young, Rockhampton Zoo koala diets (pers. comm.).
(7) Alistair Melzer, Springsure koala diets (pers. comm.).
(8) Species present on the Stanwell Site (Chamberlain pers. comm., Melzer 1991, White pers. comm.).

THE DRY RAINFORESTS OF THE FITZROY CATCHMENT - conservation status and management

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Abstract

Dry rainforests in the Fitzroy River catchment once covered far larger areas than they do today. These communities have largely been cleared for forestry, pastoral and agricultural development and now generally occur as small, isolated remnants in gullies, along streamlines and on scree slopes.

These remnants are refuges for a diverse range of plants including rare and threatened species and they are significant for native fauna. They are however, poorly represented in conservation reserves and are currently under threat from surrounding land management practices.

Their occurrence as small remnants creates problems for reservation and management. Placing rainforest remnants within National Parks and other reserves is not an answer in itself. Rather it is essential that an integrated management approach be adopted - one which involves landholders, managers and neighbours. Commitment to such an approach will help ensure the longterm survival of the dry rainforests and their continued role in responsible land use practices.

General details

Dry rainforest is the principal rainforest type in the Fitzroy catchment. It includes the subforms:- Araucarian microphyll to notophyll vine forests, low microphyll vine forest and semi-evergreen vine forest (nomenclature follows that of Webb 1978). The latter is commonly referred to as softwood or bottle tree scrub. Some of the general features which characterize these rainforests are presented in Appendix 1..

The dry rainforests of the Fitzroy catchment form part of the C1 and C2 rainforest floristic provinces of Webb *et al*. (1984). These are subhumid-humid, warm, subtropical and subhumid warm subtropical types, respectively. The core area of the C1 floristic province usually occurs on soils derived from basalt or calcareous sediments on coastal lowlands and near-coastal areas north of Brisbane and extending to moist uplands in central Queensland, while the core area of the C2 province, is between Boonah (South-east Queensland) and Biloela and generally occurs on soils derived from basic igneous rocks or calcareous sediments. The latter province is typified by semi-evergreen vine forest (Webb *et al.* 1984).

The importance of the dry rainforests for conservation

The dry rainforests of the Fitzroy catchment are important refuges for a diverse flora and are rich in rare and threatened species (Cummings 1987). An outstanding example of the latter is a 75 hectare remnant of semi-evergreen vine forest at Struck Oil, near Mt Morgan, which contains four rare and threatened plant species (Forster *et al.* 1991).

Many of the plant species which occur in the dry rainforests of the Fitzroy catchment are known to have been used for food or medicinal purposes by Aborigines and early settlers in other parts of Australia (Low 1989, 1990) and were probably also used here. Furthermore, they hold great potential for use both in the present and the future in terms of food, medicinal and horticultural purposes. For example, recent evidence from the study of pawpaw (*Carica papaya*) pollination suggests that the presence of dry rainforests within the vicinity of pawpaw plantations may be important, if not essential to the successful production of the fruit. It appears that the principal and perhaps the sole pollinators of the pawpaw are hawk moths (Sphinggids) and that the host plants in this area are commonly dry rainforest species (Anne Garrett pers. comm.).

The apparent requirement of the hawk moths for dry rainforest plants points to another vital role of rainforest remnants in the Fitzroy catchment - that of a refuge and food source for native fauna. Some examples of species for which the dry rainforests form part or all of their habitat include fruit pigeons such as the woompoo (*Ptilinopus cinctus*), wonga (*Leucosarcia melanoleuca*) and rose crown (*Ptiliinopus regina*) pigeons; the Kroombit Tops torrent frog (*Taudactylus pleione*) which appears to be restricted to Kroombit Tops; and the long-nosed potoroo (*Potorous tridactylus*) which is at the northern limit of its known distribution on Many Peaks Range (K. MacDonald pers. comm.).

The importance of retaining rainforest remnants for the maintenance of faunal species diversity and distribution is further emphasized by the example of the long-nosed bandicoot (*Perameles nasuta*) in the Central Highlands. This species, although occurring in wetter rainforests in coastal regions at the same latitude, is in the Central Highlands restricted to semi-evergreen vineforest/ thicket (softwood scrub). It is thought that the long-nosed bandicoot may now be extinct in the Central Highlands as the only patch of rainforest in which it was known to occur has been cleared for pasture (Gordon 1978).

Aside from its direct role in the maintenance of species diversity, dry rainforest also has an important function in the conservation of land and water resources. When retained on hillsides and along watercourses the community facilitates the prevention of soil erosion and salination and hence the maintenance of water quality.

Conservation status

Dry rainforests and in particular, low microphyll vine forest and semi-evergreen vine forest, are considered to be endangered vegetation communities.

The Araucarian notophyll and microphyll vineforests which were once very widespread in subcoastal areas on soils of moderate to high fertility now, as a result of clearing for agriculture, conversion to hoop pine plantations and logging of natural hoop pine, are mainly represented by small, fragmented patches. The largest remaining areas of these 'hoop pine rainforests' in the Fitzroy catchment occur on the Dawes Range within State Forest (Young and McDonald 1987).

Of the dry rainforest types, low microphyll vineforests and semi-evergreen vineforests are the most poorly represented in conservation reserves. Nix (1977) estimated that these communities once covered 6 280 km2 of the Fitzroy Region. Low microphyll vineforest however is threatened by coastal development and sandmining, while much of the semi-evergreen vineforest has been cleared for agricultural or pastoral development and in some cases for gravel deposits (Nix 1977, Young and McDonald 1987). Those that remain generally occur as small, isolated remnants on well drained and relatively fertile soils in sites which are protected from fire (Webb and Tracey 1981).

The management of dry rainforest in the Fitzroy catchment

The fact that much of the remaining dry rainforest occurs as small remnants creates problems for reservation and management which, if they are to be dealt with satisfactorily, require a thorough understanding of the ecology of the remnant and surrounding area. Furthermore, it will be necessary to have an understanding of any economic and social factors which may be associated with the use of the surrounding area.

The management of fragmented systems has two components. These are the management of the natural system or the internal dynamics of the remnant area and the management of the external influences on the natural system (Saunders *et al.* 1991). Remnants, because they are surrounded by a mosaic of agricultural or other developed land are faced with significantly altered fluxes of radiation, wind, water and nutrients - conditions which can have a marked effect on the biota of the remnant, particularly near the edge. Furthermore, the remnants are frequently subjected to impacts from fire, feral and domestic animals and weed invasion.

Rainforests are not adapted to fire and in general, undisturbed rainforests are sufficiently moist to prevent most fires from penetrating any further than the edge. Of concern however, is the repeated damage that occurs at the edge of rainforest communities as a result of regular control burning or burning to reduce rank grass and encourage fresh growth for stock. With each burn some of the rainforest flora at the edge of the community may be damaged and replaced by species from the surrounding non-rainforest flora which recover more rapidly after being burnt (*eg.* pasture species such as buffel grass). This results in a gradual 'eating away' of the rainforest stand through the replacement of the rainforest flora in the disturbed area by species which are more adapted to fire. The rainforest stand shrinks little by little with each fire event. While this may be able to be tolerated where the rainforest stand is large, it is of major concern in the case of small rainforest remnants for which any loss in size is significant. Damage to the edge of rainforest patches by fire can be avoided by maintaining a fire break away from the edge of the rainforest.

Domestic stock and feral animals such as pigs can effect the integrity of a dry rainforest community by creating tracks and camping areas which are susceptible to erosion and weed invasion. Weed seeds are likely to enter the site on the coats of stock or to be deposited on site in faeces. Pigs cause further damage by rooting up plants.
The solution to the exclusion of stock is to fence the remnant. In some instances it may not be necessary to fence the entire patch but rather, particular areas which are accessible to stock. The exclusion of feral animals such as pigs is more difficult and probably cannot be achieved by anything less than an ongoing control or eradication program.

Weed invasion is a serious threat to all our native plant communities and dry rainforest is no exception. Prevention is certainly far better than cure and the maintenance of intact and relatively undisturbed rainforest communities is an integral part of the former. Unfortunately there are few rainforest remnants in which weeds are not threatening the integrity or in some cases the survival of the community. By far the weed of greatest concern in the Fitzroy catchment is rubber vine (*Cryptostegia grandiflora*) which can occur as an unsupported multi-stemmed shrub up to three metres high or as a woody climber which is capable of growing over trees up to 15 metres high (Parsons and Cuthbertson 1992). The eradication and control of rubber vine and other 'aggressive weeds,' such as lantana (*Lantana camara*), requires regular, ongoing monitoring and a longterm commitment to their removal. Advice on the control of such weeds can be obtained from the Department of Primary Industries and the Department of Environment and Heritage.

A further issue in the management of dry rainforest remnants is the problem of isolation or distance between remnants. The degree of isolation of a remnant can have important implications for biota in regard to their dispersal from one remnant to another and hence is important in terms of the long term survival and viability of populations and indeed communities. Where the potential remains, patches of rainforest should be retained such that they are within close vicinity to one another and if possible, are linked by undisturbed or relatively undisturbed vegetation. Planting locally occurring rainforest species around and between remnants is a way to increase their size, create buffers around them and link patches or at least decrease the distance between them. Information regarding the planting of dry rainforest species can be obtained from groups such as Greening Australia, the Society for Growing Australian Plants, the Queensland Forestry Department and the Department of Environment and Heritage. Financial assistance is sometimes available for revegetation projects through programs such as 'Save the Bush' - details of which can be obtained through the Conservation Strategy Branch of the Department of Environment and Heritage and Greening Australia.

Conclusions

The dry rainforests of the Fitzroy catchment are a vital component of the landscape. They provide a refuge for a diverse range of flora and fauna, including rare and threatened species; are a source of potential food, medicinal and horticultural materials; and are important in the conservation of soil and water catchment areas. Furthermore, they are a fascinating and aesthetic recreational resource.

They are however poorly conserved with many of the remaining dry rainforests being small and isolated remnants. It is rightly stated that, "since most impacts on remnants originate from the surrounding landscape, there is clearly a need to depart from the traditional notions of reserve management and go toward integrated landscape management. It will become increasingly difficult to maintain remnants of native vegetation if the management practices in the surrounding matrix have continuous adverse impacts on them. There is a need to manage the landscape as a whole instead of as a collection of separate biotic and legal entities (Saunders *et al*. 1991)." To help address this need, a system is currently being implemented whereby the Minister of Environment and Heritage and landholders may enter into a conservation agreement pertaining to the protection and management of a particular area (Nature Conservation Act 1992). Further details regarding conservation agreements can be obtained from the Department of Environment and Heritage.

In the longterm the conservation of our dry rainforest remnants will depend on a clear understanding of the communities involved and on open communication, understanding and co-operation between landholders, managers and neighbours.

Acknowledgments

Details from this paper form part of a report funded by the National Rainforest Conservation Program.

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Appendix 1. Some general characteristics of dry rainforests.

canopy:

- two strata, the lower one is 6 to 18m tall, while the upper one consists of scattered emergents
- both strata are uneven in outline
- high diversity of species (10-30 species in the lower stratum)
- the emergents are *Araucaria* or semideciduous spp.
- the lower stratum is often dominated by species from the following families:- Sapindaceae, Euphorbiaceae, Rutaceae, Celastraceae, Oleaceae, Anacardiaceae, Moraceae

leaves:

- primarily microphyll
- frequently compound
- frequently toothed
- often hard and bluntly pointed

special lifeforms:

- plank buttresses, strangler figs, palms, large epiphytes and large-leaved herbs are generally rare or absent
- mosses and ground ferns are rare and there are no tree ferns
- large vines are conspicuous and their species diversity is high

special features:

- the ground layer is usually sparse or absent
- prickly shrubs occur commonly

habitat:

- rainfall is generally lower than for the other types of rainforest, being from 630 to 1100mm annually with a marked dry spell
- generally occur on fertile or moderately fertile soils derived from eutrophic parent rock (*eg.* basalt)

44-7

CHEMICAL ASPECTS OF HERBICIDE RESEARCH IN THE FITZROY CATCHMENT

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ABSTRACT

Agricultural chemicals remain a necessary component of economically viable agricultural production systems in the Fitzroy catchment. Herbicides are one important class of these chemicals and farmers are being encouraged to minimise soil losses and land degradation by using herbicides combined with minimum tillage for weed control.

Research presently being undertaken by the Queensland Department of Primary Industries aims at:

(i) increasing the efficiency of use of herbicides by understanding rates of breakdown and soil interactions;
(ii) determining the environmental fate of herbicide residues in the catchment.

Glyphosate ("Roundup") and 2,4D have been found to degrade rapidly under typical summer conditions (half-lives of 2 and 7 days, respectively). Atrazine breaks down more slowly (half-lives of 1 to 4 weeks) and this rate can be strongly influenced by the clay content of the soil.

In the soils tested (clay contents 40% to 70%) herbicide residues have not been found deeper than 50 cm, so for these, penetration of herbicides to groundwater is unlikely. Groundwater samples from the Dawson-Callide and Emerald areas are presently being analysed at the Biloela Research Station to test this belief.

INTRODUCTION

A diverse range of agricultural production systems exists within the catchment. Of these, beef cattle and cropping industries are dominant.

In both livestock and cropping industries, agricultural chemicals play an essential role for economic viability. We need to be concerned with the efficient use of these chemicals and their ultimate environmental fate in the region.

Herbicides are one important component in the spectrum of agricultural chemicals. To counter soil losses and land degradation, primary producers are being encouraged to reduce tillage operations and where possible adopt alternative methods for weed control including the use of herbicides. Suitable applications of 'knockdown' and 'residual' herbicides combined with minimum tillage can give effective weed management. In the western areas of the catchment, rainfall is variable and opportunity cropping to utilise available moisture may be essential for economic survival. Care with the use of 'residual' herbicides is needed so that planting options for following crops are not limited.

