Coastal floodplain management in eastern Australia: barriers to fish and invertebrate recruitment in acid sulphate soil catchments

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NON TECHNICAL SUMMARY

98/215	Coastal floodplain management in eastern Australia: barriers to fish and invertebrate recruitment in acid sulfate soil catchments

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OBJECTIVES:

(1) To develop guidelines for floodgate and tidal barrier specifications & management based on:
  (a) the relationship between recruitment of migratory and non-migratory fish and invertebrate species, and the opening size, frequency and timing of the opening of tidal barriers,
  (b) the impacts of changed hydrological conditions on the water table and water flows in associated agricultural land.

(2) To assess:
  (a) the behaviour of catadromous fish in relation to the tidal flows through openings in the barriers,
  (b) the behavioural responses of recruiting juveniles to low level (chronic) concentrations of acid sulfate soil drainage water.

(3) To develop and implement an extension program on the outcomes of the project, and to communicate the above guidelines to agricultural industry groups, local government and other agencies with interests in the management of land and water resources in coastal floodplains using demonstration study areas and supporting literature.

NON TECHNICAL SUMMARY:

Outcomes Achieved
The project has contributed to the ecologically sustainable management of coastal floodplains in eastern Australia by providing information on the inter-relationships between floodgate management, species richness, diversity and assemblages and water and habitat quality variables. The specific outputs are: a new set of guidelines entitled '*Restoring the balance: Guidelines for managing floodgate and drainage systems on coastal floodplains*' produced in collaboration with NSW Agriculture; an improved understanding of the effectiveness of floodgate management in improving fish passage and water quality; an improved understanding of the impact of chronic acid sulphate run-off on juvenile fish and prawn migration; and an appreciation of the need to address habitat rehabilitation in order to restore coastal nursery areas.

Estuarine habitats, and in particular coastal floodplains and wetlands, provide essential nursery habitat for a large number of fish and prawn species, many of which are commercially and recreationally significant. Human activities on coastal land, such as those associated with grazing and intensive cropping or industrial and residential development, can have detrimental downstream effects. For fisheries production in the estuaries of northern NSW, two of these land-based activities, drainage of acid sulfate soils and the alienation of significant habitat areas, may have severe consequences.

These two issues were addressed in this research project, the findings from which will be used to restore degraded fish habitats and enhance access to them by fish, thereby improving fisheries in affected areas. Ultimately, fishers, farmers and landholders will benefit from improved water quality in their drainage systems. The research findings will have specific implications for management of floodgates in those catchments studied and will be more generally applicable to acid sulfate soil catchments throughout NSW and Queensland.

Field work

We examined the effectiveness of two management options for floodgated drainage systems on the movement of juvenile fish and invertebrates and on water quality: (i) different opening regimes of floodgates (particularly one-way flap valves), and (ii) different gate structures.

Our results show that the numbers and biomass of estuarine fish differed significantly and consistently between drainage systems with and without floodgates. The major water and habitat quality variables of concern in systems with floodgates were:

- elevated concentrations of nutrients;
- abundance of grasses and rushes;
- absence of mangroves.

An increase in opening frequency of floodgates resulted in a significant increase in the number and diversity of marine species. Juvenile fish and prawns moved into drainage systems with opened floodgates, regardless of whether the system was a modified natural creek or a man-made drain. However, the installation of mini-sluicegate or vertical lift-gates did not improve fish passage. Examination of five different types of tidal floodgates revealed that all types let some fish through, but all designs could be improved to enhance passage of additional species. Improvements to fish passage, however, quickly disappeared when floodgates were not opened for prolonged periods of time. Hence, continued active management of floodgates (i.e. frequent and regular opening) should be maintained once it has commenced. Consideration of the spawning and recruitment times of the major commercial fish species strongly suggest that floodgates should remain open and disturbance of acid sulfate soils should be minimised during the critical, low-rainfall, winter period. This would ensure that recruitment of these species to estuarine habitats is maintained and enhanced.

Opening of floodgates resulted in significant improvements in water quality in managed drainage systems, including significantly fewer occasions where concentrations of total phosphorus, phosphate, and total aluminium were above ANZECC guidelines. Frequent openings did not, however, lower concentrations of total nitrogen in floodgated systems, and levels were often significantly above ANZECC guidelines. To improve water quality, we strongly suggest that, in addition to opening floodgates, best land management practices should be implemented to reduce nutrient input (e.g. reduced and/or more effective and efficient use of fertilizers, fencing off water courses, and rehabilitation of riparian vegetation).

Opening of floodgates also resulted in significant improvements in habitat quality in managed drainage systems, including the disappearance of waterlilies, grasses and rushes, most likely due to tidal influx. To restore fish assemblages in systems with floodgates to something resembling those in more natural systems, however, may require some active restoration (e.g. reintroduction of mangroves or seagrasses). This would be particularly important if managed drainage systems themselves are going to provide a role as fish habitat.

Laboratory work

To understand why juvenile fish were absent from many floodgated systems, we examined the possible existence of acid avoidance behaviour in juveniles of species that may be susceptible to impacts from acid sulfate soil, particularly to chronic acid sulfate discharge. We tested the predictions that juvenile fish and prawns can detect a difference in acidity and subsequently avoid low concentrations of acid, when given a choice. Laboratory experiments using Australian bass, snapper, yellowfin bream and school prawns show that juveniles of all species avoided acidified water. Snapper showed the strongest responses and school prawn the weakest. The pH levels that fish avoided in these experiments were often measured in natural systems. Thus, active avoidance behaviour may seriously affect migration patterns in areas with acid sulfate run-off. As a result, the capacity of habitats beyond acid discharge points to act as spawning or nursery areas would be reduced. These results provide strong evidence that acid sulfate run-off can impact detrimentally on commercial and recreational fishing activities.

Extension work

A Communication Strategy, jointly developed by NSW Agriculture and NSW Fisheries, was adopted at the start of the project to make research findings available in an appropriate format to various audiences, so that on-ground change would result from the research projects. The joint communication strategy has successfully continued beyond the duration of the research work. Extension and communication activities included presentations, articles, media, and meetings.

A new set of guidelines, '*Restoring the balance: Guidelines for managing floodgate and drainage systems on coastal floodplains*', was produced as a result of collaborative research between NSW Fisheries (this project) and NSW Agriculture. A Floodgate Guidelines Working Party (with members from NSW Fisheries, NSW Agriculture, the Clarence Floodplain Project, the Department of Land and Water Conservation, and the Clarence River Fishermans Cooperative) oversaw the production of the guidelines. The new guidelines were launched in Grafton in January 2004, and over 1500 copies have been distributed.

KEYWORDS:
Fish, prawns, recruitment, estuarine habitats, acid sulfate soils, tidal barriers, floodgates, drainage systems, floodplain management, water quality, migration, behaviour, New South Wales, Queensland, Australia

1. GENERAL INTRODUCTION

1.1. Background

Estuarine habitats, and in particular coastal floodplains and wetlands, are a vital component in the maintenance of estuarine and inshore fish and invertebrate stocks (Pollard, 1976; Bell and Pollard, 1989). Many of the more important commercially and recreationally significant species use a number of these habitats in succession during their ontogenetic development. Hence, the protection and restoration of the range of habitats found in estuarine and coastal areas, rather than a single key or critical habitat, is an issue receiving increasing prominence from environmental managers. This is apparent from initiatives associated with State of the Environment reporting by local, state and commonwealth governments and the strategic directions used by the National Heritage Trust and other bodies to prioritise their funding.

In Australia, the major threats to the complex of coastal floodplain and wetland habitats important to fisheries are (i) land and water management practices associated with grazing and intensive cropping, and (ii) the increasing development of river and lagoon catchments near urban centres. In northern NSW and southern Qld, these resource management and development practices have various effects, the two most important ones for fisheries being drainage of acid sulfate soils, and alienation of significant aquatic habitat areas.

Two reviews prepared for FRDC (Webbnet Land Resources Services, 1996; Cappo *et al.*, 1997) underlined the importance of protecting coastal floodplain and wetland habitats. These detailed assessments identified the need for integrated studies across land/sea boundaries, and called for a collaborative approach from several Research and Development Corporations. Two priority areas identified in these reviews as requiring further research were:

- impacts of altering tidal barrier management on water quality, fish passage and recruitment;
- fish habitat, particularly in acid sulfate soil areas.

The reviews noted that case studies with wide national application in habitat dynamics, carried out in catchment-focused studies which develop techniques, protocols and guidelines could greatly improve the management of coastal floodplains. The project described in this report attempts to provide such an approach.

This fisheries project is a significant component of an integrated initiative between three R & D Corporations (Land and Water Australia, Sugar Research and Development Corporation, and Fisheries Research and Development Corporation), the Clarence River County Council, and the Upper North Coast Catchment Management Board (previously called the Clarence River Catchment Management Committee). The initiative provided the framework for better understanding the links among land, water, agronomy, livestock and fisheries activities. The overall aim of the initiative was to investigate ways of modifying existing floodplain use to improve or enhance (i) water quality, (ii) drainage of acid sulfate affected areas, and (iii) access to aquatic habitats for fish, without undue detrimental impacts to agricultural productivity or flood protection. The integrated program sought to develop guidelines for the sustainable management of coastal river floodplains in areas of northern NSW and southern Qld that are affected by acid sulfate soil run-off. Major sub-projects in the initiative were related to (i) floodplain water table and water balance management, (ii) studies of farming systems to minimise the need for drainage of acid sulfate soils, and (iii) tidal barrier management to provide “leakiness” for fish recruitment and migration.

Previous research has shown that fish will recruit into highly modified habitats even when the habitat is not the preferred option for the particular ontogenetic stage involved (Gibbs *et al.*, 1999). That result suggests that restoration of habitats by the active management of tidal barriers is a practical way of improving fish stocks and providing ecosystem protection. This fisheries project was a stand-alone project, although it shared some sites with other component projects on land management, in particular with NSW Agriculture's "*Hydrological Effects of Flood Gate Management on Coastal Floodplain Agriculture*" (DAN 13). In addition, this project is linked with the floodgate audit project completed by the Clarence River County Council (Williams, 2000).

Finally, this integrated initiative is consistent with the "National Strategy for the Management of Coastal Acid Sulfate Soils" (2000), and addresses aspects of three out of the four national objectives, namely to:

- avoid disturbance of coastal acid sulfate soil;
- mitigate impacts when acid sulfate soil disturbance is unavoidable;
- rehabilitate disturbed acid sulfate soil and minimise acid drainage.

1.2. Need

Fish habitat in coastal floodplains and wetlands will continue to be degraded, unless practical guidelines are developed for improvement of water quality, and management of tidal barriers to allow fish passage. This is being increasingly recognised by many decision-making agencies. However, landholders will not willingly change their current management practices unless, as a minimum, there is minimal risk of adverse effects to their productivity. Guidelines for change must be developed in an integrated manner with a focus on land, water, agriculture and fisheries if all industry groups are to accept the recommended changes.

Previous studies by NSW Fisheries (some funded by FRDC) have shown that a change in coastal floodplain and wetland habitats from freshwater to estuarine, and recruitment of fish and invertebrates to these modified habitats, can be achieved by increasing the degree of "leakiness" in the tidal barrier (e.g. Gibbs *et al.*, 1999). However, few data are available on the precise relationships between fish and invertebrate recruitment and the opening size or opening regime of these tidal barriers.

A second issue is the long-term impact of chronic acid drainage, which does not necessarily cause major fish kills, but may affect the recruitment of migratory and catadromous fish and invertebrates. The life history, behaviour and demography of species such as Australian bass (*Macquaria novemaculeata*), long- and short-finned eels (*Anguilla reinhardtii* and *A. australis*), yellowfin bream (*Acanthopagrus australis*), southern herring (*Herklotsichthys castelnaui*), sea mullet (*Mugil cephalus*) and school prawn (*Metapenaeus macleayi*) show that they are particularly susceptible to such an impact. For example, the population collapse through recruitment failure of Australian bass in NSW rivers, such as the Hastings and Manning, has been partly attributed to the effects of acid drainage (J. Harris, 1989 and pers. comm.).

The management of tidal barriers and floodgates to allow fish passage, as well as the development of stable faunal communities in previously alienated habitat above these structures, can significantly enhance fish and invertebrate stocks. The consequent protection of fish habitats and fish and invertebrate species in these areas also supports biodiversity conservation.

1.3. Objectives and the achievement of those objectives

Objective 1 To develop guidelines for floodgate and tidal barrier specifications and management based on:

(a) the relationship between recruitment of migratory and non-migratory fish and invertebrate species and the opening size of, and the frequency and timing of the opening of tidal barriers.

The major study area in the Clarence river floodplain was assessed and appropriate sites were selected after reconnaissance surveys with staff from NSW Agriculture and the Clarence River County Council in early 2000. The selection of sampling sites was finalised based on the location of the sites in the floodplain and on landholders' permission to access their property. There were eight 'gated' drainage systems (six of which were opened at various times during our project) and five 'reference' drainage systems (i.e. creeks of similar dimension but without floodgates). Six of the eight floodgates were 'managed' during the project (i.e. opened for various times); four with winchgates, one with vertical liftgates, and one with a mini-sluice gate. Unfortunately, a strict Before-After-Control-Impact (BACI) design could not used as had been originally planned. More indirect, non-metric tests had to be used, therefore, to examine improvements in fish assemblages following the implementation of the new 'management regimes'.

During the fieldwork (14 trips to the Clarence catchment in 2000-2002) we compared assemblages of estuarine biota between floodgated drainage systems and reference drainage systems. Comparisons were also made before and after opening of the six 'managed' floodgates, although the variable frequency and duration of these openings made formal analyses difficult. To quantify the effects of floodgates on estuarine biota, juvenile fish and invertebrates were caught in seine nets and then counted, weighed and measured. Additional work of a complimentary nature was done on tidal floodgates on the Macleay, Hunter and Hastings rivers. Statistical analyses of various sorts were used to analyse the resulting data. The interpretation of these analyses provided the basis for developing recommendations for improving the way floodgates are managed in regions with acid sulfate soils to promote better access for juvenile fish. The results clearly show that, as expected, fish passage does improve with frequent and regular opening of floodgates.

(b) the impacts of changed hydrological conditions on the water table and water flows in associated agricultural land.

A comprehensive set of water quality variables was measured during all field trips to the Clarence River sites. Habitat variables potentially relevant for juvenile fish and invertebrates were also assessed for all but the first field trips. Similar data were also collected on many of the sampling exercises in the Macleay, Hastings and Hunter rivers. As for the biotic data described above, water quality and habitat characteristics were compared between reference systems and 'gated' systems and before and after opening of some of the gated systems.

Opening of floodgates resulted in significant improvements in water quality in managed drainage systems, especially for total phosphorus, phosphate and total aluminium. However, concentrations of total phosphorus, phosphate and total nitrogen in managed systems did not decrease to levels encountered in reference systems. Opening of floodgates also resulted in significant improvements in habitat characteristics in managed drainage systems, including the disappearance of waterlilies, grasses and rushes. In addition to opening floodgates to improve water quality within, and discharged from, gated drainage systems, additional management activities may be required.

The results of the research for both components of Objective 1 are described in detail in chapters 3 and 4 of this report. Recommendations arising from the research have been included in the recently released document *'Restoring the balance - Guidelines for managing floodgate and drainage systems on coastal floodplains'*.

Objective 2: To assess:

(a) the behaviour of catadromous fish in relation to the tidal flows through openings in the barriers.

We trialed an underwater camera near the floodgate at Marsh Drain in Palmers Channel, Clarence river, in May 2000. Unfortunately, the outcomes of this trial showed that the methodology was not feasible in estuarine waters. The visibility on the downstream side of Marsh Drain's floodgate was approximately 0.5 m, a fairly common visibility for estuarine waters. However, this is inadequate for observing the behaviour of fish and/or invertebrates around individual floodgates (floodgates are generally 1.2 x 2 m). Therefore, this part of the objective could not be achieved, and we subsequently focused on the second part of this objective.

(b) the behavioural responses of recruiting juveniles to low level (chronic) concentrations of acid sulfate soil drainage water.

We described the temporal recruitment patterns of commercially and recreationally significant species sampled in the Clarence floodplain and compared these recruitment data with information from the literature. This allowed an assessment of whether there are particular times or seasons when barriers to recruitment will have the greatest impact on these species in the Clarence River floodplain. The results suggest that closed floodgates and acute acid sulfate discharge during the high rainfall season (late summer and early autumn) may not impact significantly on the recruitment of commercially significant fish species. The low-rainfall, winter period is more critical to fish recruitment and gates should be opened during this time if possible. Floodgate closures, however, should not be maintained for long periods of time during any season, because they may lead to degraded water quality above the barrier, which may cause mortality of juvenile and adult fish trapped there.

We also built a special laboratory 'fluvarium' adapted from designs available in the scientific literature, to test whether juvenile fish and prawns could detect and actively avoid low concentrations of acid in seawater. The results showed that juveniles of the four species tested avoided acidified water, with snapper showing the strongest responses and school prawn the weakest.

The results of the research for component (b) of this objective are described in detail in chapters 5-7 of this report. Recommendations arising from the research have been included in the recently released document 'Restoring the balance - Guidelines for managing floodgate and drainage systems on coastal floodplains'. Furthermore, two papers have been published in international scientific journals, namely Limnology and Oceanography: Methods (2003), 1:39-44, and Marine Ecology Progress Series (in press).

Objective 3: ***To develop and implement an extension program on the outcomes of the project, and to communicate the above guidelines to agricultural industry groups, local government and other agencies with interests in the management of land and water resources in coastal floodplains using demonstration study areas and supporting literature.***

A Joint Communication Strategy for both NSW Agriculture and NSW Fisheries was adopted early in the project. Extension and communication activities involved presentations, articles, media, and meetings as described in chapter 8. Twenty-one of these activities were targeted at commercial and recreational fishers who appreciated the opportunity of learning about research relevant to their local fishing activities. The meetings with landholders provided an opportunity to illustrate and discuss the implications for downstream fish resources of poorly managed floodgates in a non-threatening circumstance. Communication with farmers and fishers about floodgate management has continued beyond the duration of this research project.

The production of the document '*Restoring the balance - Guidelines for managing floodgate and drainage systems on coastal floodplains*' was a major outcome from this collaborative initiative. The draft document was distributed to key stakeholders in May 2003 and feedback was integrated into a final draft in October 2003. Senator Judith Troeth launched the new set of guidelines in Grafton in January 2004.

2. METHODS TO ASSESS IMPACT OF FLOODGATES AND FLOODGATE MANAGEMENT ON FISH PASSAGE AND WATER AND HABITAT QUALITY IN COASTAL FLOODPLAINS, NSW

2.1. Introduction

The aim of the fieldwork of this project was to examine the relationship between recruitment of migratory and non-migratory fish and invertebrate species and the opening size of, and the frequency and timing of the opening of floodgates. Previous studies by NSW Fisheries (some funded by FRDC) have shown that a change in coastal floodplain and wetland habitats from freshwater to estuarine, and migration of fish and invertebrates to these modified habitats, can be achieved by increasing the degree of "leakiness" in the tidal barrier (Pollard and Hannan, 1994; Gibbs *et al.*, 1999). This suggests that opening floodgates at the right time, and for the right amount of time, allows fish to access upstream habitat and food, thereby enhancing the productivity of the fishery. However, few data are available on the precise relationships between fish and invertebrate migration and the opening size or opening regime of these tidal barriers.

Gibbs *et al.* (1999) reviewed the methods available to sample estuarine fish and invertebrate populations, and concluded that nets were the most effective way to sample for a range of species in an area. Further, they determined that seine nets were the best option for sampling in the shallow, often restricted areas around floodgates. The protocols developed in their study have been followed in the present work; the methodology used here was chosen specifically to sample only juvenile fish and invertebrates.

Three river systems were originally considered for the main part of this study, the Clarence, Macleay and Hunter rivers in northern NSW (Australia). Preliminary investigations revealed that sufficient sites were available in the Clarence to carry out the sampling design chosen for this research (see below). Although some sampling was done in the Macleay when opportunity allowed (Appendix 4), the major focus of this study was in the Clarence River. A small amount of additional work was also done on individual tidal floodgates on the Hunter and Hastings rivers (Appendix 8).

In this Chapter, we describe the study sites on the Clarence river floodplain as well as the sampling methods used for the field surveys. These sites and this methodology apply to the research reported in chapters 3-5. The Clarence river is NSW's largest coastal river system, with a catchment area of about 22,400km^2 (Roy *et al.,* 2001).

2.2. Sampling sites in the Clarence River

The Clarence river is NSW's largest coastal river system, with a catchment area of about 22,400 km^2 (Roy *et al.*, 2001). The floodplain starts around the city of Grafton, covers an area of 2100km^2 (Bell and Edwards, 1980) and is underlain by approximately 530km^2 of acid sulfate soils (Tulau, 1999). The floodplain comprises at least 1700 km of floodgated drainage systems and watercourses; approximately 186 drains and floodgated watercourses are managed by the Clarence River County Council (Williams, 2002). The entrance of the Clarence River is approximately 70 km downstream by water from Grafton, and is bordered by Iluka on the north and Yamba on the south. Major sub-catchments in the Clarence's floodplain include the Coldstream River, Sportsmans Creek and the Esk River.

In 1999/2000, the Clarence River supported the largest number of fishers (± 20%), as well as the largest fisheries (~25% by weight and by value) in NSW's estuarine commercial fisheries (Tanner and Liggins, 2001). The estuarine prawn fishery was valued at $2.3 M, comprising approximately 75% of the value of the state's total estuary prawn fisheries catch (Montgomery and Craig, 2001).

Our study was conducted on the river's floodplain between Grafton and Yamba (Figure 2.1). Sampling sites were selected on the basis of (i) the location of the sites in the floodplain, and (ii) landholders' permission to access their property. Spatially, the reference drainage systems encompassed the sites of the gated drainage systems in the floodplain. Given this distribution of sampling sites, we assumed similar species abundance and diversity at reference and gated sites.

Thirteen sampling sites were selected for the project: five drainage systems without floodgates (reference drainage systems), and eight drainage systems with floodgates (gated drainage systems) (Table 2.1). The floodgates at the eight gated systems comprised one-way (downstream opening) flap valves. Catchment-related parameters (distance to river mouth and catchment area) of these drainage systems were estimated by reference to published topographic maps (1:50,000 and 1:100,000) of the areas (Table 2.2). All 13 sites have a high acid sulfate soil potential, as determined from acid sulfate soil risk maps held by the NSW Department of Infrastructure, Planning and Natural Resources (Table 2.2).

Reference drainage systems (Figure 2.2a)

The following summary is drawn from direct observation and from information contained in Pollard and Hannan (1994) and Williams (2000).

(1) <u>James Creek</u> is situated in the Maclean No. 22 area and enters the main Clarence River from the south, 5 km north-east of Maclean. Near the mouth the fringing vegetation consists of mangroves, while further upstream these are replaced by casuarinas, eucalypts, acacias and lantana. The creek drains a catchment consisting of sugar cane near the mouth, and primarily melaleuca backswamp used for cattle grazing further upstream. Part of the upstream catchment is SEPP 14 wetland.

(2) <u>Mororo Creek</u> enters the Back Channel from the north, near its junction with the Clarence River's North Arm, 0.5 km west from Mororo bridge. Near the mouth the fringing mangroves are backed by sparse she-oaks and the surrounding land use is sugar cane. Further upstream, land use consists of sugar cane, cattle grazing and state forest. The creek drains a large melaleuca backswamp.

(3) <u>Sandy Creek</u> enters Ashby Channel from the west, 1.5 to 2 km from the North Channel. The creek is situated 3.5 km downstream from and to the north of Maclean. Near the mouth, the fringing vegetation of the creek consists mainly of mangroves, she-oaks, and gumtrees, with cattle grazing the surrounding land use.

(4) <u>Thorny Creek</u> is located on Thorny Island, 5 km north-west of Yamba. The creek drains a dense mangrove forest on the south side of Thorny Island, where it enters Romiaka Channel, opposite Romiaka Island. Most of Thorny Island is SEPP 14 wetland. Thorny Island is a crown reserve and as such is relatively undisturbed by man.

(5) <u>Upper Coldstream Creek</u> is situated about 5 km upstream from Tucabia and enters the western arm of The Forks to its south. The Forks are situated at the southern end of the Coldstream river, which in turn is a large tributary of the main Clarence river system. The Coldstream river enters the Clarence from the south, 7 km south-west of Tyndale. The fringing vegetation of the Upper Coldstream Creek consists mainly of overhanging she-oaks, and the surrounding land-use is cattle grazing. The creek drains a large SEPP 14 wetland (Crowsnest Swamp).

Table 2.1. Sampling sites at the Clarence river floodplain. CRCC stands for the Clarence River County Council. Northings and Eastings were measured with a hand held GPS (Garmin 12XL) (± 10m).

Clarence River	**CRCC**			**Openings**	**Area 1**		**Area 2**	
	Name	Location	Account #		North	East	North	East
REFERENCE (OPEN)								
James Creek		Clarence		Natural	67 44 037	(56) 05 23 528	67 43 930	(56) 05 23 524
Mororo Creek		Back Channel		Natural	67 51 577	(56) 05 23 753	67 51 648	(56) 05 23 682
Sandy Creek		Back Channel		Natural	67 45 071	(56) 05 18 885	67 45 106	(56) 05 18 848
Thorny Creek		Clarence		Natural	67 45 320	(56) 05 29 840	67 45 328	(56) 05 29 875
Upper Coldstream		Coldstream		Natural	67 13 950	(56) 05 08 823	67 13 933	(56) 05 08 777
GATED (CLOSED)								
Carrs Drain	Palmers Island Carr-61	Palmers Island No. 30	63170	Nil	67 48 543	(56) 05 30 141	67 48 477	(56) 05 30 113
Harwoods Drain	Harwood Youngs 1-12	Harwood Island No. 25	62820	Nil	67 47 462	(56) 05 26 221	67 47 450	(56) 05 26 139
GATED (MANAGED)								
Blanches Drain	Everlasting Blanch 31	Sportsmans Creek No. 12	61810	Flapgate	67 32 119	(56) 05 09 627	67 32 128	(56) 05 09 573
Carrolls Drain	Chatsworth Isl. Carrolls 44/1	Chatsworth Island No. 26	62940	Flapgate	67 48 957	(56) 05 25 726	67 48 988	(56) 05 25 663
Dennys Gully	Dennys Gully	Cowper No. 10	61680	Mini sluicegate	67 29 015	(56) 05 11 444	67 29 025	(56) 05 11 379
Marsh Drain	Palmers Ch/Marsh 18	Palmers Channel No. 23	62700	Vertical liftgate	67 41 826	(56) 05 25 689	67 41 843	(56) 05 25 621
Taloumbi # 5	Taloumbi Radial 5	Taloumbi No. 24	62780	Flapgate	67 33 047	(56) 05 28 626	67 32 973	(56) 05 28 598
Wants Drain	Wants Drain–16	Colletts Island No. 7	61420	Flapgate	67 17 684	(56) 05 09 947	67 17 688	(56) 05 09 878

Table 2.2. Sampling sites at the Clarence river floodplain. Distance from mouth and catchment area were estimated using published topographic maps; depth of pyritic level was obtained from Williams (2000) and the NSW Department of Infrastructure, Planning and Natural Resources.

CLARENCE RIVER	DISTANCE FROM MOUTH (KM)	DRAINAGE AREA (KM^2)	DEPTH OF PYRITIC LEVEL (M)
REFERENCE (OPEN)			
James Creek	18	10.5	0-1
Mororo Creek	18	7.4	1-3
Sandy Creek	24	3.8	1-3
Thorny Creek	7	0.5	0-1
Upper Coldstream	65	24.1	0-1
GATED (CLOSED)			
Carrs Drain	8	3.6	0-1
Harwoods Drain	13	0.9	0-1
GATED (MANAGED)			
Blanches Drain	41	15.6	1
Carrolls Drain	13	4.7	0-1
Dennys Gully	44	1.4	0-1
Marsh Drain	20	2.7	0-1
Taloumbi # 5	18	23.9	0-1
Wants Drain	60	1.7	1

Gated drainage systems (Figure 2.2b)

The following summary is drawn from direct observation, from information contained in Pollard and Hannan (1994) and Williams (2000) and from the Clarence River County Council (J. Challacombe, pers. comm.). The floodgates at the gated systems comprised one-way (downstream opening) flap valves.

(1) Blanches Drain is situated in the Sportsmans Creek area. Twenty percent of the previous 5 km^2 of wetland remains, after the drain was constructed and floodgates (size 2100 mm, with two box culverts) installed in 1966. The 3 km channel upstream of the floodgates joins with 12 private drains, adding another 7.5 km of drains. It supports pasture, sugar, and tea tree plantations, and drains 0.94 km^2 of SEPP 14 wetland.

(2) Carrs Drain is situated on Palmers Island. Fifty percent of the previous 2 km^2 wetland remains, after the drain was constructed and floodgates (size 1500 mm, with three box culverts) were installed in 1965. The 1.5 km channel upstream of the floodgates joins with 3 private drains, adding another 1.0 km of drain. It supports pasture and sugarcane, and drains a significant wetland area for fish breeding and waterbirds.

(3) Carrolls Drain is situated on Chatsworth Island. The mouth of the original creek has been blocked, and a new opening was constructed further to the south. Twenty percent of the previous 0.5 km^2 of wetland remains, after the mouth was diverted and floodgates (size 1500 mm, with five box culverts) installed in 1966. Carrolls Drain is approximately 3 km long, and connects with 4 private drains, adding another 2 km of drain. It supports sugar cane and has little wetland significance.

(4) Dennys Gully is situated in the Cowper area. The mouth of the original creek has been blocked, and a new opening constructed further to the north. Twenty percent of the previous 1 km^2 wetland remains, after the mouth was diverted and floodgates (size 2100 mm, with three box culverts) installed in 1966. Dennys Gully is approximately 1.2 km long, and connects with a single private drain, adding another 0.75 km of drain. It supports sugarcane and pasture and, aside from the natural creek system, has no wetland significance.

(5) Harwoods Drain is situated on Harwood Island. None of the previous 0.2 km^2 wetland remains, after the drain was constructed and floodgates (size 1500 mm, with three box culverts) installed in 1966. The 2.5 km channel upstream of the floodgates does not join with any other drains. It supports sugarcane and, aside from the drainage channel itself, has no wetland significance.

(6) Marsh Drain is situated in the Palmers Channel area. None of the previous 1.5 km^2 wetland remains, after the drain was constructed and floodgates (size 1500 mm, with two pipes) installed in 1965. The pipeculverts are situated approximately 40cm above a concrete apron. This apron stretches out for at least another meter before dropping off into silty substrate. Marsh Drain is approximately 2 km long and joins with one private drain, adding another 2 km of drain. It supports sugar cane and, aside from the drainage channel itself, has no wetland significance.

(7) Taloumbi #5 is situated in the Taloumbi No. 24 area. None of the previously substantial wetland remains, after the drain was constructed and floodgates (size 1500mm, with three pipe culverts) installed in 1973. The 2.5 km channel upstream of the floodgates joins with 3 private drains, adding another 4 km of drain. It supports pasture and sugarcane and, aside from the drainage channel itself, has no wetland significance.

(8) Wants Drain is situated in the Colletts Island area. Fifty percent of the previous 2.5 km^2 wetland remains, after the drain was constructed and floodgates (size 2100 mm, with two box culverts) installed in 1965. The 0.75 km channel upstream of the floodgates joins with one private drain, adding another 200 m of drain. It supports pasture and drains a substantial SEPP 14 wetland.

2.2.1. Sampling methods

Quantitative samples were collected every two months (July 2000 to May 2002), giving twelve sampling occasions (see Chapter 3 and 4 for exceptions). At each sampling site, two areas were selected for sampling; one area 40 m upstream from the mouth (i.e. barrier at gated sites) of the drainage system (Area 1), and a second area 120 m upstream from the mouth (i.e. barrier at gated sites) of the drainage system (Area 2) (Figure 2.3). Sites were sampled in a random order, and moon phase was not taken into consideration. In general, James Creek, Sandy Creek, and Thorny Island were sampled around high slack tide, and Mororo Creek and Upper Coldstream Creek around low slack tide.

2.2.1.1. Water quality

To minimise disturbance of the watercolumn, bottom sediments and aquatic fauna, water quality measurements and samples were taken while floating on a large rubber tube along a transect (Figure 2.5). During each sampling occasion, four water quality variables were measured and three water samples collected at each sampling area before seining. At three equidistant points along a transect across the stream channel, we measured temperature (T, 0.1°C), salinity (g/L), pH (0.1) and dissolved oxygen (DO, 0.1mg/L) using a TPS model 90FL or Horiba U-10 water quality meter. These four variables were measured at the surface and at the bottom. At the middle point, three water samples were collected according to specifications from the Environmental Analysis Laboratory at Southern Cross University. These were stored on ice and frozen at the end of the day, for later determination of conductivity (EC) (0.01 dS/m), total dissolved solids (1 mg/L), turbidity (NTU), total phosphorus (0.001 mg/L P), phosphate (0.001 mg/L P), total nitrogen (0.001 mg/L N), total Kjeldahl nitrogen (0.001 mg/L N), nitrate (0.001 mg/L N), nitrite (0.001 mg/L N), ammonia (0.001 mg/L N), total aluminium (0.001 mg/L), dissolved aluminium (0.001 mg/L), total iron (0.001 mg/L), and dissolved iron (0.001 mg/L). Samples were sent to, and analysed at, the Environmental Analysis Laboratory (Certified Laboratory Practice, Reg.No. CLP0052), according to “Standard Methods for the Examination of Water and Wastewater”, 19^{th} edition 1995, APHA. Metals were analysed by ICP-MS (Inductivity Coupled Plasma – Mass Spectrometry). Total available metals were measured on samples acidified with nitric acid and then filtered through 0.45 µm cellulose acetate, while dissolved metals were measured on samples filtered through 0.45 µm cellulose acetate and then acidified with nitric acid prior to analysis.

A permanent water quality monitoring station was established at the floodgates on Blanches Drain, as part of the companion project by NSW Agriculture. In addition, the Broadwater Sugar Mill provided data from permanent data loggers at Carrolls Drain and Marsh Drain. These two loggers measured temperature (T, 0.1°C), conductivity (mS/cm), pH (0.01) and dissolved oxygen (DO, 0.01 mg/L). Water quality was measured every fifteen minutes, from 27 October 2000 to 4 March 2002 at Carrolls Drain and from 27 October 2000 to 22 January 2002 at Marsh Drain.

2.2.1.2. Fish and invertebrates

Sampling was conducted using a fine mesh seine net (10 m headline x 2 m drop x 6 mm stretch). The net was set from the shore during daylight hours, forming a U-shape and covering an approximate area of 50 m^2. The net was then pursed up onto the shore. In a pilot study in the Clarence River in May 2000, three seine hauls caught 86% of species present (Figure 2.4). We finalised the experimental design on the basis of this result and the available labour and time resources to collect, sort and process the samples. The design had three replicate samples at each of the sampling areas, yielding six seine hauls at each site on each sampling occasion. The replicates were positioned to avoid overlapping at any point.

Large fish (> 150mm SL) were identified to species, measured (SL), weighed (g), checked for signs of ripeness, red-spot disease and overall condition, and released alive. All remaining animals were firstly euthanased with ethyl p-amino-Benzoate (Benzocaine) (100 mg/L) and then preserved in 10% formalin/seawater (Barker, 1999) before transport to the laboratory for processing.

For each seine haul, fish and invertebrates were identified to species level with the aid of published keys (Young, 1977; Grey and Dall, 1983; Robinson and Gibbs, 1982; Kuiter, 1993; Jones and Morgan, 1994; McDowell, 1996; Neira *et al.*, 1998; Edgar, 2000; Ponder *et al.*, 2000; Larson, 2001), and the total number of individuals per species was recorded. A few individuals of each species collected were sent to the Australian Museum (Sydney) to confirm their identification. For each commercially and recreationally significant species (Table 2.3), we measured the size of all individuals. For the remaining species, only the size of the smallest and the largest individuals was recorded. For fish, we measured standard length (SL, from the tip of the snout to the caudal peduncle, 0.1 cm), for prawns carapace length (CL, 0.1 cm), and for crabs carapace length and width (CL and CW, 0.1 cm). For each species, we measured total weight of all individuals combined (W, 0.1 gr). Finally, condition of individuals was noted, in particular the presence of Epizootic Ulcerative Syndrome, so-called red spot disease (Callinan *et al.*, 1989, 1995, 1996). After sorting, data entry and quality control were completed, sub-samples from all trips were deposited with the relevant collection managers at the Australian Museum. This was in addition to the samples sent for verification of taxonomic identity and provides a system of voucher specimens for any comparative work that may be done in the future.

2.2.1.3. Habitat characteristics

Stream width (0.1 m) was measured using the transect described above, and water depth (cm) measured at the three equidistant points along this transect. The proportional contribution of each substratum type (mud (particle size < 1 mm), sand (1-16 mm), fine gravel (17-32 mm), gravel (33-64 mm), cobbles (65 – 128 mm), boulders (>129 mm) and bedrock) was quantified by ranking on a 5-point scale, corresponding to absent (0), uncommon (1), common (2), abundant (3) and very abundant (4), respectively. The proportional contribution of each cover element (leaf litter, submerged vegetation (e.g. seagrass), emergent vegetation (e.g. water lillies, grass and rushes), overhanging vegetation (mangroves, overhanging terrestrial trees), filamentous algae, large woody debris (Ø >20cm), small woody debris (Ø < 20cm), undercut bank, and exposed rootmasses) were quantified by ranking on the same scale. Riparian cover (the proportional amount of stream surface area directly covered by riparian vegetation) was estimated by eye, and surrounding land use (cattle grazing or sugar cane) was noted as present (1) or absent (0).

Table 2.3. Fish and invertebrate species that were considered to be of commercial and recreational importance.

