Chapter 1 Introduction

1.1 Tropical floodplain ecology with special reference to fish habitats

Floodplains are defined as "…areas that are periodically inundated by the lateral overflow of rivers or lakes and/or by direct precipitation or groundwater" (Junk, 1997). There is now a relatively large knowledge base concerning floodplain fish ecology (Welcomme, 1979; Goulding, 1980; Vannote, 1980; Lowe-McConnell, 1985; Junk, 1992). Past research has focused on describing the life histories and the distribution of biota (Lowe-McConnell 1979; 1987; Johnson *et al.*, 1995), and aspects of the fisheries that take place in floodplain rivers (Welcomme, 1979). More recently, physical and biological concepts of riverine organization have been combined into a holistic approach that seeks to establish lotic systems as interdependent combinations of the aquatic and terrestrial landscapes (Vannote, 1980; Junk *et al.*, 1989; Johnson *et al.*; 1995, Sparks, 1995). However, the relative importance of physical and biological processes to the river-floodplain ecosystem remains largely untested (Kennard, 1995; Johnson *et al.*, 1995) due largely to the absence of a clear understanding on how large rivers work. Although the inherent complexity of large rivers and the spatial scales involved have limited the development of a cohesive theoretical framework (Johnson *et al.*, 1995), recent developments of models such as the "Flood Pulse Concept"(FPC) (Junk *et al.*, 1989), "River Continuum Concept"(RCC) (Vannote *et al.*, 1980) and Riverine Productivity Model (RPM) (Thorpe and Delong, 1994) have sought to explain how energy and biota are distributed within a catchment. The FPC examines the relationship between inundation of the floodplain and lateral exchange of inorganic and organic material and is particularly concerned with floodplain inundation. The RCC describes a longitudinal exchange of materials along the river and is more concerned with the fate of organic material derived in the catchment's headwaters. It is notable that the RCC was developed for temperate river systems whereas the FPC was developed for tropical floodplain rivers. The RPM is concerned with the autochthonous and local allochthonous input of organic carbon, especially in rivers with constricted channels.

Floodplain ecosystems include flowing channels, floodplain lakes, backwaters, gallery forests, woodlands, grasslands and shallow wetlands, and collectively these habitats harbour a large proportion of the earth's terrestrial and aquatic biodiversity (Sparks, 1995; Swales *et al.*, 1999; Gopal and Junk, 2000). In some large floodplain rivers, flood pulses are so predictable and long-lasting that plants, animals, and even human societies have adapted to take advantage of them (Sparks, 1995). Flood pulses are suggested to be the driving force for the high biodiversity of floodplains by creating heterogeneity of habitats (Junk, 1993; Gopal and Junk, 2000). Most large floodplain rivers of the world are greatly altered by human activity; rivers that have not been altered are rare, and are more than likely to be altered in the near future (Gore and Sheilds, 1995; Sparks, 1995; Zalewski and Welcomme, 2001). Tropical floodplains are the most diverse of all floodplain ecosystems (Roggeri, 1995; Gopal and Junk, 2000), and will therefore be the most impacted by development, largely because tropical floodplains are located in developing countries that do not have the economy to establish environmental sustainability into industry (Roggeri, 1995). These areas are characterised by seasonal inundation from river overflow, which induces an exchange of nutrients and organisms across a mosaic of habitats (Sparks, 1995; Zalewski and Welcomme, 2001), and the invasion of a huge biomass of organisms to these temporary habitats for food, reproduction and nursery purposes (Lowe-McConnell, 1987; Junk, 1989; Zalewski and Welcome, 2001). Wetlands are among the most threatened ecosystems in the world because they are directly destroyed (by clearing, draining and filling for agriculture and urban development), as well as bearing the impacts of all anthropogenic activities in their watershed (Gopal and Junk, 2000).