Although most herbicides exhibit a low mammalian toxicity, they can pose problems in the aquatic environment and have been detected in groundwater supplies overseas. As well, herbicides are expensive and need to be used with optimal efficiency.

These issues are being addressed in the region by current research being conducted by the Queensland Department of Primary Industries.

HERBICIDE RESEARCH

The rates of breakdown and ultimate environmental fate of herbicides used in the catchment will depend on many factors including:

(i) chemical structures of the herbicides;
(ii) solubility properties and potential for adsorption in soils
(iii) soil types and properties
(iv) temperatures and rainfall
(v) potential for off-site movement in runoff water or adsorbed to soil particles and for penetration to groundwater.

Climate and Soils

In the major cropping areas of the catchment, summer temperatures are high. Surface soil temperatures may exceed 50°C and moisture conditions vary widely from dry to moist with summer storm activity. While the high temperatures tend to increase the rate of breakdown of herbicides very dry conditions may slow this process.

Dominant soil types are neutral to alkaline with fairly high clay content which affects both the initial activity and degradation of herbicides.

Rates of Breakdown

The degradation rates of the 'knockdown' herbicides 2,4D and glyphosate ("Roundup", "Zero") and the 'residual' herbicide atrazine ("Gesaprim") have been studied at sites near Biloela and Emerald on soil types typical of large areas of the cropping regions of the catchment.

Figure 1 shows the degradation of 2,4D when applied to soil and wheat stubble in a summer fallow site at Capella. The herbicide broke down rapidly on both soil and stubble with a 'half-life' of about one week. Six weeks after application remaining concentrations of 2,4D were low. Similarly glyphosate ("Roundup") applied under summer conditions to a trial site on the Biloela Research Station degraded rapidly with a 'half-life' in soil of about two days (Figure 2).

As expected, the rate of breakdown of the 'residual' herbicide atrazine is slower but this rate can vary dramatically for different soils in the catchment. Figure 3 shows the degradation of atrazine applied in summer to a grey Vertisol at Mt Murchison near Biloela and to a black earth near Emerald. The 'half-lives' for atrazine at Biloela and Emerald were about one and four weeks respectively. This marked difference for these soils was confirmed under controlled conditions in the laboratory at the Biloela Research Station. The soils have similar pH's but quite different levels of clay (Mt Murchison 40%, Emerald 70%).

Results from southern Queensland have also shown that clay content can have a marked effect on both the initial activity and rate of breakdown of atrazine.

Environmental Fate

The solubilities of most herbicides in water are quite low. Under certain conditions however it may be possible for herbicides to move down the soil profile into groundwater or be carried off-site in surface runoff or absorbed to soil particles. Off-site movement is discouraged by conservation cropping techniques where both soil and water losses by surface runoff are minimised.

In the region at present two aspects are being investigated:

(i) are residues of herbicides accumulating in soils after many years of applications?

(ii) are herbicides penetrating to groundwater storages in the catchment?

To address the first question, tillage sites with a documented history of herbicide applications are being studied. On a tillage trial site near Capella over seven years more than 5 kg/ha each of 2,4D and glyphosate have been applied. In the tillage bays, along drainage ways and from a silt dam, soil samples down to 1.8 m or bedrock have been taken.

Glyphosate has not been detected (detection limit 0.1 mg/kg) in any of 24 samples analysed while low levels of 2,4D (0.02 mg/kg) were detected in only two surface samples. In an application trial with 2,4D at commercial rates, the herbicide was not detected (detection limit 0.005 mg/kg) after six weeks below 15 cm in the soil profile. For these herbicides and this soil type (black earth) penetration of the herbicides to groundwater is unlikely.

At the Mt Murchison site on a grey Vertisol concentrations of atrazine down the soil profile were determined before and after a sorghum crop when commercial rates of the herbicide were applied. Post-harvest, 14 weeks after atrazine application no residues were found deeper than 50 cm down the profile. Again penetration of atrazine to groundwater is unlikely.

The above results indicate that groundwaters should not contain residues of these herbicides at least where reasonable depths of heavy clay soils overly aquifers. To verify this belief, groundwater samples are presently being taken in the Dawson-Callide areas for analysis at the Biloela laboratory. This sampling will be extended to Emerald and elsewhere in the Fitzroy catchment.

Some results will be available by the time of the Symposium.

CONCLUSIONS - The Future

For the foreseeable future, agricultural chemicals including herbicides will remain an essential component of all agricultural production units in the catchment. They need to be utilised as part of economically and environmentally sustainable agricultural management systems.

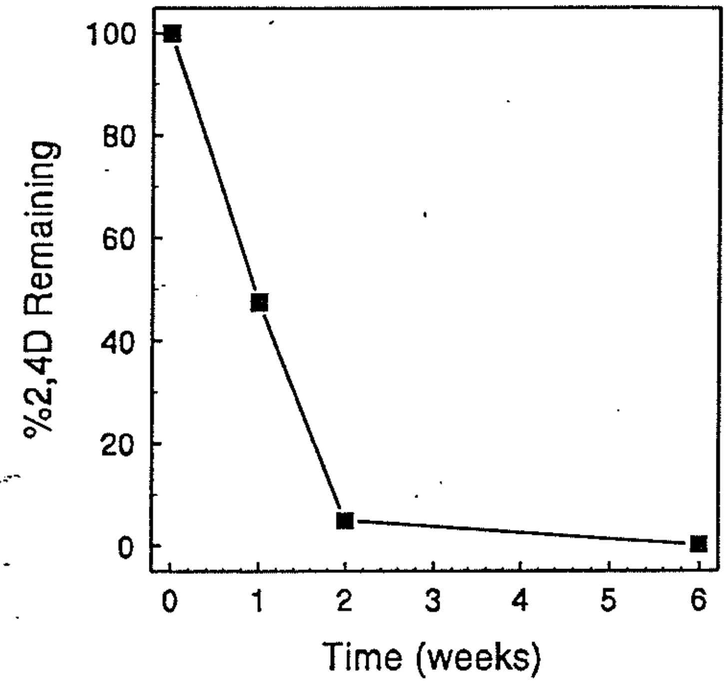
We need more information on how herbicides interact with our soils and climate so that residue levels can be predicted. We need to know more also about their environmental fate.

The heavy clay soils and high temperatures within the catchment may lead to degradation of herbicides within the soil profile making contamination of groundwater unlikely. The presence of residues in surface waters, especially on-farm storages is, however, more likely. The significance of these residues, if present, needs to be evaluated.

ACKNOWLEDGMENTS

Funding assistance for these studies from the Land and Water Resources Research and Development Corporation and the Grains Research and Development Corporation is gratefully recorded.

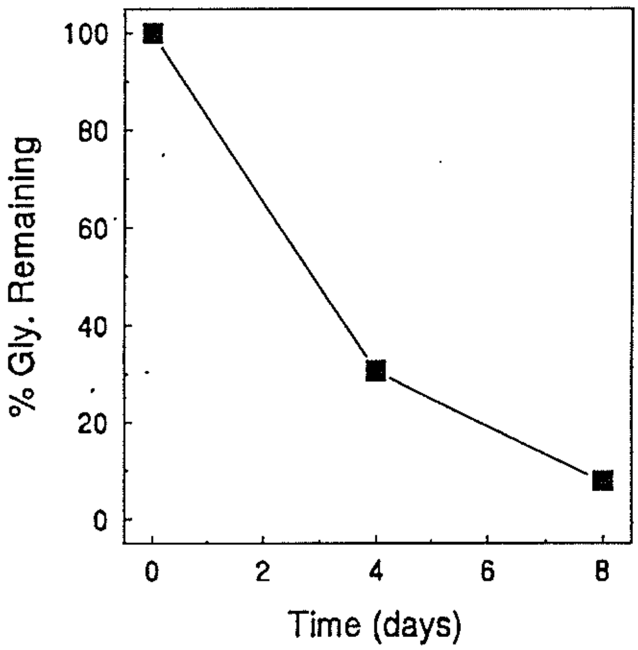
Figure 1



Degradation of 2,4D on soil and wheat stubble at Capella

■—■ % 2,4D

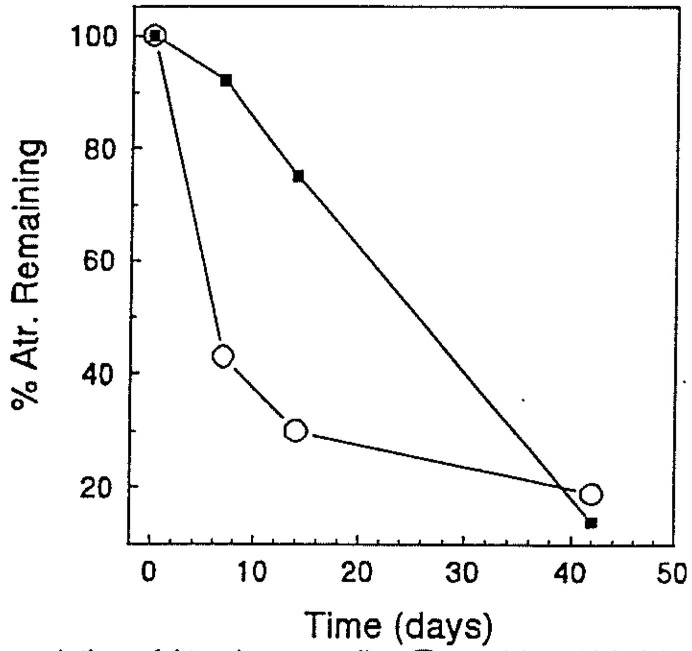
Figure 2



Degradation of Glyphosate on soil at the Biloela Research Station

■——■ % Gly.Remaining

Figure 3



Degradation of Atrazine on soil at Emerald and Mt. Murchison

■—■ Emerald

O-O Mt.Murchison

NATURAL ROTATION STRATEGIES WITH TIMBER IN CENTRAL QUEENSLAND

PREFACE OR INTRODUCTION

Southern Australia, in places, is desperately planting trees. In Central Queensland, we are removing large areas of trees. Some conservation interests want all trees left as is. In the past, land use regarding timber has been in response to short term circumstantial evidence and wishful thinking. Long term effects are contradictory to the short term effects but haven't cancelled them out on the 'computer'. The food chain nutrient cycle goes in a full circle. With land use we are attempting to manipulate that circle to suit ourselves. Our past strategies seem to be based on trying to get a flat line to curve upwards, (i.e. increased productivity), disregarding the countless members of that nutrient cycle.

This article is an attempt to document a series of well known facts that don't usually run together.

Ivan Phillis

Carlo Creek
Dingo
Queensland [illegible]

The Rural Situation to this Day.

Since 1788 as the aboriginal people relinquished Australia, (it was all rural then) they let go of a country where the only human influence was the use of fire and control of human population numbers. Flammable materials (grass, bushes, trees etc.) were not allowed to accumulate to dangerous levels and this is proved by the fact that the only native animal life in Australia, dependant on dry grass, is the mound building termite. Dry grass was not left about for animals and any that were dependent on dry grass, died out a long time ago.

With practically nothing eating Australia's dry grass, the only vegetation types not affected by fire were the rain forests (usually too wet), the deserts (not enough rainfall to grow sufficient flammable vegetation) and scrubs (protected by nest mound-building turkeys or growing in top rock, cave-in clay or salt affected areas, that grew no grass).

Enter European man with his grazing animals. These animals either didn't bring all their natural parasites with them, or the parasites couldn't adapt to the very different (drier) climate and the reduction to host population density (in comparison to where they came from.) This removed the natural controls to the population density of these grazing animals. Stoking rates were determined by the water and fodder that the seasons produced. Grass quantities decreased and the grass fire every year disappeared. Timber densities increased, as without the restriction of fire, timber was able to proceed to a higher status and accumulate land use potential with on site storage of nutrients in the associated animal and vegetable life forms.

European man was then forced into timber control to release the "on site stored" nutrients to keep up grass quantities to feed his grazing animals, so they could feed the Australian people and pay his money lenders. It was obvious to him that the timber densities were restricting grass growth. (He didn't know that timber densities had increased since the arrival of grazing animals). It was not obvious that the accumulated nutritive potential of the denser forests, provided the terrific boost to grass growth after timber treatment. He ringbarked the trees and chopped out the seedlings that grew afterwards.

There was no accumulation of nutrients as they were not stored on site, but productivity only declined slowly as nutrients weren't being tied up. Nevertheless productivity declined, so the country was ploughed, where possible, to release nutrients further and crops were grown. This increased rural inputs with expenses of fertiliser, seed, machinery, harness, horse shoes and later, tractors and fuel etc., and country towns and cities prospered. Australia is one of the most urbanised countries in the world and it has been Government policy for a long time to keep rural inputs high, to employ the urban population.

As the accumulated productivity potential of land, after clearing and ploughing, was gradually used up, property sizes became too small and expenses too high. Country towns started to die and more rural people moved to the cities. The political strength of the bush died to the point where it is no longer representing the interests of the bush. Politicians who make the correct long term decisions for their country, are seen to be against the short term circumstantial evidence, that seems apparent, so are voted out. Rural Australia is now to the point where an individuals rights, that votes don't affect, are more important than voting rights, but have not yet been used to any extent.

Because of Australia's energy reserves of coal, natural gas, uranium and some oil, the value of the Australian dollar remains high. The more a country exports, the higher the value of its currency, the higher the purchasing power of its currency and the higher its internal cost of production. At the same time, the high valued dollar means less Australian dollars for exports and it is something that rural Australia just has to live with, to a point. Meanwhile producers for the Australian domestic market have to compete with cheaper imports because of the Free Trade saga and the high Australian dollar.

