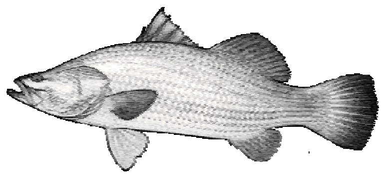
Project Report QO02005

An Investigation of the Impacts of Ponded Pastures on Barramundi and Other Finfish Populations in Tropical Coastal Wetlands

Final Report

S. J. Hyland



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1. Non-technical Summary

97/201 **The impacts of ponded pastures on barramundi and other finfish populations in tropical coastal wetlands.**

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Objectives:

1) To document the extent of ponded pastures and other pondage systems in and adjacent to coastal wetlands on the central coast of Queensland.
2) To assess the movement, growth and survival of barramundi in ponded pastures.
3) To assess the utilisation by barramundi of ponded pastures and wetlands dominated by exotic grass species.
4) To identify appropriate wetland management strategies for facilitating barramundi movement and survival in ponded pastures and other pondage systems.
5) To document the species composition of finfish populations and their relative abundance in ponded pastures.

Non-Technical Summary

The development of ponded pastures involves the construction of earthen banks to collect water for pasture development. Ponded pasture systems are particularly advantageous for cattle production in semi-arid grazing areas. There is potential for interaction between ponded pasture systems and fisheries resources where pondage systems are located in or adjacent to wetlands. The impact of ponded pastures on coastal wetlands has been investigated because of the importance of coastal wetlands as nursery areas for barramundi and other fish species.

Ponded pastures have been developed extensively on coastal plains and riverine flood plains in central Queensland providing more than 16,000 ha of pondage area in and adjacent to coastal wetlands containing barramundi habitats. Twenty-three species of fish were identified in ponded pasture systems although abundance of fish was low. Ponded pasture systems are generally shallow and unshaded, and most dry completely during the spring dry season. Water quality in ponded pasture systems was periodically poor with high pH (>9), low dissolved oxygen, (<4 ppm), and high temperatures (>32°). Mass kills of fish were not observed in ponded pastures although fish kills occurred in a variety of habitats associated with ponded pasture systems. Extremely dry conditions prevailed during the study and contributed to poor water quality in various freshwater habitats.

Barramundi occurred in 8 out of 20 ponded pasture systems examined. Interactions with barramundi are most likely to occur in pondage systems constructed across remnant tidal channels or in close proximity to upper intertidal pools. Small (50-200 mm) barramundi were subject to entrapment and high mortality in upper-intertidal pools below pondage banks adjacent to intertidal habitats during low flow conditions. Entrapment of juvenile barramundi occurred in pondage systems constructed across remnant tidal channels. A rough estimate of the rate of entrapment at one study site ranged between 39% and 78%, but further investigation is required to determine accurate entrapment rates. Most pondage systems in or near intertidal areas dried completely with complete mortality of trapped fish. Sustained survival of barramundi over several years occurred in one pondage that did not

dry completely and demonstrated the potential of ponded pasture systems to provide fish habitat.

Barramundi movement and survival under high flows could not be monitored due to the low rainfall regime that prevailed during most of the project. It is expected that large-scale inundation would be associated with widespread dispersal of juvenile barramundi and a high risk of entrapment. During high flow events, mature barramundi are likely to suffer low entrapment on their downstream migration to the estuary. An opportunity to assess mortality rates following a large-scale inundation did not arise during the study.

Barramundi were not found in shallow (<1 m) wetlands dominated by para grass but they did occur in para grass on the edge of deep-water (>2 m) aquatic habitat. While these habitats may potentially provide some value for barramundi their habitat value for this species remains uncertain and requires further investigation.

A balance between the fisheries aspects and the agricultural aspects of ponded pasture systems requires careful management of water flows and water quality. A balance will be achieved if water flows and water quality can be managed to facilitate fish movement and survival without severely restricting water collection and storage for pasture development. Ponded pasture systems have potential to increase the extent and duration of inundation in some areas. A number of design features are proposed for improving fisheries value of ponded pasture systems without sacrificing their pastoral values. Deep-water refuges and shading would assist water quality. Features for managing water flows include bywashes for managing overflows, high flow channels for diverting high flows (flood routing), and low flow diversion banks for directing low flows into pondage systems.

Careful attention to arrangement or layout of pondage banks will assist with minimising fisheries interactions. A series of short cascading embankments provides more flexibility for water flow manipulation then does a single long embankment. Pondage systems across watercourses, tidal gutters, intertidal habitats and freshwater-estuarine interfaces present high risk for fisheries resources and require careful management consideration. Ponded pasture systems should be designed to maintain the interface between estuarine and freshwater habitats rather than disrupt this critical fisheries habitat. The disruption of the estuarine-freshwater interface increases the risk of tidal intrusion on pasture and the risk of interactions with fisheries resources. The establishment of strategies to assess and manage acid sulphate soil issues during the construction or maintenance of ponded pasture systems in or adjacent to coastal wetlands is required. Existing high-risk areas will need to be managed on a case-by-case basis.

Finally, it is acknowledged that the management of ponded pastures in coastal regions involves issues other than those relating to fisheries production and pasture development. These include wading bird and other wildlife management, animal health, human health, water harvesting for non-pasture related activities as well as large-scale coastal zone processes.

2. Background

Ponded pasture systems are pondage systems in which water-loving pasture species have been established for grazing purposes and have been described in Pittaway et al. (1996). Ponded pasture systems for cattle are generally constructed from earthen embankments strategically located to collect freshwater for stock watering and for pasture development. However, Coffey (1991) notes that some ponded pastures have been developed in naturally occurring wetlands without the construction of an earthen wall. Ponded pasture systems have been developed in a variety of habitats including wetlands and lagoons associated with riverine floodplains and coastal plains. In some coastal regions ponded pastures have been established in supralittoral areas by constructing banks across tidal gutters to limit tidal intrusion to encourage pasture development. They have also been developed in dry land locations and can be found throughout the catchment in many cattle producing areas.

Para grass (*Brachiaria mutica*), aleman grass (*Echinochloa polystachya*) and hymenachne (*Hymenachne amplexicaulis*) are introduced semi-aquatic pasture species that are commonly used in ponded pastures. Para grass is native to South Africa and possibly South America (Cameron and Kelly 1970) and was released in Queensland in 1880 while hymenachne, also native to South America, was introduced in the 1970. Both species are highly water tolerant and capable of growing in greater water depths than native water tolerant pasture species. Para grass is capable of growing in water up to 60 cm deep while hymenachne and aleman grass may grow in water 2 m deep (Humphries et al. 1994). They are highly invasive in wetlands and appear to have considerable potential to displace native species (Lukacs 1996, Humphries et al. 1994).

The reported benefits of ponded pastures to cattle producers include the capacity for high stocking rates (0.3-0.6 ha/animal), provision of high feed, provision of “out of season” forage, and good dry matter yields (>30 t/ha/yr) (Middleton et al. 1996). The availability of high quality fodder from ponded pastures during the dry season allows producers to improve the condition of cattle and provides greater marketing flexibility. Ponded pastures have also been promoted as a means of “drought proofing” grazing properties, particularly in regions where rainfall is low or unreliable. Murphy and Wildin (1996) also report that ponded pastures have the potential to reduce the need for dry season supplement for cattle. The development of ponded pastures in these regions is seen as being of considerable importance to local farming systems and to regional economies (Jamieson and Bourne 1996). Ponded pasture systems for cattle production have been developed in the Northern Territory and in northern Queensland on seasonally inundated floodplains and wetlands (Stockwell et al. 1996, Kernot 1996). In the Northern Territory, a system of pondage banks has been developed for the control of saline intrusion. Pondage systems have also been developed for sugar cane production in some coastal regions of Queensland and for cattle production in New South Wales.

The Queensland Government established an Interdepartmental Ponded Pasture Steering Committee to develop policy options on ponded pastures in response to considerable community concern over environmental issues associated with ponded pastures and the introduction of exotic grass species. Public and industry comments on a discussion paper produced by the ponded pasture steering committee identified a variety of issues including fisheries related issues with the ponded pastures (Anon 1996). A ponded pastures policy options paper was subsequently produced and sets out a range of options appropriate to the future use and development of ponded pastures (Anon 1997).

3. Need

Wild production of barramundi (*Lates calcarifer*) depends partially on nursery habitats located in tropical coastal wetlands. Modifications of these habitats have potential to impact barramundi populations (Russell and Garrett, 1985). There has been considerable development of ponded pastures in northern Australia. Wildin et al. (1996) has suggested that there are some 100,000 ha of ponded pastures in northern Australia. Fisheries stakeholders have raised concern regarding the impact of ponded pastures on fisheries resources including the entrapment and survival of barramundi (Anon 1991).

The development of ponded pasture systems usually involves the construction of earthen banks and the introduction of water loving pasture species. These two elements of ponded pastures have considerable capacity to modify aquatic habitats and associated ecological processes where the ponded pasture is located in or adjacent to wetlands or watercourses. Interactions between ponded pastures and fisheries resources may occur where modifications of aquatic habitats disrupt fish movements or are associated with changes in water quality or other habitat conditions. Pondage systems in which water quality and habitat condition can be maintained may have potentially positive impacts on fisheries resources through increased extent of inundation and increased duration of inundation (Vass 1991).

Para grass (*Brachiaria mutica*), aleman grass (*Echinochloa polystachya*) and hymenachne (*Hymenachne amplexicaulis*) are highly invasive semi-aquatic grasses that have been used in ponded pasture systems. Humphries et al. (1994) has reported that there is an urgent need for action to control the spread of these species. The invasion of these species in wetlands and watercourses represents a major change in aquatic ecosystem functions (Bunn et al. 1998), but the impact on the value of coastal wetlands as barramundi nurseries is unknown.

Fish movement and the modification of coastal wetlands are two fisheries issues that are of particular significance. Fish movement between freshwater and estuarine habitats, or between instream and offstream aquatic habitats may be disrupted by inappropriately located pondage banks. In addition, the importance of coastal wetlands as fish nursery areas means that many fish species require access to and from wetlands and adjacent watercourses and estuaries. The role of coastal wetlands as fish nursery areas relates to the provision of shelter and food for juvenile stages of a variety of fish species. Pondage systems located in or adjacent to coastal wetlands are of particular interest from a fisheries perspective because of their potential to disrupt the movement of fish into or out of these important aquatic habitats.

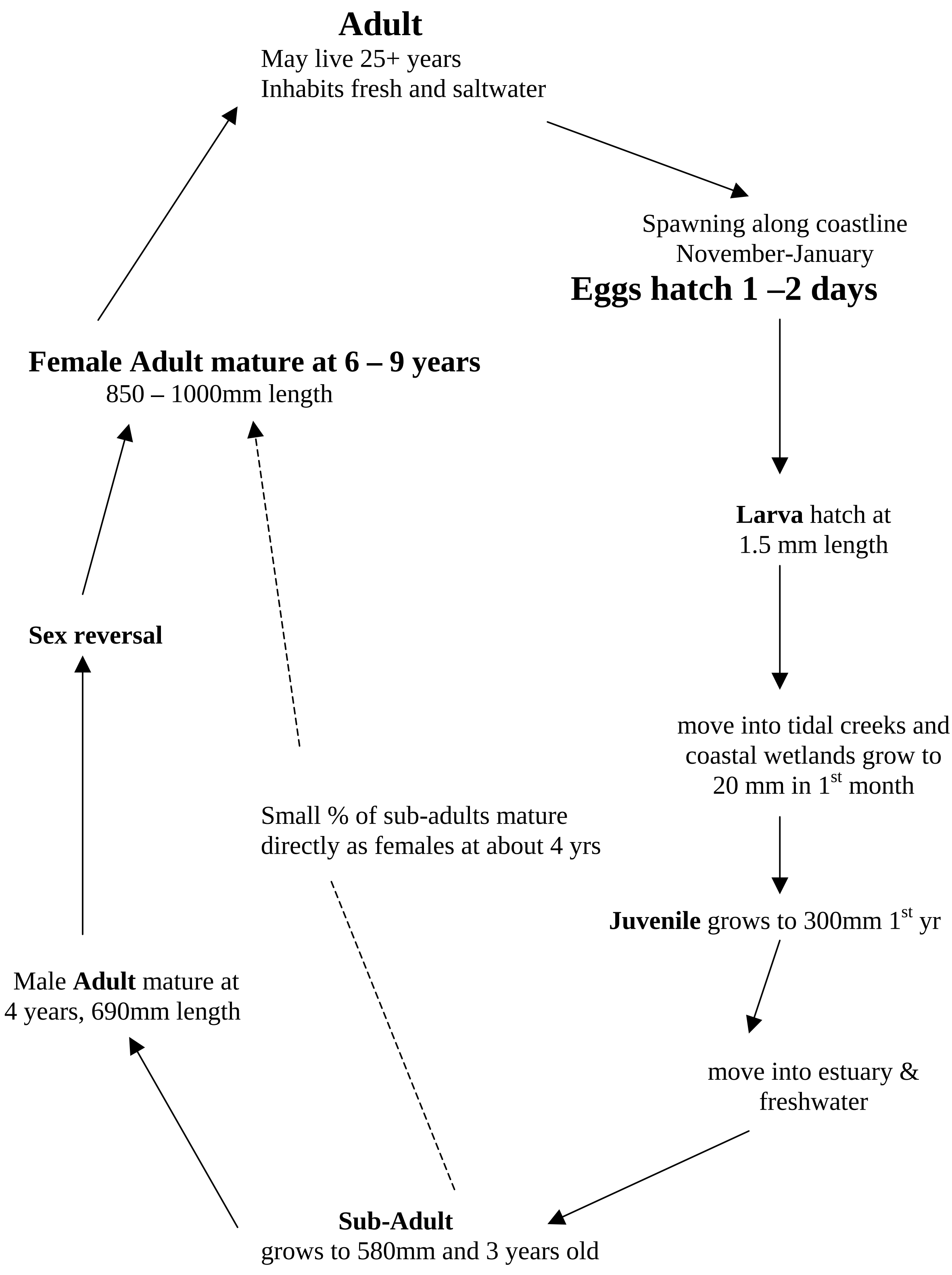
Coastal wetlands include a wide range of habitats. Some are predominantly intertidal or marine, such as mangroves, saltmarsh and seagrass, and their importance as fisheries habitats is well established (Robertson and Duke 1987, 1990). Coastal wetlands also include a variety of freshwater and brackish-water habitats. Various vegetation types including paperbark trees, reeds, sedges and water lilies, as well as submerged aquatic plant species occur in these habitats. Although many of these wetlands are highly seasonal with inundation usually associated with the summer wet season, and are available to juvenile fish for a limited time, they form a particularly important component of coastal fisheries production. For species such as barramundi, post-larval and early juvenile stages utilise coastal wetlands as nursery areas before moving into adjacent aquatic habitats as large juvenile or sub-adult stages (Figure 1) (Russell and Garrett 1982). In Queensland, barramundi reach maturity in 3 to 5 years at about 550 mm (Davis 1982). Most barramundi mature first as males before undergoing sex reversion (Davis 1987). Mature barramundi migrate from freshwater habitats to estuaries for spawning. The scope of the present investigation study has focused on ponded pasture systems located in or adjacent to coastal wetlands due to their importance as barramundi nursery. Barramundi is an important component of the recreational and commercial inshore fisheries of northern Australia (Kailola et al. 1993). The annual commercial catch of barramundi in Queensland was 738 t in 1991 and had declined to 501 t in 1995 of which 119 t were landed on the east coast (Williams 1997). Landings from the Northern Territory were around 600 t in 1990 (Kailola et al. 1993).

4. Objectives

The objectives of the investigation were: -

1) To document the extent of ponded pastures and other pondage systems in and adjacent to coastal wetlands on the central coast of Queensland.
2) To assess the movement, growth and survival of barramundi in ponded pastures.
3) To assess the utilisation by barramundi of ponded pastures and wetlands dominated by exotic grass species.
4) To identify appropriate wetland management strategies for facilitating barramundi movement and survival in ponded pastures and other pondage systems.
5) To document the species composition of finfish populations and their relative abundance in ponded pastures.

Figure 1 Life cycle of barramundi (*Lates calcarifer*)



5. Study Locations

Investigations were undertaken in ponded pasture systems associated with coastal wetlands at three primary study sites in the Fitzroy Estuary, Corio Bay and the Broad Sound and in a secondary study site on the Goorganga plains near Proserpine (Figures 2 and 3). The Fitzroy River drains a catchment of more than 140,000 square kilometres in central Queensland and contains an extensive delta system at its mouth. Corio Bay is located some 50 kilometres north of the Fitzroy River mouth and is a small, shallow embayment fed by several small coastal streams. The Broad Sound is a large embayment located some 150 kilometres north of the Fitzroy Estuary and is also associated with several small coastal streams.

The wetlands associated with Corio Bay and the Broad Sound are listed as Ramsar sites in recognition of their importance as wading bird habitats (ANCA 1996). Wetlands associated with the Fitzroy Estuary, Corio Bay, Broad Sound and Goorganga plains are all listed as nationally important wetlands (ANCA 1996). The Broad Sound and Corio Bay also contain Fish Habitat Areas declared under Queensland Government Fisheries legislation. Broad Sound and Corio Bay are also included in the Great Barrier Reef Marine Park.

Cattle production is the major land use and economic activity in the Broad Sound, Corio Bay and Fitzroy Estuary. Rockhampton is the major centre in the region and is located on the Fitzroy River some 40 kilometres upstream from the mouth. Yeppoon is a small coastal town located between the Fitzroy Estuary and Corio Bay. St. Lawrence is located at the northern end of the Broad Sound. Yeppoon and St. Lawrence provide support to the fishing industries in the region. The rainfall patterns in these regions are less reliable than for other coastal regions. The annual average rainfall for St. Lawrence, Rockhampton, and Yeppoon varies between 900 mm and 1320 mm (Figure 4). Pondage systems have been developed throughout the catchment in each of these regions. However, the scope of the present study was largely restricted to ponded pasture systems in or adjacent to coastal wetlands due to the importance of these habitats for barramundi.

Study locations in the three regions were subject to lower than average rainfall during the project associated with the 1997 el Niño event. Above annual rainfall was last received at these locations during 1990 (Figure 5). Annual rainfall at the Fitzroy location (Broad Meadows recording station) was 15.2% less than the mean annual rainfall in 1996 and 42.9% less in 1997. Annual rainfall at the Yeppoon recording station (near the Corio Bay study location) was 22.5% less than the mean annual rainfall in 1996 and 42.1% less in 1997. St. Lawrence (Broad Sound) recorded rainfall at 8.3% and 28.5% lower than the mean annual rainfall for 1996 and 1997. The breakdown of the el Niño in 1998 resulted in rainfall near the mean annual levels for St. Lawrence (1034 mm in 1998, annual mean of 1027 mm) and Broad Meadows (986 mm in 1998, annual mean of 997 mm). Rainfall at Yeppoon in 1998 (983 mm) remained below average at 25.7% less than the mean annual rainfall.

Figure 2 Location of Study Sites

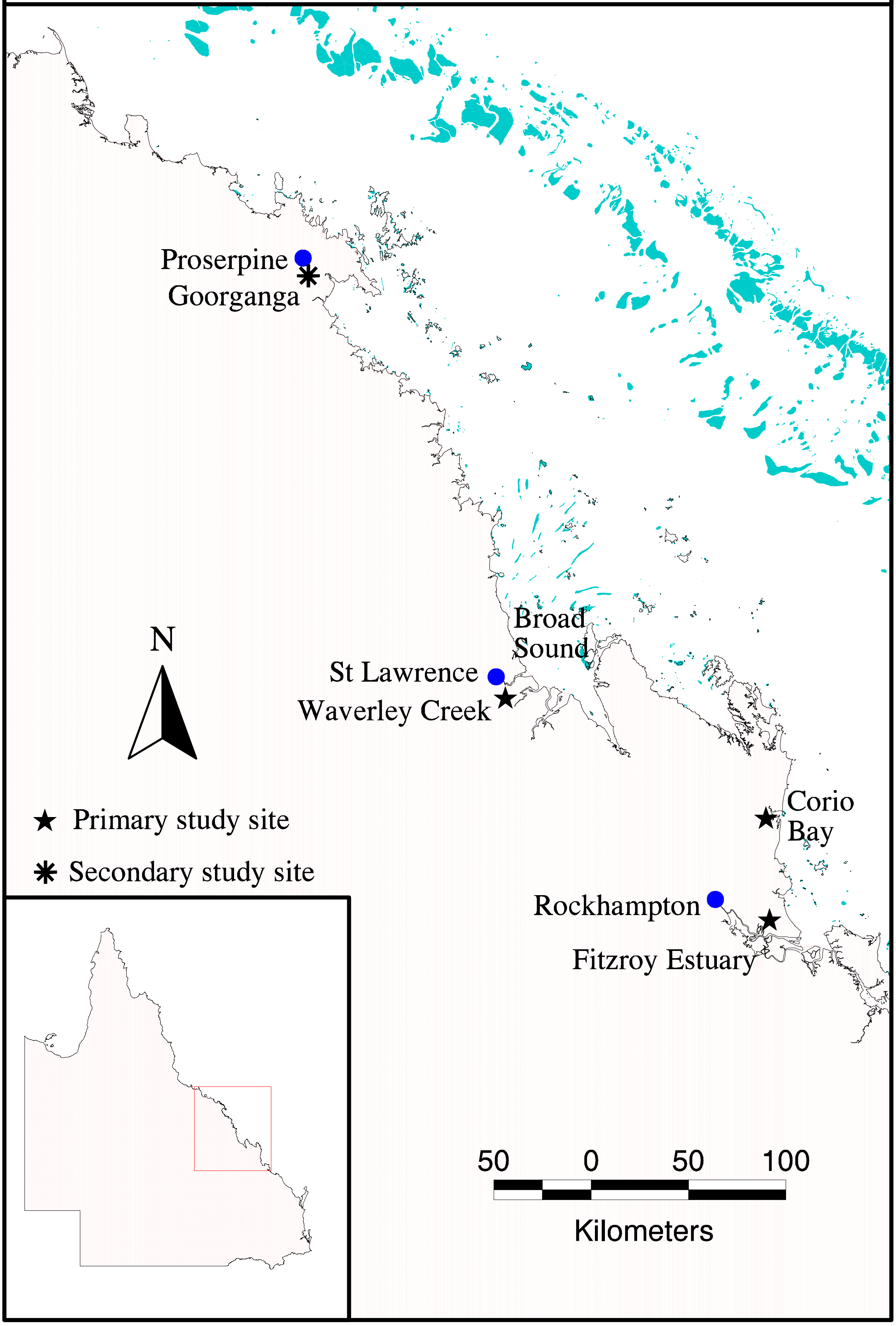


Figure 3 Location of Primary Study Areas

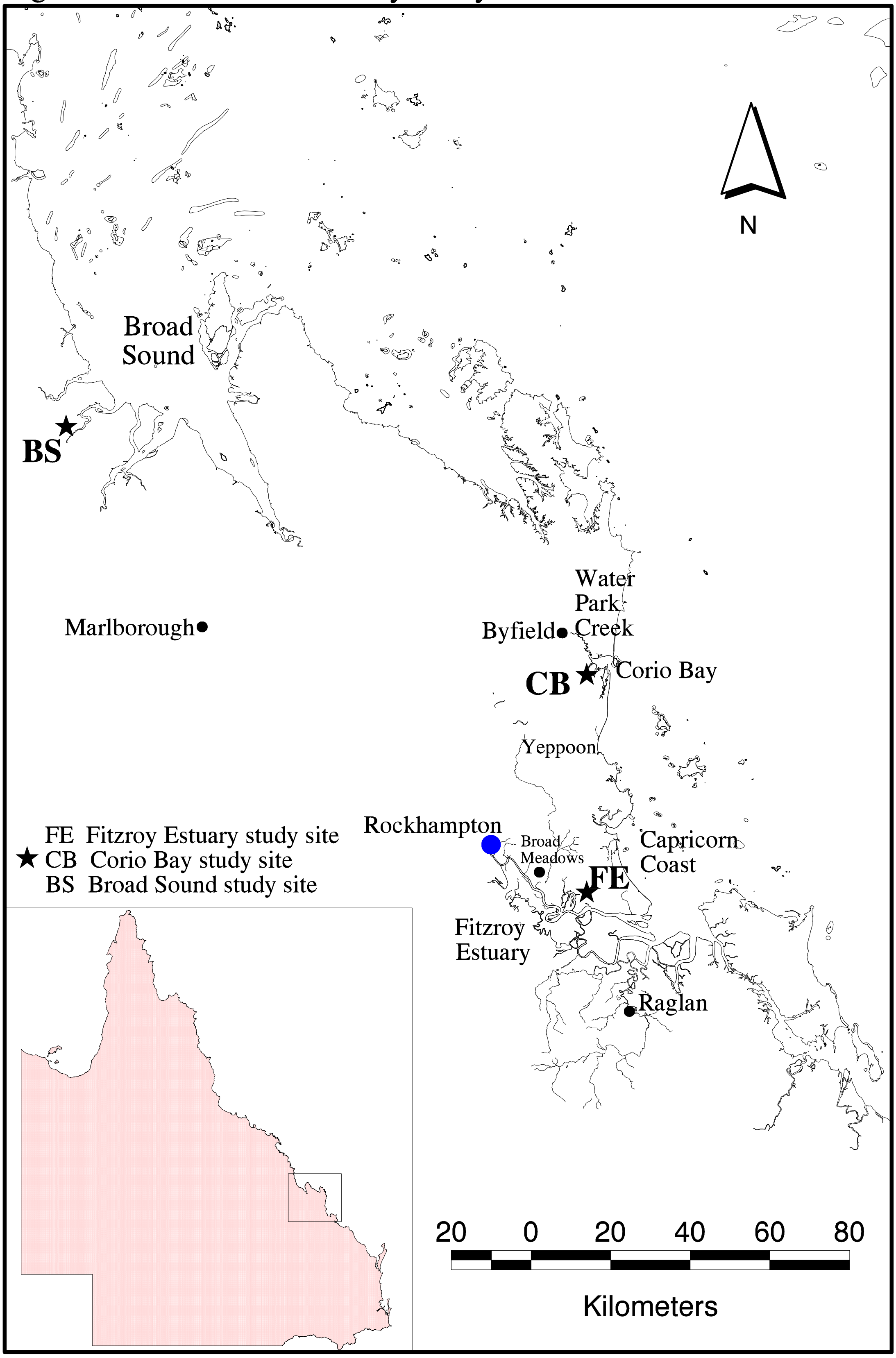


Figure 4 Average annual rainfall by location.

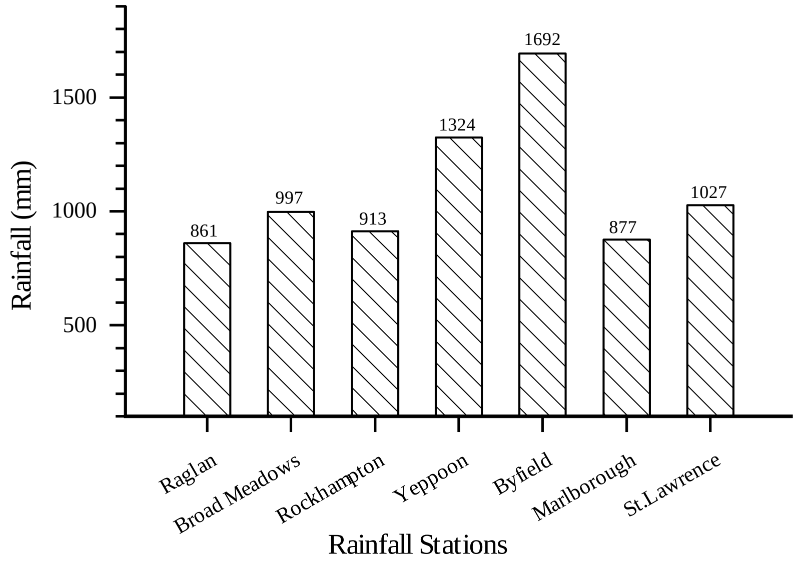


Figure 5 Annual rainfall (1990 - 1999) for St. Lawrence (Broad Sound), Broad Meadows, (Fitzroy Estuary) and Yeppoon (Capricorn Coast).

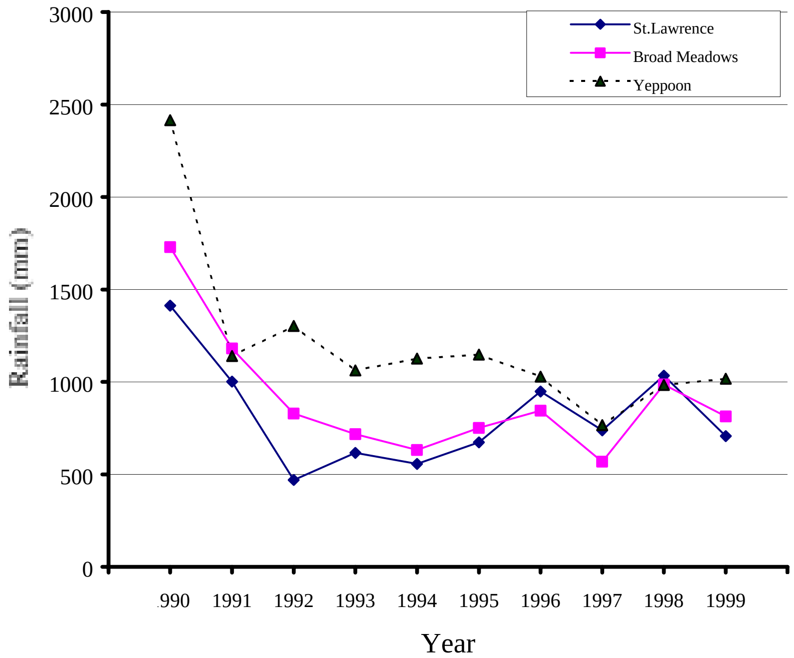
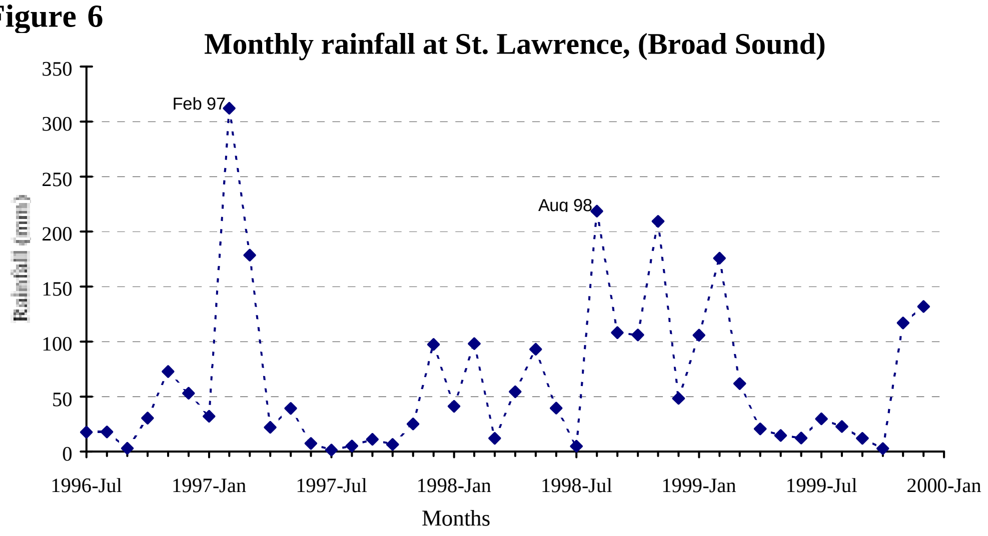
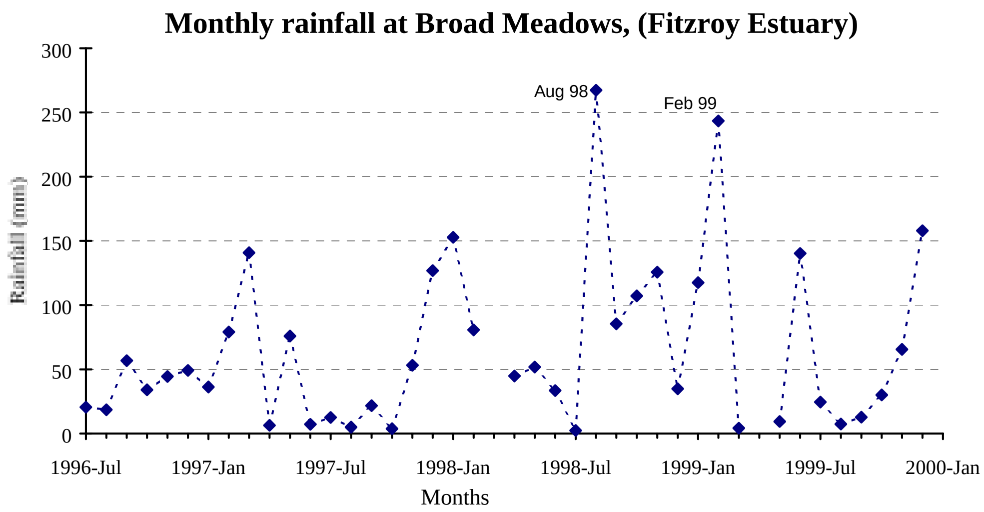


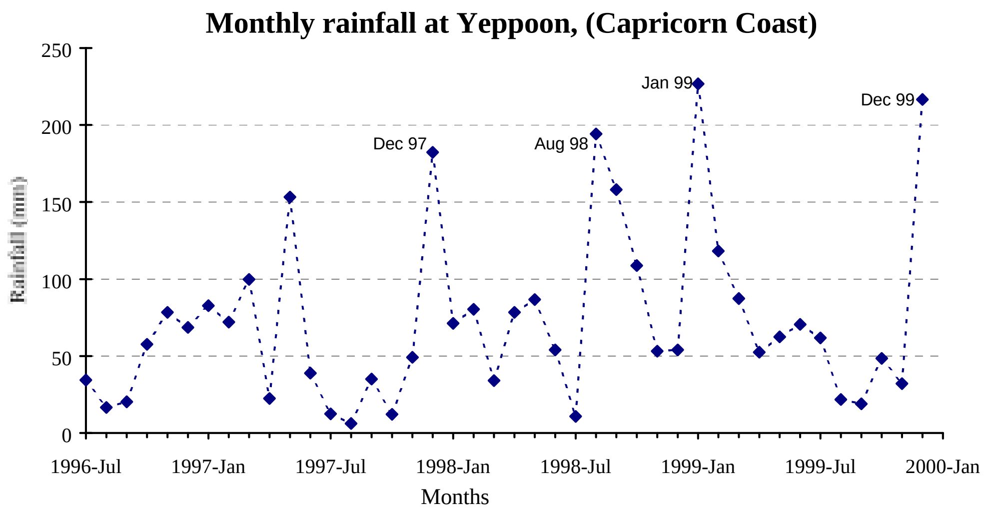
Figure 6



Monthly rainfall at St. Lawrence, (Broad Sound)
Rainfall (mm)
350
300
250
200
150
100
50
0
Feb 97
Aug 98
1996-Jul
1997-Jan
1997-Jul
1998-Jan
1998-Jul
1999-Jan
1999-Jul
2000-Jan
Months



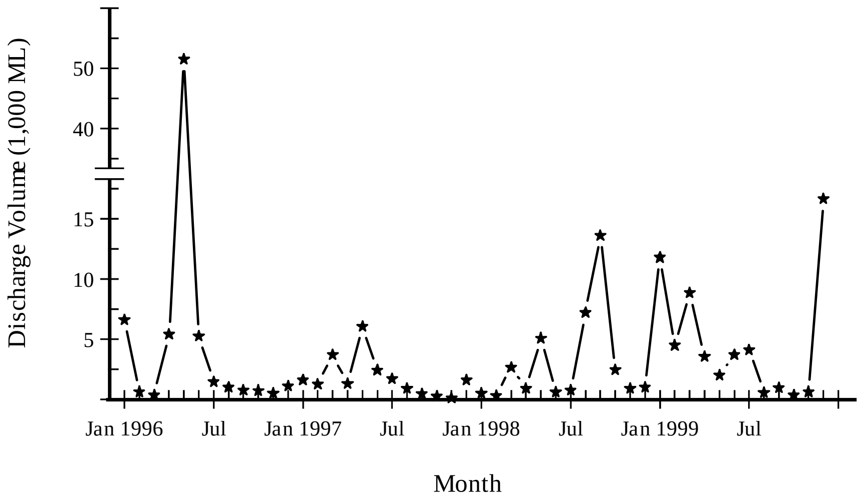
Monthly rainfall at Broad Meadows, (Fitzroy Estuary)
Rainfall (mm)
300
250
200
150
100
50
0
Aug 98
Feb 99
1996-Jul
1997-Jan
1997-Jul
1998-Jan
1998-Jul
1999-Jan
1999-Jul
2000-Jan
Months



Monthly rainfall at Yeppoon, (Capricorn Coast)
Rainfall (mm)
250
200
150
100
50
0
Dec 97
Aug 98
Jan 99
Dec 99
1996-Jul
1997-Jan
1997-Jul
1998-Jan
1998-Jul
1999-Jan
1999-Jul
2000-Jan
Months

The timing of rainfall (Figure 6) and associated flow events varied considerably between years, occurring in different seasons in successive years of the study (eg. late autumn 1999, late August and early September 1998, late autumn 1997, mid-summer 1996, and mid spring 1995). A short but intensive flow event also occurred during late December of 1999. The monthly rainfall figures do not accurately reflect the flows into or through the ponded pasture systems. Stream flow data were not available for any of the small streams associated with the pondage systems in the three primary study locations. However, stream flow data (Figure 7) for a small regulated stream (Water Park Creek) adjacent to the Corio Bay location indicated that some of the peaks in rainfall recorded at Yeppoon did not translate into major flows. For example a peak in monthly rainfall at Yeppoon in May 1997 of 150 mm produced a 5 Ml flow for the month while a larger rainfall in December 1997 produced a 2.6 Ml flow for the month. Some spatial variation in rainfall patterns between the coastal rainfall recording station of Yeppoon and the catchment of the small coastal streams will occur. Flow into pondage systems and wetlands will also be influenced by the amount of ground soakage as determined by soil moisture levels and ground water levels. The first half of the study period was particularly dry with very few flows and only partial inundation of the primary sites. Field investigations were also undertaken in wetlands and ponded pastures in the Goorganga plains location where more extensive inundation had occurred.

Figure 7 Monthly stream discharge for Waterpark Creek, Corio Bay.



The extent of inundation varied between locations. The system in the Broad Sound was completely inundated for a short time on several occasions while the other locations were only partially inundated on two occasions. Following overflow events, the pondage system in the Broad Sound became completely dry by the following spring. The Fitzroy system remained inundated for the entire study but did not undergo a major overflow. The system at Corio Bay received minor inflows on several occasions without major overflows and was partially inundated in the first year becoming dry during the second year.

Ponded pasture systems in the primary study locations.

The ponded pasture systems in the three primary study locations (Broad Sound, Fitzroy Estuary, and Corio Bay) were closely associated with upper-intertidal habitats and adjacent supra-littoral areas. In each of these systems, a large ponded area was formed by the construction of a system of earthen walls or banks across wetlands associated with the freshwater-estuarine interface of small coastal streams. All three locations contained freshwater habitats landward of the pondage systems. The Fitzroy and Broad Sound study locations contained systems constructed across tidal channels. The Corio Bay system was located in an area immediately adjacent to the upper-intertidal zone but did not contain tidal channels. In each of these systems the estuarine-freshwater interface has been substantially disrupted by the development of the ponded pasture system and small stream flows did not provide freshwater input to the adjacent estuarine habitats.

Corio Bay Study Location

At the Corio Bay location, an earthen wall some 1.2 km long forms a ponded pasture system containing an extensive shallow (<1.5 m) freshwater wetland fed by a small, intermittent coastal stream. Freshwater flow to the estuary only occurred when the pondage system was fully inundated. Historical aerial photography indicated that a portion of the ponded area previously contained a mosaic of saltmarsh and claypan. An extensive saltmarsh is located immediately downstream of the pondage bank between the pondage bank and mangroves associated with a tidal creek. This saltmarsh contains a system of shallow (<0.5 m) upper-intertidal pools and channels. This mosaic of intertidal channels, pools and saltmarsh is between 250 m and 1000 m wide. There is periodic ponding of water in the pools and channels since these pools do not drain at low water but remain inundated for several weeks. A long narrow shallow pool is also located at the downstream base of the pondage bank at this location and is connected to the series of pools and channels across the saltmarsh. Mangroves also occur along the tidal channels and along the downstream side of the pondage bank. The pondage system serves multiple uses including pasture development for cattle grazing, provision of wading bird habitat for eco-tourism and water harvesting for golf course maintenance. Substantial overflow of the bank did not occur during the investigation although anecdotal reports suggest extensive overflow along the length of the pondage bank has occurred in the past. Such overflow events are likely to provide scouring of the substrate immediately below the bank and assist the formation of shallow pools along the downstream side of the bank. The pondage system was initially established in the 1960's with the construction of a low (<1 m) earthen bank across the saltmarsh. This was later (about 1987) replaced by a more substantial earthen bank more than a metre high and more than two metres wide. Although the pondage received runoff on a number of occasions with some minor overflow, the system was partially inundated for much of the study and dried completely for more than twelve months.

Broad Sound Study Location

The ponded pasture system in the Broad Sound location supports a large shallow wetland when full. The system dries completely between inundation events. In one year this occurred as early as October while in another year the pondage did not dry until December. Within the system there is a remnant tidal channel that forms a deep (>1.5 m) section when fully inundated. This remnant tidal channel is the last portion of the system to dry. The intertidal area below the bank at the Broad Sound location contains an extensive saltmarsh and mudflat drained by large and relatively deep (>2 m) tidal channels. There is very little pooling of water in the intertidal habitats below this pondage bank.

Pondage bank at Broad Sound

This bank is some 9 km long, 2 m wide, and ranges in height from around 1 m to more than 2 m except for a number of low points (referred to as bywashes) that are level with the adjacent terrain. These bywashes direct overflow to the estuary downstream of the bank and effectively provide for a flow though the pondage system before the system is fully inundated. The bank has been constructed across the estuarine-freshwater interface of a small coastal stream that flows into a tidal section of a larger coastal stream. There is evidence of active erosion processes in the deep tidal gutters immediately downstream of the bank. A similar pondage bank is located nearby across a similar estuarine-freshwater interface associated with another small coastal stream. This system is subject to tidal intrusion around one end of the bank. The tidal intrusion has encroached into areas previously covered with pasture with a resulting decrease in pasture cover.

Pondage system at Broad Sound during dry phase showing remnant tidal channel (isolated from tidal inundation).