Scientific name	Common name
Fish	
Acanthopagrus australis	Yellow-finned bream
Anguilla australis	Short-fin eel
Anguilla reinhardtii	Long-fin eel
Caranx spp	Trevally
Engraulis australis	Australian anchovy
Girella tricuspidate	Blackfish
Herklotsichthys castelnaui	Southern herring
Hyperlophus vittatus	Sandy sprat
Hyporhamphus regulatus	River garfish
Liza argentea	Flat-tail mullet
Megalops cyprinoids	Oxeye herring
Meuschenia trachylepis	Yellow-finned leatherjacket
Mugil cephalus	Sea mullet
Myxus petardi	Freshwater mullet
Platycephalus fuscus	Dusky flathead
Pomatomus saltatrix	Tailor
Pseudorhombus jenysii	Small-toothed flounder
Rhabdosargus sarba	Tarwhine
Silago ciliata	Sand whiting
Sphyraena obtusata	Striped seapike
Synaptura nigra	Black sole
Tylosurus gavialoides	Stout longtom
Invertebrates	
Metapenaeus bennettae	Greasy back prawn
Metapenaeus macleayi	School prawn
Penaeus esculentus	Tiger prawn
Penaeus plebejus	King prawn
Portunus pelagicus	Blue swimmer

2.2.2. Data analyses

We compared species assemblages, of both abundance and biomass, between reference and gated drainage systems (Chapter 3), and between reference, managed, and gated drainage systems (Chapter 4) for each sampling occasion, using non-metric multivariate data analyses techniques (Primer 5.0 package, Plymouth Marine Laboratory, UK). These techniques are based on whether samples share particular species, at comparable levels of abundance or biomass (Clarke and Warwick, 2001). For these analyses, we averaged the number of individuals (or biomass) per species across the three seine shot replicates made within a sampling area, resulting in two replicates within a sampling site for each sampling occasion.

First, to graphically illustrate and compare assemblages between samples, a measure of similarity or dissimilarity is needed between samples (Clarke and Warwick, 2001). We used the Bray-Curtis similarity coefficient to calculate similarity matrices between reference and gated drainage systems. To reduce the weighting given to more abundant species and increase the weighting given to less abundant species (Clarke and Warwick, 2001), data were transformed using a log (x+1) transformation and standardised. The similarity matrices were subsequently plotted using non-metric multidimensional scaling (nMDS) ordinations. This technique constructs a graphical representation of similarities between species assemblages (Clarke, 1993; Manly, 1994), in our case based on variability among replicates within sites. In the ordination, these relationships are illustrated as distances, which are derived from the similarity matrices (Manly, 1994). We measured the goodness of fit between the configuration distances and the disparities, or the 'adequacy' of the nMDS technique, by 'stress' (Manly, 1994). Stress values less than 0.1 indicate that the ordination is a good representation of the data. Stress levels > 0.2 indicate that the results should be treated with caution in interpreting any apparent pattern in the samples (Clarke and Warwick, 2001).

Second, to determine whether the composition of the species assemblages differed significantly between reference and gated drainage systems, nested ANOSIM (analysis of similarity) tests were performed on similarity matrices. The ANOSIM procedure calculates the R statistic, which is compared with a distribution of R statistics (based on the null hypothesis of 'no differences'). If the calculated value of R looks unlikely to have come from this distribution (depending on the level of significance, i.e. 5%), there is evidence to reject the null hypothesis (Clarke and Warwick, 2001).

Third, to determine which species best contribute to the similarity within groups, or to the dissimilarity among groups, we used the SIMPER (similarity of percentages) procedure (Clarke and Warwick, 2001). Data were log (x+1) transformed and standardised. This procedure lists the species in decreasing order of their importance in discriminating between different groups of samples (Clarke and Gorley, 2001).

Finally, to examine which environmental variables were associated with the observed patterns in species assemblage composition between reference and gated drainage systems, we used the BIOENV procedure. This calculates a harmonic rank correlation coefficient, based on the similarity matrices of both the biotic and abiotic data (Clarke and Ainsworth, 1993; Clarke and Warwick, 2001). The larger the coefficient for a particular abiotic variable (or set of variables), the better the environmental variables are in explaining the biotic data (Clarke and Ainsworth, 1993; Clarke and Warwick, 2001). Water quality and habitat quality data were included simultaneously in these analyses; data were transformed using log (x+1) and standardised.

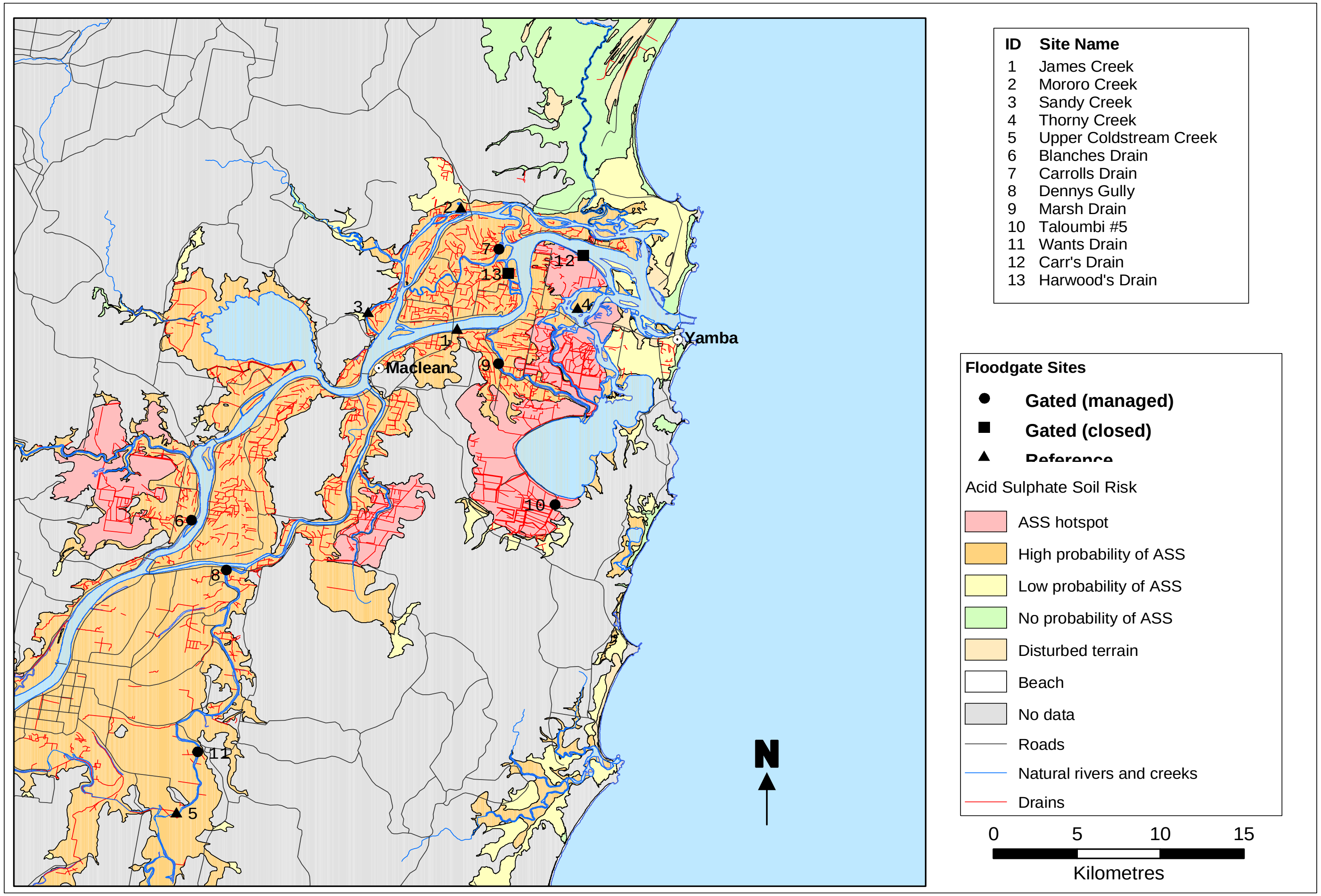
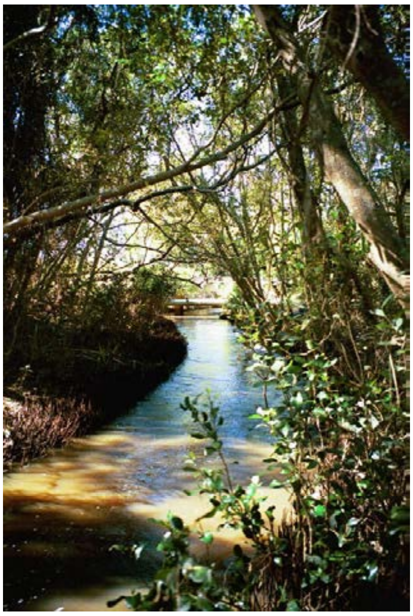


Figure 2.1. Sampling sites on the Clarence river floodplain, showing all sites sampled during this project.

(i)

(ii

(iii)

(iv)

(v)


Figure 2.2a. The reference sampling sites on the Clarence river floodplain, (i) James Creek, (ii) Mororo Creek, (iii) Sandy Creek, (iv) Thorny Creek, (v) Upper Coldstream Creek.

Figure 2.2b. The 'gated' sampling sites on the Clarence river floodplain, (i) Blanches Drain, (ii) Carrs Drain, (iii) Carrolls Drain, (iv) Denny's Gully.

(v)

(vi)

(vii)

(viii)

Figure 2.2b. (cont). The "gated" sampling sites on the Clarence river floodplain, (v) Harwoods Drain, (vi) Marsh Drain, (vii) Taloumbi #5, and (viii) Wants Drain.

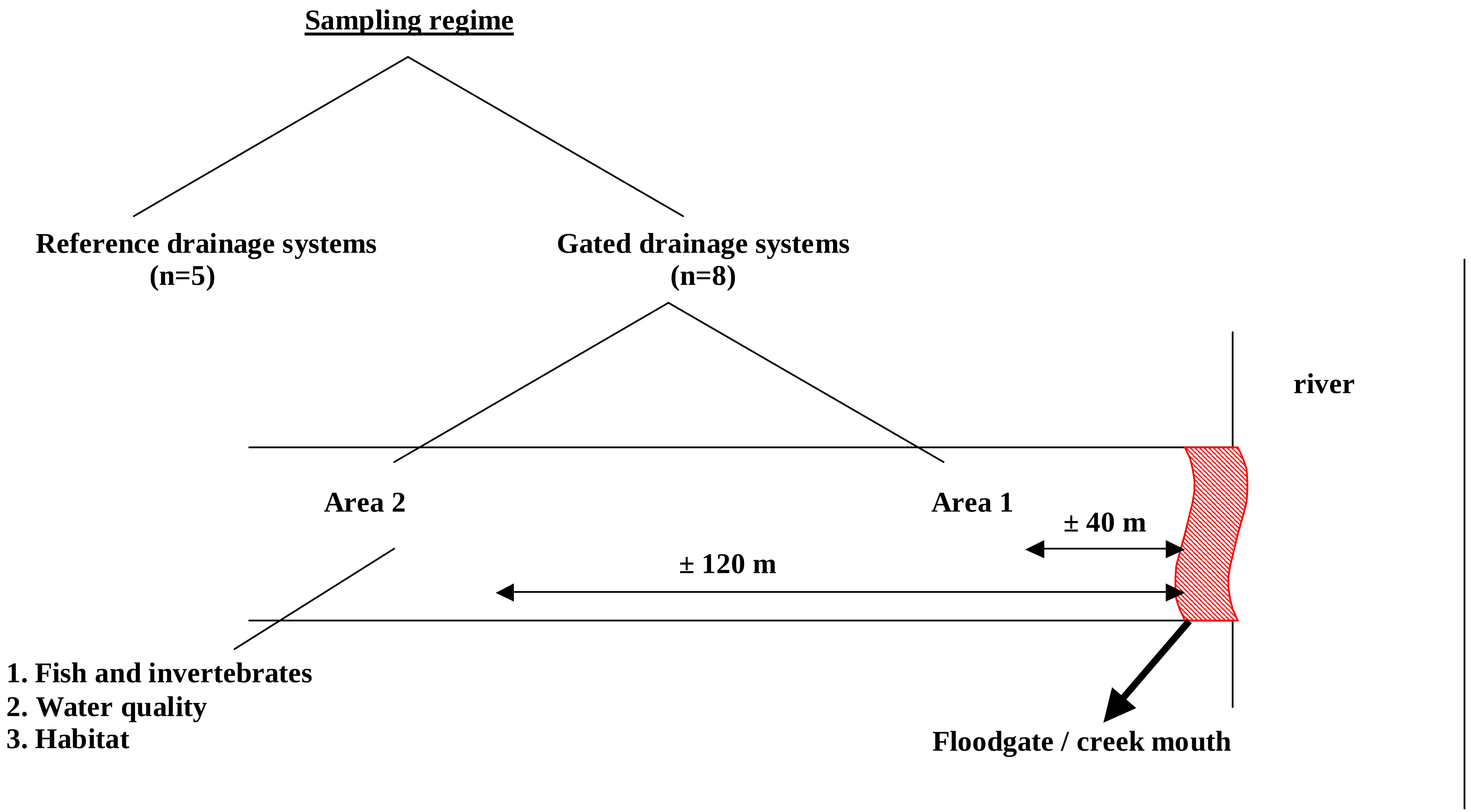


Figure 2.3. Diagram showing the experimental design for the sampling regime for fish and invertebrates, water quality and habitat variables in the Clarence river floodplain.

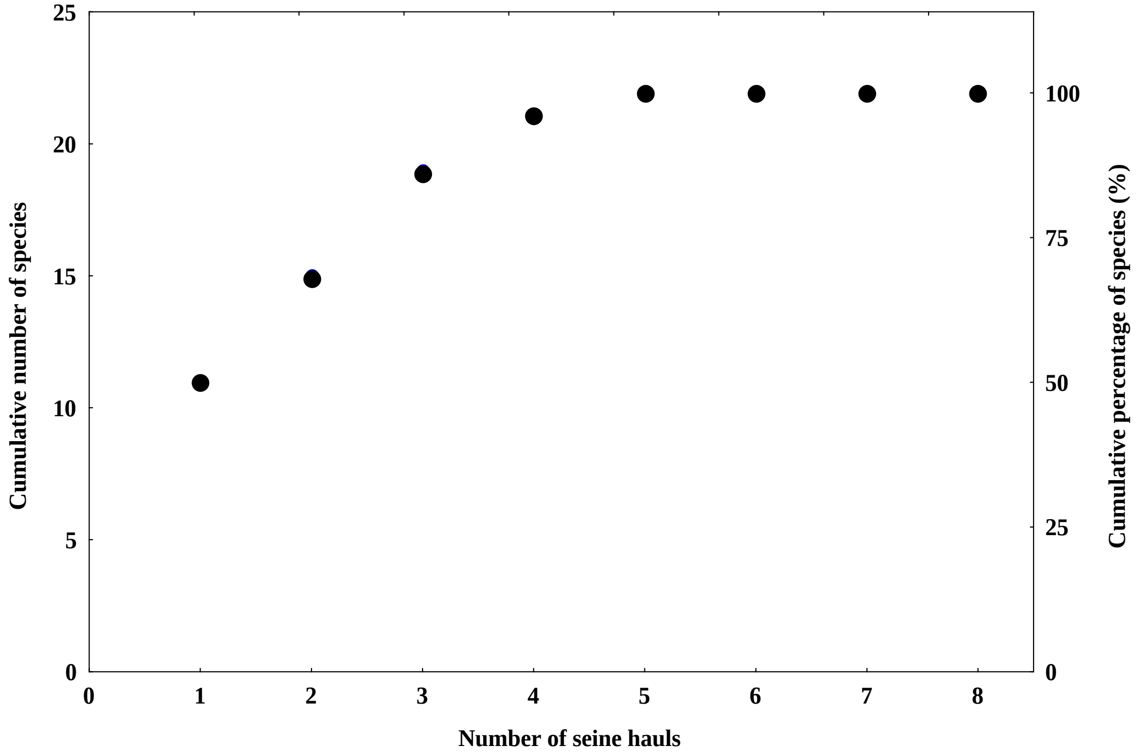


Figure 2.4. Species-area curve for pilot study at James Creek, Clarence River floodplain.

Figure 2.5. Team members taking water samples at one of the study sites in the Clarence River floodplain.

3. IMPACT OF FLOODGATES ON FISH PASSAGE AND WATER AND HABITAT QUALITY IN THE CLARENCE RIVER FLOODPLAIN, NSW

[With special input from Dean Ansell]

3.1. Introduction

Artificial draining of floodplains and wetlands results in permanently saturated soils becoming exposed to the atmosphere. When this occurs in estuaries with acid sulfate soils, which are common throughout coastal catchments in eastern Australia (National Working Party on Acid Sulfate Soils, 2000), this exposure causes a number of chemical reactions resulting in a build-up of sulfuric acid, iron and aluminium (Sammut *et al.*, 1996; White *et al.*, 1997; Preda and Cox, 2001). With the first rains, these chemicals are washed out into waterways, causing increased ‘acidity’ and a general decrease in water quality (Sammut *et al.*, 1996; Roach, 1997; Cook *et al.*, 2000; Preda and Cox, 2001). This in turn, may result in well-known fish diseases such as “red spot” or epizootic ulcerative disease (Callinan *et al.*, 1989; Virgona, 1992; Callinan *et al.*, 1993, 1995, 1996), or in worse cases, significant fish kills (Brown *et al.*, 1983; Easton, 1989; Sammut *et al.*, 1993; Callinan *et al.*, 1993, 1996).

In northern NSW and Queensland, artificial draining of coastal floodplains and wetlands is commonly achieved with the construction of flood mitigation structures, such as tidal floodgates. These structures prevent tidal access, thereby alienating significant habitat areas, blocking larval transport and restricting fish movement (Drinkwater and Frank, 1994; Pollard and Hannan, 1994; Williams and Watford, 1996; Gibbs *et al.*, 1999; Halls *et al.*, 1998). Consequently, floodgates play a role in the depletion of estuarine fish stocks by decreasing estuarine water quality as well as limiting juvenile and adult fish access to habitat and food upstream of these structures (Sultana and Thompson, 1997).

The impact of flood mitigation strategies on assemblages of fish species in NSW has been investigated in two previous studies. Pollard and Hannan (1994) did a comprehensive survey, over 10 quarterly sampling trips, of fish species at 13 sites in the lower Clarence River. Sites included ungated (ie ‘natural’) creeks, drains with gates at their mouths and drains with gates part way along them. The latter were sampled above and below those gates. Sampling involved the use of rotenone and gill nets. Gibbs *et al* (1999) did a broader scale survey along the NSW coast at three wetland systems that had restricted tidal flow and three that were considered natural. They used seine nets to sample the fish assemblages. Both studies showed that structures that prevented tidal flow resulted in depauperate fish assemblages.

As a first step towards developing management options for gated drainage systems, we used a subset of the data collected during the main study (see chapter 4) to test the general conclusions reached in previous research, especially the study by Pollard & Hannan (1994) which was done in the same general area. We wanted to test whether the use of seine nets designed especially to catch juvenile fish would consistently give the same pattern of differences as that obtained by using rotenone and gill nets which were expected to more completely sample the entire fish assemblage at a site. Further, by also collecting data on water quality and habitat characteristics, we were able to assess which variables were most likely responsible for any observed differences. In this part of the study, we delineate and compare species assemblages (fish and invertebrates), and water quality and habitat variables in reference and gated drainage systems in the lower Clarence River over a one year period.

3.2. Methods

3.2.1. Sampling sites

For this study, there were four drainage systems without floodgates (i.e. reference drainage systems; James Creek, Mororo Creek, Sandy Creek, and Thorny Creek), and five drainage systems with floodgates (i.e. gated drainage systems; Carrs Drain, Carrolls Drain, Harwoods Drain, Marsh Drain, and Taloumbi #5) (Table 2.1, 2.2; Figure 2.1, 2.2a, b). It had originally been intened to use all five reference sites in the analysis to give a balanced design. However, sampling difficulties in January 2001 (see chapter 4) meant that no data were collected, and the site was not included in analyses in this chapter. The floodgates on the gated systems all had one-way (downstream opening) flap valves and other aspects of these sites were as similar as possible. Similarly, the reference sites were selected to be as much alike as possible in terms of their pysical features.

3.2.2. Sampling methods

A detailed description of the sampling methods, including quantification of fish and invertebrates, water quality and habitat quality is given in Chapter 2. For this part of the project, six sample occasions were considered, from July 2000 to May 2001. While we attempted to sample every site during every sample trip, this was not always possible for various reasons. Carrs Drain and Harwoods Drain were not sampled during July 2000, awaiting permission from the respective landholders. Our fifth trip was scheduled to take place in March 2001. However, due to two major floods in the Clarence River in February and March that year, this trip could not be done until April 2001.

3.2.3. Data analyses

We compared species assemblages (abundance and biomass) between reference and gated drainage systems for each sampling occasion, using non-metric multivariate data analyses techniques (Primer 5.0 package, Plymouth Marine Laboratory, UK), as described in Chapter 2.

To further elucidate which water quality variables may be associated with the observed patterns in species assemblages we conducted the following analysis. We compared water quality variables against ANZECC trigger values for lowland rivers and streams for (i) physical and chemical stressors for south-east Australia (including NSW and south-east Queensland) for slightly disturbed ecosystems, and, (ii) toxicants at 95% level of protection (ANZECC, 2000). Trigger values for total aluminium are only available for pH>6.5. Total aluminium concentrations were measured on water samples taken at the surface, hence we assessed the total aluminium concentrations against the $pH_{(s)}$ measured at that area. If $pH_{(s)}$ was less than 6.5, total aluminium concentrations were not considered. Subsequently, we compared the frequencies that water quality values did not conform to ANZECC guidelines in reference and gated drainage systems from July 2000 until May 2001, using $\chi 2$ tests.

3.3. Results

3.3.1. General

A total of 312 seines were hauled during this part of the study, yielding 100 taxa (57 fish and 43 invertebrate taxa), 213,613 individuals (73,655 fish and 139,968 invertebrates), and a combined weight of approximately 62 kg (50.5 kg fish and 11.5 kg invertebrates). Of these totals, 17 of the taxa (17%) were of economic importance (14 fish species and 3 invertebrate species), accounting for 8,429 (4.0%) of the individuals (3,282 fish and 5,147 invertebrates) and approximately 19.9 kg (32.1%) of the weight (17.5 kg of fish and 2.4 kg of invertebrates). Total number of individuals and biomass per species collected in individual drainage systems are presented in Appendix 1 and 2.

Although we tried to identify to species all organisms caught, small juveniles of some fish and invertebrate species, and adults of some invertebrate species were difficult to separate. First, small juveniles of certain fish and invertebrate species could not be identified to species level (e.g. *Ambassis* species, *Amarinus* species), and were therefore combined together (e.g. as *Ambassis* spp, *Amarinus* spp). Larger individuals, however, were generally easy to identify to species and were recorded as such. Second, species of the pistol shrimp family Alpheidae are difficult to tell apart (S. de Grave, Oxford University Museum of Natural History, pers. comm.). While both the Australian Museum and Oxford University Museum of Natural History identified two species in our samples (*Alpheus richardsoni* Yaldwyn, 1971 and *Alpheus* sp.), we combined all Alpheidae species into *Alpheus* spp. Third, we found two species (*Macrobrachium cf novaehollandiae* and *M. intermedium*) of the shrimp family Palaemonidae difficult to separate. Three adult males were identified as *M cf novaehollandiae* De Man, 1908 (S. de Grave, Oxford University Museum of Natural History, pers. comm.). Juveniles and females *Macrobrachium*, including ones we identified as *M. intermedium*, were also considered to be *M cf novaehollandiae* based on rostral similarities (S. de Grave, Oxford University Museum of Natural History, pers. comm.). Hence, all *Macrobrachium* samples were recorded as *M. cf novaehollandiae*. Fourth, the introduced screwshell species *Melanoides tuberculata* Müller, 1774 and the endemic species *Melanoides ultra* Iredale, 1943 (previously *Stenomelania denisoniensis ultra* Iredale, 1943) do not exhibit a simple, obvious external character at the 1-3 cm size range to tell them apart (I. Loch, Australian Museum, pers. comm.). Hence, to prevent mis-identification, we labeled both screwshell species as *Melanoides* spp. Finally, species we initially identified as *Palaemon debilis* and *Palaemonetes atrinubes* were later combined into *Palaemon debilis*. We were advised that our samples are currently closest to *P. debilis*, although they may prove to be a new species altogether (S. de Grave, Oxford University Museum of Natural History, pers. comm.).

While we tried to avoid damaging specimens when sampling, many prawn and shrimp did sustain some damage. If we could not identify these specimens (or parts thereof) to species, they were not counted as individuals and not included in the abundance analyses. They were, however, combined and weighed as “prawn bodies” and “shrimp bodies”, and subsequently included in the biomass analyses.

Due to technical problems with the TPS model 90FL water quality meter, dissolved oxygen (DO) could only be measured in November 2000, January (only some sites), April and May 2001, and pH was not measured in January 2001. pH levels were subsequently measured on the January water samples analysed at the Environmental Analysis Laboratory. Turbidity (NTU) was only measured in April and May 2001. Water quality and habitat parameters measured at individual reference and gated drainage systems are presented in Appendix 3.

3.3.2. *Species assemblages (abundance data)*

Non-metric multidimensional scaling showed that samples collected at a single site were generally located together within one sample occasion, indicating the similarity between these samples (Figure 3.1). This strongly supports our experimental design and the results from our pilot study, that three seine replicates at each sampling area provided sufficient statistical power to detect significant differences between the two treatments. The ordinations showed clear separations between the abundance assemblages of the reference and gated drainage systems across all six sampling occasions. All six ordinations were good representations of the data (stress levels ranging from 0.07 to 0.10). This indicated that samples from the reference drainage systems were consistently more similar to each other than to those from the gated drainage systems, and vice versa.

Nested ANOSIM revealed that, across all six sampling occasions, species assemblages based on abundance at individual sites within a treatment differed significantly more from each other than between the two treatments (Table 3.1). Nevertheless, in four out of six sampling occasions (September, November, January and May) samples collected in reference drainage systems were significantly different from those collected in gated drainage systems. In April, the treatment effect was non-significant.

SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species assemblages (based on abundance) between treatments, explained 75.9% to 85.9% of average dissimilarity between treatments (Table 3.2). For the six sampling occasions, 16 species out of the 100 taxa collected were most important in contributing to the total average dissimilarity in species abundance assemblages between treatments. Five of these sixteen species (*Acetes sibogae australis*, *Hypseleotris compressus*, *Metapenaeus macleayi*, *Phylipnodon grandiceps* and the exotic *Gambusia holbrooki*) consistently contributed to these dissimilarities. *Gambusia holbrooki* was consistently more abundant in gated drainage systems, while *H. compressus* and *P. grandiceps* were more abundant in gated drainage systems on five out of the six sampling occasions. In contrast, *A. sibogae australis* and *M. macleayi* were consistently more abundant in reference drainage systems. Three commercially signficant species contributed to the total average dissimilarities, namely *Acanthopagrus australis*, *Liza argentea*, and *M. macleayi*.

BIOENV revealed that various combinations of 11 out of the 47 water quality and habitat variables best described the biotic patterns shown in the nMDS ordinations (Table 3.3; Figure 3.1). On all six sampling occasions, the combination of three environmental variables always involved both water quality and habitat variables. The correlations between the combination of three environmental variables and the biotic patterns shown in the nMDS ordinations (Figure 3.1) ranged from 0.461 to 0.822 (Table 3.3). Nutrients contributed to the combinations of environmental variables five out of six times; total nitrogen three times, and nitrite and total phosphorus once. Mangroves contributed to the combinations of environmental variables three out of six times. Only once did an acid sulfate soil discharge by-product (dissolved iron) contribute to these combinations of environmental variables.

Table 3.1. Summary of two-way nested ANOSIM tests examining differences among species assemblages (based on abundance data) between treatments (reference vs gated drainage systems) for the six sampling occasions in the lower Clarence River floodplain. Significance levels in red are p<0.05.

Year	Month	Source of variation	Permutations	Global R	Significance level
2000	July	Treatment	35	0.315	0.09
		Site (Treatment)	999	0.953	0.002
	September	Treatment	126	0.325	0.03
		Site (Treatment)	999	0.907	0.001
	November	Treatment	126	0.431	0.02
		Site (Treatment)	999	0.726	0.001
2001	January	Treatment	126	0.409	0.03
		Site (Treatment)	999	0.904	0.002
	April	Treatment	126	0.134	0.23
		Site (Treatment)	999	0.820	0.001
	May	Treatment	126	0.413	0.02
		Site (Treatment)	999	0.593	0.001

Table 3.2. SIMPER results showing the species ranked in decreasing order of importance (1-10 only) that contributed to the total average dissimilarity in species assemblages (based on abundance data) between treatments (reference vs gated drainage systems) for the six sampling occasions in the lower Clarence River floodplain. Percentage of average dissimilarity between treatments for each sampling occasion, and percentages of cumulative contribution by first ten species to dissimilarity are given. Numbers in bold indicate species that were more abundant in reference sites, and species in red indicate species significant for commercial and/or recreational fisheries.

Scientific name	2000			2001		
	July	September	November	January	April	May
Average dissimilarity	83.43%	79.92%	85.90%	82.81%	77.43%	76.70%
Acanthopagrus australis		8				
Acetes sibogae australis	**1**	**3**	**2**	**10**	**10**	**1**
Afurcagobious tamarensis			**10**			
Ambassis jacksoniensis			**6**	**9**	**2**	**9**
Ambassis marianus				**8**	**7**	**7**
Gambusia holbrooki	8	9	8	3	1	3
Gobiomorphus australis					9	4
Gobiopterus semivestitus	**9**					10
Hypseleotris compressus	5	2	1	1	3	**2**
Liza argentea		**7**	**9**	**2**	**6**	
Metapenaeus macleayi	**7**	**5**	**7**	**7**	**4**	**5**
Palaemon debilis	**3**	**1**	3	**4**		**8**
Philypnodon grandiceps	2	4	4	6	**5**	6
Philypnodon sp1	4					
Pseudogobius olorum	**6**	**6**	**5**	**5**		
Pseudomugil signifer	**10**	**10**			8	
Cumulative contribution	76.14%	66.69%	61.19%	64.03%	67.11%	68.20%

Table 3.3. BIOENV results showing sets of three environmental variables that best describe the biotic patterns shown in the nMDS ordinations of species assemblages (based on abundance data) (Figure 3.1) for the six sampling occasions in the lower Clarence River floodplain. ** indicates that the environmental variable was more common or present at higher concentrations at reference sites. The correlation coefficient (Spearman), based on the similarity matrices of both the biotic and abiotic data, is given for each sampling occasion.

	2000			2001		
	July	September	November	January	April	May
Correlation Coefficient	0.822	0.655	0.805	0.710	0.552	0.461
Total phosphorus (mg/L P)					*	
Total nitrogen (mg/L N)	*	*	*			
Nitrite (mg/L N)				*		
Dissolved iron (mg/L Fe)						**
Cobble			*			
Seagrass						**
Other submerged vegetation		*		*		
Grasses and Rushes			*		*	
Mangroves	**	**				**
Exposed rootmasses	**			**		
Cattle grazing					**	

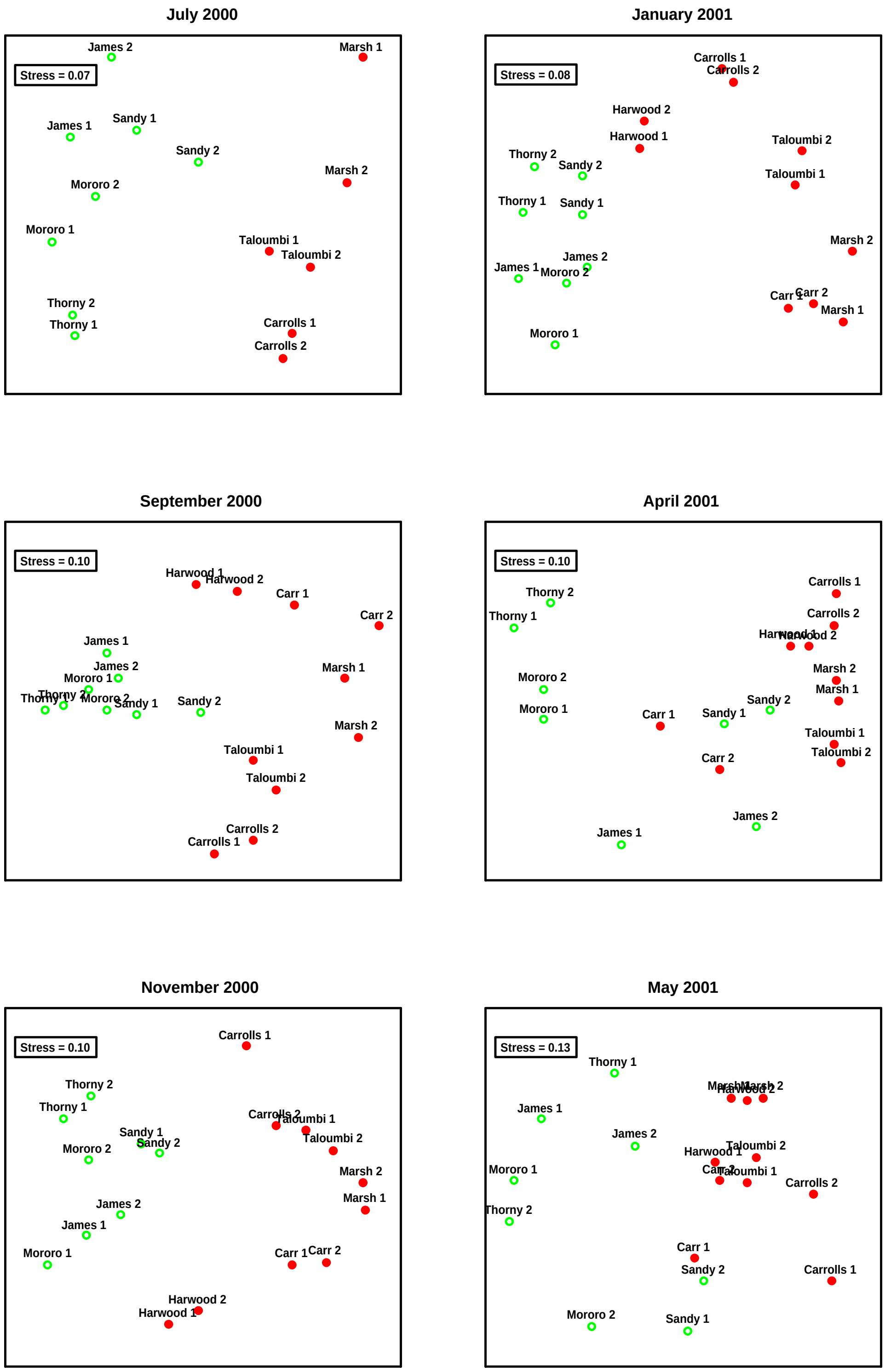


Figure 3.1. Clarence River. Non-metric multidimensional scaling (nMDS) ordinations of species assemblages (based on abundance data) on each of the six sampling occasions in the Clarence River floodplain. The ordinations are based on log (x+1) transformed abundances and Bray-Curtis similarities. Green open symbols are reference drainage systems and red closed symbols are gated drainage systems.

3.3.3. Species assemblages (biomass data)

Non-metric multidimensional scaling showed that samples collected at a single site were generally located together within a sample occasion, indicating the similarity between these samples (Figure 3.2) and further supporting the sampling design used. The ordinations showed clear separations between the biomass assemblages of the four reference drainage systems and the five gated drainage systems across all six sampling occasions. All six ordinations were good representations of the data (stress levels ranging from 0.07 to 0.13). Samples from the reference drainage systems were more similar to each other than to those from the gated drainage systems, and vice versa.

Nested ANOSIM on the biomass data showed identical patterns to the abundance data (section 3.3.2; see Table 3.4). SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species assemblages (based on biomass) between treatments, explained 77.6% to 88.2% of average dissimilarity between treatments (Table 3.5). For the six sampling occasions, 19 species were most important in contributing to the total average dissimilarity in species assemblages between treatments. Two of these, (*Hypseleotris compressus* and *Phylipnodon grandiceps*) consistently contributed to these dissimilarities. Biomass of *H. compressus* and *P. grandiceps* was greater in gated drainage systems on five out of the six sampling occasions. Five commercially signficant species contributed to the total average dissimilarities, namely *A. australis*, *Anguilla reinhardtii*, *L. argentea*, *Mugil cephalus* and *M. macleayi*.

BIOENV revealed that various combinations of 13 out of the 47 water quality and habitat variables best described the biotic patterns shown in the nMDS ordinations (Table 3.6; Figure 3.2). On five out of six sampling occasions, this combination of three environmental variables involved both water quality and habitat variables; the combination of environmental variables in September only included habitat variables. The correlations between the combination of three environmental variables and the biotic patterns shown in the nMDS ordinations (Figure 3.2) ranged from 0.518 to 0.795 (Table 3.6). Grasses & rushes and mangroves contributed to the combination of environmental variables four and three out of six times, respectively. Nutrients contributed to the combinations of environmental variables three out of six times; once each for total nitrogen, total Kjeldahl nitrogen, and total phosphorus. Discharge by-products contributed twice to the combinations of environmental variables, once each for dissolved aluminium and dissolved iron.

Table 3.4. Summary of two-way nested ANOSIM tests examining differences among species assemblages (based on biomass data) between treatments (reference vs gated drainage systems) for the six sampling occasions in the lower Clarence River floodplain. Significance levels in red are $p<0.05$.