In most tropical areas, floodplains are very extensive (e.g., Gran Pantanal, Paraguay, 100,000 km^2; and the Fly River, Papua New Guinea 45,000 km^2). They fluctuate between aquatic and terrestrial ecosystems depending on the flooding cycle (Welcomme, 1979; Junk, 1992; Roggeri, 1995; Swales *et al.*, 1999). By world standards, Australia has small floodplain rivers: none were included in a recent review of large floodplain rivers (Swales *et al.*, 2000). There has been little research undertaken on the ecology of northern Australia’s floodplain rivers with the exception of the Alligator Rivers Region (e.g., Bishop *et al.*, 1980, 1991, 2001). Most floodplain research has been conducted in southeastern Australia, especially on the Murray-Darling Basin (Lawrence, 1988; Gehrke, 1990, 1991; Arthington 1995; Humphries *et al.*, 1999). Little research has been conducted on the identification, assessment and rehabilitation of largely modified floodplains in tropical Australia, yet economically these floodplains are very important to agricultural and grazing industries (Lukacs and Finlayson, in press). On the east coast, catchments such as the Fitzroy River, Burdekin River, Herbert River and Tully River have received little attention although they comprise some of the most impacted environments in the region (Lukacs and Finlayson, in press). Sugar cane, cattle and to a lesser extent horticulture and urban development have greatly reduced the extent of floodplain habitats (Lukacs and Finlayson, in press). Research is needed to address the impacts, understand basic ecology and to establish integrated management of these systems to provide the economic and environmental sustainability (Arthington *et al.*, 1997).

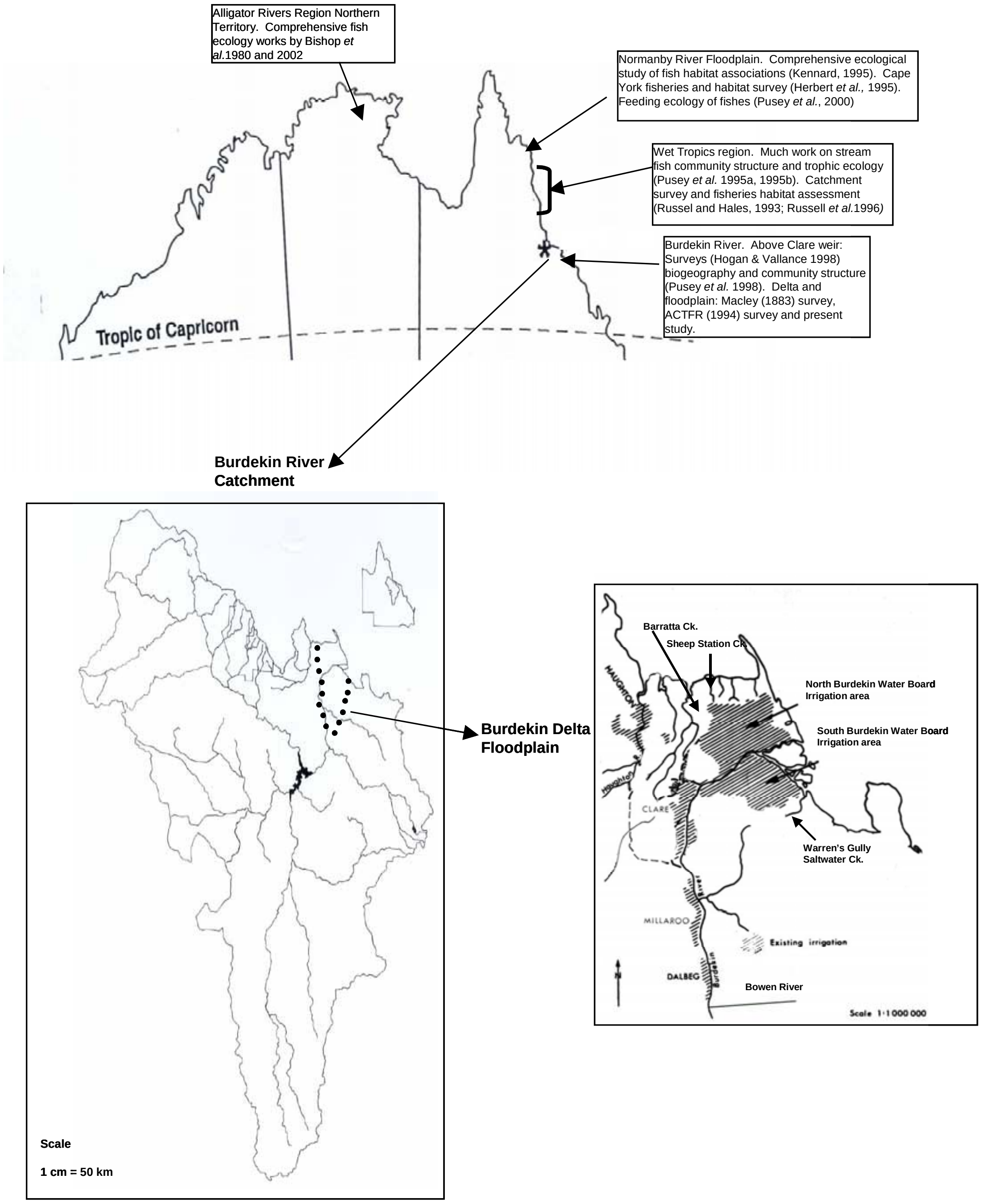
Detailed ecological research conducted in Australian tropical floodplain rivers has focused mainly on unmodified systems, such as; Alligator rivers region, Normanby River and Cape York Peninsula (Bishop *et al.*, 1980, 2001; Kennard, 1995; Herbert *et al.*, 1995). The theoretical basis underpinning much of this research is derived from research on large floodplain rivers in South America, North America, Asia and Africa, which have more predictable magnitude and duration of flooding than Australian systems. Puckridge *et al.* (1994) compared biologically significant hydrological characteristics of 52 rivers world-wide and found that Australian rivers are some of the most variable in flow in the world, grouping only with rivers in South African dry climates. The special flow characteristics of Australian rivers make application of river productivity models difficult. The Burdekin River, which is the focus of this study, is a "dry climate" river with regard to its flow and ecology.