Fitzroy Study Location

The Fitzroy study site was located on the northern bank of the Fitzroy River, where a ponded pasture system had been constructed across a number of tidal channels. Some of these channels previously drained an oxbow formation. During low inundation levels the remnant tidal channels retain water when the remainder of the system is dry. These water bodies become quite brackish during the low inundation levels. There is an extensive area of pasture dominated by para grass adjacent to the remnant tidal channels. This system is fed by water flowing through a ephemeral wetland located between the pondage system and a small freshwater stream. Drainage lines from surrounding slopes also direct runoff into the pondage systems, some via the oxbow formation. The stream feeds the wetland which drains into the estuary via a number of tidal channels. The main sections of the pondage banks have been constructed across these tidal channels. Several tidal channels with a saltmarsh-claypan mosaic between 20 and 100 m wide occur below the banks. Mangroves have established along the downstream side of this bank.

The main ponded pasture system was constructed in the 1960’s (Wildin et al. 1996) with the blocking of a number of tidal channels. Historical aerial photography indicates that prior to the construction of the banks, the tidal channels drained an extensive area of saltmarsh and claypan. Much of this area adjacent to the remnant tidal channels has been successfully converted to pasture by removing the tidal influence. However, pasture species have not established in the remnant tidal channels.

Naturally occurring wetlands associated with the freshwater section of the creek were utilised for cattle production from around the 1920’s when the wetlands were drained early in the twentieth century to make it more suitable (ie less water-logged) for cattle. The draining of the marsh was effected by the creation of channels to improve drainage. Once constructed, the main drainage channel allowed tidal intrusion to occur which threatened the viability of the newly established pastures. The channel was consequently blocked off with an earthen barrier to limit tidal intrusion. Tidal intrusion remains a threat to pastures and works have recently been undertaken to increase the height of the barrier to prevent entry of salt water on the larger of the spring tides.

Pondage system formed by blocking of tidal channel at Fitzroy location.

Section of pondage system adjacent to Fitzroy River showing remnant tidal channel isolated from estuary.

Mangrove growth along pondage bank adjacent to Fitzroy River.

6. Distribution and Extent of Ponded Pastures

6.1 Introduction

Ponded pasture systems are a system of earthen pondage banks developed by the cattle industry area to collect surface runoff for the enhancement of pastures. They have been widely developed since the 1930's in northern Australia particularly in semi arid pastoral areas such as the coastal region of central Queensland and have become an important component of cattle production in areas where rainfall is unreliable or inconsistent (Wildin et al. 1996). Many ponded pasture systems also occur in association with other forms of pondage systems for livestock watering, irrigation, or town water supplies.

Concern over potential interactions between ponded pasture systems and fisheries resources has been raised by Garrett (1991) and Coates and Unwin (1991) and by the representatives of the fishing industry (Anon 1991). The lack of documentation on the distribution and extent of ponded pastures has limited the assessment of potential interactions. An investigation in the distribution and extent of ponded pastures was therefore considered appropriate to assess the interactions with fisheries resources.

6.2 Methods

The distribution and location of pondage systems were established by a combination of ground truthing, aerial survey and examination of aerial photographs and LANDSAT TM satellite imagery. The main area of interest was the coastal region between Raglan and St. Lawrence (Figures 1 and 2) where pondage systems have been constructed close to coastal wetlands. Three localities, the Fitzroy Estuary, Corio Bay and the Broad Sound were of particular interest due to the large number of pondage systems developed in close proximity to coastal wetlands and barramundi habitats.

The locations of pondage banks were digitised on a GIS system (ARC/INFO). The extent of inundation were determined by examining Landsat TM satellite imagery taken following the last major inundation event which occurred during the summer of 1990-1991. After assessing imagery from a number of years (1988, 1991, 1995, and 1997), it was decided to use the 1991 imagery since this contained the most extensive water cover in the coastal wetlands as a result substantial rainfall during the summer of 1990-1991. The imagery used to estimate the extent of inundation was captured in July 1991 for the Gladstone and Yeppoon regions and in September 1991 for the St. Lawrence region. These data should not be considered as representing the maximum possible extent of inundation because of partial drying between the time of inundation and the time of image capture.

Ground based observations on inundation patterns were also made during a partial inundation event in March 1999. Inundation observed at this time was not associated with any substantial overflow and therefore did not provide any additional data on the extent of inundation associated with an extensive wet season. Observations were not made for systems located in the upper catchment. Observations were also made on pondage systems in other localities including Carmila, Koumala and Proserpine (Figure 1) although these were not mapped nor included in the estimate of ponded areas.

6.3 Results

6.3.1 Distribution and extent of pondage banks

Maps of the location of pondage banks in the Fitzroy Estuary and Corio Bay region are shown in Appendix 3 and those in the Broad Sound region are shown in Appendix 4. The area of inundation associated with the mapped pondage systems was 8,270 ha in the Broad Sound and 8,036 ha in the Fitzroy Estuary and Corio Bay. These estimates of pondage areas represent the extent of inundation following low to moderate water flows and are not considered to represent maximum inundation levels. The total length of pondage banks was 57 km in the Broad Sound region and 78 km in the Fitzroy Estuary and Corio Bay regions. There were 75 pondage systems identified in the Fitzroy Estuary and Corio Bay. Some 80 systems were mapped in the Broad Sound region. Most of the systems examined were used for pasture and cattle production and many of these dried completely during the study. Additional pondage systems have been constructed in the Fitzroy region for water harvesting including a variety of weirs and causeways. The location of other stream barriers is shown in Appendix 3 and highlights the extent of stream barriers in one form or another that exist in the region.

The length of pondage banks varied from less than 10 m to about 18 km. The areas of inundation for individual pondage systems measured from imagery and ground truthing varied from less than 0.5 ha to 4453 ha. The area of inundation for most pondage systems ranged between 1 and 100 ha. The number of pondage systems identified in this study by inundation area is presented in Table 1.

Table 1 Size of pondage areas in and adjacent to coastal wetlands in central Queensland.

Inundated Pond Area (ha)	Number of Pondage Systems	
	Keppel Coast	Broad Sound
< 1 ha	5	9
≥ 1 < 10 ha	24	29
≥ 10 < 100 ha	33	33
≥ 100 < 1000 ha	12	7
≥ 1000 ha	1	2

6.3.2 Pondage bank design

Pondage banks varied in height from less than 0.5 m to more than 2 m. Many pondage systems contained multiple bank structures. Many of the older levee banks constructed on upper-intertidal areas to keep saltwater out of pasture were usually no more than 0.5 m in height. Some of the larger banks that had been constructed in supra-tidal areas over the last 20 to 30 years were more than 1.5 m high and often more than 2 m wide. These substantial structures provided vehicular access in some of the systems. However, most systems were formed from smaller pondage banks particularly where located way from watercourses or supra-tidal areas.

All banks were constructed from earthen material, although a few incorporated rock or concrete structures to reduce erosion during high flow events. The effectiveness of these structures was not determined. Most pondage systems did not have any water flow control structures. However, the system in the primary Broad Sound study location contained a number of bywashes for directing excess flow out of the pondage system to the estuary. The bywashes minimise the risk of the system overtopping and damaging the earthen bank. One bank constructed across a tidal channel in an upper-intertidal location contained sluice gates with drop boards to provide some control over water flow. Another bank across a freshwater drainage line also contained a sluice gate with drop boards. One system had pipes with one way flaps or manually operated valves. These were intended for water flow control but had become inoperative due to corrosion. A small number of pondage banks located in the upper-intertidal area also had open pipes through the bank to facilitate tidal flows to remnant tidal channels. In one of these systems, a mound of earth had been placed across the upstream entry to the pipe effectively restricting water flow to periods of near-full inundation levels. One property holder commented on the benefit of incorporating pipes (referred to as “gurglers”) through the bank to provide for water flow and control of water level, however, this design feature had not been included in any of the systems examined. Breaches of pondage banks were reported for some of systems during high flow events in the past.

Earth for the banks was sourced from the site of the pondage system, from other areas on the property or from elsewhere depending on the available fill and quantity required. In many locations, material had been scraped from the ground adjacent to the pondage bank. The resulting borrow pits were usually shallow, often between 0.5m and 1 m deep, and located either on the landward or the seaward side of the bank. Ponding of water occurs in the borrow pit where material has been extracted and entrapment of fish in these pools was occasionally observed. These borrow pits were common along the side of many banks.

6.3.3 Location of pondage banks

The investigation concentrated on ponded pasture systems in or adjacent to coastal wetlands associated with the coastal plains. In these areas, ponded pasture systems have been developed mostly in association with the lower reaches of small coastal streams (refer to maps in Appendix 3 and 4 for details). Many of these are located offstream in association with drainage lines from adjacent slopes. Ponded pasture systems have also been constructed adjacent to freshwater sections of streams and across tidal channels draining supra-littoral areas. The later appeared to be concentrated on the northern side of the Fitzroy Estuary and the western side of the Broad Sound. Extensive development of ponded pasture systems immediately above the mangrove zone has occurred in the southern Fitzroy Estuary.

The south-east side of the Broad Sound also contained an extensive system of ponded pastures. The systems on the eastern side of the Broad Sound were strategically located to collect runoff from surrounding slopes and were generally not associated with permanent freshwater habitats. However, a number of systems to the south of these were located in close proximity to tidal channels.

Ponded pasture systems have also been developed extensively in the region between the southern end of the Broad Sound and the Capricorn coast. This area is not located near to tidal influences but contains an extensive system of freshwater wetlands and was not assessed in the present study due to limited time and resources.

Many of the upper intertidal areas and seasonally inundated supra-tidal wetlands in the Fitzroy region and Capricorn coast have been modified with the construction of roads and weirs and other structures associated with urban development. In addition to ponded pasture systems, many of the small coastal streams flowing into the Fitzroy Estuary also have weirs or levee banks located across the watercourse at the estuarine freshwater interface to restrict tidal influence. Most of coastal streams in the study areas have been modified by the construction of barriers or banks either in the estuarine-freshwater interface or in the lower freshwater reaches. The location of pondage banks and other barriers such as weirs and causeways across streams associated with the Fitzroy Estuary is shown in Appendix 3.

Preliminary assessments indicated that the extent of ponded pastures in areas between St. Lawrence and Townsville was not as extensive as in the primary study region. Although ponded pasture systems were present in these areas (particularly the Clairview, Proserpine and Wunjunga regions) many of these were dry at the time, and the full extent of pondage systems was not determined. Other pondage systems associated with water harvesting were also present in these regions and some of these had disrupted the estuarine–freshwater interface.

6.4 Discussion

There has been extensive development of ponded pasture systems in central Queensland with more than 16,000 ha in or adjacent to coastal wetlands in the Fitzoy estuary, Corio Bay and the Broad Sound. Cummins (1991) reported 11,900 ha of ponded pastures existed in these regions, suggesting that there has been a recent expansion of ponded pasture systems. Some of the expansion has occurred as a result of repairs and increasing heights of existing pondage banks while a number of additional systems have been established (Chapman pers com).

There is a high concentration of pondage banks in and adjacent to supra-tidal areas in the Fitzoy Estuary, Corio Bay, western Broad Sound and south-east Broad Sound regions. Some very large ponded pasture systems are located in supra-tidal habitats in these regions. Ponded pasture systems close to intertidal areas have been developed for reclamation of salt scalded areas (Wildin et al. 1996). The tidal range in the study regions is comparatively large with up to 5 m tidal ranges in the Fitzroy region and up to 7 m in the Broad Sound. Extensive areas of marine plains with low gradients also occur in these regions. These areas contain several hundreds of metres of upper-intertidal areas that are subject to tidal inundation on a few high spring tides each year. These areas are often not recognised by property holders as intertidal. High water marks are not easily determined. Property holders have rehabilitated many areas successfully for pasture development. In other areas, rehabilitation has not been successful, and grazing of salt tolerant vegetation occurs.

Pittaway (1996) reported that pondage banks constructed to prevent saltwater intrusion were not typical of ponded pasture systems, and were constructed mainly prior to or during the 1960's. However, these systems have been maintained and are of significance from a management point of view due to their proximity to intertidal habitats. The maintenance of this style of system in Corio Bay and the Broad Sound is also of particular interest due to their proximity to the intertidal areas associated with declared fish habitat areas and the Great Barrier Reef Marine Park. Further assessment of ponded pasture in these habitats is required. In particular, the increase in extent and duration of inundation with the development of ponded pasture systems in supra-tidal areas may provide potential benefit for fisheries resources.

Ponded pasture systems have been established in association with a range of coastal wetlands in central Queensland. The location of pondage systems in and adjacent to coastal wetlands provides considerable potential for interaction with fisheries resources based on the reported importance of coastal wetlands for a variety of fish species and for barramundi production (see Section 8). The Fitzroy Estuary, Corio Bay and Broad Sound contain a high concentration of pondage banks in association with a variety of aquatic habitats including supra-tidal areas containing claypans and saltmarsh, remnant tidal channels and various freshwater habitats. Ponded pasture systems that disrupt the estuarine freshwater interface are of interest because of the potential for disruption of fish movement (see Section 8). The distribution of ponded pastures in freshwater habitats in upper catchment locations has not been addressed in this study and requires further investigation from a fisheries perspective.

Fisheries issues have not been considered in the development of most ponded pasture systems. Some features that provide control over water flow such as sluice gates with drop boards or bywashes are present in a small number of banks. Further assessment of the use of sluice gates and drop boards in ponded pasture systems or the suitability of bywashes as fishways (particularly rock ramp and rock pool style fishway following Thorncraft and Harris (1996)) may assist with control of fish movement where needed. An assessment of design features for managing fisheries issues is presented in Section 10. Chapman (1996) has reported that pondage systems are very site specific and detailed assessment is required. In coastal areas, such assessment should address the impact of the system on the estuarine freshwater interface. Many of the systems examined consist of a single bank to maximise collection of runoff from adjacent slopes. The size of the pondage system is determined by the area of slopes providing the runoff and models for determining suitable bank heights based on catchment area and evaporation rates have been developed by Lawrence and Key (1996). From a fisheries perspective, it is suggested that a series of banks may provide more flexibility in controlling water flow than a single long bank. A series of cascading banks may provide more opportunity to concentrate water and manipulate water flow to facilitate fish movement. Further assessment of pondage systems in supra-tidal areas is required in light of the scale of some of these systems. Pondage systems in cane growing areas (Koumala and Sarina regions) have also been developed in similar habitats and are likely to present similar issues (disruption of estuarine -freshwater interface, and modification of upper-intertidal habitats) as ponded pasture systems.

Pondage bank with sluice gate adjacent to mangroves, Broad Sound.

7. Species Composition of Fish Populations in Ponded Pasture Systems

7.1 Introduction

The location of ponded pasture systems in or adjacent to coastal wetlands has attracted the attention of fisheries stakeholders due to potential modification of fisheries habitat and entrapment of fish (Anon 1991). The role of coastal wetlands in fisheries production has received considerable attention over recent years. In particular, concern has been raised over the impact of ponded pastures on barramundi stocks because this species is strongly dependent on coastal wetlands as nursery areas and because of the importance of this species in commercial and recreational fisheries in northern Australia (Russell and Garrett 1983). However, there is a lack of information on the occurrence of fish species in ponded pasture systems. The present investigation of barramundi in ponded pasture systems provided an opportunity to also document the occurrence of other fish species in these systems. Such information is required to assess the potential for interaction between ponded pastures and fisheries resources.

7.2 Methods

Twelve ponded pasture systems were assessed initially on the basis of accessibility, and property holder support, as well as proximity to unbanked freshwater sites and to estuarine habitats. From these, three primary study locations were selected in the Fitzroy Estuary, Corio Bay and Broad Sound regions. The primary study locations are shown in Figure 3. The details of each location are described in Section 5. At each location, a freshwater habitat was located immediately upstream of the ponded pasture system and estuarine habitats were located immediately downstream of the pondage system. In two of the systems (Broad Sound and Fitzroy Estuary), the ponded pasture system had been constructed on supra-tidal and upper-intertidal habitats drained by tidal channels that had been blocked with the construction of the bank. Water pooled in these remnant tidal channels as inundation levels receded. Remnant tidal channels were not present in the system at Corio Bay.

Fish populations in the ponded pasture systems and associated freshwater sites at the two primary locations (Fitzroy Estuary and Broad Sound) were sampled primarily with gill nets over two years. Gill nets with stretched mesh of 50 mm, 100 mm, 150 mm and 200 mm were set at dusk and left for two to three hours. Barramundi populations were also sampled using a boat mounted Smith-Root 7.5 kw electrofishing unit. Electrofishing was undertaken during late afternoon and dusk. Sampling opportunities in the ponded pasture systems were severely restricted by dry conditions that prevented the implementation of the intended bimonthly sampling program. Gill netting became impractical where pond depths were shallow (<1 m) or nets could not be set due to dense aquatic plants or snags.

In the Corio Bay and Fitzroy Estuary systems, there were very low inundation levels. Water flows into the systems were low and were not associated with any substantial overflow of either pondage system. The ponded pasture systems at the Corio Bay and Broad Sound locations dried completely during the study. During dry conditions, the pondage system in the Fitzroy Estuary remained partially inundated because of seepage of tidal water through the pondage bank. Additional samples were obtained with cast nets, bait traps, and seine nets when pondage systems became too shallow to sample with gill nets. The salinity of two of the systems (Fitzroy and Broad Sound) increased as water levels dropped and reduced the effectiveness of electrofishing. The ponded pasture system in the Corio Bay location became too shallow to sample either with electrofisher or nets early in the study and dried completely at the end of the first year of study. This system remained dry for another 12 months and sampling of this ponded pasture system and the associated freshwater habitat was discontinued soon after the initial assessment. A number of alternative ponded pasture systems were investigated during the study as dry conditions restricted the sampling opportunities in the primary locations. Twenty sites in ponded pasture systems were investigates in total. Additional sampling of intertidal channels located immediately downstream of the pondage banks was undertaken in each of the three primary locations. Upper-intertidal pools adjacent to the ponded pasture system at the Corio Bay location were also sampled. These estuarine sites were sampled with gill nets, seine nets and cast nets. Abundance of fish species were recorded. Additional details of barramundi investigations are presented in Section 8.

7.3 Results

7.3.1 Fish species in ponded pasture systems

A total of 23 finfish species in 15 families were identified from ponded pasture systems (Table 2). Bony bream (*Nematalosa erebi*) was the most numerically abundant fish species in samples from pondage systems. Various small-bodied prey species such as rainbow fish (*Melanotaenia splendida*), ambassids (*Ambassis* spp.), goby (*Mugilogobius sp*.), fly-speckled hardyhead (*Craterocephalus stercusomuscarum*), and gudgeons (*Hypseleotris* spp.) were also abundant in samples from ponded pasture systems. Fish species of commercial or recreational importance present in ponded pasture systems included barramundi (*Lates calcarifer)*, flat tail mullet (*Liza subviridis*), sea mullet (*Mugil cephalus*) and long finned eels (*Anguilla reinhardtii*). Tarpon (*Megalops cyprinoides*), and big herring (*Elops hawaiensis*) were also present in ponded pasture systems and attract some interest as a sportsfish. Spangled perch (*Leiopotherapon unicolor*) was also common in samples from pondage systems. Catfish were present in very low numbers in ponded pasture systems. Two species of tandan catfish (*Neosilurus hyrtlii* and *Porochilus rhendal*) were also recorded in low numbers while a single specimen of the lesser salmon catfish (*Arius graeffei*) was captured.

The number of finfish species per pondage system ranged from 1 to 16 (Figure 8). Baramundi (*Lates calcarifer*) occurred in 8 of the 20 systems including two of the three ponded pasture systems in the primary study locations. The Broad Sound ponded pasture system contained 16 species and the Fitzroy Estuary ponded pasture system contained one less (15) (Table 3). Samples of the fish populations in the Fitzroy ponded pasture system were dominated by two species (bony bream (*Nematalosa erebi*) and barramundi (*Lates calcarifer*) with another 13 species representing 5 families (Ambassidae, Teraponidae, Megalopidae, Mugilidae, and Eleotridae) present in low numbers. However, species representing Melanotaenidae , Ambassidae, Gobiidae, and Clupeidae were well represented in samples from the Broad Sound ponded pasture system. Samples from the ponded pasture system at Corio Bay contained only six species representing five families.

Figure 8 Number of fish species in each pondage system.

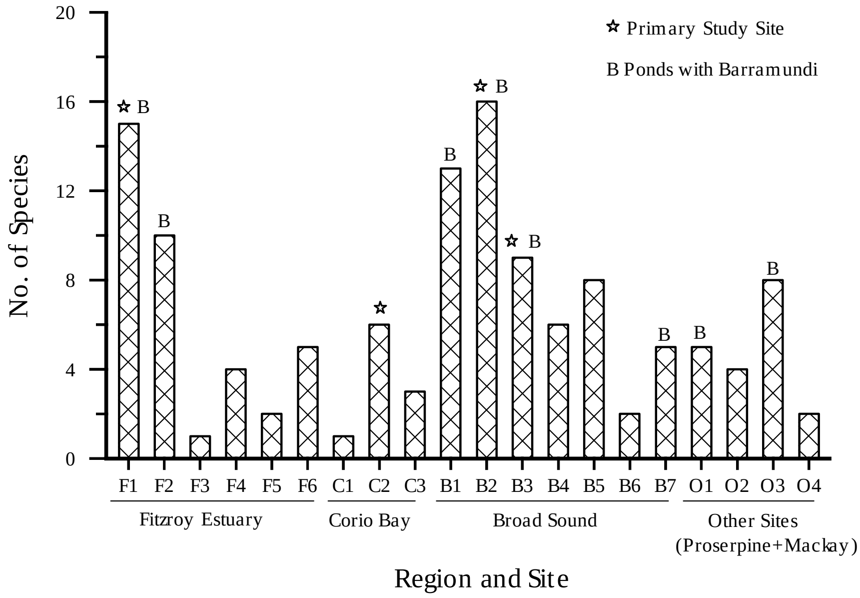


Table 2 Abundance of fish species in samples (pooled over all times and sites) from ponded pasture systems.

Family	Genus and Species	Abundance
Clupeidae	*Nematolosa erebi*	1248
Melanoteiniidae	*Melanotaenia splendida*	734
Ambassidae	*Ambassis agassizi*	686
Ambassidae	*Ambassis sp.*	479
Gobiidae	*Mugilogobius sp.*	468
Atherinidae	*Craterocephalus stercusmuscarum*	327
Centropomidae	*Lates calcarifer*	204
Eleotridae	Gudgeons unidentified	119
Teraponidae	*Leiopotherapon unicolor*	97
Eleotridae	*Hypseleotris spA.*	41
Mugilidae	*Liza subviridis*	38
Ambassidae	*Ambassis marianus*	28
Eleotridae	*Hypseleotris compressa*	27
Megalopidae	*Megalops cyprinoides*	26
Anguillidae	*Anguilla reinhardtii*	11
Elopidae	*Elops hawaiiensis*	11
Eleotridae	*Mogurnda adspersa*	7
Plotosidae	*Neosilurus hyrtlii*	7
Scatophagidae	*Scatophagus argus*	6
Mugilidae	*Mugil cephalus*	3
Plotosidae	*Porochilus rendahli*	1
Gobiidae	*Bathygobius fuscus*	1
Ariidae	*Arius graeffei*	1

Table 3 Abundance of fish species in samples from ponded pasture systems by location.

Genus and Species	Location					
	Primary Sites			Additional Sites		
	Fitzroy	Broad Sound	Corio Bay	Fitzroy 1	Fitzroy 2	Fitzroy 3
Ambassis agassizi	24	609	58		29	60
Ambassis sp.		480				
Ambassis marianus	28					
Anguilla reinhardtii	4	1	6		4	
Arius graeffei	1					
Bathygobius fuscus	1					
Craterocephalus stercusmuscarum	11	316			2	
Elops hawaiiensis		11				
Gudgeons unidentified	16	103			2	
Hypseleotris compressa	5	13	9	142		57
Hypseleotris spA.	6	35			61	16
Lates calcarifer	125	80				
Leiopotherapon unicolor	18	51	29	47	30	3
Liza subviridis	16	22				
Megalops cyprinoides	18	8				
Melanotaenia splendida		733	6			
Mogurnda adspersa		5	2			
Mugil cephalus	1	2				
Mugilogobius sp.		468				
Nematolosa erebi	874	374			133	84
Neosilurus hyrtlii		7				
Porochilus rendahli		1				
Scatophagus argus		6				

7.3.2 Fish species in aquatic habitats associated with ponded pasture systems

Some 24 species in 15 families of finfish (Table 4) were identified from freshwater sites located upstream of ponded pasture systems and 62 species in 34 families (Table 5) were identified from estuarine sites associated with the pondage systems in the three primary locations.

Bony bream (*Nematolosa erebi*) was the most abundant species in samples from freshwater sites. Spangled perch,(*Leiopotherapon unicolor*), Gudgeons (*Hypseleotris spA, Hypseleotris compressa, Mogurnda adspersa*), barramundi (*Lates calcarifer*), Ambassids (*Ambassis agassizi*), and rainbow fish (*Melanotaenia splendida)* were the next most abundant species in the freshwater sites. Twenty one species were recorded from the freshwater site in the Fitzroy location, 15 species from the Broad Sound freshwater site and 7 species from the freshwater site in Corio Bay (Table 6). The abundance (pooled over all times for each site) of fish species in each estuarine site in the primary locations is presented in Table 7. The number of finfish species by habitat type within each primary location is presented in Figure 9. In the Corio Bay location, there were 53 species in estuarine sites. There were 30 species from estuarine sites in the Fitzroy location. In the Broad Sound location, there were 15 species from freshwater sites and 12 species from estuarine sites. The comparatively small number of species present in the estuarine sites at Broad Sound reflects the difficult access and consequent low sampling effort applied to this habitat compared to corresponding habitat sites in the Fitzroy and Corio regions.

Figure 9 Number of fish species by habitat type and location.

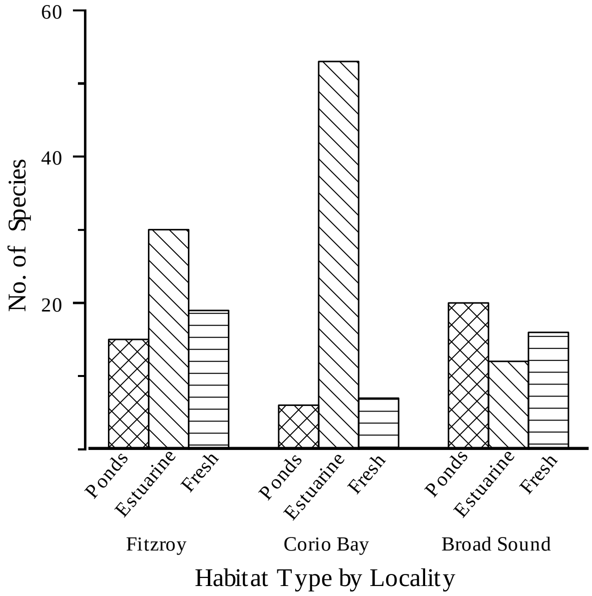


Table 4 Abundance of fish species in samples (pooled over all sites and times) from freshwater sites in the primary locations.

Family	Genus and Species	Abundance
Clupeidae	*Nematolosa erebi*	3075
Teraponidae	*Leiopotherapon unicolor*	571
Eleotridae	*Hypseleotris spA.*	555
Centropomidae	*Lates calcarifer*	482
Ambassidae	*Ambassis agassizi*	422
Melanotaeniidae	*Melanotaenia splendida*	204
Eleotridae	*Hypseleotris compressa*	189
Megalopidae	*Megalops cyprinoides*	85
Eleotridae	*Mogurnda adspersa*	68
Anguillidae	*Anguilla reinhardtii*	43
Plotosidae	*Neosilurus hyrtlii*	34
Eleotridae	*Gudgeons unidentified*	30
Poeciliidae	*Gambusia affinis*	26
Apogonidae	*Glossamia aprion*	15
Teraponidae	*Amniataba percoides*	11
Plotosidae	*Tandanus tandanus*	6
Atherinidae	*Craterocephalus*	6
Elopidae	*Elops hawaiiensis*	5
Mugilidae	*Mugil cephalus*	3
Plotosidae	*Porochilus rendahli*	3
Ambassidae	*Ambassis sp.*	2
Mugilidae	*Liza subviridis*	1
Eleotridae	*Hypseleotris galii*	1
Belonidae	*Strongylura krefftii*	1

Table 5 Abundance of fish species in samples (pooled over all sites and times) from estuarine sites.

Family	Genus and Species	Abundance
Ambassidae	*Ambassis marianus*	49
	Ambassis agassizi	173
	Ambassis vachellii	470
Anguillidae	*Anguilla reinhardtii*	1
Apogonidae	*Glossamia aprion*	11
Ariidae	*Arius graeffei*	4
Atherinidae	*Craterocephalus stercusmuscarum*	96
Belonidae	*Strongylura strongylura*	8
Bothidae	*Pseudorhombus arsius*	2
Centropomidae	*Lates calcarifer*	470
Chanidae	*Chanos chanos*	102
Clupeidae	*Herklotsichthys castelnaui*	82
	Nematolosa erebi	407
Eleotridae	*Hypseleotris compressa*	14
	Hypseleotris spA.	2
	Mogurnda adspersa	9
	Oxyeleotris lineolatus	2
	Gudgeons unidentified	1000
Elopidae	*Elops hawaiiensis*	156
Engraulidae	*Thryssa hamiltonii*	10
Gerridae	*Gerres sp.*	139
	Gerres subfasciata	38
	Gerres filamentosus	102
	Gerres macrosoma	5
Gobiidae	*Gobiidae unidentified*	12
	Glossogobius circumspectus	3
	Bathygobius fuscus	6
Hemiramphidae	*Arrhamphus sclerolepis*	2
Hemirhamphidae	*Hyporhamphus quoyi*	1
Leiognathidae	*Leiognathus decorus*	69
	Leiognathus equulus	10
Lutjanidae	*Lutjanus russelli*	2
Megalopidae	*Megalops cyprinoides*	36
Melanotaeniidae	*Melanotaenia splendida*	249
Monodactylidae	*Monodactylus argenteus*	15
Mugilidae	*Liza subviridis*	478
	Mugil cephalus	119
	Valamugil georgii	23

Table 5 (continued) Abundance of fish species in samples (pooled over all sites and times) from estuarine sites.

Mugilidae	*Mugilidae unidentified*	110
	Myxus elongatus	53
	Liza argentea	15
	Valamugil seheli	5
	Liza vaigiensis	1
	Rhinomugil nasutus	3
Muraenesocidae	*Muraennsox cinereus*	1
Pleuronectidae	*Achirus pavonius*	2
Plotosidae	*Neosilurus hyrtlii*	1
Polynemidae	*Eleutheronema tetradactylum*	4
Pomadasyidae	*Pomadasys hasta*	9
Pseudomugilidae	*Pseudomugil signifer*	54
Scatophagidae	*Scatophagus argus*	29
	Selenotoca multifasciata	326
Siganidae	*Siganus sp.*	2
Sillaginidae	*Sillago analis*	3
Sparidae	*Acanthopagrus australis*	7
	Acanthopagrus berda	3
Sphyraenidae	*Sphyraena jello*	8
Teraponidae	*Amniataba percoides*	4
	Leiopotherapon unicolor	27
	Terapon jarbua	106
Tetraodontidae	*Marilyna pleurosticta*	105
	Torquigener sp.	12

Table 6 Abundance of fish in samples from freshwater sites by location.

Genus and Species	Location		
	Fitzroy	Broad Sound	Corio Bay
Ambassis agassizi	27	106	289
Ambassis sp.	2		
Amniataba percoides	11		
Anguilla reinhardtii	9	30	4
Craterocephalus stercusmuscarum	1	5	
Gambusia affinis	26		
Glossamia aprion	15		
Gudgeons unidentified	14	16	
Hypseleotris compressa	95	41	53
Hypseleotris galii	1		
Hypseleotris spA.	24	531	
Lates calcarifer	122	360	
Leiopotherapon unicolor	9	129	433
Liza subviridis	1		
Megalops cyprinoides	5	72	8
Melanotaenia splendida		1	203
Mogurnda adspersa	4	5	59
Mugil cephalus	3		
Nematolosa erebi	286	2789	
Neosilurus hyrtlii	21	13	
Porochilus rendahli		3	
Strongylura krefftii	1		
Tandanus tandanus	4	2	

Table 7 Abundance of fish in samples from estuarine sites by location.

Genus and Species	Location		
	Fitzroy	Broad Sound	Corio Bay
Acanthopagrus australis			7
Acanthopagrus berda			3
Achirus pavonius			2
Ambassis agassizi	51	8	114
Ambassis vachellii			470
Ambassis marianus	6		43
Amniataba percoides	4		
Anguilla reinhardtii	1		
Arius graeffei	4		
Arrhamphus sclerolepis			2
Bathygobius fuscus			6
Chanos chanos			102
Craterocephalus stercusmuscarum	96		
Eleutheronema tetradactylum	2		2
Elops hawaiiensis	34	9	113
Gerres filamentosus	10	2	90
Gerres macrosoma			5
Gerres sp			139
Gerres subfasciata	5		33
Glossamia aprion	11		
Glossogobius circumspectus			3
Gobiidae unidentified			12
Gudgeons unidentified juvenile			1000
Herklotsichthys castelnaui			82
Hyporhamphus quoyi			1
Hypseleotris compressa	9		5
Hypseleotris spA.	2		
Lates calcarifer	166	2	302
Leiognathus decorus			69
Leiognathus equulus	2		8
Leiopotherapon unicolor	14	2	11
Liza argentea			15
Liza subviridis	146	48	284
Liza vaigiensis			1
Lutjanus russelli			2
Marilyna pleurosticta			105
Megalops cyprinoides	22		14
Melanotaenia splendida	109	2	138
Mogurnda adspersa	3		6
Monodactylus argenteus			15
Mugil cephalus	74		45
Mugilidae unidentified	7		103

Muraennsox cinereus			1
Myxus elongatus			53
Nematolosa erebi	386	9	12
Neosilurus hyrtlii	1		
Oxyeleotris lineolatus	2		
Pomadasys hasta			9
Pseudomugil signifer	3		51
Pseudorhombus arsius			2
Rhinomugil nasutus		3	
Scatophagus argus	3	19	7
Selenotoca multifasciata	11		315
Siganus sp.			2
Sillago analis		1	2
Sphyraena jello			8
Strongylura strongylura			8
Terapon jarbua	8	1	97
Thryssa hamiltonii			10
Torquigener sp.			12
Valamugil georgii	2		21
Valamugil seheli			5

Juvenile barramundi (*L. Calcarifer*) (Photo courtesy of G. Schmidt)

7.4 Discussion

Ponded pasture systems provide habitat for up to 23 species of teleosts. The potential value of ponded pasture systems as fish habitat however is reduced by the low relative abundance of most fish species and by the ephemeral nature of most of these systems. Bony bream was the most abundant species in samples from both ponded pasture systems and freshwater habitats over all sites and times. A variety of potential prey species including Ambassids, rainbow fish, gudgeons, hardyheads and herrings were also present. A small number of recreationally or commercially important species including barramundi, mullet, giant herring, and eels were present in ponded pasture systems and barramundi was the most abundant of these. While the interaction between ponded pastures and fisheries resources involves barramundi and possibly sea mullet, interactions with other commercial or recreational species have not been identified. In particular, eels are an important component of freshwater habitats and their presence in ponded pasture systems is of considerable interest due to its commercial fisheries value and to its aquaculture potential.

Ponded pasture systems and the associated freshwater habitats at the Broad Sound and Fitzroy locations contained a similar variety of fish species. Fourteen of the 15 teleost families in the ponded pasture system also occurred in the associated freshwater habitats. Five estuarine or marine dependent species (*Lates calcarifer* (barramundi), *Megalops cyprinoides* (tarpon), *Elops hawaiiensis* (big herring), *Anguilla reinhardtii* (eel) and *Mugil cephalus* (sea mullet)) that occurred in the ponded pasture systems also occurred in the freshwater habitats. Barramundi (*Lates calcarifer*) were present in two of the three primary study locations and were not present in any of the systems located away from coastal wetlands or estuarine habitats. (Movement and survival of barramundi in the ponded pasture systems is described in Section 8.)

Three specimens of *Mugil cephalus* (sea mullet) were captured from ponded pasture systems and a single individual of this species was also captured from associated freshwater habitats. This species was well represented in samples from intertidal habitats associated with the ponded pasture systems. Its paucity in ponded pasture systems and associated freshwater habitats suggested substantial disruption of recruitment had occurred. Juvenile stages of this species move from estuarine habitats to freshwater habitats. Barriers such as pondage banks located between freshwater and estuarine habitats are likely to restrict this movement particularly in the absence of large scale flows.

An individual specimen of the marine dependent species, *Scatophagus argus*, was captured in *a* ponded pasture system but absent from the associated freshwater habitats. Three species *Glossamia aprion* (mouth almighty), *Strongylura krefftii* (long tom), and *Amniataba percoides* (banded grunter) that occurred in the freshwater habitats did not occur in the ponded pasture system and this may be related to habitat requirements, feeding requirements or lack of shelter from predators such as barramundi or eels.

Kowarsky and Ross (1981) reported 16 species of fish in a study of the fishway on the tidal barrage on the Fitzroy River. After modification of the fishway on the barrage, Stuart and Mallen-Cooper (1999) reported 29 species of fish. These previous studies reported a number of freshwater species that were not present in ponded pasture systems or in the associated freshwater habitats. Bullrout, (*Notesthes robusta*), snub nosed gar (*Arramphus* *sclerolepis*), leathery grunter (*Scortum hillii*), golden perch (*Macquaria ambigua*), and western carp gudgeon (*Hyseleotris klunsingeri*) have been reported in these other studies but were not captured during the present investigation. Some of these (*S. hillii, M. ambigua, and H. klunsingeri*) are not expected in coastal wetlands or in freshwater habitats associated with ponded pasture systems. The absence of the bullrout (*Notesthes robusta*), snub nosed gar (*Arramphus sclerolepis*) and also the low numbers of catfish in ponded pasture systems remains unexplained. Their absence from ponded pasture systems may be related to habitat requirements, to feeding requirements or to restrictions on recruitment due to the ephemeral nature of aquatic habitat in the ponded pasture.

Representative species of the 15 teleost families that occurred in the freshwater and ponded pasture systems also occurred in the upper-intertidal sites and this suggests displacement of freshwater species to the upper estuarine habitats during low flows. However, the intertidal habitats contain a greater diversity of fish populations with an additional 22 families.

A ponded pasture system in an upland location across a drainage line from slopes contained two freshwater species (*Leiopotherapon unicolor* (spangled perch) and *Hypseleotris sp* (gudgeons)). Ponded pasture systems in upland locations have less potential for fisheries interactions compared to ponded pasture systems in or adjacent to coastal wetlands. There appears little scope for interaction with barramundi resources where ponded pasture systems are located in upland locations.

The relative abundances of many fish species in samples from both ponded pasture systems and the associated freshwater sites were low. The prevailing dry conditions restricted inundation levels and the availability of aquatic habitat. Related impacts on fish recruitment were considered likely although fish populations (particularly freshwater dependent species) appeared to recover rapidly following inundation of ponded pasture systems. Bony bream and barramundi were the most abundant species in the one system that remained inundated. Gudgeons, ambassids and hardyheads occurred in low numbers in samples from the Fitzroy ponded pasture system and this may be related to the predation by species such as barramundi.

Recruitment of estuarine-dependant species into a ponded pasture system occurred at one location (Broad Sound) following an overflow event. In ponded pasture systems, populations of smaller-bodied freshwater fish species such as gudgeons and ambassids recovered with partial inundation even following complete drying. Partial inundation without any substantial overflow occurred in the Fitzroy and Corio systems without recruitment of estuarine-dependant species despite proximity to extensive intertidal habitats. Following complete drying of one of these locations (Corio Bay) recovery of small freshwater species occurred following partial inundation. Populations of estuarine-dependant fish species did not recover, as a result of a lack of substantial flow between the pondage system and the adjacent estuarine habitat. The pondage system in the Fitzroy location contained a small population of mature barramundi in association with species such as mullet, bony bream and tarpon.

Estuarine habitats generally contain a diverse array of habitats supporting a high diversity of fish species. Studies of fish populations in estuarine habitats in northern Australia have provided counts of 197 species in a northern Gulf of Carpentaria estuary (Blaber et al. 1989) and 91 species in a north-east Queensland estuary (Blaber 1980). These studies indicate the importance of estuarine habitats for as fish. Considerably fewer species (53) were recorded from upper-intertidal pools and channels at Corio Bay although these are unlikely to represent estuarine fish species that use these habitats. Further investigation is required to assess the impact of ponded pasture systems on estuarine habitats and associated fish populations where the systems have been constructed across tidal channels or close to intertidal habitats.

Pondage system across drainage line on hill side in southern Fitzroy delta.

8. Movement, Growth and Survival of Barramundi

8.1 Introduction

In tropical Australia, coastal wetlands provide important nursery areas for a variety of fish species including barramundi (*Lates calcarifer*). Barramundi supports valuable commercial and recreational fisheries in northern Australia. Russell and Garrett (1983 and 1985) have documented the importance of coastal wetlands as barramundi nursery areas. The destruction of nursery areas has been identified as a serious threat to local barramundi populations on the east coast of Queensland (Russell and Garrett, 1985). The biology and ecology of barramundi has also been studied in Northern Territory by Griffin (1993, 1994 and 1995), in Northern Territory and the Gulf of Carpentaria by Davis (1982, 1984, 1985), Davis and Reid (1982) and Davis and Kirkwood (1984), in Queensland (Dunstan 1959) and in New Guinea by Moore (1982), Moore and Reynolds (1982) and Reynolds and Moore (1982). Management issues associated with wild and cultured stocks of this species have been presented in Copeland and Grey (1986).

In the tropical coastal regions of Australia, there is considerable concern from commercial and recreational fishing sectors over possible adverse impacts on wild barramundi production from pondage bank development in and adjacent to coastal wetlands. There is particular interest in the risk of entrapment of barramundi in ponded pasture systems and the alienation of upper intertidal habitats and mangrove habitats from tidal inundation (Anon 1991). Anecdotal reports suggest that fish kills involving barramundi have occurred in pondage systems in the past (Anon 1991).

Information on the growth, survival and movement of barramundi in ponded pastures and other pondage systems is required to determine the nature of impacts on barramundi production. Such information is also required to establish a more informed discussion between the fishing industry and agricultural sectors. Ultimately, strategies are required for managing ponded pastures and other pondage systems to balance the fisheries related needs with the requirements of agricultural sectors and other wetland users.