Year	Month	Source of variation	Permutations	Global R	Significance level
2000	July	Treatment	35	0.241	0.11
		Site (Treatment)	999	0.910	0.001
	September	Treatment	126	0.344	0.048
		Site (Treatment)	999	0.884	0.001
	November	Treatment	126	0.513	0.02
		Site (Treatment)	999	0.741	0.001
2001	January	Treatment	126	0.422	0.03
		Site (Treatment)	999	0.752	0.002
	April	Treatment	126	0.244	0.1
		Site (Treatment)	999	0.790	0.001
	May	Treatment	126	0.325	0.02
		Site (Treatment)	999	0.692	0.001

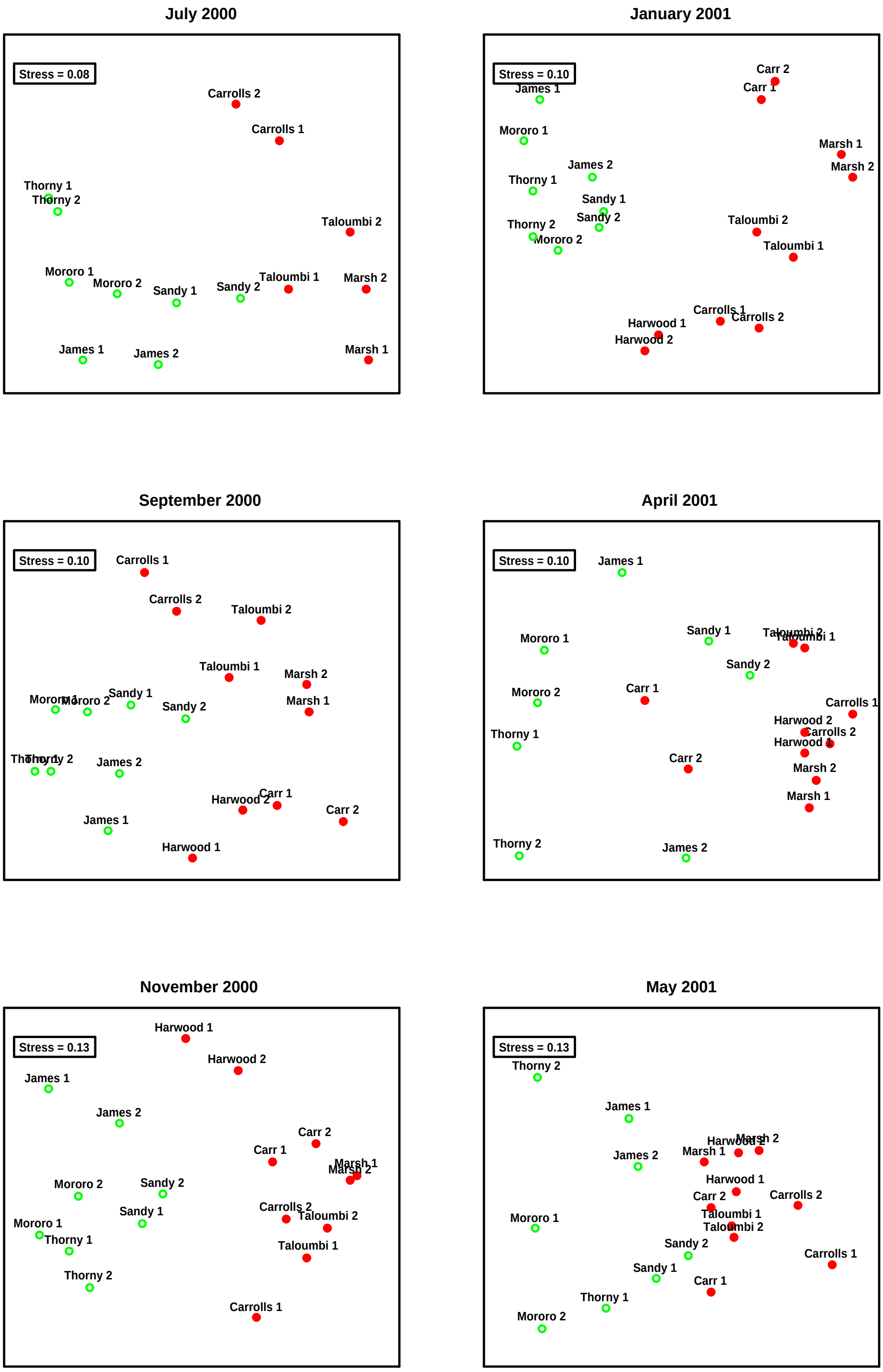


Figure 3.2. Clarence River. Non-metric multidimensional scaling (nMDS) ordinations of species assemblages (based on biomass data) on each of the six sampling occasions in the Clarence River floodplain. The ordinations are based on log (x+1) transformed abundances and Bray-Curtis similarities. Green open symbols are reference drainage systems and red closed symbols are gated drainage systems.

Table 3.5. SIMPER results showing the0 species ranked in decreasing order of importance (1-10 only) that contributed to the total average dissimilarity in species assemblages (based on biomass data) between treatments (reference vs gated drainage systems) for the six sampling occasions in the lower Clarence River floodplain. Percentage of average dissimilarity between treatments for each sampling occasion, and percentages of cumulative contribution by first ten species to dissimilarity are given. Numbers in bold indicate species that were more abundant in reference sites, and species in red indicate species significant for commercial and/or recreational fisheries.

Scientific name		2000			2001	
	July	September	November	January	April	May
Average dissimilarity	87.10%	80.38%	88.23%	85.15%	79.59%	77.61%
Acanthopagrus australis		7		**10**		
Acetes sibogae australis	**1**	**4**	**10**			**4**
Ambassis jacksoniensis			**7**	**9**	**4**	**9**
Ambassis marianus			**9**	**3**	**7**	**3**
Anguilla reinhardtii	6					
Arrhamphus sclerolepis					**10**	
Gambusia holbrooki		10		7	1	5
Gerres subfasciatus	**10**		**5**			
Gobiomorphus australis					**8**	2
Hypseleotris compressus	2	1	1	2	2	**1**
Liza argentea		**6**	**3**	**1**	**3**	**10**
Metapenaeus macleayi	**5**	**2**	**4**		**5**	**6**
Mugil cephalus				8		8
Palaemon debilis	**4**	**3**	6	**5**		
Philypnodon grandiceps	3	5	2	4	**6**	7
Philypnodon sp1	7					
Pseudogobius olorum	**9**	8	8	6		
Pseudomugil signifer		**9**			9	
Tetractenos glaber	**8**					
Cumulative contribution	69.63%	61.98%	57.89%	62.56%	68.24%	67.81%

Table 3.6. BIOENV results showing sets of three environmental variables that best describe the biotic patterns shown in the nMDS ordinations of species assemblages (basedon biomass data) (Figure 3.2) for the six sampling occasions in the lower Clarence River floodplain. ** indicates that the environmental variable was more common or present at higher concentrations at reference sites. The correlation coefficient (Spearman), based on the similarity matrices of both the biotic and abiotic data, is given for each sampling occasion.

		2000			2001	
	July	Sept	Nov	Jan	April	May
Correlation Coefficient	0.795	0.672	0.760	0.711	0.556	0.518
Total phosphorus (mg/L P)					*	
Total nitrogen (mg/L N)			*			
Total Kjeldahl nitrogen (mg/L N)				*		
Dissolved aluminium (mg/L)	*					
Dissolved iron (mg/L)						**
Seagrass						**
Other submerged vegetation				*		
Grasses and Rushes	*	*	*		*	
Mangroves	**				**	**
Filamentous algae			*			
Large woody debris		**				
Exposed rootmasses				**		
% Riparian cover		**				

3.3.4. Water quality and ANZECC guidelines

Several water quality variables measured in the reference and gated drainage systems during the six field trips from July 2000 to May 2001 did not conform to ANZECC guidelines (2000) (Table 3.7).

3.3.4.1. Chemical stressors

Chemical stressors, including $pH_{(s)}$, $pH_{(b)}$, total phosphorus, phosphate, total nitrogen, turbidity, $DO_{(s)}$ and $DO_{(b)}$, were often outside the range of trigger values for lowland rivers and streams in south-east Australia (including NSW and south-east Queensland) for slightly disturbed ecosystems (ANZECC, 2000) (Table 3.7a).

Values for $pH_{(s)}$ and $pH_{(b)}$ were outside the recommended range of 6.5 – 8.0 a total of 27 out of 104 times (26%) (Table 3.7a). However, the frequency that pH values did not conform to ANZECC guidelines in reference and gated systems did not differ significantly for either surface or bottom readings.

Total phosphorus concentrations were above the recommended value of 0.05 mg P/L 21 out of 52 times (40%) (Table 3.7a). The frequency that total phosphorus concentrations did not conform to ANZECC guidelines in gated systems was significantly higher than in reference systems (χ^2=19.02, df=1, p<0.00001).

Table 3.7. Results of $\chi 2$ tests comparing the frequencies that water quality values did not conform to ANZECC guidelines (2000) in reference and gated drainage systems. Trigger values are given for lowland rivers and streams for (i) physical and chemical stressors for south-east Australia (including NSW and south-east Queensland) for slightly disturbed ecosystems, (ii) toxicants at 95% level of protection (ANZECC, 2000). Numbers in red indicate significant difference between expected and observed frequencies.

July 2000 - May 2001	Trigger values (ANZECC, 2000)	Reference drainage systems	Gated drainage systems	$\chi 2$	p
a. Physical and chemical stressors					
PH (s)	6.5 - 8.0	7/24	7/28	0.11	0.74
PH (b)	6.5 - 8.0	6/24	7/28	0.00	1.00
Total phosphoros (mg/L P)	0.05 mg P/ L	2/24	19/28	19.02	<0.00001
Phosphate (mg/L P)	0.02 mg P/L	1/24	14/28	13.23	0.0003
Total nitrogen (mg/L N)	0.5 mg N/L	6/24	21/28	12.94	0.0003
Turbidity (NTU)	6-50 NTU	0/8	4/10	4.11	0.04
DO (s) (mg/L)	5.0 mg/L	1/12	5/14	2.73	0.10
DO (b) (mg/L)	5.0 mg/L	2/12	7/14	3.17	0.08
b. Toxicants					
Total aluminium (mg/L)	0.05 mg/L (pH>6.5)	7/17	11/21	0.47	0.49
Ammonia (mg/L N)	0.9 mg N/L	0/24	0/28	n/a	n/a
Nitrate (mg/L N)	0.7 mg N/L	0/24	0/28	n/a	n/a

Phosphate concentrations were above the recommended value of 0.02mg P/L 15 out 52 times (29%) (Table 3.7a). The frequency that total phosphorus concentrations did not conform to ANZECC guidelines in gated systems was significantly higher than in reference systems (χ^2=13.23, df=1, p=0.0003).

Total nitrogen concentrations were above the recommended value of 0.5 mg N/L 27 out of 52 times (52%) (Table 3.7a). The frequency that total nitrogen concentrations did not conform to ANZECC guidelines in gated systems was significantly higher than in reference systems (χ^2=12.49, df=1, p=0.0003).

Turbidity was outside recommended levels of 6-50 NTU on 4 out of 18 times (22%) (Table 3.7a). Turbidity did not conform to ANZECC guidelines in gated systems significantly more often than in reference systems (χ^2=4.11, df=1, p=0.04).

Finally, concentrations of both $DO_{(s)}$ and $DO_{(b)}$ were below levels considered stressful to many freshwater fish (i.e. 5 mg/L) a total of 15 out of 52 times (29%) (Table 3.7a). However, the frequency that DO values did not conform to ANZECC guidelines in reference and gated systems did not differ significantly for either surface or bottom readings.

3.3.4.2. Toxicants

Toxicants, including total aluminium, were above the 95% protection level trigger values for slightly–moderately disturbed ecosystems (ANZECC, 2000) (Table 3.7b). Total aluminium concentrations were above the recommended value of 0.05 mg/L (at pH>6.5) 18 out of 38 times (47%) (Table 3.7b). The frequency that total aluminium concentrations did not conform in reference and gated systems did not differ significantly. Ammonia concentrations were never above recommended value of 0.9 mg N/L out of 52 times sampled (Table 10.7b). Similarly, nitrite concentrations were never above recommended value of 0.7 mg N/L out of 52 times sampled (Table 10.7b).

3.4. Discussion

The clear separations in the twelve nMDSs plots indicate that species assemblages of juveniles (based on either abundance or biomass) differed significantly and consistently between the reference and gated drainage systems examined in the Clarence River floodplain (Figure 3.1, 3.2). These results are in general agreement with similar studies on the impact of flood mitigation strategies on species assemblages in NSW (Pollard and Hannan, 1994; Gibbs *et* al., 1999) and overseas (e.g. Halls *et. al*., 1998). In particular, our results confirm the findings from an earlier study in the Lower Clarence River (Pollard and Hannan, 1994) and therefore reinforce the need for finding better ways of managing floodgates on coastal floodplains. Numerous studies have shown that channelisation of rivers has resulted in decreases in fish and invertebrate species diversity as well as biomass (e.g. Swales, 1982). Other studies have reported an increase in numbers of stress-tolerant, exotic species with increasing levels of disturbance (e.g. Leidy and Fiedler, 1985).

Our results indicate that the differences in species assemblages between reference and gated sites is not only due to gates acting as physical barriers to fish passage, but also to a combination of reduced water and habitat quality in gated systems. The presence in gated sites of species that have a marine phase in their life cycle, such as yellowfin bream (*Acanthopagrus australis*), long-fin eel (*Anguilla reinhardtii*), flat-tailed mullet (*Liza argentea*), sea mullet (*Mugil cephalus*) and tarwhine (*Rhabdosargus sarba*), and prawn species such as greasy back prawn (*Metapenaeus bennettae*), schoolprawn (*Metapenaeus macleayi*) and king prawn (*Penaeus plebejus*) (Appendix 1, 2), indicates that floodgates do not provide a perfect seal. Individuals of these species may be small enough to move through cracks during flood tides, or strong enough to enter the gated systems against the flow during ebb tides. The relatively low numbers of these species in gated sites compared to reference sites (Appendix 1), however, indicates that movement of juvenile fish is severely reduced by floodgates.

The implementation of flood mitigation structures has resulted in the removal of spatial and temporal heterogeneity in environmental conditions, such as tidal exchange, flow, salinity and dissolved oxygen. Moreover, floodgates prevent the survival of mangroves upstream through exclusion of tidal water and mangrove propagules (SPCC, 1978; Pollard and Hannan, 1994). Results of the SIMPER and BIOENV analyses indicate that the reduced water and habitat quality in gated systems most likely resulted in these systems being dominated by fish and invertebrate species tolerant of the altered conditions (Table 3.2, 3.5; Appendix 1, 2). These more homogenous environments are more suitable for species that prefer still or sluggish waters, such as the native gudgeons *Hypseleotris compressus*, *Philypnodon grandiceps*, *P. sp.*, and *Gobiomorphus australis* (Larson and Hoese, 1996), and the exotic mosquitofish *Gambusia holbrooki* (McDowall, 1996). In addition, the construction of floodgates initiated a change in water quality variables such that conditions that prevail there now are most likely outside the tolerances of many species. For example, dissolved oxygen concentrations in gated systems tended to be below ANZECC guidelines more often than in reference systems (Table 3.7), and fluctuated widely on a 24 hour basis in several of the gated systems we monitored (BSES, unpublished data; S. Johnston, NSW Agriculture, pers. comm.). Both *G. holbrooki* (McKinsey and Chapman, 1998) and *H. compressus* (R. Pearson, James Cook University, pers. comm.) are species that tolerate low concentrations of dissolved oxygen. The establishment of fish assemblages comprised of low numbers of these two stress tolerant species, and possibly also *P. grandiceps* and *G. australis* (Larson and Hoese, 1996) (Table 3.2, 3.5), has been associated with decreases in environmental heterogeneity due to anthropogenic disturbance (e.g. Leidy and Fiedler, 1985).

3.4.1. Life history characteristics

3.4.1.1. Distribution and migration

Discharge of poor quality water from gated drainage systems (Table 3.7) also may create barriers to movement, potentially affecting migration and recruitment of fish and mobile invertebrate species. Partial or complete recruitment failure may occur if juveniles avoid such discharges. As a result, the capacity of habitats beyond the floodgate and/or discharge point to act as spawning or nursery areas may be reduced, with potential effects on population genetics as well as stock size. Although we were not able to adequately sample adult fish in our study, it is likely that reproductive opportunities for fish which need to move either upstream or downstream as part of a spawning migration would be further reduced if adults actively avoided discharges of poor water quality.

In coastal floodplains in eastern Australia, water quality variables that may affect migration and recruitment behaviour of aquatic fauna include temperature (e.g. Aziz and Greenwood, 1981; McKinnon and Gooley, 1998), suspended sediments (e.g. Prosser *et al.*, 2001), turbidity (e.g. Blaber and Blaber, 1980), pesticide concentrations (e.g. Davies *et al.*, 1994), and discharges of sulfuric acid and associated (trace-) metals in acid sulfate soil areas (Roach, 1997; Cook *et al.*, 2000; Preda and Cox, 2001; Chapter 7). The population collapse of the Australian bass (*Macquaria novaemaculeata*) in the Hastings and Manning rivers (New South Wales), due to recruitment failure, has been partially attributed to acid sulfate discharge (Harris, 1989 and pers. comm.). Our results suggest that concentrations of total phosphorus, phosphate, and total nitrogen in water discharged from gated drainage systems (Table 3.7) may also affect migration and recruitment behaviour, but specific experiments to examine this have not been conducted.

3.4.1.2. Reproduction

Species assemblages in gated drainage systems were dominated by relatively high numbers of a few species (Appendix 1). The potential ability of the most prominent species in the gated sites to complete their life cycle within the drainage systems may partly explain the assemblage structures in these sites. Details on the reproductive biology and life history for the most abundant gudgeons in our study (*Hypseleotris compressus*, *Philypnodon grandiceps*, *P. sp.*, and *Gobiomorphus australis*) are sparse, and mostly obtained from aquarium observations (Larson and Hoese, 1996). However, some information is available for *Hypseleotris compressus*, which deposits its eggs on rock, weed or sand during the warmer months (Auty, 1978; Larson and Hoese, 1996). The abundance of grasses and rushes in gated systems (Table 3.3; Appendix 3) could provide ample spawning substrate, and make the species self-sustaining in a gated drainage system. *Gambusia holbrooki* is a life-bearer (McDowall, 1996) and could thus sustain itself anywhere where conditions are favourable.

3.4.1.3. Shelter, diet and predation

The species assemblages of gated systems are most likely affected by the reduced water and habitat quality both directly and indirectly. For example, the relative abundance of mangroves contributed six out of 12 times (50%) to the combination of environmental variables that best describe the biotic patterns shown in the ordinations (Figure 3.1, 3.2). Riparian vegetation regulates ecosystem patterns and processes in most streams and rivers and can affect species assemblages. Clearing (or absence) of riparian vegetation has profound impacts on aquatic ecology (Bunn *et al.*, 1999; Pusey and Arthington, 2003). Clearing decreases the amount of organic matter and woody debris entering streams, thus decreasing sources of habitat and food for aquatic organisms. More sunlight penetrates the stream, thereby also increasing water temperature, favouring growth of filamentous algae and macrophytes. Bank erosion and sediment loads increase following removal of riparian vegetation (Prosser *et al.*, 2001; Hossain *et al.*, 2002), resulting in the smothering and disappearance of habitat and food sources for invertebrates and fish (Koehn and O'Connor, 1990). Nutrient input also increases (Prosser *et al.*, 2001) while nutrient uptake by primary producers changes (Udy and Bunn, 2001), affecting water quality as well as nutrient pathways to secondary consumers such as fish (Bunn *et al.*, 1999). These impacts can eventually facilitate overall changes in water quality, habitat quality and diversity, trophic dynamics, and the structure of aquatic communities.

In addition to environmental conditions, predator-prey relationships may influence which species do or do not occur in gated drainage systems. Invertebrate species such as *M. macleayi*, *Palaemon debilis*, and *Acetes sibogata australis* were present in large numbers and great biomass in reference systems (Table 3.2, 3.4; Appendix 1, 2), and are most likely important food sources for juvenile *A. australis* and *L. argentea* (Pease *et al.*, 1981b; Ballagh, 2002). These invertebrate species may not be able to tolerate the environmental conditions present in gated systems, although physiological experiments would be required to verify this. Thus, the absence of significant numbers and biomass of these invertebrates may contribute to the lack of juveniles of commercially harvested omnivorous and carnivorous fish species in gated systems.

The prevalence of *G. holbrooki* in the gated systems may also be due, in part, to the species being an 'adaptable predator' (McDowall, 1996). Gut analysis has shown that *G. holbrooki* prey on the eggs and adults of *Hypseleotris galli* and *Pseudomugil signifer* (Ivantsoff and Aarn, 1999), both of which were in low abundance or absent in the presence of *G. holbrooki* (Appendix 1, 2). *G. holbrooki* affects the breeding success of *P. signifer*, with concerns raised about the conservation of this species in the presence of *G. holbrooki* (Howe *et al.*, 1997). Given the aggressiveness of this species towards native fish, control measures for *G. holbrooki* should be considered in these systems.

4. THE EFFECTIVENESS OF FLOODGATE MANAGEMENT IN IMPROVING FISH PASSAGE AND WATER AND HABITAT QUALITY IN THE CLARENCE RIVER, NSW

4.1. Introduction

Analysis of data collected every 2 months in 2000-2001 clearly showed that floodgates in the lower Clarence River result in different upstream assemblages of fish and invertebrates compared to similar sites without floodgates (chapter 3). Our results confirm the findings of Pollard and Hannan (1994) and therefore reinforce the need for finding better ways of managing floodgates on coastal floodplains. If floodgates act as a major barrier to fish movement, improvements might take the form of either more frequent opening of traditional floodgates (i.e., with flap valves) or using alternative designs that are 'leakier' and/or easier to open and close.

The aim of this part of the study was to examine the effectiveness of two management options for floodgated drainage systems on fish passage, as well as on water and habitat quality in these systems. Here, we assessed the effectiveness of (i) different opening regimes of floodgates (i.e. one-way (downstream opening) flap valves), and (ii) different gate structures. Our objectives were to (i) examine and compare patterns in the species abundance assemblages in reference, managed and gated drainage systems, (ii) examine and compare patterns in the species biomass assemblages in reference, managed and gated drainage systems, and (iii) determine which environmental variables are associated with the observed patterns in species assemblages. We predicted that, with active floodgate management (i.e opening and closing of gates), juvenile fish and invertebrates would utilise these floodgated drainage systems more extensively.

4.2. Methods

All thirteen sampling sites were used for this study (see Figures 2.1, 2.2; Table 2.1).

4.2.1. Opening regimes of gated drainage systems

Winch structures to open floodgates on four drainage systems, as well as two vertical liftgates and a mini-sluice gate at two other systems were installed at our study sites (Table 2.1), and tested by CRCC at various times throughout our project. After landholders received appropriate OH&S training by CRCC, gates and structures were opened at various times during our project (see 1.3.2.1. and 1.3.2.2.; Table 4.1). To support the landholders in opening their gates, while at the same time minimising detrimental impact on agriculture (i.e. overtopping of saline water), we handed out and mailed NSW Tide Charts to five landholders at Blanches Drain, and to each landholder at Carrols Drain and Taloumbi #5. We asked all landholders to keep detailed records of the number of gates they opened (if relevant), date and time of opening and closing, as well as anything else they considered noteworthy and relevant to this project.

4.2.2. Sampling methods

Samples were collected every two months (July 2000 to May 2002) totalling twelve sampling occasions. Quantification of fish and invertebrates, water quality and habitat parameters followed the procedures described in Chapter 2.

Table 4.1. Floodgate opening dates and times for four managed floodgated drainage systems in the Clarence river floodplain; a. Blanches Drain, b. Carrols Drain, c. Taloumbi #5, and d. Wants Drain. Total number of openings, and duration of openings (in min. and in hrs.) are given.

a. Blanches Drain

Number	Date open	Time open	Date closed	Time closed	Duration (hrs)	Duration (min)
1	26-Jul-00	approx 12:00	27-Jul-00	approx 12:00	24.00	1,440
2	22-Nov-00	approx 14:00	25-Nov-00	approx 10:00	68.00	4,080
3	23-Dec-00	approx 13:00	28-Dec-00	approx 10:00	117.00	7,020
4	24-Jan-01	approx 7:00	25-Jan-01	approx 18:00	35.00	2,100
5	1-Mar-01	7:45	4-Mar-01	9:45	74.00	4,440
6	14-Mar-01	17:00	21-Mar-01	12:45	164.00	9,840
7	28-Mar-01	8:45	4-Apr-01	17:00	176.00	10,560
8	16-Apr-01	17:15	21-Apr-01	7:30	111.00	6,660
9	23-Apr-01	approx 17:00	30-Apr-01	approx 17:00	168.00	10,080
10	16-May-01	9:30	19-May-01	9:30	72.00	4,320
11	31-May-01	approx 12:00	1-Jun-01	approx 15:00	27.00	1,620
12	12-Jun-01	approx 12:00	16-Jun-01	approx 15:00	98.00	5,880
13	28-Jun-01	approx 12:00	30-Jun-01	approx 12:00	48.00	2,880
14	12-Jul-01	approx 11:00	16-Jul-01	approx 12:00	96.00	5,760
15	27-Jul-01	approx 11:00	31-Jul-01	approx 9:00	94.00	5,640
15					**1,372**	**82,320**

b. Carrols Drain

Number	Date open	Time open	Date closed	Time closed	Duration (hrs)	Duration (min)
1	3-Aug-01	15:00	3-Aug-01	16:00	1.00	60
2	4-Aug-01	7:00	4-Aug-01	7:05	0.05	5
3	4-Aug-01	13:00	4-Aug-01	13:45	0.45	45
4	5-Aug-01	6:30	5-Aug-01	7:00	0.30	30
5	6-Aug-01	6:30	6-Aug-01	7:00	0.30	30
6	7-Aug-01	6:15	7-Aug-01	6:45	0.30	30
7	13-Sep-01	10:00	13-Sep-01	12:15	2.15	135
8	16-Sep-01	13:00	16-Sep-01	16:00	3.00	180
9	17-Sep-01	14:00	17-Sep-01	17:00	3.00	180
10	1-Oct-01	15:00	1-Oct-01	17:00	2.00	120
11	2-Oct-01	16:00	2-Oct-01	17:30	1.30	90
12	10-Oct-01	9:00	10-Oct-01	13:00	4.00	240
13	8-Nov-01	6:30	8-Nov-01	10:30	4.00	240
14	11-Nov-01	13:00	11-Nov-01	14:00	1.00	60
15	13-Nov-01	15:00	13-Nov-01	16:30	1.30	90
16	16-Nov-01	14:00	16-Nov-01	18:30	4.30	270
17	17-Nov-01	15:00	17-Nov-01	19:00	4.00	240
18	2-Dec-01	15:00	2-Dec-01	19:00	4.00	240
19	3-Dec-01	7:00	3-Dec-01	10:30	3.30	210
20	10-Dec-01	13:00	10-Dec-01	15:30	2.30	150
21	13-Dec-01	13:00	13-Dec-01	18:00	5.00	300
22	17-Dec-01	6:00	17-Dec-01	7:30	1.30	90
23	18-Dec-01	6:00	18-Dec-01	7:30	1.30	90
24	20-Dec-01	6:00	20-Dec-01	8:30	2.30	150
25	27-Dec-01	13:00	27-Dec-01	15:00	2.00	120
26	23-Jan-02	10:30	23-Jan-02	13:30	3.00	180
27	24-Jan-02	13:00	24-Jan-02	14:00	1.00	60
28	26-Jan-02	13:30	26-Jan-02	15:00	1.30	90
29	27-Feb-02	14:30	27-Feb-02	15:30	1.00	60
30	28-Feb-02	18:30	28-Feb-02	19:25	0.55	55
31	1-Mar-02	17:00	1-Mar-02	18:00	1.00	60
32	16-Mar-02	16:00	16-Mar-02	18:00	2.00	120
33	26-Mar-02	14:00	26-Mar-02	17:00	3.00	180
34	12-Apr-02	17:30	12-Apr-02	18:00	0.30	30
35	13-Apr-02	12:00	13-Apr-02	13:00	1.00	60
36	14-Apr-02	12:30	14-Apr-02	15:30	3.00	180
37	27-Apr-02	13:00	27-Apr-02	14:30	1.30	90
38	28-Apr-02	12:30	28-Apr-02	16:30	4.00	240
38					**80.00**	**4,800**

c. Taloumbi #5

Number	Date open	Time open	Date closed	Time closed	Duration (hrs)	Duration (min)
1	31-Aug-01	9:35	31-Aug-01	10:50	1.15	75
2	05-Sep-01	11:50	05-Sep-01	13:25	1.35	95
3	11-Sep-01	n/a	11-Sep-01	n/a	3.00	180
4	12-Sep-01	n/a	12-Sep-01	n/a	1.00	60
5	13-Sep-01	n/a	13-Sep-01	n/a	1.00	60
6	17-Sep-01	n/a	17-Sep-01	n/a	2.00	120
7	18-Sep-01	n/a	18-Sep-01	n/a	2.00	120
8	19-Sep-01	n/a	19-Sep-01	n/a	2.00	120
9	21-Sep-01	n/a	21-Sep-01	n/a	2.00	120
10	27-Sep-01	9:30	27-Sep-01	10:30	1.00	60
11	07-Oct-01	7:00	07-Oct-01	8:30	1.30	90
12	18-Oct-01	12:00	18-Oct-01	13:00	1.00	60
13	28-Oct-01	10:00	28-Oct-01	16:30	4.30	270
14	01-Nov-01	10:30	01-Nov-01	11:30	1.00	60
15	20-Nov-01	7:00	20-Nov-01	8:30	1.30	90
16	12-Dec-01	13:00	12-Dec-01	13:30	0.30	30
17	17-Dec-01	15:30	17-Dec-01	16:30	1.00	60
18	21-Dec-01	11:30	21-Dec-01	13:10	1.40	100
19	23-Dec-01	10:45	23-Dec-01	11:30	0.45	45
20	04-Jan-02	13:30	04-Jan-02	14:00	0.30	30
21	14-Jan-02	10:00	14-Jan-02	11:00	1.00	60
22	15-Jan-02	11:00	15-Jan-02	12:00	1.00	60
23	18-Jan-02	8:00	18-Jan-02	13:00	5.00	300
24	07-Feb-02	9:00	07-Feb-02	13:00	4.00	240
25	21-Feb-02	7:15	21-Feb-02	7:45	0.30	30
26	11-Mar-02	13:45	11-Mar-02	14:15	0.30	30
27	22-Mar-02	14:00	22-Mar-02	14:30	0.30	30
28	10-Apr-02	8:50	10-Apr-02	9:15	0.25	25
29	27-Apr-02	10:30	27-Apr-02	11:00	0.30	30
30	17-May-02	13:15	17-May-02	14:00	0.45	45
31	20-May-02	13:00	20-May-02	17:00	4.00	240
32	21-May-02	13:00	21-May-02	17:00	4.00	240
33	22-May-02	13:00	22-May-02	17:00	4.00	240
33					**56.55**	**3,415**

d. Wants Drain

Number	Date Open	Time open	Date closed	Time closed	Duration (hrs)
1	25-Jul-00	lunch time	± 2 wks later	n/a	336
2	early Sep 01	n/a	± 3 wks later	n/a	504
2					**840**

e. Marsh Drain

Number	Date open	Time open	Date closed	Time closed	Duration (hrs)	Duration (min)	Notes
1	15-Jan-02	n/a	n/a	n/a			
2	16-Jan-02	n/a	n/a	n/a			
3	19-Jan-02	n/a	n/a	n/a			
4	20-Jan-02	n/a	n/a	n/a			
5	31-Jan-02	n/a	n/a	n/a			
6	02-Feb-02	n/a	n/a	n/a			
7	11-Feb-02	n/a	n/a	n/a			
8	13-Feb-02	n/a	n/a	n/a			
9	19-Feb-02	n/a	20-Feb-02	n/a			
10	26-Feb-02	n/a	n/a	n/a			
11	01-Mar-02	n/a	n/a	n/a			Drain filled to capacity
12	02-Mar-02	n/a	n/a	n/a			Drain filled to capacity
13	03-Mar-02	n/a	n/a	n/a			Drain filled to capacity
14	04-Mar-02	n/a	n/a	n/a			Drain filled to capacity
15	16-Mar-02	n/a	n/a	n/a			
16	18-Mar-02	n/a	n/a	n/a			
17	20-Mar-02	n/a	n/a	n/a			
18	21-Mar-02	n/a	n/a	n/a			
19	2-Apr-02	n/a	2-Apr-02	n/a	4:00	240	
20	5-Apr-02	n/a	5-Apr-02	n/a	3:00	180	
21	6-Apr-02	n/a	6-Apr-02	n/a	2:00	120	
22	9-Apr-02	n/a	9-Apr-02	n/a	3:00	180	
23	13-Apr-02	n/a	13-Apr-02	n/a	4:00	240	
24	18-Apr-02	n/a	18-Apr-02	n/a	3:00	180	
25	24-Apr-02	n/a	24-Apr-02	n/a	2:00	120	Not opened for a week - too much water
26	1-May-02	n/a	1-May-02	n/a	4:00	240	
27	5-May-02	n/a	5-May-02	n/a	5:00	300	
28	10-May-02	n/a	10-May-02	n/a	5:00	300	
28							

4.2.3. Data analyses

4.2.3.1. General

The study originally had a BACI design, with one year before opening and one year after opening of floodgated drainage systems. However, the eventual opening regimes of the six gated drainage systems (see chapter 1; Table 4.1) did not allow for analyses according to a BACI design. Consequently, gated sites were defined as “managed” if the gate(s) had been opened during the two months preceeding, or during a field trip. The samples collected at that site during that field trip were subsequently considered to come from a “managed” site. If the gate(s) had not been opened in the two months since the previous field trip, a site was defined as “gated” or “un-managed”. Thus, a site could be a “gated” site one trip, a “managed” site the next, and return to being a “gated” site, depending on the opening regime of the floodgates. A gated site was considered “managed” regardless of whether the opening was due to a floodgate opening, or due to an opening of a different structure (i.e. mini-sluice gate, vertical liftgate).

4.2.3.2. Non-metric multivariate analyses

We used non-metric multivariate data analyses to examine whether, with active floodgate management (i.e opening and closing of gates), juvenile fish and invertebrates would utilise these gated drainage systems. We compared species assemblages (both abundance and biomass) between reference, managed and gated drainage systems for each sampling occasion, using non-metric multivariate data analyses techniques (Primer 5.0 package, Plymouth Marine Laboratory, UK), as described in Chapter 2.

4.2.3.3. Relationship between floodgate opening and species richness and diversity

The effect of floodgate opening on species richness and diversity was assessed for gated sites, where floodgates were actively opened at least once during our project (i.e. Blanches Drain, Carrols Drain, Taloumbi #5 and Wants Drain; Table 4.1). For each site, floodgate opening was described as (i) the total time (in min), and (ii) the frequency of floodgate opening during the two months preceding, or during a field trip. Species richness (Krebs, 1999), including mean number of species and mean number of commercial species, was calculated for each of the four sites for each trip by averaging the total number of (commercial) species in Area 1 and in Area 2. Species diversity, including abundance of species and biomass of species, was calculated for each of the four sites for each trip using the Shannon-Wiener function (Krebs, 1999). For each sampling occasion at a site, the Shannon-Wiener function was calculated for Area 1 and Area 2 for abundance and biomass separately, and subsequently averaged to obtain an average species diversity for a site. The relationship between species richness and diversity, and floodgate opening was examined using regression analyses (Zar, 1984).

4.2.3.4. Water quality and ANZECC guidelines

To examine whether water quality improved with management of gated drainage systems, we conducted the following analysis. We compared water quality variables against ANZECC trigger values for lowland rivers and streams for (i) physical and chemical stressors for south-east Australia (including NSW and south-east Queensland) for slightly disturbed ecosystems, and, (ii) toxicants at 95% level of protection (ANZECC, 2000). Trigger values for total aluminium are only available for pH>6.5. Total aluminium concentrations were measured on water samples taken at the surface, hence we assessed the total aluminium concentrations against the $pH_{(s)}$ measured at that area. If $pH_{(s)} \leq 6.5$, total aluminium concentrations were not considered. Subsequently, we compared the frequencies that water quality values did not conform to ANZECC guidelines in (i) reference and gated drainage systems, (ii) reference and managed drainage systems, and (ii) gated and managed drainage systems, from July 2000 until May 2002, using $\chi 2$ tests (Zar, 1984).

4.3. Results

4.3.1. General

While we attempted to sample every site during every sampling trip, this was not always possible. First, Carrs Drain and Harwoods Drain were not sampled during July 2000, awaiting permission from the respective landholders. Second, Dennys Gully was not included in our sampling regime until September 2001, as excessive amounts of azola (duckweed) made it impossible to haul a seine net at this site (Figure 2.2b, iv). Similarly, the Upper Coldstream location could not be seined during January 2001, due to excessive amounts of elodea (Canadian pondweed) (Figure 4.1).

A total of 879 seines were hauled in the Clarence river during this study, yielding 128 taxa (68 fish and 60 invertebrate taxa), 670,072 individuals (194,059 fish and 476,013 invertebrates), and a combined weight of approximately 157.2 kg (120.6 kg fish and 36.6 kg invertebrates). Of these totals, 27 of the taxa (21%) were of economic importance (22 fish species and 5 invertebrate species), accounting for 19,418 (2.9%) of the individuals (6,582 fish and 12,836 invertebrates) and approximately 51.7 kg (32.9 %) of the weight (45.8 kg fish and 5.9 kg of invertebrates). Potential occurrence of redspot disease was only observed on two adult freshwater mullet (*Myxus petardi*) captured in the Coldstream in May 2001. These two fish showed healing sores and scratches, mostly likely signs of recovery from redspot disease (R. B. Callinan, NSW Fisheries, pers. comm.).

Although we tried to identify to species all organisms caught, small juveniles of some fish and invertebrate species, and adults of some invertebrate species were difficult to separate (see Chapter 3). Further, damaged prawn and shrimp bodies that could not be identified to species were only included in the biomass analyses (see Chapter 3).

Five fish were returned to the field without measuring their weight; two bullrouts (*Notesthes robusta*), two long-fin eels (*Anguilla reinhardtii*), and one smooth toadfish (*Tetractenos glaber*). Their weights were estimated from species-specific log(SL) x log(W) relationships calculated on individuals of known sizes and weights. These five weight estimates were subsequently used in the analyses.

Due to technical problems with the TPS model 90FL water quality meter, dissolved oxygen (DO) was not measured in July and September 2000 and only at some sites in January 2001, and pH was not measured in January 2001. pH levels were subsequently measured on the January water samples analysed at the Environmental Analysis Laboratory. Turbidity (NTU) was not included in the measurements until April 2001.

Figure 4.1. Clarence river. Upper Coldstream Creek in January 2001, showing excessive amount of elodea (Canadian pondweed), making seining impossible.