1.2 Australian floodplain fish ecology

Tropical regions in Australia have received little research focus due largely to problems of access and cost (Herbert *et al.*, 1995) (see Fig. 1.1). Magela Creek and the Alligator Rivers Region (ARR) in the Northern Territory is a relatively pristine system in a region with a monsoonal climate. This region has been studied in some detail in order to provide baseline data needed for the establishment of a monitoring programme associated with the Ranger Uranium Mine. Bishop *et al.* (1991, 2001) undertook ecological studies on 37 species of freshwater fish in the ARR and found extensive migration and strong lateral movement of fishes during inundation for feeding and spawning purposes (Bishop *et al.,* 2002).

However, most published work in the north-east region on floodplain fishes has focused largely on survey work, habitat assessment and impact assessment (examples include: Hortle and Pearson, 1990; Russell and Hales, 1993; ACTFR, 1994; Tait, 1994; Herbert, 1995; Russell *et al.*, 1996; Cappo *et al.*, 1998), most of which do not include detailed ecological investigations. Ecological work includes: Kennard (1995), who found that fish community structure was largely determined by instream habitat complexity and structure in floodplain habitats on the Normanby River; Herbert *et al.* (1995), who examined fish diversity and habitat structure on Cape York Peninsula and found that lagoons are particularly important habitats for fish that require macrophyte cover and these habitats act as refuge during drought, and that flooding is very important for rejuvenation of habitats, migration and spawning; Pusey and Kennard. (1996) who found that biodiversity was higher in catchments with low flow variability; Pusey *et al.* (2000b), who found high levels of trophic partitioning in rivers of eastern Cape York Peninsula, largely due to phylogenetic determinants of body size, morphology and foraging mode; and Bunn *et al.* (1997) who found that introduced grasses, especially *Brachiaria mutica* (para grass), contributed little organic carbon to food webs in a wet tropics stream. In the wet tropics stream fish ecology has received some attention (see Beumer, 1979; Pusey *et al.*, 1995a,

Figure 1.1. Fish and fish habitat research locations within the tropics. Location and size of the Burdekin River. Map of Burdekin Delta floodplain.