8.2 Methods

Investigations focused on three ponded pasture systems; one each in the Fitzroy Estuary, the Broad Sound and Corio Bay (Figures 2 and 3). These locations were known to have supported substantial barramundi populations in the past and brief descriptions of each are contained in Section 5. These ponded pasture systems were each associated with small coastal streams and were located in between freshwater habitats and intertidal habitats. The freshwater habitat usually receded to a series of lagoons during the dry season. The intertidal habitats included mangroves, mudflats and saltmarsh associated with tidal channels. The intertidal habitat at the Corio Bay location also contained a mosaic of shallow pools associated with saltmarsh and claypan. The ponded pasture system in the Broad Sound location dried completely during spring in each year of the study. The ponded pasture system at the Corio Bay site remained dry for just over twelve months during the study. The ponded pasture system in the Fitzroy location remained inundated for the whole study.

Barramundi in ponded pasture systems and associated freshwater sites at the Fitzroy and Broad Sound locations were sampled with gill nets and electrofishing apparatus over two years. Four 25 m gill nets were used on each sampling occasion with stretched mesh sizes of 50, 100, 150 and 200 mm. Some site conditions required the use of shorter lengths of nets. Gill nets were set at or immediately prior to dusk and left for 2 to 3 hours before samples were collected. In circumstances where gill netting or electrofishing was not possible due to inadequate water depth as water levels receded, samples were obtained with cast nets and seine nets. Intertidal gutters immediately below the pondage bank were also sampled irregularly using gill nets. Fish populations in upper-intertidal pools below the pondage bank at Corio Bay were also sampled with cast nets and seine nets during inundation events. Total lengths and weights of captured barramundi were recorded. Barramundi larger than 350 mm were tagged with 75 mm dart tags. Barramundi between 150 mm and 350 mm in length were tagged with a small plastic t bar anchor tag. Tagged barramundi were released at the location of capture. Other species of finfish were identified and abundances recorded (refer to Section 7).

Annual rainfall was below the annual mean by between 8% and 22% in 1996 and between 28% and 42% in 1997 across the three primary study locations (Figures 2, 3 and 4). The lower than average rainfall patterns limited the extent of inundation in wetlands and ponded pasture systems at the primary locations. The ponded pasture systems at Broad Sound and Corio Bay dried completely during the study and sampling opportunities were restricted. The third ponded pasture system in the Fitzroy location did not dry completely although sampling with gill nets and electrofisher were restricted by the shallow conditions (approx 0.75 m at the deepest). The lack of inundation in the primary study locations prevented implementation of the planned bi-monthly sampling schedule and sampling was implemented opportunistically according to inundation, access and adequate water depths. Additional sites were sampled in the Broad Sound and Fitzroy Estuary regions to assess alternative sites, but most of these were also characterised by low levels of inundation. Populations of barramundi in wetlands associated with a pondage system were also sampled at a secondary site located in a region (Proserpine, Map 1 in Section 5) where substantial summer rain had been received and recruitment of barramundi into coastal wetlands was more likely. Samples from this secondary location provided information on the size structure for barramundi populations in wetlands associated with a ponded pasture system in a wet coastal area in comparison with those from the semi-arid coastal regions of the Broad Sound, Corio Bay and Fitzroy Estuary.

It was intended that seasonal population estimates be calculated to assess survival of barramundi in a ponded pasture system at one of the primary locations. Dry conditions and low catch rates prevented the calculation of seasonal population estimates. Survival of barramundi was assessed from recapture rates at primary locations and through the investigation of mass kills of barramundi that occurred in the region during the study. Recapture rates for barramundi were pooled over times to provide an estimate of barramundi population size at four sites (Fitzroy pondage, Fitzroy freshwater, Broad Sound freshwater, and Proserpine freshwater). Population estimates at each site were obtained by multiplying the number of tagged releases by the proportion of captured barramundi that had been tagged previously. Results from tagging sessions on consecutive days were pooled so that tagging over two to three successive days were treated as a single tagging session. Fish recaptured on the day of release were excluded. Catch rates and recapture rates in successive sampling sessions were generally low and population estimates were possible only for July and October 1998 in the Broad Sound and Fitzroy locations and in August 1998 on the Proserpine location. Recapture rates were inadequate to obtain reliable estimates of seasonal variation in population sizes.

8.3 Results

8.3.1 Barramundi Population Structure

The size of barramundi over all samples from ponded pasture systems (pooled over all times and sites) ranged from 200 to 1300 mm. A summary of the proportion of small (<350 mm), medium (350-550 mm), and large (>550mm) size classes of barramundi by location and habitat type is presented in Table 8. The Broad Sound pondage supported a population of predominantly small barramundi with most (88%) less than 350 mm (Figure 10). Freshwater sites above this pondage system supported barramundi ranging from 250 mm to 850 mm with a small proportion (5.5%) less than 350 mm. In contrast, the Fitzroy pondage system contained a population of barramundi ranging from 400 mm to 1300 mm with most (89.4%) greater than 550 mm (Figure 10). All barramundi captured from the freshwater site above the Fitzroy pondage system were more than 500 mm in length. No juvenile (<400 mm) barramundi were captured from freshwater or pondage sites at the Fitzroy primary location. No barramundi were captured in the pondage system or the freshwater site at Corio Bay.

All barramundi captured in samples from upper-intertidal sites at the Corio Bay and Fitzroy primary locations were less than 350 mm (Figure 11). The size of barramundi from upper intertidal sites at Corio Bay was 50 mm to 250 mm (Figure 11). The upper intertidal habitat at Corio Bay was the only location where very small (<150 mm) barramundi were captured. Nine barramundi were captured from intertidal habitats in the Broad Sound.

Additional sites were investigated to assess whether the observed absence of small juvenile barramundi at the Fitzroy location and the low numbers of small barramundi at the Broad Sound were related to sampling. It was also of interest to assess whether the paucity of juvenile stages were site specific or reflected a more wide spread pattern. Samples were obtained from a secondary estuarine site in the Fitzroy Estuary and from wetland associated with a ponded pasture system in Proserpine. Barramundi in samples from freshwater sites at the Proserpine location ranged in size from 200 mm to 850 mm (Figure 12) with a high proportion (40%) of small (200-350 mm) fish. A large proportion (79%) of juvenile barramundi was also present in samples from an estuarine tidal lagoon in the Fitzroy Estuary (Figure 12). Barramundi captured at this estuarine site ranged between 200 to 900 mm. The results of sampling at these additional sites confirmed that the absence of juvenile stages at the primary sites was not a consequence of sampling procedures.

Table 8 Proportion of barramundi by size class at each habitat type for each location.

Location	Habitat Type and Size Class											
	Freshwater				Ponded Pasture System				Intertidal			
	Size Class mm				Size Class mm				Size Class mm			
	<350	350-550	>550	n	<350	350-550	>550	N	<350	350-550	>550	n
Fitzroy	-	-	100%	122		12%	78%	125	100%	-	-	30
Corio Bay	-	-	-	0	-	-	-	0	99.6%	0.4%	-	274
Broad Sound	5.5%	47.7%	46.8%	325	88%	6.8%	3.4%	75	-	-	100%	9
Proserpine (2° site)	40.5%	38.1%	21.4%	42	50.4%	29.9%	19.7%	117	Not Sampled			

Log transformed mean daily catches and minimum and maximum daily catches of barramundi from each study location are presented in Figure 13. The largest daily catch rate of 157 barramundi occurred in the estuarine site below the pondage bank in Corio Bay with the next largest daily catch of 94 barramundi occurring in the Proserpine location. Daily catch rates of barramundi at other locations were ranged between one and 35. Highly skewed distribution of catch data contributed to high standard deviation and variation and no statistically significant differences in daily catches between locations.

There was no indication of any large-scale recruitment of juvenile barramundi in freshwater or pondage sites at the Fitzroy location or in the freshwater site at the Broad Sound location. Small (50 mm–150 mm) barramundi recovered from upper intertidal pools at Corio Bay indicated some recruitment to these upper-intertidal sites had occurred. Low catches of small (<450 mm) barramundi during the second half of the study suggested a lack of recruitment. In addition, there was also high mortality of barramundi in freshwater sites at the Fitzroy and Broad Sound locations. Details of mortality at these locations are presented in Section 8.3.4.

Figure 10 Size frequency of barramundi from Fitzroy and Broad Sound locations by habitat type.

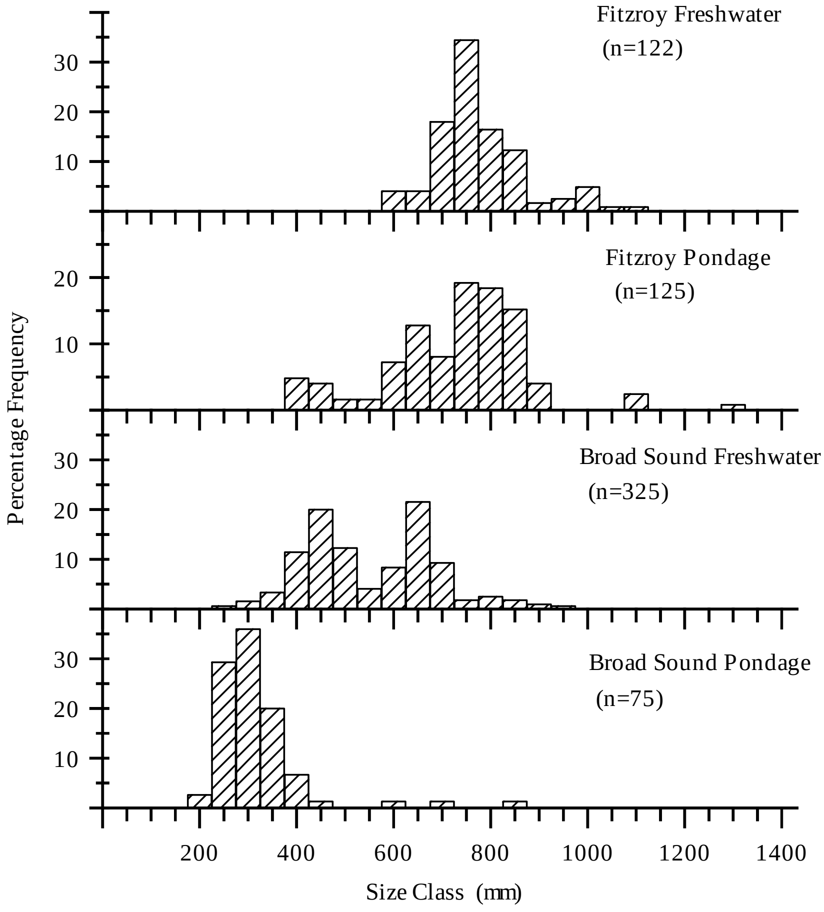


Figure 11 Size frequency of barramundi from intertidal sites (Corio Bay and Fitzroy Estuary).

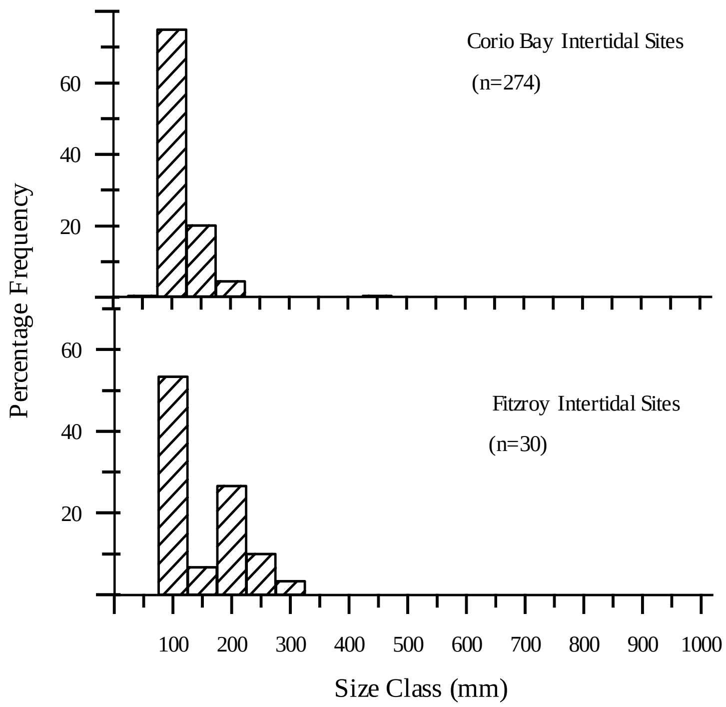


Figure 12 Size frequency of barramundi from Fitzroy tidal lagoon and Proserpine freshwater site.

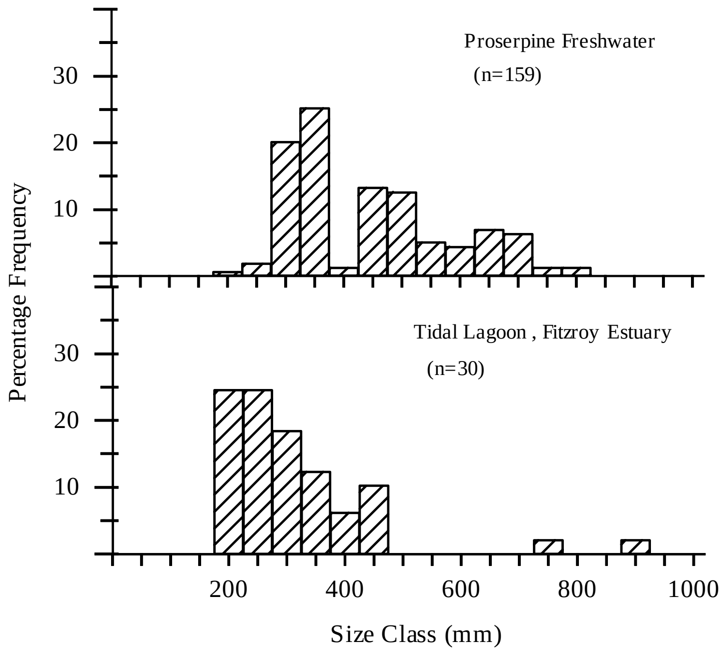
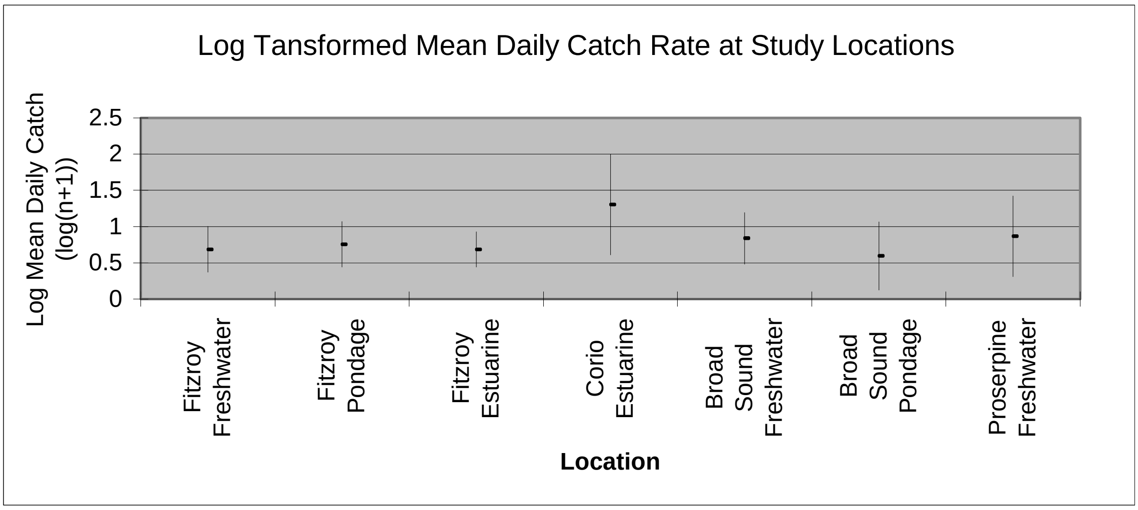
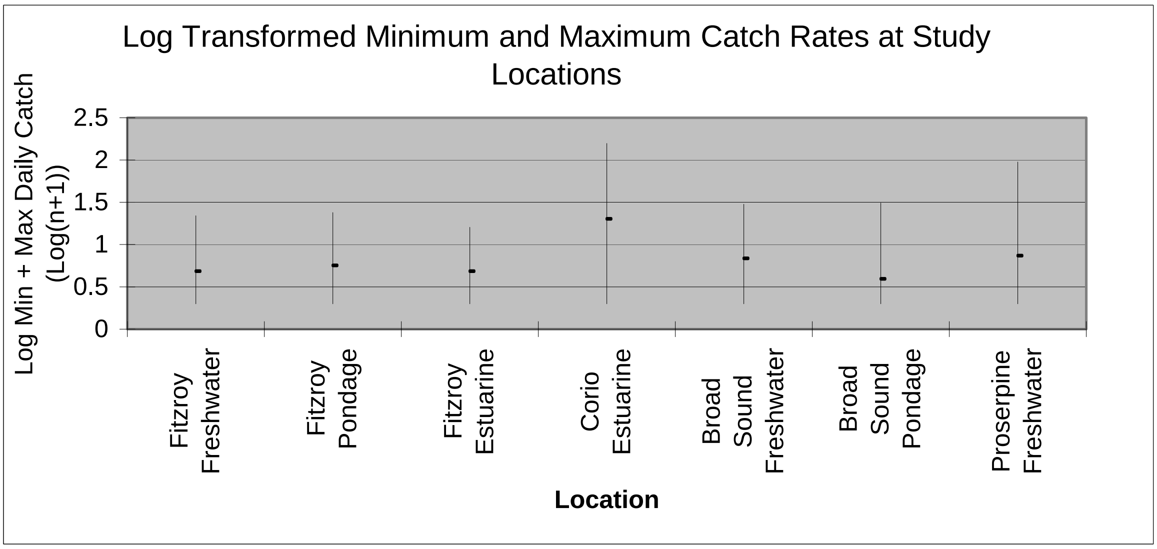


Figure 13 Log transformed barramundi catch rates by location.





8.3.2 Recapture Rates

Barramundi populations in two ponded pasture systems and associated freshwater sites were studied over twelve months. Additional samples were also collected from an upper intertidal location adjacent to a pondage system in Corio Bay and from a secondary site at Proserpine. Some 437 barramundi were tagged and released during the sampling of all sites. The size of tagged barramundi ranged from 200 mm to 1300 mm and their weights ranged from 96 g to 19000 g. There were 113 recaptures in total providing a recapture rate of 38.7%. These recaptures include five fish that were recaptured within five days of the release. Thirteen fish were recapture twice and one was recaptured three times. Fishers recaptured 9 tagged barramundi. Thirty eight tagged fish were recovered following a fish kill in the freshwater site at Broad Sound. Most recaptures were made at or close to the site of release. Three tagged barramundi released in freshwater habitats were recaptured in adjacent estuarine habitats. Four fish had moved from downstream within the freshwater location. The number of barramundi released and recaptured by release location and recapture location is shown in Table 9.

Table 9 Summary of tagged barramundi releases and recaptures by location.

Location	No of Tag Releases	Number of Recaptures By location of recapture			Total Recaptures	
		Freshwater	**Pondage System**	**Estuary**	**No of Recapt's**	**%**
Fitzroy Estuary						
Freshwater	88	19	-	-	19	21.6%
Pondage System	36	-	24	-	24	66.7%
Estuary	15	-	-	-	-	-
Corio Bay						
Estuary	10	-	-	-	-	-
Broad Sound						
Freshwater	129	55	-	1	56	43.4%
Pondage System	3	-	-	-	-	-
Estuary	1	-	-	-	-	-
Secondary Sites						
Fitzroy Delta Freshwater	7	-	-	-	-	-
Corio Bay Freshwater	1	-	-	-	-	-
Proserpine Freshwater	146	12	-	2	14	9.58%
Proserpine Pond	1	-	-	-	-	-
Total	**437**	**86**	**24**	**3**	**113**	**38.67%**

8.3.3 Population Estimates

Recapture rates were used to estimate population sizes at four sites, Fitzroy freshwater, Fitzroy ponded pasture system, Broad Sound freshwater, and Proserpine freshwater. Each of the four sites was isolated from upstream freshwater sites and adjacent estuarine habitats due to a lack of flow until spring 1998. Each site was effectively a closed system for a large part of the study. Barramundi catches, tag release rates and recapture rates for these four sites are presented in Tables 10, 11, 12 and 13. No recaptures were made at the Broad Sound ponded pasture system where all tagged fish perished when the system dried. The estimates of the size of the barramundi population in the Fitzroy freshwater site were 150 (July), 224 (September) and 203 (October). Population estimates for the Broad Sound freshwater location were 297 (July) and 438 (October). The estimates of the size of the barramundi population in the pondage system in the Fitzroy Estuary were 48 (July) and 72 (October). The size of barramundi populations at the secondary site in Proserpine was estimated at 595 (August).

The population estimate for October was higher than the July estimate at three of the sites. A lack of water flow in the pondage system and freshwater site in the Fitzroy location system during this time effectively isolated each site from adjacent aquatic habitats. There was no opportunity for recruitment or emigration at these sites so that the differences in population estimates between winter and spring most likely arises through error associated either with changes in catchability or low recapture rates. Seasonal changes in population size could not therefore be calculated reliably. However, the results provide a general indication of the population size of the barramundi populations in the freshwater sites associated with pondage systems in the Broad Sound and Fitzroy locations. The estimate for the Proserpine suggests a greater abundance of barramundi at this site.

A mass kill of barramundi occurred at the Broad Sound freshwater site in March 1999. This provided an indication of the abundance of barramundi at this site and provided a useful comparison with population estimates obtained from tag recapture rates. The kill involved 148 barramundi including 38 tagged fish. (Details of the mass kill are provided in Section 8.3.4). The occurrence of the kill provided an opportunity to measure the proportion of tagged to untagged barramundi at that time. It also provided an opportunity to measure the proportion of tagged fish remaining at the site in relation to the number of tagged fish released at the site prior to the kill. These observations provide estimates of the emigration rate and of the population size. No barramundi were captured during sampling of the lagoon after the mass kill. Barramundi observed in the kill were extensively bloated and had been blown to the shore. It was considered that if all the barramundi had become bloated to the extent of those observed, most would have floated to the surface. The number of barramundi in the kill was therefore considered close to the total population at the time of the kill.

An estimate of the population size at the site was calculated by assuming the ratio of tagged to untagged fish in the population at the time of the mass kill was the same as that prior to the first flow event (August). There were 38 tagged fish in a total of 148 barramundi in the mass kill or 25.7%. No additional barramundi had been tagged and released at this site between August and the following March when the mass kill occurred. There had been 83 tagged barramundi released in the site at August 1998. A population estimate of 323 is obtained if the same proportion of tagged to untagged barramundi is applied. This is similar to the July population estimate from recapture rates of 297. The lagoon is approximately 800 m long and varies in width between 10 and 50 m providing a surface of some 16 ha. The population estimates suggest a density in the lagoon of around 18.5 to 20 barramundi per hectare.

Table 10 Tagged barramundi release and recapture data with population estimate for the Fitzroy freshwater site.

Date	No. of Fish Caught	No. of Fish 1st Releases	No. of Tagged Fish 1st Re-Capture	No. of Tagged Fish 2nd Re-Capture	Cumulative Number of Tagged Fish	Cumulative Number of Tagged Recaptured Fish	Estimated Population Size
26/11/97	1	1			1		
16/02/98	2	2			3		
22/04/98	2	2			5		
3/06/98	1	1			6		
9/07/98	11	11			17		
16/07/98	8	8			25		
21&22/0	**12**	**10**	**2**		**(25)**		**150**
21/07/98	9	8	1		33	1	225
22/07/98	3	2	1		35	2	99
27/07/98	6	5#			40		
28/07/98	6	6			46		
8/09/98	2	2			48		
14/09/98	14	11	3		59	5	224
21/09/98	2	2			61		
13&14/1	**10**	**7**	**2**	**1**	**(61)**		**203**
13/10/98	9	6	2	1	67	7	183
14/10/98	1	1			68		
10/11/98	4	4			72		
30/3/99	3	1	2		73	9	109
27/5/99	21	14	7		87	16	219
25/10/99	2	1	1		88	17	174

one fish released without tag.

Table 11 Tagged barramundi release and recapture data with population estimate for Fitzroy ponded pasture system*.

Date	No. of Fish Caught	No. of Fish 1st Release	No. of Tagged Fish 1st Re-Capture	No. of Tagged Fish 2nd Re-Capture	Cumulative Number of Tagged Fish	Cumulative Number of Re-captured Tagged Fish	Estimated Population Size
26/09/96	4	4			4		
6/11/96	1		1			1	
1/04/97	1		1			2	
1/12/97	5	5			9		
17/02/98	9	7	1	1	16	4	40
21/04/98	1	1			17		
2/06/98	1	1			18		
4&15/7/98	**8**	**5**	**3**		**(18)**		**48**
14/07/98	7	4	3		22	7	
15/07/98	1	1			23		
15/09/98	3	3			26		
30/9 & 1/10/98	**14**	**9**	**5**		**(26)**		**72**
30/09/98	9	7	2		33	9	117
1/10/98	5	2	3		35	12	55
26/11/98	3	-	1	2	35	15	
9/2/99	3	1	2		36	17	
14/9/99	4	-	4		36	21	

* Barramundi recaptured within a week of release were not included.

Table 12 Tagged barramundi release and recapture data with population estimate for the Broad Sound freshwater site.*

Date	No. of Fish Caught	No. of Fish 1st Release	No. of Tagged Fish 1st Re-Capture	No. of Tagged Fish 2nd Re-Capture	Fish not Released	Cumulative Number of Tagged Fish	Cumulative Number of Tagged Recaptured Fish	Estimated Population Size
9/12/97	11	11				11		
10/12/97	4	4				15		
11/12/97	4	4				19		
27/01/98	4	4				23		
28/01/98	5	5				28		
25&26/3 /98	**33**	**32**	**1**			**(28)**		**924**
25/03/98	29	28	1			56	1	812
26/03/98	4	4				60		
17/06/98	12	10	1		1	70	2	720
29&30/7 /98	**17**	**13**	**3**	**1**		**(70)**		**297**
29/07/98	6	5	1			75	3	420
30/07/98	11	8	2	1		83	6	275
6,7&8 /10/98	**37**	**30**	**7**			**(83)**		**438**
6/10/98	23	18	5			101	11	381
7/10/98	7	6	1			107	12	707
8/10/98	7	6	1*			113	13	749
18/1/99	5	3	1	1		116	15	

* tagged fish recaptured within a week of release not included in calculation of population estimate.

Table 13 Tagged barramundi release and recapture data with population estimate for the Proserpine site.

Date	No. of Fish Caught	No. of Fish 1st Release	No. of Tagged Fish 1st Re-Capture	No. of Tagged Fish 2nd Re-Capture	Total Number of Tagged Fish	Total Number of Tagged Re-captured Fish	Estimated Population Size
25/02/98	3	3			3		
28/04/98	9	9			13		
29/04/98	10	9	1		22	1	
30/04/98	10	10			32		
5/08/98	93	88	5		120	6	595
6/08/98	28	28			148		

Barramundi (*L.calcarifer*)

8.3.4 Survival

There were no mass kills of fish reported or known to have occurred in any of the pondage systems investigated during the study. The ponded pasture system in the Broad Sound location dried completely by spring in each year of the study. Barramundi in this system were isolated from both the adjacent estuary and the adjacent freshwater habitats and appeared to have undergone a steady decline as the pond dried rather than dying in mass. Barramundi survived for several years in the Fitzroy ponded pasture system. This system remained inundated during the study. There were, however, numerous fish kills reported for a number of freshwater sites and some estuarine sites in the region during the study. Some of these were investigated and found to contain barramundi. The location of mass kills of fish is presented in Appendix 5 and a description of fish species involved presented in Table 14. A number of these mass kills of fish occurred during severely dry conditions as water bodies dried up. Other kills occurred during or following rainfall events provided flows with increased loads of organic material into water bodies. Two mass kills of fish also occurred in upper-intertidal habitats where fish had become stranded in pools isolated from the main estuarine channel. The following observations on survival of barramundi were made for a variety of habitat types including a ponded pasture system that dried completely, a ponded pasture system that remained inundated, unbanked freshwater habitats adjacent to ponded pasture systems, and two intertidal locations.

8.3.4.1 Survival in ponded pasture systems.

The ponded pasture system at the Broad Sound contained a population of small barramundi that were isolated from the adjacent estuarine habitats and from the adjacent permanent freshwater habitats as water levels receded. Barramundi catches (Figure 14) declined as water levels in this system receded and this pond dried completely by the end of spring in each year. The drying of the pond was not associated with any obvious large scale fish kills at least none that were detected or reported. There was evidence of large scale feeding by a variety of birds including pelicans in ponds as water levels receded. Predation by birds most likely represented a substantial pressure on the fish population in the ponded pasture system.

The permanently inundated system in the Fitzroy location supported a population of mature barramundi. A substantial number of recaptures was made at this site during the study and some fish had been recaptured on several occasions. However, in December 1999, a single dead barramundi was recovered from this system. The cause of death was not established, but there appeared to be a substantial algal bloom at the time. It is unknown whether further fish deaths had also occurred either at this time or subsequently since monitoring of the pond had been discontinued. However, prior to this event, recaptures of tagged barramundi indicated that there was high survival of barramundi over several years in this pondage system. (After the completion of field investigations, a mass kill of fish was reported at this site by local fishers but details of the event were not available at the time of this report.)

Table 14 List of mass kills of fish reported in the study locations

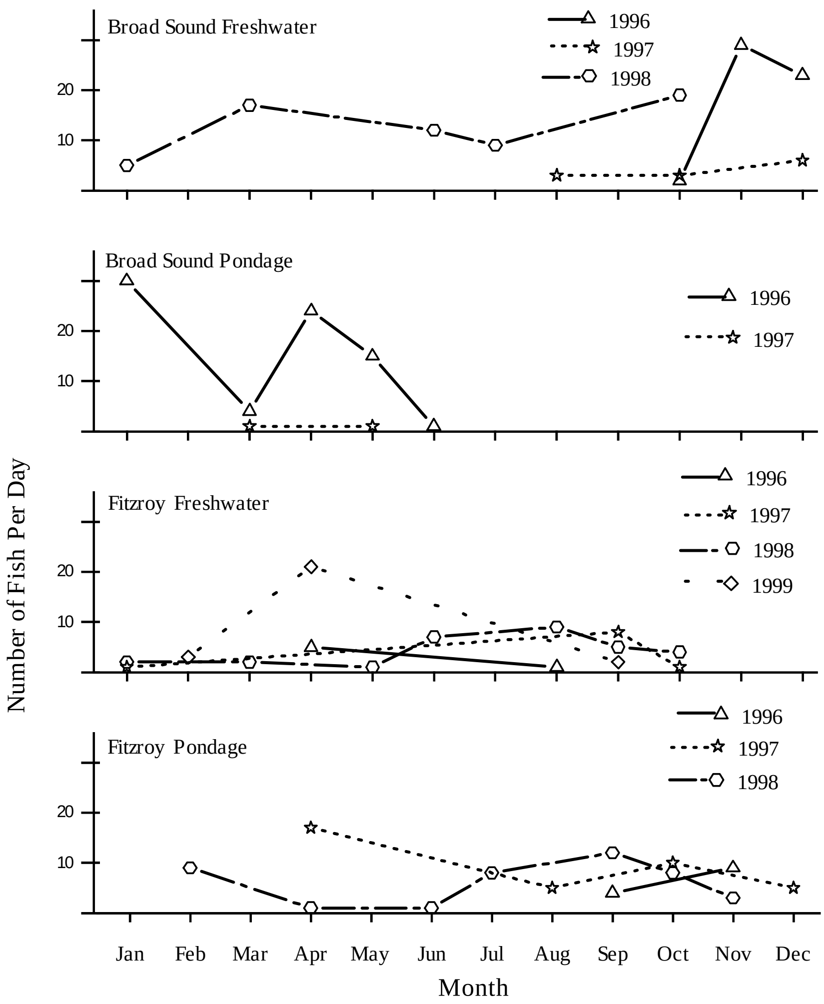
Location	Habitat Type	Condition	Fish species involved (and number)
Yeppen Lagoon	Freshwater Lagoon	In flow following rain	13 species >20,000 fish (all species); approx 12 tonne (all species) 200 barramundi
Pink Lily Lagoon	Freshwater Lagoon	Drying	Approx 1000 long finned eels
Woolwash	Lagoon	Inflow following rain	12 species mostly catfish and bony bream 2 barramundi
Gavial Creek	Freshwater Lagoon	Unknown	6 species mostly bony bream no barramundi
Nankin Creek	Freshwater stream	Unknown	Bony bream (>1000)
Nankin Creek overflow (adjacent to pondage system)	Freshwater Lagoon	Drying	3 species catfish, mullet and barramundi 177 barramundi (approx 1 tonne) barramundi size 580–940 mm TL 205 mullet and 95 catfish
Pumpkin Creek	Estuarine-freshwater interface	Road crossing with box culvert	1 species >10,000 small (50-100mm) bony bream.
Raglan Dam	Freshwater Dam	Drying	>20 barramundi
Inkerman Creek	Upper inter-tidal pool	Drying	>1500 barramundi (350mm TL) and mud crabs
Sandfly Creek	Upper intertidal pool (below pondage bank)	Drying	Not identified, too decomposed
Fishing Creek	Upper intertidal lagoon (formed from borrow pit)	High temperature	>12 species including barramundi

Table 14 (Continued)

Location	Habitat Type	Condition	Fish species involved (and number)
Home Creek	Freshwater Lagoon Above pondage system	Small inflow following rain	148 barramundi bony bream
Lagoon St. Lawrence	lagoon	Unknown	Unidentified
Horseshoe Lagoon	Marlborough	Unknown	Unidientified
Clairview Creek	Lagoon	Unknown	Unidentified
Twelve Mile Creek	Lagoon	inflow from rain	Barramundi; striped butterfish (Martin, Sawnok + Brill, Pers. Com.)
Balnagoan Creek	Bunded tidal creek	unknown	Unidentified

Pondage System in Fitzroy Estuary

Figure 14 Monthly catch per day of barramundi.



8.3.4.2 Survival in unbanked freshwater habitats.

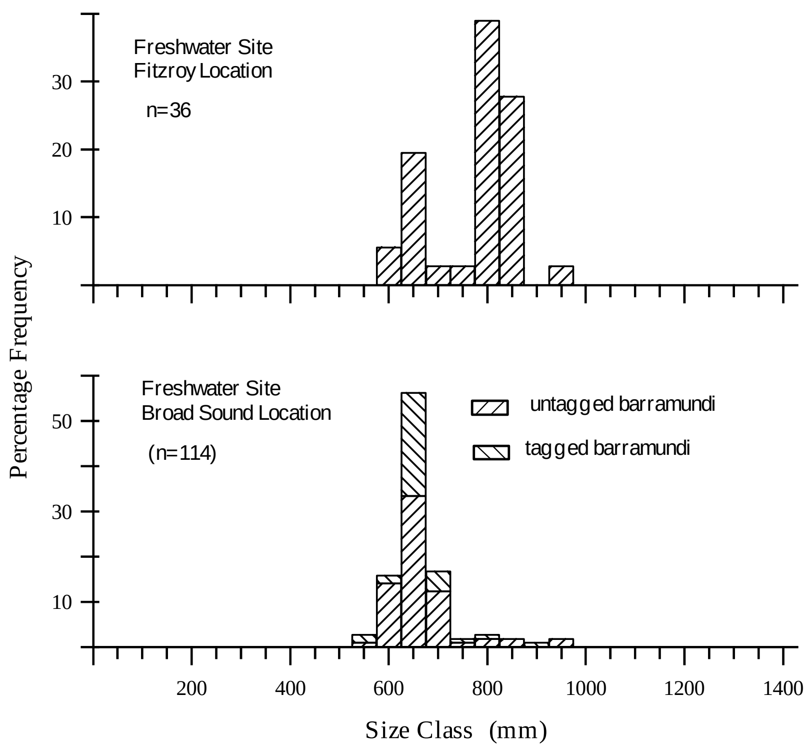
A number of mass kills of fish occurred in various freshwater habitats in the region during the study. Mass kills of fish also occurred in the freshwater sites at both Fitzroy and Broad Sound primary study locations. These were investigated and are of particular interest due to the monitoring of fish populations that had occurred prior to the mass kills.

A mass kill of fish in the freshwater site at Broad Sound study location occurred during March 1999 and was reported by the property holder on the first morning of the kill. The kill was investigated that afternoon and found to involve 148 barramundi as well as a large number (>1500) bony bream and a small number of eels. This population of barramundi had been monitored for some two years up to August 1998. Some 83 barramundi had been tagged and released at the site and numerous recaptures had been made during sampling. Estimates of the size of the barramundi population at this site have been presented in an earlier section. There was no indication of any mortality of barramundi at the location prior to March 1999.

The cause of the fish kill appeared to have been extremely low dissolved oxygen resulting from an influx of anoxic water and organic matter brought in to the lagoon after rainfall. The resultant inflow to the lagoon increased the water level by more than half a metre. This did not appear to have produced any substantial overflow and was not great enough to flush the lagoon completely. Chemical analyses of samples of flesh, viscera, water and sediment for herbicides, insecticides and heavy metals indicated the concentration of these were not abnormally high and suggested that chemical contamination was not a contributing factor to the kill (Appendix 6).

Thirty-eight tagged barramundi were recovered from the kill and 112 of the dead barramundi were measured. Barramundi ranged in size from 530 mm to 870 mm. Size frequency of tagged and untagged barramundi in this kill were similar (Figure 15). The mass kill appeared to have included all barramundi at the site since subsequent sampling failed to capture any barramundi. All the dead barramundi that were recovered in the kill were extremely bloated and were found floating at the surface. One live barramundi was also found at the surface and this animal displayed very weak uncoordinated movements and did not survive long after handling. There were no barramundi collected from below the surface or from the substrate.

Figure 15 Size frequency of barramundi in mass kills.



Some 133 barramundi were recovered in the twenty-four hours following the commencement of the kill. There were 15 additional barramundi that floated to the surface over the following 24 hours. The mass kill was investigated during the late afternoon of the day on which the kill was discovered and reported. The proximity of the lagoon to farm facilities meant that the kill was noticed as farm work began in the morning and had occurred at some stage during the preceding night (most likely early morning). All dead barramundi were removed from the lagoon. It is considered that all the barramundi that were in the lagoon had died and had floated to the surface. There is often an unknown proportion of fish that may not float to the surface in a mass kill of fish. However, it was apparent that the barramundi had suffered a considerable degree of bloating in the early stages of decay and it is considered that most of the dead fish had risen to the surface.

A mass kill of fish occurred in the freshwater site of the Fitzroy study location during February 2000. An investigation of the site revealed that the kill involved more than a 1000 bony bream (*Nematalosa erebi*) that were in an advanced state of decay and unsuitable for collection of samples to assess presence of contaminants. There were no other species present in the kill. Measurements of dissolved oxygen indicated extremely low (<4ppm) dissolved oxygen levels and suggested a high BOD load. A large amount of organic matter (mostly leaves) associated with several dead trees that had fallen across the stream could have contributed to the low dissolved oxygen at the site. However, since the decaying fish may also have contributed to the low oxygen levels, the cause of the kill remained uncertain. In a site immediately downstream from the fish kill site, leaves of pasture species (para grass and *Hymenachne*) that had invaded the stream bank had also died.

A local property holder had indicated that spraying of pasture grass had occurred along the bank. The property holder indicated (in February 2000) that there had been a fish kill in the system in July 1999. This kill had not been reported at the time and details of the kill are not available. There was no information available on the size and species composition of fish in the July 1999 kill or whether barramundi had been involved in the kill. This site had previously been monitored over two years without any indication of barramundi mortality. The single species in the February kill may reflect the loss of other species (particularly barramundi) in the previous July kill, and the lack of any subsequent recruitment.

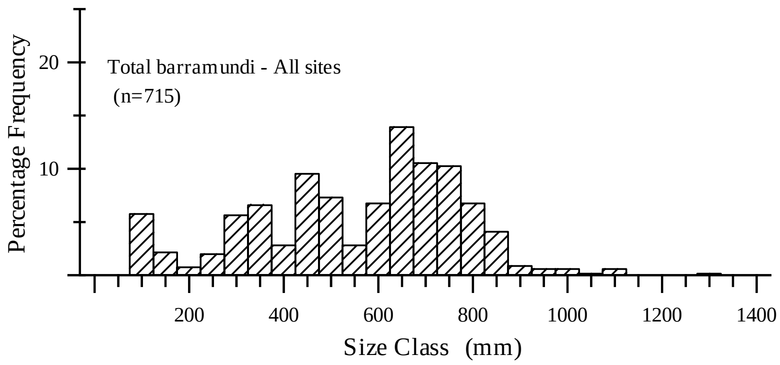
A mass kill of fish had also occurred in a freshwater site associated with the Fitzroy ponded pasture system prior to the commencement of the study. This kill included some 177 barramundi in the 8-10 kg weight range and 600 mm – 950 mm size range (Figure 15). These animals died as water levels in the lagoon receded to less than 0.5 m. Two other fish species (*Arius* sp. and *Mugil cephalus)* were also involved in this in this kill. The deep green colour of the water at the time of the kill indicated an algal bloom had been in progress. Analyses of water samples collected from the site indicated a large density (2,323,000 cells per ml) of cyanobacteria dominated by *Pseudanabaena* sp.. Other cyanobacteria in the sample included *Anabaena aphanizomenioides, Pseudanabaena galeata, Pseudanabaena limnetica, Anabaenopsis elenkinii*, and *Anabaenopsis* sp. (L. Fabro, Central Queensland University). The relationship between the bloom and the mass kill is not clear but the high density of blue green alga suggests potential for gill clogging. The toxicity of the cyanobacteria strains present at this site was undetermined. The presence of cyanobacteria in lagoons and ponded pasture systems requires further investigation.

8.3.4.3 Mortality in intertidal habitats

Juvenile stages of barramundi were captured in an upper intertidal pool immediately below the pondage bank at Corio Bay during March 1998. These fish were tagged and released into the same pool. None of the releases were recovered and the pool dried in the following weeks. There was no opportunity for these fish to return to the estuary because of the lack of connections between this pool and the estuary. Similarly, there was no connection to either the pondage system or the associated freshwater habitat. It is assumed that this population suffered complete mortality. The carcasses of fish (including a variety of estuarine dependant species) were observed at a nearby upper intertidal pool below the pondage banks at the same location habitat in the year preceding this study. Fish trapped in upper-intertidal pools immediately below pondage banks suffer high mortality.

A mass kill of juvenile barramundi also occurred in an upper-intertidal site in the Fitzroy delta where small (<350 mm) barramundi had become stranded in an upper intertidal location where water had ponded along a road embankment and became isolated from the adjacent estuarine channel. The deaths appeared to have occurred as the ponded water dried. The kill involved more than 1500 barramundi and reflects the high risk for entrapment of barramundi in upper-intertidal locations where ponding of water occurs.