4.3.2. Opening regimes of gated drainage systems

4.3.2.1. Floodgate management through opening of one-way flap valves

Blanches Drain was opened a total of 15 times, with the first opening on 26 July 2000 and the last one on 27 July 2001 (Table 4.1a). Gates were opened by landowners at different times of the year, for varying lengths of time and for various reasons. In general, longer opening times were not achieved because landowners did not want saline water to overtop the drains and spill over onto this farmland. Both gates were opened during each opening. The duration of the shortest opening was 27 hrs, while the longest opening lasted 176 hrs. Blanches Drain was opened for a total of 1372 hours, comprising 15.7% of the total hours per year.

Carrols Drain was opened a total of 38 times, with the first opening on 3 August 2001 and the last one on 28 April 2002 (Table 4.1b). Number and location of gates opened varied from opening to opening, but generally all three floodgates were opened during each opening. Gates were opened just before low tide, and kept open until water level in the drain reached 0.4 m (measured at the floodgates). The duration of the shortest opening was 5 mins, while the longest opening lasted 5 hrs. Carrols Drain was opened for a total of 80 hours, comprising 0.9% of the total hours available in a year.

Taloumbi #5 was opened a total of 33 times, with the first opening on 31 August 2001 and the last one on 22 May 2002 (Table 4.1c). In general, one of the three floodgates was opened during each opening, and gates were usually opened on incoming tides. The duration of the shortest opening was 25 mins, while the longest opening lasted 5 hrs. Taloumbi #5 was opened for a total of 56.55 hours, comprising 0.7% of the total hours per year.

Wants Drain was opened twice, once in 2000 and once in 2001 (Table 4.1d). The specific aim of both openings was to wet cattle grazing land with freshwater in the dry season (Figure 4.2a). Both floodgates were opened during both openings. In 2000, the gates were opened on 25 July and left open for approximately two weeks. In 2001, the gates were opened in early September and left open for approximately three weeks. Wants Drain was opened for a total of approximately 840 hours, comprising 9.6% of the total hours per year.

4.3.2.2. Floodgate management through installation of structures onto flap-valves

Two vertical liftgates, one on each pipe, were installed on Marshes Drain in November 2001 (Figure 4.2b). One vertical liftgate on Marshes Drain was opened a total of 28 times, with the first opening on 15 January 2002 and the last one on 10 May April 2002 (Table 4.1e). Opening size of the vertical liftgate varied from opening to opening, including openings of 15 cm. Openings were relatively short but frequent in the beginning, but increased in duration to 4 to 5 hours towards the end of the project.

A mini-sluice gate was installed on the southern-most boxculvert at Dennys Gully in September 2001 (Figure 4.2c). To enhance fish passage the sluicegate was designed with a horizontally, rather than vertically, opening gate, at the request of NSW Fisheries. To prevent saltwater overtopping further upstream, a backwater retention structure was installed 1 to 1.5 km upstream from the gate on 8 October 2001 (Figure 4.2d). After installation, the mini-sluice gate was opened for a weekend, and subsequently closed because of high tides. After the September 2001 field trip, the mini-sluice gate was kept open almost permanently. To assess why fish passage had not improved with installation and opening of the mini-sluice gate (see *Results*), the floodgate on which the mini-sluice gate was installed was opened completely approximately two weeks prior to the last field trip (May 2002).

a.

b

c.

d

Figure 4.2. Floodgate openings and opening structures in the Clarence river floodplain; a. Wants Drain floodgates in open position, b. vertical liftgate on Marshes Drain, c. mini-sluicgate on Dennys Gully, and d. backwater retention structure in Dennys Gully. Note flooded grazing land on both sides of Wants Drain.

4.3.3. Species abundance

Non-metric multidimensional scaling showed that samples collected at a single site were generally located together within one sample occasion (Figure 4.3). In general, the ordinations showed clear separations between the abundance assemblages of reference and gated drainage systems across all twelve sampling occasions, with the exception of one reference site (Upper Coldstream Creek). Abundance assemblages from this reference site were consistently located with those from gated drainage systems. Abundance assemblages in managed sites were generally located with those from gated drainage systems (and Upper Coldstream Creek), with the exception of Carrols Drain. Abundance assemblages from this site, when managed, were mostly located with those from reference drainage systems. All twelve ordinations were good representations of the data (stress levels ranged from 0.07 to 0.13).

Nested ANOSIM revealed that, across all twelve sampling occasions, species abundance assemblages at individual sites within a treatment differed significantly more from each other than between the two (reference, gated) or three (reference, gated, managed) treatments (Table 4.2). Treatment effects were non-significant on all twelve occasions.

SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species abundance assemblages between treatments (reference vs gated), explained 71.53% to 84.53% of average dissimilarity between treatments (Table 4.3a). Eighteen species out of the 128 taxa collected were most important in contributing to the total average dissimilarity in species abundance assemblages between treatments. Three of these eighteen species (*Hypseleotris compressus* and *Metapenaeus macleayi*, and the exotic *Gambusia holbrooki*) consistently contributed to these dissimilarities. *Gambusia holbrooki* was consistently more abundant in gated drainage systems, while *H. compressus* was more abundant in gated drainage systems on eleven out of the twelve sampling occasions. In contrast, *M. macleayi* was consistently more abundant in reference drainage systems. Across the twelve sampling occasions, two commercially significant species contributed to the total average dissimilarities, namely *Liza argentea* and *M. macleayi*.

SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species abundance assemblages between treatments (reference vs managed), explained 69.50% to 82.09% of average dissimilarity between treatments (Table 4.3b). Twenty-two species were most important in contributing to the total average dissimilarity in species abundance assemblages between treatments. Two of these species (*H. compressus* and *M. macleayi*) consistently contributed to these dissimilarities. *Hypseleotris compressus* was more abundant in managed drainage systems on eight out of the ten sampling occasions. In contrast, *M. macleayi* was consistently more abundant in reference drainage systems. Across the ten sampling occasions, three commercially significant species contributed to the total average dissimilarities, namely *L. argentea*, *M. macleayi* and *Mugil cephalus*.

SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species abundance assemblages between treatments (managed vs gated), explained 45.24% to 71.50% of average dissimilarity between treatments (Table 4.3c). Twenty-four species were most important in contributing to the total average dissimilarity in species abundance assemblages between treatments. Four of these species (*H. compressus*, *Gobiomorphus australis* and *Philypnodon grandiceps*, and the exotic *G. holbrooki*) consistently contributed to these dissimilarities. *Gambusia holbrooki* was more abundant in gated drainage systems nine out the ten sampling occasions. *Gobiomorphus australis*, *H. compressus* and *P. grandiceps* were more abundant in gated drainage systems five out the ten sampling occasions. Two commercially significant species contributed to the total average dissimilarities, namely *M. macleayi* and *M. cephalus*.

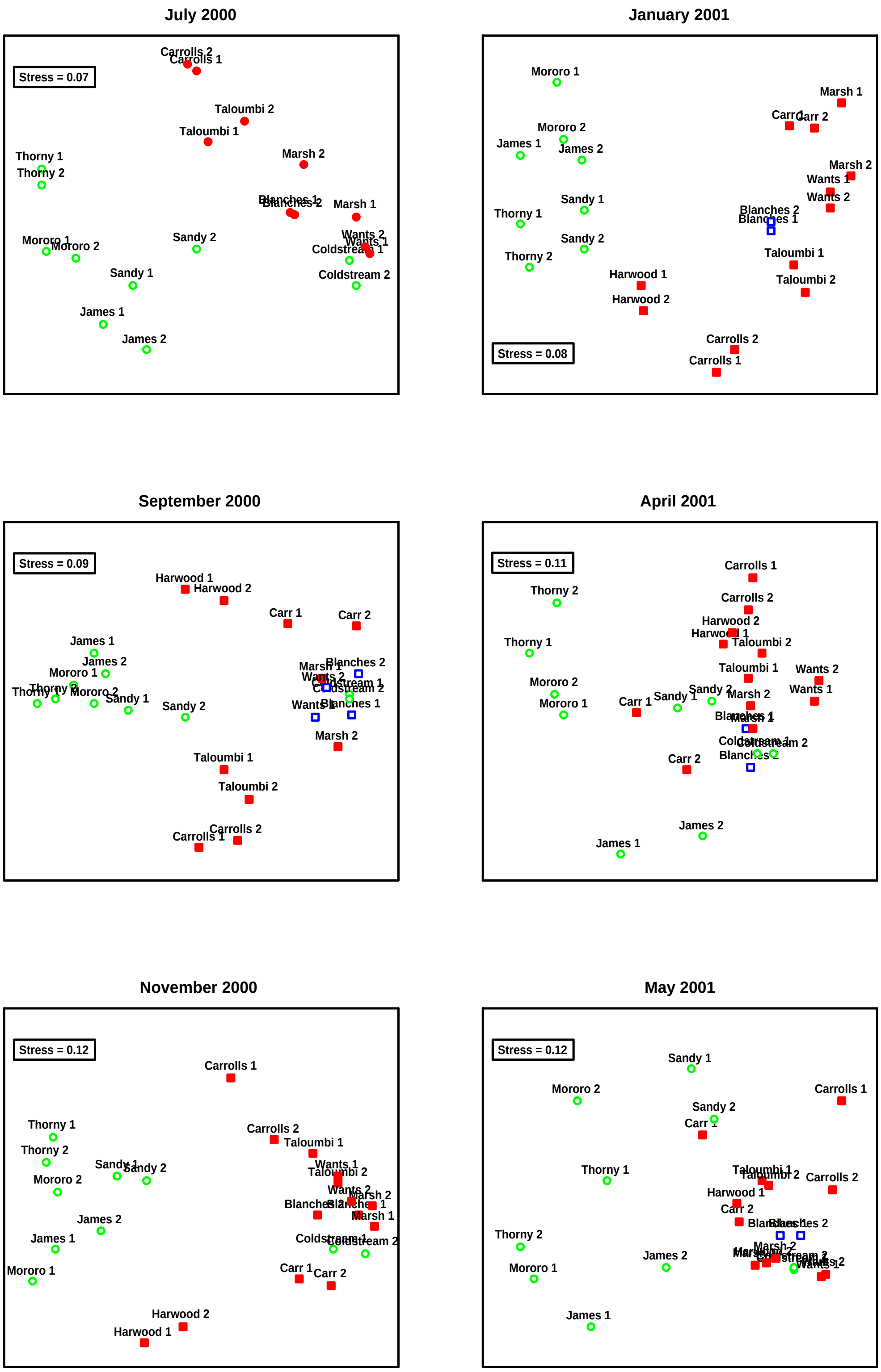


Figure 4.3. Clarence river. Non-metric multidimensional scaling (nMDS) ordinations of species abundance on each of the 12 sampling occasions in the Clarence river floodplain. The ordinations are based on log (x+1) transformed abundances and Bray-Curtis similarities. Green open circles are reference systems, red solid squares are gated drainage systems, and blue open squares are managed gated systems.

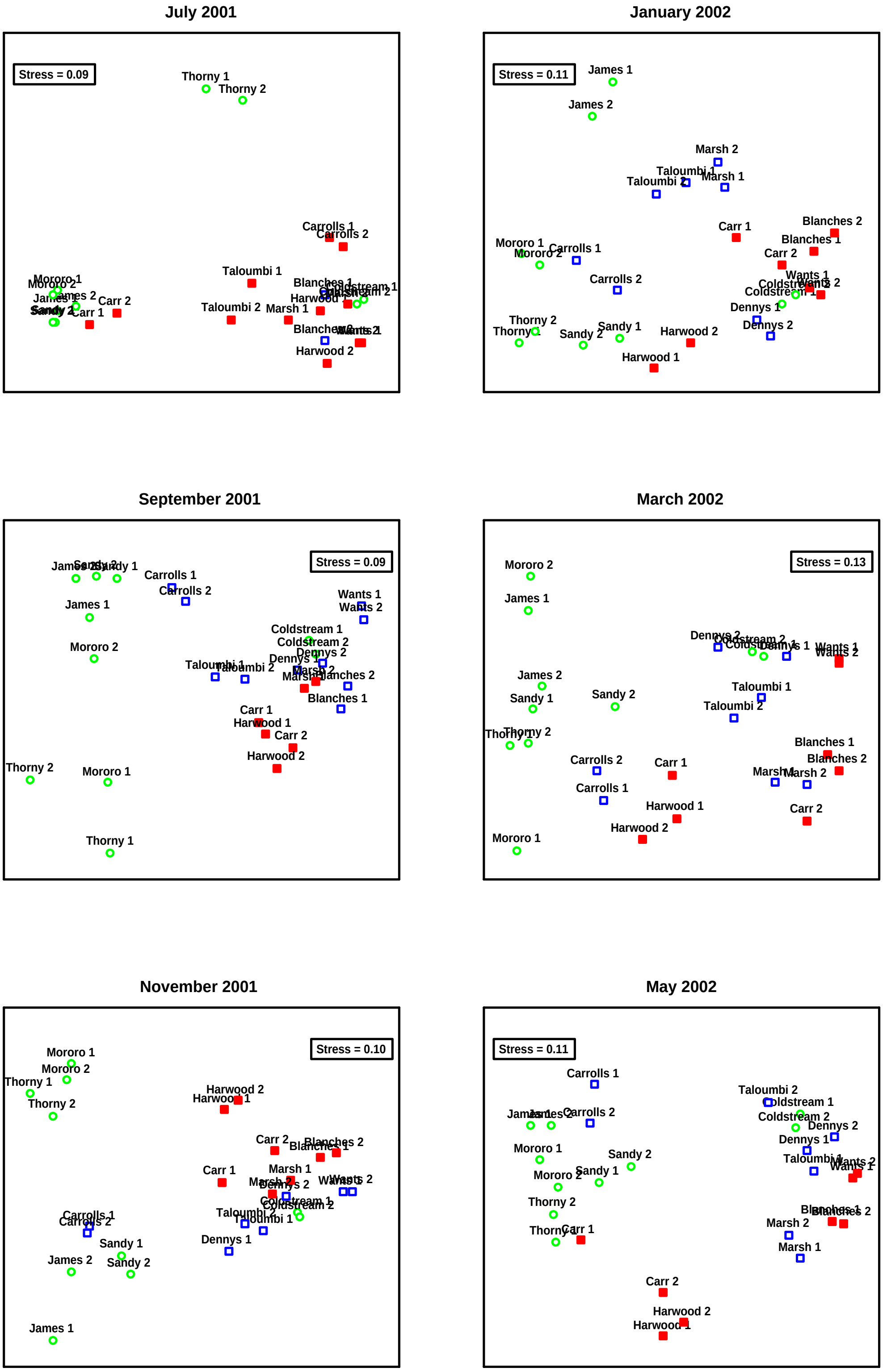


Figure 4.3. continued.

Table 4.2. Summary of two-way nested ANOSIM tests examining differences in species assemblages (based on abundance data) between treatments (July and November, reference vs gated; all other months, reference vs managed vs gated drainage systems) for the twelve sampling occasions in the lower Clarence river floodplain. Significance levels in red are p<0.05.

Year	Month	Source of variation	Permutations	Global R	Significance level
2000	July	Treatment	126	-0.176	0.87
		Site (Treatment)	999	0.93	0.001
	September	Treatment	999	0.176	0.90
		Site (Treatment)	999	0.95	0.001
	November	Treatment	792	0.041	0.36
		Site (Treatment)	999	0.841	0.001
2001	January	Treatment	999	0.155	0.17
		Site (Treatment)	999	0.887	0.001
	April	Treatment	999	-0.233	0.96
		Site (Treatment)	999	0.880	0.001
	May	Treatment	999	-0.113	0.79
		Site (Treatment)	999	0.731	0.001
	July	Treatment	999	-0.194	0.92
		Site (Treatment)	999	0.895	0.001
	September	Treatment	999	-0.168	0.94
		Site (Treatment)	999	0.845	0.001
	November	Treatment	999	-0.192	0.93
		Site (Treatment)	999	0.945	0.001
2002	January	Treatment	999	-0.175	0.92
		Site (Treatment)	999	0.975	0.001
	March	Treatment	999	-0.149	0.90
		Site (Treatment)	999	0.812	0.001
	May	Treatment	999	-0.175	0.91
		Site (Treatment)	999	0.959	0.001

Table 4.3. SIMPER results showing the species ranked in decreasing order of importance (1-10 only) that contributed to the total average dissimilarity in species assemblages (based on abundance data) between treatments for the twelve sampling occasions in the lower Clarence river floodplain; (a) reference vs gated, (b) reference vs managed, and (c) managed vs gated. Percentages of average dissimilarity between treatments, and percentages of cumulative contribution by first ten species to dissimilarity are given. Numbers in bold indicate species that were more abundant in reference (a and b) or managed (c) sites; species in red indicate species significant for commercial and/or recreational fisheries.

a) Reference vs Gated

Species Name	2000			2001						2002		
	July	Sept	Nov	Jan	April	May	July	Sept	Nov	Jan	March	May
Average dissimilarity	79.26%	76.33%	82.63%	84.53%	74.57%	71.53%	73.60%	73.71%	73.31%	79.24%	82.55%	79.79%
Acetes sibogae australis	**2**	**3**	**4**	**10**		**1**	**1**	**2**	**2**	**2**	**3**	**2**
Ambassis jacksoniensis			**7**	**9**	**3**					**10**	**10**	
Ambassis marianus				**8**	**10**	**7**				**5**	**8**	
Corixidae spp.						8	5					
Favonigobius exquisites												**9**
Fluviolanatus subtortus								10	8	9		
Gambusia holbrooki	5	7	6	2	1	2	4	6	10	7	2	6
Gobiomorphus australis	**8**		9		8	4	**2**	**3**	4	**3**	**4**	**8**
Gobiopterus semivestitus	**10**	10						8				
Hypseleotris compressus	1	1	1	1	2	**3**	3	1	1	1	1	1
Hypseleotris galii					**5**	10						
Liza argentea		**9**	**10**	**3**	**7**			**9**	**6**			
Metapenaeus macleayi	**9**	**6**	**8**	**6**	**4**	**5**	**8**	**5**	**5**	**8**	**5**	**4**
Palaemon debilis	**4**	**2**	2	**4**		**9**	**6**	4	3	4	**6**	3
Philypnodon grandiceps	3	4	3	7	**6**	6	7		7			**10**
Philypnodon sp1	6	8					9					
Pseudogobius olorum	**7**	**5**	**5**	**5**			**10**	**7**	9	**6**	7	5
Pseudomugil signifer					9						**9**	**7**
Cumulative contribution	73.97%	63.97%	57.55%	63.35%	60.77%	65.04%	71.97%	71.90%	63.43%	64.74%	62.64%	57.77%

Table 4.3. Continued

b) Reference vs Managed

Species Name	2000			2001						2002		
	July	Sept	Nov	Jan	April	May	July	Sept	Nov	Jan	March	May
Average dissimilarity	N/a	77.43%	n/a	82.09%	71.32%	72.63%	80.61%	73.14%	69.50%	71.67%	74.58%	78.00%
Acetes sibogae australis		**3**		**9**		**2**	**2**	**2**	**2**	**2**	**2**	**2**
Ambassis agassizii					3	6						
Ambassis jacksoniensis				**7**	**4**					**8**	**10**	**8**
Ambassis marianus				**10**	**9**	**8**				**5**		
Caridina nilotica		8							10			9
Corixidae spp.						1	1					
Cymodetta spp.										9		
Diplonychus spp.						10						
Fluviolanatus subtortus								10				
Gambusia holbrooki				2	1	3	7				3	
Glyptophysa gibbosa							8					
Gobiomorphus australis		6			6	4	**4**	3	**3**	**3**	**4**	**10**
Gobiopterus semivestitus							**10**	**9**				
Hypseleotris compressus		1		1	**2**	**5**	3	1	1	1	1	1
Hypseleotris galii		4			**7**							
Liza argentea		**10**		**5**	**8**			**8**	**8**			
Metapenaeus macleayi		**5**		**8**	**5**	**7**	**6**	**4**	**6**	**10**	**6**	**4**
Mugil cephalus							5					
Palaemon debilis		**2**		**4**			**9**	**6**	**4**	**7**	**5**	**3**
Philypnodon grandiceps		9		3	**10**	9		5	5	6	7	**6**
Pseudogobius olorum		7		**6**				7	7	**4**	9	**7**
Pseudomugil signifer									**9**		**8**	**5**
Cumulative contribution	n/a	66.97%	n/a	67.26%	74.23%	70.95%	79.61%	69.80%	60.40%	61.05%	58.92%	54.00%

Table 4.3. Continued

c) Managed vs Gated

Species Name	2000			2001						2002		
	July	Sept	Nov	Jan	April	May	July	Sept	Nov	Jan	March	May
Average dissimilarity	n/a	60.27%	n/a	50.73%	52.77%	45.24%	55.85%	52.45%	52.62%	66.64%	63.37%	71.50%
Acetes sibogae australis							3	**5**	**1**	**1**		
Afurcagobious tamarensis											**10**	
Ambassis agassizii				**5**	**1**	**2**						
Ambassis jacksoniensis												**10**
Caridina nilotica		**5**		**6**					**9**			**5**
Corixidae spp.					7	**1**	**1**					
Cymodetta spp.										**6**	**8**	
Diplonychus spp.					9	**9**						
Dytiscidae spp.										9		
Fluviolanatus subtortus								**8**	7	10	**9**	6
Gambusia holbrooki		7		**2**	3	3	5	4	6	8	1	4
Glyptophysa gibbosa							10					
Gobiomorphus australis		**3**		9	6	**7**	8	**3**	5	**5**	**2**	7
Gobiopterus semivestitus		9						7				
Hypseleotris compressus		**1**		**3**	2	4	4	**2**	4	2	**3**	**1**
Hypseleotris galii		4			8	10		**10**	10			9
Melanotaenia duboulayi						**8**						
Metapenaeus macleayi				**8**	4	6	**6**	**9**				
Mugil cephalus							**2**					
Palaemon debilis		8		10				1	2	4	7	2
Philypnodon grandiceps		2		1	10	5	7	**6**	**3**	**3**	**4**	**8**
Philypnodon sp1		6		7			9					
Pseudogobius olorum		10		4					**8**	7	5	3
Pseudomugil signifer					5						**6**	
Cumulative contribution	n/a	79.96%	n/a	69.58%	65.99%	65.50%	74.06%	65.88%	59.81%	61.74%	59.19%	53.92%

BIOENV revealed that various combinations of 14 out of the 47 water quality and habitat quality parameters best described the biotic patterns shown in the nMDS ordinations (Table 4.4; Figure 4.3). On eleven of the sampling occasions, the combination of environmental variables involved both water quality and habitat variables. The correlations between the combination of environmental variables and the biotic patterns shown in the nMDS ordinations (Figure 4.3) ranged from 0.602 to 0.876 (Table 4.4). Nutrients contributed to the combinations of environmental variables 10 out of 12 times; total nitrogen and phosphate four times each, nitrite three times, total Kjeldal nitrogen twice, and total phosphorus once. Nutrient concentrations were higher at gated drainage systems during these ten sampling occasions. Seagrass, mangroves, and grasses and rushes contributed to the combinations of environmental variables four out of twelve times each. Seagrass and mangroves were more abundant at reference sites, while grasses and rushes were more abundant at gated sites. Only once did an acid sulfate soil discharge by-product (dissolved aluminium) contribute to these combinations of environmental variables.

4.3.4. Species biomass

As with the abundance data, biomass data from individual sites clumped together within a sample occasion (Figure 4.4). Again, the ordinations showed clear separations between the biomass assemblages of reference and gated drainage systems across all twelve sampling occasions, with the exception of Upper Coldstream Creek. Biomass assemblages from this reference site were consistently located with those from gated drainage systems. Biomass assemblages in managed sites were generally located with those from gated drainage systems and Upper Coldstream Creek, with the exception of Carrols Drain. Biomass assemblages from this managed site were mostly located with those from reference drainage systems. All twelve ordinations were good representations of the data (stress levels ranged from 0.09 to 0.14).

Nested ANOSIM revealed that, across all twelve sampling occasions, species biomass assemblages at individual sites within a treatment differed significantly more from each other than between the two (reference, gated) or three (reference, gated, managed) treatments (Table 4.5). Treatment effects were non-significant in all twelve occasions.

SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species biomass assemblages between treatments (reference vs gated), explained 72.21% to 86.85% of average dissimilarity between treatments (Table 4.6a). Nineteen species were most important in contributing to the total average dissimilarity in species biomass assemblages between treatments. *Hypseleotris compressus* was the only species that consistently contributed to these dissimilarities; its biomass was higher in gated drainage systems on eleven sampling occasions. Five commercially significant species contributed to the total average dissimilarities, namely *Acanthopagrus australis*, *Anguilla reinhardtii*, *L. argentea*, *M. macleayi* and *M. cephalus*.

SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species biomass assemblages between treatments (reference vs managed), explained 71.72% to 85.01% of average dissimilarity between treatments (Table 4.6b). Twenty-one species were most important in contributing to the total average dissimilarity in species biomass assemblages between treatments. Again, *Hypseleotris compressus* was the only species that consistently contributed to these dissimilarities; its biomass was higher in managed drainage systems on eight sampling occasions. Six commercially significant species contributed to the total average dissimilarities, namely *Acanthopagrus australis*, *Anguilla reinhardtii*, *L. argentea*, *M. macleayi*, *M. cephalus* and *Myxus petardi*.

SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species biomass assemblages between treatments (managed vs gated), explained 49.01% to 71.70% of average dissimilarity between treatments (Table 4.6c). Twenty-four species were most important in contributing to the total average dissimilarity in species biomass assemblages between treatments. Three of these (*H. compressus*, *Gobiomorphus australis* and *Philypnodon grandiceps*).

consistently contributed to these dissimilarities. Biomass of *G. australis* was higher in gated drainage systems on seven sampling occasions. In contrast, biomass of both *H. compressus* and *P. grandiceps* was higher in managed drainage systems on six sampling occasions. Four commercially significant species contributed to the total average dissimilarities, namely *A. reinhardtii*, *L. argentea*, *M. macleayi*, and *M. cephalus*.

BIOENV revealed that various combinations of 14 of the 47 water quality and habitat parameters best described the biotic patterns shown in the nMDS ordinations (Table 4.7; Figure 4.4). On nine occasions, the combination of environmental variables involved both water quality and habitat variables. The correlations between the combination of three environmental variables and the biotic patterns shown in the nMDS ordinations (Figure 4.4) ranged from 0.550 to 0.800 (Table 4.7). Nutrients contributed to the combinations of environmental variables ten times; phosphate five times, total nitrogen and total Kjeldal nitrogen three times each, and nitrite and nitrate once each. Nutrient concentrations were higher at gated drainage systems during all sampling occasions. Mangroves, and grasses and rushes contributed to the combinations of environmental variables five and six times, respectively. Mangroves were more abundant at reference sites, while grasses and rushes were more abundant at gated sites. Only once did an acid sulfate soil discharge by-product (dissolved iron) contribute to these combinations of environmental variables.

Table 4.4. BIOENV results showing sets of three environmental variables that best describe the biotic patterns shown in the nMDS ordinations of species assemblages (based on abundance data) (Figure 4.3) for the twelve sampling occasions in the lower Clarence river floodplain. ** indicates that the environmental variable was more common or present at higher concentrations at reference sites. The correlation coefficient (Spearman), based on the similarity matrices of both the biotic and abiotic data, is given for each sampling occasion.

	2000			2001						2002		
	July	Sept	Nov	Jan	April	May	July	Sept	Nov	Jan	March	May
Correlation coefficient	0.876	0.723	0.804	0.715	0.633	0.603	0.623	0.698	0.743	0.602	0.754	0.737
Total phosphorous	*											
Phosphate	*	*				*	*					
Total nitrogen	*		*							*	*	
Total Kjeldahl nitrogen										*	*	
Nitrite				*	*				*			
Dissolved aluminium								*				
Cobble			*									
Seagrass				**		**	**	**				
Grasses and Rushes		*	*		*							*
Mangroves		**				**		**	**			
Small woody debris												**
Undercut bank									*			
Exposed rootmasses				**						**	**	
Cattle grazing					*							*

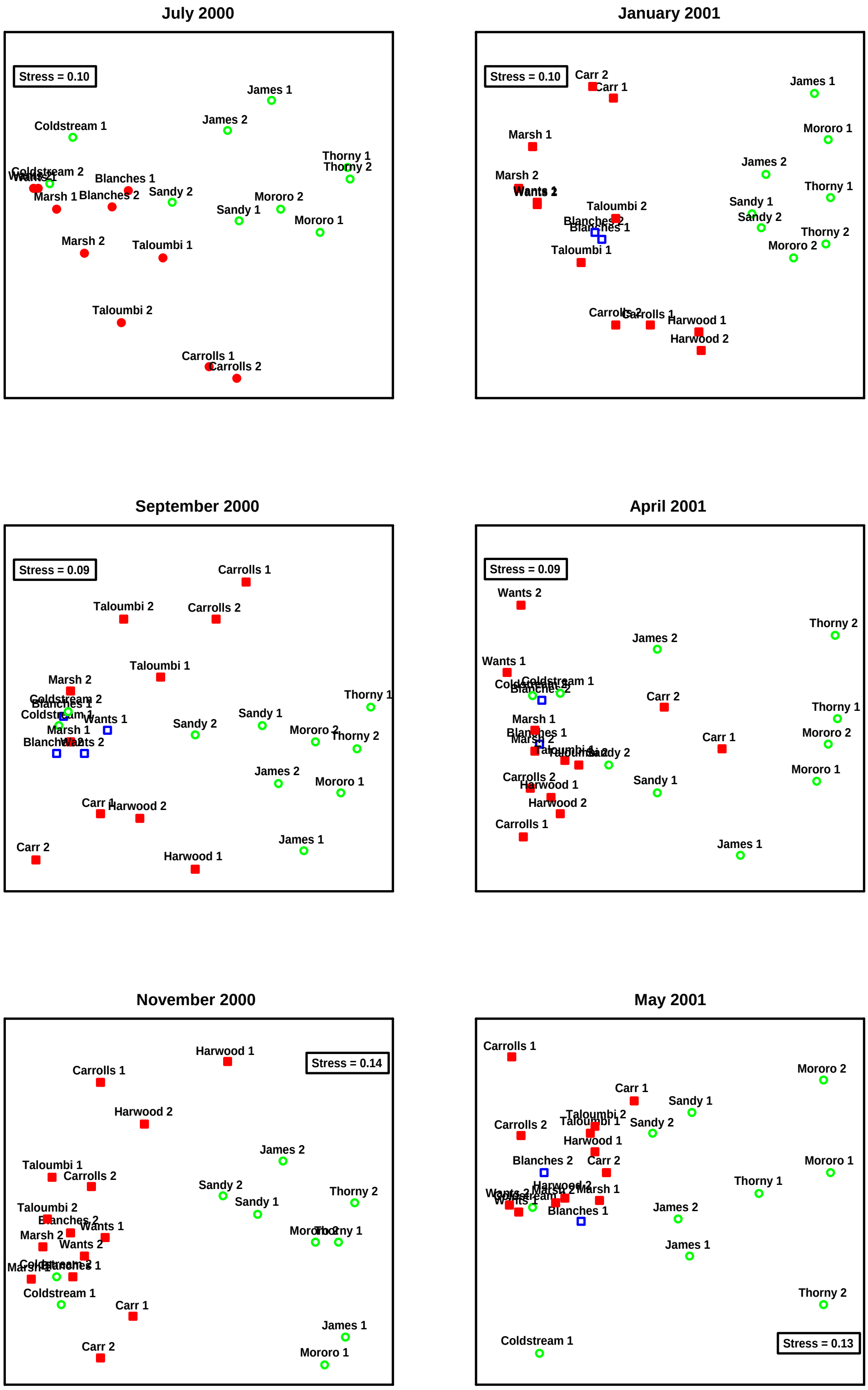


Figure 4.4. Clarence river. Non-metric multidimensional scaling (nMDS) ordinations of species biomass on each of the 12 sampling occasions in the Clarence river floodplain. The ordinations are based on log (x+1) transformed abundances and Bray-Curtis similarities. Green open circles are reference systems, red solid squares are gated drainage systems, and blue open squares are managed gated systems.

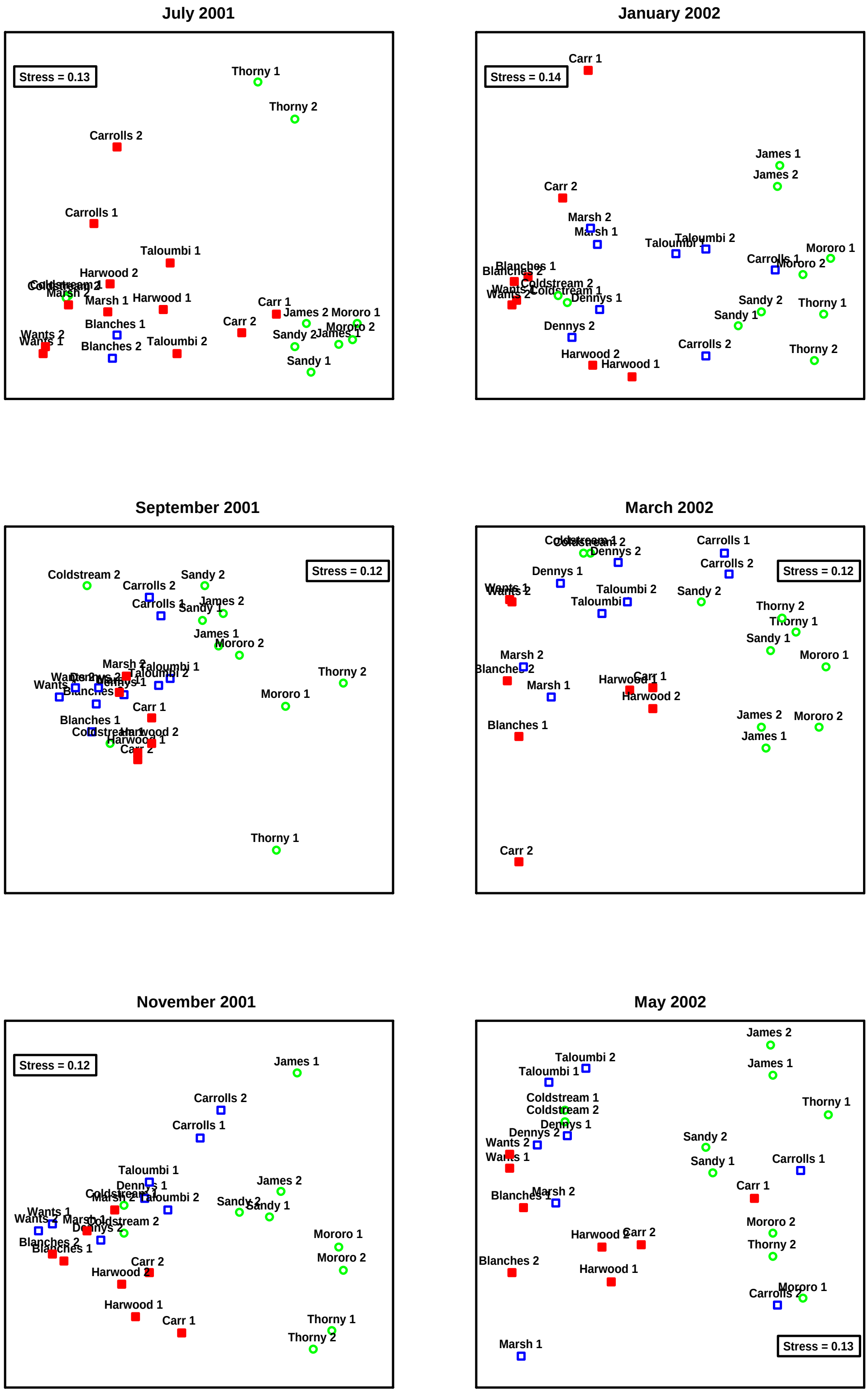


Figure 4.4. continued.

Table 4.5. Summary of two-way nested ANOSIM tests examining differences in species assemblages (based on biomass data) between treatments (July and November, reference vs gated; all other months, reference vs managed vs gated drainage systems) for the twelve sampling occasions in the lower Clarence river floodplain. Significance levels in red are $p<0.05$.