There are large numbers of concerned people in the cities that want information from Australia's rural industries, because they are being told that Rural Australia is wrecking life for all of them. Australians eat the produce from cultivation, three meals a day, plus snacks, plus a-drink in the evening. In Cental Queensland if cultivation has contour banks and a strip of timber left, it supposedly sheds all blame.

The beef industry, on the other hand, is mainly export and seems to be copping increasing amounts of media flak. Even John Williamson is singing about treading in "Cow Poo."

In Central Queensland, we have available, a completely sustainable method of beef production off grass,. At the moment the sustainability is mainly by accident, but if we make it deliberate, we can improve the process. By improved rotations and ley farming principles we can have sustainable grain production.

Droughts and dry seasons are an important part of sustainable rural production in Central Queensland as they ensure that the limiting factor of production is rainfall and not soil fertility. Rural producers are too small to cope with droughts on their own, but Australia benefits by them and must adapt to take advantage of them, instead of hoping droughts don't come, then pointing the finger and blaming rural people when they do.

To evaluate present land use in the brigalow and associated land types of Central Queensland, first, we have to know what it was like just before European man and his horses, cattle, sheep and rabbits arrived, and how the land was managed. A 'control plot' would be ideal, but there is none. The nearest thing to a 'control plot' that I know of, is the str of country between the road and railway line, on the Springsure line, south of Emerald, from the seven mile railway crossing to Gindie (10 kilometres, the last 1½ kilometres being Downs Country.) This strip of land has been fenced off from property stock for about 80 years, and has been burnt almost every year until about 15 years ago, when steam trains stopped running, removing the main fire risk.

While this country was burnt every year, but not stocked, it was very open brigalow with some Blackbutt and Yellowwood, with the odd currant bush and plenty of grass. On the eastern side of this strip (control plot) of country, is another strip between the Springsure-Emerald road and the Lockmead fence. The strip hasn't been stocked for 80 years, but has hardly ever been burnt, with the result that there is a lot more timber and less grass. Since the 'control plot' has not been getting burnt every year, it is gradually resembling the strip across the road, with every Brigalow tree having a clump of regrowth under it. This scenario is quite visible and recognisable in 1991.

What is not visible is the Brigalow country through the fences on each side of the road in Lockmead and Mosquito, as this country is now cleared and ploughed. Before it was pulled it was thick, clumpy, whipstick Brigalo with some Yellowwood, Blackbutt, Sandalwood, red Bahuhina and currant bush, but not much grass. This country was never burnt, because stock normally had it eaten out before the end of winter. The only burning in normal years would be black Spear Grass on the odd 'sand ridge' and grass on open Downs country.

As the 'control plot' was the only burnt country in the area, it h plenty of native fauna after the first rain, verified by car damage and dead roos. Before European man, drinking water was the limiting factor to roo and wallaby populations, with these populations much higher once artificial waters were provided. What I'm trying to prove is that the appearance in timber and grasses of the 'control plot' is nearly authentic. This is what the 'old timers' reckon the country looked like when they firs saw it and I think their description is correct.

The original inhabitants influence on this country with their use of fire, is common sense and completely practical. Apart from hunting reasons and making it easier to get about, if they didn't reduce their fire risk by 'strategic burning', they wouldn't have survived over time. Every few years lightning lit fires would put them at great risk.

The effect of burning this 'unstocked' country every year, (where it would burn), kept timber densities down and grass densities up. It put the vegetation through a mild crisis every year, that set back most regrowth, removed the odd old tree and removed the old dry flammable grass. The new grass regrowth after the first rain was not flogged into the ground as native animal (roo) numbers were insuffícent. This burning had the effe of putting the country through a variable rotation. In this rotation, trees and their regrowth had varying lengths of time to tie up nutrients and then release nutrients on their death (partial or complete), as their part in the nutrient chain (food chain if you like). This rotation never allowed this Brigalow country to reach its full potential in timber density where a tree can't grow until another tree dies of old age, parasites, disease, lightningstrike etc. to give it room and release nutrients to do so.

When an area of vegetation is allowed to reach its full potential, using available moisture, light and soil nutrients, on reaching this potential, nutrients are held 'on site' in the form of vegetable, animal, insect and micro organic life forms. These nutrients become available in the life and death rotation involving these life forms. when man interferes he seems to want to start back with bare ground by removing the 'on site' storage of nutrients. A little of these nutrients are used to produce grain, beef or wool. Some nutrients are stored on site as animals, plants, insects and micro organisms, but there is great room for improvement in this area and if the rotational cycle of life and death of the participants is speeded up, production obviously increases without inputs from outside e.g. fertilizer.

Brigalow lends itself ideally to rotation of timber and grass in a grazing situation. If farming is put in the rotation, leucaenia may be necessary to provide the timber portion of the rotation as the brigalow would be removed.

Government and taxation attitudes need revising on timber and land care matters. Grazing-induced over dense scrubs and forests need pulling and tordoning. This however is just a running cost and not a capital improvement, as with the job done correctly there should be enough regrowth in the production cycle for the job to be done again in seven years. This timber and regrowth treatment should be depreciable over 5 years. To write it off in one year may cause overuse for tax avoidance purposes.

Clearing country for farming should not be regarded as improving the value of that country making it a capital improvement, because within the cycle once the benefit of that timber has been taken advantage of, more timber has got to be put back in the cycle. The original clearing cost is not a permanent improvement, but a cost to take advantage of short term potential. It will probably be more costly to put timber back in the cycle. Clearing costs therefore are not capital improvements and should be depreciable over 5 years to allow the land holder to reestablish timber (e.g. Leucaenia) in his land use rotation.

Property areas seem to have been calculated for when all the 'on site stored potential' of a block has been realised. Areas are usually too small to allow 'natural rotation strategies' to restore nutrients and so continue the viable rotation (cycle). The paddock that has been timber treated and is now full of regrowth, is looked down on and classed as Bad luck or bad management. We don't want the whole property to be in that condition, but we do want all the paddocks to be at varying stages in that cycle. Central Queensland is fortunate in that most properties have sufficient area and timber left for this strategy to begin to apply, though most brigalow blocks probably need 50% more area to be viable propositions after their original potential starts to decline, so that the natural rotation strategies can be applied.

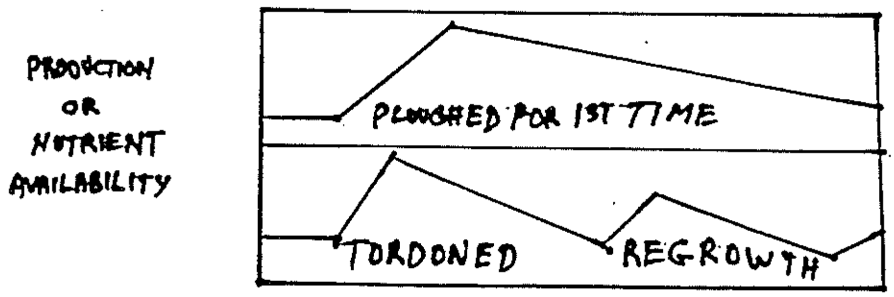
Fire tolerance and the 'luck of the draw' regarding fire, were the limiting factors regarding timber density in this Brigalow country and not rainfall as one would expect.

European man and his animals have changed this. The limiting factor to native and domestic animal populations, drinking water, has been remo with bores, dams and pipelines. Increased populations of native animals and populations of domestic animals and rabbits, have removed fire as the limiting factor to timber density. With grazing animals eating all grass out of the Brigalow country before the end of winter, so that fire could not limit timber density, Brigalow and its associated timbers reached their full potential that climate and soil would allow.

The Brigalow country on Brigalow Blocks in Area 3 taken off Barwon Park and Junee in 1970, had reached this stage. This Brigalow country consisted mainly of 'scrubs' of small adult trees and very little grass. These Brigalows 'scrubs' had tied up all available nutrients, seemingly waiting for some catastrophy to allow trees to have room to grow and be replaced. Even roos and wallabies only lived around the edges and got a feed elsewhere. These scrubs were thickest below tableland country with very little grass in 1971, but had old charred wood all through them from past fires. It was hard to believe a fire would ever burn there.

These scrubs had been with fire and no grazing for 40,000 years and then with grazing and very little fire for about 80 years (not until artificial waters were put in the vicinity, so probably only 50 years).

When the old timers ploughed country for the first time, whether cleared timbered country, or open grass country, they didn't expect a good crop until the 3rd year. In other words, it normally took 3 years for the existing vegetation (plant roots, micro organisims, surplus insects etc.) to break down and release their nutrients. With ringbarked or tordoned forest country, the same 3 year rule probably applies, but I've never heard it said. After 3 years the country gradually fades.



If a complete kill is obtained in the first tordoning and then the seedlings chopped out with a maddock (as was done further south i.e. ringbarking and sucker bashing) so that the timber is removed completely, the graph for tordoning would resemble that for clearing and ploughing. There would be a big release of nutrients for 3 years after the first kill, then the nutrient availability and production of that country would decline over time to a point where 'improved' pasture species and fertilizer would be the necessary options to keep that land producing.

Where the timber is tordoned, but plenty of seedlings get room to grow and do so, those seedlings and their associated animal, insect, plant and micro organic life forms, tie up nutrients sooner than country where the timber is killed out, but after seven years (old timers rule of thumb) the regrowth can be tordoned so the production graph line curves up again. While this seedling crop keeps coming and can be tordoned every seven years, the production line on the graph will curve up and down and will average well above the line for untordoned, 'high timber-density from grazing' country and well above the production line for completely timber removed country.

When you scrub-pull, tordon or blade plough, the extra production you get is from released nutrients from the plant, animal, insect and micro organic life forms involved (of course often moisture availability is involved).

You are harvesting a crop like collecting a golden egg. If you kill out the timber so that good seedling 'coverage' can't occur, you are killing the goose that laid the golden egg.

Improved pasture species are always a good idea because they are, no doubt, plants that have adapted to the pressures of our hard-footed grazing animals over thousands of years and take the pressure off our native plants. From an economic point of view of least, we wish to avoid using fertilizer's in Central Queensland.

When someone ringbarks a tree and gets a dramatic increase in grass growth under that tree, the majority seem to want to blame that tree for the grass not growing there, like that, all the time, instead of giving the tree credit for storing up nutrients and then releasing them after its death. People that blame the tree want to do away with trees except for shade and shelter. People who give credit to the tree want trees to keep growing and dieing. The former end up with a degraded piece of country, which is one extreme. The other extreme is the 'so called greenie' point of view, that wants to retain the artificially dense scrubs and forests, as is, believing that to be the ultimate and not realising that the tied-up nutrient level of those scrubs makes the available nutrient level below that required by some native plants and animals, helping their extinction, as well as removing the contribution of that land to Australia all round.

The best thing about the Brigalow country of Central Queensland is the difficulty of obliterating the Brigalow. I was personally involved in clearing, ploughing and bashing the brigalow off 60 acres on Lockmead in the 1950's and 60's and that 60 acres doesn't grow much more than galvanised burr these days.

With brigalow suckers and dry grass, you don't ever need to feed molasses and urea. The problem lies in keeping grass quantities up and sucker quantities down. On country without big melonholes and with a tall introduced grass like Biloela Buffel, this can be done by fire without destocking (depending on stocking rate) in most seasons. Where the stocking rate interferes as in holding paddocks and close to waters, mechanical means (chain or offset) or 245T spraying has been used successfully to maintain the status quo.

Blade ploughs would be O.K. if enough timber is left i.e. deliberately missed every blade width. Pellets of timber killing chemical tend towards the extreme that should be avoided in my opinion.

It seems to be more difficult to keep up sufficient timber density in eucalypt forest country, so obviously a lot more trees should be left as seed trees. They can always be killed next time and a seedling left in their place. It seems to be very difficult to get tordon gangs to leave trees. Apparently it takes great mental effort to decide which tree to leave and the wishful thinkers dream of 'no trees at all' seems to prevail.

Native Animals in Central Queensland

In the early nineteen twenties, Bill Quinn worked as a stockman on Batheaston, on the Isaacs River in Central Queensland. There were four or five koala bears to every gum tree on the river flats (extremely overpopulated). Then the bears started to die, sitting on the ground at the base of the trees. Bill Quinn did post mortems on some of the dead bears and found them to be completely overrun with worms and concluded that they died from internal parasites (worms).

Oakey Creek, in the properties of Girrah, Barwon Park and Wilpeena, in the nineteen twenties, was described as the "home of bears". In 1926-27, after the last open shooting season, there were still plenty of bears on Oakey Creek. Then they started to die, since blamed on the kidney disease. Did internal parasites weaken the bears to the extent that the kidney disease was able to finish them off?

There was no "loss of habitat" in these areas in the nineteen twenties and there is still plenty of habitat in both these areas to this day, but no bears.

The population explosion of these bears, putting their numbers past the critical population density, that puts their parasites into the "bears extinction phase" was probably caused by two things.

The aboriginal people, of the Mackenzie-Isaacs River area, were disrupted many years before the 1920's. No doubt they ate plenty of bears and kept their numbers down. Bears came down into the lower forks of trees in the heat of the day for shade, as gum trees have little shade from leaves, especially up the tree. Young bears often camp low down in the forks of trees an would be easy game for the hunter.

Back around this time, a wave of distemper, nearly wiped out the dingo population. A northern New South Wales authority on dingoes, claims that dingoes get a lot of bears as they travel between trees.

Bears in Central Queensland inhabit open forest. When the aboriginal people controlled these forests, they burnt the grass whenever it would burn. This burning, done for many thousands of years, kept timber densities down and grass quantities up. Koala bears faeces (droppings) fall into the grass under the trees. The eucalyptus content of these dropping make them quite flammable when dry and fire destroys them and the parasite eggs they contain.