Figure 16 Size frequency of barramundi from all sites and times.



8.3.5 Growth and Condition

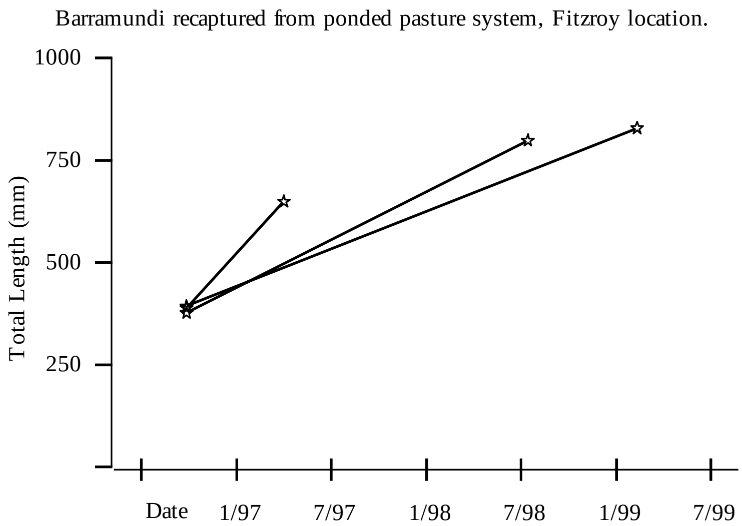
The size frequency of barramundi over all samples (all sites and times) indicates there were up to five cohorts of barramundi at 100, 250, 450, and 650 mm (Figure 16). Seasonal size frequencies were calculated for barramundi from freshwater sites and from pondage systems and are presented in Appendix 7. A modal progression from 400 mm (spring 1996) through 650 mm (autumn 1997), to 750 mm (summer 1997-98) was apparent in seasonal size frequencies for barramundi in the Fitzroy pondage system. Although this system was isolated from the estuary for the duration of the study, the presence of barramundi in the 400 mm size class during spring 1996 indicates that at least some barramundi had entered this location as juveniles. Samples sizes from 1998 to 1999 at this location were too small to identify any patterns. Sample sizes from freshwater sites in the Fitzroy location were also too small to identify any definite trends apart from a shift in mode from 750 mm in winter 1998 to 850 mm in autumn 1999.

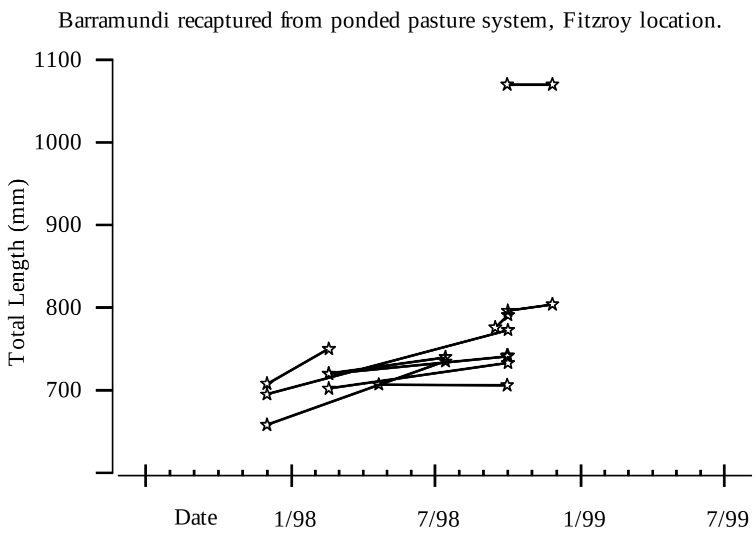
There were no modal progressions apparent in size frequencies for the Broad Sound pondage system. This system had dried completely by the end of spring each year resulting in the loss of juvenile barramundi that were present in the system during winter. In the Broad Sound freshwater location, two cohorts were present at 400 mm and 700 mm for summer 1997/98. Barramundi samples from this site showed a progression from 450 mm in autumn 1998 to 600 mm in autumn 1999. The size frequencies of barramundi from the Proserpine freshwater site indicate the presence of juvenile barramundi in the 300 to 350 mm size class in winter 1998. A similar recruitment of juvenile barramundi was not evident in freshwater sites or pondage sites at other locations.

Recaptures of tagged barramundi exhibited growth increments ranging from 13 mm (8 g) to 421 mm (5619 g) over a period of liberty of up to 656 days. Growth of recaptured barramundi in the pondage system in the Fitzroy Estuary ranged from 8 mm to 421 mm. Growth increments of recaptured tagged barramundi ranged up to 38 mm per month or 9.7 mm per week. A detailed analysis of growth was restricted by a lack of length at age data and further work is required to identify variations related to release size and seasonal factors.

Comparisons of mean growth increments between pairs of sites were completed using Students T test and results are presented in Table 15. Barramundi recaptured from the pondage system in the Fitzroy Estuary displayed a higher mean growth increment than recaptured barramundi in the adjacent freshwater site. Growth increments for recaptured barramundi from the Broad Sound freshwater site were not significantly different from recaptures from the Fitzroy pondage system. There was a very highly significant difference in growth increments for barramundi from the freshwater site from Broad Sound compared to the freshwater site in the Fitzroy Estuary. Growth increments will be dependent on length at release and time before recapture. Most of the barramundi recaptured at the freshwater site and ponded pasture site at the Fitzroy location were between 650 mm and 800 mm at the time of release. While most of the barramundi tagged and released at the freshwater site at the Broad Sound location were less than 650 mm. The release size, time of release, recapture size and time of recapture for individual barramundi are presented in Figures 17 and 18.

Figure 17 Release and recapture size for individual recaptured barramundi from the Fitzroy location. (Each line represents an individual barramundi with the release size indicated by the star at the left side of the line and the recapture size indicted by the star at the right side of the line.)





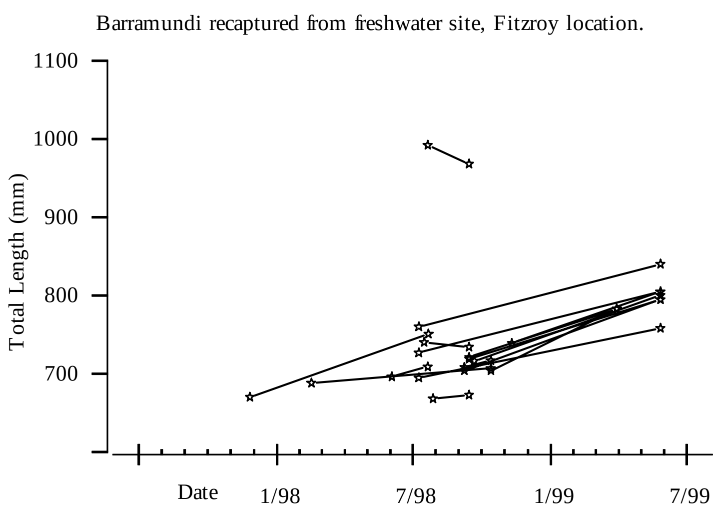
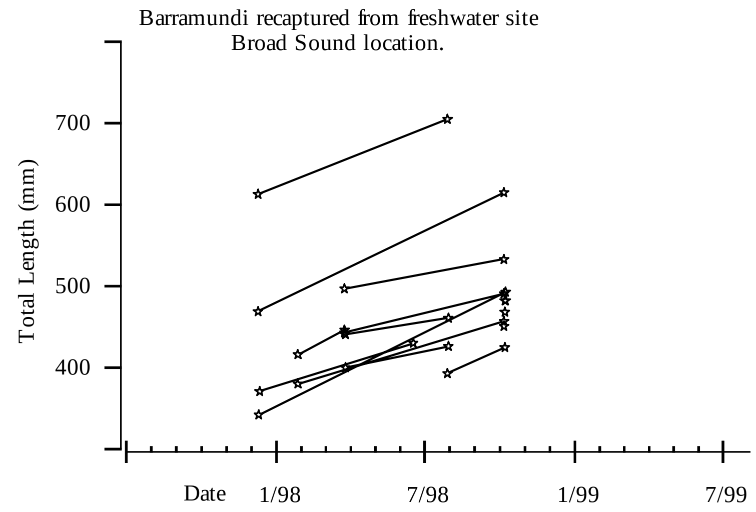
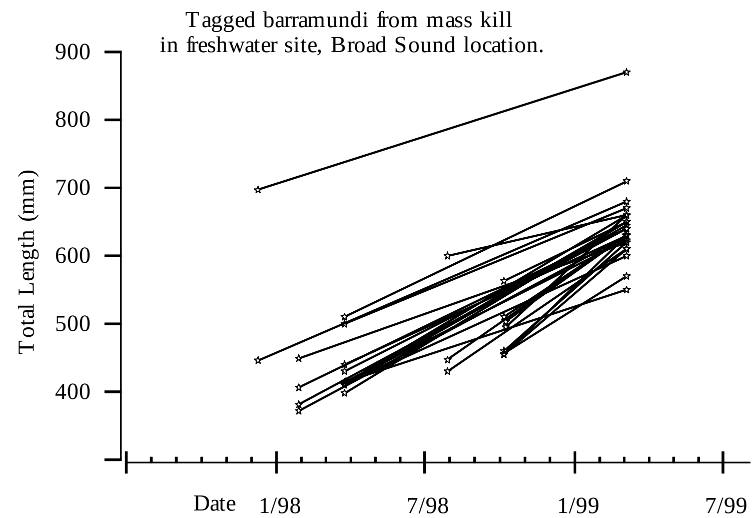
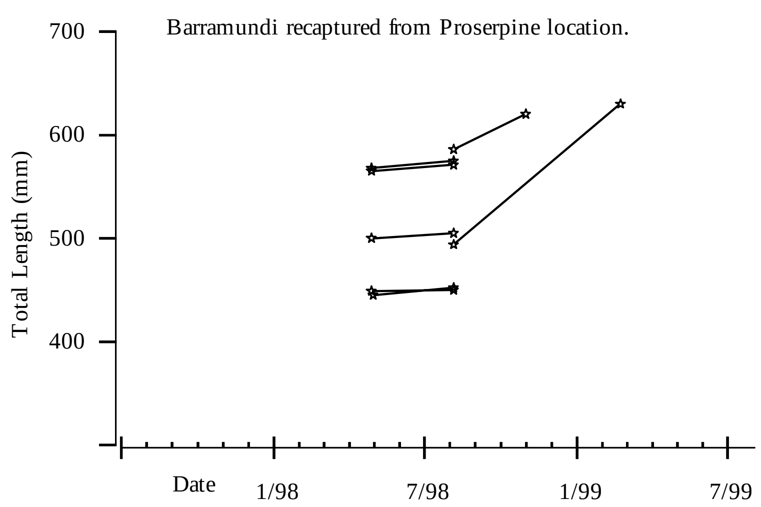


Figure 18 Release and recapture sizes for individual recaptured barramundi at Broad Sound and Proserpine locations. (Each line represents an individual barramundi with the release size indicated by the star at the left side of the line and the recapture size indicted by the star at the right side of the line.)







An index of the condition of barramundi was calculated on the basis of weight and length. A comparison of mean condition indices for barramundi from various habitats (Fitzroy freshwater, Fitzroy pondage, Fitzroy Estuary, Broad Sound freshwater, and Broad Sound pondage) are summarised in Table 16. There was a very highly significant difference in mean condition index for barramundi from the Fitzroy freshwater site (1.23) compared with the Fitzroy pond (1.289) and with the Fitzroy Estuary (1.152). There was also a very highly significant difference in condition index for barramundi from the Fitzroy estuarine site compared with all other sites. However, there was no significant difference in mean condition index for barramundi from the Fitzroy freshwater site compared with either the Broad Sound freshwater or pondage site. Nor was there any significant difference between the Broad Sound freshwater site and the Broad Sound pond. There was however, a significant difference between the Fitzroy pond and the Broad Sound freshwater but not the Broad Sound pond.

Table 15 Paired comparison of mean growth increments (mm per week) by location.

Location	Fitzroy Pond	Fitzroy Freshwater	Broad Sound Freshwater
Fitzroy Pond	3.1 (17)	s	ns
Fitzroy Freshwater	P = 0.045	1.3 (17)	vhs
Broad Sound Freshwater	P = 0.141	P = 0.000	4.3 (48)

Mean growth increments (and number of observations) are displayed along the diagonal for each site.

ns = not significant P > 0.05 hs = highly significant P < 0.01
s = significant P < 0.05 vhs = very highly significant P < 0.001

Table 16 Paired comparison of mean condition indices by location.

Location	Fitzroy Freshwater	Fitzroy Pond	Fitzroy Estuary	Broad Sound Freshwater	Broad Sound Pond
Fitzroy Freshwater	1.23 (53)	vhs	vhs	ns	ns
Fitzroy Pond	P = 0.001	1.289 (123)	vhs	s	ns
Fitzroy Estuary	P = 0.001	P = 0.000	1.152 (49)	vhs	vhs
Broad Sound Freshwater	P = 0.252	P = 0.011	P = 0.000	1.247 (192)	ns
Broad Sound Pond	P = 0.230	P = 0.157	P = 0.001	P = 0.672	1.256 (33)

Location, mean condition index (and number of observations)	Corio Bay estuary, 1.233 (265)	
	Significance	P value
Fitzroy estuary, 1.157 (48)	hs	0.004
Fitzroy freshwater, 1.230 (53)	ns	0.864
Fitzroy pond, 1.289 (123)	hs	0.003
Broad Sound pond, 1.256 (33)	ns	0.342
Broad Sound freshwater, 1.247 (192)	ns	0.457

Location, mean condition index (and number of observations)	Fitzroy fish kill, 0.124 (35)	
	significance	P value
Fitzroy freshwater, 1.230 (53)	vhs	0.000
Fitzroy pond, 1.289 (123)	vhs	7.51 E-130
Fitzroy estuary, 1.157 (48)	vhs	2.76 E-44

Mean condition index (and number of observations) are displayed along the diagonal for each site.
ns = not significant $P > 0.05$ hs = highly significant $P < 0.01$
s = significant $P < 0.05$ vhs = very highly significant $P < 0.001$

8.3.6 Movement

8.3.6.1 Movement of tagged barramundi

Most recaptures were made at the location of release (Table 9). None of the tagged barramundi released within pondage systems were recaptured outside the pondage site. Similarly none of the releases at the Fitzroy freshwater location were recaptured outside of the site. A single fish released in the freshwater site at Broad Sound was recaptured (by a fisher) in the adjacent estuary. Six fish released in the fresh water site at Proserpine were recaptured in the adjacent estuary. None of the fish released at the upper intertidal site in the Corio Bay location were recaptured.

8.3.6.2 Flow events and barramundi movement

At the Corio Bay location, a large number of small barramundi (50-200 mm TL) were captured in an upper intertidal pool below the pondage bank. Ten barramundi were tagged and released at this site, but none were recaptured suggesting a lack of movement from this site to the adjacent estuary or freshwater habitats. There were no major flows between the pondage system and these upper-intertidal pools during the study. The connection between the upper-intertidal pools and the adjacent estuary was limited to short periods at the spring high tide. The upper-intertidal pools appeared to be inundated with tidal flows at these times and remained inundated for 10 to 15 days following the spring tides before drying. It is assumed that trapped fish suffered high mortality. The large numbers of birds found in these habitats represent a substantial predation pressure for trapped fish. A fish kill was observed in a similar habitat nearby indicating that populations of trapped fish in upper-intertidal pools suffer high mortality.

In the Broad Sound location, the pondage system contained a small population of juvenile barramundi. This system dried completely, resulting in the total loss of trapped barramundi. The freshwater habitat associated with this system contained a large population of mostly mature barramundi. This site remained isolated from the pondage system and from the adjacent estuary for most of the study until the end of 1998 when a flow occurred. The presence of a substantial population of barramundi in the freshwater site above the pondage system indicates that there had been substantial recruitment of barramundi in the past. This would have required recruits to leave the estuary, move through the pondage system and enter the freshwater site. Bywashes are low points along the bank and serve as overflow points along the bank. Excess water return to the estuary through the bywashes. The design of the bywashes results in a small flow through the bywash even if the pondage system is not full. This arrangement assists with maintaining a small flow between the pondage system and the estuary. It is considered that movement of fish through the pondage system at this location is assisted by the inclusion of bywashes in the pondage bank.

8.3.6.3 Emigration

A flow event at the Broad Sound location during spring and summer 1998 provided an opportunity for the mature fish to leave the freshwater site, move through the pondage system and enter the adjacent estuary. This system contains a number of bywashes directing overflow into the estuarine habitats. Following the flow event, a local angler in the adjacent estuary recaptured a single tagged barramundi. During the autumn after the flow event, a substantial fish kill occurred in the freshwater site (and is described in the section of survival). Sampling completed following the kill indicated that no barramundi remained in the freshwater site. The number of tagged barramundi (38) in the kill as a proportion of the total number of tagged barramundi (129) released in the kill was used as an indicator of the migration rate from the site during the previous flow event. It was estimated that some 236 fish or 73% of the 323 barramundi resident in the freshwater site had migrated from the freshwater site during the flow. During the following spring (1999), three barramundi skeletons were observed in the dry pondage system between the freshwater site and the estuary. The lengths of the skeletons were measured and were in the same size class as the fish from the freshwater site and as those in the fish kill. Any fish moving downstream from the freshwater site are required to move through the pondage system to enter the estuary. The three trapped fish represent 1.3% of the estimated 236 barramundi that emigrated from the freshwater lagoon over the summer flow. At 1.3%, the entrapment in ponded pasture systems of barramundi emigrating from freshwater habitats is small. Further work is required to determine if entrapment rates for emigrating fish are similar in ponded pasture systems without bywashes.

8.3.6.4 Recruitment

There was no indication of any large-scale recruitment of juvenile barramundi in freshwater or pondage sites at the Fitzroy location. There was an absence of early stage juvenile (<350 mm TL) barramundi in samples from these sites (Figure 8). Juvenile stages were present in the pondage system at the Broad Sound location during the winter and spring of 1996 and these suffered complete mortality as the pond dried during spring. Early juvenile stages (250-300 mm) were also present in the freshwater site at this location in low numbers. Early stage juveniles (<350 mm TL) appeared in samples from intertidal sites at Corio Bay and the Fitzroy Estuary (Figure 11), and a freshwater site at Proserpine (Figure 12), but were absent from freshwater sites and pondage sites in the Fitzroy and Broad Sound.

Sampling was undertaken in the Proserpine site to assess the abundance of early stage juveniles in this location. This site had received higher rainfall and greater inundation than the primary locations. Samples from Proserpine contained a greater proportion of small barramundi than did samples from the primary study locations. Although the largest daily catch of barramundi was made at the Proserpine site, the data were inadequate to test for any significant differences in abundance of barramundi between sites. It is of interest to determine whether the absence of small (<350 mm) barramundi in samples from the freshwater site and from the pondage system at the Fitzroy location reflected low recruitment but the data were considered inadequate to confirm this. No clear patterns were identified in recruitment of small barramundi other than the absence of small barramundi at this location.

Investigations of additional sites indicated the presence of early juvenile (<350 mm TL) stages of barramundi in upper-intertidal pools at Corio Bay and at the estuarine–freshwater interface of a small stream near the Fitzroy location. The presence of early stage juveniles in the upper-intertidal habitats immediately below these barriers suggest that the upstream movement to freshwater habitats had been disrupted. Appendix 8 contains maps of locations in the Broad Sound and Fitzroy regions where small barramundi were captured during investigations of additional sites.

8.3.6.5 Entrapment of small barramundi in ponded pasture systems

There is no reliable data on the rate of entrapment of juvenile barramundi with pondage systems due to the difficulty in monitoring the rate of barramundi immigration and emigration to and from pondage systems. An alternative method for calculating entrapment rates has been obtained by extrapolating from the data collected on catch rates in the Broad Sound pondage system and data on catch rates and population estimates in the Broad Sound freshwater site. This involved calculating the range of sample catch rates (as the number of barramundi per gill net sample) for the Broad Sound freshwater site. The catch per sample expressed as a proportion of the population estimate for this site ranged from 2 to 10%. This proportion is applied to convert the sample catch rate for the pondage system to a population estimate. A catch rate of 21 barramundi per sample was obtained during the sampling of the pondage when adequate water depth was available to sample with gill nets. If this catch represents between 2% and 10 % of the total population then the barramundi population in the pondage system was between 210 and 1050. With a population estimate in the freshwater site of 323 (Section 8.3.3) then an entrapment rate of between 39.2% and 77.7 % is obtained. These calculations do not take into account factors such as mortality of recruits entering the freshwater system, return of small barramundi to the estuary after entering the pondage system, or size shifts in the population over the period of sampling. Low sample sizes and the skewed distribution of catch data prevented the calculation of error limits and further work is required to validate these estimates. Such validation is critical to assessing the impact of pondage systems on barramundi production.

8.4 Discussion

8.4.1 Movement

The entrapment of barramundi in ponded pastures located on or near coastal wetlands relates to the movement by barramundi between estuarine and freshwater habitats at different life stages. Post-larval stages and small juvenile stages of barramundi require access to coastal wetlands that are utilised as nursery areas (Russell and Garrett 1983). Older juvenile stages require access from wetlands to the main watercourse that may be either the main estuary adjacent to the wetland or a freshwater stream above the wetland. In addition, mature barramundi from upstream habitats require access to river-mouths for spawning. There are therefore three life stages (early juvenile stage, the late juvenile stage and the mature stage) of the barramundi that are at risk of entrapment by poorly located pondage banks. The level of risk depends on the style of the ponded pasture system, the proximity to upper-intertidal habitats including nursery areas and estuarine–freshwater interfaces, as well as the level of inundation and flow.

Early juvenile stages are at risk of entrapment in pools and lagoons below pondage banks where the lack of flow prevents the barramundi from accessing nursery areas or freshwater habitats. This is the case in the Corio Bay pondage system where early stage juvenile (<350 mm) barramundi were trapped in shallow pools immediately below the pondage bank. Russell and Garrett (1983) have reported the importance of upper-intertidal habitats as barramundi nursery areas. These habitats are usually temporarily inundated by a combination of spring high tides and seasonal flooding and require connection either to permanently inundated freshwater habitats or to the estuary.

In the absence of adjacent freshwater habitats then a connection to the estuary is important to facilitate emigration when the pools dry or when the stages outgrow the habitats since these habitats usually consist of shallow pools. In circumstances where freshwater habitats are located nearby then the upper intertidal pools provide an additional role to facilitate movement between the estuary and freshwater habitats, particularly during low flow events. The disruption of barramundi movement from upper intertidal habitats to adjacent freshwater habitats by inappropriately located pondage banks will be particularly severe under low flows. The influence of any freshwater seepage through the bank under low flows may also hinder the return of the barramundi to the estuary if there is adequate seepage to elicit a directional movement response by the barramundi. This appears to be the case at the Corio Bay location where fish aggregated in pools immediately below the bank where they were isolated from the estuary as water levels receded and eventually dried.

The aggregation of early stage barramundi in the upper intertidal pools is a combination of two mechanisms. One will be the use of shallow upper-intertidal pools by barramundi as nursery areas (presumably for feeding or predator avoidance) and secondly as a directional movement response to freshwater flows to facilitate movement from the estuary to the freshwater habitats. Russell and Garrett (1983) report the entry of juvenile barramundi into supralittoral pools eight weeks after initial inundation in Norman River (south east Gulf of Carpentaria). The entry of juvenile barramundi in pools in this study occurred during March. Moore (1982) reported that juvenile barramundi leave coastal wetlands in June – July in New Guinea. Possible differences in the timing of the movement of juvenile barramundi from estuary to freshwater may be related to latitudinal differences in seasonal rainfall patterns.

Late juvenile stages (350-550 mm) of barramundi are found in pondage systems where water flows are adequate to facilitate movement from the estuary. Entrapment will occur if the fish are unable to leave as the water flows recede. This is the case in the Broad Sound ponded pasture where juvenile barramundi are able to enter the pondage system with some being trapped and others moving through the pondage system to the associated permanent freshwater habitat. The bywashes were included in the pondage design to prevent overtopping and to accommodate overflows but these also effectively facilitate fish movement in and out of the pondage during flow events. The role of bywashes in providing a connection to the estuary under low flows is an important feature of this design. Fish entering the pondage system under low flow may be able to move onto permanent freshwater habitat located upstream of the pondage system. However, a number of fish still become entrapped as the flow recedes, unable to move to the freshwater habitats or return to the estuary. The proportion of barramundi that are trapped in the pondage system is important in assessing the impact of ponded pastures on barramundi. Preliminary estimates of between 39% and 77% entrapment rates for this system require validation. It is also likely that entrapment rates will vary between systems and will be strongly dependent on the location of the pondage bank in relation to nursery areas or spawning areas.

A number of large (>580 mm) barramundi were trapped in the pondage system at the Fitzroy location over a number of years due to a lack of flow through the system preventing the movement of these stages to the adjacent estuary. The entrapment rate in this case was considered to be high since there were few opportunities for the barramundi to leave the system. There is indication that at least some of these barramundi were trapped at an early age and have grown while in the pondage system. The risk of entrapment to mature stages during their downstream migration appears to be low and will only occur during low flows where overflow is inadequate to provide a connection to the estuary. These trapped large fish represents a potential loss of spawners for that season or until adequate flow is available to allow movement to the estuary. It is of interest that large barramundi may survive several years trapped in systems that do not become completely dry, as long as water quality is maintained.

The findings of the investigation are largely related to low to moderate flow patterns that predominated through the study. The study location is a low rainfall area (for a tropical coastal region) and low to moderate flows would be expected to prevail. The inconsistent pattern of rainfall has promoted the interest and support for extensive development of ponded pastures by the cattle industry in the region. Obviously, periods of low flow will be associated with fewer opportunities for large-scale movements.

The findings of the investigation are relevant for years characterised by low rainfall and low flows. The patterns of movement and entrapment of barramundi in ponded pastures during high flow events remains to be determined. Large-scale inundation associated with a high flow event would provide an opportunity for wide spread dispersal of post larval and juvenile stages of barramundi based on the reported broadcast spawning behaviour by barramundi (Davis 1987). It is important to note that in the present study some 40% of pondage systems investigated contained barramundi. The dispersal of barramundi in the study locations had been restricted during recent years by the low rainfall and lack of inundation. It is expected that the occurrence of barramundi in ponded pastures in or near coastal wetlands would be substantially greater following a major inundation event due to the more widespread dispersal of post-larval stages.

The risk of barramundi entrapment will also be related to the timing of the inundation. Widespread dispersal and entrapment of post-larval and juvenile stages is expected with a high inundation event. Entrapment would be greater where the inundation event coincides with a recent spawning of barramundi and dispersal of post-larval stages. Greater entrapment is likely with widespread inundation during summer than during early spring or late autumn. The most recent high flow and major inundation in the coastal region of central Queensland occurred in 1990. Concern over the impacts of ponded pastures on barramundi were reported in the following year (Anon 1991). It is suggested that there is minimal risk of entrapment of mature stages under high flows due to large scale drowning out of pondage systems that would provide opportunity for fish to return to the estuary.

Pondage banks located in or adjacent to coastal wetlands and watercourses have considerable potential to disrupt barramundi movements. The disruption of barramundi movements and the risk of barramundi entrapment are likely to depend on a variety of factors. These include the proximity of banks to the estuarine–freshwater interface, proximity to nursery areas, proximity to spawning locations, the design of the bank, the prevailing flow regimes and rainfall patterns, the level of flow, the extent of inundation, and the synchronisation of flow events with life cycle timing. The findings of this study suggest that influence of pondage banks on the pattern of barramundi movement will vary with the design and location of pondage banks and the connections to adjacent aquatic habitats. There is considerable potential for managing fish movement through improved design features. Management of pondage banks is discussed in a later section.

8.4.2 Survival

Patterns in survival of barramundi associated with pondage systems varied between location and habitat type. Mortality of fish trapped in pondage systems that dry completely is obviously high. The mortality of fish isolated in upper-intertidal pools below pondage banks is also believed to be high. The fate of barramundi in pondage systems where water levels is maintained is less conclusive with indications that high survival over a number of years is possible where water quantity and quality are adequate.

The survival of barramundi trapped in pondage systems will be dependent on the ecology of the system including predation pressures, water quantity and quality. The pondage system in the Fitzroy Estuary remained inundated for the duration of the study and supported a substantial barramundi population with apparent high survival for several years. The survival of barramundi at this site during extremely dry conditions and low levels of recruitment (which had prevailed for some considerable time prior to and during much of the study) is considered to be of major significance. Survival of barramundi in permanently inundated pondage systems such as this indicates the value of suitable refuges where water quality can be maintained to provide potentially valuable fisheries habitat. A contributing factor to the permanent inundation of this pond appeared to be seepage of tidal water through the bank into the pond. Ponds located in the intertidal zone have the benefit of tidal inflows for maintenance of water levels. The maintenance of water quality may also be aided by tidal inflows.

Despite the high survival of barramundi in the permanently inundated system, this style of pondage system contributed very little to fisheries production since the lack of flows from the pondage system to the estuary prevented large barramundi from leaving the pondage. There is some potential for a recreational fishery based on trapped barramundi in some ponds and there were reports of recreational fishing in some pondage systems. In systems characterised by small barramundi, size limits may restrict the appropriateness of recreational fishing other than those based on catch and release. In other areas where barramundi are of legal size than there is potential for recreational fishing. The recreational potential of fish resources in pondage systems was not explored in this investigation.

8.4.3 Recruitment

The level of entrapment and survival of barramundi in ponded pastures are the critical factors central to the interaction between ponded pastures and barramundi resources contributing to reduced recruitment to the fishery. The entrapment and mortality of early juvenile stages in pools below pondage banks has considerable potential to impact recruitment of post larval stages from the estuary to nursery areas or freshwater wetlands. At Corio Bay, barramundi were absent from the freshwater habitat and pondage system throughout the study and largely as a result of a disruption of the recruitment of early juvenile stages. The pondage bank at the Broad Sound location included bywashes for excess water flows and these appeared to provide opportunities for recruitment resulting in the entrapment of late juvenile stages of barramundi. The complete mortality of these stages represents additional reduction in recruitment levels although this has not been quantified. Variations in recruitment patterns and survival rates are likely to have contributed to some of the variation of size structure for barramundi populations observed in various habitats and locations.

Variations in recruitment patterns (amongst other factors such as predation) may also have contributed to the variation in population sizes of various habitat types (freshwater sites and pondage systems) and locations. Factors that influence recruitment and predation pressures are likely to be particularly important and may include habitat structure and associated processes such as timing and magnitude of flow events. In both the Fitzroy and Corio localities, early juvenile (<350 mm) stages of barramundi were only present in samples from intertidal habitats. It was clear that the recruitment of juvenile barramundi from the intertidal habitats to the pondage systems and the associated freshwater sites was completely disrupted by low flows and the role of the pondage bank as a barrier to fish movement at the estuarine–freshwater interface.

In the Broad Sound locality, the barramundi population in the ponded pasture system was dominated by juvenile stages that did not survive beyond spring when the pond dried each year. The presence of barramundi in freshwater sites above this pondage clearly indicates that the pondage bank had not prevented recruitment from the estuary to the freshwater at some stage in the past. Recruitment is most likely facilitated by the inclusion of by-washes in the pondage system that allows some water flow even under the low to moderate patterns encountered during the study.

The barramundi population in sites at the Fitzroy location was dominated by large barramundi with few small stages in samples from either the pondage system or the freshwater habitats. There was low recruitment of juvenile stages of barramundi to freshwater habitat at this location during the study. The presence of large barramundi in the freshwater habitats suggests that this site had also been subject to substantial recruitment at sometime in the past. This most likely occurred at the last major flow event in association with a major wet season in 1990-1991.

The absence of early juvenile stages some in freshwater sites may indicate either low levels of recent recruitment or low survival of early stage juveniles entering these sites. Low levels of recruitment into the freshwater systems may be related to low flow patterns associated with lower than average rainfall which may have contributed to the disruption of the movement of early juvenile stages of barramundi from the estuarine habitats to the freshwater sites. The impact of low flows on spawning success was not explored in this study but it is expected that this would be a contributing factor to low recruitment levels and is worthy of further exploration.

Low survival of early stage juveniles entering freshwater habitats may be related to habitat condition (refer to water quality section) or to predation. Griffin (1994) has described failure of barramundi recruitment into barramundi in alternate years associated with high predation on recruits by larger size classes. It is worth noting that the population at the Proserpine location was dominated by juvenile stages with few mature stages while the primary locations contained a large proportion of older fish. Cannibalism of smaller stages recruiting to these habitats is likely and has been reported by Griffin (1987). A better understanding of the processes driving barramundi recruitment would assist the development of guidelines or strategies for managing interactions between ponded pastures and barramundi.

The movement and survival of barramundi in ponded pastures are major fisheries issues associated with ponded pastures. Trends in the survival of barramundi are evident in the results of the investigation. In particular, the results suggest high mortality of barramundi in intermittently inundated ponded pastures and low mortality in systems where water quality can be maintained. Growth patterns for barramundi in ponded pasture systems have not been identified and further assessment is required for those systems that remain permanently inundated.

It was evident during the study that the survival of barramundi in freshwater habitats associated with ponded pastures is also poor. A number of mass-kills of fish involving barramundi occurred during the investigation, and represent a major loss of resource. The overall numbers of barramundi in samples was generally low with population estimates (in the primary locations ranging from 50 to 300) also considered low. Barramundi numbers in recruitment events and in freshwater habitats might be expected to occur in the thousands from other research (Griffin 1994 Northern Territory). Griffin (1992,1994) used a closed area depletion method to estimate the size of the barramundi population at two sites in the Northern Territory. The results of the Northern Territory study indicated that a 400 m length of billabong in one site contained 398 barramundi and that the 6 kilometres of lagoon system contained some 6000 barramundi. Griffin (1994) obtained yearly estimates of the barramundi population as a second site (a billabong 450 m in length) over six years of between 200 and 1100. The present study provided a rough estimate of between 297 and

323 barramundi in a lagoon some 800 m in length providing a density estimate of between 18.5 and 20 barramundi per hectare.

The current investigation has revealed evidence of the disruption to barramundi movements by inappropriately located pondage banks and of high mortality of barramundi trapped in ephemeral ponded pasture systems. It remains to be determined how barramundi recruitment and production has been impacted and whether these impacts can be separated from other sources of variation such as rainfall and inundation patterns, other forms of modification to nursery areas, and trends in fishing effort.

Wetland associated with pondage system, Corio Bay.

Freshwater lagoon in grazing system, Fitzroy Estuary

Freshwater lagoon in grazing system, Fitzroy Estuary

9. Water Quality and Vegetation in Ponded Pasture Systems

9.1 Introduction

Ponded pasture systems have been developed for cattle production in many areas of northern Australia and are described in Pittaway et al. (1996). The development of ponded pastures involves the construction of an earthen bank for the collection and storage of surface run-off and the introduction of exotic species of water-loving grasses to provide feed for cattle. The development of ponded pastures has potential to increase the area of wetland. However, the development of earthen banks and the introduction of exotic pasture species in or near coastal wetlands involve substantial change to fisheries habitats whose impacts have not been fully identified.

Concern has been raised about the impact of ponded pastures on fisheries resources (Anon 1991). The impact on barramundi movement and survival has been a focus of a previous section because of the importance of barramundi to commercial and recreational fisheries and relates to the entrapment of fish in pondage systems. The location of ponded pastures in or adjacent to coastal wetlands has considerable potential for the interaction with fisheries resources. A variety of fish species utilise coastal wetlands as nursery areas and these habitats are considered vital for the sustainability of many tropical fisheries. Barramundi production is particularly dependent on tropical coastal wetlands and has been reported to be under threat from loss of coastal wetlands (Russell and Garrett 1983). The modifications to coastal wetlands with the development of ponded pastures are therefore of considerable interest for fisheries management. This section examines water quality and vegetation distribution of ponded pastures in the primary study locations to provide an overview of the value of these systems as fish habitats.

9.2 Methods

Water quality and vegetation communities were examined in three ponded pastures in the Broad Sound, Corio Bay and the Fitzroy Estuary in association with monitoring of fish populations reported in a previous section of this report. Fish populations in ponded pastures and freshwater lagoons were sampled with a variety of gill nets (50 mm to 200 mm stretched mesh sizes), bait nets, cast nets, and electrofishing techniques. Depth profiles of water quality parameters including dissolved oxygen, pH, temperature, conductivity, and turbidity were recorded using a Horiba water quality meter. Readings were obtained every 1 m. Twenty-four hour profiles of water quality were obtained from pondage systems at the Fitzroy, Corio Bay and Broad Sound locations and from the freshwater sites in the Fitzroy and Broad Sound locations. The profiles were obtained by recording DO, pH, conductivity and turbidity every 30 minutes over a 24 hour period with a YSI 6000 Sonde set at between 0.5 and 1 m water depth. Ground cover in and adjacent to the ponded pasture at Broad Sound was assessed using ground truthing, aerial photography and satellite imagery.

9.3 Results

9.3.1 Pondage design, location and vegetation

The location of ponded pasture systems and the associated ground cover types for each of the three primary study locations (Broad Sound, Corio Bay and Fitzroy Estuary) are presented in maps in Appendix 9. Each system is close to estuarine habitats supporting barramundi, and located between a small coastal stream and the upper intertidal zone. Each pondage system was established with the construction of an earthen bank across the estuarine–freshwater interface and the adjacent coastal plain. The form of this interface varied between locations, but generally included a mosaic of supra-littoral areas associated with one or more remnant tidal channels and a variety of brackish water or freshwater wetlands.

The pondage bank at Corio Bay and in the Fitzroy location was constructed with material sourced from off site usually extracted from nearby hill sides or slopes. The bank at the Broad Sound location was at least partly composed of fill material excavated from on-site. These local excavations resulted in numerous borrow pits on either side of the bank. These were generally shallow pools between 0.5 and 1m in depth. Fish including mullet, ambassids and herrings were often observed in the pools located on the estuarine side of the pondage bank. Fish were not observed in the pools on the pondage side of the bank.

Historical photographs indicated that prior to the construction of the pondage bank, the supra-littoral area in Corio Bay previously contained a mixture of salt-marsh and claypan habitat without a well defined tidal channel. This pondage system contains freshwater and exhibits no substantial increase in salinity as the water levels recede (see water quality section). The pondage system contains a mixture of water lilies, reeds and para grass. Para grass was particularly well established along the intermittent stream that feeds the pondage system. *Melaleuca* sp. occurs along the edges of the pondage system. The mix of vegetation types (reeds, lilies and para grass in the pondage system changed with season and inundation extent although this change was not quantified. Substantial mangrove colonisation had occurred along the estuarine side of the pondage bank at this location. A series of shallow pools occurred along the estuarine side of the pondage bank.

The pondage systems in the Fitzroy and Broad Sound locations included remnant tidal channels. These channels have been isolated from tidal inundation by the construction of the earthen bank across the original tidal channels. At the Fitzroy location, the earthen bank crosses several tidal channels that had previously drained an oxbow formation. The tidal channels on the estuarine side of the bank are fringed with mangroves. The remnant channels on the ponded side of the bank contain a number of dead trunks of mangroves that had died since the bank had been constructed and had subsequently prevented tidal inundation. A mosaic of salt-marsh and clay pan areas occurred in close proximity to the tidal channels. Para grass was not established in or immediately adjacent to the remnant tidal channels on the landward side of the bank. Mangroves had become well established along the estuarine side of the bank at the Fitzroy location. Water depths in the channel during inundation are from 1.5 m to 2 m. The adjacent plains become inundated to depths up to 0.75 m.

At the estuarine side of the pondage bank at the Broad Sound location was mainly bare mud, clay pan and salt-marsh with very few mangroves. There was evidence of substantial erosion with deepening of tidal gutters immediately below the bank. At one end of the bank there was substantial tidal intrusion occurring into para dominated pasture. The pondage bank at the Broad Sound location also contained several bywashes or low points for overflow to the estuary.

With the advancing dry season and receding water levels, the inundated areas in both locations were restricted to the remnant tidal channels. This occurred between September and early December each year. The Fitzroy location however, did not dry completely. Water levels at this site appeared to be maintained by seepage of tidal water through the bank. Water could be observed trickling out at the base of the estuarine side of the bank at low tide.

The distribution of para grass was restricted to freshwater influenced areas in both the Fitzroy and Broad Sound locations. Salt influenced areas were either bare or dominated by salt tolerant species. In two of the study locations, the range of habitats in the pondage system included salt-marsh dominated areas associated with remnant tidal channels and areas dominated by freshwater pasture species such as para grass.

The remnant tidal channels were largely devoid of vegetation and formed open water ponds that dried completely during spring. Para grass extended up to the edge of the more salt-influenced areas but was not well established in any of the strongly salt-influenced habitats such as those adjacent to mangroves, on salt-marshes or clay pans or in blocked tidal channels. Sections of pondage systems that were previously tidal or retained strong salt influence were largely dominated by reeds or sedges (Cyperacae), salt-marsh species or other halophytes. Para grass was well established in areas that were located away from saline influences and formed shallow (<1 m) wetlands when inundated.

In the Corio System, the pondage system contained an extensive area of para grass adjacent to sedges, reeds and Melaleucas. The composition of aquatic vegetation varied seasonally and with changes in the extent of inundation. During the wet phase para grass quickly became dominant and was associated with poor water quality and very few fish of any species.

9.3.2 Barramundi

A summary of the results of the barramundi sampling (details of which were presented in a previous section) and are briefly summarised as follows. Barramundi were not present in the pondage system or freshwater site at the Corio Bay location. Barramundi populations in the freshwater sites above ponded pasture systems in the Fitzroy and Broad Sound locations contained mostly large barramundi (> 500 mm TL). The pondage system in the Broad Sound contained only small barramundi (<450 mm TL). Within the pondage systems at the Fitzroy and Broad Sound locations, barramundi only occurred in the remnant tidal channels. Barramundi were not captured in shallow (<1 m) sections of the pondage system or in adjacent wetlands dominated by para grass. These areas were generally inundated to less than 1 m depth and were inundated for short times during the study.

The lack of major flow events and partial inundation of primary locations for much of the study prompted additional investigations to be undertaken in a pondage system and associated wetland dominated by para grass at a secondary site (Goorganga Creek) near Proserpine. This site had been subject to more extensive inundation than the primary locations and contained a large freshwater wetland associated with a small pondage bank. The wetland was fed by a stream that contained a series of deep (>2 m) lagoons fringed with para grass and *Hymenachne*. This stream contained a variety of habitats including mats of para grass, lilies, submerged vegetation, overhanging trees and large organic debris and barramundi were captured from most of these. A summary of barramundi catches by habitat type is presented in Table 17 and it is of interest that barramundi were captured in lilies or in floating mats of para grass associated with the stream. Sample sizes were inadequate to allow any statistical comparison of abundance in various habitats and further investigation is required to assess habitat preferences. Barramundi were also captured in an additional site fringed with lilies and containing heavy growth of submerged aquatic vegetation. Barramundi were not present in shallow (<0.5 m) para grass dominated wetlands adjacent to the lagoons or stream.