1995b; Perna, 1996). Pusey *et al.* (1995a) found high fish biodiversity largely related to high habitat diversity resulting from low annual variation in flow. Pusey *et al*. (1995b) found high resource partitioning in habitats of low diversity with high overlap in mouth size, but low overlap in mouth size of related species. Perna (1996) found that fish communities in small streams are resilient to seasonal flooding with deterministic factors (such as competition and predation) largely controlling community dynamics. Beumer (1979) found low diversity of fish species related to the variable flow regimes in the Black-Alice River. There have also been technical reports written by Queensland Department of Primary Industries (DPI) on fisheries values and fish habitat values in selected catchments in the Wet Tropics as pre-cursors to the development to Integrated Catchment Management planning (Russell and Hales, 1993; Herbert *et al.*, 1995; Russell *et al.*, 1996). Most reports indicated that riparian clearing and non-point source pollution had the greatest impact on instream biodiversity. A large review by Cappo *et al.* (1998) focused on fish habitat in Australia, which included tropical Queensland. Loss of wetlands was identified as a key factor in declining fisheries production. However, detailed investigations of large tropical floodplain rivers, which have a high degree of impact and altered hydrology, are limited (Bishop, 2001; Pusey, 2003).

Kennard (1995) examined the ecology of tropical floodplain fish in north Queensland, and focussed on habitat selection, trophic ecology and community dynamics in relation to habitat complexity of off-channel and channel lagoon habitats in a largely unimpacted catchment bordering and within Lakefield National Park. Kennard (1995) showed that fish select shallow habitats with a high occurrence of microhabitats for a combination of reasons other than niche specialisation. Fish utilised these edge habitats for foraging, reproduction and predator avoidance. Smaller juveniles of the largest fish species were found in backflow and floodplain billabongs indicating these habitats are particularly important as nursery areas (Bishop *et al.*, 2001). Larger species tended to recruit primarily in early to mid-wet season. The results of this work have relevance to the management of floodplains in rivers to the south of the Normanby. For example, it is noteworthy that large woody debris (LWD) was a significant determinant of fish assemblage structure (acting as a refuge from predators) in lagoons of the Normanby River (Kennard 1995). In catchments that have been modified for agriculture, such as the Burdekin River, one of the main features of the modification is the removal of riparian habitat (Pusey and Arthington, 2003), and reduction of the input of LWD. Without this microhabitat there may be secondary impacts to fish community structure and abundance.

Flood pulses are postulated to be of great importance to floodplain structure and function (Junk *et al.*, 1989); however, on the north-eastern coast of Australia the morphology and climate is such that runoff is seasonal and generally rapid, and therefore native fish may not have evolved the same floodplain associations as observed elsewhere in the world (Puckridge *et al.*, 1998). Runoff is even more rapid in agricultural catchments due to modifications to reduce inundation times for crops (Tait, 1994; Perna and West, 1998). The fish in these rivers may be more reliant on the more permanent river channels and deep-water lagoons than on the floodplain itself, due to the short duration of inundation (Herbert, *et al.* 1995), and high risk of isolation in ephemeral waters. Research in the Murray-Darling suggests that the floodplain is not nearly as important as previously believed for species such as golden perch, which as larvae actively avoid off-channel habitats (Gehrke, 1991). The "low flow recruitment hypothesis" of Humphries *et al.* (1999) suggests that the low levels of flood predictability in the Murray-Darling may lead to fish using other cues, such as temperature, to initiate spawning. The same may be true of the north-eastern dry tropics. The flood-pulse is no doubt important to the transport of nutrients to and from the floodplain but native Australian fish may not invade the floodplain to the degree shown elsewhere. Australia's high variability in timing and duration of inundation may make floodplain habitats high-risk areas for colonisation (Gehrke, 1991).