Parasite larvae climb up grass and attach to their hosts as they move through the grass between trees. If the grass has been burnt, (no grass), the parasite larvae are much less efficient at finding a host. Much less fire, more timber, and less grass, these days, makes once ideal habitat for bears into "habitat unsatisfactory."

Bears obviously require eucalyptus trees (of satisfactory varieties) for fodder, but they require the density of these trees to be low enough for plenty of grass growth, so that annual burning is possible, for parasite control.

Grey Kangaroos There are no red kangaroos in the Mackenzie River area. Grey kangaroo numbers vary from year to year, sometimes few, sometimes plenty. Their numbers must average many times that before European settlement, because of the huge increase in drinking water (artificial waters i.e. bores, dams and pipelines).

Post mortems on grey kangaroos verify this. They are completely overrun with internal parasites and their resistance lowered so that they die in large numbers in wet weather, droughts and fires. Old buck Roos often have a handful of large round worms, at each stifle joint in the back legs and all their muscles are a dark red haemorrhaging mess from migrating round worms. Their liver is full of tapeworms and their lungs with more parasites. These roos "standard of existence" is horrific.

The excessively high internal parasite numbers affecting these roos are caused partly by the overpopulation of roos (in comparison to the ages past) and partly by the lack of burning. Roos travel well and following storms and fresh burns is their way of existence. Their parasites have come through the ages on these conditions and modern times must be a picnic for them.

The partly-nomadic way of life of kangaroos is probably responsible for their survival. These are quite a few closely related species of marsupial that probably are host to the same species of internal and external parasites as kangaroos. Some of these species are restricted to habitat e.g. a patch of thick scrub to protect them from eagles and dingoes, and they can't keep leaving their parasite eggs and larvae behind them. The reason for the near extinction of the Nail-Tail Wallaby in Central Queensland may be the amplification of parasite numbers due to increased kangaroo numbers and of course the lack of fire to restrict parasite numbers.

Wallaroos require a home habitat of broken gullies or rocky hillside, as a retreat to stay "one jump ahead" of dingoes. Stinker (swamp) wallabies and red shoulder wallabies require an area of scrub or prickle bushes for protection against eagles and dingoes. Wallaroos and wallabies require suitable food outside their home habitats. In the aboriginal peoples time, this was provided by burnt country beside their home habitats. Before scrub pulling, which started about the 1950's, the lack of burning had resulted in an increase in timber densities, decrease in grass quantities and a further decrease in burning. This put the vegetarian native animals under severe nutritional stress (starvation) and the lack of fires allowed their parasites optimum access to their hosts, maximising stress and lowering their resistance to disease

Whiptail wallabies live and feed in open forested hills. They don't seem to share their habitat much with kangaroos, just overlap on the edges. The massive increase in available drinking water (artificial water) would have caused a great increase in numbers since aboriginal peoples time and the increase in timber densities and the irregularity and lack of fires, would have caused increased nutritional and parasitical stress to these wallabies, but they are survivors.

When walking drought cattle from Emerald to Wallaroo in 1964, Cecil Campbell at Christmas Creek told me how, many years earlier, he had seen a mob of scrub turkeys, about half a mile long and a couple of hundred yards wide, walking in the same direction, along a box creek flat. Where and why they were going was a mystery. The prickly pear outbreak caused a large increase in scrub type cover for scrub turkeys and may have contributed to over population. Soon after the prickly pear, scrub turkeys disappeared from many of the scrubs in Central Queensland. Locals say the grub of the cactoblastis moth when eaten by turkeys and death adders, bored out through their stomach walls and they died from peritonitis. It seems likely that overpopulation and then parasite counter attack may have contributed to their demise.

Scrub turkeys live and nest in scrub, but feed outside the scrub in the evening. Small patches of scrub with burnt open frost or creek flat around, seem to be ideal. The only timber in Central Queensland, that can't stand fire is the softwood scrub. Softwood scrub and scrub turkeys, obviously had an arrangement, whereby the scrub protected the turkeys and the turkeys kept the leaves, twigs, bark and grass, raked up into their nesting mounds, so keeping fire out of these scrubs.

Plain turkeys are plentiful in the Mackenzie River area. Comparison with numbers a century ago is not known. I've heard of them busting on windscreens of cars and being a mass of worms. This would indicate a higher than normal population density, but lack of fires would also cause a great increase in their parasite numbers.

Emus are always about in the MacKenzie River area, but are, no doubt, influenced by more drinking water and less fires.

Dingoes in the Mackenzie River area seem to vary from plenty to too many. Rabbits arrived in the Mackenzie River area about 1975 and have provided a food source for dingoes and must help a lot more pups to survive the starvation phase, after their parents abandon them. The types of soil and the hopelessness of burrows in this soil in wet weather, mean that rabbits don't burrow in this area. This, plus the ravaging hordes of mosquitoes and sandflies with myxomatosis, have stopped rabbits reaching plague numbers here. However they do contribute to a higher population of dingoes, which put increased pressure on all other animals. Black headed python numbers increased with the rabbit.

Where there are plenty of dingoes, there are very few foxes and foxes have very little effect on anything in the Mackenzie River area. There are only a few cats about.

The one introduced animal in the Mackenzie River area to have a major effect, is the cane toad. Since the arrival of the cane toad, at about 1975, the goannas (both sand, black and the "eungie" yellow goanna) have died out. A lot of brown snakes died at the start of the toad invasion, but now they are back. Green diamond back water snakes like toads and their numbers increased. Toads didn't affect black headed python numbers. Blade ploughing provides increased habitat for snakes and they use it.

Echidnas use hollow logs, broken gullies, cracked soil, prickle bushes and regrowth for habitat, and ants nests for food, so are quite at home in the cattle country of Mackenzie River. When disturbed they burrow in the soil, so they don't survive farming, but don't tend to live out on completely cleared areas.

Possums were once plentiful, but then got very scarce. They are now very much on the comeback, so probably went through a similar crisis to the koala bears, but never got quite as low in numbers.

There are other species of native wild life in Central Queensland, that I haven't mentioned, but they are all effected by the same problems. Animals can't adapt to one type of human influence for 40,000 years and then carry on under a new system.

The use of fire with the grazing industry of Australia, was learnt from the aborigines, because European man did not bring any of this knowledge with him. The nutritive requirements of sheep, cattle and horses are similar to vegetarian marsupials in many cases, but because of the huge increase in numbers, the dry grass is eaten to keep these animals going to the next grass growing season. Now fire is not a regular influence on vegetation. Timber and woody shrub densities have increased and grass quantities declined. To return to the adapted balance of the last 40,000 years, scrub pulling and forest tordoning are necessary.

The main reason for the decline of the Hairy Nosed Wombat over the last 100 yeas, is probably due to the lack of fire. Shutting the wombat up in its own National Park and throwing the matches away would be guaranteeing its extinction. Vegetation that evolved over a long period of time, influenced by aborigines and suited to wombats, would have changed, forcing the wombats to gradually withdraw to what is the best offering, probably causing overcrowding within that small area. This overcrowding (exceeding critical population density) puts their parasites on a permanent "butchers picnic" footing.

All native animals have a built in safety mechanism to ensure their survival over bad (dry or wet) times. If their nutritive requirements aren't up to a certain level, they don't reproduce. Fire, as used by the aborigines, kept the nutritive value of vegetation up to a sustainable level. Lack of fire, causes a marked reduction in the nutritive value of vegetation, changes in the varieties of vegetation, a lowering in the reproductive rate of animals and maybe extinction.

When you visit a National Park, you will see a sign - no dogs or cats - When you get to the camping area you might find plenty of quiet kangaroos and wallabies, and at night, possums. Most visitors put the presence of quiet native animals down to no dogs or cats, but that is only a small part of the story. Outside the camping area, the country is, most likely overgrown with rank mature vegetation and the animals are not getting the nutrition they need. They are attracted to the slashed camping areas regrowth and when they get familiar enough, they start cadging from the visitors (who love it), but aren't chased away by dogs and cats.

Every few years, the accumulated flammable materials within the National Parks (flammable materials were not allowed to accumulate to hazardous levels in aborigines time) catch alight and put the animals and vegetation into an unnatural and unnecessary disaster. This is regarded as an Act of God and how terrible, but it is just plain stupidity. The bushfires in Queensland National Parks in 1991 were a disgrace and many heads should have rolled. Wardens on the job, know that fire hazards have got to be kept down by burning as soon as frost, or the season, will allow, but apparently they are not allowed to do so. The native animals are not dependant on dry grass to get them through the season but they are dependant on the few nutritious shoots that come after the early burn.

It is stupid to have a National Park unsuited to native animals, so that they have to go to private property to get a feed, or take great risks feeding on the slashed side of highways. National Parks that have unnaturally high densities of timber through lack of fire consistently and hugh fires occasionally, require some scrub pulling and tordoning so that their native animals can get back to the conditions they are geared to handle.

All National Parks need resident wardens that run the Parks the same way they have been run for the last 40,000 years. There is no other reason for having them. All land in Queensland, regardless of title, remains Queensland and Australia. To take it out of production by making it a National Park, if it is a better proposition for tourism, makes sense, but if its just for a political point, its criminal. More pressure, through the economy, gets put on all the rest of the land in Queensland.

Most native animals run on private property. Most of the expertise regarding requirements, habits and population density of native animals is known by ordinary Queenslanders, but an awful lot more needs to be known. To solve demarcation issues and get all the expertise available, committees of people (land owners and interested persons) could be formed, representing areas like the Rural Fires Brigades, but organised by the National Parks and Wildlife. The job of these "Wildlife Brigades" would only be advisory.

Tasks would be:-

Advise on:-

1. Reduction of fire risk and maintenance of vegetation nutrition i.e. burning.

2. Wildlife densities. Optimum wildlife densities under different conditions, are not known and need to be established. Faecal parasite egg counts need to be obtained at different population densities and at different pasture and climatic conditions, so that when overcrowding occurs, it can be measured and surplus animals shifted to new locations or eliminated.

3. Releasing of land from National Parks that have no tourist potential.

4. Choosing land suitable for National Parks.

5. Payment of incentives to land holders by reduction of rent or reimbursement of portion of rates, if those landholders have performed "in the public good" by providing for native animals and vegetation.

P.S. The section on the Hairy Nosed Wombat is an attempt to apply practical parasitology to the wombat, that applies to other marsupials, because the wombat requires all considerations. If the conclusions applied prove incorrect, kindly disregard only the section on the Hairy Nosed Wombat.

THE FISHERIES RESOURCES OF THE FITZROY REGION

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Abstract

Commercial and recreational fisheries along the central Queensland Coast are among the State's most substantial, and involve premier food species such as Barramundi and Mud Crabs. The maintenance of this highly-valued resource is intimately associated with coastal wetland, estuarine and riverine environments found in the catchment areas of the local streams. These environments provide essential habitat for the life cycles of the target species.

Urban, rural and industrial developments in the river catchments can diminish the ecological value of these areas and can adversely impact fisheries. Catchment management planning authorities need to consider fisheries issues in their deliberations if this natural resource is to be sustained.

Introduction

The Central coast region of Queensland is well situated from a fishing perspective possessing a large variety of fishes, including the highly sought after *Barra,* taken by the commercial and recreational fishers. The region also possesses important fisheries habitat. The presence of the near pristine Narrows and associated wetlands between the mainland and Curtis Island provides significant habitat resources contributing to the commercial and recreational fisheries in the region. In addition the region has the Fitzroy River (Australia's second largest river system to that of the Murrary Darling), the Calliope River and the Boyne River, each with an extensive catchment.

Recreational fishing is an important activity in the Fitzroy region. A survey of Queensland residents in 1985 (Anon, 1986a) determined that 38,000 recreational fishers (15 year or older) fished inshore areas from approximately Baffle Creek (between Bundaberg and Gladstone) to Flaggy Rock (between Rockhampton and Sarina). These fishers spent a minimum of 200,000 days fishing in this region. Twenty per cent of these participants were visitors from within Queensland beyond the Fitzroy/Mackay statistical region. These figures do not include tourists from interstate and overseas who may engage in fishing while visiting the area, so the true level of recreational fishery activity will be substantially greater than this.

In Queensland the commercial fishery catch is worth approximately $290 million, of which 75% of the catch by weight and 80% by value is derived from species which spend part of their life in shallow water habitat (Quinn, 1992). Many of the these species represent high value product (e.g. Barramundi and prawns). In some districts including the area defined for this paper, the estuarine component of the commercial catch is higher. The Fitzroy region produces a commercial catch of approximately 100 tonnes of estuarine fin fish annually and 47 tonnes of mud crabs. In addition, the area's shallow water habitat contributes directly to the multimillion dollar offshore prawn fishery by providing environments essential for juvenile prawns.

In this paper we provide an outline of the commercial estuarine fisheries in the Fitzroy River region, discuss the general biology of the fish on which these fisheries are based, and explore the ecological relationship of wetland habitats and river flow regimes with these fisheries. The paper is based mainly on the catches of the commercial fisheries because total catch statistics are collected on this sector, while the concurrent catch data for the recreational sector are unavailable. As we have emphasized above, the recreational fishery is extemely important and will probably grow as the population of the region grows with increased leisure time and as the number of tourist anglers escalates.