Table 17 Abundance of barramundi captured by electrofishing in various aquatic vegetation types. (Proserpine).

Habitat Type	Length (m) fished	Abundance of Barramundi
Unvegetated bank	100	4
Overhanging trees /large organic debris	150	3
Para grass	200	6
Lilies	350	12
Reeds	50	1
Submerged vegetation	100	1
Mid Channel	100	1

9.3.3 Water quality

The minimum and maximum values of water quality parameters for each habitat type (estuarine, pondage and freshwater) at the three primary locations are presented in Table 18. These results show that at certain times there are very low levels of dissolved oxygen in all three habitat types across each location.

Elevated pH (>9) readings were recorded at some sites including site in intertidal habitats at Corio Bay, and in pondage systems and freshwater sites at all three locations. The high pH values appeared to be associated with algal blooms at these sites. An extremely low pH (2.48) was recorded at the intertidal site in Corio Bay. Soil samples from ponded pastures in Corio Bay and in Broad Sound were obtained with the assistance of the Department of Natural Resources and tested for acidity. Results and indicate that high levels of peroxide oxidisable sulfur are present in the sediments in pondage systems at Corio Bay (Tables 19) and Broad Sound (Table 20) although these are not present uniformly throughout the location. The Department of Natural Resources completed a survey of acid sulphate soil in the Corio Bay region and found extensive deposits (Ross et al. 2000). The distribution of acid sulphate soils in coastal regions of central Queensland has not been assessed but it is likely that there will be high acidity or potential acidity of soils in areas near mangroves and intertidal mudflats.

High temperatures (>33ºC) were recorded for pondage and freshwater sites at the Fitzroy and Broad Sound locations. High temperatures (>34ºC) were also recorded for intertidal sites at the Fitzroy and Corio Bay locations. Salinity ranged between 0 and 40 ppt within the pondage system at the Fitzroy and between 0.2 and 75 ppt at the Broad Sound locations. Salinity in these sites increases as the water levels recede and salt concentrations increase. High levels of salinity (75-100 ppt) were also recorded in upper intertidal sites.

Results of the twenty four hour profiles of water quality (DO, pH, temperature, conductivity and turbidity) of pondage sites and freshwater sites in selected seasons are presented in Appendix 10. Profiles from all seasons were not obtained. The patterns in dissolved oxygen, pH and temperature are of most interest. The twenty four hour profile for the Fitzroy pondage systems during December showed pH values ranging from 8 to 9. Daily temperature range at this site during December was 28ºC to 34ºC. Dissolved oxygen during the December recording ranged between 5 and 10 ppm. During April, pH at this site was consistently above 9. A twenty four hour profile of water quality in the Broad Sound ponded pasture system during October indicated extremely high pH between 9 and 10.5 in association with a dissolved oxygen range between near zero and more than 10ppm. Only one profile was obtained from the pondage system at Corio Bay in October 1999 and this showed consistently low (<1ppm) dissolved oxygen levels over twenty four hours.

The diurnal patterns in water quality at the Fitzroy freshwater site for November and April did not show any extreme pH levels or extremely low dissolved oxygen levels. However, a profile of water quality in para grass in the adjacent wetland showed extremely low dissolved oxygen (<2 ppm) consistently over twenty four hours in combination with temperatures of 16.5ºC in August. A profile obtained at the same site in September also recorded low dissolved oxygen levels (< 2 ppm) with a temperature range of 21.5ºC to 22.5ºC.

Table 18 Summary of water quality by location and habitat type.

Corio Bay Location

Habitat Type		pH	Conductivity ms/cm	Turbidity (ntu)	Dissolved Oxygen (O2)	Temperature (C)	Salinity (ppt)
Intertidal	Min	2.48	0.00	1.00	0.11	11.60	0.0
	Max	9.1	165	942	14.4	36.3	100.0
Pondage System	Min	5.74	0.00	3.00	0.05	15.80	0.0
	Max	7.91	2.7	520	9.44	27.4	4.0
Freshwater	Min	5.72	0.05	0.00	0.05	10.50	0.0
	Max	7.65	3.28	545	8.29	31	1.6

Fitzroy Location

Habitat Type		pH	Conductivity ms/cm	Turbidity (ntu)	Dissolved Oxygen (O2)	Temperature (C)	Salinity (ppt)
Intertidal	Min	6.11	0.20	4.00	1.28	17.10	0.00
	Max	8.35	59.2	466	14.62	34.4	39.5
Pondage System (Supralittoral)	Min	6.17	0.25	0.00	0.14	15.7	0.00
	Max	9.7	69.9	998	16.95	33.4	40.0
Pondage System (Freshwater)	Min	6.65	0.14	32.00	1.48	18.60	0.10
	Max	8.62	2.33	171	13.19	22.1	1.10
Freshwater	Min	6.07	0.14	0.00	0.02	16.7	0.00
	Max	10.0	498	847	16.9	35.4	2.10

Broad Sound Location

Habitat Type		pH	Conductivity ms/cm	Turbidity (ntu)	Dissolved Oxygen (O2)	Temperature (C)	Salinity (ppt)
Intertidal	Min	7.90	5.90	70.00	4.8	17.00	3.0
	Max	8.8	10	700	10.9	24	5.0
Pondage System	Min	6.84	0.51	5.19	2.08	16.10	0.20
	Max	9.94	50.7	847	18.47	32.5	75.0
Freshwater	Min	5.79	0.07	1.00	0.07	13.90	0.00
	Max	9.76	7.55	537	11.88	34.3	4.10

Water quality in the freshwater site at the Broad Sound during summer displayed a range in pH between 8 and 10, a range in dissolved oxygen between 4 and 10ppm and a range in temperature between 29 and 32 ºC. A twenty four hour profile taken at this site in March 1999 after the fish kill indicated dissolved oxygen ranged from 2 to 4 ppm and a temperature range of 27ºC to 29ºC.

9.4 Discussion

9.4.1 Suitability of near intertidal areas for ponded pastures

There is considerable variation in the form and design of ponded pastures and some of these have been described in Pittaway et al. (1996). The three systems examined in detail for this study varied considerably in their design, location, vegetation cover, and water quality.

Residual salinity in ponded pasture systems will influence the establishment of pasture species such as para grass that tend to have low salt tolerance. Ponded pastures developed across tidal channels become either brackish or strongly saline as water levels recede and are therefore unsuitable for the establishment of para grass. Coffey (1991) refers to the development of ponded pastures on marine and estuarine areas (containing salt couch and claypan) of central and north Queensland to protect marine plains from soil erosion and salt encroachment and to promote pasture production. Wildin and Chapman (1988) reported that newly established pondage systems established in saline areas could be filled with surface flow from seasonal rainfall and drained to reduce residual salt. There was little evidence of residual salinity in the Corio Bay pondage. The location of this system previously contained salt-marsh associated with saline upper intertidal habitats but without any tidal channels. The construction of the pondage bank has effectively converted a mosaic of brackish supralittoral and saline upper intertidal habitats to a freshwater wetland despite high salt concentrations in pools immediately below the pondage bank. It is suggested that the elimination of salt from the site to produce a freshwater wetland system was assisted by the absence of a well defined tidal channel prior to bank construction. This site is in an area that receives slightly more rainfall than the other study locations. (1200 mm in Yeppoon compared with 900 mm in Broad Sound and Rockhampton). It remains to be determined whether this level of rainfall is significant in reducing saline conditions in supralittoral habitats to assist with the successful establishment of freshwater pondage systems and pasture.

Although ponded pastures constructed across tidal channels are useful for collection of water, they do not appear to be suitable for the development of high quality pasture systems due to residual saline influence during periods of low inundation. The water in the remnant tidal channels within pondage systems such as in the Fitzroy and Broad Sound locations became brackish or saline under low inundation levels. This occurs even though the water in the pondage system contains very little salt during inundation events. However, the persistence of saline influences during low levels of inundation reduces their suitability for the establishment of para dominated pasture. The source of salt in these systems most likely relates to residual salt in the sediments of the remnant tidal channels although it appears that seepage of tidal water through the pondage bank occurred at one of these locations.

Planning for ponded pasture systems should include an assessment of the risk of salt influences particularly near intertidal areas. It is considered that upper intertidal areas containing remnant tidal channels are unsuitable for the development of pasture using low salt tolerant pasture species. Supralittoral areas may be suitable for ponded pasture provided there is adequate freshwater input. The ponded pastures in the three primary locations were constructed with long earthen banks located across coastal wetlands associated with the estuarine-freshwater interface. However, the distribution of para grass in these systems is restricted to freshwater influenced areas, particularly those associated with freshwater marshes or wetlands and plains adjacent to the lower freshwater reaches of streams.

The use of halophytes as pasture in near intertidal areas requires further investigation. During drought conditions in this study, cattle were often observed grazing on marine plants. Adam (1990) has referred to the use of saltmarsh for grazing in northern hemisphere but this issue has not been investigated in northern Australia. The management of grazing by cattle on marine plants requires further attention. These considerations do not apply to areas where saline ground water has risen to the surface. Gordon (1996) has identified circumstances where ponded pasture systems may contribute to salinity.

9.4.2 Water quality.

The results of the present study suggest that water quality in ponded pastures is periodically poor in deep (>1 m) pondage systems and persistently poor in shallow systems dominated by pasture species. The combination of high pH, low dissolved oxygen and high temperatures are likely to present stressful conditions for fish. High temperatures (> 32ºC) occurred in some of the study sites. Low dissolved oxygen levels also occurred periodically most likely as a result of high biological oxygen demand associated with either an algal bloom, the collapse of an algal bloom, or decomposition of organic matter form terrigenous sources. Algal blooms are usually associated with elevated pH (Boyd 1990). In combination with the low oxygen levels and high temperatures, these conditions will be considerably stressful for fish.

In shallow wetlands dominated by para grass the dissolved oxygen levels are persistently low throughout twenty four hour cycle. This is most likely due to the accumulation of organic matter on the substrate of the wetland as a result of the rapid growth of para grass and the rapid shedding of leaf material. The persistently low oxygen levels in wetlands dominated by para grass suggest these habitats have little value as fish habitats. Bunn et al. (1998) have reported that para grass invasion of channels associated with cane-lands has a pronounced influence on aquatic ecosystem function. These influences include high sediment deposition, and high benthic respiration from accumulated organic matter and limited oxygen penetration of sediments and few benthic organisms (Bunn et al. 1998). Bunn et al. (1997) reported that very little of the primary production from para grass is transferred into the aquatic food web. Barramundi populations are likely to be impacted by para invasion where changes in the trophic structure of wetlands affect their fish nursery functioning or where water quality is severely degraded.

The spread of introduced semi-aquatic pasture grass species in shallow wetlands appears to be associated with changes in plant species composition and changes in water quality. The impact of shallow wetlands characterised by low oxygen levels on fish movement remains to be determined. This is particularly important for species such as barramundi that move between estuarine and freshwater habitats. In locations such as the Fitzroy and Corio Bay study sites, the freshwater streams drain into intermittently inundated wetlands that are dominated by para grass and are located on the freshwater side of the pondage system. Barramundi are required to cross these wetlands to move between the estuarine habitats or the pondage systems and the associated freshwater habitats. The influence of poor water quality on the distribution of barramundi remains to be determined. In the present study, the distribution of barramundi appeared to be influenced by disruption to movement patterns and recruitment processes by the combination of pondage banks acting as barriers and low water flows as presented in a previous section of this report.

Para grass also occurs as floating mats on the edge of deep (>2 m) streams represents a substantially modified aquatic habitat that has not been investigated. Barramundi were captured in these habitats in the present study but the function of floating mats of para grass connected to deep (>2 m) water in the provision of shelter or food for barramundi has yet to be determined.

9.4.3 Acid sulphate soils

There are many ponded pastures located in or near coastal wetlands containing mangroves in central Queensland. In many regions on the east coast of Queensland, these habitats are known to contain potential acid sulphate soils (Sammut and Lines-Kelly 1996). The disturbance of acid sulphate soils is known to be associated with fish kills and red spot disease through degraded water quality (Sammut and Lines-Kelly 1996). Low pH values (3.5) occurred in an upper-intertidal pool immediately below the pondage bank at the Corio Bay location when the pondage system had dried. Results of soil analyses indicated acid sulphate soil were present at this location (Table 19) and suggested that the pool had been impacted by leachate draining from acid sulphate soils at a time when the sediments were exposed to air. Soil analyses also indicated the presence of potential acid sulphate soils at the Broad Sound ponded pasture system (Table 20). Strategies for the management of acid sulphate soils need to be considered in the development and maintenance of ponded pastures. Guidelines for managing acid sulphate soils have been outlined by Ahern et al. (1998b). This is particularly important if construction or maintenance involve earth moving operations in locations containing acid sulphate soils. Leachate from acid sulphate soils in sediments underlying existing ponded pastures presents a risk during a dry phase and will require further investigation to assess and manage the risk to fisheries resources. There are likely to be similarities in the management strategies for acid sulphate soils in ponded pastures as with management of acid sulphate soils in northern New South Wales where related studies are being undertaken to assess the interaction between floodgates and fisheries resources (M. Barwick pers com).

Table 19 Results of analyses of soil samples from ponded pastures system at Corio Bay.

Habitat Type	Site No.	Depth m	Locality	A.M.G. Reference	Landform	Texture	S_{POS} %	TAA mH^+/t	TPA mH^+/t	Acid Sulfate Hazard
Melaleuca wetlands	CQA112	0-0.1	Sandfly Creek	264935mE; 7458407mN	Swamp	Medium	0.300	4	86	Low
Freshwater stream (dry)	CQA113	0.8-1.0	Sandfly Creek	265378mE; 7459366mN	Drainage line	Fine	0.015	2	2	Very Low
Upper intertidal	CQA114	0.2-0.3	Sandfly Creek	266220mE; 7458958mN	Supratidal flat	Fine	0.073	8	28	Low
Upper intertidal	CQA114	0.6-0.7	Sandfly Creek	26220mE; 7458958mN	Supratidal flat	Fine	0.125	2	23	Low
Upper intertidal	CQA114	1.2-1.3	Sandfly Creek	266220mE; 7458958mN	Supratidal flat	Fine	2.478	14	1380	Extreme
Pondage pasture	CQA115	0.3-0.4	Sandfly Creek	266255mE; 7458978mN	Swamp	Fine	0.014	11	11	Very Low
Ponded pasture	CAQ115	0.75-0.85	Sandfly Creek	266255mE; 7458978mN	Swamp	Fine	0.884	27	490	High
Ponded pasture	CQA115	1.4-1.5	Sandfly Creek	266255mE; 7458978mN	Swamp	Fine	0.312	0	0	Very Low

Notes: Hazard ratings based on peroxide oxidisable sulfur content (S_{POS}) and total potential acidity (TPA)
Further interpretation of S_{POS} and TPA can be found in the QASSIT guidelines.

Table 20 Results of analyses of soil samples from ponded pastures system at Broad Sound.

Habitat Type	Site No.	Depth m	Locality	A.M.G. Reference	Landform	Texture	S_{POS} %	TAA mH^+/t	TPA mH^+/t	Acid Sulfate Hazard
Coastal plain in pondage system	CQA119	1.2-1.3	Home Creek	765496mE; 7520532mN	Plain	Fine	0	0	0	Nil
Remnant tidal channel in pondage system	CAQ120	2.0-2.2	Home Creek	763752mE; 7518860mN	Drainage line	Medium	0.268	0	0	Very Low
Remnant tidal channel in pondage system	CAQ120	3.3-3.5	Home Creek	763752mE; 7518860mN	Drainage line	Medium	0.147	0	0	Very Low
Upper intertidal mud flat	CAQ121	1.0-1.2	Home Creek	763738mE; 7518883mN	Supratidal flat	Medium	0.741	19	446	High
Coastal plain in pondage system	CAQ122	1.0-1.2	Home Creek	763795mE; 7519144mN	Plain	Fine	1.441	1	756	Very High
Coastal plain in pondage system	CAQ123	1.5-1.7	Home Creek	761950mE; 7519510mN	Plain	Fine	0.989	0	0	Very Low
Coastal plain in pondage system	CAQ123	1.8-2.0	Home Creek	761950mE; 7519510mN	Plain	Fine	1.036	0	0	Very Low
Coastal plain in pondage system	CQA123	2.4-2.6	Home Creek	761950mE; 7519510mN	Plain	Fine	0.692	0	0	Very Low
Coastal plain in pondage system	CQA124	2.0-2.2	Home Creek	760718mE; 7519366mN	Plain	Fine	0.763	0	263	Moderate
Coastal plain in pondage system	CQA124	2.8-3.0	Home Creek	760718mE; 7519366mN	Plain	Fine	1.159	0	590	High
Coastal plain above pondage system	CQA125	2.25-2.5	Home Creek	760008mE; 7517766mN	Scroll plain	Fine	0.150	0	48	Low
Coastal plain above pondage system	CQA125	2.7-3.0	Home Creek	760008mE; 7517766mN	Scroll plain	Fine	0.861	0	382	Moderate

Notes: Hazard ratings based on peroxide oxidisable sulfur content (S_{POS}) and total potential acidity (TPA)
Further interpretation of S_{POS} and TPA can be found in the QASSIT guidelines.

Pondage system in Broad Sound

Freshwater habitat upstream of pondage system in Fitzroy Estuary

10. Managing Fisheries Habitat in Ponded Pasture Systems

10.1 Balancing agricultural demands and fisheries requirements.

The development of ponded pastures has been driven by the agricultural requirement for water collection and storage for pasture development and is particularly strong in regions with low rainfall. In localities where the ponded pastures have been developed in or near coastal wetlands the pondage bank serves an additional role in limiting tidal intrusion. The fisheries aspects of ponded pastures involve managing fish movement and maintaining survival. The balance between agricultural requirements and fisheries issues is therefore largely related to managing water flows and water quality. It is important to recognise that the management of ponded pasture systems and coastal wetlands is not restricted to the balance of agricultural and fisheries requirements. A range of other issues need to be addressed including other wildlife values (eg wading birds, crocodiles or frogs), non-agricultural water harvesting (eg urban water supplies or golf course maintenance), aquaculture and ecosystem functioning (eg maintenance of estuarine or coastal zone processes).

Ponded pasture systems are basically a water management system for providing water collection and storage for pasture development. The management of water flows for fisheries purposes relates to minimising the risk of fish entrapment and facilitating fish movement, particularly between freshwater and estuarine habitats for species like barramundi.

Water quality issues need to be considered by cattle producers to ensure that pasture development is not adversely affected by poor water quality, particularly saline influences. Water quality requirements for pasture production are less stringent than for fish survival or stock watering. Water quality requirements for stock watering however can be critical in relation to blue-green algae outbreaks. Blooms of blue green algae occurred in one of the study locations and appeared to be associated with stock deaths. Sound management of water quality is obviously important for fish survival. At the very least this will require maintenance of adequate water volume and water chemistry suitable for fish survival. Beyond this, strategies for maintenance of ecosystem processes need to be considered.

10.2 Managing water flows for fish movement.

Three strategies are suggested for managing water flows to facilitate fish movement in ponded pastures. These include the use of fishways, provision for a series of cascading banks as an alternative to the long single bank design that prevails, and provision of bywashes or bypass channels. Obviously these strategies all rely on adequate water to maintain a flow and are therefore useless in circumstances where adequate water is simply not available. In these circumstances, an alternative strategy is to provide pondage designs and or locations to minimise entry of fish into the storage system.

The viability of fishways based on rock pool and rock ramp designs in pondage systems should be assessed in some situations. A feasibility study is required to assess the costs and difficulties associated with locating, transporting and positioning suitable rock materials, and stabilising the structure to withstand high flows. It is recognised that fishways based on rock ramp and pool designs may not be appropriate for some pondage systems. In large impoundments such as dams and other water storage facilities, fish movement is facilitated by the provision of concrete fishways of various designs. In the case of earthen embankments used for ponded pastures, substantial concrete fishway structures are unlikely to be economically viable for the property holder.

In some cases, fish movement may need to be facilitated through the provision of water flows between pondage systems and adjacent estuaries or freshwater habitats. The provision of bywashes (or low points in the bank wall to direct overflow to the adjacent aquatic habitat) in pondage designs is likely to assist fish movement. Careful appraisal is required to identify design features that provide water flow management for assisting the movement of fish without increasing the rate of entrapment of fish within the ponded pasture. It is suggested that water flows and therefore fish movement might be facilitated by developing designs that provide water flows around the pondage system. Such a design might include channels which divert the bulk of high flows away from the pondage system but which include low diversion banks for directing some low flows into the pondage system. These features would be particularly useful in pondage systems on coastal plains and riverine flood plains subject to substantial fish recruitment particularly during periods of high flows and inundation events associated with major flooding. The development of management strategies that minimise the entry of fish to pondage systems may reduce the direct impact on specific fisheries resources such as barramundi. In some areas this may be possible through careful site selection away from nursery areas or freshwater estuarine interfaces. Further assessment of pond bank design is warranted to identify features that may restrict entry of fish. A series of short pondage banks located off-stream or at the base of slopes may be more appropriate for restricting fish entry than long banks near wetlands. Some ponded pasture systems in upper catchment locations are designed in this manner and an assessment of these would be useful.

The design of most existing systems is based on earthen banks located across or adjacent to wetlands or watercourses. Such designs do not provide good control of water flow and fish movement. Alternative designs that provide either a series of cascading banks or compartments within existing wetlands are likely to be more suitable for regulating or manipulating water flow and fish movement. Details of such designs would most likely need to be developed on a site by site basis. A feature for concentrating water into successive pondage systems would be useful for maintaining adequate volumes of water for fish.

Pondage systems on coastal plains and riverine flood plains will be subject to fish recruitment particularly during periods of high flows and large-scale inundation events associated with major flooding. Management of fish movement and entrapment under large-scale inundation has yet to be addressed.

10.3 Managing ponded pastures for fish survival.

The survival of fish in ponded pastures will require the maintenance of an adequate volume of water and adequate quality for fish survival. Many ponded pastures in low rainfall areas are generally shallow (<1 m) and have large surface areas. In the study location, these systems generally dry completely during spring. The critical issue to maintaining fish survival in these systems is firstly to ensure adequate water volumes. If a minimum water volume can not be maintained then design features that minimise entry of fish should be included in the system.

Design features that assist with the maintenance of a minimum volume of water include deep-water sections, wind breaks and shade to reduce evaporation, and provision for concentrating water volumes during periods of low inundation. The inclusion of a deep section in ponded pastures would provide a method of reducing the ratio of surface area to volume during periods of low inundation. This also provides a refuge for fish to avoid conditions of poor water quality, particularly high temperatures in shallow sections of the system. Features that reduce evaporation will assist the maintenance of water levels and volumes. Many of ponded pastures examined in the current study occur in coastal plains and riverine flood plains. These locations have generally been managed to increase pasture and therefore usually contain few trees. The provision of wind breaks (such as trees) will reduce evaporation and have been used in the management of aquaculture ponds (Boyd 1990). A method for concentrating the volume of water remaining during periods of low inundation levels could be implemented with a design based on a series of short cascading pondage banks. Such a system will require a system of control valves to allow draining water from one pond to the next as water levels recede. Development of this option will require feasibility studies including a cost benefit analysis.

Ponded pastures are characterised by periodically poor water quality including high temperatures, low dissolved oxygen, and high pH. The impact of poor water quality on fish in ponded pastures has not been directly observed in this study. The growth and survival of fish is strongly dependent on water quality both directly through sublethal and lethal effects of exposure to environmental factors at levels outside their tolerance range and indirectly through modification to ecosystem functions (eg changes in trophic structure). A variety of pond management options have been developed for the aquaculture industry (Boyd 1990). Some of these (eg mobile aerators) may be appropriate to ponded pasture systems depending on costs. Studies of freshwater streams and billabongs have however indicated that maintenance of aquatic ecosystem functions is assisted by riparian vegetation and that one of the mechanisms by which this occurs is through the shading provided by riparian vegetation. It is considered that the provision of deep water sections with shading may provide the most effective method for managing water for fish survival quality in ponded pasture systems.

Environmental factors other than dissolved oxygen, pH, temperature or conductivity have not been assessed in this study. It is likely that additional factors have an important role in determining water quality of ponded pastures particularly nitrites, ammonia and algal toxins (Boyd 1990). Algal blooms have been implicated in cattle deaths (Hallegraaeff 1992). Nutrients have been reported to be high in fish ponds occurring in pastures (Boyd 1976). Pittaway and Chapman (1996) have suggested that ponded pastures can provide a strategy to reduce the nutrient and silt load leaving grazing land. The role of nutrient cycling in ponded pastures and wetlands dominated by pasture species requires further investigation.

10.4 Acid sulphate soils

Acid sulphate soils are known to occur in coastal lowlands along much of the east coast of Australia (Sammut and Lines-Kelly 1997). The location of ponded pastures in regions containing acid sulphate soil has significance for property holders undertaking earth works associated with construction or maintenance of ponded pastures. Relevant agencies should be consulted before earthworks are undertaken in areas suspected of containing acid sulphate soils.

Although acid sulphate soils occurred in each of the primary study locations their distribution was not uniform and some areas within each pondage system contained low levels of acidity. Information of the distribution of acid sulphate soils within and adjacent to ponded pastures is needed to assess and manage the risks of acid sulphate soils when undertaking modifications or maintenance. For example, although high acidity levels were found at a site along the pondage bank at Corio Bay, low acidity levels occurred on the western edge of the pondage system adjacent to a *Melaleuca* forest. The development of a high flow channel along this western edge for restoring the connection between the estuarine habitats with the freshwater habitats presents the least risk of disturbance of acid sulphate soils on the available data.

Guidelines for assessment and analysis of acid sulphate soils (Ahern et al. 1998a) and management guidelines) for acid soils (Ahern et al. 1998b) are available. State and national draft strategies for management of acid sulphate soils are in preparation and will be relevant to the management of ponded pastures.

10.5 Managing the spread of pasture species

Exotic species of water-loving grasses such as para grass, aleman and hymenachne are capable of growing in greater water depths than those occupied by native aquatic plant species. These exotic grass species are highly invasive in wetlands and have the capacity to exclude the native species of aquatic plants. A draft weed strategy for Hymenachne has been produced (Csuhres 2000) to address the adverse impact of this species and to address the release of other ponded pasture species with weed potential.

10.6 Ponded Pasture Policy Options

A number of policy options have been prepared by the Ponded Pasture Steering Committee following the preparation and review of a discussion paper (Anon 1996, 1997). The options address several issues in addition to fisheries issues associated with ponded pastures and have been the basis of a set of recommendations currently before the Queensland Government. The management issues discussed in this report seek to address some of the fisheries issues associated with ponded pastures but should be considered the context of the broader range of issues presented in the discussion paper.

11. Benefits

This investigation has provided considerable information regarding the extent of ponded pastures in central Queensland, the species composition of fish populations in ponded pastures, and the movement and survival of barramundi in ponded pastures. The information provides a better understanding of the interaction between ponded pasture systems and fisheries resources and identifies specific issues that require attention. This will provide a more informed discussion of the fisheries issues associated with ponded pastures. Options for managing the movement and survival of barramundi in ponded pastures have been identified. Design features to manage water flow for pasture development and barramundi movement have been suggested to balance agricultural and fisheries requirements. Strategies for facilitating fish survival through managing water quality are also presented. The proposed management options aim to provide a balance between agricultural needs for water storage and pasture development with the fisheries requirements for maintenance of water quality and habitat access for barramundi.

Discussions and consultation with property holders and industry groups indicated there is widespread support for sustainable development strategies. Sustainable aquatic resource management in the study area will require the support of property holders and cattle producers. However, the adoption of strategies has been hampered in the past by the complexity of issues and a lack of available information on appropriate management strategies. The present study has focused attention on some of the issues and has provided base from which to identify and address the high risk areas. The involvement of some property holders and cattle producers in the investigations has assisted to foster a greater understanding of the fisheries issues associated with coastal wetlands.

A clear benefit of the present investigation is the identification of specific fisheries issues associated with ponded pastures located in or adjacent to coastal wetlands. The results indicate that ponded pastures constructed across remnant tidal channels or gutters will impact barramundi. This impact has not been quantified but the large number of tidal gutters associated with pondage banks in the study area suggest that there is potential for improved barramundi production through more appropriate management of these habitats. In addition, locations containing upper-intertidal pools where small barramundi may become trapped due to pondage banks preventing upstream movement require careful management. The most suitable management strategy will vary with the design and location of pondage systems and because these vary considerably will need to addressed on a case by case basis.

12. Further Development

Barramundi recruitment in coastal wetlands.

The current investigation has highlighted the extent of modification to barramundi nursery areas caused by ponded pastures, the potential for disruption to movement of small barramundi in certain locations, and the poor condition of freshwater habitats associated with coastal wetlands. The modification of barramundi nursery areas by the development of ponded pasture systems is one of several factors that have potential to impact barramundi recruitment and production. Other forms of wetland modification (weirs, causeways, roads, rubbish tips, and various urban and industrial developments) have also placed substantial pressure on wetlands in the study region. Habitat degradation in combination with below average rainfall and possible increase in fishing pressure suggest there is considerable risk of substantially reduced recruitment. Further assessment is required to determine whether the suspected low abundance of juvenile barramundi in this study reflects a decline in recruitment.

Trialing of strategies to manage barramundi movement and survival.

Modifications of high risk ponded pasture systems to facilitate barramundi movement and survival have potential to improve barramundi production. The results of the present study clearly indicate the extent of ponded pasture development and the potential for disruption to movement of small barramundi. A variety of design features for managing water movement and fish survival have been proposed based on the observations made in the present investigation. A practical assessment of these strategies is required to ensure their appropriateness and cost effectiveness. Management strategies and design features are more likely to be implemented if their effectiveness can be demonstrated. A demonstration site open to inspection by property holders with similar systems and by other stakeholders would be extremely useful for encouraging adoption of effective design features.

Impact of ponded pastures on barramundi under widespread inundation

The impact of ponded pastures during widespread inundation has yet to be determined. Predictions on the pattern of barramundi entrapment and survival following widespread inundation have been made but require testing. The effectiveness of proposed design features for facilitating fish movement and survival also require testing under major flows and inundations.

Inundation patterns encountered during this study were either low to moderate or of only short duration. An opportunity to assess the impact of ponded pastures under a major flow or extensive inundation did not occur. It is considered that the impacts of a large-scale inundation would involve widespread dispersal of post-larval barramundi stages. The entrapment and survival of barramundi under such conditions are yet to be assessed. It suggested that under the high inundation a greater proportion of ponded pastures in or adjacent to coastal wetlands would contain barramundi, although the entrapment rates in individual pondage systems may be similar to those resulting from periods of low inundation. The survival of entrapped barramundi might be expected to be proportional to the duration of inundation with low survival as the pondage systems dry.

Risk Management

A method for quickly assessing the risk that ponded pastures pose to barramundi or other fisheries resources would be very useful. Indicators for the level of risk to barramundi would assist the management of the interaction between ponded pastures and barramundi resources. These are likely to be based on the design of the ponded pasture and their proximity to nursery areas or spawning grounds. It is considered that a similar method for assessing locations of new ponded pasture proposals would also be extremely useful. The assessment of ponded pastures according to the potential risk to barramundi resource would assist in focussing effort on systems that most need attention. The present investigation has identified the location of systems across remnant tidal channels and systems in close proximity to upper-intertidal pools as high risk.

Barramundi Entrapment Rates

Barramundi movement and survival are critical issues in the impact of ponded pastures on barramundi. A reliable estimate of the rate of entrapment of barramundi in ponded pastures is required to assess the impact of ponded pastures on barramundi. Although a very rough estimate was obtained in this study, this provided an indication of the range of possible entrapment rates and further refinement is required.

Inundation patterns and barramundi production

A number of factors are likely to influence barramundi production and recruitment. The modification of coastal wetlands containing barramundi nursery areas is of particular concern. The development of inappropriately located ponded pastures is one form of modification. Most coastal regions contain a variety of other modifications including weirs, causeways, roads, rubbish tips, golf courses, and the development of industrial and housing estates. The impact on barramundi production of these modifications in combination with a period of steady increase in recreational fishing pressure and a high number of summers with low rainfall over the last ten years in north-east Australia is of particular interest. The likelihood of substantially reduced recruitment under these circumstances is considered extremely high and of concern to the fishery and further assessment is considered appropriate.

An assessment of the survival of juvenile barramundi that do not have access to nursery areas due to reduced access from pondage banks or other barriers would be extremely useful and would complement the present investigation into the impact of pondage banks.

Fish Habitat Condition and Pastures

A major issue associated with ponded pastures is the spread of introduced pasture species. The impact of these species on aquatic ecosystem functioning and on water quality appears substantial although the processes involved are poorly understood and require further attention. It strongly suggested that the nursery value of wetlands dominated by introduced pasture species is low. Considerably more work is required to assess the condition and value of barramundi habitats modified by the spread of pasture species. The low dissolved oxygen levels in wetlands dominated by introduced pasture species may limit or reduce fish movement. Further work is required to confirm this and determine whether specific management strategies are required. The role of nutrient in wetlands associated with pastures also requires further study to determine whether there are significant differences in nutrient flows and if so whether these impact the role of wetlands as fish nursery areas. The occurrence of algal blooms and particularly toxin producing blue-green algal blooms in ponds located in pastures is of particular interest for both agricultural and fisheries stakeholders. The occurrence of acid sulphate soils in locations containing ponded pastures is a major issue that requires careful attention.

Similar fisheries issues in other pondage systems

There is potential for extension of results to similar systems in other locations. The extent of ponded pasture development and related impacts in the coastal regions of northern Queensland and the Gulf of Carpentaria are yet to be determined. It is likely that the issues associated with the management of barramundi movement and survival in ponded pastures will be similar to those for saline intrusion control banks in the Northern Territory. The effectiveness of management strategies including the implementation of fishways in saline control banks in the Northern Territory is of particular interest. It is likely that some fisheries issues associated with ponded pastures will overlap with issues associated with the impact of flood gates in northern New South Wales (albeit with a different set of species).

Other issues associated with ponded pastures.

Ponded pastures often support large numbers of waterfowl and wading birds. A variety of fish species are likely to become prey to fish-eating birds. The interactions between fisheries species and other wildlife in ponded pastures has not been examined. Aspects of these interactions will need consideration in assessment of management strategies particularly in areas such as Corio Bay where the ponded pastures are also managed for wading bird habitats to provide an eco-tourism attraction.

The aquaculture potential of pondage systems was of interest to some property holders. In light of the expanding aquaculture industry and the role of aquaculture in providing diversification for primary producers, an assessment of the aquaculture potential of pondage systems would appear to be appropriate.

Pondage Bank in Broad Sound

Freshwater habitat upstream of pondage system in Fitzroy Estuary..

13. Conclusions

Objective 1 To document the extent of ponded pastures and other pondage systems in and adjacent to coastal wetlands on the central coast of Queensland.

The extent of ponded pastures development in and adjacent to coastal wetlands in central Queensland is substantial with more than 16,000 ha mapped in this investigation. Considerable modification of coastal wetlands in the Fitzroy Estuary, Corio Bay and Broad Sound regions has occurred with the development of ponded pasture systems in supra-tidal habitats and across the estuarine–freshwater interfaces in many locations. A variety of other stream barriers have been developed in wetlands and watercourses in the Fitzroy estuary and have compounded the disruption of aquatic habitats in this region.

Objective 2 To assess the movement, growth and survival of barramundi in ponded pastures.

Barramundi occurred in 40% of ponded pasture systems examined in this study. There is considerable potential for ponded pasture systems to impact barramundi production through the disruption to movement of early juvenile stages and late juvenile stages where the system is located in or adjacent to upper-intertidal habitats. Mass kills of fish did not occur in any of the ponded pasture systems that were monitored. There is complete mortality of late juvenile stages trapped in ponded pasture systems that dry completely. These did not appear to die in mass but perished gradually. Barramundi survival over several years was recorded in one ponded pasture system where water quality was maintained.

Barramundi movement in ponded pasture systems is dependent on flow patterns and bank design. Under moderate flows, large (>580mm) barramundi were able to move from freshwater habitats through an associated ponded pasture system that contained bywashes. Under low to moderate flows, early juvenile stages of barramundi were trapped in upper-intertidal pools below a ponded pasture system where the banks had been constructed across an upper-intertidal habitat. Large barramundi were also trapped within a ponded pasture system at a third location. A rough, preliminary estimate of the rate of entrapment (between 38 and 72%) of small barramundi in ponded pasture systems requires validation. A reliable estimate of entrapment rates is required to quantify the impact of ponded pastures on barramundi production. Age at size data were not obtained in the project and prevented analyses of growth rates and growth characteristics for different habitat types.

Objective 3. To assess the utilisation by barramundi of ponded pastures and wetlands dominated by exotic grass species.

Barramundi were not captured in shallow wetlands or ponded pasture systems dominated by para grass. Barramundi were however recovered from amongst floating mats of para grass on the edge watercourses. There are several water quality issues associated with ponded pasture systems and wetlands dominated by pasture species that have potential to impact their value as barramundi habitats. Preliminary analyses of water quality data indicate that ponded pasture systems and shallow wetlands dominated by introduced pasture species are periodically subject to very poor water quality including low dissolved oxygen and high pH. Persistent low dissolved oxygen in one system was attributed to high biological oxygen demand associated with build up of organic matter. Further work is required to assess the impact of para grass on barramundi habitats.

Objective 4 To identify appropriate wetland management strategies for facilitating barramundi movement and survival in ponded pastures.

A number of management strategies and design features have been identified for managing fish movement and survival to minimise interactions between ponded pasture systems and fisheries resources. These strategies aim to balance the fisheries requirements for fish movement and survival with the agricultural needs of water collection for pasture development. Management of ponded pastures systems in and adjacent to coastal wetlands requires careful attention on a case by case basis.

The investigation has identified locations for ponded pasture systems that present a high risk of interaction with fisheries resources. These include ponded pasture systems that are located across tidal channels draining upper-intertidal and supra-tidal areas and those that are located in close proximity to upper-intertidal pools. These areas are often unsuitable for pasture development because of saline influences. Locations across estuarine-freshwater interfaces are also high risk.

Some general guidelines should include locating pondage systems away from high risk locations, including design features which facilitate water flow (such as bywashes, diversion channels and flood routing), and including features which maintain water quality (shade and deep water sections) and habitat diversity. In many coastal wetland locations, the management of acid sulphate soils will need to be carefully considered when proposing construction of new systems and modification or maintenance of existing systems.

Successful management of interactions between ponded pasture systems and fisheries resources will require broad support from all stakeholder groups.

5) To document the species composition of finfish populations and their relative abundance in ponded pastures.

Some 23 species representing 15 families of finfish were identified in ponded pasture systems and include a variety of predators (eels, barramundi), filter feeders (herrings), detritivores (mullet), and prey species (ambassids, gudgeons).

14. Acknowledgements

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15. References

Adam, P. 1990 Salt-marsh Ecology. Cambridge University Press 1990

Ahern, C.R., Ahern, M.A. and Powell, B. (1998a) Guidelines for sampling and analysis of lowland acid sulphate soils (ASS) in Queensland 1998. QASSIT, Queensland Department of Natural Resources, Resource Sciences Centre, Indooroopilly.

Ahern, C.R., Stone Y. and Blunden B. 1998b Acid sulphate soils management guidelines. In Acid sulphate soil manual. Ed by Ahern,C.R., Blunden B. and Stone Y., Acid sulphate soils management committee, Wollongbar, NSW, Australia.

ANCA (Australian nature Conservation Agency) 1996 A Directory of Important Wetlands in Australia Second Edition. ANCA , Canberra.

Anon 1991 Unpublished Proceedings of the Probing Ponded Pastures Workshop. July 1991. University of Central Queensland.

Anon 1996 Ponded Pastures Discussion Paper. Queensland Government Unpublished paper prepared by the Interdepartmental Steering Committee on Ponded Pastures. Qld Department of Primary Industries

Anon 1997 Ponded Pastures Policy Options Paper. Unpublished Paper prepared by the Ponded Pastures Steering Committee. Qld Department of Primary Industries. 39pp

Appleton, C.C. 1983. Wetlands and Public Health. *J. Lim. Soc. South Africa*. **9** (2): 117-122.

Baltz, D.M., Fleeger, J.W., Rakocinski, C.F. and McCall, J.N. 1998. Food, density, and microhabitat: factors affecting growth and recruitment potential of juvenile salt-marsh fishes. *Envir. Biol. Of Fishes*. **53**(1): 89-103.

Bayley, P.B. 1991. The Flood Pulse Advantage and the Restoration of River-Floodplain Systems. *Research and Management*. **6**: 75-86.

Blaber, S.J.M. 1980. Fish of the Trinity Inlet System of North Queensland with Notes on the Ecology of Fish Faunas of Tropical Indo-Pacific Estuaries. *Aust. J. Mar. Freshwater Res.* **31**: 137-46.

Blaber, S.J.M., Brewer, D.T., and Salini, J.P. 1989. Species Composition and Biomasses of Fishes in Different Habitats of a Tropical Northern Australian Estuary: Their Occurrence in the Adjoining Sea and Estuarine Dependence. *Estuarine, Coastal and Shelf Science*. **29**: 509-531.

Boyd, C. E. 1990 Water Quality in Ponds for Aquaculture. Birmingham Publishing Co. Alabama

Boyd, C. E. 1976 Water chemistry and plankton in unfertilized ponds in pastures and woods. Trans.Am.fish Soc., **105**:634-636

Bunn, S.E., Davies, P.M., Kellaway, D.M., and Prosser, I.P. 1998. Influence of invasive macrophytes on channel morphology and hydrology in an open tropical lowland stream, and potential control by riparian shading. *Freshwater Biol.* **39**: 171-178.

Bunn, S.E., Davies, P.M., and Kellaway, D.M. 1997. Contributions of sugar can and invasive pasture grass to the aquatic food web of a tropical lowland stream. *Aust. J. Mar. Freshwater Res.* **48**(2): 173-179.

Cameron, D.G. and Kelly, T.K. 1970 Para grass for wetter country. Qld Ag. J., **96**:386-392.

Coates, M. and Unwin L. 1991 Ponded pastures and the habitat requirements of barramundi, *Lates calcarifer*. in Anon 1991 Unpublished Proceedings of the Probing Ponded Pastures Workshop. July 1991. University of Central Queensland.

Coffey, S. G. 1991 Historical perspectives, current status and current construction guidelines for ponded pastures in Queensland - overview paper. in Anon 1991 Unpublished Proceedings of the Probing Ponded Pastures Workshop. July 1991. University of Central Queensland.