Floodplain habitats in northern Australia may experience much harsher conditions during the dry season than occur in (or are experienced in) channel habitats (Hillman, 1986; Tait 1994; Kennard, 1995; Herbert *et al.*, 1995). Lagoons tend to have much more exposure to sun and thus higher growth of macrophytes, leading to enhanced oxygen fluctuation (Kaenel *et al.*, 2000). Falling water levels due to evaporation, increase turbidity through resuspension of sediments and fine particulate organic matter, which in turn increase microbial Biological Oxygen Demand (BOD) (J. Faithful pers. com.; Wood and Armitage, 1997). Lowered water levels may also reduce micro-habitat availability and diversity (Kennard, 1995). These differences require a review of theories such as the RPM and FPC (Junk *et al.*, 1989; Thorpe and DeLong, 1994), to account for the effects of high levels of flow variability and harsh environmental conditions characteristic of Australian floodplain habitats.

1.3 Agricultural impacts and floodplain habitat function in tropical Australia

The tropical fresh waters of Australia are very important to agriculture and fisheries and are increasingly under pressure for development (Bishop *et al.*, 2001). The area planted to sugar cane is expanding in both north-eastern and north-western Australia. There are expectations that agriculture (rice and cotton) will expand in the Northern Territory along with a growing aquaculture industry (Lukacs and Finlayson, *in press.*). There is a common perception that floodplains in the north are under little pressure and more often than not in pristine or near pristine condition (Storrs and Finlayson, 1998; Finlayson *et al.*, 1998). There has been a strong drive since the early 1990's to identify and classify important wetlands (see Australian Nature Conservation Agency, 1996; Blackman *et al.*, 1999;) so that they may be protected or developed in a sustainable manner. There are many more intact wetlands and floodplains in the north of Australia than in the south; however, without establishing a set of values for these ecosystems the same *ad hoc* development undertaken in the past century may also be carried out in the north (Finlayson and Lukacs, in press).

The main reason for the agricultural development of wetlands is the nutrient-rich alluvial soils in the floodplain areas and their proximity to a water source. Natural floodplain processes have been altered in some catchments, by river regulation and water diversion to irrigate agriculture (EPA, 1999). The most common form of modification is deforestation and channelization for optimum crop production (EPA, 1999). Shallow lagoons have been filled in and levelled in catchments such as the Herbert (80% loss) and Tully-Murray (71% loss) (Tait, 1994; Johnson *et al.*, 1997; EPA, 1999), and many kilometres of riparian corridor have been cleared for increased production (Finlayson and Lukacs, *in press*). During periods of low world prices for sugar, landholders attempt to compensate by increasing their production, thus clearing and planting more cane. The loss of riparian habitat has many impacts on fish community structure and conservation (Pusey and Arthington, 2003).

No single source has quantified the total cover of wetland habitats on the east coast of Queensland but it is suspected that there is much more wetland habitat in Queensland than any other state (EPA, 1999; Blackman *et al.*, 1999). Most tropical floodplains of north-eastern Queensland (at least north to the Daintree River) have been modified for agriculture, mostly sugar cane, grazing, and bananas in the wetter catchments (Russell and Hales, 1993; Tait, 1994; Russell *et al.*, 1996; Arthington *et al.*, 1997; Johnson *et al.*, 1997; EPA, 1999; Lukacs and Finlayson, *in press*). These modifications have had flow-on effects to fish and fish habitats. Increased sediment loads, migration barriers, weed infestation and chemical use have affected the floodplains and their associated fish communities (ACTFR, 1994; Arthington *et al.*, 1997; Pusey and Arthington, 2003). The most direct change has been in hydrology, with water levels being maintained through pumping (e.g., the Burdekin), or drainage systems to divert water more rapidly (Perna and West, 1998). Effects include decreased riparian diversity, increase in grassy bank cover, decrease in in-stream habitat complexity, increased erosion and increased mean flow velocities (Nilsson and Svedmark, 2002). The riparian corridor is a key ecosystem linking the aquatic and terrestrial ecosystems (Junk *et al.*, 1989; Nilsson and Svedmark, 2002; Pusey and Arthington, 2003). Increased water levels from irrigation infrastructure kill riparian trees through inundation (Nilsson and Svedmark, 2002), aid invasive weed growth (Gutierrez *et al.*, 2001), supply a continuous (not necessarily increased) nutrient load, which leads to prolific weed growth, and generally carry an increased total suspended solids load (Arthington *et* al., 1997; Gutierrez *et al.*, 2001).