Year	Month	Source of variation	Permutations	Global R	Significance level
2000	July	Treatment	126	-0.228	0.94
		Site (Treatment)	999	0.885	0.001
	September	Treatment	999	-0.171	0.91
		Site (Treatment)	999	0.879	0.001
	November	Treatment	792	0.088	0.23
		Site (Treatment)	999	0.783	0.001
2001	January	Treatment	999	0.153	0.20
		Site (Treatment)	999	0.751	0.001
	April	Treatment	999	-0.19	0.92
		Site (Treatment)	999	0.815	0.001
	May	Treatment	999	-0.043	0.62
		Site (Treatment)	999	0.722	0.001
	July	Treatment	999	-0.191	0.92
		Site (Treatment)	999	0.857	0.001
	September	Treatment	999	-0.148	0.90
		Site (Treatment)	999	0.688	0.001
	November	Treatment	999	-0.074	0.71
		Site (Treatment)	999	0.867	0.001
2002	January	Treatment	999	-0.093	0.76
		Site (Treatment)	999	0.982	0.001
	March	Treatment	999	-0.059	0.69
		Site (Treatment)	999	0.809	0.001
	May	Treatment	999	-0.174	0.93
		Site (Treatment)	999	0.822	0.001

Table 4.6. SIMPER results showing the species ranked in decreasing order of importance (1-10 only) that contributed to the total average dissimilarity in species assemblages (based on biomass data) between treatments for the twelve sampling occasions in the lower Clarence river floodplain; (a) reference vs gated, (b) reference vs managed, and (c) managed vs gated. Percentages of average dissimilarity between treatments, and percentages of cumulative contribution by first ten species to dissimilarity are given. Numbers in bold indicate species that were more abundant in reference (a and b) or managed (c) sites; names in red indicate species significant for commercial and/or recreational fisheries.

a) Reference vs Gated

Species Name	2000			2001						2002		
	July	Sept	Nov	Jan	April	May	July	Sept	Nov	Jan	March	May
Average dissimilarity	81.31%	76.40%	81.67%	86.85%	75.86%	76.28%	72.21%	73.14%	75.14%	84.09%	83.50%	78.98%
Acanthopagrus australis		6		**8**				**7**				
Acetes sibogae australis	**2**	**5**				**6**	**1**	**2**	**2**	**5**	**9**	**7**
Ambassis jacksoniensis			**10**	**9**	**4**	**9**			**8**	**9**		
Ambassis marianus				**3**	**8**	**5**				**2**	**2**	
Anguilla reinhardtii	8									4	7	
Gambusia holbrooki		9	9	7	1	2	5	6			6	6
Gerres subfasciatus			**5**					**8**	**6**		**8**	**8**
Gobiomorphus australis	**6**	**10**	6		**9**	3	2	3	5	3	**3**	5
Hypseleotris compressus	1	1	1	2	2	**1**	3	1	1	1	1	1
Hypseleotris galii					**7**		7					
Liza argentea		**7**	**3**	**1**	**3**	**10**			**3**	**6**	**4**	**10**
Metapenaeus macleayi	**4**	**2**	**4**		**5**	**4**	**4**	**4**	**4**	**8**	**5**	**2**
Mugil cephalus				10		8	**10**		**10**			
Palaemon debilis	**5**	**3**	8	**5**			**9**	5	7	7	**10**	**4**
Philypnodon grandiceps	3	4	2	4	**6**	7	6		9			**9**
Philypnodon sp1	10											
Pseudogobius olorum	**9**	**8**	7	6			8	**9**		10		3
Pseudomugil signifer					**10**			**10**				
Tetractenos glaber	**7**											
Cumulative contribution	65.22%	59.33%	55.18%	62.19%	62.26%	62.82%	66.78%	65.28%	61.76%	60.73%	59.25%	56.66%

b) Reference vs Managed

Species Name	2000			2001						2002		
	July	Sept	Nov	Jan	April	May	July	Sept	Nov	Jan	March	May
Average dissimilarity	n/a	75.74%	n/a	85.01%	72.66%	78.69%	72.94%	76.82%	71.72%	73.14%	73.39%	77.36%
Acanthopagrus australis				**8**				**6**		8	8	**10**
Acetes sibogae australis		**4**				**6**	**1**	**3**	**2**	**3**	**9**	**7**
Ambassis agassizii					2	8						
Ambassis jacksoniensis				**9**	**5**					7		**5**
Ambassis marianus				**4**	**8**	**5**			**10**	**2**	**3**	
Anguilla reinhardtii						1						
Carassius auratus						2						
Corixidae spp.						10	2					
Gambusia holbrooki		10		5	1	4	7				10	
Gerres subfasciatus								**7**	**8**		**7**	**8**
Gobiomorphus australis		5			**10**	3	**5**	2	6	**6**	**5**	**9**
Hypseleotris compressus		1		1	**3**	**7**	3	1	1	1	1	1
Hypseleotris galii		6			**7**		9					
Liza argentea		**9**		**2**	**4**				**4**	5	**2**	**6**
Melanotaenia duboulayi					9							
Metapenaeus macleayi		**2**			**6**	**9**	**6**	**4**	**5**		6	**2**
Mugil cephalus				7			**4**		7			
Myxus petardi								**10**				
Palaemon debilis		**3**		**6**				**9**	**9**	**9**		**4**
Philypnodon grandiceps		7		3			**8**	5	3	4	4	**3**
Pseudogobius olorum		**8**		**10**			**10**	8		10		
Cumulative contribution	n/a	65.69%	n/a	71.19%	76.59%	68.36%	77.78%	64.23%	61.69%	60.27%	60.36%	54.44%

c) Managed vs Gated

Species Name	2000			2001						2002		
	July	Sept	Nov	Jan	April	May	July	Sept	Nov	Jan	March	May
Average dissimilarity	n/a	57.27%	n/a	51.58%	51.77%	56.65%	54.15%	49.01%	53.76%	71.70%	65.85%	69.27%
Afurcagobious tamarensis											**9**	
Ambassis agassizii				**7**	**1**	**7**		**10**				
Ambassis jacksoniensis										**9**		**8**
Ambassis marianus				**9**					**10**	**7**	**8**	
Anguilla reinhardtii						**1**			7	4	6	**6**
Carassius auratus						**2**						
Corixidae spp.						**8**	**2**					
Diplonychus spp.					10							
Gambusia holbrooki		6		**4**	2	4	6	6			4	5
Gobiomorphus australis		**2**		5	7	**10**	8	**4**	8	5	3	4
Gobiopterus semivestitus		10						8				
Hypseleotris compressus		**1**		**3**	3	**3**	7	**5**	5	3	**2**	**1**
Hypseleotris galii		**4**			9		9	**9**				10
Liza argentea										**6**		
Macrobrachium cf novaehollandiae				10								
Melanotaenia duboulayi					**4**							
Metapenaeus macleayi		7		**8**	8	5	3	1	**4**		**5**	**9**
Mugil cephalus		9		1		9	**1**		**2**			
Palaemon debilis								2	6	8	10	3
Philypnodon grandiceps		3		2	6	**6**	4	**3**	**1**	**2**	**1**	**7**
Philypnodon sp1		5					10					
Pseudogobius olorum				6					**9**	**10**	**7**	2
Pseudomugil signifer					5							
Cumulative contribution	n/a	72.05%	n/a	70.29%	70.61%	77.40%	76.19%	66.35%	60.07%	65.43%	65.75%	61.06%

Table 4.7. BIOENV results showing sets of three environmental variables that best describe the biotic patterns shown in the nMDS ordinations of species assemblages (based on biomass data) (Figure 4.4) for the twelve sampling occasions in the lower Clarence river floodplain. ** indicates that the environmental variable was more common or present at higher concentrations at reference sites. The correlation coefficient (Spearman), based on the similarity matrices of both the biotic and abiotic data, is given for each sampling occasion.

	2000			**2001**						**2002**		
	July	**Sept**	**Nov**	**Jan**	**April**	**May**	**July**	**Sept**	**Nov**	**Jan**	**March**	**May**
Correlation coefficient	0.800	0.758	0.759	0.731	0.664	0.550	0.644	0.713	0.724	0.622	0.692	0.699
Phosphate	*	*		*			*		*			
Total nitrogen	*		*								*	
Total Kjeldahl nitrogen				*				*			*	
Nitrate						*						
Nitrite					*							
Dissolved iron	*											
Seagrass							**	**				
Grasses and Rushes		*	*		*			*		*		*
Mangroves		**				**			**	**	**	
Filamentous algae			*							*		
Small woody debris												**
Undercut bank						*			*			
Exposed rootmasses				**	**							
Cattle grazing												*

4.3.5. Relationship between floodgate opening and species richness and diversity

4.3.5.1. Species richness

Species richness in the four managed gated sites, where floodgates were actively opened at least once during our project (i.e. Blanches Drain, Carrols Drain, Taloumbi #5 and Wants Drain; Table 4.1), ranged from 2.5 to 25.5 species for mean number of species, and from 0.0 to 5.0 for mean number of commercial species. In these four systems, species richness did not increase with an increase in total opening time of floodgates (Figure 4.5a, b; Table 4.8a, b). In contrast, both mean number of species and mean number of commercial species increased significantly with an increase in opening frequency of floodgates (Figure 4.5c, d; Table 4.8c, d).

4.3.5.2. Species diversity

Species diversity in the four managed gated sites, ranged from 0.402 to 3,289 for abundance, and from 0.442 to 2.949 for biomass. Species diversity (abundance) did not increase with an increase in total opening time of floodgates (Figure 4.6a; Table 4.9a). While species diversity (biomass) tended to increase with an increase in total opening time of floodgates (Figure 4.6b; Table 4.9b), the variance in species diversity (biomass) explained by total opening time was small (R^2=0.08). In contrast, species diversity for both abundance and biomass increased significantly with an increase in opening frequency of floodgates (Figure 4.6c, d; Table 4.9c, d).

4.3.6. Effect of two different gate structures on fish passage

The vertical liftgates on Marsh Drain were opened on a regular and frequent basis (Table 4.1e), which resulted in improved water quality (Appendix 3; BSES, unpublished data) but not in improved fish passage (Figure 4.3, 4.4; Appendix 1, 2).

The mini-sluice gate on Dennys Gully was opened almost permanently, which resulted in improved water quality (Appendix 3) but not in improved fish passage (Figure 4.3, 4.4; Appendix 1, 2). Comparisons between catches immediately downstream (Figure 4.7a, b) and upstream (Figure 4.7c) from the floodgates in March 2002 revealed that species assemblages were very different, with large numbers of southern herring (*Herklotsichthys castelnaui*, n=1,046) and flat-tail mullet (*Liza argentea*; n=54) present below, but completely absent above the floodgates. Similar results were obtained in May 2002, when one floodgate had been completely open for two weeks.

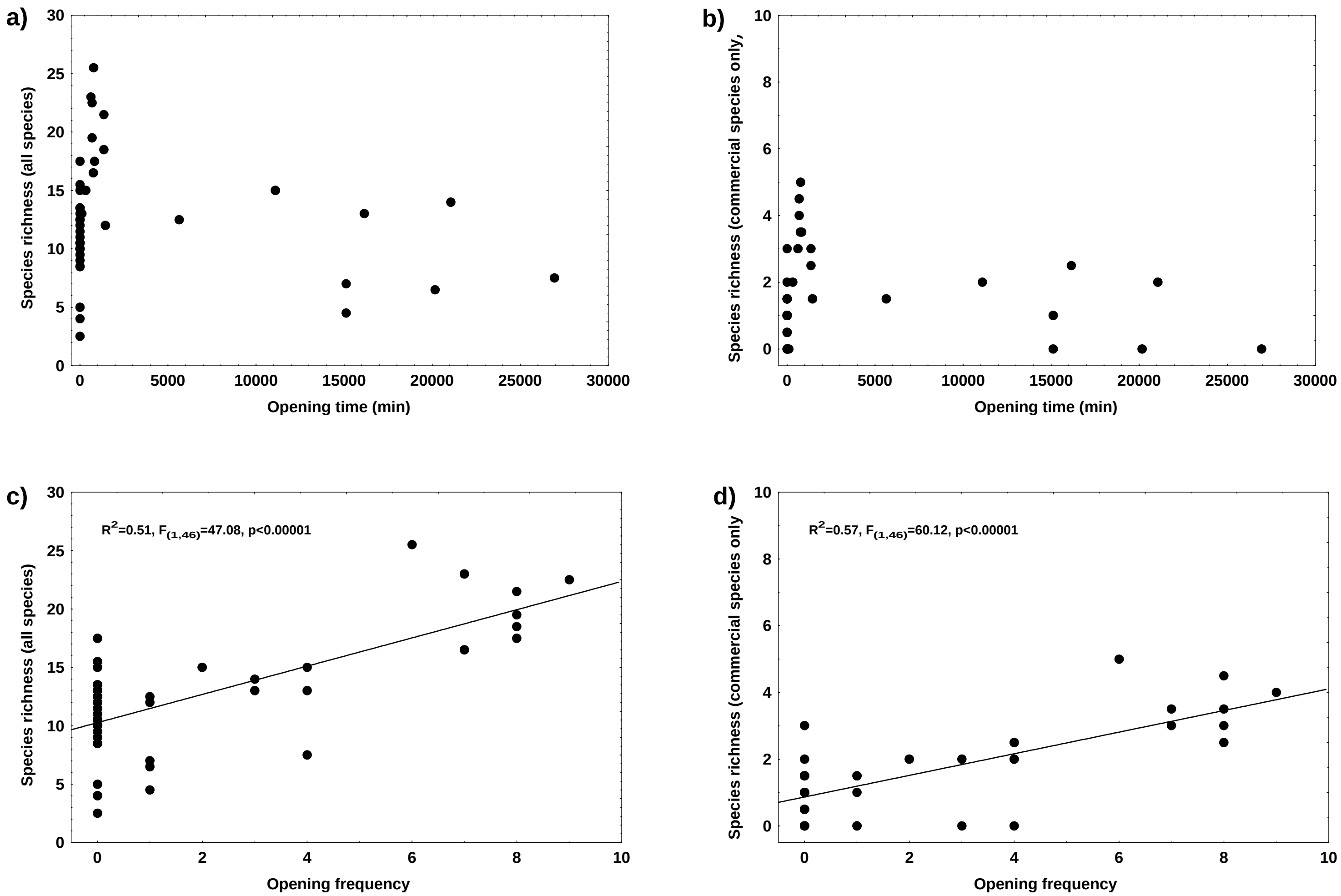


Figure 4.5. Species richness (mean number of species, mean number of commercial species) in four managed gated sites of which floodgates were actively opened at least once during our project (i.e. Blanches Drain, Carrols Drain, Taloumbi #5 and Wants Drain; Table 4.1), against (a, b) total opening time of floodgates, and (c, d) frequency of floodgate openings.

Table 4.8. Results of multiple regression analyses, examining relationships between mean species richness (all species, or commercial species only) and floodgate opening regimes (time or frequency) (Figure 11.5). Bold numbers indicate a significant effect of opening regime.

a) Species richness $F_{(1,46)}$=2.23, R^2=0.05, p<0.14

Variable	β	S.E. of β	t(46)	P
Intercept			16.84	**<0.00001**
Time (min)	-0.22	0.14	-1.49	0.14

b) Species richness (commercials only) $F_{(1,46)}$=0.70, R^2=0.02, p<0.41

Variable	β	S.E. of β	t(46)	P
Intercept			7.69	**<0.00001**
Time (min)	-0.12	0.15	-0.83	0.41

c) Species richness $F_{(1,46)}$=47.08, R^2=0.51, p<0.00001

Variable	β	S.E. of β	t(46)	P
Intercept			17.28	**<0.00001**
Frequency	0.71	0.10	6.86	**<0.00001**

d) Species richness (commercials only) $F_{(1,46)}$=60.12, R^2=0.57, p<0.00001

Variable	β	S.E. of β	t(46)	P
Intercept			6.15	**<0.00001**
Frequency	0.75	0.10	7.75	**<0.00001**

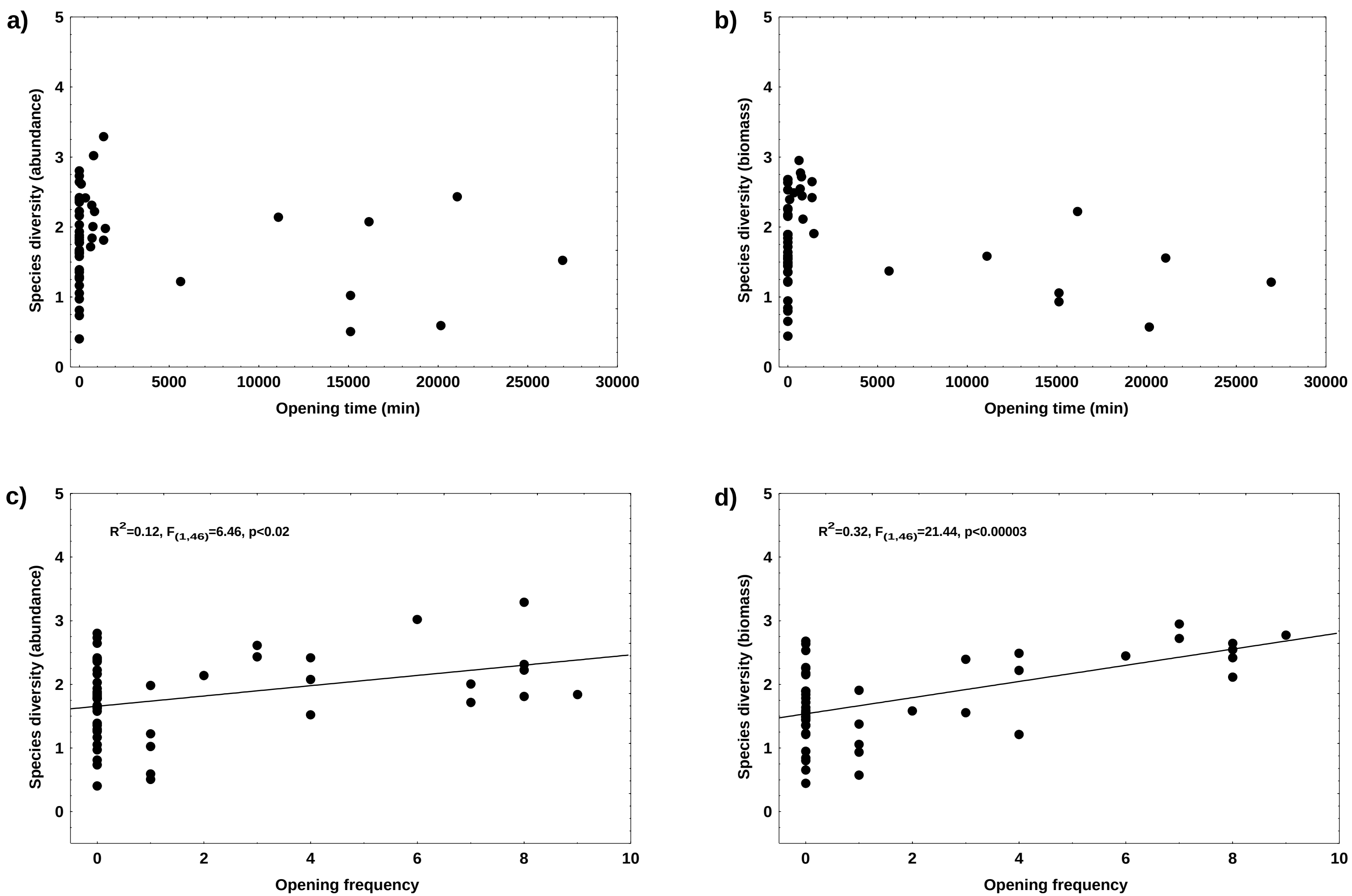


Figure 4.6. Species diversity (abundance, biomass) in four managed gated sites of which floodgates were actively opened at least once during our project (i.e. Blanches Drain, Carrols Drain, Taloumbi #5 and Wants Drain; Table 4.1), against (a, b) total opening time of floodgates, and (c, d) frequency of floodgate openings.

Table 4.9. Results of multiple regression analyses, examining relationships between mean species diversity (abundance or biomass) and floodgate opening regimes (time or frequency) (Figure 11.6). Bold numbers indicate a significant effect of opening regime.

a) Species diversity (abundance) $F_{(1,46)}$=1.87, R^2=0.04, p<0.18

Variable	β	S.E. of β	t(46)	P
Intercept			17.85	**<0.00001**
Time (min)	-0.20	0.14	-1.37	0.18

b) Species diversity (biomass) $F_{(1,46)}$=4.06, R^2=0.08, p<0.05

Variable	β	S.E. of β	t(46)	P
Intercept			18.52	**<0.00001**
Time (min)	-0.28	0.14	-2.01	0.05

c) Species diversity (abundance) $F_{(1,46)}$=6.46, R^2=0.12, p<0.02

Variable	β	S.E. of β	t(46)	P
Intercept			15.45	**<0.00001**
Frequency	0.35	0.14	2.54	**<0.02**

d) Species diversity (biomass) $F_{(1,46)}$=21.44, R^2=0.32, p<0.00003

Variable	β	S.E. of β	t(46)	P
Intercept			16.60	**<0.00001**
Frequency	0.56	0.12	4.63	**<0.00003**

a.

b

c.

Figure 4.7. Downstream samples were hauled immediately below the mini-sluice gate at Dennys Gully in March 2002 (a). Examples of the samples collected at this site are shown for above (b) and below (c) the floodgate.

4.3.7. *Water quality and ANZECC guidelines*

Various water quality parameters measured in reference, gated, and managed drainage systems from July 2000 to May 2002 did not conform to ANZECC guidelines (2000) (Table 4.10).

4.3.7.1. Chemical stressors

Chemical stressors, including $pH_{(s)}$, $pH_{(b)}$, total phosphorus, phosphate, total nitrogen, turbidity, $DO_{(s)}$ and $DO_{(b)}$, were often outside the range of trigger values for lowland rivers and streams in south-east Australia (including NSW and south-east Queensland) for slightly disturbed ecosystems (ANZECC, 2000) (Table 4.10a).

Values for $pH_{(s)}$ and $pH_{(b)}$ were outside the recommended range of 6.5 – 8.0 a total of 97 (33%) out of 292 times (Table 4.10a). However, the frequency that pH values did not conform to ANZECC guidelines in reference, gated, or managed systems did not differ significantly for either surface or bottom readings.

Total phosphorus concentrations were above the recommended value of 0.05 mg P/L 52 (36%) out of 146 times (Table 4.10a). The frequency that total phosphorus concentrations did not conform to ANZECC guidelines was significantly higher in gated than in reference systems (χ^2=36.86, df=1, p<0.00001), and in managed than in reference systems (χ^2=10.49, df=1, p=0.001). In contrast, the frequency that total phosphorus concentrations did not conform to ANZECC guidelines was significantly lower in managed than in gated systems (χ^2=4.55, df=1, p=0.03).

Phosphate concentrations were above the recommended value of 0.02mg P/L 35 (24%) out 146 times (Table 4.10a). The frequency that phosphate concentrations did not conform to ANZECC guidelines was significantly higher in gated than in reference systems (χ^2=27.95, df=1, p<0.00001), and in managed than in reference systems (χ^2=7.79, df=1, p=0.005). In contrast, the frequency that phosphate concentrations did not conform to ANZECC guidelines was significantly lower in managed than in gated systems (χ^2=4.10, df=1, p=0.04).

Total nitrogen concentrations were above the recommended value of 0.5 mg N/L 76 (52%) out of 146 times (Table 4.10a). The frequency that total nitrogen concentrations did not conform to ANZECC guidelines was significantly higher in gated than in reference systems (χ^2=33.40, df=1, p<0.00001), and in managed than in reference systems (χ^2=16.01, df=1, p=0.0001). In contrast, the frequency that total nitrogen concentrations did not conform to ANZECC guidelines was not significantly different in managed and gated systems.

Turbidity was outside recommended levels of 6-50 NTU a total of 37 (37%) out of 101 times (Table 4.10a). The frequency that turbidity did not conform to ANZECC guidelines in reference, gated or managed did not differ significantly.

Finally, concentrations of both $DO_{(s)}$ and $DO_{(b)}$ were below levels stressful to many freshwater fish (i.e. 5 mg/L) a total of 52 (23%) out of 226 times (Table 4.10a). However, the frequency that DO did not conform to ANZECC guidelines in reference, gated, or managed did not differ significantly.

4.3.7.2. Toxicants

Toxicants, including total aluminium and ammonia, were above the 95% protection level trigger values for slightly – moderately disturbed ecosystems (ANZECC, 2000) (Table 4.10b). Total aluminium concentrations were above the recommended value of 0.05 mg/L (at pH>6.5) 22 (19%) out of 114 times (Table 4.10b). The frequency with which total aluminium concentrations did not conform to ANZECC guidelines in reference vs gated systems and reference vs managed systems did not differ significantly. In contrast, the frequency with which total aluminium concentrations did not conform to ANZECC guidelines in managed systems was significantly lower than in gated systems (χ^2=4.82, df=1, p=0.03).

Ammonia concentrations were above the recommended value of 0.9 mg N/L on only 2 (1%) out of 141 times (Table 4.10b). The frequency with which ammonia concentrations did not conform to ANZECC guidelines did not differ significantly among the three treatments. Nitrite concentrations were never above the recommended value of 0.7 mg N/L (Table 4.10b).

Table 4.10. Results of $\chi 2$ tests comparing the frequencies that water quality values did not conform to ANZECC guidelines (2000) in (i) reference and gated drainage systems, (ii) reference and managed drainage systems, and (iii) gated and managed drainage systems, from July 2000 until May 2002. Given are trigger values for lowland rivers and streams for (i) physical and chemical stressors for south-east Australia (including NSW and south-east Queensland) for slightly disturbed ecosystems, and, (ii) toxicants at 95% level of protection (ANZECC, 2000). Numbers in red indicate significant differences between frequencies.

July 2000 - May 2002	Trigger values (ANZECC, 2000)	Reference drainage systems	Gated drainage systems	Managed gated drainage systems	Reference vs Gated		Reference vs Managed		Gated vs Managed	
					χ^2	p	χ^2	p	χ^2	p
a. Physical and chemical stressors										
pH $_{(s)}$					1.70	0.19	1.70	0.19	0.05	0.83
PH $_{(b)}$					0.86	0.35	0.86	0.35	0.03	0.85
Total phosphoros (mg/L P)	0.05 mg P/ L	5/59	37/60	10/27	36.86	<0.00001	10.49	0.001	4.55	0.03
Phosphate (mg/L P)	0.02 mg P/L	2/59	27/60	6/27	27.95	<0.00001	7.79	0.005	4.10	0.04
Total nitrogen (mg/L N)	0.5 mg N/L	13/59	45/60	18/27	33.40	<0.00001	16.01	0.0001	0.65	0.42
Turbidity (NTU)	6-50 NTU	13/40	13/37	11/24	0.06	0.81	1.14	0.29	0.70	0.40
DO $_{(s)}$ (mg/L)	5.0 mg/L	7/45	11/44	4/24	1.23	0.27	0.01	0.90	0.63	0.43
DO $_{(b)}$ (mg/L)	5.0 mg/L	10/45	13/44	7/24	0.62	0.43	0.41	0.52	0.00	0.97
b. Toxicants										
Total aluminium (mg/L)	0.05 mg/L (pH>6.5)	8/47	13/46	1/21	1.68	0.19	1.90	0.17	4.82	0.03
Ammonia (mg/L N)	0.9 mg N/L	0/54	1/60	1/27	0.91	0.34	2.03	0.16	0.34	0.56
Nitrate (mg/L N)	0.7 mg N/L	0/54	0/60	0/27	n/a	n/a	n/a	n/a	n/a	n/a

4.4. Discussion

The nMDSs comparisons covering more sites and a longer time frame confirmed the results presented in chapter 3. Species abundance and biomass differed consistently between the reference and gated drainage systems, except for the nominal reference site at Upper Coldstream Creek (Figure 4.3, 4.4). Species assemblages from this site were consistently located with those from gated drainage systems. This site is the furthest upsteam of all the sites (see Figure 2.1) and therefore has reduced tidal movement. It is possible that migratory species do not usually move this far up the system which would explain why this site is more similar to gated sites than to the other reference sites used. Further, this site was often partially or wholly choked with floating weed which may indicate quite different physiochemical conditions at this site (e.g. Figure 4.1).

Species assemblages in managed drainage systems were generally located with those from gated drainage systems, except for one managed site (Figure 4.3, 4.4). Species assemblages in this site (Carrols Drain) were mostly located with those from reference drainage systems. The two 'anomalous' sites (Upper Coldstream Creek and Carrols Drain) most likely contributed to our inability to detect significant differences among treatments in ANOSIM analyses (Tables 4.2, 4.5). Nevertheless, the results of SIMPER analyses showed that species assemblages in managed sites still resembled more closely those in gated sites than those in reference sites (Table 4.3, 4.6).

Whilst species assemblages did not differ significantly, an increase in opening frequency of floodgates did result in a significant increase in species richness and species diversity in managed systems (Table 4.8, 4.9; Figure 4.5, 4.6). The increase in mean number of all species and mean number of commercial species, including species such as yellowfin bream (*Acanthopagrus australis*), southern herring (*Herklotsichthys castelnaui*), sandy sprat (*Hyperlophus vittatus*), flat-tailed mullet (*Liza argenta*), sea mullet (*Mugil cephalus*), and schoolprawn (*Metapenaeus macleayi*), indicates that fish passage does improve with frequent and regular opening of floodgates. Interestingly, juveniles moved into drainage systems with open floodgates, regardless of whether the system was a modified natural creek or a man-made drain. In contrast, species richness or species diversity did not increase with increased opening times of floodgates (Table 4.8, 4.9; Figure 4.5, 4.6). This is most likely due to the fact that long opening times (i.e. days to weeks) were usually followed by long closing times (i.e. days to weeks) (Table 4.1), resulting in a sudden and sustained decrease in water quality in these drainage systems (Table 4.10; S. Johnston, NSW Agriculture, pers. comm.) and gates acting again as physical barriers to fish passage.

Fish passage did not improve in the two systems where different gate structures were tested. In Marsh Drain, this may have been due, in part, to the position of the culvert pipes relative to the bottom (see Chapter 2), as well as to the relatively small openings of the liftgates. On the other hand, we cannot explain why fish passage did not improve in Dennys Gully, even after one of the flapgates had been completely opened. Southern herring (*Herklotsichthys castelnaui*) is pelagic, and was present in large numbers immediately below the floodgates in March and May, but not upstream from the floodgates. In contrast, we caught 126 southern herring in Taloumbi #5 upstream from the floodgates in January (Appendix 1), indicating that this species does swim through large and dark structures. We hypothesise that the quality of the water discharged from Dennys Gully may play a role, but our results indicate that this would involve variables other than those measured in this study (e.g. herbicides). For example, results from work on juvenile salmon suggest that sub-lethal levels of atrazine may affect migration behaviour (Moore *et al.*, 2003). To examine whether the structure itself or other factors prevented improvements in fish passage in our study, we recommend that use of either mini-sluice gates or vertical liftgates be further assessed on other gated drainage systems.

Opening of floodgates can be an avenue to manage exotic species, such as *Gambusia holbrooki*. The results from the SIMPER analysis (Table 4.3, 4.6) indicate that opening floodgates reduces the their relative abundance and biomass in managed systems compared to gated systems. Opening floodgates may be an effective means of reducing the numbers of *G. holbrooki* and its detrimental impact on native fish fauna. This includes predation on the eggs and adults of *H. galli* and

Pseudomugil signifer (Ivantsoff and Aarn, 1999), and its impact on the breeding success of *P. signifer* (Howe *et al*., 1997).

Opening of floodgates resulted in significant improvements in water quality in managed drainage systems (BSES, unpublished data; S. Johnston, NSW Agriculture, pers. comm.), including significantly fewer occasions where concentrations of total phosphorus, phosphate and total aluminium were above ANZECC guidelines (Table 4.10). In contrast, concentrations of total nitrogen in managed and gated systems did not differ, and were significantly more often above ANZECC guidelines than those in reference systems (Table 4.10). Moreover, concentrations of total phosphorus, phosphate and total nitrogen in managed systems did not decrease to levels encountered in reference systems (Table 4.10). This is of particular concern, given that the BIOENV analyses (Table 4.4, and 4.7) indicate that nutrients are the water quality component most frequently associated with the differences between species assemblages present in gated and reference drainage systems. The lack of a large enough decrease in nutrient concentrations in managed sites may thus be one of the reasons why species assemblages in most managed sites did not come to resemble those in reference sites (Figure 4.3, 4.4). In addition to opening floodgates to improve water quality, we recommend that best land management practices should be implemented to reduce nutrient input, including a reduction and/or more efficient use of fertilizers, fencing off watercourses and rehabilitation of riparian vegetation.

Opening of floodgates also resulted in significant improvements in habitat quality in managed drainage systems, including the disappearance of waterlillies, grasses and rushes due to tidal influx. The results of the BIOENV analyses (Table 4.4, 4.7) indicate that grasses and rushes are a significant habitat quality component, frequently associated with the differences between species assemblages present in gated and reference drainage systems. Consequently, the elimination of grasses and rushes as a result of floodgate opening would likely result in more ‘natural’ assemblages of fish. For example, these plants may limit the spawning substrate available for species such as *Hypseleotris compressus*, *Philypnodon grandiceps*, *P. sp.*, and *Gobiomorphus australis* (Larson and Hoese, 1996), thereby preventing them from completing their life cycles within drainage systems. Additional habitat quality components will need to be addressed, however, if more natural assemblages of fish are to be restored. This would be particularly important if managed drainage systems themselves are going to provide a role as fish habitat. The restoration of mangroves and seagrass would be a good first step.

In general, improvements in fish passage and water quality quickly disappeared when floodgates were not opened for prolonged periods of time (Table 4.8, Figure 4.5; S. Johnston, NSW Agriculture, pers. comm.). This often occurred because landholders managing floodgates were not always present or had the time to open and/or close floodgates. Juveniles that recruited into managed drainage systems disappeared from these systems when the floodgates were closed again. It is not known whether this is due to migration out of the drainage system or to mortality related to a sudden decrease in water quality. If the latter is the case, the hoped for remedy could make matters even worse and valuable recruits would be lost to the fisheries. Hence, management of floodgates should be maintained once it has commenced. A further example of changed opening regimes providing initial benefits but then suffering from a failure to maintain that new opening regime is given in Appendix 4 for a floodgate on the Macleay river.

In addition, opening floodgates always carries the risk of overtopping adjacent land with saline water. This is a real and serious risk to the landholder, given that tidal heights are not always predicted accurately and are affected by local weather conditions. An additional problem with vertical lift gates is that they are difficult to open and close during strong currents (V. Castle, Clarence river canegrower, pers. comm.). This means that landholders may not always be able to close these types of gates when required, again increasing the risk of saline overtopping. To improve and maintain fish passage as well as to minimise the risk of saline overtopping, installation of automated systems, as opposed to floodgates that need to be managed manually by winches, is highly desirable (see Appendix 5 for a preliminary assessment of automated floodgates).

5. TEMPORAL PATTERNS OF RECRUITMENT TO THE CLARENCE RIVER FLOODPLAIN BY COMMERCIALLY SIGNIFICANT FISH AND PRAWN SPECIES

[With special input from Bruce Pease]

5.1. Introduction

Many of the commercially significant species of coastal fish and prawns in south-eastern Australia spawn in the ocean but use estuaries as nursery grounds during their early life history stages (Dunstan, 1968; Pollard, 1976; Pease *et al*., 1981a; Bell and Pollard, 1989; West and King, 1996; Hannan and Williams, 1998). Most of these species enter the estuary as post-larvae and each species generally recruits to estuarine habitats at a specific time of the year. Pease *et al*. (1981a) and Hannon and Williams (1998) both found two seasonal peaks in the recruitment of commercially significant fish species to estuarine habitats, with one in spring and the other in autumn.

Closed floodgates form an obvious barrier to recruitment of estuarine fish. Acid sulfate soil discharge may create areas or pockets of water within coastal floodplains that are toxic to some aquatic species or simply avoided by others. If the area of poor water quality is large enough to span the entire channel of the estuary or a tributary it may also form a barrier to fish movement. The barrier will be relatively larger and possibly more toxic to smaller, early life history stages of fish and invertebrates recruiting to the estuary. The timing of floodgate closures and acid sulfate soil discharge events can have serious implications for recruitment of commercial fish and invertebrates to habitats upstream of these barriers. In this chapter our objectives were to (a) describe and summarise the temporal recruitment patterns of commercially significant species sampled during this study and (b) compare the recruitment data from this study with information in the literature to determine whether there are particular times or seasons when barriers to recruitment will have the greatest impact on commercially significant species in the Clarence River floodplain.

5.2. Methods

A detailed description of the Clarence River sampling sites and methods is given in Chapter 2. All individuals of each commercially and recreationally significant species that were captured during the study (Appendix 1) were weighed and measured. Standard length (SL), of all fish was measured to the nearest millimeter from the tip of the snout to the posterior edge of the caudal peduncle. Carapace length (CL) of all prawns and crabs was measured to the nearest millimeter from the posterior edge of the orbit to the posterior edge of the carapace.

We combined size frequency data from all control sites in the Clarence River for each sample month. Length frequency histograms were constructed for each of the commercially significant species. There were sufficient size frequency data for sandy sprat (*Hyperlophus vittatus*), silver biddy (*Gerres subfasciatus*), yellowfin bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*), flat-tail mullet (*Liza argentea*), sea mullet (*Mugil cephalus*), school prawn (*Metapenaeus macleayi*) and eastern king prawn (*Penaeus plebejus*) to provide an indication of the temporal recruitment patterns of these species in the Clarence River floodplain during the study period. Larval fish and prawns were generally not captured by the nets used during this study, therefore fish of these species that were less than 25 mm SL (Pease *et al.*, 1981a; Pease *et al.*, 1981b; Hannan and Williams, 1997) and prawns that were less than 4 mm CL (Young and Carpenter, 1977; Coles and Greenwood, 1983) were defined as “small juveniles”. The presence of the smallest individuals in these size classes indicated the timing of initial recruitment of young-of-the-year and the peak monthly abundances of small juveniles indicated the primary recruitment period.

The primary recruitment periods (months) for the commercially significant species from this study were then compared with available published and unpublished sources of recruitment data for these species. Seasons of peak recruitment were then identified where peak abundances of small juveniles occurred in the majority of data sets. Seasons rather than months were identified because samples from most sources were collected bimonthly or quarterly. Seasonal summaries also absorb the expected high levels of inter-annual and spatial variability in annual fish recruitment.

5.3. Results and Discussion

5.3.1. Sandy Sprat

Small juvenile sandy sprat recruited to the sample sites from November through April in 2001 (Figure 5.1). Insufficient numbers were caught in 2002 to indicate recruitment patterns. It appears that the initial recruitment of sandy sprat to the Clarence River floodplain occurred in November during this study.

The sandy sprat is a temperate fish species endemic to the southern waters of Australia from Kalbarri (WA) to Moreton Bay (QLD), excluding Tasmania (Neira *et al*., 1998). Spawning of sandy sprats is believed to occur in inshore marine waters throughout the year, with a peak in spawning activity in late autumn to early spring (Neira *et al.*, 1998; Kailola *et al.*, 1993). Larvae have been caught in coastal waters off Sydney throughout the year (Gray *et al*., 1992; Gray, 1993). Larvae have been found in Lake Macquarie from September to July (Miskiewicz, 1987) and in Tuggerah lakes from October to May (Marsden, 1986). Juveniles occur in a wide range of shallow estuarine habitats (Pease *et al*., 1981a) while adults occur predominantly in inshore coastal waters (Kailola *et al.*, 1993). Small juveniles have been found in Botany Bay from June through October (personal communication from Bruce Pease on data collected during the study by Pease *et al*., 1981) and in the Clarence River estuary in September (personal communication from Trudy Walford on data collected during the study by West and King, 1996). Therefore, it appears that small juveniles may recruit to estuaries in NSW throughout the year, but spring is the only season that recruitment of small juveniles has been reported in all studies.

5.3.2. Silver Biddy

Small juvenile silver biddies recruited to the sample sites initially in January during both years. Recruitment occurred from January through April during 2000 and from January through May during 2001 (Figure 5.2). Therefore, the initial recruitment of silver biddies to the Clarence River floodplain occurred in January and extended through May during this study.