Chapman, D. J. 1996 Overview: Design criteria for pondage systems. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin, J.H. and McDonald, C.K. pp. 64-67.

Copland, J.W. and Grey, D.L. (eds). 1986. Management of Wild and Cultured Sea Bass/Barramundi (*Lates calcarifer*). Proceedings of an international workshop, Darwin, N.T. Australia. 24-30 September 1986. pp.15-49.

Csurhes, S. (MS) Weeds of National Significance - The Hymenachne (*Hymenachne amplexicaulis*) Draft Strategy. Department of Natural Resources. 16pp

Cummins, V.G. 1991 Ponded pastures in Unpublished Proceedings of the Probing Ponded Pastures Workshop. July 1991. University of Central Queensland.

Davis, T.L.O., and Kirkwood, P. 1984. Age and Growth Studies on Barramundi, *Lates calcarifer* (Bloch), in Northern Australia. *Aust. J. Mar. Freshwater Res*. 35: 673-689.

Davis, T.L.O. 1982. Maturity and Sexuality in Barramundi, *Lates calcarifer* (Bloch), in the Northern Territory and South-eastern Gulf of Carpentaria. *Aust. J. Mar. Freshwater Res.* **33**: 529-545.

Davis, T.L.O., and Reid, D.D. 1982. Estimates of Tag Shedding Rates for Floy FT-2 Dart and FD-67 Anchor Tags in Barramundi, *Lates calcarifer* (Bloch). *Aust. J. Mar. Freshwater Res.* **33**: 1113-1117.

Davis, T.L.O. 1984. A Population of Sexually Precocious Barramundi, *Lates calcarifer*, in the Gulf of Carpentaria, Australia. *Copeia.* 1: 144-149.

Davis, T.L.O. 1985. Seasonal Changes in Gonad Maturity, and Abundance of Larvae and Early Juveniles of Barramundi, *Lates calcarifer* (Bloch), in Van Diemen Gulf and the Gulf of Carpentaria. *Aust. J. Mar. Freshwater Res.* 36: 177-190.

Davis, T.L.O. 1987 Biology of wildstock *Lates calcarifer* in Northern Australia. Pp 22-29, in Management of wild and cultured sea bass/barramundi (*Lates calcarifer*). Ed by J.W. Copeland and D. L. Grey. ACIAR Proceedings 20. Canberra Australian Centre for International Agricultural Research.

Dunstan, D.J. 1959. The Barramundi *Lates calcarifer* (Bloch) in Queensland Waters. Division of Fisheries and Oceanography, Technical Paper No. 5. Commonwealth Scientific and Industrial Research Organisation, Australia.

Garrett, R. W. 1991 Utilisation of wetlands habitats by coastal fishes in northern Australia. In Anon 1991 Unpublished Proceedings of the Probing Ponded Pastures Workshop. July 1991. University of Central Queensland.

Gordon, I. 1996 The salinity hazard of ponded pastures. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin, J.H. and McDonald, C.K. pp. 108-113.

Griffin, R.K. 1987 Life history, distribution, and seasonal migration of barramundi in the Daly river, Northern Territory, Australia. Am. Fish.soc.Symp. **1**:358-63.

Griffin, R. K. 1992 Barracade 92 Preliminary report of Closed Area Depletion Experiment Corroboree Billabong September 1992. Unpublished Report, Fisheries Division, Northern Territory Department of Primary Industry and Fisheries.

Griffin, R.K. 1994 Barracade 94 Preliminary report of Closed Area Depletion Experiment Corroboree Billabong September 1994. Unpublished Report, Fisheries Division, Northern Territory Department of Primary Industry and Fisheries.

Griffin, R.K. 1994. The Barramundi Population of Yellow Waters Billabong, Kakadu National Park. Fishery Report No. 33. Fisheries Division, Northern Territory Department of Primary Industry and Fisheries.

Hallegraeff, G.M. 1992. Harmful Algal Blooms in the Australian Region. *Mar. Poll. Bull.* 25(5-8): 186-190.

Humphries, S.E., Groves, R.H., and Mitchell, D.S. 1994 Plant invasions: homogenising Australian ecosystems. Conservation biology in Australia and Oceania, (eds C. Moritz and J. Kikkawa), Pages 149-70. Surrey Beatty &Sons, Chipping Norton, NSW.

Jamieson, A. and Bourne, A. 1996 Economic Analysis of Ponded Pastures. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin, J.H. and McDonald, C.K. pp. 38-42.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt,R.E., McNee, A., and Grieve, C. 1993 Australian Fisheries Resources. Commonwealth of Australia. Published by Bureau of Resource Sciences, DPIF and FRDC.

Kernot J. 1996 Ponded Pasture Experience in North Queensland in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin, J.H. and McDonald, C.K. pp. 22-23.

Kowarsky, J. and Ross, A.H. 1981. Fish Movement Upstream through a Central Queensland (Fitzroy River) Coastal Fishway. *Aust. J. Mar. Freshwater Res.* 32: 93-109.

Lawrence P.A. and Key A.J. 1996 Reliability of shallow water storages for ponded pastures in central Queensland. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin,J.H. and McDonald, C.K. pp.54-63.

Lukacs, G. P. 1996 Ponded Pastures as an environmental threat: Some research recommendations. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin,J.H. and McDonald, C.K. pp.119-120.

Middleton, C., Wildin J. and Venamore, P. 1996 Overview: Beef production from ponded pasture systems. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin,J.H. and McDonald, C.K. pp.15-21.

Moore, R. 1979. Natural Sex Inversion in the Giant Perch (*Lates calcarifer*). *Aust. J. Mar. Freshwater Res*. 30: 803-813.

Moore, R. 1982. Spawning and Early Life History of Barramundi, *Lates calcarifer* (Bloch), in Papua New Guinea. *Aust. J. Mar. Freshwater Res.* 33: 647-661.

Moore, R. and Reynolds, L.F. 1982. Migration Patterns of Barramundi, *Lates calcarifer* (Bloch), in Papua New Guinea. *Aust. J. Mar. Freshwater Res.* 33: 671-82.

Murphy K. and Wildin J. 1996 Animal Nutrition and Ponded Pastures. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin, J.H. and McDonald, C.K. pp. 52-53.

Pittaway, P. 1996 A workshop summary of the issues. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin, J.H. and McDonald, C.K. pp. 127-130.

Pittaway,P.A. and Chapman, D.G. 1996 The downstream benefits of ponded pastures. Pp 297-299 in Proc. Nat. Conf. On downstream effects of land use. Hunter, H.M., Eyles, A.G. and Rayment, G.E. Rockhampton 1995 Dept. of Natural Resources, Queensland, Australia.

Pittaway, P.A., Wildin, J.H., and McDonald, C.K.(eds.) 1996 Beef production from ponded pastures. Tropical Grassland Society of Australia Occasional Publication No 7.

Reynolds, L.F. and Moore, R. 1982. Growth Rates of Barramundi, *Lates calcarifer* (Bloch), in Papua New Guinea. *Aust. J. Mar. Freshwater Res.* 33: 663-670.

Robertson, A.I. and Duke, N.C. 1990. Mangrove fish-communities in tropical Queensland, Australia: spatial and temporal patterns in densities, biomass and community structure. *Mar. Biol.* 104: 369-379.

Robertson, A.I. and Duke, N.C. 1987. Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. *Mar. Biol.* 96:193-205.

Ross, D.J., Malcolm, D.T. and Hall, I.R. 2000 Pyritic sediments in geological map units of pleistocene age on the central Queensland coast. In Acid sulphate soils: Environmental issues, assessment and management, Technical Papers. Ahern, C.R., Hey, K.M., Watling, K.M., and Eldershaw, V.J. (Eds), Brisbane, 20-22 June, 2000, Department of Natural Resources, Indooroopilly, Queensland, Australia.

Russell, D.J. and Garrett, R.N. 1983. Use by Juvenile Barramundi, *Lates calcarifer* (Bloch), and other Fishes of Temporary Supralittoral Habitats in a Tropical Estuary in Northern Australia. *Aust. J. Mar. Freshwater Res.* 34: 805-811.

Russell, D.J. and Garrett, R.N. 1985. Early Life History of Barramundi, *Lates calcarifer* (Bloch), in North-eastern Queensland. *Aust. J. Mar. Freshwater Res.* **36**: 191-201.

Sammut, J. and Lines-Kelly, R. 1996 Acid Sulphate soils Acid sulphate soils Management Advisory Committee(ASSMAC). Department of the Environment, Sport and Territories and the Australian Seafood Industry Council.

Stockwell, T. Andison, R. and Lemcke, B. 1996 Producer experience in the Northern Territory. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin,J.H. and McDonald, C.K. pp. 24-29.

Stuart, I. and Mallen-Cooper, M. 1999 An assessment of the effectiveness of a vertical slot fishway for non-salmonid fish at a tidal barrier on a large tropical /subtropical river. Regul. Rivers: Res. Mgmt. **15**: 575-590

Thorncraft, G.A. and Harris, J.H. 1996 Assessment of rock-ramp fishways. Report for Environmental Trusts, NSW Environment Protection Authority, Border Rivers Commission, Department of Land and Water Conservation, and Wyong Shire Council. NSW Fisheries Research Institute and the Cooperative Research Centre for Freshwater Ecology.

Vass P. 1991 Ponded pasture could benefit barramundi. Qld Fisherman **9**: 18.

Wildin, J. H. and Chapman, D. G. 1988 Ponded pasture systems – Capitalising on available water . QDPI Extension Bulleting RQR87006.

Wildin, J.H., Chapman, D.G., Chamberlan, J., 1996 Overview:-Ponded pasture systems and use. in Beef Production from Ponded Pastures. Tropical Grassland Society of Australia Occasional Publication No 7 edited by Pittaway, P.A., Wildin, J.H. and McDonald, C.K. pp. 4-7.

Williams, L.E. 1997 Queensland's fisheries resources: Current condition and recent trends 1985-1995. Information Series QI97007 Department of Primary Industries Queensland. 101pp

16. <u>Appendices</u>

Appendix 1: Intellectual property

There is no intellectual property in the sense of patents or commercially marketable information associated with this research.

Landsat TM imagery used in this report were supplied under Copyright © Commonwealth of Australia by the Australian Centre for Remote Sensing (ACRES), a business unit of the Australian Surveying and Land information Group (AUSLIG),

Appendix 2: Project Staff

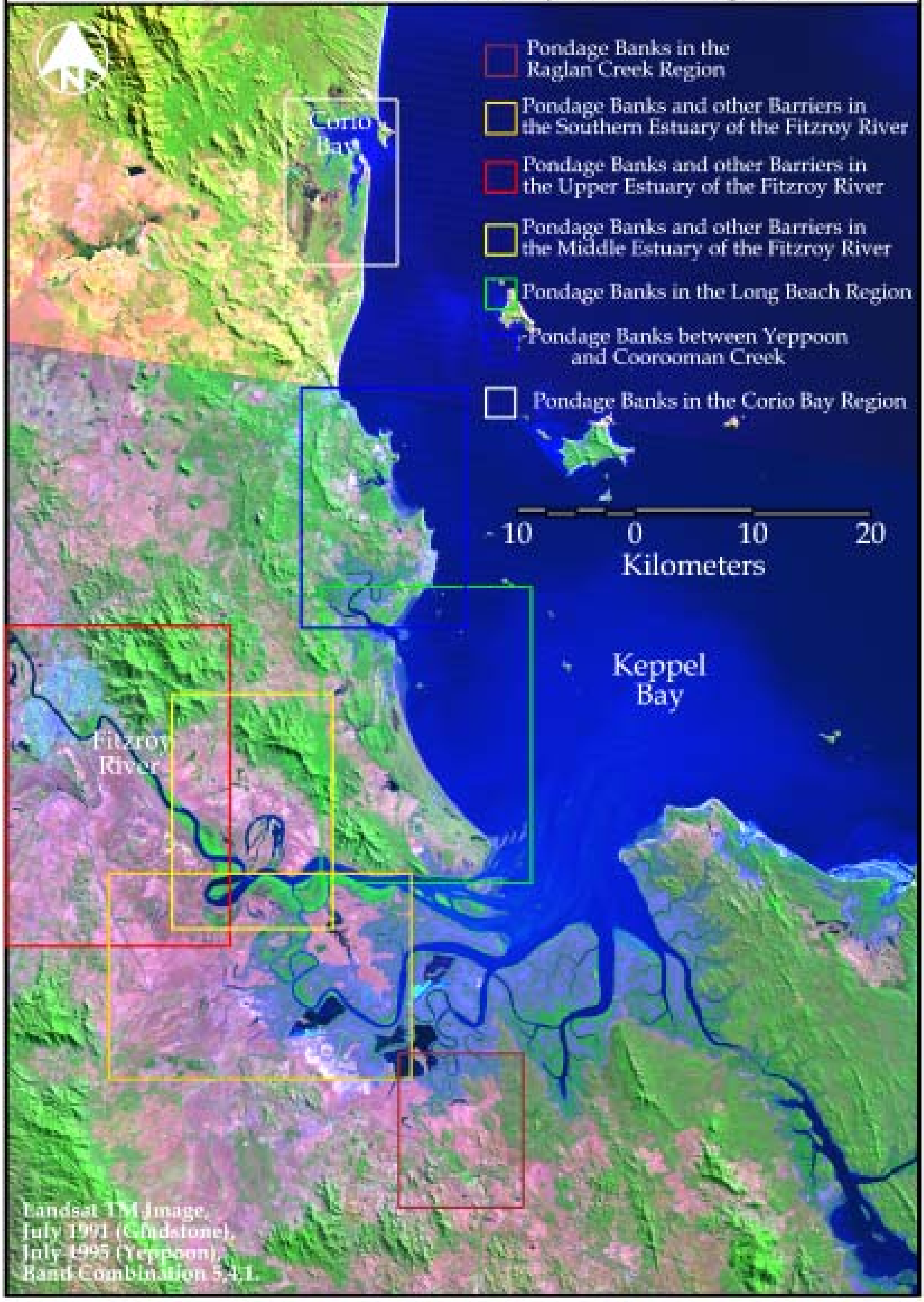
Mr. Stuart Hyland	(Principal Investigator)
Mr. Ian Conaghan	(Fisheries Technician 1/7/1997 – 20/12/1999)
Ms. Patrizia Radini	(Fisheries Technician 1/2/2000 – 30/6/2000)

Appendix 3

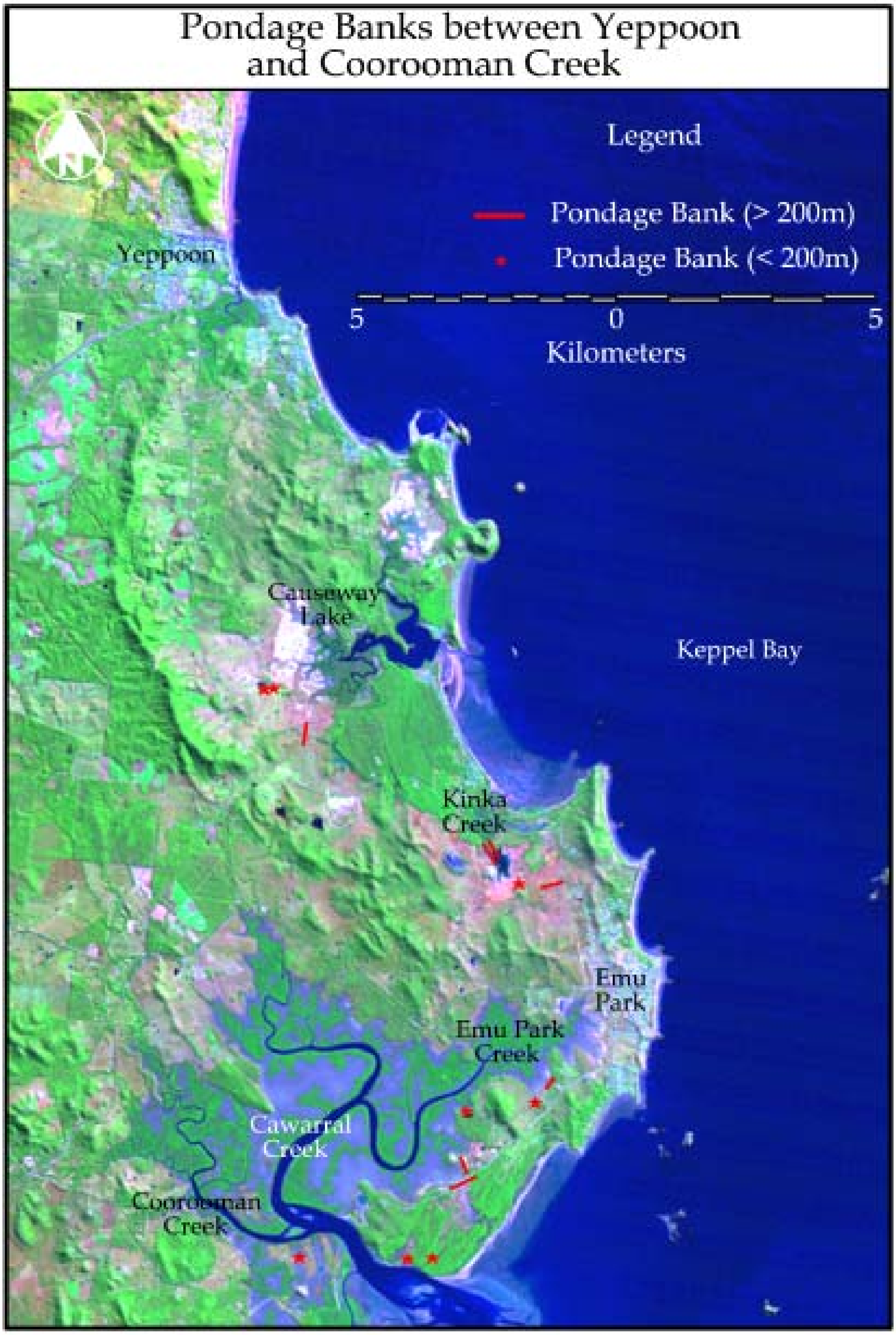
Location of pondage banks and other barriers in the Fitzroy Estuary and Corio Bay regions. (Maps on following eight pages.)

Landsat TM imagery used in this report were supplied under Copyright © Commonwealth of Australia by the Australian Centre for Remote Sensing (ACRES), a business unit of the Australian Surveying and Land information Group (AUSLIG),

Key Map of Pondage Locations in the Keppel Coast and Fitzroy River Region

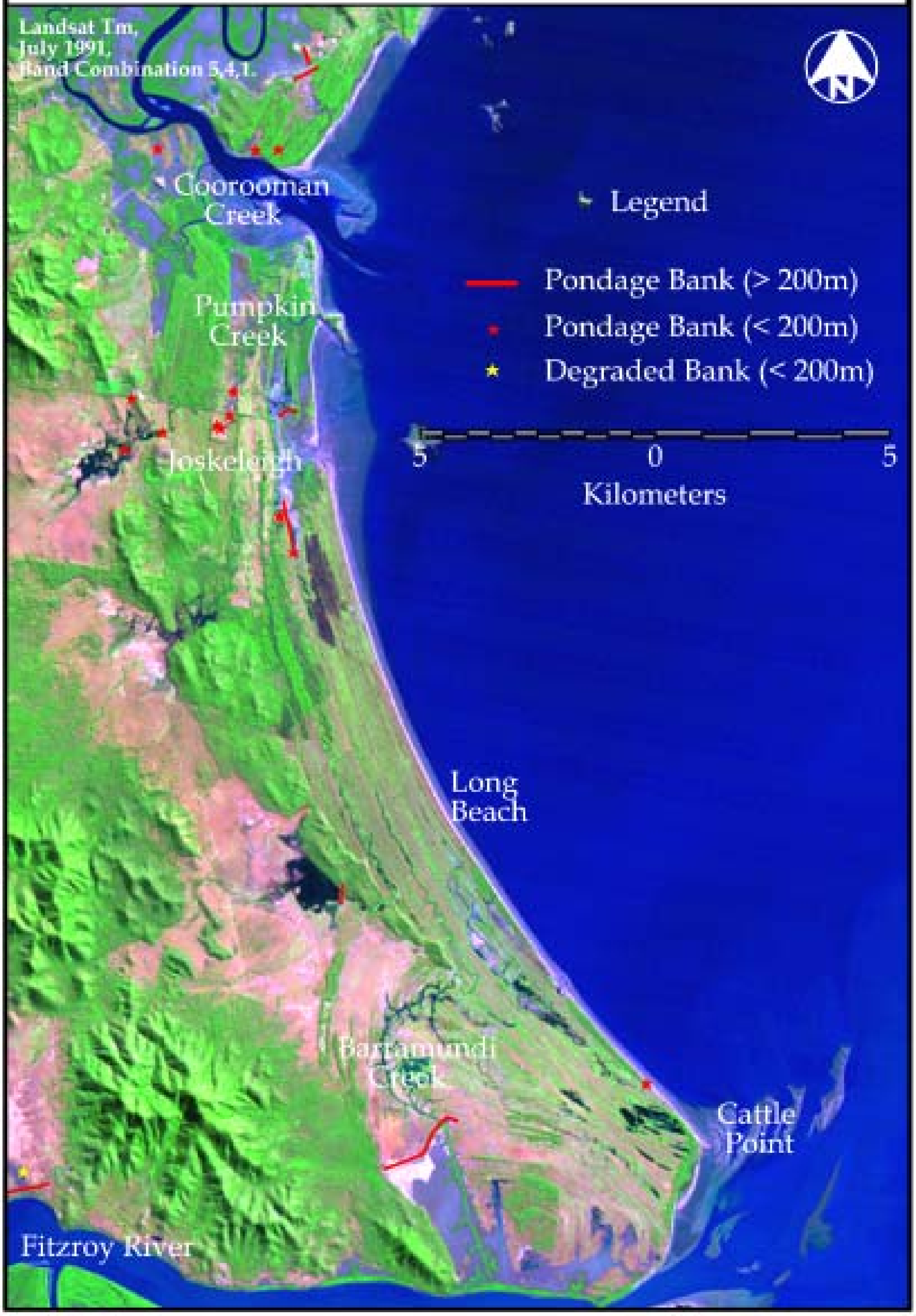


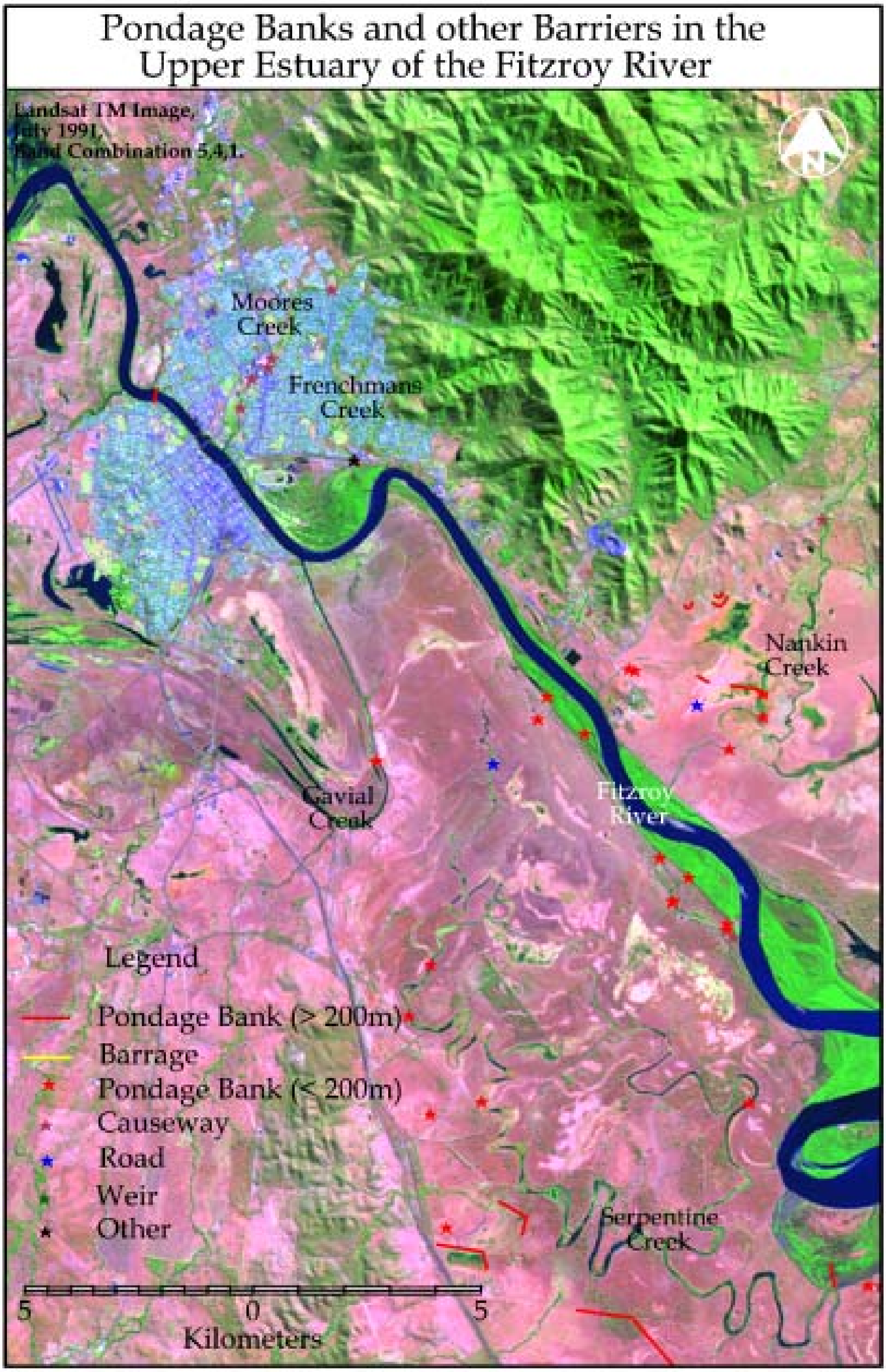
Pondage Banks in the Corio Bay Region



Pondage Banks between Yeppoon
and Coorooman Creek
Legend
Pondage Bank (> 200m)
Pondage Bank (< 200m)
5
0
5
Kilometers
Yeppoon
Causeway
Lake
Keppel Bay
Kinka
Creek
Emu
Park
Emu Park
Creek
Cawarral
Creek
Coorooman
Creek

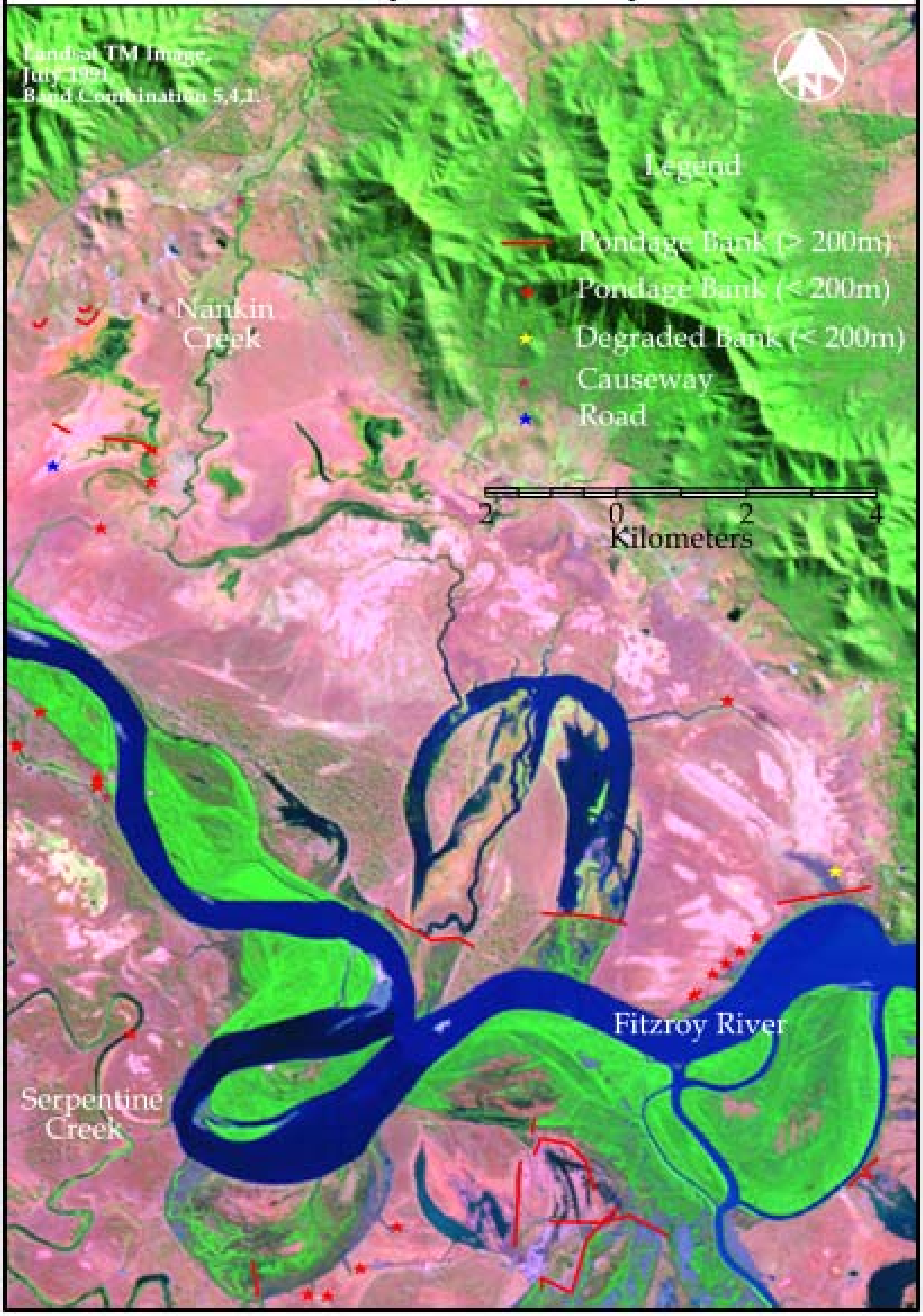
Pondage Banks in the Long Beach Region



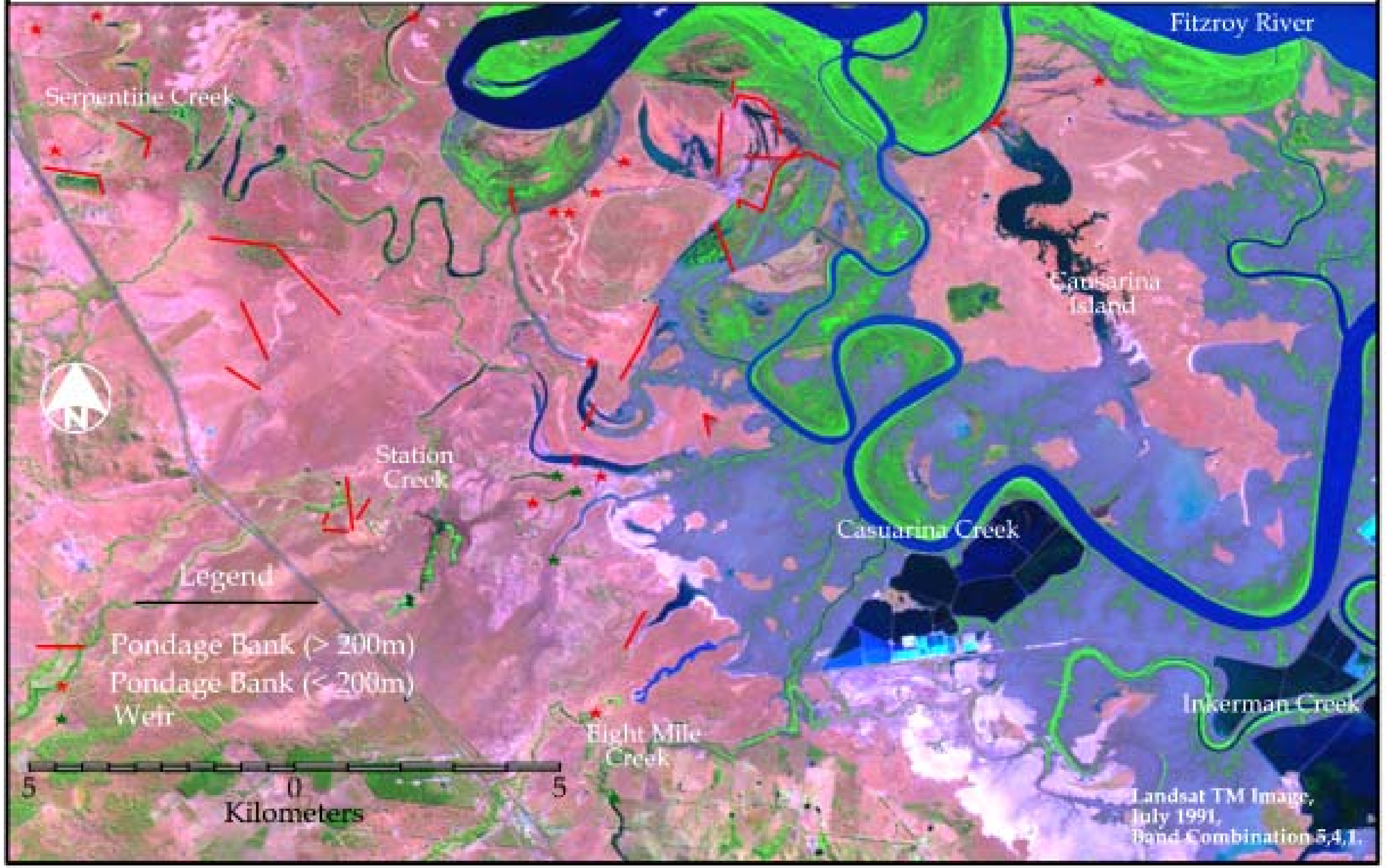


Pondage Banks and other Barriers in the Upper Estuary of the Fitzroy River
Landsat TM Image, July 1991, Band Combination 5,4,1.
Moores Creek
Frenchmans Creek
Nankin Creek
Fitzroy River
Gavial Creek
Serpentine Creek
Legend
Pondage Bank (> 200m)
Barrage
Pondage Bank (< 200m)
Causeway
Road
Weir
Other
5
0
5
Kilometers

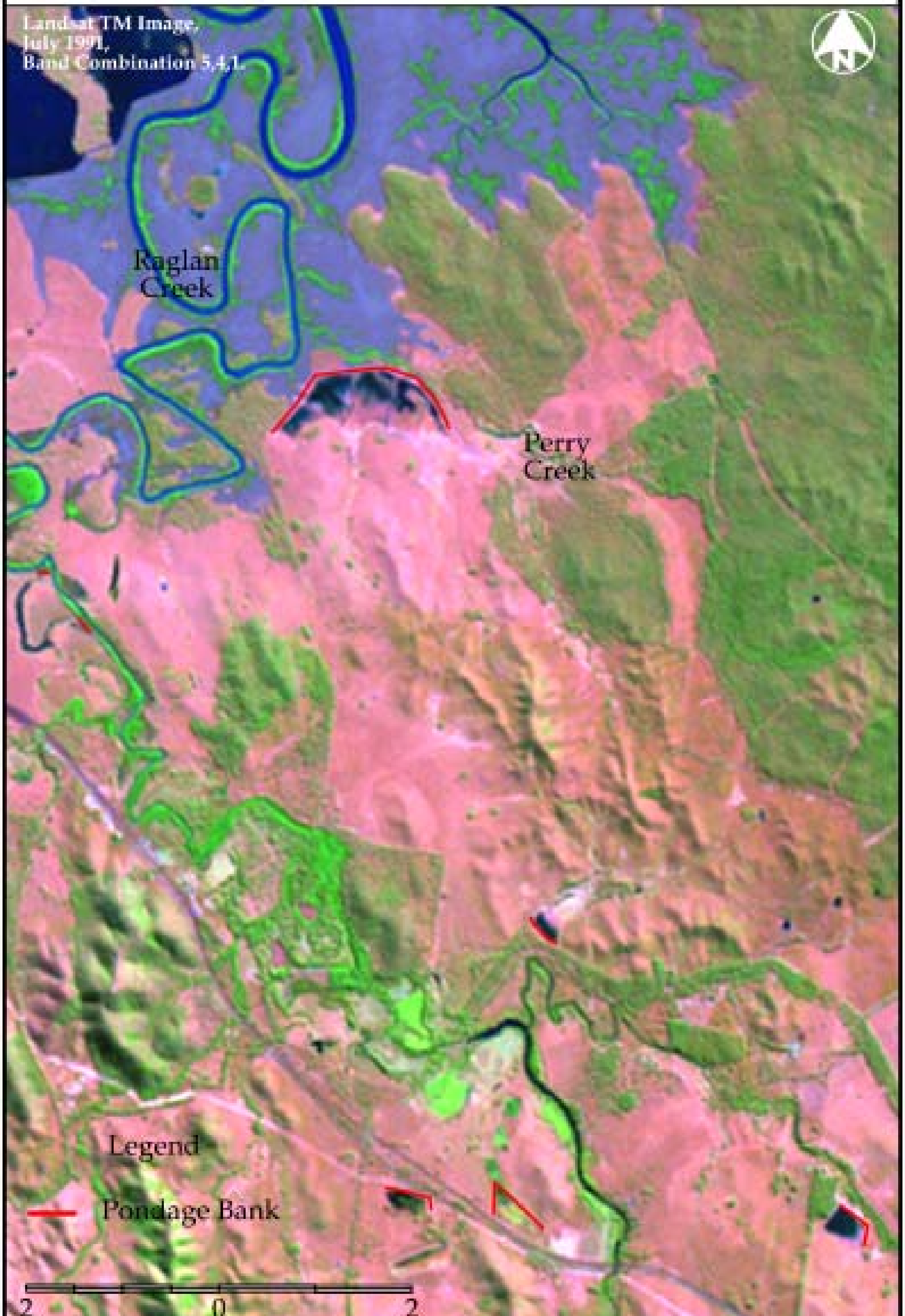
Pondage Banks and other Barriers in the Middle Estuary of the Fitzroy River



Pondage Banks and other Barriers in the Southern Fitzroy Estuary and Delta



Pondage Banks in the Raglan Creek Region



Appendix 4

Location of pondage banks in the Broad Sound region.
(Maps on following six pages.)