1.3.1 Impacts on the Burdekin floodplain

The Burdekin River, in north Queensland has one of the largest delta floodplains in Australia (1,250 km^2) with a large sugarcane and grazing industry (Hopley, 1970). The river's hydrology is highly modified as a succession of impoundments has been built along the river over the past 60 years. Several weirs, located in the lower floodplain section of the river within 60 km of the mouth, were built to harvest water for the expanding sugar industry. The most recent developments have been the Burdekin River Irrigation Area (BRIA) (1989 first operations). Since the construction of the Burdekin Falls Dam in 1986, water is released on demand to pump stations within Clare Weir and downstream (sand dams), where it is pumped into either artificial channels or natural overflow distributary streams (Plantation, Sheep Station, Kalamia, Iya and Warren's Gully), to service the BRIA and the water board areas. The North and South Burdekin water boards (NBWB and SBWB) are constituted under the State Water Act 1989 to use part of the flow of the Burdekin River to replenish groundwaters in the north and south of the Burdekin River Floodplain (NBWB and SBWB annual reports, 2002).

A major impact on the floodplain habitats in the Burdekin is due to the invasive floating and emergent grassy weeds. The main floating plant species is the water hyacinth *Eichhornia crassipes*, which forms heavily compacted mats that provide a "hydroponic platform" for (other) introduced and native grasses to grow on. Elsewhere, infestations of *E. crassipes* form impenetrable mats across the water surface, limiting access by humans, animals and machinery (Julien *et al.*, 2001). Navigation and fishing are obstructed, and irrigation and drainage systems become blocked (Julien *et al.*, 2001). In its native range, *E. crassipes* only becomes a problem when hydrology is changed, nutrients increased, or natural enemies recover more slowly than the weed (Julien *et al.*, 2001). Within the Burdekin region the cost of *E. crassipes* infestation to the irrigation system, recreational fishery, vector control, and fish habitat values is very high. In some areas that have been overgrown for extended periods it is possible to walk and even ride a motorcycle over the mats (C. Perna and S. Manwaring, pers. observation; J. Tait, pers. com.). Besides reducing habitat values on the floodplain, hyacinth has many other negative impacts in the region. For example, it may encourage the proliferation of mosquitoes, important vectors of human and animal diseases, by improving breeding sites (Julien *et al.* 2001). It may dramatically increase water loss (through evapo-transpiration at rates up to four times that of evaporation), imposing higher operational costs on water supply schemes (Julien *et al.*, 2001).

Hyacinth may cause severe flooding and damage to infrastructure during periods of high flow (Wijeyaratne and Perera, 2000).

The impact of *E. crassipes* on fish is dramatic. By forming densely packed mats it essentially blocks out most of the pathways for oxygen production and transfer in the water column (Julien *et al.*, 2001). *Eichhornia crassipes* shades out submerged aquatic macrophytes, and in lentic lagoons excludes the establishment of phytoplankton. By restricting the oxygen production in the water, hyacinth essentially reduces the fish community to those species that are most tolerant of low oxygen levels (EPA, 1999). Therefore, *E. crassipes* may be a driving force in the reduced fish and habitat diversity on the floodplain.