The silver biddy is a tropical fish species endemic to northern Australia, where it occurs from Albany (WA) to Wollongong (NSW) (Neira *et al*., 1998). Silver biddies are believed to spawn in estuaries (Pease *et al*., 1981; Hannan and Williams, 1998;) where they remain throughout their lives. Based on seasonal peaks in the abundance of reproductively ripe adults (Pease *et al*., 1981) and larvae (Marsden, 1986; Miskiewicz, 1987), most spawning activity occurs during the summer. Small juveniles recruit to shallow vegetated (mangrove and seagrass) habitats (Pease *et al*., 1981b; Hannan and Williams, 1998), while larger juveniles and adults disperse to a wide range of shallow and deep estuarine habitats (Pease *et al.*, 1981b). Small juveniles have been found in Botany Bay from February through June (Pease *et al*., 1981b), in the Clarence River estuary from December through August (personal communication from Trudy Walford on data collected during the study by West and King, 1996) and from Lake Macquarie primarily during the period from April through

June (Hannan and Williams, 1998). Therefore, small juveniles recruited to the estuaries of NSW in summer and autumn during all studies except that of Hannan and Williams (1998), when they recruited in autumn and winter.

5.3.3. Yellowfin Bream

Initial recruitment of fish less than 20 mm SL occurred in July during both study years (Figure 5.3). Small juveniles were found from July through November, with a progressive increase in the size of each year-class through May to a size of 40 to 70 mm SL. The lack of fish greater than 70 mm SL indicates that one year-old fish generally leave the sampled habitats between May and July, when the next year-class arrives.

Yellowfin bream are endemic to Australia, and inhabit coastal and estuarine waters from Townsville (Qld) to the Gippsland Lakes (Vic) (Rowland, 1984). It is believed that yellowfin bream spawn in the surf zone of inshore coastal waters near the mouths of estuaries and rivers over a protracted period of time, with peak spawning activity in NSW and SE Queensland in late autumn and winter (Munro 1944; Roughley, 1964; Pollack, 1982; Neira *et al.,* 1998). Larvae recruit to estuaries from ocean waters over a protracted period (Marsden, 1986; Miskiewicz, 1986; Miskiewicz, 1987; Gray *et al.,* 1992; Gray, 1993) and are found in coastal waters almost all year round. Within the estuary, competent post-larvae approximately 13-14 mm TL (Pollock *et al.*, 1983) recruit to vegetated habitats, primarily mangroves and *Zostera* seagrass beds (Blaber and Blaber, 1980; Pease *et al.*, 1981b; Pollack *et al.,* 1983; West and King, 1996). In Botany Bay, Pease *et al*., (1981) found that recruitment to these habitats by small juveniles <25 mm FL (fork length) peaked from April through June. Hannan and Williams (1998) found recruitment by small juveniles peaked from June through August. West and King (1996) found the highest abundance of juveniles (unspecified size) in the Clarence River in September. In Moreton Bay, Pollock *et al.* (1983) found that juveniles (<40 mm FL) were most abundant in these habitats in October and November. It appears that small juvenile yellowfin bream recruit to the estuaries of NSW and southern Queensland primarily in winter and spring, with limited recruitment throughout the year in some locations.

The studies in Botany Bay by Pease *et al*. (1981b) also sampled a wide range of size classes from a wide range of shallow and deep unvegetated habitats. They found that yellowfin bream larger than 65 mm FL generally moved out of the shallow vegetated habitats and into a wide range of other shallow and deep habitats throughout the estuary. Adults are found in a wide range of salinities, from almost fresh to marine waters. Thus it is believed that the disappearance of juveniles larger than 70 mm SL in our study was related to this dispersal of larger juveniles to other habitats in the Clarence River floodplain.

5.3.4. Tarwhine

Initial recruitment of fish less than 20 mm SL occurred in July during both study years (Figure 5.4). Small juveniles were found from July through November then each year-class appeared to leave the sampled habitats after November.

The tarwhine is a tropical fish species that is found throughout the Indo-west Pacific region from east Africa to Japan (Neira *et al*., 1998). In eastern Australia it occurs from Townsville, (Qld) south to Gippsland Lakes (VIC). It is believed that tarwhine spawn in inshore coastal waters (Pease *et al*., 1981b; Hannan and Williams, 1998). Larvae have been found in the coastal and estuarine waters of NSW from April to December (Marsden, 1986; Miskiewicz, 1986; Miskiewicz, 1987; Gray *et al.,* 1992; Neira *et al*., 1998), indicating that spawning occurs during that period. Juveniles live in estuaries and adults live in inshore coastal waters (Pease *et al*., 1981b; Radebe *et al*., 2002). Small juveniles recruit almost exclusively to *Zostera* seagrass beds, while juveniles > 25 mm TL move to deeper unvegetated estuarine habitats (Pease *et al.*, 1981b; Hannon and Williams, 1998). Small juveniles have been found in Botany Bay from August through December (Pease *et al*., 1981b), in the Clarence River in August and September (personal communication from Trudy Walford on data collected during the study by West and King, 1996) and in Lake Macquarie from June through December (Hannan and Williams, 1998). Therefore, it appears that small juvenile tarwhine recruit to estuarine habitats in NSW primarily in the winter and spring.

5.3.5. Flat-tail Mullet

Small juvenile flat-tail mullet recruited to the sample sites from July through November during both years (Figure 5.5). The recruiting year-class remained at the sample sites through May, growing throughout the year. Larger juveniles, which were probably from the previous year-class, were also relatively abundant in July, March and April.

Flat-tail mullet are endemic to the southern and eastern waters of Australia, where they occur from Fremantle (WA) to Cooktown (QLD) (Thomson, 1996). They are believed to spawn in inshore coastal waters, near the mouths of estuaries in the autumn (Pease *et al*., 1981b). Small juveniles recruit to mangrove habitats in estuaries (Pease *et al*., 1981b) then large juveniles move to upper estuarine and freshwater habitats (Thomson, 1996). Adults are found in a wide range of shallow estuarine and inshore coastal habitats. Small juveniles have been found in Botany Bay all year around, with peak abundances in the mangrove habitat from June through December (Pease *et al*., 1981b). Small juveniles have also been found in the Clarence River from July through December (personal communication from Trudy Walford on data collected during the study by West and King, 1996). Therefore, it appears that the recruitment of small juvenile flat-tail mullet into the estuaries of NSW occurs primarily in the winter and spring. Low abundances of large juveniles in our samples from September through January may be the result of subsequent movement to upper estuarine and freshwater habitats.

5.3.6. Sea Mullet

Small juvenile sea mullet recruited to the sample sites from July through November during both years (Figure 5.6). No sea mullet were sampled from January through May.

Sea mullet inhabit coastal waters and estuaries in tropical and warm temperate waters of all seas around the world between the latitudes of 40^{o}N and 40^{o}S (Thomson, 1996). Spawning takes place at sea, and in NSW this probably takes place in winter (Thomson, 1996). Small juveniles enter the estuaries and make their way to upper estuarine and freshwater habitats. After spending approximately three years in these habitats, reproductively mature fish congregate in large schools in the estuaries in autumn before migrating out to the oceanic spawning grounds. Small juveniles have been found in mangrove and *Zostera* seagrass habitats in Botany Bay from June through October (Pease *et al*., 1981), in *Zostera* habitats within Lake Macquarie in August and September (Hannan and Williams, 1996) and in shallow vegetated habitats in the Clarence River from July through January (personal communication from Trudy Walford on data collected during the study by West and King, 1996). Therefore, it appears that small juveniles recruit to the estuaries of NSW in the winter and spring.

5.3.7. School Prawn

Juvenile school prawns were found at the study sites all year round, but small juveniles were most abundant from May through September during both years. There was also an initial peak in the abundance of small juveniles in January 2000 (Figure 5.7).

The school prawn is endemic to eastern Australia, with a range that extends from Tin Can Bay (Qld) to Corner Inlet (Vic) (Ruello, 1973). School prawns spawn in the sea, primarily from February through May (Racek, 1959; Kailola *et al.*, 1993). Timing of the spawning run is linked to floods and river discharge (Ruello, 1973; Glaister, 1978). They are believed to be semelparous (spawn once before dying). The postlarvae enter estuaries in the summer and autumn, then move to upper estuarine brackish and freshwater habitats and remain until the next summer and autumn before migrating to sea to spawn and die. Coles and Greenwood (1983) found that small juvenile school prawns recruited to estuarine habitats in southern Queensland primarily between April and July. They also found juvenile school prawns in upper estuarine habitats throughout the year. Therefore, it appears that recruitment of small juvenile school prawns to estuarine habitats in southern Queensland and northern NSW occurs primarily in the autumn and winter.

5.3.8. Eastern King Prawn

Relatively low numbers of small juvenile king prawns in the samples made it hard to determine a seasonal recruitment pattern. In 2000, small juvenile king prawns were found during all months sampled except November and April, but were most abundant from July through September. In 2001, they were found during all months except November and were most abundant from March through April (Figure 5.8).

The eastern king prawn is endemic to eastern Australia, with a range that extends from Mackay (Qld) to Port Philip Bay (Vic) and northwestern Tasmania (Kailola *et al.,* 1993). They are believed to be semelparous and spawn at sea in the warmer waters of northern NSW and southern Queensland over most of the year, but mainly between January and August (Racek, 1959; Montgomery, 1990). Postlarvae recruit to the estuaries south of the spawning grounds throughout the year where juveniles remain in the marine-dominated lower reaches (Young and Carpenter, 1977; Coles and Greenwood, 1983) for approximately one year before emigrating to ocean waters, where they attain sexual maturity at an age of 1-2 years old. In southern Queensland, Young and Carpenter (1977) found that the peak recruitment of small juveniles occurred from July through September, while Coles and Greenwood (1983) found that peak recruitment occurred from April through June. Therefore, it appears that small juvenile eastern king prawns recruit to estuarine habitats in southern Queensland and northern NSW at any time of the year but a peak in recruitment generally occurs in autumn and winter.

5.4. Summary of critical recruitment periods

Seasonal recruitment periods for the commercially significant species collected during this study are summarised in Table 5.1. Recruitment periods are defined as the seasons that the greatest numbers of small juveniles (fish < 25mm SL and prawns < 4 mm CL) were collected during this study and reported in the literature. It is believed that these are the primary periods when these commercially significant species arrive at the estuarine habitats sampled in this study. It should be noted that a number of species, such as sandy sprats, yellowfin bream, school prawns and king prawns may recruit outside the primary recruitment period in low abundances for the remainder of the year.

Table 5.1. Summary of primary periods of recruitment to estuarine habitats in south-eastern Australia by commercially significant species collected during this study.

Species	Summer	Autumn	Winter	Spring
Sandy sprat				X
Silver biddy	X	X		
Yellowfin bream			X	X
Tarwhine			X	X
Flat-tail mullet			X	X
Sea mullet			X	X
School prawn		X	X	
King prawn		X	X	

Larger juveniles of the commercially significant species were often found in these habitats outside the primary recruitment periods. In fact, juvenile silver biddies, yellowfin bream, flat-tail mullet and school prawns were found throughout the year. However, the abundance of larger juveniles often decreases as they disperse to a wider range of habitats within the catchment.

Most (6) of the eight species in Table 5.1 recruited during winter. These fish and prawn species all spawn outside of the estuary, in the ocean. The majority (4 out of 6) were fish species that recruit through the winter and spring. The silver biddy is the only species in Table 5.1 that is known to spawn inside the estuary and is also the only one of these fish species that recruits primarily during the summer and autumn. This is consistent with the findings of Hannan and Williams (1998), who found that ocean spawning fish recruited to *Zostera* beds in Lake Macquarie primarily in winter and spring, while estuary spawning fish recruited primarily in the autumn and winter. They also found that the majority of ocean spawning recruits were commercially significant species, while the majority of estuary spawning fish were not commercially significant.

Floodgates form physical barriers that can be manually opened. Pollard and Hannan (1994) recommended opening floodgates at all times except immediately prior to and during floods in the main river system in order to maximise the beneficial effects on the commercial and recreational fisheries of the lower Clarence River system. However, agricultural benefits may be maximised in many instances by leaving floodgates closed as much as possible. Therefore, it is important to determine whether there are critical periods when it is particularly beneficial to open the floodgates.

A summary of long-term average monthly rainfall for the Clarence River region (Figure 5.0) shows that rainfall follows a well-defined, consistent seasonal pattern. Rainfall and the associated incidence of flood events are highest in late summer and early autumn, when the tropical monsoons typically extend southward from the Coral Sea. Average rainfall during the late winter and early spring is less than one quarter of the annual peak.

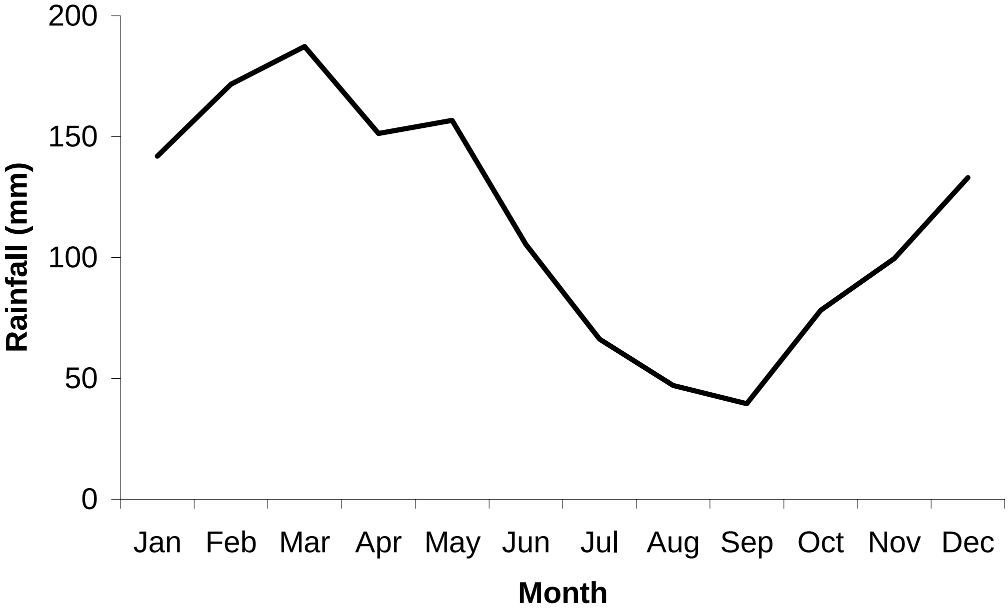


Figure 5.0. Average monthly rainfall during the 35 year period from 1960 to 1995 at the Harwood Island sugar mill on the Clarence River.

Because of the high rainfall in late summer and early autumn, it is reasonable to expect that floodgates will remain closed for longer periods during those seasons. Table 5.1 indicates that these closures will have less impact on fewer of the commercially significant species than closures during the winter and spring. However, closures should not be maintained for long periods of time during any season because they may lead to degraded water quality above the barrier, which may cause mortality of juvenile and adult fish and prawns trapped there.

Closed floodgates during winter potentially impact on the recruitment of most commercially significant species because that is when these primarily ocean spawning species recruit to estuarine habitats. The barrier formed by closed floodgates during winter probably has the maximum impact on recruitment of species that generally move to the upper estuarine or freshwater habitats as juveniles, such as flat-tail mullet, sea mullet and school prawns. Species that remain in marine dominated lower estuarine habitats, such as tarwhine and king prawns are likely to be less affected.

Barriers to recruitment are also formed when rainfall and flood events cause acidification and toxicity of discharge from acid sulfate soils (Sammut *et al*., 1995; Sammut *et al*., 1996; Roach, 1997; Johnston *et al*., 2003). These barriers are likely to form most often during the high rainfall period in summer and early autumn. Fortunately, flood events during that period are less likely to impact on recruitment of commercially significant species (Table 5.1). However, anthropogenic disturbance of acid sulfate soils during the low rainfall winter period may result in smaller scale barriers that have a more significant impact on recruitment of commercially significant species during that season.

Because the majority of non-commercial fish species recruit to estuarine habitats in autumn (Hannan and Williams, 1996), it is possible that barriers to recruitment during the high rainfall period may have a much more significant impact on the diversity of non-commercial species upstream from the barrier compared to the impact on production of commercially significant species. However, estuary spawning resident species may also be much more tolerant of degraded water quality from acid sulfate soils. In fact, temporal recruitment strategies of estuarine fish and invertebrate species are probably the result of evolutionary adaptation to seasonal rainfall patterns and associated increased flow and turbidity (Blaber, 2000). Floods during the spawning and recruitment period for estuary spawners may actually help to disperse the population within the estuary. In contrast the recruits of ocean spawning species may find it difficult to make their way upstream against strong currents and rapidly changing salinities during flood conditions (Domingos, 1992).

In summary, it appears that an increase in the frequency of floodgate closures and toxic conditions from acid sulfate soils during the high rainfall season (late summer and early autumn) may impact on the recruitment of fewer commercially significant species than similar conditions during the winter and spring. This is because most of the commercially significant species are ocean spawners that recruit primarily during low rainfall conditions in winter and spring. However, closure periods should be minimised at all times of the year to reduce impacts on the recruitment of non-commercial estuary spawning species and the potential mortality of juveniles and adults of commercially significant species trapped behind these barriers for extended periods. Floodgates should remain open and disturbance of acid sulfate soils should be minimised during the critical, low-rainfall, winter period to ensure that recruitment of commercially significant species to estuarine habitats is maintained.

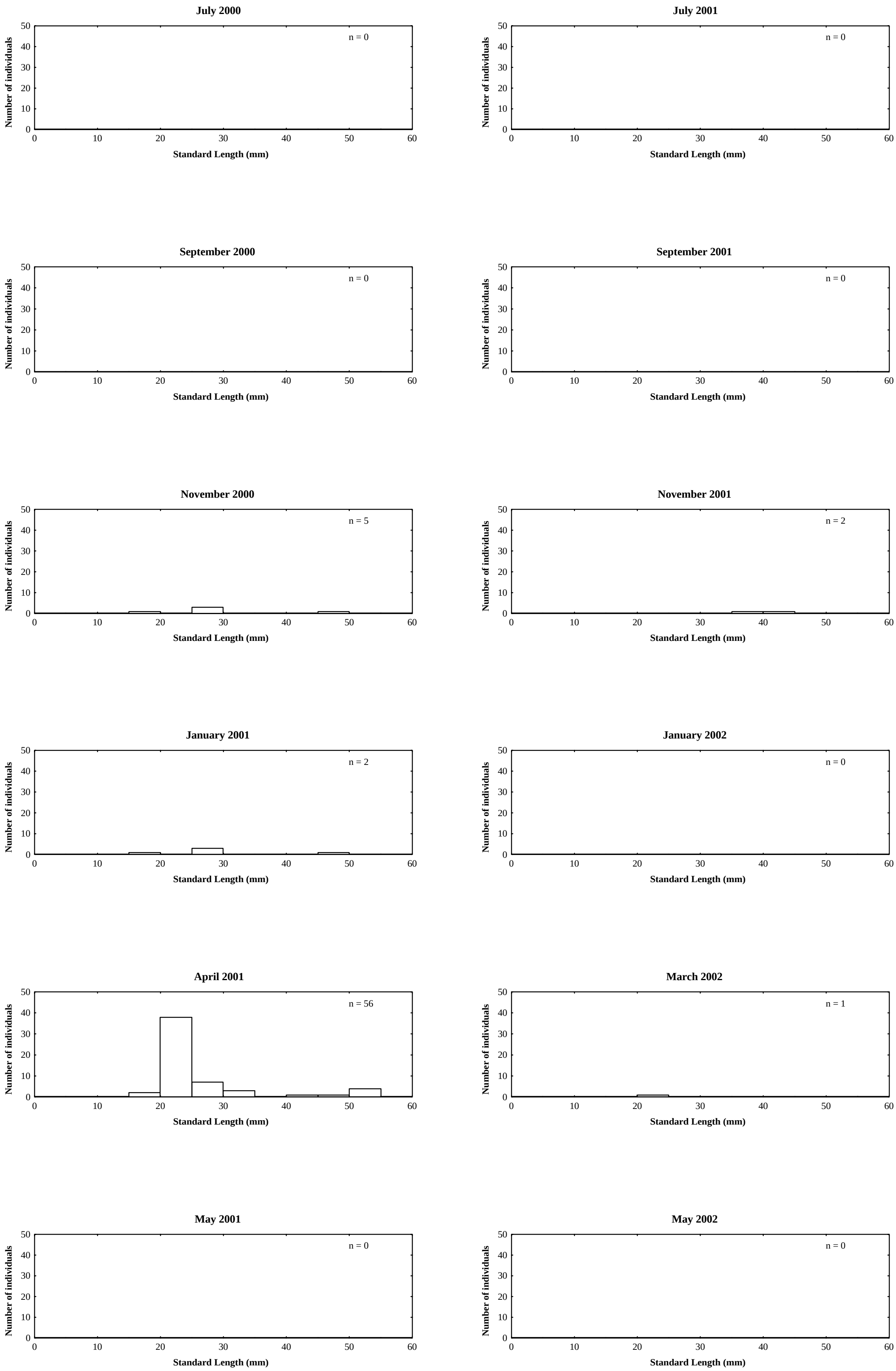


Figure 5.1. Size frequency distributions of sandy sprats captured in the Clarence River floodplain from July 2000 – May 2002.

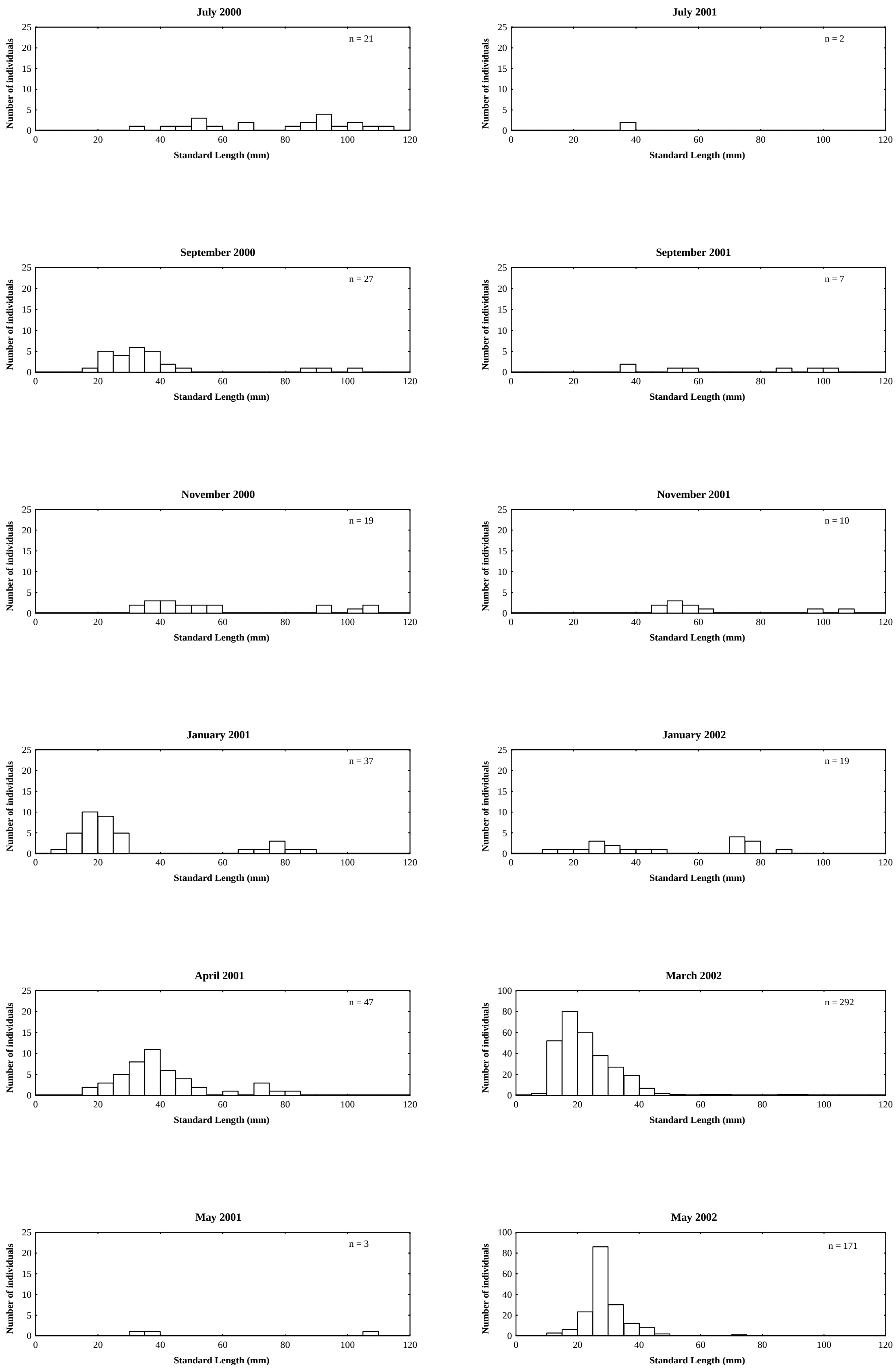


Figure 5.2. Size frequency distributions of silver biddies captured in the Clarence River floodplain from July 2000 – May 2002. Note different scales on y-axes in March and May 2002.

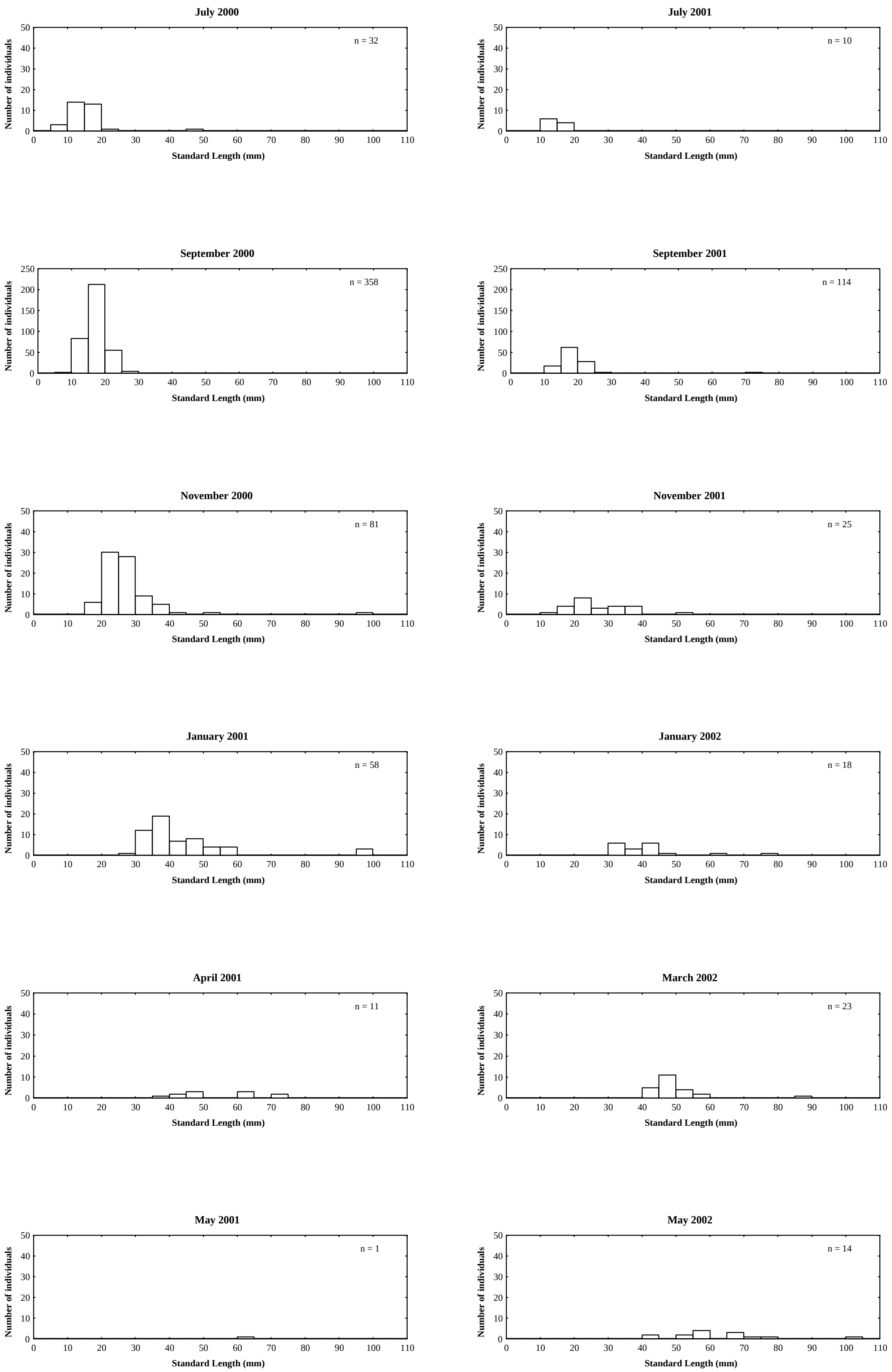


Figure 5.3. Size frequency distributions of yellowfin bream captured in the Clarence River floodplain from July 2000 – May 2002. Note different scales on y-axes in September.

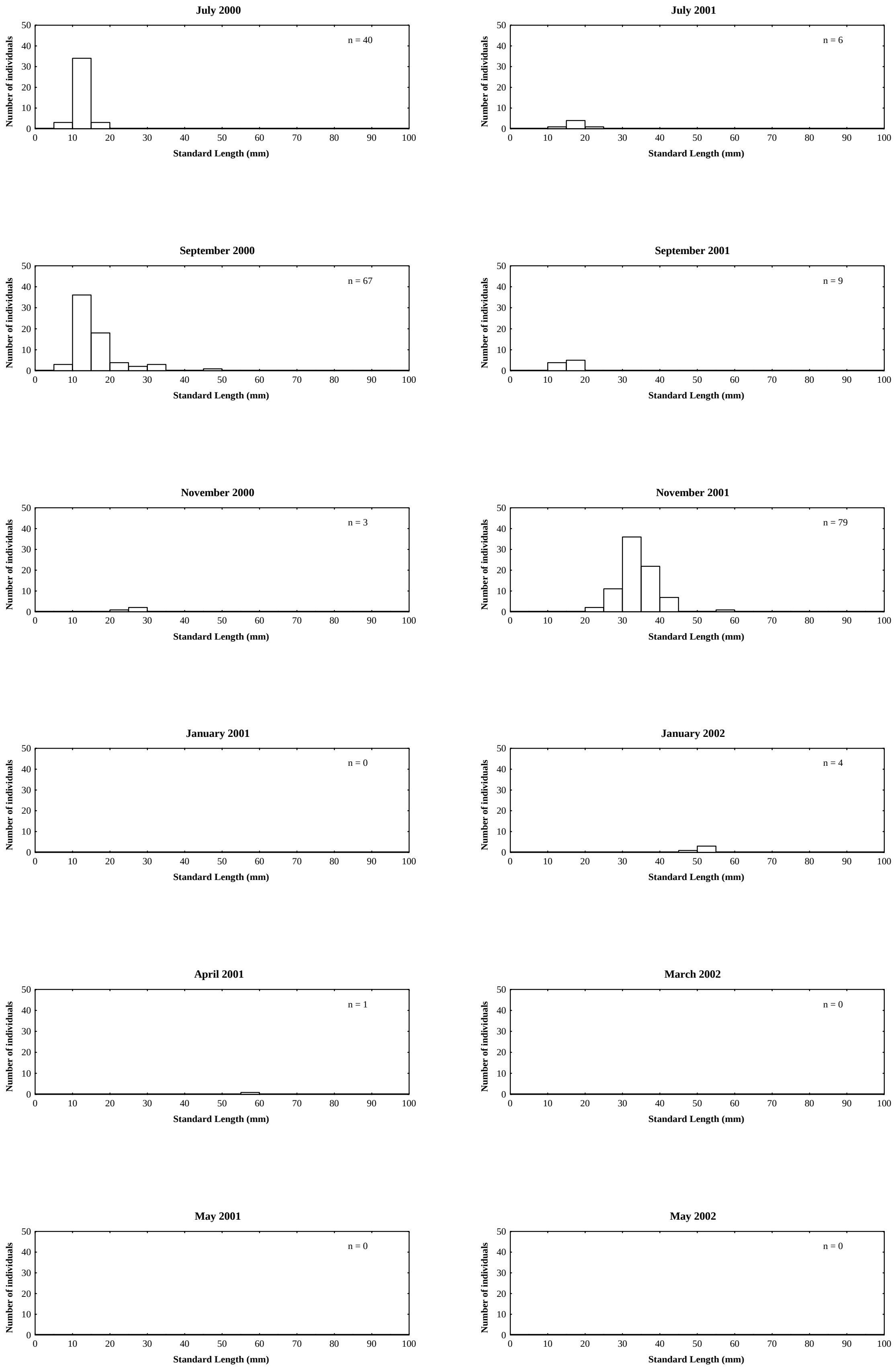


Figure 5.4. Size frequency distributions of tarwhine captured in the Clarence River floodplain from July 2000 – May 2002.

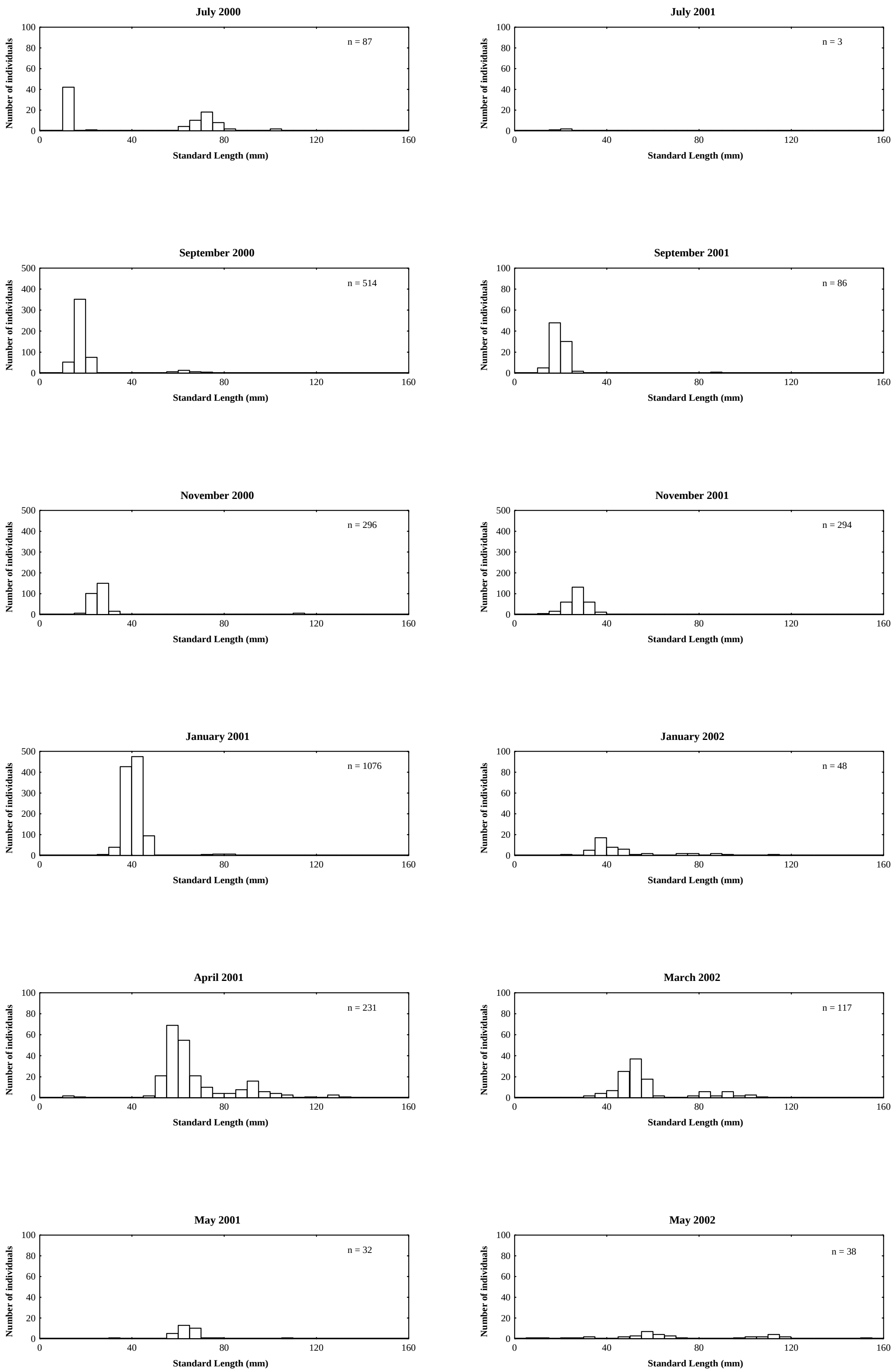


Figure 5.5. Size frequency distributions of flat-tail mullet captured in the Clarence River floodplain from July 2000 – May 2002. Note different scales on y-axes.