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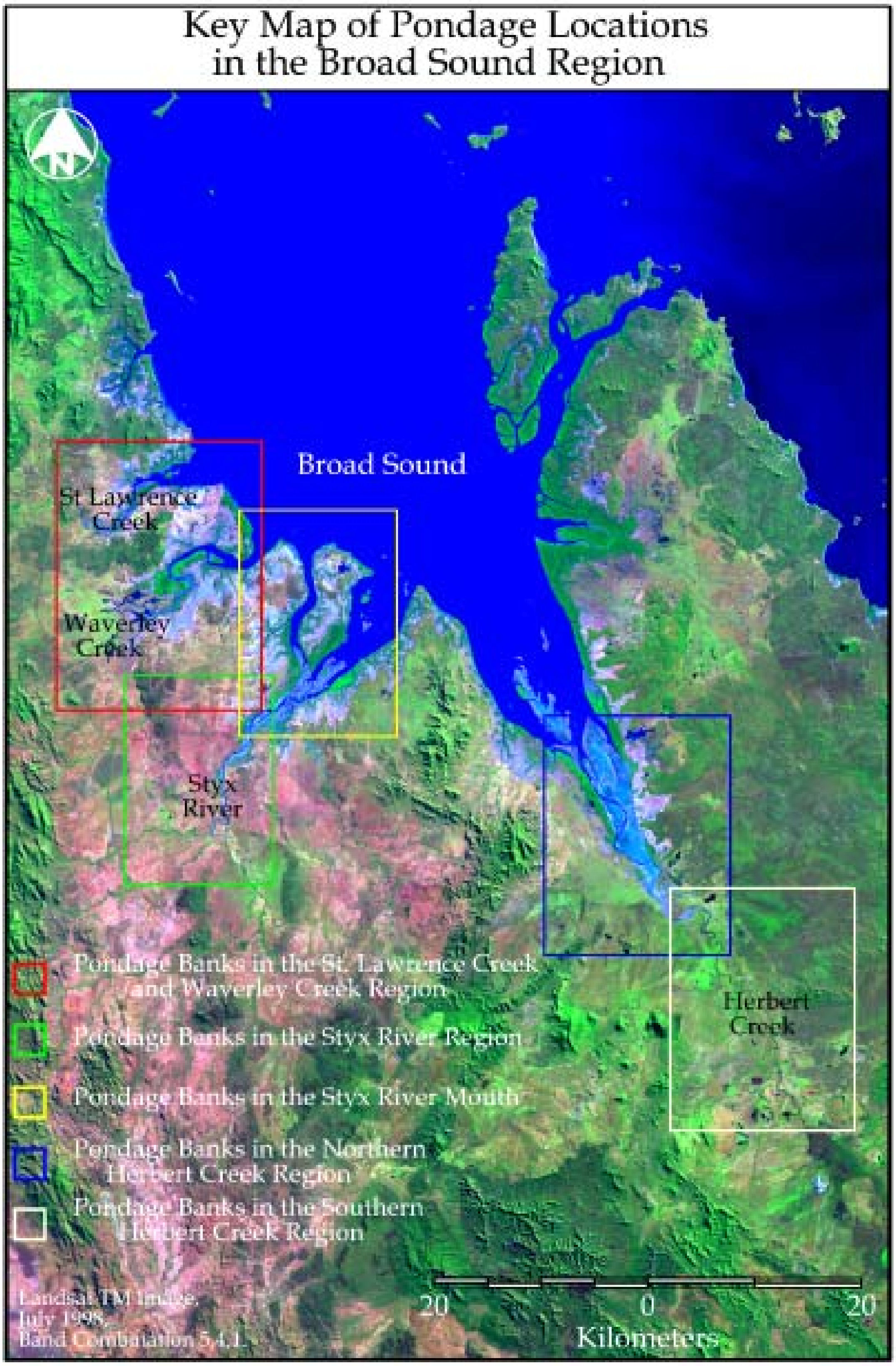
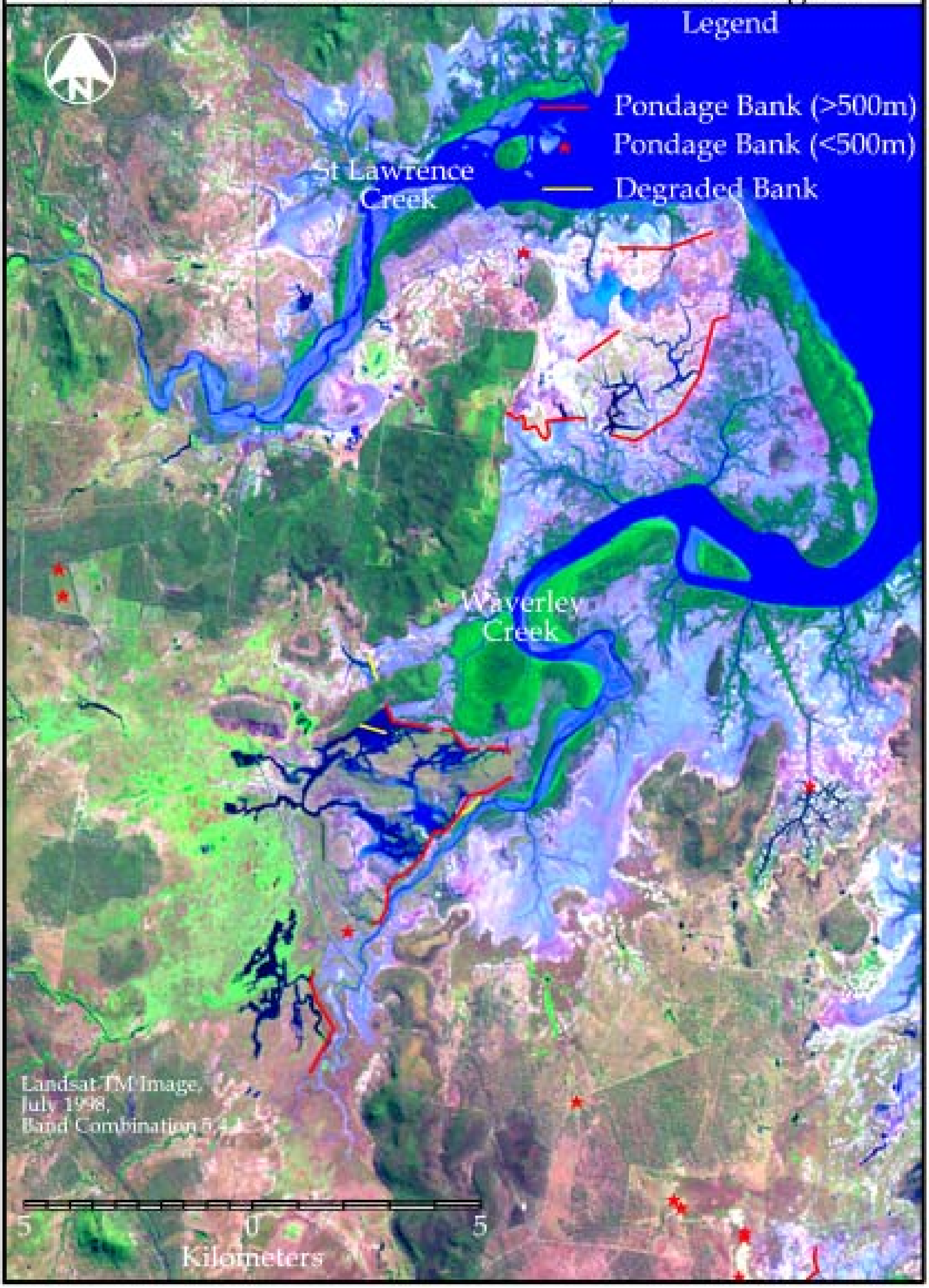
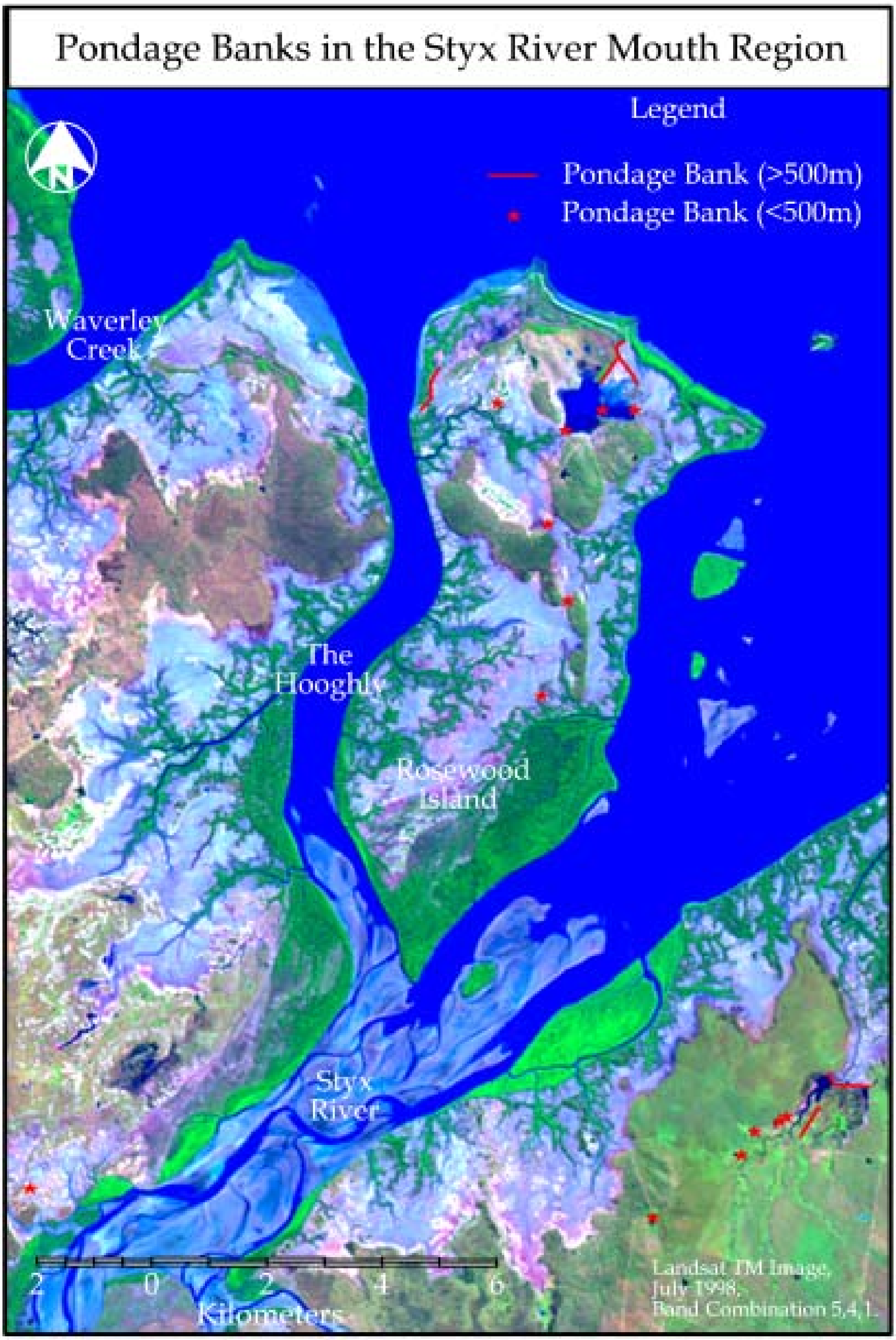
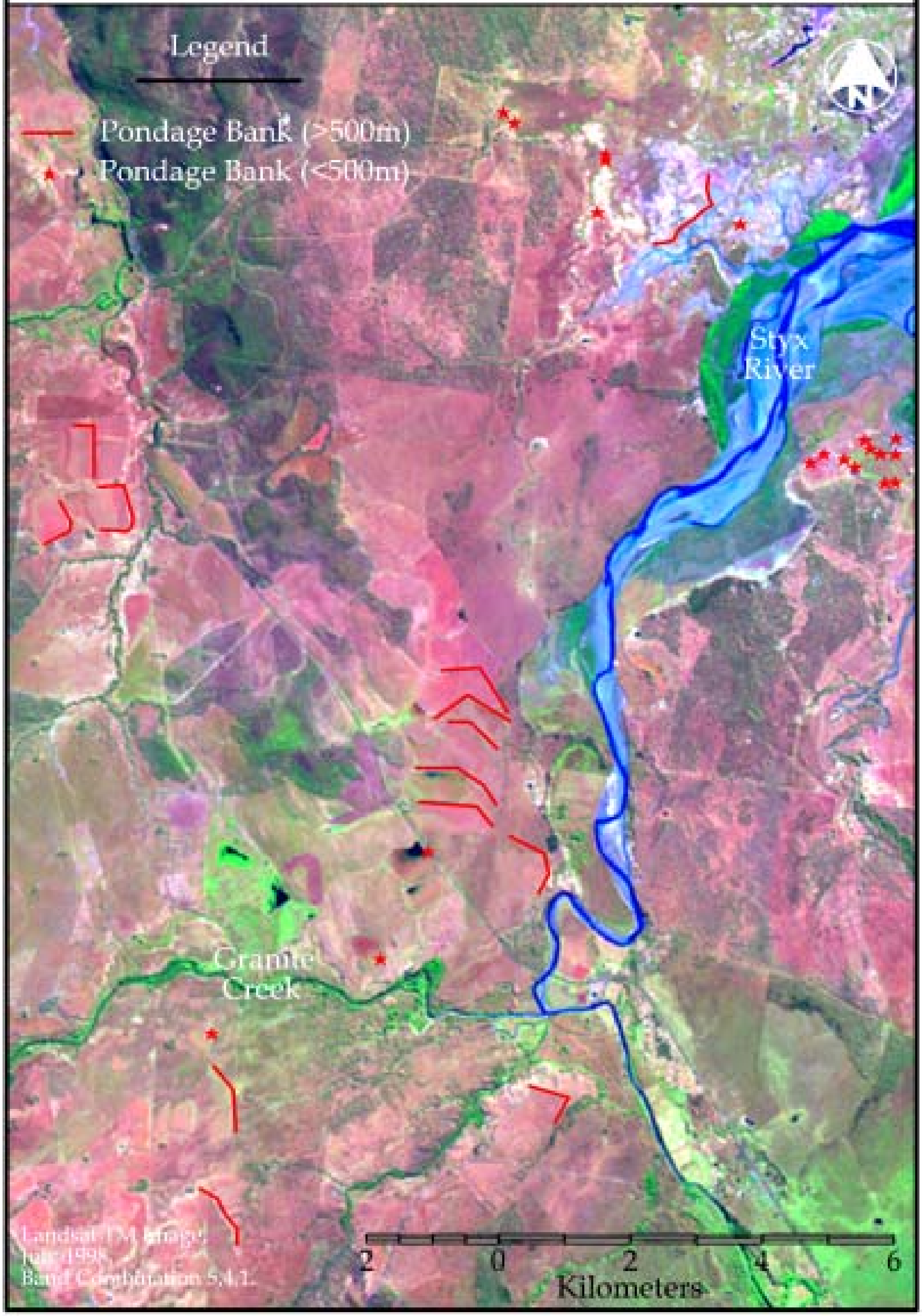

Key Map of Pondage Locations
in the Broad Sound Region
Broad Sound
St Lawrence
Creek
Waverley
Creek
Styx
River
Herbert
Creek
Pondage Banks in the St. Lawrence Creek
and Waverley Creek Region
Pondage Banks in the Styx River Region
Pondage Banks in the Styx River Mouth
Pondage Banks in the Northern
Herbert Creek Region
Pondage Banks in the Southern
Herbert Creek Region
Landsat TM Image,
July 1998,
Band Combination 5,4,1.
20
0
20
Kilometers

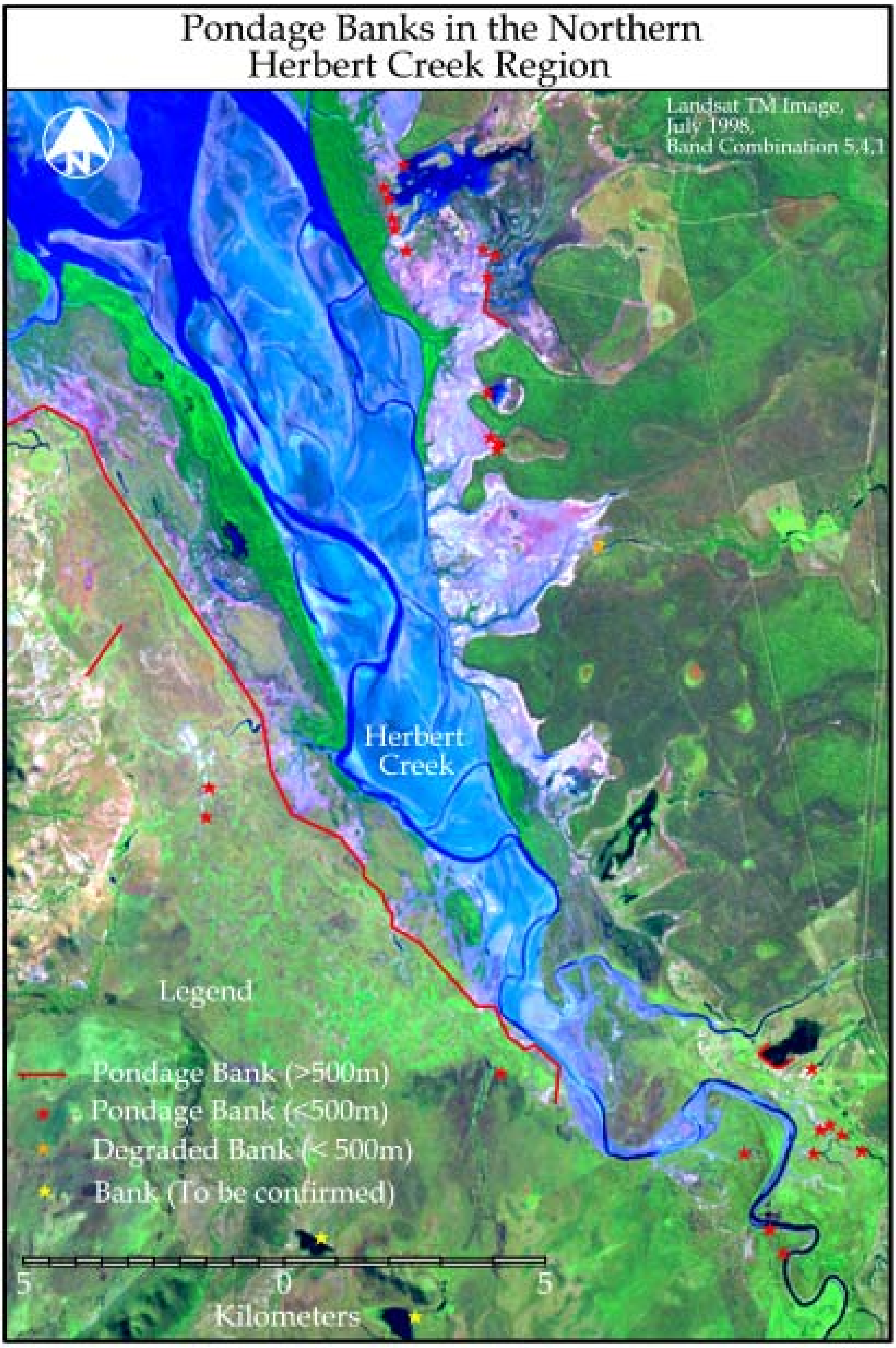
Pondage Banks in the
St. Lawrence Creek and Waverley Creek Region




Pondage Banks in the Styx River Mouth Region
Legend
Pondage Bank (>500m)
Pondage Bank (<500m)
N
Waverley Creek
The Hooghly
Rosewood Island
Styx River
2 0 2 4 6
Kilometers
Landsat TM Image, July 1998, Band Combination 5,4,1.

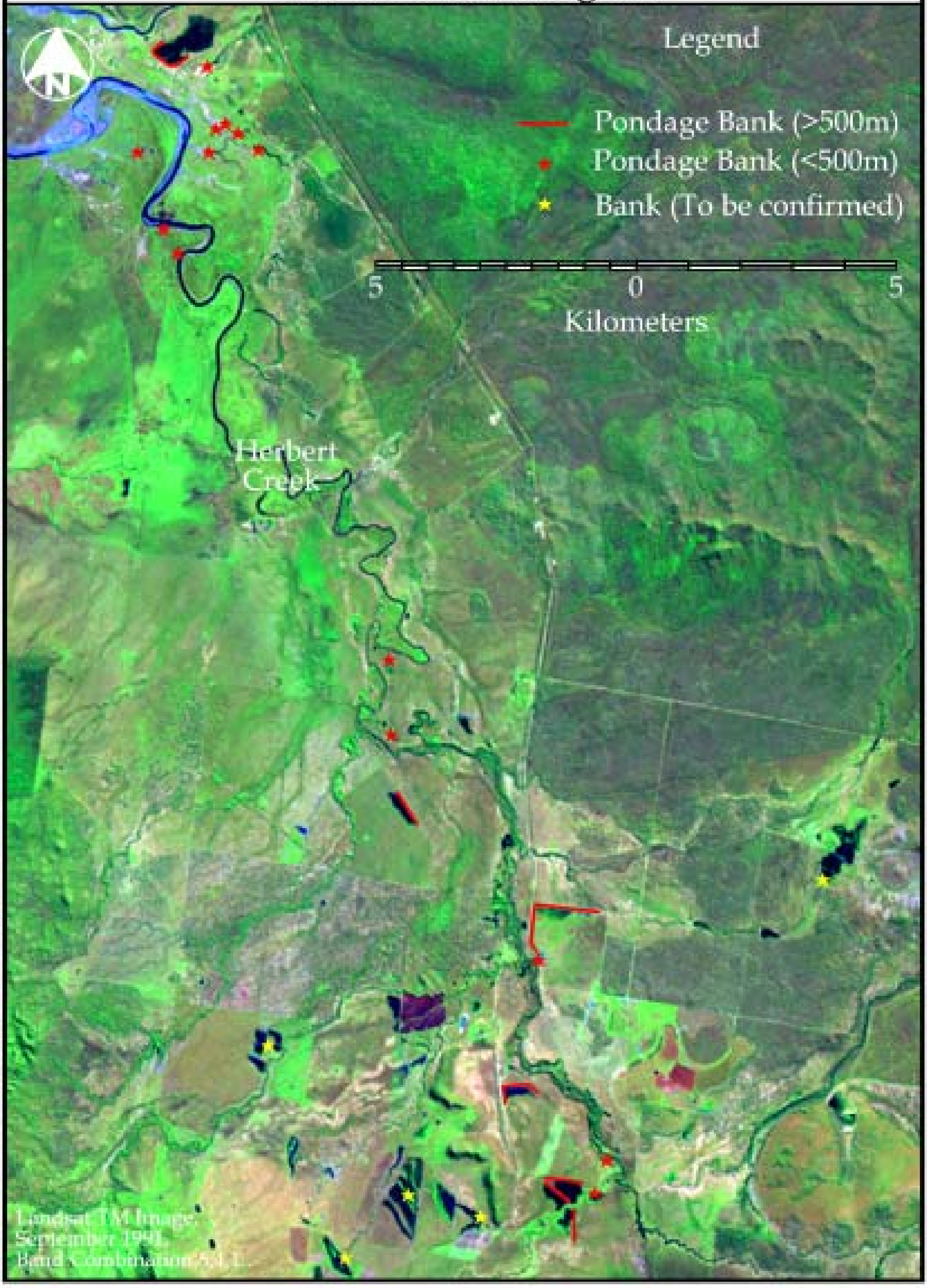
Pondage Banks in the Styx River Region





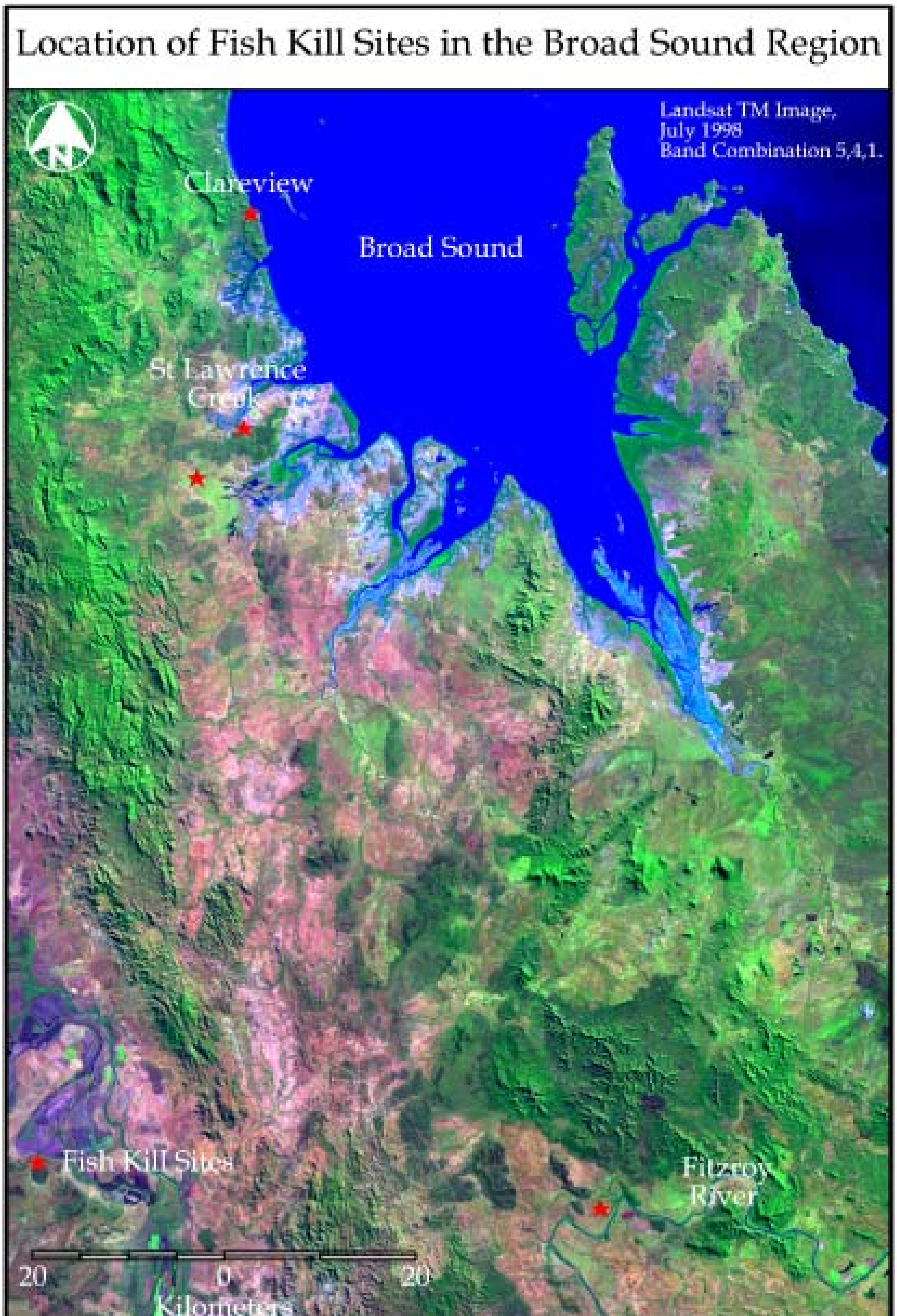
Pondage Banks in the Northern Herbert Creek Region
Landsat TM Image, July 1998, Band Combination 5,4,1
N
Herbert Creek
Legend
Pondage Bank (>500m)
Pondage Bank (<500m)
Degraded Bank (< 500m)
Bank (To be confirmed)
5 0 5
Kilometers

Pondage Banks in the Southern
Herbert Creek Region



Appendix 5

Location of fish kills in the Fitzroy Estuary, Corio Bay and Broad Sound regions.
(Maps on following two pages.)


Location of Fish Kill Sites in the Broad Sound Region
Landsat TM Image,
July 1998
Band Combination 5,4,1.
N
Clareview
Broad Sound
St Lawrence
Creek
Fish Kill Sites
Fitzroy
River
20
0
20
Kilometers

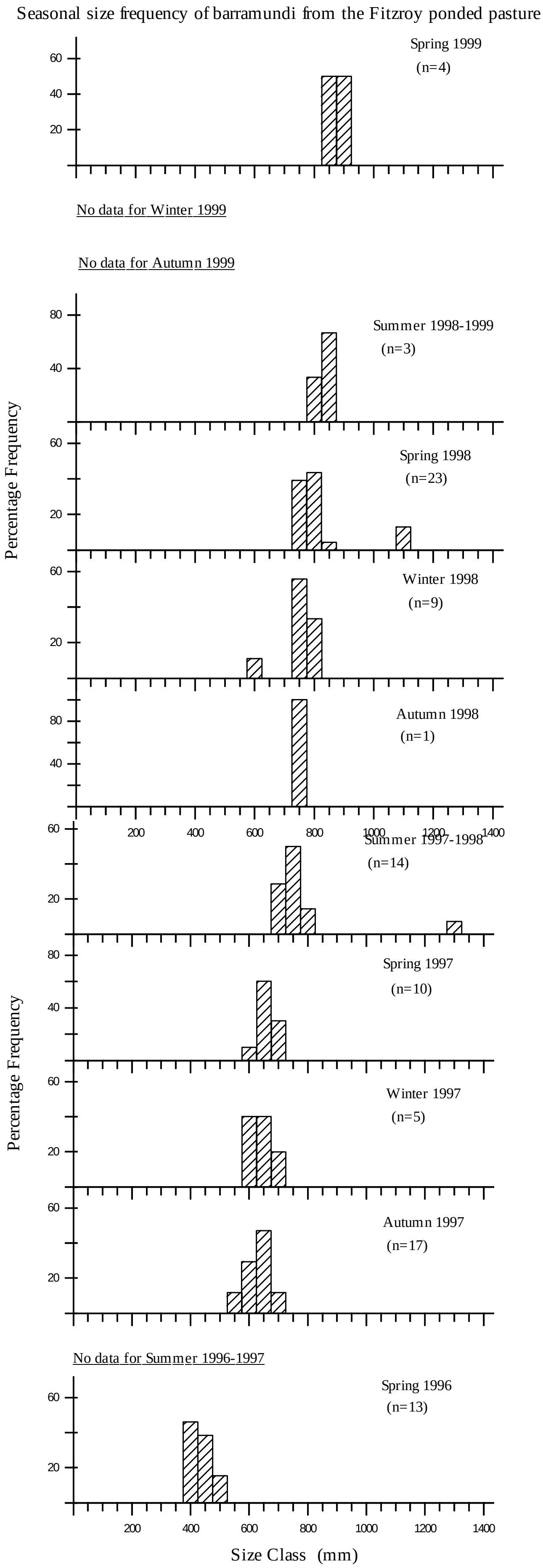

Location of Fish Kill Sites
in the Keppel Coast Region
Landsat TM Image,
July 1991 (Gladstone),
July 1991 (Yeppoon),
Band Combination 5,4,1.
N
Corio
Bay
Keppel
Bay
Rockhampton
Fitzroy
River
Raglan
Creek
Fish Kill Sites
10
0
10
20
Kilometers

Appendix 6 Results of pesticide and heavy metal analyses on barramundi (flesh & viscera), water and sediment samples from mass kill of barramundi in Broad Sound freshwater site, March 1999.

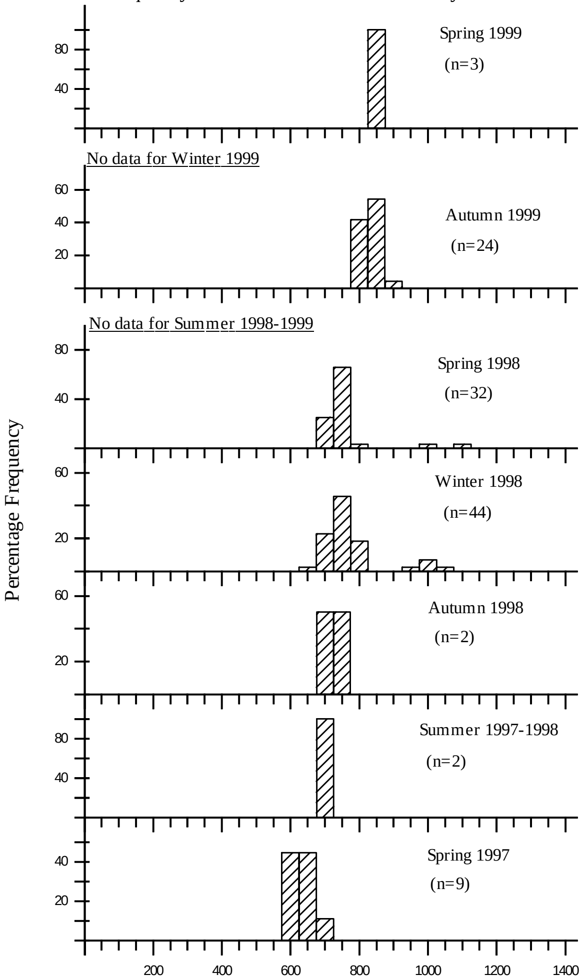
Client Ref. CC9903SJH-	**001**	**002**	**003**	**004**	**008**	**009**
Lab. Ref. 98EP-	**1636**	**1637**	**1638**	**1639**	**1643**	**1644**
Sample Description	**Barramundi Flesh**	**Barramundi Viscera**	**Water**	**Water**	**Sediment**	**Sediment**
Phenoxy herbicides			<1 μg/L			
Organochlorine Pesticides	<0.01 mg/kg	<0.01 mg/kg	<0.1 μg/L			<5 μg/kg
Organophosphorus Pesticides	<0.05 mg/kg	<0.05 mg/kg	<0.5 μg/L			<10 μg/kg
Glyphosate			<50 μg/L			
Triazine herbicide	<0.1 mg/kg	<0.1 mg/kg	<1 μg/L			<100 μg/kg
Urea herbicide	<0.1 mg/kg	<0.1 mg/kg	<1 μg/L			<100 μg/kg
Synthetic Pyrethroids	<0.1 mg/kg	<0.1 mg/kg	<0.1 μg/L			
Lipid Content %	2.8	30				
Copper	0.3 mg/kg	10.3		5 μg/L	14 mg/kg	
Lead	<0.5	<0.5		<50 μg/L	13 mg/kg	
Cadmium	<0.05	<0.05		<10 μg/L	<1 mg/kg	
Nickel				<20 μg/L		
Chromium	0.2	0.2		<10 μg/L	32 mg/kg	
Zinc	5.3	9.8		<10 μg/L	50 mg/kg	
Iron				3600 μg/L		
Manganese				660 μg/L		
Arsenic				<100 μg/L	<15 mg/kg	
Selenium				<100 μg/L		
Mercury				<50 μg/L	<0.2 mg/kg	
Aluminium				<100 μg/L		

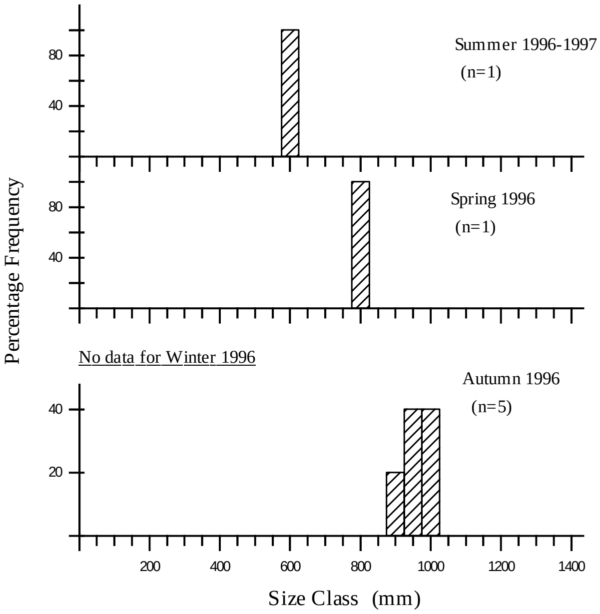
Analytical Methods undertaken by Queensland Health Scientific Services
1. Pesticides – water QPM-021 plus GC/MS 2. Pesticides – sediment QPM-030 and 031 – Results on a dry weight basis
3. Pesticides – Fish solvent extraction, GPC cleanup and determination by GC/MS 4. Metals – sediment MGM-017, 021, 024

Appendix 7 Seasonal size frequencies of barramundi for primary locations.

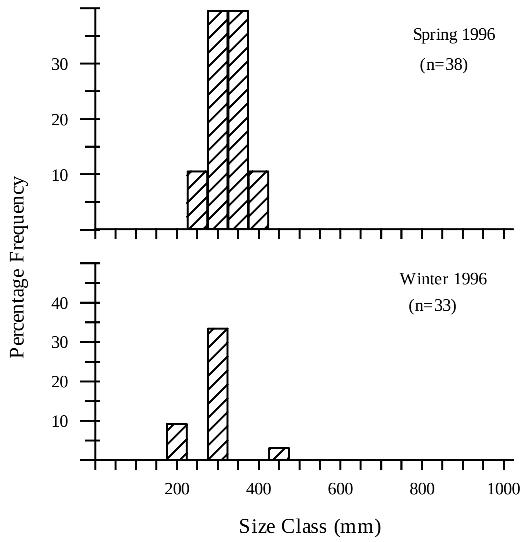


Seasonal size frequency of barramundi from the Fitzroy freshwater site

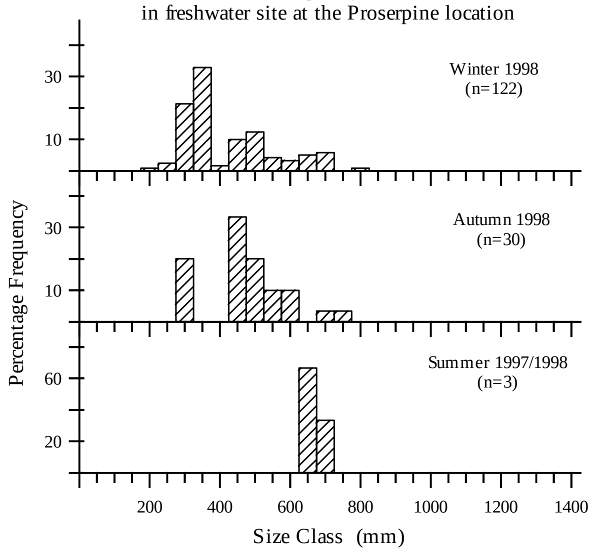


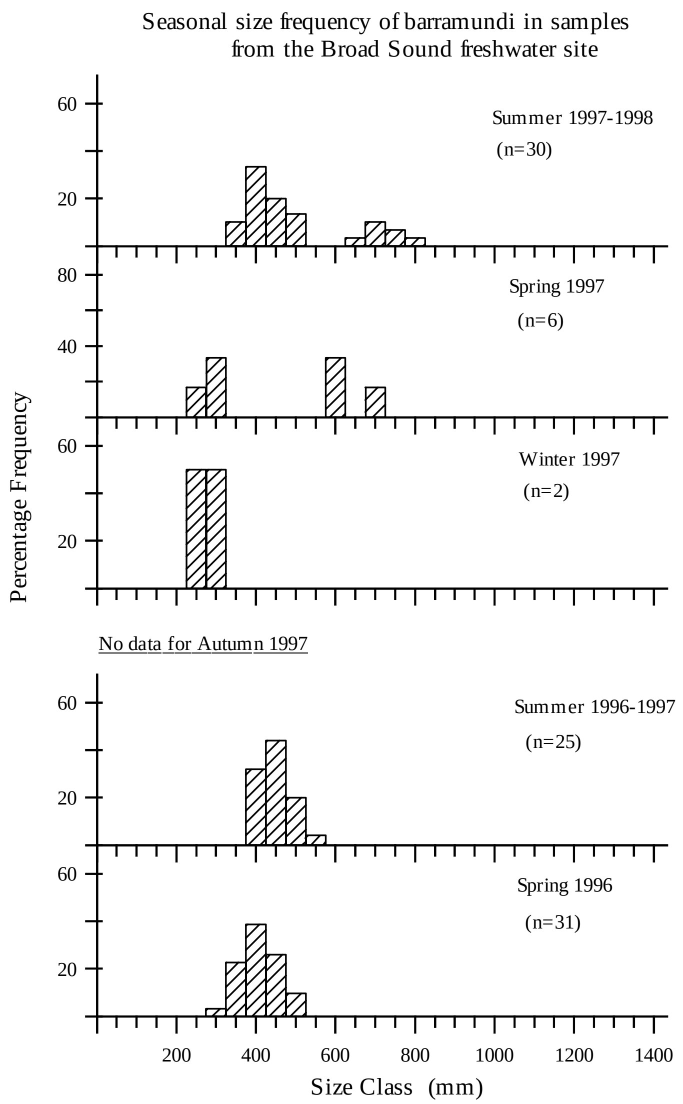


Seasonal size frequency of barramundi from the Broad Sound ponded pasture



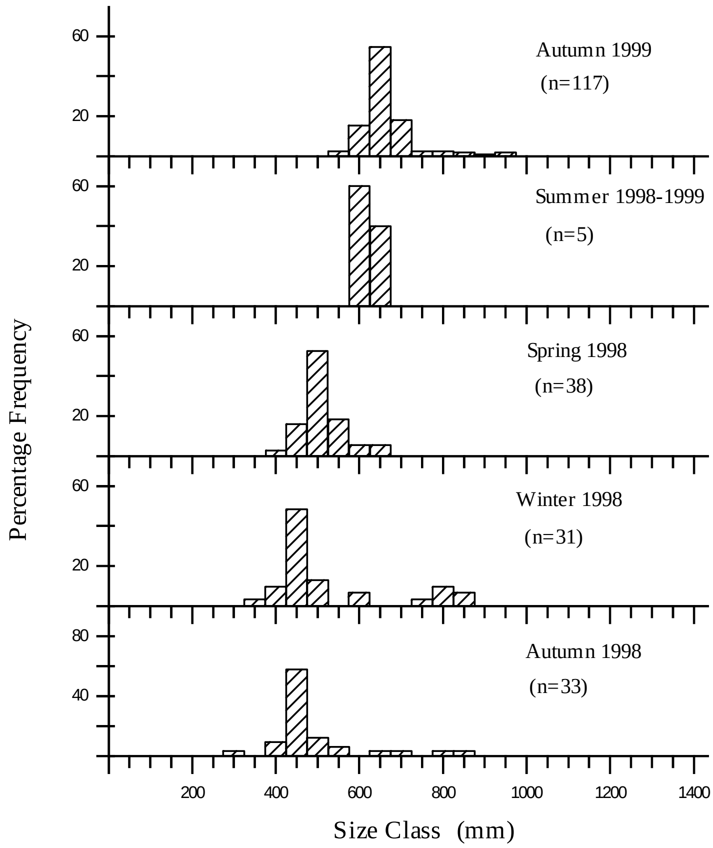
Seasonal size frequency of barramundi
in freshwater site at the Proserpine location




Seasonal size frequency of barramundi in samples
from the Broad Sound freshwater site
Summer 1997-1998
(n=30)
Spring 1997
(n=6)
Winter 1997
(n=2)
No data for Autumn 1997
Summer 1996-1997
(n=25)
Spring 1996
(n=31)
Percentage Frequency
Size Class (mm)
60
20
80
40
60
20
60
20
60
20
200
400
600
800
1000
1200
1400

Seasonal size frequency of barramundi in samples
from the Broad Sound freshwater site

No data for Spring 1999

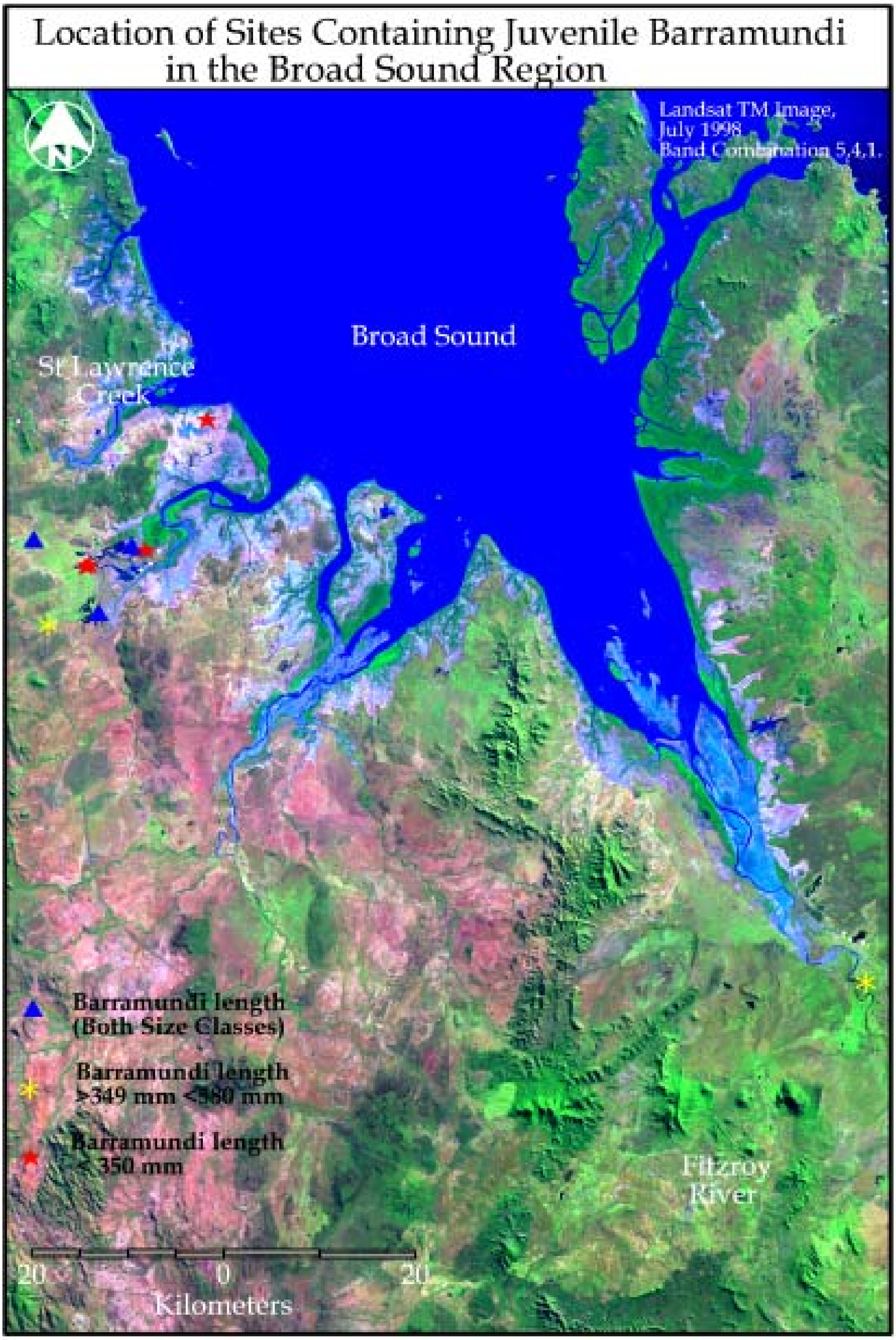


Appendix 8

Location of sites where juvenile barramundi were captured.