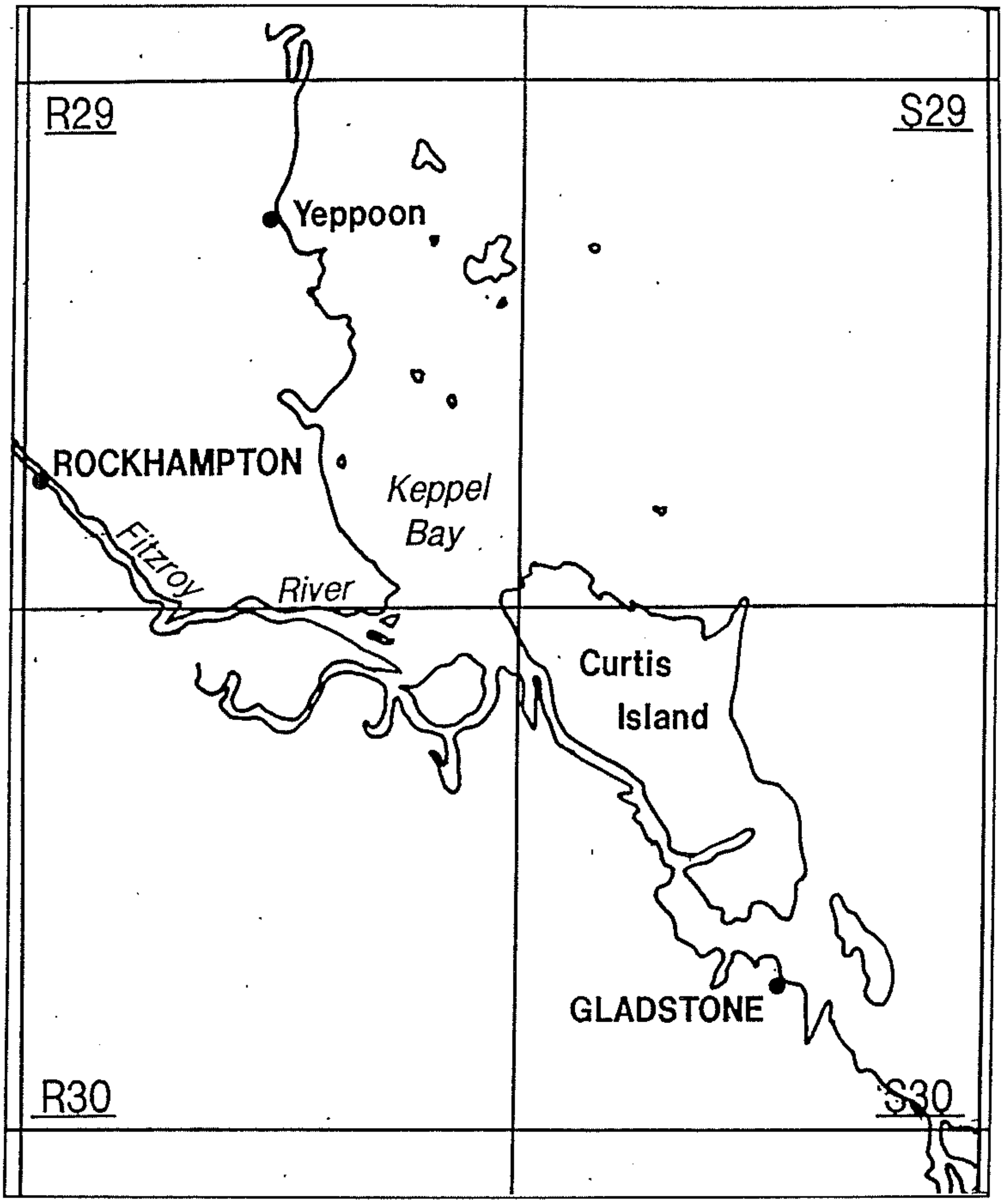
Commercial Fishery

Fishing in the Fitzroy region has a long history. The first Inspectors of Fisheries were appointed at Rockhampton and Gladstone, under the Fisheries Act of 1887 shortly after the Act was passed. The commercial fisheries were limited to supplying the local population because of spoilage during transport, although in 1928/29 30,000 tins of turtle soup were manufactured by a company operating at Heron Island (Anon, 1986b).

No compulsory catch statistics were required from commercial fishers until 1988 with the commencement of CFISH, a database of commercial catch and effort information. From that date, commercial fishers were required to submit details of their fishing operations in a comprehensive logbook record. The data presented in this paper were extracted from CFISH in June 1992. The catch information relates to the three fishing grids as shown on Map 1, ie catches from south of Corio Bay to approximately 10 km south of Tannum Sands.

Although data for the 1988 year are presented in this paper (eg Table 1, Figure 1), the 1988 data have not been used in determining averages. The logbook system was being implemented then and may be understated as commercial fishers became familiar with the logbook system. In addition, no statements of the status of stocks can be made, because of the short time frame that data have been collected and the lack of recreational catch information.

The four most important estuarine fish groups taken in the Fitzroy region, by weight, are Mullet, King Salmon, Blue Salmon and Barramundi (Table 1). Several



Map 1. Map of the Fitzroy Region. The grid references refer to the grid system of CFISH (the Commercial FISH catch logbook program).

species within the family Mugilidae, are represented by the group Mullet. Sea Mullet *(Mugil cephalus)* represents the main species. These four species groups represent approximately 90% of the total estuarine finfish catch. The catch of these species has not changed dramatically over the four years although there is a general increase in annual catch over the period (Figure 1). Approximately 40% of the total estuarine finfish catch for the Fitzroy region is made in Grids R29 and S30, with the remainder in Grid R30.

Table 1. Total catch of fish, crustaceans and molluscs, by year, taken by commercial fishers for the years 1988-1991. Average catch calculated for the years 1989-1991. (Source CFISH).

	1988	1989	1990	1991	Average 1989/91
Crabs					
Mud Crabs	21.21	33.09	50.78	58.27	**47.38**
Sand Crabs	0.32	0.24	0.30	0.11	**0.21**
Other Crabs	0.02	0.01	0.00	0.00	**0.02**
Total Crabs	**21.55**	**33.34**	**51.08**	**58.38**	**47.60**
Prawns					
Banana Prawns	33.20	16.81	17.50	10.17	**14.82**
Other Prawns	7.96	4.17	4.78	1.75	**3.56**
Total Prawns	**41.16**	**20.97**	**22.28**	**11.91**	**18.39**
Estuarine Fish					
Mullet	18.95	22.11	25.55	29.20	**25.62**
Salmon - King	19.59	15.94	21.34	31.83	**23.04**
Salmon - Blue	13.86	23.06	18.05	21.18	**20.76**
Barramundi	13.60	10.90	17.82	26.27	**18.33**
Whiting - Summer	2.47	2.67	2.53	2.86	**2.69**
Jew (Mulloway)	5.13	1.02	1.26	0.65	**0.98**
Gar	0.36	0.71	1.73	3.56	**2.00**
Queenfish	1.14	1.94	0.62	0.38	**0.98**
Flathead	0.79	1.04	1.12	1.12	**1.09**
Bream Silver	1.18	0.78	0.80	1.11	**0.90**
Other Estuarine	4.18	3.35	3.43	2.88	**3.22**
Total Estuarine Finfish	**81.25**	**83.51**	**94.26**	**121.04**	**99.60**
Pelagic Fish					
Mackerel - Spanish	4.39	4.43	2.67	5.68	**4.26**
Mackerel - Grey	3.38	6.22	1.69	2.37	**3.43**
Other Pelagic	0.99	4.47	1.90	1.82	**2.73**
Total Pelagic	**8.75**	**15.12**	**6.27**	**9.87**	**10.42**
Total Reef	**0.74**	**1.17**	**0.55**	**1.70**	**1.14**
Total Sharks Fins	**32.42**	**23.04**	**16.47**	**25.85**	**21.79**

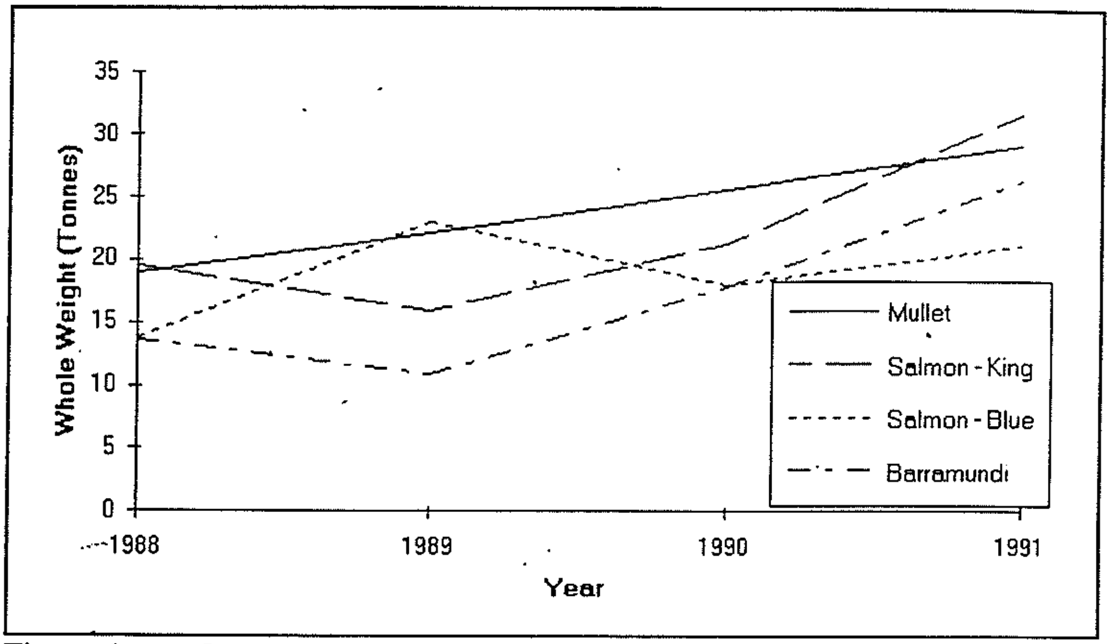


Figure 1 Commercial catch of Mullet, Barramundi, King Salmon and Blue Salmon taken from the Fitzroy region in the period 1988 - 1991 (CFISH data).

Most of the Mullet are taken with beach seine nets. Operators encircle the school of fish with the nets near to shore and then haul them into the shore. This technique is used to catch Tailor (*Pomatomus saltatrix*) in southern Queensland waters as well as Bait Fish which school closer to shore. The Mullet schools are located visually, so the technique is limited to clear water environments. Seine netting is most commonly used in sandy areas especially on ocean beaches and is rarely used in muddy estuaries where soft substrates and snags make seining difficult. Only small quantities of Mullet are taken in grid R30, which is mostly represented by the mouth of the Fitzroy River. Approximately 60% of the Mullet is caught in grid S30 with the remainder taken in R29. Grids R29 and S30 are characterised by open foreshores and a number of sandy beaches. The distribution of fishing effort follows that of catch (R29 - 29%; R30 - 6%; S30 - 65%).

Catch statistics for Barramundi, King Salmon and Blue Salmon taken over the four year period shows that approximately 20 tonnes is taken of each. These catch proportions are typi ıl for the east coast fishery south of Mackay (Russell, 1988). King Salmon is second in value to Barramundi in the east coast set gill net fishery while Blue Salmon forms an important economic component for local consumption (Russell, 1988).

Barramundi, King Salmon and Blue Salmon are caught mainly in gill nets. The management arrangements for these fishing apparatuses are discussed by Healy (in this Symposium). These nets can capture a variety of fish species depending on the size of the mesh of the net. The most commonly used set gill nets in rivers are of monofilament netting with a mesh size ranging from 15.0 cm to 21.5 cm stretched mesh. On the foreshore, monofilament nets from 10.0 cm to 21.5 cm stretched mesh are used. While gill nets do not directly select for the species they catch (Clay, 1981), a knowledgeable fisher may select the fish size by the mesh of the net and the species composition of the net catch by the location of the net. Barramundi and King Salmon tend to be caught with the larger mesh sizes while Blue Salmon tend to be caught in smaller size mesh nets.

The proportions of Barramundi and King Salmon caught in each of the three grids (Figure 2) are similar. Most Blue Salmon are caught in grid S30 which coincidentally shows the lowest percentage catch of Barramundi and King Salmon. This proportional variation in catch in the three grids probably reflects the different habitats available and the biology of the target species as well as the relative seasonal effort levels. Blue Salmon is mainly a "winter fishery", while Barramundi and King Salmon are more readily taken in the warmer months (Russell, 1988).

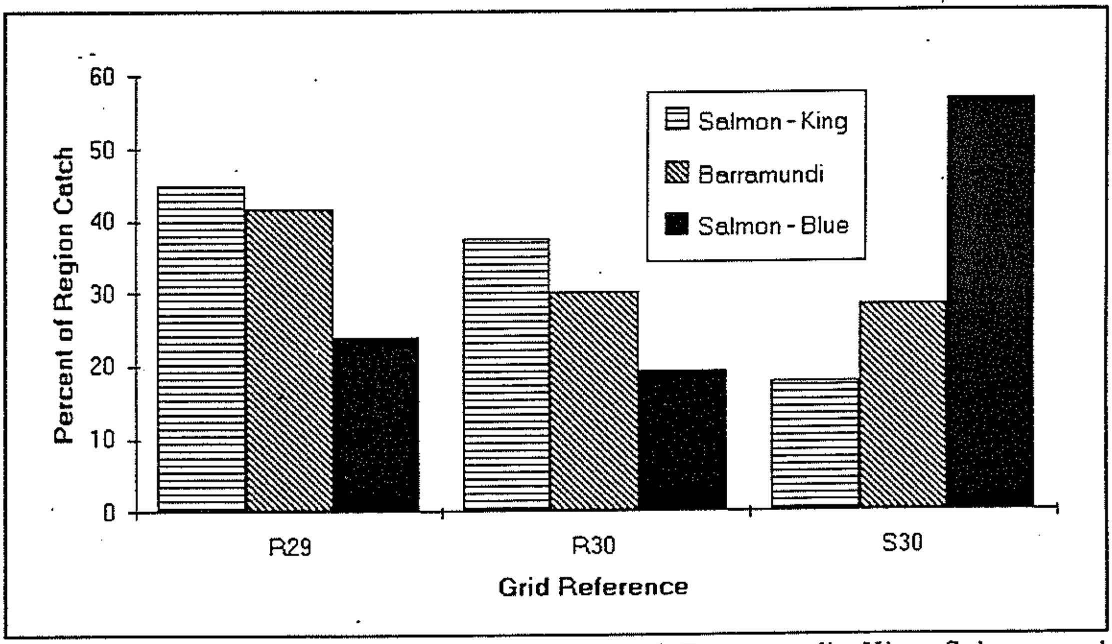


Figure 2. Average proportion of catches of Barramundi, King Salmon and Blue Salmon taken by commercial fishers in Grids R29, R30 and S30 during the period 1989-1991.