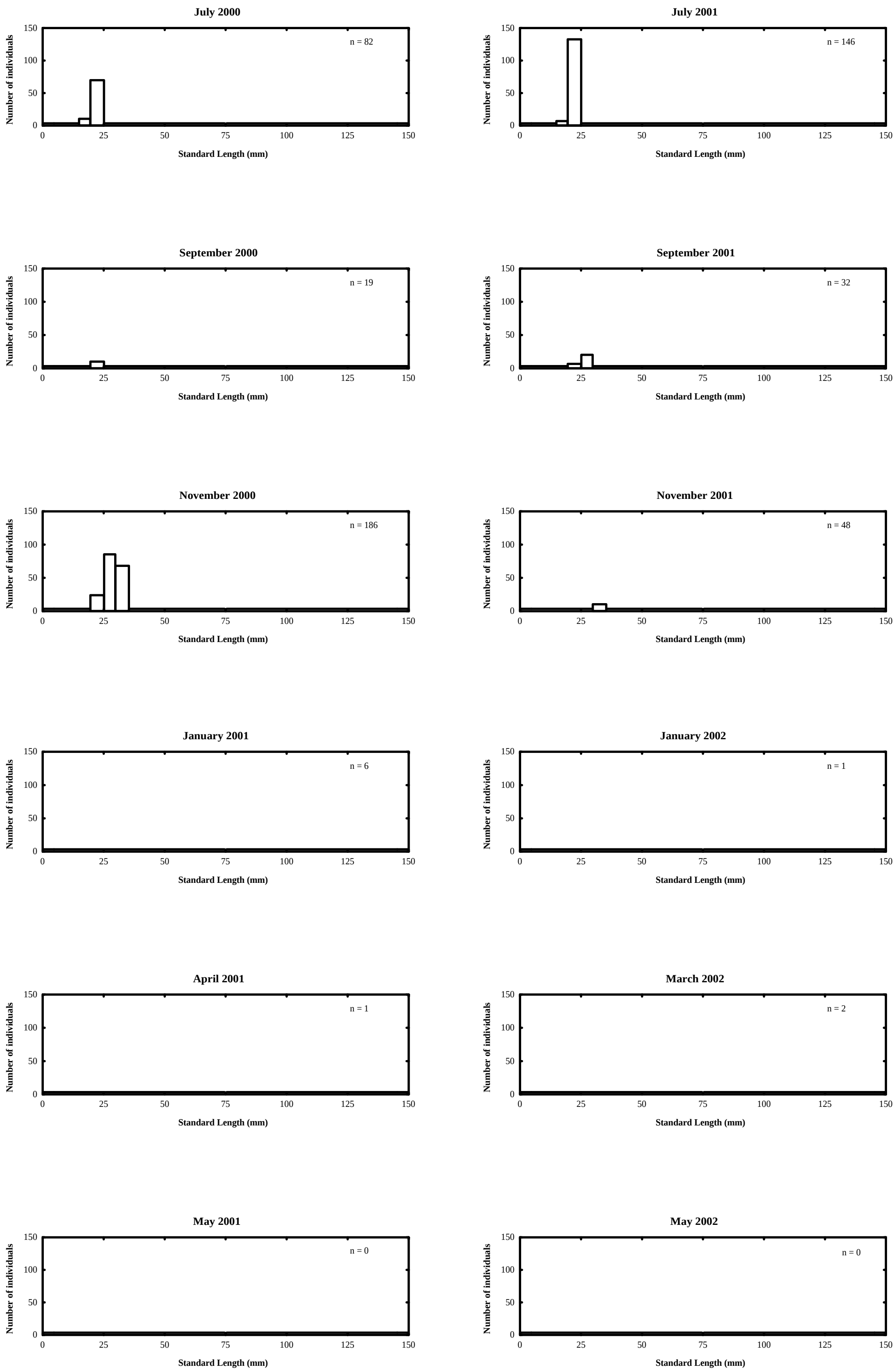


Figure 5.6. Size frequency distributions of sea mullet captured in the Clarence River floodplain from July 2000 – May 2002.

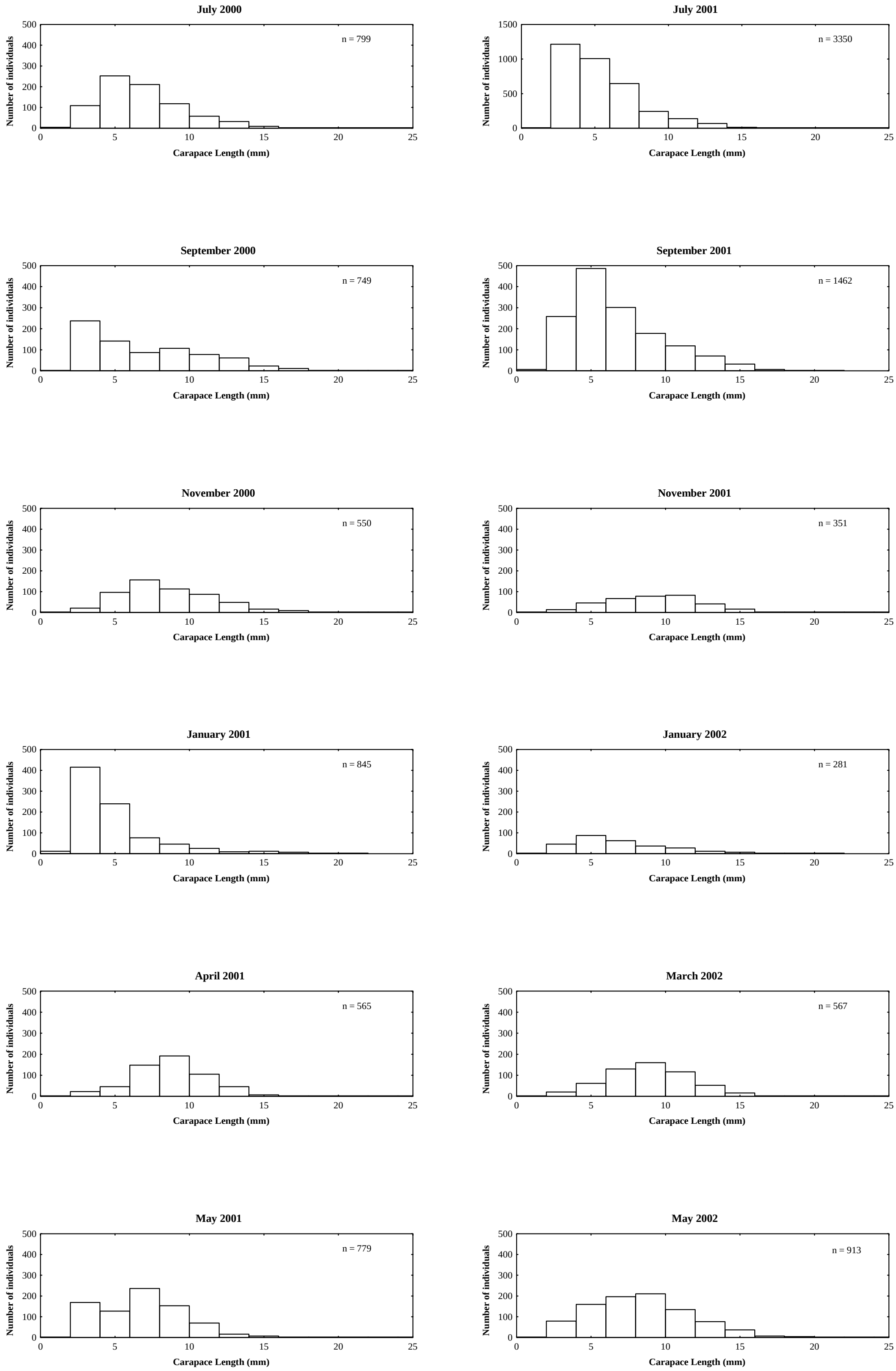


Figure 5.7. Size frequency distributions of school prawns captured in the Clarence River floodplain from July 2000 – May 2002. Note different scales on y-axes.

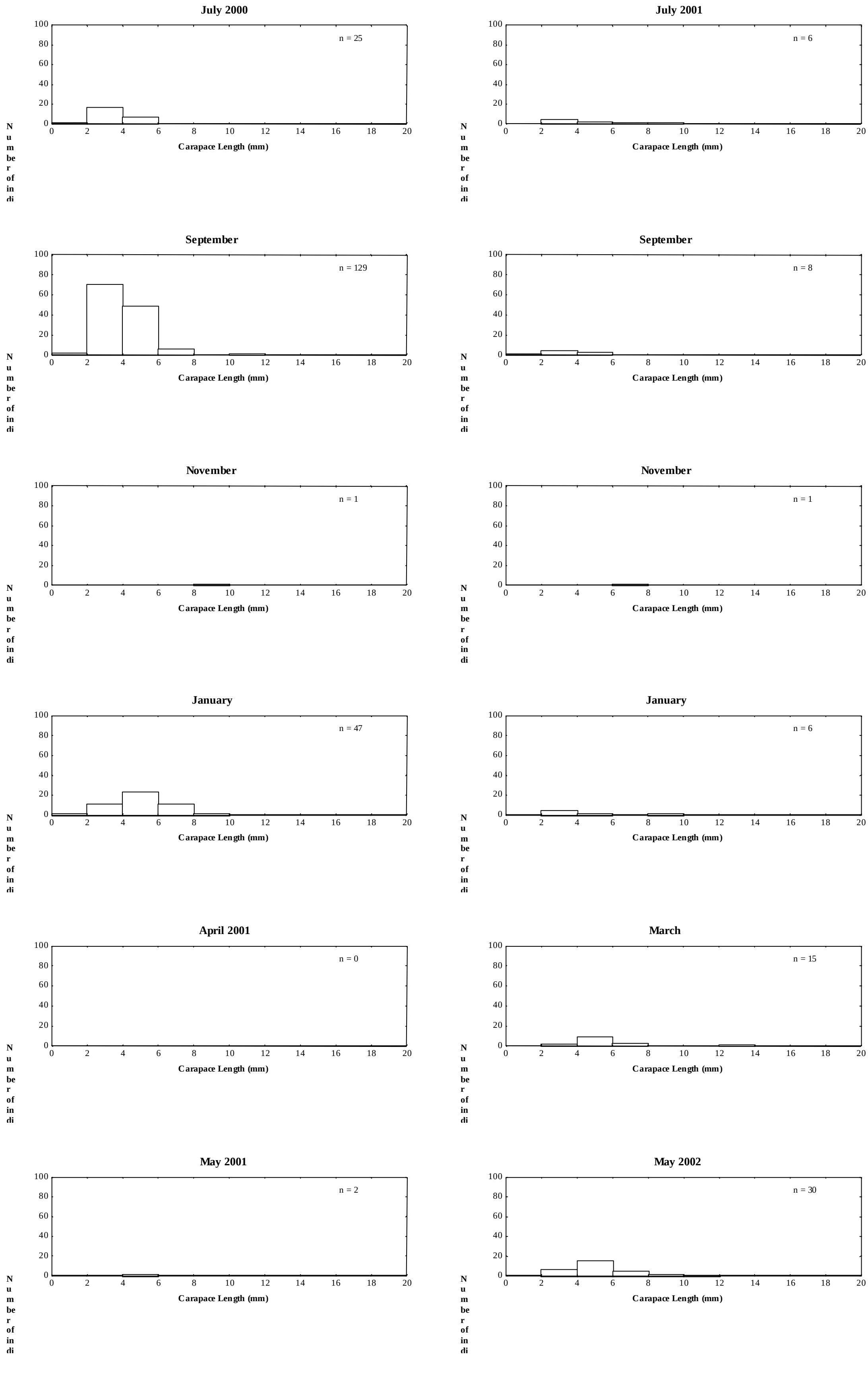


Figure 5.8. Size frequency distributions of king prawns captured in the Clarence River floodplain from July 2000 – May 2002.

6. A FLUVIARIUM WITH CONTROLLED WATER QUALITY FOR PREFERENCE - AVOIDANCE EXPERIMENTS WITH FISH AND INVERTEBRATES

[Note: The contents of this chapter have recently been published as a scientific paper. See Kroon FJ, Housefield GP (2003). A fluviarium with controlled water quality for preference – avoidance experiments with fish and invertebrates. Limnol Oceanogr Methods 1:39-44].

6.1. Introduction

Sustainable management of aquatic ecosystems includes maintaining adequate water quality for aquatic fauna. Inadequate water quality may elicit a response in aquatic fauna, such as fish and mobile invertebrates, including preference, physiological adjustment, or avoidance. For example, discharges of inadequate water quality may create barriers to movement, potentially affecting migration of fish and invertebrate species. If adults avoid such discharges then spawning migrations may be affected, while migrations to nursery habitats may be affected if juveniles avoid such discharges. As a result, the capacity of habitats beyond the discharge point to act as spawning or nursery areas may be reduced, with potential effects on population genetics as well as stock size.

Behavioural research into the role of chemoreception in fish has expanded to include potential environmental stressors, such as temperature (e.g. Richardson *et al*., 1994), acidification (e.g. Jones *et al*., 1985a, b; Peterson *et al*., 1988), turbidity (e.g. Cyrus and Blaber, 1987; Boubée *et al*., 1997), and aquatic pollutants (e.g. Brown *et al*., 1981). This work has built on the knowledge and expertise gained from behavioural research on individual recognition (e.g. Olsén, 1989; Olsén and Winberg, 1996), schooling (e.g. Keenleyside, 1955), homing in salmonids (e.g. Cooper and Hirsch, 1981; Erkinaro *et al*., 1999), reproductive behaviour (e.g. Liley and Stacey, 1983; Olsén *et al*., 1998), and alarm substance (e.g. Pfeiffer, 1981).

Fluviariums, in particular, have been used to examine preference – avoidance behaviour in fish. The sharp gradient in fluviariums provides aquatic organisms with a choice of (usually) two water qualities, sharply demarcated at a relatively narrow boundary zone. Behavioural responses examined in fluviarium studies have included choices associated with pH (Davies, 1991; Åtland and Barlaup, 1996; Åtland, 1998; Chapter 7), waste discharge (Smith and Bailey, 1990), pheromones (Bjerselius *et al*., 1995), and chemical cues released by siblings (Olsén and Höglund, 1985; Olsén, 1986, 1989; Olsén and Winberg, 1996).

The fluviarium described here, as with most fluviariums used to date, was modified from the design of Höglund (1961). A detailed description of a more recently constructed and up-dated fluviarium, however, is missing from the literature. The fluviarium described here integrates hydrodynamic design and extensive control of water quality to provide consistent experimental conditions, while at the same time being affordable.

6.2. Methods

6.2.1. Design considerations of fluviarium

Design of the system was based upon the constraint that limited amounts of fresh and salt water (i.e. maximum of 4000 litres day^{-1}) would be available for this study. Furthermore, the combination of materials and equipment used to construct the system was selected on the basis of minimum cost.

The fluviarium was modified from the design of Höglund (1961) and Olsén and Höglund (1985), and is detailed in Figure 6.1a and b. The entire fluviarium was constructed of fibreglass (inner dimensions: 2600 mm length x 700 mm width x 300 mm height), and consisted of two channels with a test area (inner dimensions: 480 mm length x 700 mm width x 300 mm height) (Figure 6.1b). To provide the strongest possible contrast with the experimental animals, the inside of the fluviarium was coated in white gelcoat. In addition, two baffles consisting of 800 µm nitrile mesh on white plastic eggcrate (a type of diffuser for suspended ceiling lighting) with a cell configuration of 10 x 10 mm were placed upstream and downstream from the test area (Figure 6.1b).

To establish and maintain a laminar flow in the system, we included three diffusers, one separator, and five baffles (Figure 6.1b). The diffusers and separator were constructed of fibreglass and coated with white gelcoat. Two diffusers were placed at the upstream end, and one diffuser was placed at the downstream end of the fluviarium (Figure 6.1b). The separator started at the upstream end and was placed exactly in the middle of the fluviarium (Figure 6.1b). Baffles consisting of foam blocks (low density) were placed upstream from the two diffusers (2 blocks, 350 mm length x 200 mm height x approximately 100 mm width), as well as upstream (2 blocks, 350 mm length x 200 mm height x approximately 100 mm width) and downstream (1 block, 710 mm length x 200 mm height x approximately 100 mm width) from the test area (Figure 6.1b). All baffles were held in place by compression against the sidewalls and by a bar from above. This was sufficient to allow foam of this porosity to resist a flow of 20 litres min^{-1}.

The fluviarium was fed from either one of three, 4000-litre polypropylene round feeder tanks (Figure 6.1a); one for estuarine water from Port Stephens, one for fresh water from a local bore, and one for mixing to achieve a desired salinity. Each feeder tank had air stones for continuous aeration, to ensure the test water was well mixed and to minimise CO_2 concentration in the test water. The aims of the latter were to (i) obtain stable pH levels during experiments, and (ii) prevent the formation of free CO_2 during acidification of test water, as free CO_2 itself can elicit a preference – avoidance response in fish (e.g. Jones *et al.*, 1985b). Water was pumped at approximately 20 litres min^{-1} through 260 µm filters into each of the two independent constant-head boxes of the fluviarium channels (Figure 6.1b), using a centrifugal pump (Onga model 413 400 watt, 145 litres min^{-1} @ 145 kPa). From here, the water flowed through the test area into the outflow pipes (Figure 6.1b). The two outflow pipes established water height at 110 mm (Figure 6.1b).

During experiments, animals were kept in either one of two rectangular holding tanks (400 litres poly-ethylene) (Figure 6.1a). Water in these tanks, whether fresh, marine or brackish, was recycled and filtered through a vortex XL Diatomaceous earth filter (1 µm capacity). Both tanks had air stones for continuous aeration, and were kept indoors in artificial illumination at natural daylight hours, at ambient temperature.

The entire system was established on reinforced concrete and enclosed by a tunnel house (9000 by 6200 cm) covered in panda plastic (black inside, white outside), providing blackout conditions. The tunnel house had a second clear layer inside providing an insulating air gap. The test area was illuminated from above by two pairs of 1200 mm red colour fluorescent tubes (GE 36 watt) fitted with translucent acrylic plastic, one pair at each side of the fluviarium. Such diffuse illumination minimised reflections or shadows in the test area, and thus on the videotapes. Finally, to minimise potential observer effects on the animals (Martin and Bateson, 1993), panda plastic was placed around the fluviarium during experiments.

6.2.2. *Precise control of water quality*

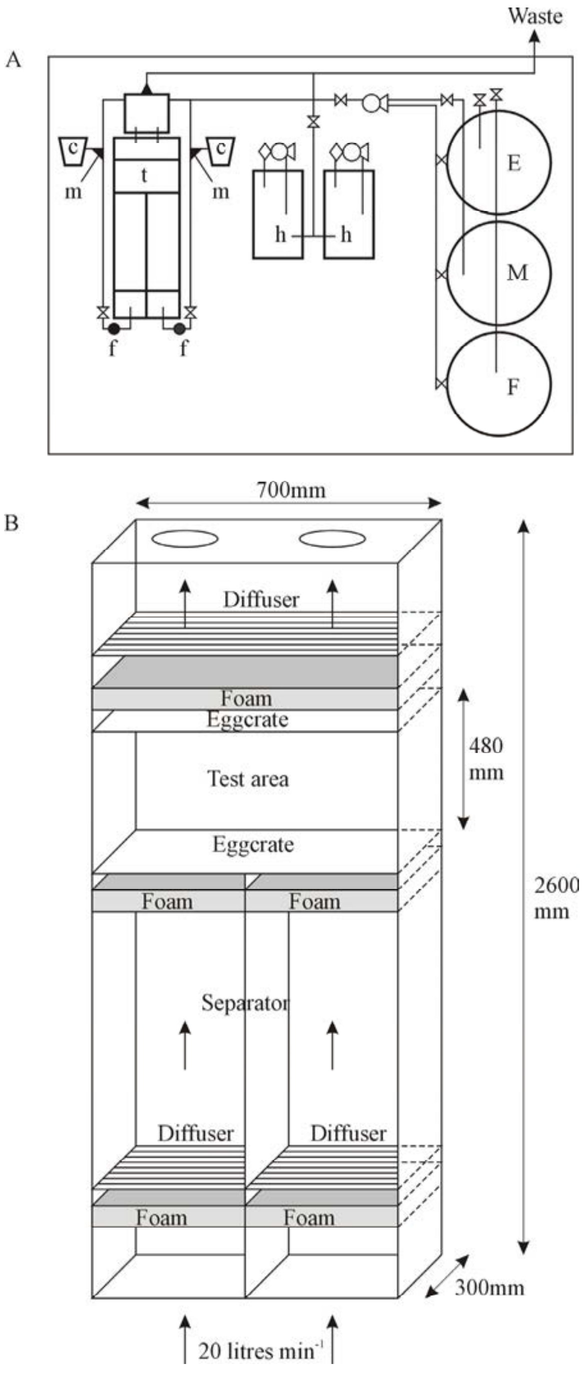


Figure 6.1. Fluviarium. (a) General lay-out of the facility, and, (b) detailed outline of the fluviarium. Abbreviations: c = container with acid solution or water, f = flowmeters, h = holding tanks, m = Mazzei injectors, t = test area, E = estuarine water input, F = freshwater input, M = mixing tank. Dimensions are in mm, and arrows in (B) indicate direction of flow. See text for detailed description.

The fluviarium was constructed to examine acid avoidance behaviour in juvenile fish and prawns (Chapter 7). To this effect, sulfuric acid (98% tech grade; Allied Pacific Specialty Chemicals, Parramatta) was added to the water to regulate levels of acidity. Approximately two litres of H_2SO_4 were metered using a pump (Acemite Lubrequip) from a 200 litres drum into Winchester bottles. Using a bottle-top dispenser, mixed predetermined volumes of H_2SO_4 were mixed with 20 litres of water to obtain precise levels of acidity. Apparatus for constant pH control in the fluviarium consisted of two Mazzei injectors (Model 584 from PPS), one attached to either side of the continuous-flow dilution system (Figure 6.1a), with an uptake of 20 litres 70 min^{-1} of pH-adjusted water. To confirm a drop in acidity, acidity profiles of water flowing through the test area were obtained by measuring pH in the experimental lateral half of the intake area every 30 seconds. The acidity profile was measured until it stabilised, generally five minutes after the Mazzei injectors were turned on. Subsequently, the pH of the untreated channel was also checked.

6.2.3. Behavioural observations using video

The behavioural response of juveniles in the system described here was noted as location (e.g. Olsén and Höglund, 1985; Peterson *et al*., 1988; Bjerselius *et al*., 1995; Newman and Dolloff, 1995; Olsén and Winberg, 1996), but could also include duration and activity (Olsén and Höglund, 1985; Smith and Bailey, 1990; Winberg *et al*., 1993; Åtland and Barlaup, 1996; Åtland, 1998). The positions of the individual juveniles were recorded continuously, with a digital video camera (Sony Digital Handycam, DCR-TRV 520E PAL) on digital videocassette (Sony Digital Recording 8mm Videocassette) using Infra-Red Images mode. The video camera was positioned approximately 150 cm above the test area, ensuring that it covered the whole area. Subsequently, the image analyses program 'Scion 4.02 Beta release' was used to enhance the infrared images.

6.2.4. Standard operating procedures

In control runs, untreated water was added to both lateral halves of the fluviarium. In experimental runs, untreated water was added to one lateral half, while a test solution (e.g. acidified water) was added to the supply line of the other half. The experimental and control channel were alternated randomly to negate any bias fish may have for either side.

Before starting a run, a container with acid solution (experimental run) or water (control run) was prepared, and placed under one of the Mazzei injectors (Figure 6.1a). The fluviarium was then filled with water (i.e. not acidified), using the recycling mode, ensuring that the two flow meters (Dwyer, VFC-152; 0–40 litres min^{-1}) (Figure 6.1a) were set correctly for laminar flow. A flow of 20 litres min^{-1} resulted in a laminar flow. The video camera was positioned correctly and the pH probe was set up in the experimental channel (i.e. channel that was going to receive acidified water).

Ten naïve juvenile fish or prawns were gently transferred from one of the holding tanks into the test area. They were left to settle for at least fifteen minutes to establish themselves in the test area. Panda plastic around the test area was closed to prevent visual disturbance from affecting fish behaviour. Time of introduction of juveniles was noted, and video recording was started remotely.

Fifteen minutes after introduction, a 70-minute run was started by changing from recycling mode to flow-through mode, and turning on the Mazzei injectors. This resulted in acid solution (experimental run) or water (control run) being added to the water entering the test area via the experimental channel. The drop in acidity was confirmed as described above. Subsequently, the run continued without anyone present in the tunnel house to minimise potential observer effects on the animals (Martin and Bateson, 1993).

At the end of each run, all ten animals were collected from the test area and returned to the holding facilities. To ensure that individuals were tested only once, used animals were kept in a separate holding tank. The fluviarium and foam blocks were rinsed and cleaned thoroughly between experiments.

6.2.5. Behavioural response of juveniles

The behavioural response of juveniles to two different water qualities (i.e. pH levels) was assessed as follows. One image was grabbed every minute using the frame grabber 'Scion LG3', totalling 60 images or frames per run. To ensure juveniles had sufficient time to show a preference, and thus prevent a mean biased over time, the first frame was grabbed ten minutes after a run had started. For each frame, the position of each individual juvenile (i.e. position of the snout) was determined visually, and the number of individuals in each lateral half of the test area was counted. This procedure was repeated for all 60 images, and the total number of individuals in each lateral half of the test area over all 60 images was calculated. Subsequently, the mean percentage of juveniles in each lateral half of the test area was determined for all 60 frames combined. This provided us with the mean proportion of juveniles in the experimental half of the test area over a 60 minute run. This mean proportion was considered the behavioural response of the juveniles in that particular run, and was entered as a single replicate in the data analysis. In control runs, a flip of a coin determined the "experimental half" of the test area.

6.2.6. Assessment of the fluviarium

To determine the stability and sharpness of demarcation of the two water masses within the test area, dye tracers (food colouring) were used (Figure 6.2a). Water intake was adjusted to achieve proper demarcation. A flow of 20 litres min^{-1}, measured with the two flow meters (Figure 6.1a), resulted in a laminar flow with stable and sharp demarcation (Figure 6.2b). Dye tracer tests were repeated on a regular basis, to ensure proper demarcation of the two water masses across time.

To examine whether animals would distribute themselves evenly in the test area under control conditions, the system was tested as follows. Juvenile snapper (*Pagrus auratus*, 20 – 40 mm SL) were obtained from the Aquaculture Marine Hatchery facilities at the Port Stephens Fisheries Centre in July and August 2001. Four control runs were conducted according to the standard operating procedures described above. The results revealed that the behavioural response of juvenile snapper, i.e. the mean proportion of juveniles in the experimental half of the test area over a 60 minute run (mean 49.95% ± 4.90 S.E., n=4), was not significantly different from the expected distribution (mean 50.00%). These results showed that the system worked as desired, and could be used to study preference – avoidance responses in fish and mobile invertebrates.

6.3. Discussion

The fluviarium described in this paper offers an affordable and working system to study preference – avoidance behaviours of aquatic biota. The system provides consistent experimental conditions through the ability to control in detail the acidity levels in the experimental channel. Using this system, such extensive control can and has been achieved with other water quality variables, such as levels of salinity (James Knight, pers. comm. 2002).

An important feature of this design includes fish being continuously exposed to both water qualities, without getting trapped in either of the two channels. This ensured that fish were able to continuously choose between the two water qualities. Consequently, the behaviours observed were true reflections of preference – avoidance responses. In some studies on preference – avoidance behaviours, fish were given a one-off choice between two different water qualities, after which they became trapped in either one of the channels (e.g. Rehnberg and Schreck, 1987; Newman and Dolloff, 1995; Boubée *et al*., 1997). Changes in behaviour are not possible in such a set up and results may not necessarily reflect true preference – avoidance behaviour. This is of particular concern when schools of individuals are tested (e.g. Rehnberg and Schreck, 1987; Newman and

Dolloff, 1995; Boubée *et al*., 1997), and the behaviour of individuals is not independent of behaviour of other individuals in the school.

a)

b)

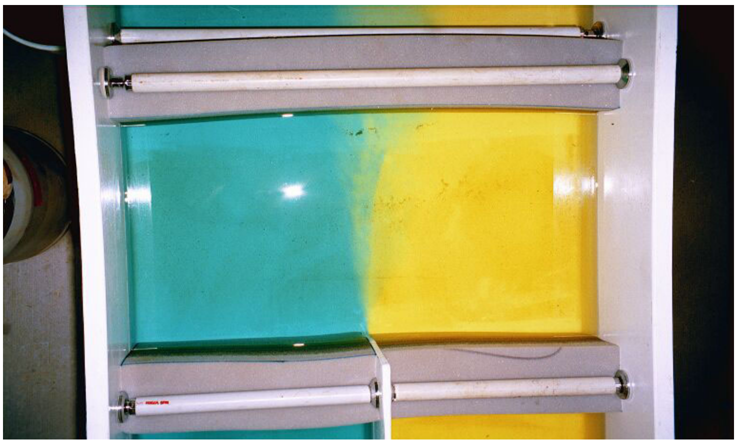


Figure 6.2. Fluviarium. (a) Testing the stability and sharpness of demarcation of the two water masses in the fluviarium, using dye tracers (food colouring), and, (b) detail showing the demarcation within the test area.

Proper experimental design and data analyses are critical aspects of measuring behaviour (Martin and Bateson, 1993), including examining behavioural responses in two-choice maze studies. Experimental design requires careful consideration and should take into account the use of controls, as well as order effects and interactions (Martin and Bateson, 1993). Our experiments examined acid avoidance behaviour in juvenile fish and prawns (Chapter 7). Individual fish were only used once to avoid potential order effects. Interaction effects were not an issue in our experiments, as the effect of only one water quality component (i.e. pH) was examined. However, if the effect of more than one variable is to be examined simultaneously (e.g. effect of temperature, salinity and pH combined), each combination of variables must be represented in the experimental design. This may provide constraints on the feasibility of such a study, as the number of runs that need to be conducted to obtain sufficient statistical power would increase exponentially.

Correct data analyes assumes that individual data points are statistically independent of one another. This assumption of independence is often violated in behavioural research, including two-choice maze studies. A common error is to take multiple records of an individual animal and treat them as though they were independent (so-called "pooling fallacy"; Machlis *et al*., 1985). Rather, multiple records on the same subject should be averaged to obtain an individual data point for that subject. In our experiments, we averaged repeated measurements (i.e. 60 video frames) on the same subjects within a run to obtain a single replicate for that run for data analysis. Thus, our sample size was equal to the number of runs conducted, and not the number of video frames grabbed.

In fluviariums, the behavioural response of aquatic organisms is generally examined in individuals (Olsén and Höglund, 1985; Olsén, 1986, 1989; Bjerselius *et al*., 1995; Olsén and Winberg, 1996), but has included examination of schools of up to 22 individuals (Richardson *et al*., 1994). Using individuals may not necessarily be a good reflection of the situation in the field, but provides data on completely independent individuals. On the other hand, using schools means that the behaviour of one individual is not independent of that of other individuals. In our experiments, the use of groups of ten juveniles as opposed to individual juveniles was thought to be more appropriate, since juveniles generally move in schools. The assumption made was that if individual runs were conducted and analysed over an appreciable time (i.e. 60 minutes), the average equilibrium behaviour of the 10 individuals in the school would reflect the properties of the run, and would not be affected by the initial state of the run. Our results from the four control runs conducted with juvenile snapper show that this was a reasonable assumption.

The system described here was designed and used to examine acid avoidance behaviour in juvenile fish and prawns (Chapter 7). However, the system can be used or modified to study behavioural responses of aquatic biota to a wide variety of environmental variables, including habitat quality or combinations of two or more environmental variables. For example, the presence of suitable habitat may alleviate strong avoidance behaviour to low acid levels, as has been shown for zinc avoidance by fathead minnows (*Pimephales promelas*) (Korver and Sprague, 1989). The choice of (combination of) variables is limitless, but is dictated by the nature of the problem under investigation. In any choice experiment, however, it is vital to know the values of the studied variable in the field to ensure that the experiment reflects choices that may be encountered in the field.

Behavioural studies conducted with the system described can complement LD_{50} studies. LD_{50} trials provide valuable information regarding the physiological tolerances of species to certain substances, however, they do not provide information on a species' behaviour in response to these substances. A combination of laboratory studies, including preference-avoidance experiments and LD_{50} trials, as well as field observations on natural populations and environmental variables, will provide a solid combination of scientifically sound data for sustainable management of aquatic ecosystems.

7. AVOIDANCE OF ACIDIFIED WATER BY COMMERCIAL FISH AND PRAWN SPECIES

[Note: The contents of this chapter have recently been accepted for publication as a scientific paper. See Kroon FJ (in press). Avoidance of acidified water by commercial fish and prawn species. Mar. Ecol. Prog. Ser.]

7.1. Introduction

Oxidized or unoxidized sulfidic sediments, known as ‘acid sulfate soils’ (ASS) (Dent, 1986), occur in coastal floodplains around the world, covering an area of at least 12m ha (Dent and Pons, 1993). Extensive areas are found in Indonesia, the Gyuanas, the Orinoco Delta, and West Africa (Dent and Pons, 1993). In Australia, acid sulfate soils occur primarily along the eastern and northern coastlines, as well as in parts of Western Australia, South Australia and Victoria. The extent of ASS in Australia has recently been estimated at 4M ha (National Working Party on Acid Sulfate Soils, 2000).

Acid sulfate soils contain iron sulfides, primarily iron pyrite (FeS_2). Pyrite remains stable under reduced conditions below the water table. Exposure to oxygen due to natural or artificial draining of ASS, however, results in the oxidation of pyrite into hydrogen, sulfate and iron (for detailed chemical reactions, see Dent, 1986; White *et al.*, 1997). Sulfuric acid, in turn, enhances the breakdown of metal-bearing sediments (Sammut *et al.*, 1996; Preda and Cox, 2001; see also White *et al.*, 1997). Subsequent rain events leach sulfuric acid from sediments and mobilise metals, resulting in a reduction in water quality (Sammut *et al.*, 1996; Roach, 1997; Cook *et al.*, 2000; Preda and Cox, 2001).

Discharges of sulfuric acid and associated (trace-) metals can have immediate and severe ecological impacts (e.g. Sammut *et al.*, 1995, 1996a, b; White *et al.*, 1996). In Australia, fish kills have been reported in both naturally (Brown *et al.*, 1983) and artificially (Easton, 1989; Callinan *et al.*, 1993, 1996; Sammut *et al.*, 1993) drained acid sulfate soil catchments. These fish kills were associated with acidic water (pH < 5.0) and high concentrations of dissolved aluminium (Brown *et al.*, 1983; Hart *et al.*, 1987; Fraser *et al.*, 1992). pH values below 3-4 are lethal to most fish species (Wendelaar Bonga and Dederen, 1986), however, elevated concentrations of inorganic aluminium are most likely the primary cause for fish mortality in these acidified waters (Driscoll *et al.*, 1980). The seasonal occurrence of epizootic ulcerative syndrome (EUS), or red spot disease (Callinan *et al.*, 1989), has also been associated with (Virgona, 1992; Callinan *et al.*, 1993, 1995), and related to (Callinan *et al.*, 1996) discharge from acid sulfate soils.

Potential long-term ecological impacts of chronic acid sulfate discharge are less well known. Chronic acid sulfate discharge may create barriers to movement, potentially affecting migration of fish and invertebrate species (Brown *et al.*, 1981; Easton, 1989). This is particularly the case when chronic run-off coincides both temporarily and spatially with movement patters of migratory fish and invertebrate species (e.g. Chapter 5). If adults avoid such discharges spawning migrations may be affected, while migrations to nursery habitats may be affected if juveniles avoid such discharges. As a result, the capacity of habitats beyond the discharge point to act as spawning or nursery areas may be reduced, with potential effects on population genetics as well as stock size. The population collapse of the Australian bass (*Macquaria novemaculeata*) in the Hastings and Manning rivers (New South Wales), due to recruitment failure, has been partially attributed to acid sulfate discharge (Harris, 1989 and pers. comm.).

In this study, we examined the possible existence of acid avoidance behaviour in juvenile Australian bass (*Macquaria novemaculeata*), and three other commercially or recreationally important species - snapper (*Pagrus auratus*), yellowfin bream (*Acanthopagrus australis*), and schoolprawn (*Metapenaeus macleayi*). The life history, behaviour and demography of these species suggest they may be susceptible to impacts from acid sulfate soil, including chronic acid sulfate discharge (Chapter 5). We hypothesised that chronic acid sulfate discharge does not affect movement of migratory fish and prawns. We tested the predictions that (i) juvenile fish and prawns can detect a difference in acidity, and (ii) juvenile fish and prawns avoid low concentrations of acid, when given a choice. Schools of ten individuals were given a simultaneous choice between two water qualities (in this case pH) in paired channels of a laboratory stream, thus providing them with a choice in a preference – avoidance situation.

7.2. Methods

7.2.1. Study species

The distributions of the four study species overlap with the distribution of acid sulfate soil catchments in eastern Australia (National Working Party on Acid Sulfate Soils 2000). In addition, the life history, behaviour and demography of these species suggest they may be susceptible to impacts from acid sulfate soil, including chronic acid sulfate discharge (see species descriptions below). All four species contribute significantly to the commercial and / or recreational fisheries in eastern Australia (Steffe *et al*., 1996; Gibbs, 1997; Tanner and Liggins, 2000; Kennelly and McVea, 2001), as well as in other states and territories within Australia (Kailola *et al*., 1993). The contribution of these species to the indigenous fisheries has not been documented.

7.2.1.1. Snapper

In Australia, snapper *(Pagrus auratus)* (Bloch and Schneider) (Family Sparidae) occurs from Shark Bay (Western Australia) to Mackay (Queensland) (Kailola *et al*., 1993). In eastern Australia, populations at the northern end of the species range (latitude 21º to 24º) spawn offshore from June to September (Ferrell and Sumpton, 1997). In NSW, pelagic larvae enter Tuggerah Lakes from August to October (Marsden, 1986), and Lake Macquarie year-round with a peak abundance occurring in September (Miskiewicz, 1986, 1987). Settlement takes place following metamorphosis (12.0 - 13.3 mm, Neira *et al*., 1998), and juveniles adopt a more benthic lifestyle (Foscarini, 1988).

Juvenile and small adult snapper occur in estuaries and bays (Francis, 1994; Neira *et al*., 1998). Juveniles (6.5 - 19.5 cm FL) were captured in Moreton Bay (Qld), Pittwater, Port Jackon, Wallis Lake and the mouth of the Manning River (NSW) between December and February (Ferrell and Sumpton, 1997). Both 0^+ and 1^+ year classes were present in Port Jackson (7 - 13 cm FL), with a 1 cm overlap at about 11 - 12 cm (Ferrell and Sumpton, 1997). In Queensland, Hervey Bay and Moreton Bay support large numbers of 0^+ and 1^+ year-class juveniles (Ferrell and Sumpton, 1997).

Not enough juvenile snapper could be captured in the field for the experiments. Hence, juveniles were obtained from the Aquaculture Marine Hatchery facilities at the Port Stephens Fisheries Centre (NSW Fisheries, Taylors Beach) from July to September, 2001 and 2002.

7.2.1.2. Yellowfin bream

Yellowfin bream *(Acanthopagrus australis)* (Günther) (Family Sparidae) is endemic to Australia, and inhabits coastal and estuarine waters from Townsville (Qld) to the Gippsland Lakes (Vic) (Rowland, 1984). The species inhabits rivers up to the limit of brackish waters, but rarely enters fresh waters (Kailola *et al*., 1993; Blaber and Blaber, 1980).