(Maps on following two pages.)


Location of Sites Containing Juvenile Barramundi
in the Keppel Coast Region
Landsat TM Image,
July 1991 (Gladstone),
July 1991 (Yeppoon),
Band Combination 5,4,1.
Corio
Bay
Keppel
Bay
Rockhampton
Fitzroy
River
Raglan
Creek
Barramundi length
(Both Size Classes)
Barramundi length
>349 mm <580 mm
Barramundi length
< 350 mm
10
0
10
20
Kilometers

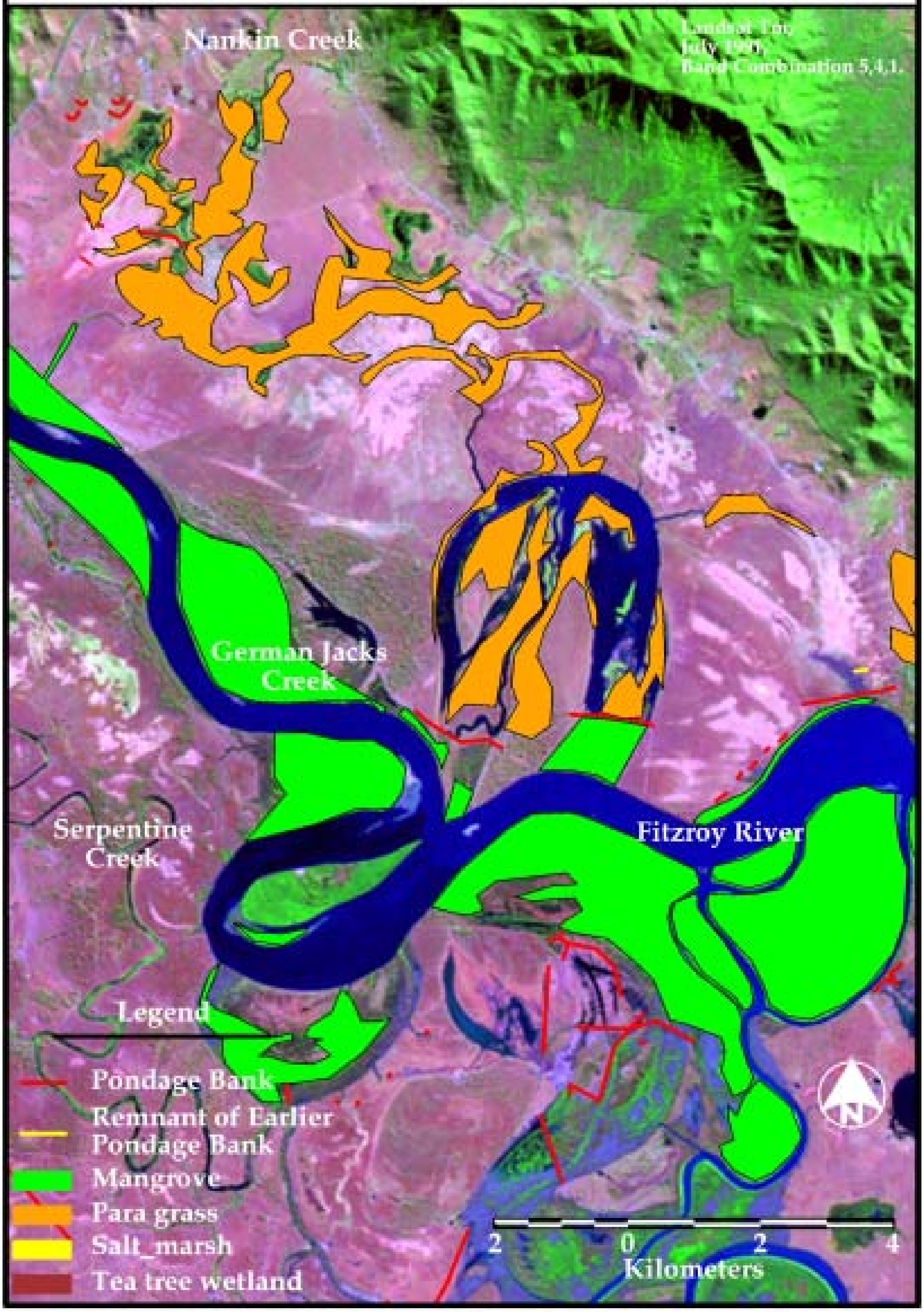

Location of Sites Containing Juvenile Barramundi
in the Broad Sound Region
Landsat TM Image,
July 1998
Band Combination 5,4,1.
N
Broad Sound
St Lawrence
Creek
Barramundi length
(Both Size Classes)
Barramundi length
>349 mm <580 mm
Barramundi length
< 350 mm
Fitzroy
River
20
0
20
Kilometers

Appendix 9

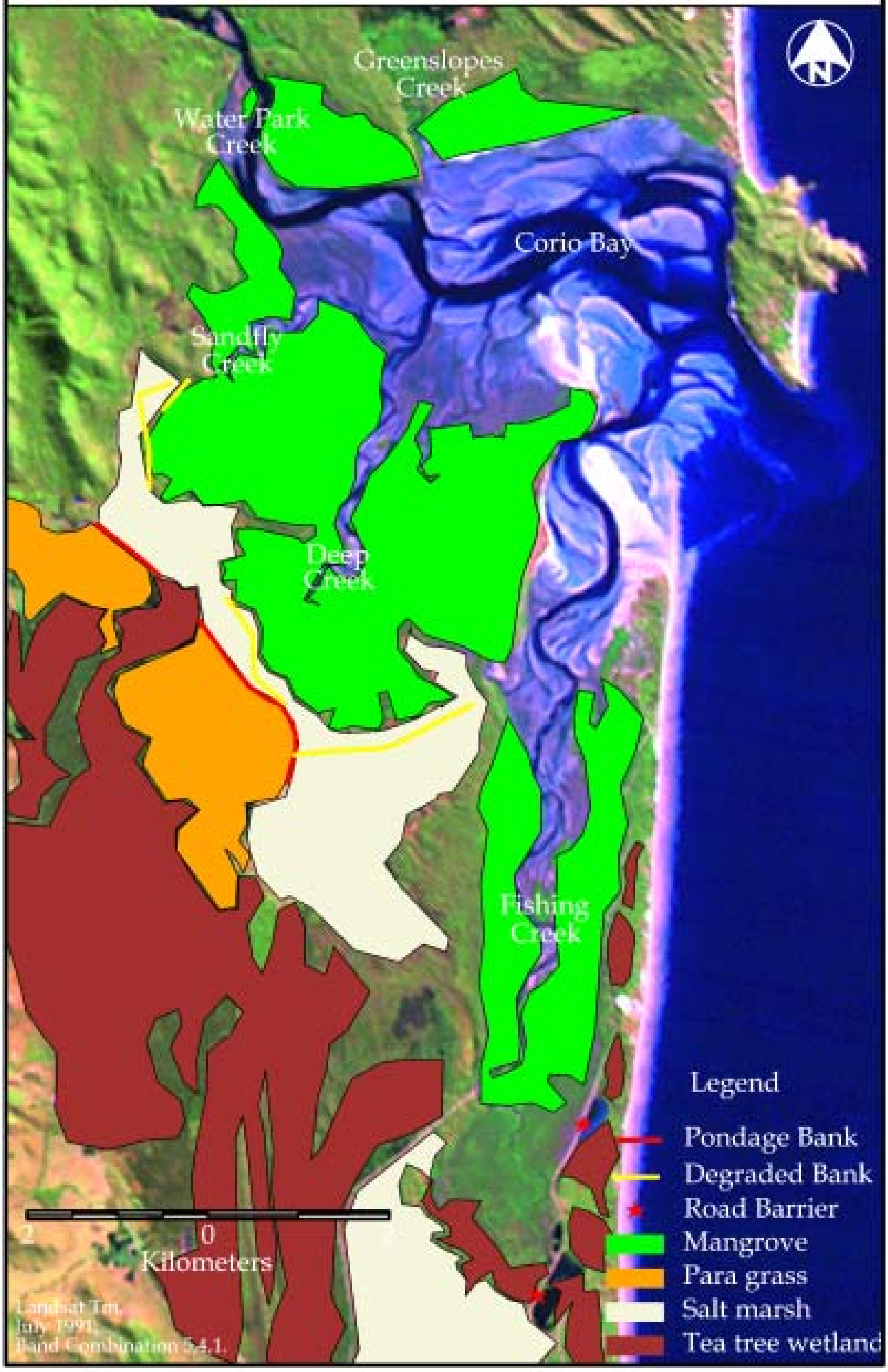
Vegetation cover associated with ponded pasture systems in the primary study locations in the Fitzroy Estuary, Corio Bay and Broad Sound.

(Maps on following three pages.)

Location of Pondage Banks and Key Vegetation Types on Nankin Creek Wetlands

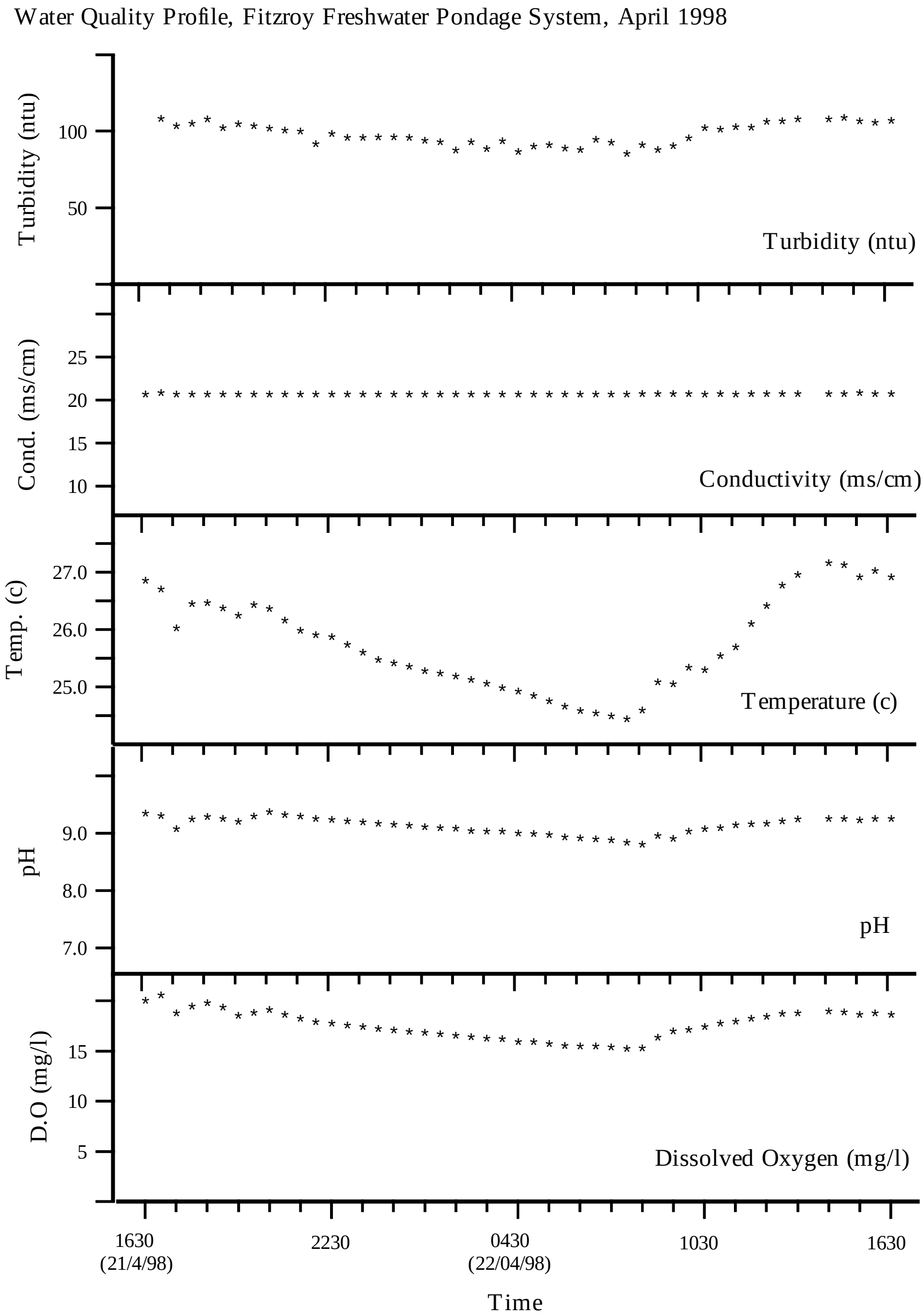


Key vegetation types in the Corio Bay pondage area

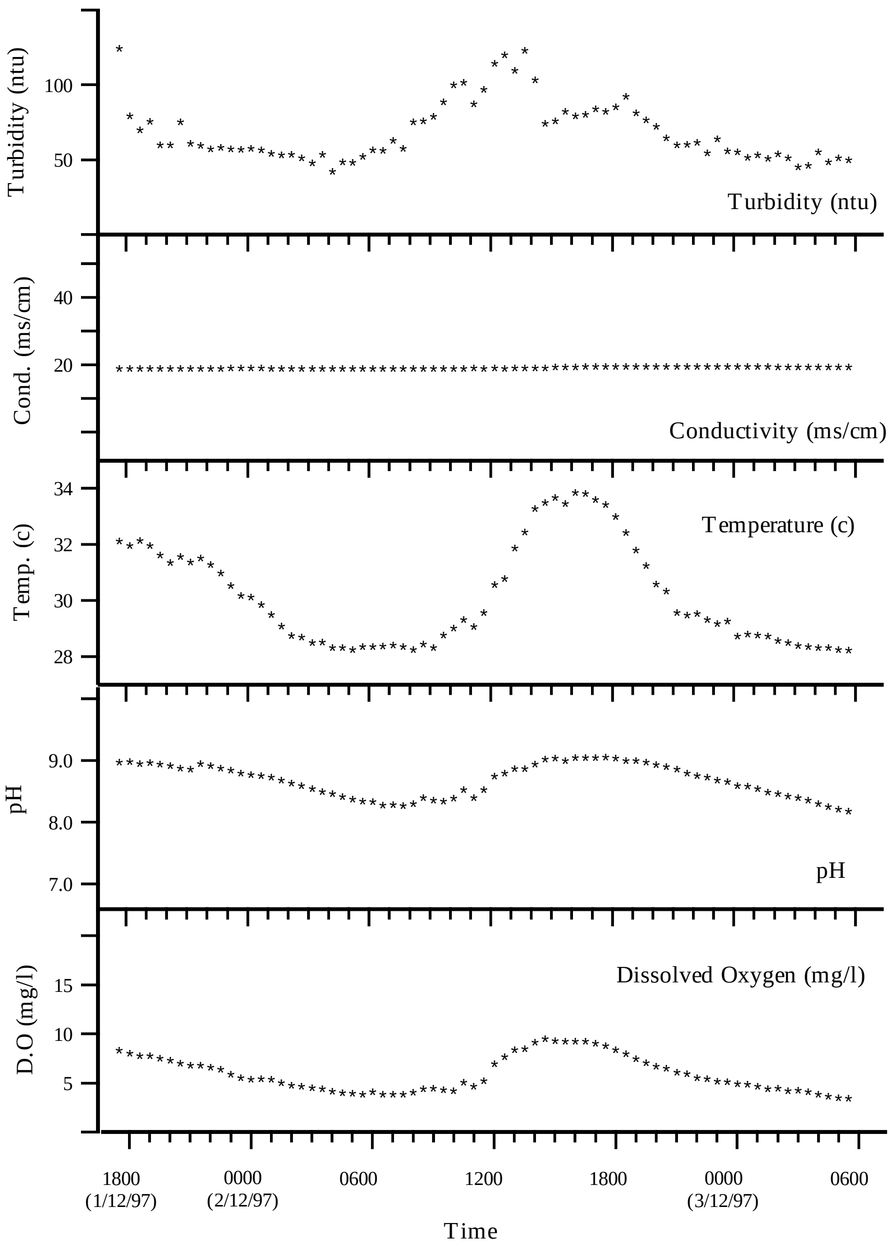



Pondage Banks and Key Vegetation Types
in the Waverley Creek Pondage Region
Waverley
Creek
Bund
Creek
Home
Creek
Amity
Creek
Legend
Pondage Bank
Degraded Bank
Freshwater wetland
Mangrove
Para grass
Salt marsh
1 0 1 2
Kilometers
Landsat TM Image,
September 1991,
Band Combination 5,4,1.
N

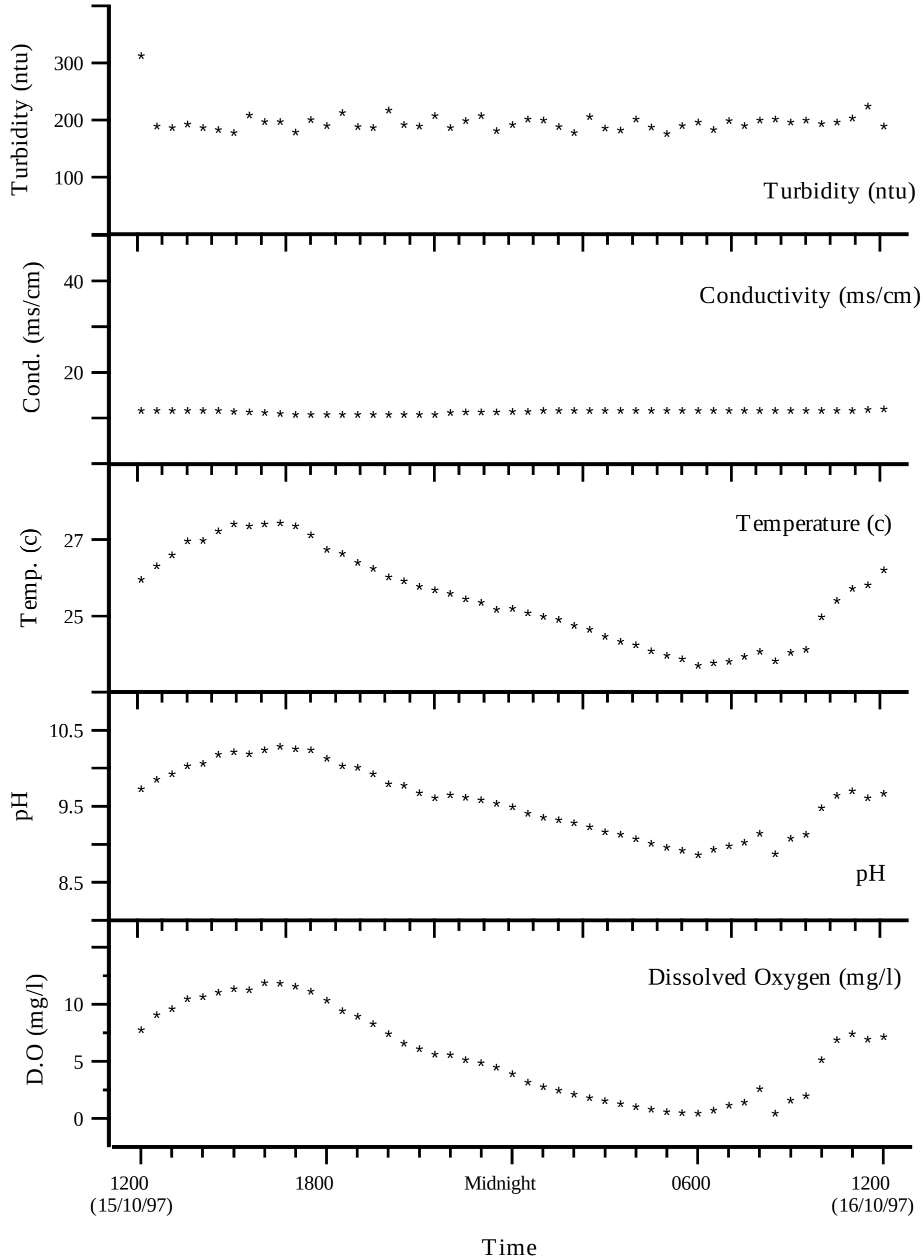
Appendix 10 Twenty-four hour water quality profiles in primary locations.



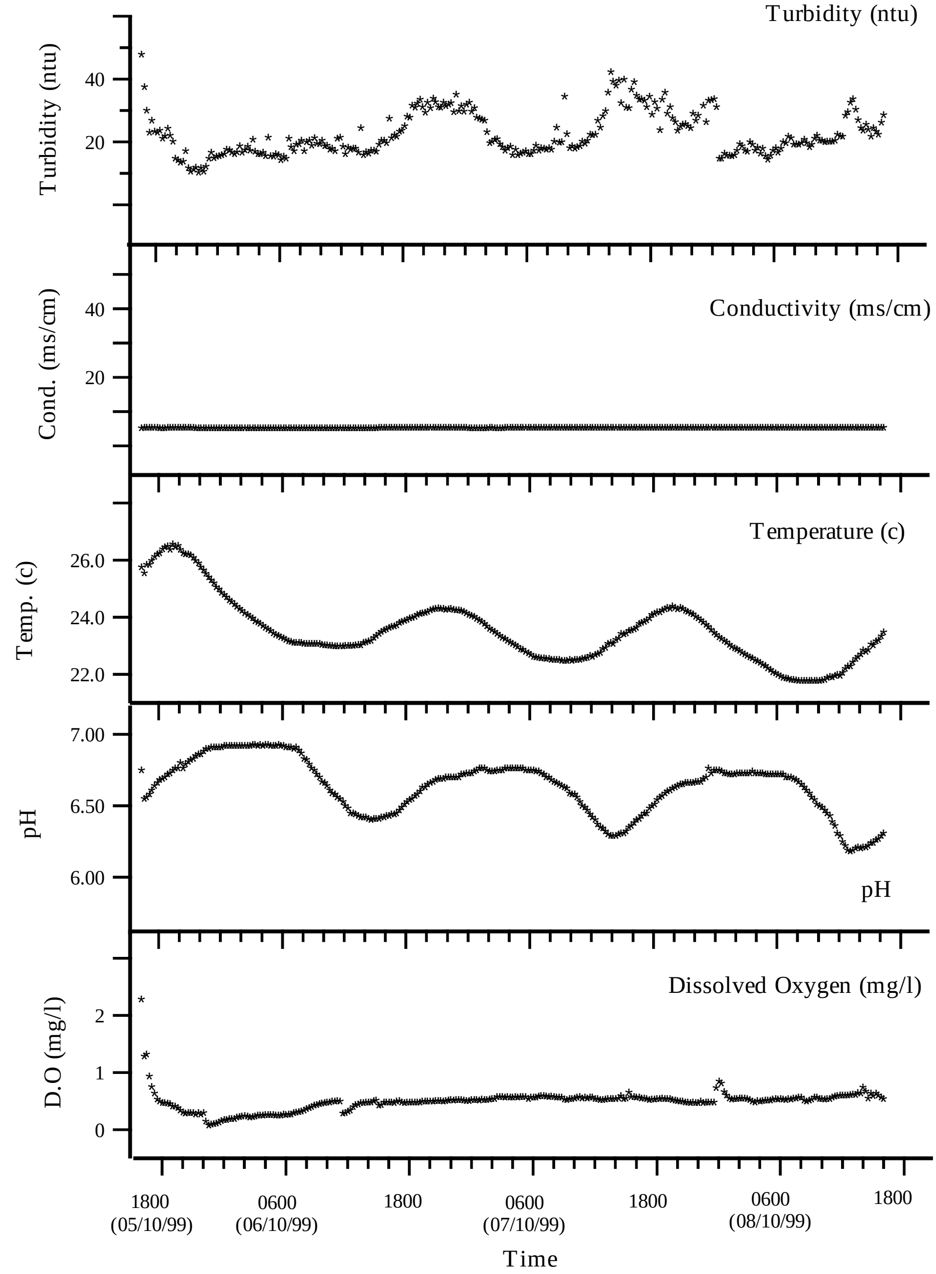
Water Quality Profile, Fitzroy Pondage System, December 1997



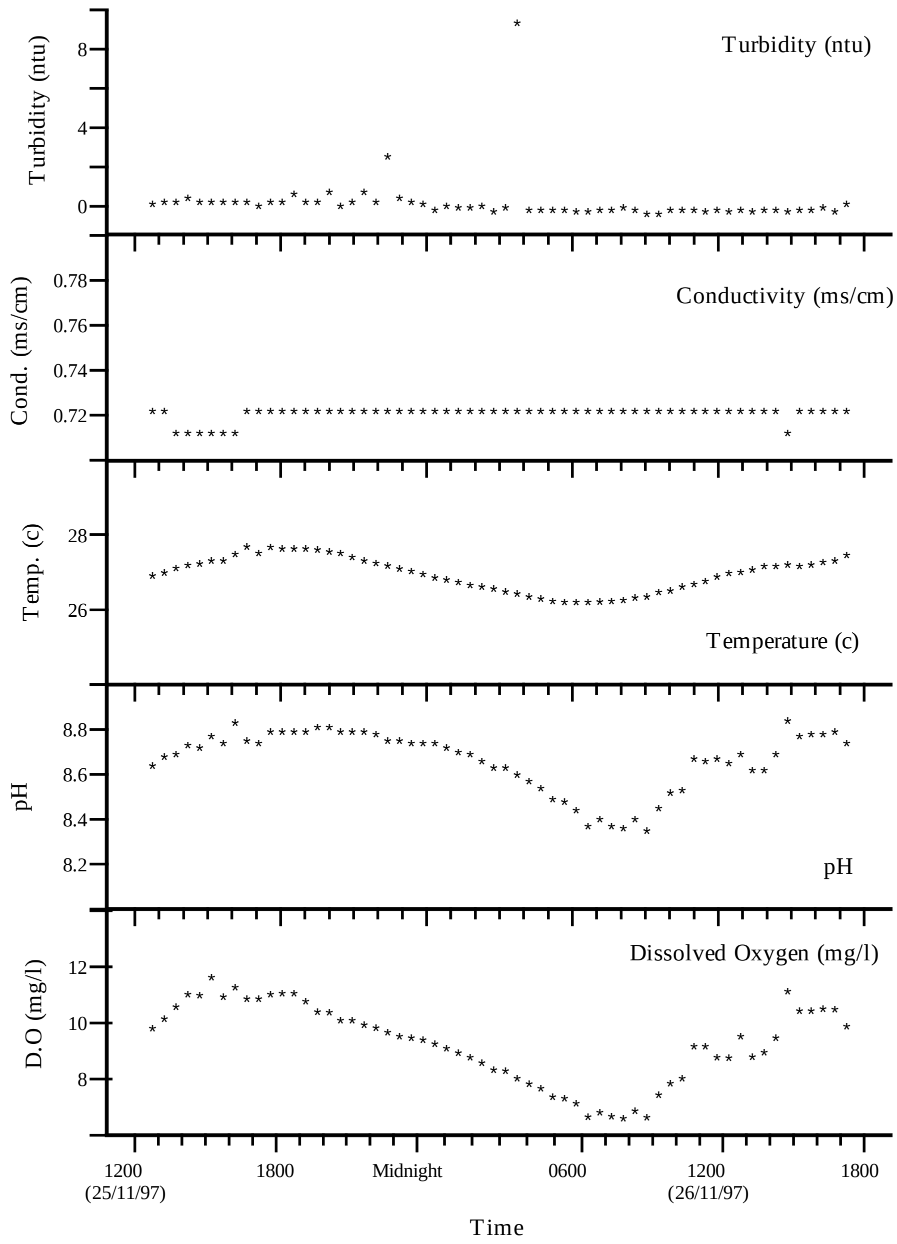
Water Quality Profile, Broad Sound Pondage System, October 1997



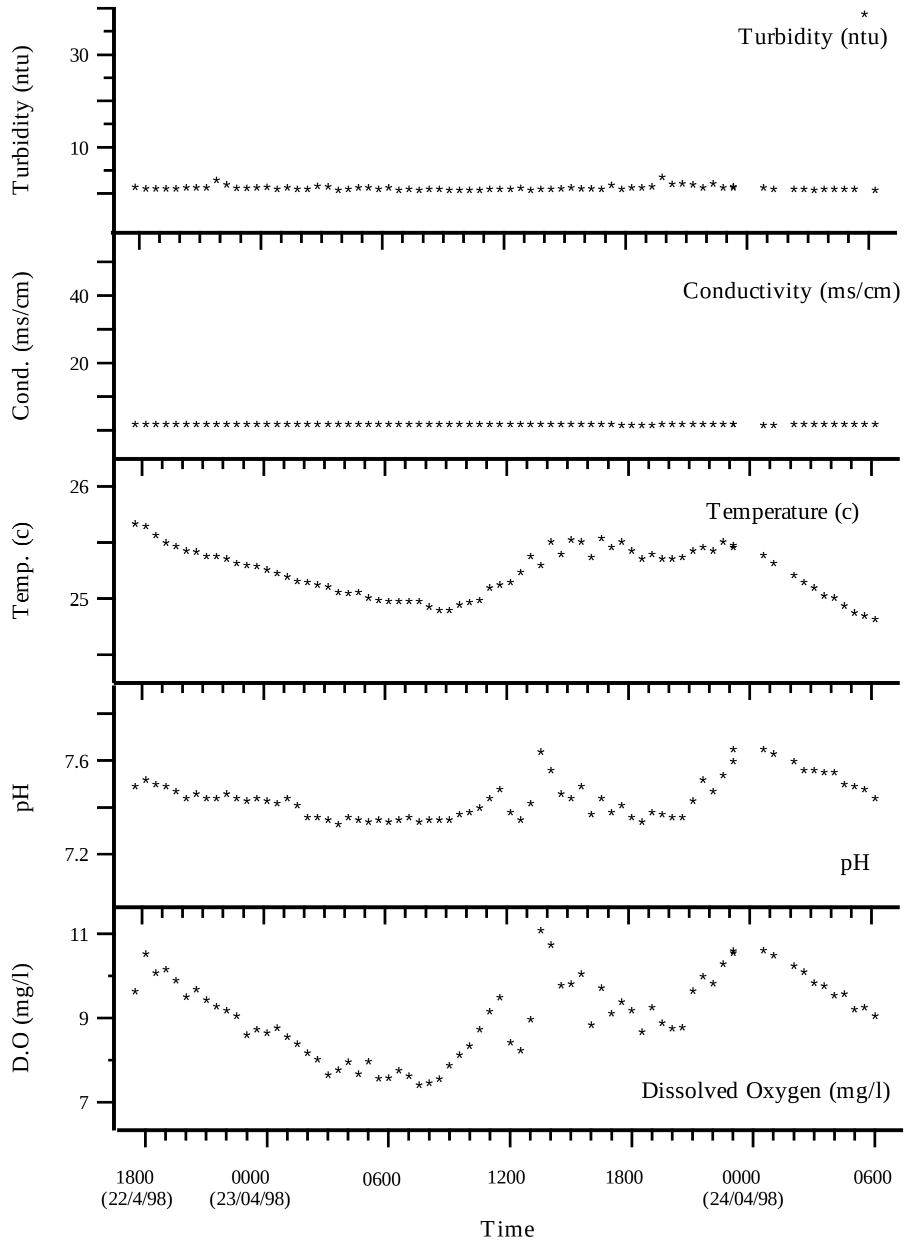
Water quality profile, Corio Bay ponded pasture system, October 1999



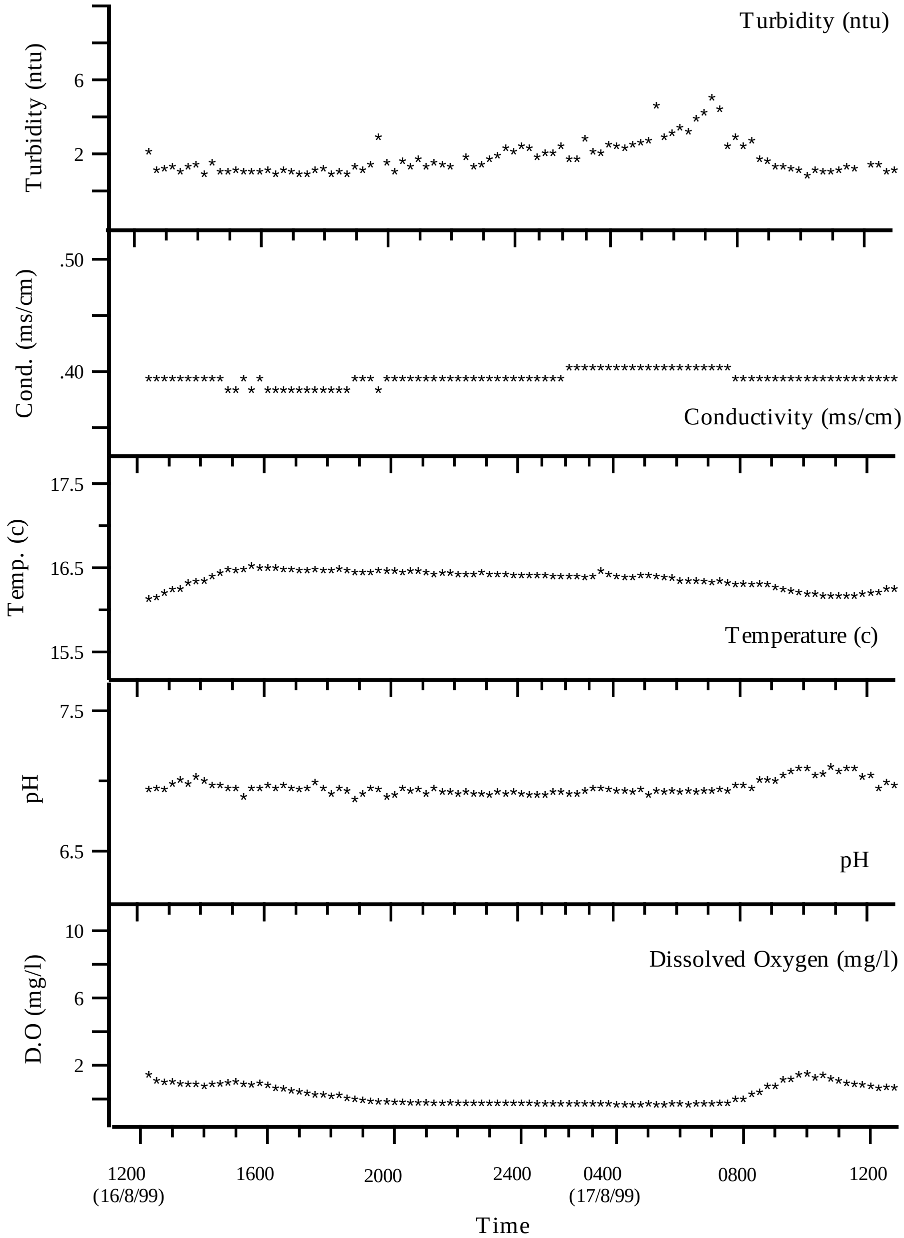
Water Quality Profile, Fitzroy Freshwater Site, November 1997

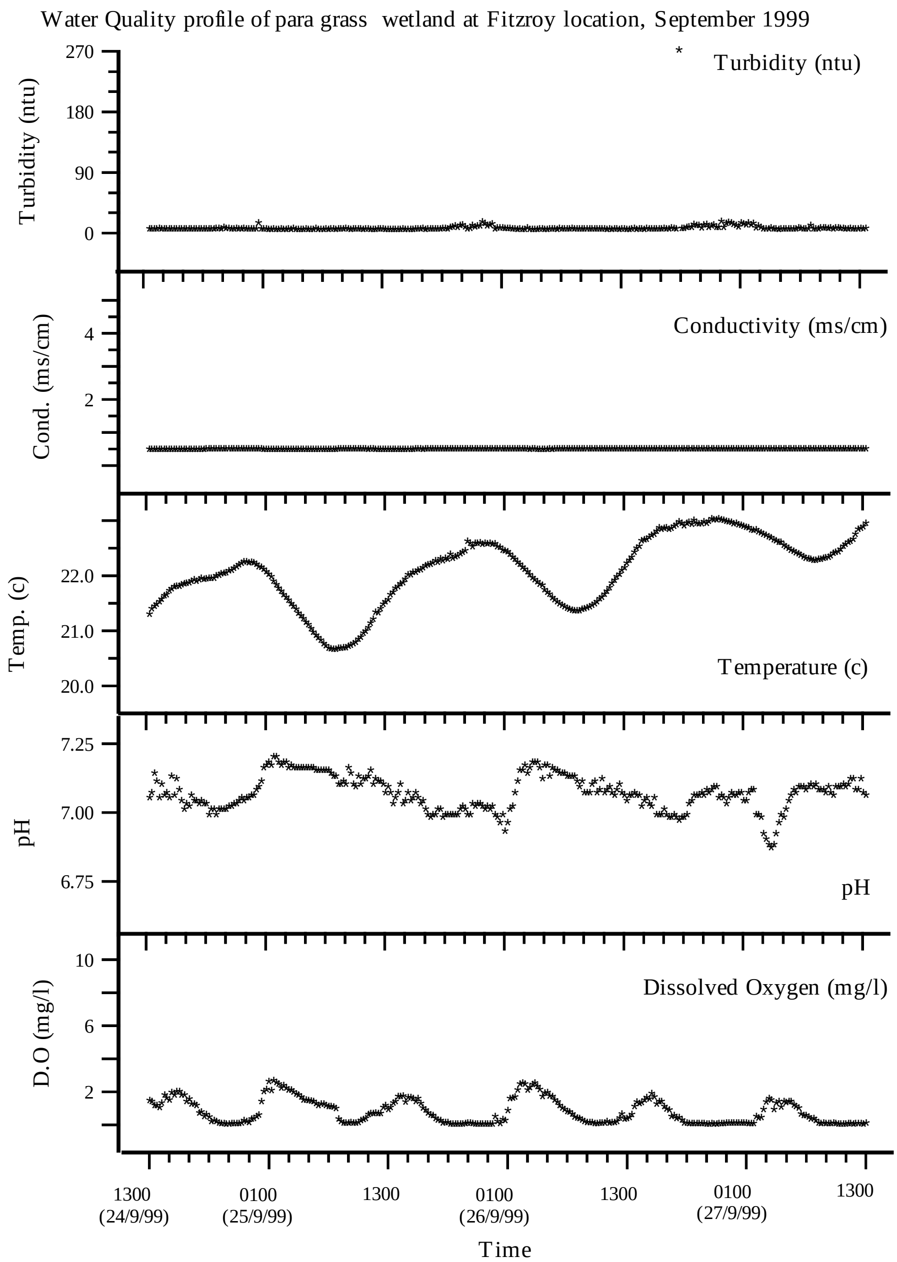


Water Quality Profile, Fitzroy Freshwater Site, April 1998

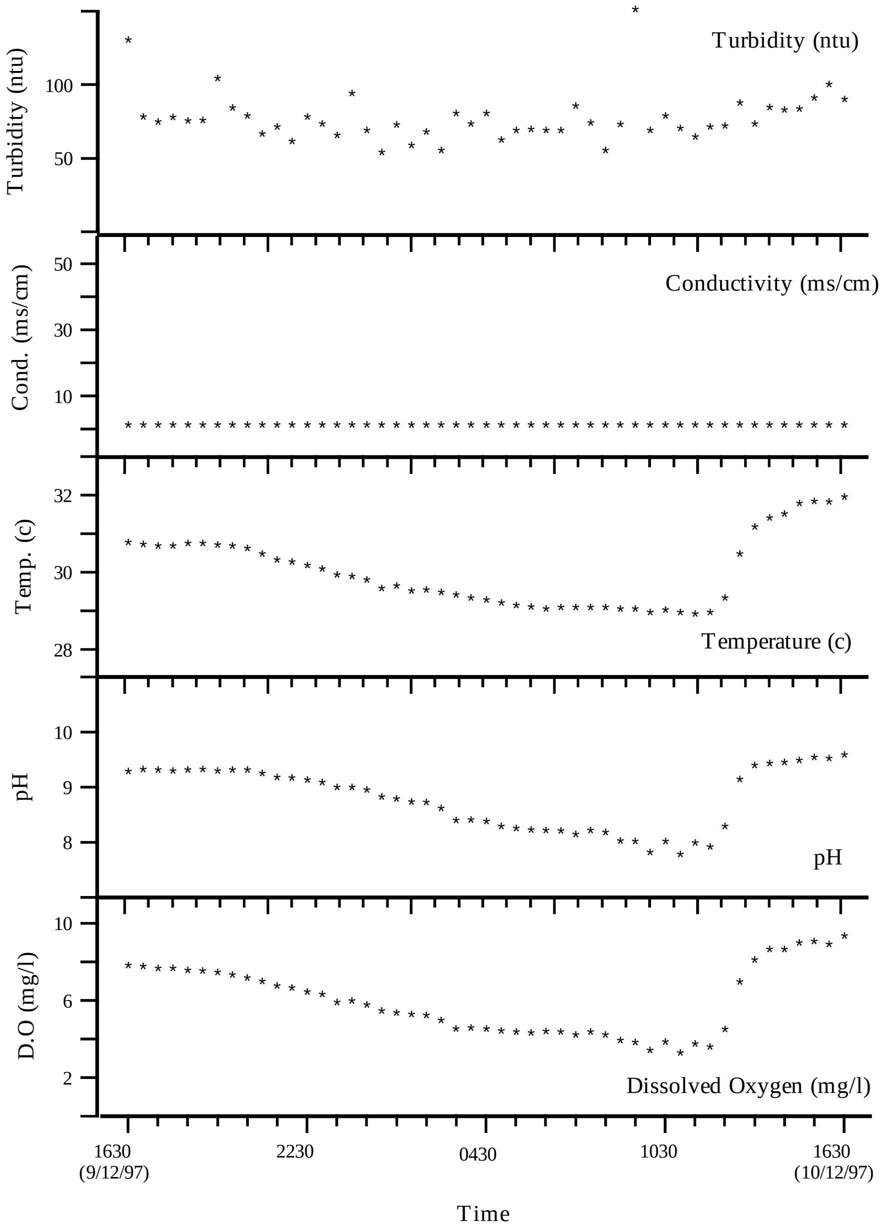


Water Quality Profile, Fitzroy Freshwater Site, August 1999
(in Para grass)




Water Quality profile of para grass wetland at Fitzroy location, September 1999
Turbidity (ntu)
270
180
90
0
Conductivity (ms/cm)
Cond. (ms/cm)
4
2
Temp. (c)
22.0
21.0
20.0
Temperature (c)
pH
7.25
7.00
6.75
Dissolved Oxygen (mg/l)
D.O (mg/l)
10
6
2
1300 (24/9/99)
0100 (25/9/99)
1300
0100 (26/9/99)
1300
0100 (27/9/99)
1300
Time

Water Quality Profile, Broad Sound Freshwater Site, December 1997



Water Quality Profile, Broad Sound Freshwater Site, March 1999