Only minor catche (less than 5 tonnes annually in total) of the other estuarine fish species (listed in Table 1) were taken in the three grids. Small catches of Pelagic and Reef fish (Table 1) were also made, although larger catches of these fish are recorded from waters offshore of the three grids.

Central Queensland is famous for its Mud Crabs. The average annual commercial catch of mud crabs (47 tonnes) in the Fitzroy region represents approximately 12% of the State's catch. Mud crabs are also keenly sought after by recreational fishers. Approximately 70% of the region's commercial mud crab catch occurs within Grid S30 which contains the Narrows. An additional 23% occurs within R30 (mouth of the Fitzroy River). The percentage of days fished by commercial mud crabbers in the three grids reflects this distrubtion of catch (R29 - 9%; R30 - 31%; S30 - 60%).

Biology of Estuarine Fish

The catchments, waterways and wetland habitats of the Fitzroy region have a critical role in maintaining its fisheries resources. To appreciate just how important, an understanding of the life cycle of the fish is required. Unfortunately our knowledge of many species of fish and crabs is incomplete. The following briefly outlines what is known of the life histories of the important species taken by commercial and recreational fishers.

Most estuarine fish of importance to the recreational or commercial fisheries have similar life cycles. Adults congregate to spawn at specific times of the year around river mouths or along nearby foreshores. During spawning, eggs are released by females into the water and are fertilised with milt released from males. The eggs and hatched larvae are planktonic for a week or two and are transported by tides and winds into sheltered bays and estuarine areas. In these protected habitats, the larvae settle out and develop into juveniles. Juvenile fish inhabit different estuarine regions depending on the species, ranging from freshwater (Mullet, Barramundi) to near oceanic waters (Whiting, Grunters). After a couple of years, fish grow to maturity, then reproduce to continue the cycle.

Blue Salmon (*Eleutheronema tetradactylum*) and King Salmon (*Polydactylus sheridani*) follow this general pattern. Spawning takes place in offshore waters (Kowtal, 1972) and juveniles become reasonably abundant in the lower estuaries and infrequently enter tidal swamps (Russell & Garrett, 1983, Davis, 1988). Grunters (Pomadasysidae), and Breams (Acanthopagridae) spawn in shallow water near the mouths of riversand creeks, and juveniles utilise shallow water habitat as nursery areas (Day *et al*, 1981, Pollock, 1982). It should be noted that some reef fish such as Snappers and Jacks (Lutjanidae) and pelagic fish such as Mackerel (Scombridae) also use shallow estuarine habitat as juvenile nursery areas although the adults live and spawn in offshore environments.

The juveniles of Sea Mullet (*Mugil cephalus*) grow to adult fish in the upper estuary or in freshwater. Maturing Sea Mullet congregate in estuaries in their third year in late summ.. and depart on their spawning migrations in early autumn. Schools of Mullet migrate northwards along the coast to spawn in early winter. Mullet from Queensland and NSW estuaries participate in the migrations, which may be hundreds of kilometers and vary among individuals. Not all mature fish participate in these migrations and many remain in the upper estuary or in freshwater. Spawning takes place during winter with post-larval fish being observed in estuaries in late winter. As they develop, young fish move up the estuary to brackish or freshwater, reaching lakes and streams by the beginning of their third year. By this time males are 33 cm and females 31 cm in length. Sea

Mullets are highly fecund with each female able to produce 2.5 million eggs in one spawning (Halliday, 1991).

Barramundi (*Lates calcarifer)* also follows this general life cycle pattern (Figure 3). Spawning takes place in brackish water near river mouths, between November and January and is synchronised with the phase of the moon. Female barramundi are highly fecund. A 1.2 m female can produce 40 million eggs a year. Milt from several males is needed to fertilise eggs from one female, so males outnumber females fish on the breeding grounds (Davis, 1985, Griffin, 1985, Garrett, 1987, Grey, 1987).

The young fish hatch from the egg within 24 hours and are carried by the tide into coastal mangrove swamps and estuaries (Moore, 1982, Russell & Garrett, 1985, Davis, 1985). As the wet season develops, swamps and adjacent floodplains backup with fresh water and so increases the habitat available for juvenile fishes. These areas provide a comparatively safe and productive area for the early stages of the Barramundi's life cycle.

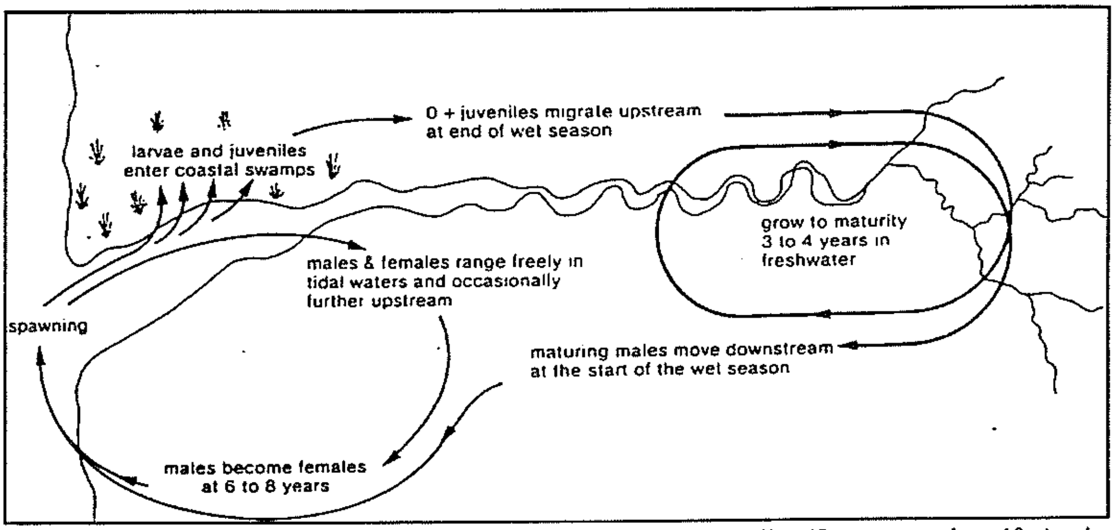


Figure 3. Generalised life history of Barramundi (*Lates calcarifer*) in Australia (After Grey, 1987).

The young Barramundi will later move upstream to the freshwater sections of streams unless prevented by an impassable barrier. Here they remain until three or four years of age, by which time they are usually 60 to 70 cm in length and weigh three to four kilograms. At this time they have reached sexual maturity as males. In areas without an extensive river system or freshwater hinterland, young barramundi may spend their entire life cycle in the estuarine or coastal habitat.

At the end of the dry season, the newly-matured fish migrate downstream to spawn. However, fish may be landlocked in billabongs during the dry season, and may have to wait until the wet season to be able to move to the mouth of the estuary. After the spawning season, most Barramundi remain in the estuarine section of the river or in adjacent coastal areas. When Barramundi are 6 to 8 years old, they undergo a change in sex from male to female. By this time they have reached 85 to 100 cm long and weigh between 7 and 12 kg.

Mud Crabs are associated with mangrove-lined estuaries. Mating of Mud Crabs occurs between a recently moulted (soft) female and an intermoult (hard) male within a protective burrow. After mating, the male protects the female until her shell hardens. Female Mud Crabs may migrate 10 to 30 km offshore in depths of 20 to 40 m to release their fertilised eggs. Female Crabs carry millions of eggs in a mass under their abdomens, attached to their swimmerets. The eggs hatch to release planktonic larvae called zoea which moult though four stages to megalopa larval stages which moult to a juvenile Crab. During the larval phase which lasts approximately 2-3 weeks, the larvae are carried by on-shore winds and tides into shallow water. Juvenile Mud Crabs are found in estuarine areas such as mangrove-lined creeks and intertidal wetland mangrove areas. They enter the fishery after 2 to 3 years (Fielder & Heasman, 1978, Anon, 1991).

Offshore from the Fitzroy region is an important fishery for penaeid prawns with an annual catch in excess of 350 tonnes. Changes to estuarine and wetland areas in the region will impact directly on the prawn fishery. Adult Prawns typically spawn in oceanic water producing up to 400,000 eggs per individual female. The eggs and the larvae which hatch after 18 hours are planktonic, and rely on winds and tidal currents to move into inshore waters. These movements are assisted by the larvae moving vertically towards the surface within the water column. The post-larvae settle out of the plankton in sheltered shallow wetland habitats often in seagrass beds. After a few months of rapid growth in the nursery area, juvenile Prawns migrate into deeper water to complete the cycle (Courtney, *et al*, 1991) and to enter the fishery.

Important Fisheries Habitats in the Fitzroy Region

The most prominent wetland habitats of fisheries importance in the region are those contained in the Fitzroy River and the Narrows. The area also possesses a number of significant inlets, creeks and rivers (Auckland and Colosseum Inlets, Cawarral and Pumpkin Creeks, Calliope and Boyne Rivers).

The Fitzroy River has been the focus of this symposium. From a fisheries view point, the importance of the river relates to the extent of its waterways and the habitats they support. The estuarine region of the Fitzroy River possesses a extensive mangrove forest which has been measured as 225km^2 or about 4.9% of the state's total mangrove cover (Anon, 1984). In addition to the mangrove area, extensive areas of saltmarsh (approximately 214km^2) are associated with the estuary. Several areas of saltmarsh have been modified to form evaporation ponds for the production of salt (Anon, 1984). In addition, there are large areas of low-lying land adjacent to the estuary which become flooded during the wet season.

The Narrows is a significant estuarine area formed between the mainland and Curtis Island. The Narrows has an area of 73.6km^2 of mangrove forests with extensive areas of saltmarsh (57.5km^2) mainly in the northern section.

Cawarral Creek and Pumpkin Creek have 15.2km^2 (13.7km^2 and 1.5 km^2, respectively) of extensive Mangroves and 16.9 km^2 (16.7km^2 and 0.2 km^2, respectively) of saltmarsh habitat associated with the estuaries. The Colosseum Inlet has extensive mangrove stands totalling 44 km^2 and an extensive area of saltmarsh (20.7km^2).

Unlike the above estuarine systems, the estuaries adjacent to Gladstone (Auckland Inlet, Calliope River and Boyne Rivers) have all been subject to extensive land reclamation for harbour, industrial and residential developments. Despite these losses, the remaining area of 22.7km^2 of mangroves (1.4km^2, 6.5km^2 and 14.8km^2, respectively) and 11.4km^2 of saltmarsh (0.7km^2, 3.2km^2 and 7.5km^2, respectively) associated with these estuaries is considerable.

Below the tide line, important fisheries habitats also occur. Extensive seagrass beds are found at the northern, western and southern waters of Great Keppel Island, the southern end of the Narrows, between Curtis Island and Facing Island, and adjacent to Collosseum Inlet (Lee Long *et al*, 1992). Other areas of seagrass could be expected to be present in the region although not mapped by these authors, particularly at the mouth of the Conners, Raglan, Deception, and Casuarina Creeks.

Relationship between Wetland Habitats and Fisheries Productivity

As we have attempted to show, the fisheries of the Fitzroy region are dominated by species associated with estuarine habitats. Fish species may be characterised as estuarine dependent when estuaries, or estuarine environments, are essential habitat for at least one stage of the life cycle and without which a viable population would cease to exist (Blaber *et al*, 1989). These authors found that at least a third of the 197 species recorded in a tropical north Queensland estuary fitted this category and these made up one half of the fish biomass. Commercially important food-fish were included in this listing.

Worldwide, many studies have examined the relationship between inshore habitats and catch of fish. Empirical formulas have been developed in tropical Atlantic and Pacific areas throu h studies (Turner, 1977; Martosubroto and Naamin 1977; Staples *et al*, 1985) that found significant correlations between mangrove areas and adjacent catches of prawns. Nixon (1980) has shown that commercial landings of estuarine dependent species on a unit area basis are correlated with the ratio of saltmarsh to open water area among most of the major regions of the US east and Gulf coasts.

More locally, Morton (1990) showed that Queensland east coast mangrove areas were important areas for fisheries. In his study in Moreton Bay, 46% of the fish species sampled, 75% of the number and 94% by weight taken were of direct economic importance. A conservate estimate of the marketable fish taken during the 13 "monthly" samples was \$A8,380$ha^{-1}yr^{-1}$ (1988 value). These values did not take into account the juveniles of commercially and recreationally important fish also found within the mangrove area.

The importance of shallow water habitat as a nursery area for tropical Australian fish species was demonstrated by Beumer (1978) and Robertson & Duke (1987). Their work showed that the density of prawns and juvenile fish in mangrove, seagrass and mudflat habitat in four different tropical estuaries in northern Queensland was an order of magnitude greater than in the adjacent nearshore habitat.

Mangrove areas have also been shown to be important sources of food and nutrients. The smaller particles of detritus (Particulate Organic Matter; POM) are exported from mangrove areas to offshore areas. Robertson (1986) estimated that the net export rate of POM from Hinchinbrook Island, north of Townsville, was 19.5$kg^{-1}ha^{-1}$day to 15.3$kg^{-1}ha^{-1}$day. This material forms the basis of benthic food chains in waters adjacent to mangrove areas.