One of the most important factors contributing to the rapid growth of *E. crassipes* in the Burdekin is a sustained water level. Without the natural "dry back" of floodplain lagoons and channels, *E. crassipes* has an extended growing season. Within six months, lagoons up to 1 ha in area can be covered by *E. crassipes,* and under ideal conditions it can double its mass in two weeks (EPA, 1999). Because chemical and mechanical control are costly and ineffective on all but small infestations (Julien *et al.*, 2001), *E. crassipes* is left to grow freely. Its seed viability is between 5 and 20 years (Julien *et al.*, 2001), so complete control is not feasible. Seeds sink after release, and germinate as water levels change (Julien *et al.*, 2001), but in areas where water levels are constant (such as the Burdekin), reproduction is primarily vegetative. Physical, chemical and biological control can maintain infestations, but input of urban, agricultural and industrial contaminants must be controlled for long-term rehabilitation (Gutierrez *et al.*, 2001). Outbreaks of aquatic weeds are the result of changes in the physical, chemical and biological conditions brought about by the uncontrolled flow of nutrients from urban, agricultural and industrial centres, and in silt eroded from watersheds (Gutierrez *et al.*, 2001).

There has been limited research on fish community dynamics on the Burdekin River below Clare Weir, mainly surveys lacking any detailed analysis of fish community structure (MacLeay, 1883; ACTFR, 1994). Without pre-dam or pre-irrigation data it is difficult to find remnant or representative data on what the fish communities were like before the modifications. However, assessment of the present communities and habitat conditions can be made and compared with remnant sites, while taking into consideration issues of connectivity and recent flow events. This assessment forms part of the present study.

1.4 Aims and structure of this study

The main purpose of this study is to examine fish habitat values and rehabilitation techniques in the highly modified distributary streams of the Burdekin Delta floodplain. These streams are now used as irrigation channels to deliver water to cane growers. Water is released from the Burdekin Falls Dam to Clare Weir, where it is distributed to the various downstream extraction points to be pumped out of the river via sand dams and small weirs into the existing overflow channels of the distributary streams. With the change in hydrological regime there have been many changes in fish habitats along the streams. Changes include increased flow velocities and sediment loading, infrastructure that creates barriers, weed infestation, water logging and clearing of riparian trees, and an overall change from seasonally isolated water bodies (lagoons) to perennial flowing streams with intermittent deep holes. There have been massive modifications to land cover, which has changed from forested *Eucalyptus* woodlands, *Melaleuca* swamps, sedge wetlands and grassland, to cane paddocks (Hopley, 1970). However, there have been remnant wetland areas identified and conserved within the landscape that retain many of the more natural habitats and fish communities.

This study describes physical habitats and physico-chemical water quality that contribute to the quality of fish habitat on the Burdekin Floodplain. Habitat mapping was conducted at 25 sites, once across the greater floodplain, recording riparian condition and composition, in-stream habitat cover and diversity and morphological structure of the lagoons (Chapter 2). Repeat water quality sampling was conducted over two years at ten sites, in conjunction with fish sampling (Chapter 3). More detailed water quality investigations were conducted seasonally to understand the temporal changes in water quality (Chapter 3). Nine fish surveys were conducted to document spatial and temporal changes in fish communities (Chapter 4). Connectivity to recruitment sources was documented using maps and aerial photos, and weed infestation was documented. A case study of the effects of mechanical weed removal on a lagoon ecosystem was undertaken (Chapter 5).

It was hypothesized that:

i) the altered hydrology has decreased habitat values through increased sediment loads, flow velocities, migration barriers and increased weed infestation;

ii) the poor habitat quality, caused by weed infestation, has caused low fish diversity and abundance;

iii) reduced connectivity, caused by weeds and infrastructure, has lead to low diversity and low abundance of larger fish species, and absence of most saltwater–derived species; and

iv) after weed removal, water quality, especially dissolved oxygen levels, would improve and be maintained above sub-lethal and acute levels, instream habitat diversity would increase with native submerged macrophytes establishing in the open water, and fish species diversity and abundance would increase through recruitment.