Seagrasses are important to fisheries as they perform many of the same functions as mangrove forests. In addition to stabilising the substrate, they serve as nursery habitats and as a primary food source for fish, many invertebrates, turtles and dugongs. Seagrass beds exhibit high productivity and are important to the shallow coastal and estuarine ecosystems (Hillman *et al*, 1989) by exporting nutrients (Moriarty & Boon, 1989) and by providing shelter and a source of food (Bell & Pollard, 1989).

Seagrass areas are especially important for our prawn fisheries. Staples *et al* (1985) showed that 90% of the two commercially significant tiger prawn species (*Penaeus esculentus* and *Penaeus semisulcatus*) were found in seagrass habitats, whereas 97% of the banana prawns (*Penaeus merguiensis*) was found in mangrove areas. The endeavour prawn, *Metapeneaus endeavouri* was found mainly on seagrasses (70% seagrass, 20% algal beds, 10% mangrove areas), while *Metapenaeus ensis* occurred equally on seagrass and mangrove areas. These workers proposed that the distributions of the nursery habitats were the major controlling factor to the distribution of these prawns. They concluded that destruction of estuarine vegetation (mangroves and seagrasses) is likely to lead to corresponding declines in catches of prawns in the local fisheries.

It is not only vegetated sub-littorial habitats which are important to fisheries production. Russell and Garrett (1983) demonstrated that the critical nursery habitat for barramundi in the Gulf of Carpentaria is the supratidal and high tidal mudflats and saltpans around the estuary margins. Ridd *et al* (1988) have shown that these tropical salt flats export nutrient in the form of silicate, orthophosphates and nitrate into the estuarine waters of the Gulf of Carpenaria.

Impacts on Fisheries Production of Alterations to Wetland Habitats

Garrett (1991) offered that in coastal Queensland, habitat modification and destruction, including stream barriers of various sorts, appear significant modern-day regulators of fish populations. The available evidence strongly supports the view that the consequences of modifying or destroying critical wetland habitats must be a decline in fishery catches, be these recreational or commercial.

Loss of shallow water habitat can have a direct negative impact on fisheries. Dio *et al* (1973, cited in Turner 1986) found a significant negative relationship between reclamation of non-vegetated intertidal areas and yields of *Penaeus japonicus* in the Seto Inland Sea, Japan.

Not only is there the impact caused by loss or modification of fisheries habitat, but there is the impact caused by lack of access to areas. Harris (1984) estimated that up to a half of the wetland and stream habitat potentially usable by migratory fishes in rivers and streams in south-eastern Australia had been lost by the construction of physical barriers to fish passage. These barriers were in the form of weirs, barrages, and dams for flood control and water supplies for domestic, agricultural, grazing and industrial use.

Some fish species of major economic importance are affected. As already discussed, the life cycle of Barramundi and Mullet require the movement of fish to freshwater habitats. Stream barriers with inefficient fishways, or lacking fishways prevent the movement of these fish to freshwater habitats. Many of the fishways incorporated with stream barriers have not proven to be effective (Harris, 1984, Russell, 1991).

The impacts of effective movement of fish across these barriers are manyfold. Migrating fish congregate above and below these barriers, and suffer high mortalities. In addition, the whole river system cannot be used by the fish population and consequently the holding capacity of the river is reduced.

There is another impact of these fish barriers, and this relates to water flow. Australian tropical fish species have evolved in an environment of annual floods. These floods provide a period of high export of nutrient outflow from land runoff and landlocked lagoons, resulting in plankton blooms in near-shore coastal waters. They also flush fish out of the lower estuaries for spawning or migratory purposes. Ruello (1973) postulated that continued reduction of river flows would permanently reduce stocks of commercially important penaeid prawns. Much the same could be said for our fin fish resources.

As well providing an export of nutrients, flooding results in large areas of low lying coastal areas becoming inundated with water to form extensive albeit seasonal wetlands. Many native fish (eg Barramundi) time their spawning to coincide with this period of ample food supply and extended nursery areas. With the construction of stream barriers and the diversion of the flood waters, down-stream flooding is minimised. Along with the decreased export of nutrients, the seasonally available wetlands critical for enhanced fish production are diminished in area, function and capacity.

Catchment Management for Fisheries Resources

There has been an impact on regional fisheries production ever since the first trees adjacent to rivers and streams were cleared. The impacts of humankind's early activities were probably minimal. Today, our impacts on fish habitats and consequently fisheries production, can potentially be large. We now have the technology to reclaim and destroy intertidal areas, to dam rivers and to drain low lying land on a vast scale.

Such activities result in a variety of impacts in the catchement, including alteration in rainfall cycles, sedimentation, pollution (chemical and sewage), physical disturance, and reclamation (Hatcher *et al*, 1989). In addition, the construction of stream barriers effects the migration of fish. All of these impacts can reduce the fishery productivity of coastal waters because the integrity and accessibility of coastal wetland and riverine habitats are critical in the life cycles of fish and prawns. For example, Russell (1988) suggests that the observed decline in Queensland east coast Barramundi landings is due, in part, to the destruction of wetlands associated with coastal developments as young Barramundi were unable to make use of alternative nearshore habitats for nursery purposes when coastal wetlands were destroyed or made inaccessible.

Understanding the relationships between the life cycles of fishes and their ecological needs is necessary in designing, evaluating and managing activities affecting river catchments. In the Fitzroy area, these activities include dredging, draining and ponding as well as developments for rural, urban, tourist and industrial use. Catchment management plans must also consider changes in river flow and access caused by stream barriers on local fish productivity. From a fisheries resource viewpoint, all the waterways of the catchment - swamps, fresh, estuarine and marine and associated habitats must be considered in the catchment management process.

Fisheries Division of the Queensland Department of Primary Industries has had since 1969 an ongoing program of identifying important habitats and protecting these via Fish Habitat Reserves (highest level of protection of core conservation areas) and Wetland Reserves (secondary level of protection; often as a buffer zone around a core con: rvation area). In the Fitzroy region, declared Fish Habitat Reserves are at the Broadsound, Corio Bay, Colosseum Inlet, Seven Mile Creek and Rodds Harbour. The region also has Wetland Reserves at Wild Cattle Creek, Boyne Creek and Turkey Creek. The Department is presently developing Fisheries Reserves over sections of Cooroman and Cawarral Creeks and the wetland habitats of the Narrows is to be surveyed in 1993/94.

Fish productivity in the Fitzroy region can be maintained by implementing a management strategy to minimise further loss or alienation of wetland areas.

Valuable fisheries resources can be sustained by insuring that critical habitats at key life stages are maintained. Odum (1984) and Middleton *et al* (1985) espouse a holistic approach to habitat management, so that all consequences of changes to an ecosystem (from the headwater to offshore areas) are considered. This process has much to recommend it.

The geographic area encompassed by the catchment of the Fitzroy River and related streams has long been a focus for human interests and activities. The bountiful natural resources of the region ensure that this interest will continue. If we are to make wise use of the Fitzroy area's fisheries resources, and promote their sustainable harvest into the future, then these resouces must receive due consideration in the catchment management process. Maintaining the long term integrity of our coastal wetlands and riverine habitats is vital for natural resource production. All catchment users have the responsibility and a role to play in this endeavour.

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ENVIRONMENTAL MANAGEMENT AT STANWELL POWER STATION CONSTRUCTION SITE

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1. INTRODUCTION

Responsible environmental management extends over the life of a project. The Queensland Electricity Commission has a strong commitment to the environment. This paper confirms that commitment to the local region by detailing the range of environmental strategies put into place during the planning and construction phases of Stanwell Power Station. It will be shown that these strategies are consistent with the principles of integrated catchment management.

Stanwell Power Station is situated on 1475 hectares approximately 30 kilometres west of Rockhampton. Commercial electricity generation will commence in March 1993 with construction complete and the station at full commercial load by March 1996.

2. PRINCIPLES OF ENVIRONMENTAL MANAGEMENT

Environmental involvement generally commences with the preparation of an Environmental Impact Statement (EIS). The Queensland Environmental Impact Assessment process is now more centralised as the Department of Environment and Heritage must be consulted on designated developments such as a coal-fired power station. The principal legislation is Section 29 of the State Development and Public Works Organisation Act. By delegation, the Executive Head of the Department of Environment and Heritage is responsible for this section. It provides a guideline for analysis of the environmental effects of development proposals and public works in Queensland.

An EIS describes the project and discloses the possible and probable effects of the project on the environment. The purpose of the Assessment is not to decide for or against the study. It is a tool the decision maker can use to assess the likely environmental consequences of the decision. The Environmental Impact Assessment is merely one stage of a much bigger process.

During the construction phase, environmental management priorities include:

(a) Preparation of documentation required by legislation;

(b) Establishment and documentation of ongoing environmental procedures for the site operations staff;

(c) Establishment of an environmental awareness both on-site and within the local community; and

(d) Providing an immediate and professional response to the site management on environmental issues.

During the operation and eventual disposal of the plant, specialised environmental investigations and auditing ensure that any environmental impact is minimised.

3. STANWELL ENVIRONMENTAL IMPACT ASSESSMENT

Time and cost constraints dictated that the Environmental Impact Assessment was only feasible once the preferred site was chosen. This preferred site stage is when the environmental impact of most developments is formally assessed according to the requirements of the Act. A report was released in 1982 to an extensive list of 40 Advisory Bodies, including government instrumentalities and business and community groups. This report provided details of the existing physical, biological and social systems. Based on the comments received, several detailed investigations were undertaken. Results of these field studies together with existing data were incorporated in a 250 page report entitled "Preliminary Environmental Impact Assessment" released again to the Advisory Boards in 1984.

The final report was prepared from a revision of the preliminary document and released in 1985. It should be noted that legislation does not require both a preliminary and final report to be issued. This process was adopted as it is believed that the final report stands as a more complete document suitable for widespread distribution as a public reference.

It must be remembered that every development at a proposed site is unique, and the State development and Public Works Organisation Act provides a flexible legislative framework to accommodate this uniqueness. The procedure described here for Stanwell was developed specifically for Stanwell. It not only met the legislative requirements but also was useful in highlighting the environmental issues associated with this project. Based on this work approval for the stack height was approved and approval in principle for water discharge limits were obtained. Internally, the Environmental Impact Assessment also allowed scope for modifications to the proposal during the construction phase to further minimise any environmental impact on the area.

4. LEGAL GUIDELINES

Environmental legislation in Australia has always been the prerogative of the States. The Commonwealth can pass legislation only for those areas under its direct control. As a result, there are several hundred statutes, regulations and by-laws that deal with environmental control. The reference point for the Queensland Electricity Commission is the Queensland Electricity Act. Under this Act, the Queensland Electricity Commission and distribution boards are required to ensure that proper steps are taken to consider the environmental impact during planning and operation of its works.

While many pieces of legislation may apply in ensuring that the proper steps are taken into consideration, the operation of coal-fired power stations involve three principal pieces of State legislation. These are the Clean Air Act, the Clean Waters Act and the Contaminated Land Act.

4.1 Clean Air Act

The Clean Air Act was introduced by the Queensland Government in 1963. It was proclaimed in 1965 for the Brisbane and Ipswich areas and in 1970 for the rest of Queensland. It is administered by the Department of Environment and Heritage.

This Act aims to prevent or minimise air pollution from industrial sources. It defines "Air Pollution" as "the emission into the air of any air impurity". These impurities include smoke, soot, dust, ash (including fly ash), cinders, solid particles of any kind, gases, fumes, mists, and odours of an offensive or noxious nature. Under the Act, industry is divided into scheduled and non-scheduled categories. Coal-fired power stations are scheduled premises, that is they are a potentially significant air pollution source.

Stack emissions are licensed and subject to the conditions of the Act. The principal atmospheric emissions from a coal-fired power station are carbon dioxide, sulphur dioxide, nitrogen oxide and particulates or fine dust. The limits under the Act and the power station emission ranges are presented below. It is interesting to note that not all gases emitted as listed in legislation. Sulphur dioxide is such an example.

	PARTICULATES	SULPHUR DIOXIDE	NITROGEN OXIDES
EXISTING EQUIPMENT	$0.8g/m^3$ before 1972 $0.45g/m^3$ after 1972	not listed	1220ppm as NO
NEW EQUIPMENT	$0.08g/m^3$	not listed	800 ppm as NO
POWER STATION EMISSION LICENCE	$0.23g/m^3$	not listed (300ppm actual)	600-800ppm

The Clean Air Act currently refers to stack emissions and not ground-level concentrations. A new policy has been proposed which will review stack emission levels, establish formal goals for ground-level concentrations, and recommend a minimum buffer zone around heavy industry.

The Queensland Electricity Industry policy on air emissions is "We will continue to design, operate and maintain plant to meet atmospheric emission levels which have been set to minimise effects on the environment. We will continue to generate our electricity from the most cost-effective options."

4.2 Clean Waters Act

The control of water pollution in Queensland is by the Clean Waters Act. It was proclaimed in February 1973 and came into operation on 1 March 1973. Prior to then, water pollution was the subject of some 14 separate pieces of legislation, most of which were superseded by this Act.

Water pollution can be defined as any change in the properties of any waterway likely to cause a nuisance or render the waterway harmful to the health, safety or welfare of people, fauna or flora. The Act is administered by the Department of Environment and Heritage. It aims to "preserve and, where necessary, restore the quality of the State's waters by prohibiting indiscriminate, uncontrolled dumping or discharge of waste-waters and other polluting matter."

Any liquid waste discharged from a power station is licensed under this Act. A licence will stipulate the quantity and quality of the discharge, and may impose other conditions such as monitoring. Typically, pH, temperature and conductivity are the minimal requirement. The Director General of the Department of Environment and Heritage is responsible for determining discharge standards and monitoring. Stanwell has been monitoring the quality of local creeks since late 1990.

The Department of Environment and Heritage (DEH) has issued water discharge licence W941 for Stanwell. It came into effect on 8 September 1992 and shall expire on 31 March 1993. The requirements of the licence are summarised below.

LICENCE PARAMETER	LICENCE REQUIREMENT
Discharge location	Northern Stormwater Dam spillway.
Quantity of wastes	Daily discharge shall not exceed 18,000 cubic meters, except as a result of rainfall.
Monitoring points	1. Northern Stormwater Dam spillway. 2. Brickworks Road crossing of Neerkol Creek. 3. Adjacent to stream-gauging station 130008A on Neerkol Creek.
Quality of discharge wastes	Suspended solids <100mg/L; pH 6.5-8.0; Dissolved solids <1450mg/L; Chloride <400mg/L; Dissolved oxygen >2mg/L; temperature shall not exceed 2 Celsius degrees above monitoring point 2; total residual chlorine <0.05mg/L..
Sampling frequency	Not less than weekly including daily discharge and rainfall measurements.
Monitoring of receiving waters	Temperature of waters at Sample locations 2 and 3 to be taken not less than weekly.
Reporting	A report detailing all results of the measurement of turbidity during the preceding calendar year to the chief executive (Clean Waters Act) by 1 March. A copy of all records to be made available to the chief executive upon request.

In addition to the licensing of discharges, the Act also places a "duty of special care" on us to ensure that water pollution is not likely to result from our activities.

The Queensland Electricity Industry policy is "We will protect the aquatic environment by ensuring that water discharged from power stations is of acceptable quality, quantity and temperature."

4.3 Contaminated Land Act

One of the most recent pieces of environmental legislation in Queensland is the Contaminated Land Act. It was proclaimed in December 1991 and came into force in 1 January 1992.

The Act is now administered by the Department of Environment and Heritage. It establishes a public Register of Contaminated Sites and provides for the identification, assessment and remediation, if necessary, of contaminated land. While not listed as a scheduled premises, the operations at a power station site, such as oil storage and chemical treatment plants, mean that the site is regarded as a probable contaminated site.

The Act defines contaminated land as "land, a building or structure on land, or matter in or on land, that, in the opinion of the Director is affected by a hazardous substance so that it is, or causes other land, water or air to be, a hazard to human health or the environment." Under the Act, each power station site must be registered. An assessment of the land must be undertaken if there is to be a change of land use, such as rezoning or subdivision, or if the land is to be sold. The Queensland Electricity Commission is presently commencing site assessment of its older and disused power station sites. Based on the results of the assessment, site remediation may be necessary.

5. ENVIRONMENTAL MANAGEMENT DURING CONSTRUCTION

Stanwell draws its water from the Fitzroy River and is licensed to discharge waters into the Neerkol Creek system which feed back to the Fitzroy River. Coal is railed from Curragh and the station will be licensed to discharge a waste gas stream into the atmosphere. Ash produced from the burning of coal will be directed to an ash disposal area which will be progressively rehabilitated.

The cost of environmental protection at a power station will be in the range of 5-10% of the cost of the project. In the case of Stanwell, environmental protection measures will be in the range of $75-225 million. The precise interpretation of "environmental cost" is the reason for the range. Generally, on-site dams, precipitators, and part of the cost of the stack are some of the major environmental costs.

There are four major areas addressed as part of responsible on-site environmental management during construction. They are coordination of land, water and air management, and the generation of environmental awareness both at site and within the local community. The environmental professional must develop both programs and attitudes that promote these goals. The Queensland Government strategy for integrated catchment management has as its purpose the integrated management of land, water and related biological resources to achieve the sustainable and balanced use of these resources.

For the Stanwell site, examples of the type of issues that may be addressed under these headings include:

PRIORITY	EXAMPLES
LAND MANAGEMENT	VEGETATION MONITORING REVEGETATION MANAGEMENT OF SITE GENERATED REFUSE CONTROL OF NOXIOUS WEEDS WILDLIFE MANAGEMENT
WATER MONITORING	MONITORING LOCAL CREEKS MONITORING GROUNDWATER ANALYSIS OF DRINKING WATER FISH STOCKING OF SELECTED DAMS SURVEY OF NUISANCE INSECT POPULATIONS
AIR MONITORING	AIR QUALITY MONITORING WEATHER MONITORING EVAPORATION RATES OF ON-SITE DAMS MEASUREMENT OF RESPIRABLE DUST LEVELS WIND SPEED FOR WORKER SAFETY AT HEIGHTS RAINFALL RELATED TO DAM CAPACITIES
PUBLIC INFORMATION	INVOLVEMENT OF ON-SITE PERSONNEL CONTACT WITH GOVERNMENT AND COMMUNITY GROUPS INVOLVEMENT IN COMMUNITY ACTIVITIES INVOLVEMENT WITH LOCAL SCHOOLS SITE TOURS FOR THE LOCAL COMMUNITY

5.1 Program Development Aims

Environmental management activities on a construction site reflect the integrity of the industry. They should be:

(a) Properly researched, trialled and documented programs;

(b) Proactive;

(c) Planned with all significant points of view taken into account;

(d) Meet all legislative requirements; and

(e) Aim to raise the environmental awareness of people both on site and within the local community.

5.2 Program Development Guidelines

To achieve these aims, the following steps, as appropriate, are recommended:

(a) Close liaison between the environmental professional and site management.

(b) Contact with the appropriate government department. This can be effectively achieved by courtesy calls on a semi-regular basis and inviting their representative to visit the site. The results are up-to-date information on the facilities being offered by that department and the opportunity to develop joint projects. Such projects will have the quite considerable back-up expertise of the department and are generally very cost-effective. This contact should be ongoing.

(c) Contact with the major local conservation/environmental group(s). The same rules apply as with government departments, that is, courtesy calls and site visits. In this way, there is access to current community attitude about the construction. In the case of Stanwell, the Capricorn Conservation Council are now regular visitors and discuss environmental issues and inspect the site. They give environmental talks to school children visiting the site and provide feedback on public comment.

(d) Contact with the local centre for higher education. This is the longer-term source of many of the professionals who will work at the site. Contact allows the submission of project and thesis work for appropriate students. It is also an opportunity to obtain vacation students to undertake specific projects. These activities further prepare future employees for the power industry.

6. PRACTICAL APPLICATIONS

The real indication of successful environmental management is in the programs put into place and the results obtained. Three programs which have been undertaken and are designed to illustrate the range of studies undertaken are presented below.

6.1 Fish Stocking Project

In conjunction with the Department of Primary Industries Fisheries Division, Stanwell are undertaking a fish stocking project in the main water storage dam. 11 200 finglings (5600 each of silver and golden perch) were released in May 1992 as part of a two year study to determine the suitability of silver perch to the Fitzroy Catchment area.

Silver Perch naturally occur in the Murray-Darling system of Southern Queensland, western New South Wales, and northern Victoria. They are not presently found in the Fitzroy Catchment area. Silver perch inhabit rivers and large tributaries, also lakes and reservoirs. It is seen in open waters frequently below rapids and weirs. Spawning takes place from early November to late January after migrating upstream. Eggs hatch in about 30 hours at 26-27 degrees centigrade. Larval development takes 18 days. Maturity occurs after 2-3 years. Their diet consists of aquatic insects, molluscs, earthworms, and plant material. The species is important in the commercial and recreational fishery with individuals reaching 1.5kg.

The control species is the golden perch. They occur naturally throughout the Murray-Darling system and also the Fitzroy-Dawson system. They inhabit slow-flowing, turbid streams and backwaters. Golden perch spawn in spring and early summer flood periods. Hatching requires 24-33 hours. Maturity for males takes 2-3 years and 4 years for females. The species is much sought after by both amateur and commercial fishermen. The fish grows up to 5 kilograms with weights of up to 23 kg recorded.

6.2 Koala Habitat

In 1991, an investigation was initiated by Stanwell Construction to determine if koalas were present in the buffer zone around the Stanwell Power Station site. Through the Australia Koala Foundation, a detailed assessment of the site was undertaken. This study concluded:

(a) The tree species present were typical of a koala habitat area.

(b) The site was large enough to support a koala population.

(c) No evidence of koalas were found on the site.

The report also recommended investigation into the typical nutrient requirements associated with the koala diet and the potential effect of station emissions on Stanwell koala fodder trees. In early 1992, a report into these issues concluded:

(a) The tree species at the Stanwell site were typical koala fodder. The nutrient levels were within the range found in koala habitat areas.

(b) The limited data available indicated that no adverse effects could be expected from power station atmospheric emissions.

In recent months, discussions have been held with the Department of Environment and Heritage. These discussions have led to a koala workshop to further assist Stanwell develop its proposal to introduce koalas to the area. In summary, the workshop concluded:

(a) The issue of koala relocation is a very sensitive issue. The preferred approach is to develop this proposal as a research project.

(b) There was support in principle from the representatives of the Department of Environment and Heritage (DEH), Wildlife Preservation Society, University of Queensland, and University of Central Queensland (UCQ).

(c) A conservation agreement should be formulated with the DEH prior to the introduction of koalas. The agreement should recognise the presence of the power station and not interfere with the operation of the station.

(d) The source of the koalas generated significant discussion. It is important that relocation was not seen to encourage the destruction of natural habitat. Agreement was reached that up to thirty koalas could be initially released onto the site.

(e) The proposal needs performance indicators. Because this has not been undertaken as a research project in the past, some thought must be given to establish short and long term monitoring programs to determine these performance indicators. A five-year assessment plan should be developed.

(f) Based on the successful introduction of koalas to the area, the workshop participants would like a range of issues addressed. These include trying to identify why koalas settled in the area, breeding patterns, health performance, nutritional preferences, and the effect of the power station on both the koala and fodder species.

6.3 Tree Planting Projects

Over the past two years, there has been close cooperation between Stanwell and the Queensland Forest Service. During that time sever tree planting projects have been undertaken. These include two agroforestry trials, one of which is being replicated at four locations throughout Central and Southern Queensland, annual Arbor Day activities, and programs that have involved local schools, Greening Australia, Rockhampton City Council, Capricorn Conservation Council, and the Australian Trust for Conservation Volunteers.

The first of these projects is the main agroforestry trial underway at the site. Eight species of native tree common to the area have been planted at different spacings. In total, 3000 to 4000 trees have been planted in this trial. The trial has included some extremes in conditions, including an extended dry period in 1991. This has been reflected by the range of success of some species. To date, the Eucalyptus teretircornis appears to have performed the best. This tree, also known as the Forest Red Gum or Blue Gum is a native of Eastern Australia and Papua New Guinea. It prefers medium to heavy soils in an open, sunny position, and is drought and frost resistant. It generally occurs in open-forest formation or as scattered trees on alluvial flats. In drier areas, it prefers alluvial flats subject to occasional flooding. In higher rainfall areas it grows on lower slopes of hillsides and extends to mountain slopes and plateaux. It prefers fairly rich alluvial soils, sandy or gravelly loams which are moist but not waterlogged. Associated species include carbeen (E. tessellaris), long-fruited bloodwood (E. polycarpa), pink bloodwood (E. intermedia), white gum (E. alba), red mahogany (E. resinifera), ghost gum (E. papuana), spotted gum (E. maculata), narrow-leafed red ironbark (E. crebra), grey box (E. moluccana), grey ironbark (E. paniculata), red bloodwood (E. gummifera), poplar box (E. populnea) and Molloy red box (E. leptophleba), as well as numerous other genera such as Angophora, Casuarina, Melaleuca, Acacia and Callitris.

The Eucalyptus tereticornis is a major koala food tree. It is also used by gliders, possums, blossom-bats, lorikeets, rosellas and honeyeaters, snakes, lizards and many other plant eating insects. It is used as a nesting site by many birds. Commercially, it is useful in heavy construction and is a source of pollen.

This information, based on a combination of practical and theoretical knowledge, is of benefit not only to the land management strategy for the Stanwell site but also to the wider community.

7. COMMUNITY OWNERSHIP

The local community includes both site employees and local residents. It is their long-term environmental interests that need to be addressed. This can be achieved by:

(a) Personal contact. This is often very time-consuming. Power station open days are often the best opportunity to pursue this avenue.

(b) Contact with the local schools. This is generally an effective method of group education. The schools can visit for an environmental lecture and site visit. The lectures should include a guest speaker, for example from the local conservation council, to ensure that balanced information is presented to the students.

(c) Contact with local government representatives. They represent the local community and are often the people who would receive any public complaint. It is important that they are fully orientated with site activities.

(d) Contact with the local environmental community group. This allows access to sometimes the more extreme views within the community, however experience has found that the rewards of such an association are of significant benefit.

(e) Promotion in internal publications. Internal publications often provide the most effective method of disseminating information within the industry.

As an example, any discharge of water from an operating power station may be viewed with suspicion by the local community. At Stanwell in the late 1980s, the local community was concerned about the possible downgrading of the water quality and potential flooding of local creeks as a result of station discharges.

A water monitoring program for the local creek system was undertaken, based on the extensive work carried out in the early to mid 1980s. Monitoring now occurs both upstream and downstream of the proposed discharge point. The baseline results and location of sampling points were also displayed at the station open day for the local community to see and comment on. Local residents generally showed an interest in knowing the chemistry of their local creek system. A report commissioned by QEC concluded that soil survey results indicate that there is sufficient areas of suitable soils downstream of Stanwell Power Station to utilise all extra water supplies.

8. SUMMARY

The aims of both Stanwell and catchment environmental management are essentially the same. It involves an integrated strategy for achieving the sustainable and balanced use of land, water and biological resources. Significant planning and development has been undertaken to minimise the environmental impact of Stanwell Power Station on the local environment and to undertake a series of community-based programs to benefit the environmental management of the Fitzroy Catchment system.