The yellowfin bream is catadromous, migrating downstream to spawn in the open sea near river entrances (Pollock, 1984). Spawning occurs during late autumn and winter in NSW (Pease *et al*., 1981b; Pollock, 1982; Rowland, 1984), and from May to August in Moreton Bay (Pollock, 1982). In NSW, larvae enter Tuggerah Lakes from January to May, and in September and October (Marsden, 1986), and Lake Macquarie year-round except November, with peak abundances occurring between January and July (Miskiewicz, 1986). In Queensland, planktonic postlarvae (9 - 14 mm FL) were most abundant at surf bar entrances to Moreton Bay from July to September (Pollock *et al*., 1983).

Settlement takes place at approximately 13 - 14 mm TL (Pollock *et al*., 1983; Neira *et al*., 1998). Postlarvae and small juveniles (20 - 100 mm) are found in shallow estuarine areas (Blaber and Blaber 1980; Pollock *et al*., 1983). In Botany Bay, postlarvae and small juveniles (10 - 34 mm FL) appear to be most abundant in July and October (Worthington *et al*., 1992). In the Clarence River, the highest abundances of juveniles occur in July and September (West and King, 1996; Kroon *et al*., 2004). In Moreton Bay, postlarvae and small juveniles (<40 mm FL) were most abundant in October and November (Pollock *et al*., 1983), while larger juveniles (5 - 10 cm) were most abundant from December to March (Pollock, 1982).

In 2001, juvenile yellowfin bream were captured using a seine net and baited funnel traps in the Port Stephens estuary from October to December, and using a seine net in the Myall river in November. From October 2002 to January 2003, juvenile yellowfin bream were captured using bait traps and a seine net in the Port Stephens estuary. Not enough juvenile yellowfin bream could be captured in 2002, and additional hatchery-reared juveniles were obtained from Glen Searl (Searl Aquaculture, Palmers Island, NSW). Runs were conducted with either wild or hatchery-reared juveniles, but never with a mixture of both. To avoid a potential confounding effect of size (wild juveniles were significantly larger than hatchery-reared juveniles, Table 7.1), the behavioural responses of wild and hatchery-reared juvenile bream were analysed separately.

7.2.1.3. Australian bass

The Australian bass (*Macquaria novemaculeata*) (Steindachner) (Family Percichthyidae) is endemic to eastern Australia, and inhabits coastal rivers from the Mary river and Fraser Island (Qld) to Wilson's Promontory (Vic) (Harris and Rowland, 1996; Allen *et al*., 2002).

The Australian bass migrates to lower reaches of estuaries to spawn (Harris 1986b; Harris and Rowland, 1996). Spawning takes place in brackish water between May and early September (Harris, 1986b). Metamorphosis takes place at approximately 25 - 30 mm TL, when larvae are about three months old; small juveniles reach about 100 mm TL in their first year (Harris, 1986b). Juveniles (20 - 50 mm TL) migrate from the breeding grounds to upstream habitat through spring and summer (Harris, 1986b), although this migration can continue through the 0^+ and 1^+ classes (Harris, 1983). Most males remain in tidal waters while females travel further upstream (Harris, 1985).

Not enough juvenile Australian bass could be captured in the field for the experiments. Hence, juveniles were obtained from the Aquaculture Marine Hatchery facilities at the Port Stephens Fisheries Centre (NSW Fisheries, Taylors Beach) in October and November in 2001, and in November and December 2002.

7.2.1.4. School prawn

The school prawn (*Metapenaeus macleayi*) (Haswell) (Family Penaeidae) is endemic to Australia, and inhabits coastal rivers from Tin Can Bay (Qld) to Corner Inlet (Vic) (Ruello, 1973). Postlarvae and juveniles are found in brackish and freshwater areas of estuaries throughout the year (Racek, 1959; Ruello, 1973; Glaister, 1977), while adults predominantly inhabit inshore ocean waters (Racek, 1959; Ruello, 1973).

The species is catadromous, migrating to the ocean to spawn. The spawning run takes place during spring – summer (Racek, 1959; Ruello, 1973; Glaister, 1978a), and spawning occurs from February to May (Racek, 1959; Ruello, 1977; Glaister, 1978b). In NSW, postlarvae (6 - 8 mm TL) enter estuaries in summer and early autumn (Racek, 1959; Ruello, 1973; Maguire, 1980). In Queensland, postlarvae enter the Noosa River between April and June (Coles and Greenwood, 1983), while in southern Moreton Bay postlarvae (1 - 10 mm CL) were most abundant in summer (November to March) (Young, 1978). Juveniles move upstream and generally inhabit brackish areas during autumn and winter, although smaller individuals are found up into the freshwater reaches (Racek, 1959; Ruello, 1973).

Due to their small size, we were unable to capture juvenile school prawns while entering coastal estuaries. Rather, we captured immature, juvenile schoolprawns in upper and lower estuaries on their summer migration to the ocean. In 2002, juvenile school prawns were captured using a try-net in the Karuah River during the day (January – March), and the Hunter River at night (February). More juvenile school prawns were captured in the Port Stephens estuary at night, by seine net (February) and dipnet (March – April). In 2003, juvenile school prawns were captured using a commercial otter trawl in the Hunter river from January to March.

Table 7.1. Conditions during preference – avoidance runs, including mean temperature (˚C), pHc, and salinity (g/L), and average mean length (SL or TL) (± SD), conducted with juvenile (a) *Pagrus auratus*, (b) *Acanthopagrus australis* (wild), (c) *A. australis* (hatchery), (d) *Macquaria novemaculeata*, and (e) *Metapenaeus macleayi*. Number of preference-avoidance runs is given for each species.

	Mean	s.d.	Minimum	Maximum
(a) *Pagrus auratus* (n=17)				
pH_c	8.1	0.1	8.0	8.3
Temperature (˚C)	15.1	0.8	13.8	16.5
Salinity (g/L)	30.3	2.9	20.3	33.4
Mean SL (mm)	29	4	22	37
(b) *Acanthopagrus australis* (n=24)				
pH_c	8.0	0.1	7.8	8.2
Temperature (˚C)	22.9	2.3	18.3	25.7
Salinity (g/L)	33.4	1.8	28.6	36.5
Mean SL (mm)	34	10	22	49
(c) *Acanthopagrus australis* (n=22)				
pH_c	8.1	0.1	8.0	8.3
Temperature (˚C)	19.5	1.0	17.7	21.4
Salinity (g/L)	33.0	1.7	28.0	34.5
Mean SL (mm)	17	1	16	21
(d) *Macquaria novemaculeata* (n=43)				
pH_c	7.4	0.4	6.7	8.5
Temperature (˚C)	23.5	2.1	17.9	27.3
Salinity (g/L)	0.5	0.1	0.2	1.0
Mean SL (mm)	19	2	15	24
(e) *Metapenaeus macleayi* (n=47)				
pH_c	8	0.1	7.6	8.2
Temperature (˚C)	24.1	0.8	22.3	25.9
Salinity (g/L)	34.4	2.1	30.1	36.5
Mean TL (mm)	85	7	62	95

7.2.2. *Operating procedures*

The experiments were conducted using the fluviarium system described in Chapter 6. Here, we only describe the operating procedures when conducting a run; see Chapter 6 for more detailed information on the system.

In control runs, untreated water was added to both lateral halves of the fluviarium. In experimental runs, untreated water was added to one lateral half, while a test solution (e.g. acidified water) was added to the supply line of the other half. The experimental and control channel were alternated randomly to negate any bias fish or prawns may have had for either side of the fluviarium.

Before starting a run, a container with acid solution (experimental run) or water (control run) was prepared, and placed under one of the Mazzei injectors (Figure 6.1a). The fluviarium was then filled with water (i.e. not acidified), using the recycling mode, ensuring that the two flow meters (Figure 6.1a) were set correctly for laminar flow. A flow of 20 litres min^{-1} resulted in a laminar flow (Figure 6.2b). The video camera was positioned correctly and the pH probe was set up in the experimental channel (i.e. the channel that was going to receive acidified water).

Ten naïve juvenile fish or adult prawns were gently transferred from one of the holding tanks into the test area. They were left to settle for at least fifteen minutes to establish themselves in the test area. Black panda plastic around the test area was closed to prevent visual disturbance from affecting fish behaviour. Time of introduction of juveniles was noted, and video recording was started remotely.

Fifteen minutes after introduction, a 70-minute run was started by changing from recycling mode to flow-through mode, and turning on the Mazzei injectors. This resulted in acid solution (experimental run) or water (control run) being added to the water entering the test area via the experimental channel. To confirm a drop in pH, pH profiles of water flowing through the test area were obtained by measuring pH in the experimental lateral half of the intake area every 30 seconds. The pH profile was measured until it stabilised, generally five minutes after the Mazzei injectors were turned on. The pH of the untreated channel was also checked, and temperature (ºC) and salinity (g/L) were measured in both channels. Subsequently, the run continued without anyone present in the tunnel house to minimise potential observer effects on the animals (Martin and Bateson, 1993).

At the end of each run, all ten animals were collected from the test area and measured. Standard length was measured for fish (SL, from tip of the snout to caudal peduncle, 1 mm), while total length was measured for prawns (TL, 1 mm). Subsequently, animals were returned to the holding facilities. To ensure that individuals were tested only once, used animals were kept in a separate holding tank. The fluviarium and foam blocks were rinsed and cleaned thoroughly between experiments.

7.2.3. *Data analyses*

The behavioural response of fish and prawns to two different water qualities (i.e. pH levels) was assessed as follows. One image from the video footage was grabbed every minute using ‘frame grabber’ software (Scion LG3), giving 60 images or frames per run. To ensure individuals had sufficient time to show a preference, and thus prevent a mean biased over time, the first frame was grabbed ten minutes after a run had started. For each frame, the position of each individual (i.e. position of the snout) was determined visually, and the number of individuals in each lateral half of the test area was counted. This procedure was repeated for all 60 images. Subsequently, the mean percentage of individuals in each lateral half of the test area was determined for all 60 frames combined. This gave a mean proportion of individuals in the experimental half of the test area over a 60 minute run. This mean proportion was considered the behavioural response of the individuals in that particular run, and was entered as a single replicate in the data analysis. In control runs, a flip of a coin determined the "experimental half" of the test area.

The following analyses were conducted for each species separately, and for wild and hatchery-reared *A. australis* separately. First, to examine whether a behavioural avoidance response existed the individual replicates were plotted against pH_e. A linear regression was fitted to the relationship between the behavioural response and pH_e. The responsiveness of each species to pH_e was measured as the slope of the fitted lines.

Second, to examine whether other variables may have affected the behavioural responses, Principal Component Analysis (PCA) with Varimax rotation (Manly, 1984) was used. Of particular interest were (1) the pH difference (ΔpH) between the control (pH_c) and experimental (pH_e) channel ($\Delta pH = pH_c - pH_e$), (2) temperature (T), and (3) salinity of the water used in a run, and (4) mean length of individuals used in a run. These variables could not be held constant in runs for any of the species, since (i) runs were conducted in two subsequent years for three out of four species (*A. acanthopagrus* (wild), *M. novemaculeata*, *M. macleayi*), and (ii) runs within a year were conducted over a period of two to three months for all four species. In particular, ΔpH was included because similar amounts of sulfuric acid added to either estuarine or bore water did not always result in similar pH_e due to variations in pH_c (see Table 2). Thus, ΔpH rather than pH_e could have been the main variable affecting behavioural responses. Preliminary correlation analyses revealed strong and significant correlations between the five variables (pH_e, ΔpH, temperature, salinity, mean length). PCA was used to define variables that could be used to summarise relationships among sets of these interrelated variables, for each species separately. Subsequently, the principal component scores for each run (i.e. actual values of individual cases for the principal components) were used as independent variables in a multiple regression model, with the behavioural response as dependent variable.

7.3. Results

7.3.1. Snapper *(Pagrus auratus)*

We conducted 17 runs for snapper in 2001. Unfortunately, all runs done in 2002 (36 in total) could not be reliably analysed due to water temperatures being too low for juvenile snapper (B. Bardsley, NSW Fisheries, pers. comm.), resulting in snapper not responding to the sulfuric acid. Mean values (± sd) of pH_c, T and salinity for these runs are given in Table 7.1a. Average mean SL was 29 mm (± 4 SD), ranging from a mean minimum of 22 mm to a mean maximum of 37 mm (Table 7.1a). This size range coincides with the size range at which juvenile snapper would be migrating into estuaries and bays (Francis, 1994; Ferrell and Sumpton, 1997; Neira *et al*., 1998).

Avoidance behaviour of juvenile snapper significantly increased with a decrease in pH_e ($F_{(1,15)}$ = 28.78, R^2 = 0.66, p = 0.00008, Table 7.2a). On average, juvenile snapper were equally distributed across the two channels during control runs (mean 47.3 % ± 10.4 SD, n = 5, Figure 7.1a). Juvenile snapper started to avoid the experimental channel when given a choice between water with pH 8.1 and water with pH 7.5 (Figure 7.1a). When given a choice between pH 8.1 and 6.9, the average behavioural response was almost 100% avoidance of the more acidic water (pH 6.9) (Figure 7.1a).

Preference-avoidance behaviour of juveniles was further analysed by examining the relationships between behavioural response, and water quality / fish size principal components. PCA with Varimax raw rotation identified two main trends in the variance of water quality / fish size components: i) a negative relationship between pH_e and ΔpH (PC 1, accounting for 45% total variation), and, ii) a positive relationship between T and mean SL (PC 2, accounting for 24% total variation, Table 7.3). Multiple regression analysis revealed that the behavioural response of juvenile snapper was significantly and positively related to PC 1 (B = 15.16, p = 0.001), but not to PC 2 (B = -0.62, p = 0.87, Table 7.4a).

7.3.2. Yellowfin bream *(Acanthopagrus australis)*

Twenty-four runs were conducted with wild yellowfin bream (11 in 2001, 13 in 2002). Mean values (± sd) of pH_c, T and salinity for these runs are given in Table 7.1b. Average mean SL was 34 mm (± 10 SD), ranging from a mean minimum of 22 mm to a mean maximum of 49 mm (Table 7.1b). This size range coincides with the size range at which juvenile yellowfin bream migrate into shallow estuarine areas (Blaber and Blaber, 1980; Pollock *et al*., 1983; Worthington *et al*., 1992; Neira *et al*., 1998).

Avoidance behaviour of wild juvenile yellowfin bream significantly increased with a decrease in pH_e ($F_{(1,22)} = 14.76$, $R^2 = 0.40$, $p < 0.0009$, Table 7.2b). On average, juvenile yellowfin bream were equally distributed across the two channels during control runs (mean 54.5 ± 15.2 SD, n=2, Figure 7.1b). Juveniles started to avoid the experimental channel when given a choice between water with pH 8.1 and water with pH 7.5 (Figure 7.1b). This avoidance response increased when given a choice between pH 8.0 and 6.9, to an average of approximately 85% avoidance when given a choice between pH 8.0 and 6.5 (Figure 7.1b).

PCA with Varimax raw rotation identified two main trends in the variance of water quality / fish size components: i) a negative relationship between pH_e and ΔpH (PC 1, accounting for 41% total variation), and, ii) a positive relationship between temperature and mean SL (PC 2, accounting for 40% total variation, Table 7.3). Multiple regression analysis revealed that the behavioural response of juvenile yellowfin bream was significantly and negatively related to PC 1 (B = -10.85, p = 0.00003), but not to PC 2 (B = -3,40, p = 0.11, Table 7.4b).

Twenty-two runs were also conducted with hatchery-reared yellowfin bream in 2002. Mean values (± sd) of pH_c, T and salinity for these runs are given in Table 7.1c. Average mean SL was 17 mm (± 1 SD), ranging from a mean minimum of 16 mm to a mean maximum of 21 mm (Table 7.1c). This size range coincides with the size range at which juvenile yellowfin bream migrate into shallow estuarine areas (Blaber and Blaber, 1980; Pollock *et al*., 1983; Worthington *et al*., 1992; Neira *et al*., 1998).

Avoidance behaviour of hatchery-reared juvenile yellowfin bream significantly increased with a decrease in pH_e ($F_{(1,20)} = 40.60$, $R^2 = 0.67$, $p < 0.00001$, Table 7.2c). On average, juvenile yellowfin bream were equally distributed across the two channels during control runs (mean 65.2 ± 23.8 SD, n = 2, Figure 7.1c). Juveniles started to avoid the experimental channel when given a choice between water with pH 8.1 and water with pH 7.5 (Figure 7.1c). This avoidance response increased when given a choice between pH 8.1 and 7.0, to almost 100% avoidance when given a choice between pH 8.0 and 6.6 (Figure 7.1c).

PCA with Varimax raw rotation identified two main trends in the variance of water quality / fish size components: i) a negative relationship between pH_e and ΔpH (PC 1, accounting for 43% total variation), and, ii) a negative relationship between salinity and mean length (PC 2, accounting for 38% total variation, Table 7.3). Multiple regression analysis revealed that the behavioural response of juvenile yellowfin bream was significantly and positively related to PC 1 (B = -18.12, p = 0.000006, Table 4c), but not to PC 2 (B = -1.12, p = 0.71, Table 7.4c).

7.3.3. Australian bass *(Macquaria novemaculeata)*

Forty-three runs were conducted with Australian bass (8 in 2001, 35 in 2002). Mean values (± sd) of pH_c, T and salinity for these runs are given in Table 7.1d. Average mean SL was 19 mm (± 2 SD), ranging from a mean minimum of 15 mm to a mean maximum of 24 mm (Table 7.1d). This size range coincides with the size range at which juvenile Australian bass migrate from lower estuaries into upstream habitat (Harris 1986b).

Avoidance behaviour of juvenile Australian bass significantly increased with a decrease in pH_e ($F_{(1,41)} = 20.21$, $R^2 = 0.33$, $p < 0.00006$, Table 7.2d). On average, juvenile Australian bass were equally distributed across the two channels during control runs (mean 45.4 ± 21.4 SD, n = 13, Figure 7.1d). Juvenile Australian bass started to avoid the experimental channel when given a choice between water with pH 7.4 and water with pH 6.9 (Figure 7.1d). This avoidance response increased to an average of approximately 90% avoidance, when given a choice between pH 7.3 and 6.5 (Figure 7.1d).

PCA with Varimax raw rotation identified two main trends in the variance of water quality / fish size components: i) a negative relationship between pH_e and ΔpH (PC 1, accounting for 37% total variation), and, ii) a positive relationship between temperature and mean length (PC 2, accounting for 33% total variation, Table 7.3). Multiple regression analysis revealed that the behavioural response of juvenile Australian bass was significantly and positively related to PC 1 (B = -13.78, p < 0.00001), but not to PC 2 (B = -1.59, p = 0.53, Table 7.4d).

7.3.4. School prawn *(Metapenaeus macleayi)*

Forty-seven runs were conducted with school prawn (19 in 2002, 28 in 2003). Mean values (± sd) of pH_c, T and salinity for these runs are given in Table 7.1e. Average mean TL was 85 mm (± 7.2 SD), ranging from a mean minimum of 62 mm to a mean maximum of 95 mm (Table 7.1e). This size range coincides with the size range at which immature schoolprawn migrate from brackish estuarine areas to the ocean (Ruello, 1973).

Avoidance behaviour of juvenile school prawns significantly increased with a decrease in pH_e ($F_{(1,45)} = 59.42$, $R^2 = 0.57$, $p < 0.000001$, Table 7.2e). On average, juvenile school prawns were equally distributed across the two channels during control runs (mean 46.2 ±13.4 SD, n=8, Figure 7.1e). Juvenile school prawn started to avoid the experimental channel when given a choice between water with pH 7.9 and water with pH 5.9 (Figure 7.1e). This avoidance response increased to an average of approximately 80% avoidance, when given a choice between pH 8.0 and 5.0 (Figure 7.1b).

PCA with Varimax raw rotation identified two main trends in the variance of water quality / prawn size components: i) a negative relationship between pH_e and ΔpH (PC 1, accounting for 42% total variation), and, ii) a negative relationship between temperature and mean length (PC 2, accounting for 28% total variation, Table 7.3). Multiple regression analysis revealed that the behavioural response of juvenile school prawn was significantly and negatively related to PC 1 (B = 11.99, p < 0.00001), but not to PC 2 (B = 1.49, p = 0.32, Table 7.4e).

Table 7.2. Results of multiple regression, using pHe as independent and behavioural response as dependent variables, or preference - avoidance runs conducted with juvenile (a) *P. auratus*, (b) *A. australis* (wild), (c) *A. australis* (hatchery), (d) *M. novemaculeata*, and (e) *M. macleayi*.

a) *Pagrus auratus* $F_{(1,15)} = 28.68$, $R^2 = 0.66$, $p < 0.0001$

Variable	B	S.E. of B	$t_{(15)}$	p
Intercept	-248.41	50.75	-4.90	0.0002
pH_e	36.10	6.75	5.36	0.00008

b) *Acanthopagrus australis* (wild) $F_{(1,22)} = 14.76$, $R^2 = 0.40$, $p < 0.00089$

Variable	B	S.E. of B	$t_{(22)}$	p
Intercept	-121.73	40.78	-3.00	0.007
pH_e	21.73	5.66	3.84	0.0009

c) *Acanthopagrus australis* (hatchery) $F_{(1,20)} = 40.60$, $R^2 = 0.67$, $p < 0.00001$

Variable	B	S.E. of B	$t_{(20)}$	p
Intercept	-300.80	51.67	-5.82	0.00001
pH_e	45.14	7.09	6.37	0.000003

d) *Macquaria novemaculeata* $F_{(1,41)} = 20.21$, $R^2 = 0.33$, $p < 0.00006$

Variable	B	S.E. of B	$t_{(41)}$	p
Intercept	-129.73	35.33	-3.67	0.0007
pH_e	22.68	5.05	4.50	0.00006

e) *Metapenaeus macleayi* $F_{(1,45)} = 59.42$, $R^2 = 0.57$, $p < 0.000001$

Variable	B	S.E. of B	$t_{(45)}$	p
Intercept	-32.12	8.78	-3.66	0.0007
pH_e	10.33	1.34	7.71	<0.0000001

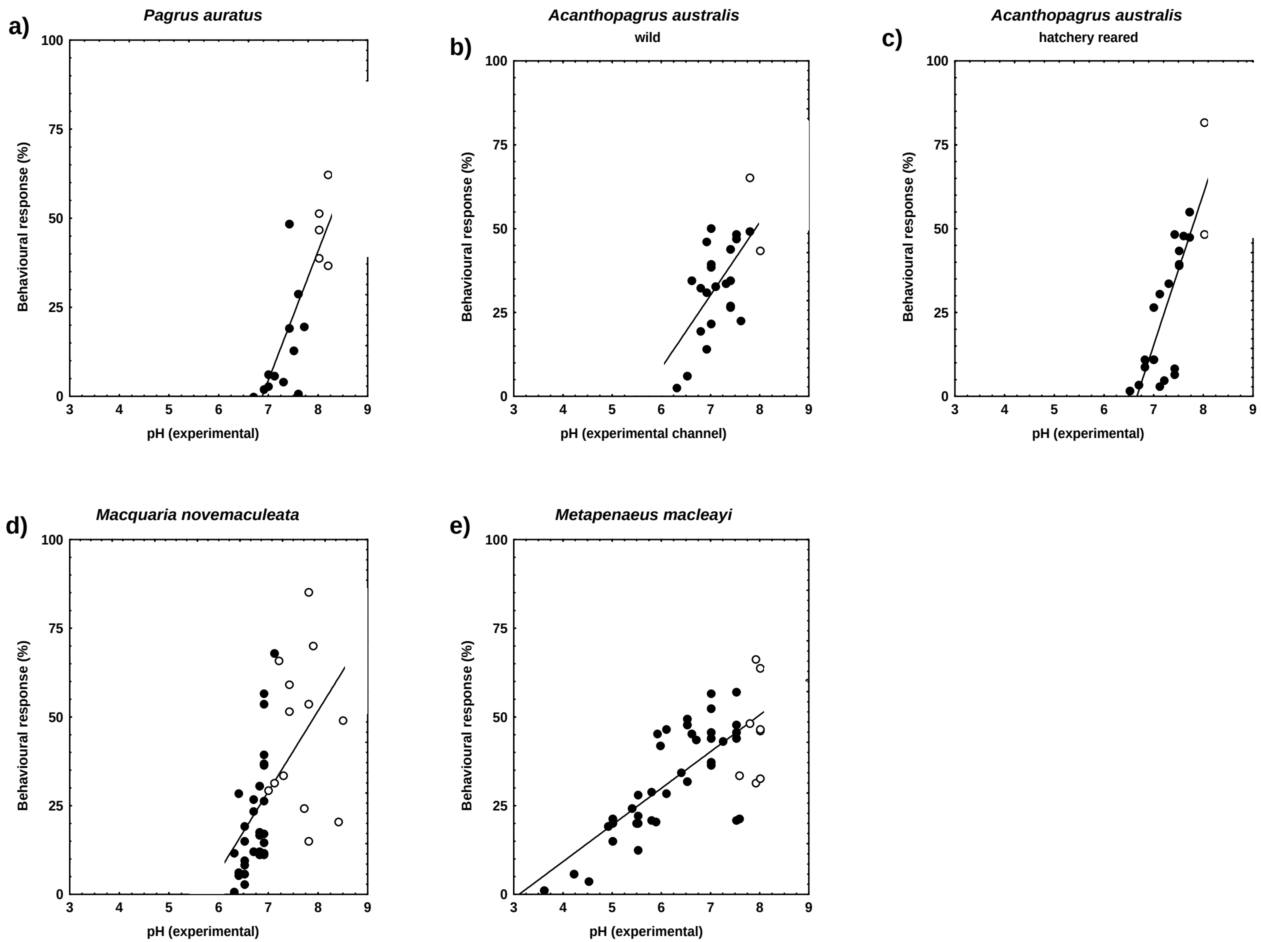


Figure 7.1. Behavioural response (%) of juvenile (a) *Pagrus auratus*, (b) *Acanthopagrus australis* (wild), (c) *A. australis* (hatchery reared), (d) *Macquaria novemaculeata*, and (e) *Metapenaeus macleayi*, when given a simultaneous choice between two water qualities (i.e. sulfuric acid) in paired channels of a laboratory stream. Green circles are control runs, and red circles are experimental runs. See Chapter 6 for detailed description of methods.

Table 7.3. Principal component loadings examining trends in variance of five parameters, for each species studied. Bold numbers are parameters that contributed >70% to principal components. Percentage of total variance accounted for by each principal component is given in parentheses.

PCA	*Pagrus auratus*		*Acanthopagrus australis* (wild)		*Acanthopagrus australis* (hatchery)		*Macquaria novemaculeata*		*Metapenaeus macleayi*	
Components	PC 1 (45 %)	PC 2 (24 %)	PC 1 (41 %)	PC 2 (40 %)	PC 1 (43 %)	PC 2 (38 %)	PC 1 (37 %)	PC 2 (33 %)	PC 1 (42 %)	PC 2 (28 %)
pH_e	**0.95**	-0.01	**-0.96**	0.10	**-0.98**	0.13	**-0.92**	0.03	**0.99**	0.05
ΔpH	**-0.96**	-0.04	**0.98**	-0.04	**0.96**	0.02	**0.82**	0.32	**-0.98**	0.00
Salinity (g/L)	0.53	0.38	0.39	0.51	-0.02	**-0.93**	-0.56	-0.03	0.33	0.53
Temperature (°C)	-0.25	**0.72**	0.03	**-0.92**	0.50	0.38	0.11	**0.86**	0.14	**-0.71**
Mean length (mm)	0.24	**0.74**	0.15	**-0.94**	-0.12	**0.94**	0.07	**0.89**	0.08	**0.78**
Eigenvalue	2.29	1.16	2.15	1.91	2.15	1.90	2.16	1.32	2.13	1.36

Table 7.4. Multiple regression results using Principal Component Analyses. Transformed variables were used as independent, and behavioural response as dependent variables.

a) *Pagrus auratus* $F_{(2,14)} = 7.82$, $R^2 = 0.53$, $p < 0.005$

Variable	B	S.E. of B	$t_{(14)}$	p
Intercept	22.84	3.72	6.14	0.00003
PC 1	15.16	3.84	3.95	0.001
PC 2	-0.62	3.84	-0.16	0.87

b) *Acanthopagrus australis* (wild) $F_{(2,21)} = 15.39$, $R^2 = 0.59$, $p < 0.00008$

Variable	B	S.E. of B	$t_{(21)}$	p
Intercept	33.91	2.01	16.90	<0.000001
PC 1	-10.85	2.05	-5.29	0.00003
PC 2	-3.40	2.05	-1.66	0.11

c) *Acanthopagrus australis* (hatchery) $F_{(2,19)} = 19.34$, $R^2 = 0.67$, $p < 0.00003$

Variable	B	S.E. of B	$t_{(19)}$	p
Intercept	27.92	2.85	9.79	<0.000001
PC 1	-18.12	2.92	-6.21	0.000006
PC 2	-1.12	2.92	-0.38	0.71

d) *Macquaria novemaculeata* $F_{(2,40)} = 15.19$, $R^2 = 0.40$, $p < 0.00001$

Variable	B	S.E. of B	$t_{(40)}$	p
Intercept	28.64	2.49	11.52	<0.00001
PC 1	-13.78	2.52	-5.48	<0.00001
PC 2	-1.59	2.52	-0.63	0.53

e) *Metapenaeus macleayi* $F_{(2,44)} = 33.16$, $R^2 = 0.60$, $p < 0.00001$

Variable	B	S.E. of B	$t(45)$	p
Intercept	34.57	1.47	23.55	<0.00001
PC 1	11.99	1.48	8.08	<0.00001
PC 2	1.49	1.48	1.00	0.32

7.4. Discussion

The results support the predictions that juvenile fish and prawn can detect a difference in acidity, and avoid low concentrations of acid when given a choice. The results showed that juveniles of all four species examined avoided acidified water, with snapper showing the strongest avoidance response and school prawn the weakest. However, other variables such as ΔpH, temperature, salinity, and mean length of individuals used in a run may have affected the behavioural responses, as they could not be kept constant over the timeframes the experiments were conducted. For all four species, PCA and multiple regression analyses showed that the behavioural response of juveniles was strongly and significantly related to PC 1, which described a relationship between pH_e and ΔpH, but not to PC 2, which described a relationship between other variables (Table 3, 4). Thus, for all four species the behavioural response of juveniles was related to the acidity of the water, and not to the other variables examined.

This study indicates that the acidic component of acid sulfate discharge alone has the potential to affect migration of the species studied in the field. First, the pH levels avoided in these experiments were well within the magnitude of natural systems (Sammut *et al*., 1996; White *et al*., 1997; Preda and Cox, 2001). In addition, the distributions of the four study species overlap with the distribution of coastal acid sulfate soil in eastern Australia (National Working Party on Acid Sulfate Soils 2000). Furthermore, the size range of juveniles used for all four species coincides with the size range at which these juveniles may encounter acid sulfate soil discharge while migrating through a coastal estuary. Other components of acid sulfate discharge, such as dissolved aluminium and dissolved iron, may affect migration as well but were not examined here. For example, laboratory studies showed that behavioural avoidance of acid water with dissolvded aluminium was stronger than of acid water alone, in juvenile brook charr (*Salvelinus fontinalis*) (Gunn and Noakes, 1986), lake charr (*S. namaycush*) (Gunn *et al*., 1987), and brown trout (*Salmo trutta*) (Åtland, 1998). In contrast, no behavioural avoidance response to dissolved aluminium was documented at pH 5.0 for juvenile lake charr (*S. namaycush*) (Gunn *et al*., 1987) and Atlantic salmon (*Salmo salar*) (Åtland and Barlaup, 1996). This suggests that behavioural avoidance of dissolved aluminium may be triggered by low pH, at least in salmonids.

This study is the first to document acid avoidance behaviour in an invertebrate species, and in Australian fish species. Laboratory studies on impacts of acid rain have documented avoidance behaviour of low pH levels in fish species in Europe (Höglund, 1961; Davies, 1991; Åtland and Barlaup, 1996; Åtland, 1998) and North America (Jones *et al*., 1985; Gunn and Noakes, 1986; Gunn *et al*., 1987; Peterson *et al*., 1988; Newman and Dolloff, 1995). Field observations of acid avoidance behaviour in fish or invertebrates are scarce; such behaviour is usually inferred from lack of fish in acidic zones (e.g. Johnson and Webster, 1977; Åtland and Barlaup, 1996).

The observed difference in acid avoidance behaviour between the four species (Figure 3) may be related to differences in natural distribution, life history stage, and chemosensory detection of the acid. First, the strength of the species' responses may be related to the acid buffering capacity of the water the juveniles occur in. Snapper live in the marine environment (Kailola *et al*., 1993), with juveniles and small adults occurring in estuaries and bays (Francis, 1994; Neira *et al*., 1998). These environments would naturally be well buffered against pH fluctuations. In contrast, school prawn may have encountered and adapted to fluctuations in pH, as they generally inhabit brackish and freshwater areas during autumn and winter as juveniles (Racek, 1959; Ruello, 1973). These are generally the areas were acid sulfate soils are located in Australian coastal floodplains (e.g. Tulau and Naylor, 1999). Examination of the behavioural response of postlarvae or small juvenile school prawn to acidified water, when migrating upstream, would elucidate whether such adaptation does occur. The estuarine distribution of juvenile yellowfin bream and Australian bass (Blaber and Blaber, 1980; Pollock *et al*., 1983; Harris, 1986b; Worthington *et al*., 1992), as well as the strength of their behavioural responses, is intermediate compared to the juveniles of the other two species (Figure 3). The response of yellowfin bream was stronger in hatchery-reared juveniles than in those caught in the wild (Figure 3b, c). While this difference may be partly due to an effect of rearing environment, wild juveniles were also significantly larger than hatchery-reared ones (Table 1), and an effect of size can thus not be excluded.

Second, chemosensory detection of acid most likely differs between fish and prawns, given the differences in structure and function in chemoreceptors in fish (Caprio, 1988) and prawns (Laverack, 1988), and may affect behavioural response to low concentrations of acid. School prawn often remained in the acidified side of the test area followed by a quick retreat to the non-acidified side, whereas juveniles of all three fish species would rapidly return to the non-acidified side. Yet, chronic acid exposure is most likely detrimental to survival of school prawn. Growth of the closely related black tiger prawn, *Penaeus monodon*, was significantly reduced during chronic exposure to acidified seawater ($pH \leq 5.5$) compared to growth at $6.1 \leq pH \leq 7.8$, and mortality occurred at $pH \leq 5.1$ (Allan and Maguire, 1992). This poses the interesting possibility that school prawn do not express avoidance behaviour to low concentrations of acid, despite having physiological sensitivity to it.

Behavioural observations on fish and prawns in a laboratory situation, such as conducted during this study, may not necessarily be directly applicable to the species' natural habitat. Preference - avoidance behaviour in the field will be affected by a number of other motivational or environmental factors, including reproduction, competition, feeding, predation, as well as water quality, water velocity, and habitat availability. These other factors may override potential avoidance of acid sulfate discharge, especially if there is no physiological cost to do so. For example, the presence of suitable habitat may alleviate strong avoidance behaviour to low acid levels, as has been shown for zinc avoidance by fathead minnows (*Pimephales promelas*) (Korver and Sprague, 1989).

The avoidance response of fish and prawn species to acidified water in the laboratory may also simply reflect a preference for water with a higher pH, and may not necessarily be related to the species' physiological tolerance. This does not appear to be the case for juvenile snapper, which do not survive exposure to pH 7.0 for prolonged period of time (S. Fielder, NSW Fisheries, pers. comm.). In addition, low levels of acidity most likely affect growth and survival of school prawn, as it does in the closely related *P. monodon* (Allan and Maguire, 1992). On the other hand, survival of juvenile Australian bass (20-23 mm) exposed to $pH \geq 4.0$ was similar to that in untreated freshwater (pH unreported) after 96 hours (Hyne and Wilson, 1997). However, survival at pH 4.0 was reduced to 65% when 500 ug $litre^{-1}$ aluminium was added (Hyne and Wilson, 1997). I am not aware of any comparative information for yellowfin bream. In a review on consequences of acidic precipitation for aquatic ecosystems, Haines (1981) concluded that pH at which reproductive failure may occur in the laboratory is generally in agreement with field pH known to affect a species. Moreover, the lowest pH in the field is generally higher than the lowest pH in the laboratory, possibly because associated trace metals may be present in the field (Haines, 1981). Hence, it is highly likely that the pH levels shown to cause avoidance behaviour in this study affect migration patterns of the species studied in the field.

In summary, the result indicates that the acidic component of acid sulfate discharge alone has the potential to affect migration of the species examined in the field. If juvenile snapper, yellowfin bream and Australian bass avoid such discharges, large parts of potential nursery habitat may not be used. If juvenile school prawns avoid such discharges on their migration to the ocean, spawning migrations may be disrupted. This may eventually result in recruitment failure in areas with acid sulfate discharge, and could thus have potential effects on stock size. Hence, the suggestion that the population collapse of the Australian bass in the Hastings and Manning rivers (New South Wales), due to recruitment failure, can be partially attributed to acid sulfate discharge (Harris, 1989, pers. comm.), is thus entirely plausible.

8. EXTENSION AND COMMUNICATION ACTIVITIES

8.1. Introduction

A Joint Communication Strategy for both NSW Agriculture and NSW Fisheries was adopted during the August 2000, CFP meeting (see Appendix 6). The aim behind the strategy was to make the research findings available in an appropriate format to various audiences, so that on-ground change would result from the research projects. The combined communication strategy encompassed both research projects, was strategically planned, involved a variety of formats, and has continued beyond the duration of at least this research project.

Specific extension and communication activities conducted as part of this Joint Communication Strategy, as well as activities conducted in addition to this Strategy, are outlined in detail in Table 8.1, and summarised in Table 8.2. In total, 107 activities were conducted, approximately 20% of which were targeted at commercial and recreational fishing activities.

8.2. Commercial fishers and recreational angling groups

In total, 21 activities were targeted at commercial fishers and recreational angling groups. For the commercial fishers, this included two articles in R&D News, two articles in The Queensland Fishermen, one article in Fisheries NSW, presentations to Estuarine General MAC and Estuarine Prawn Trawl MAC meetings, distribution of CFP newsletters via the Clarence River Fishermans Cooperative to all its members, and a short presentation of the project to commercial fishermen in Maclean during a Set Pocket Net Draw. In addition, fifty A3 posters outlining the research project were handed or mailed out to Fishermans Cooperatives in coastal NSW and their equivalents in QLD. Invitations were also sent to the Clarence River Fishermans Cooperative for the Community Forum in Maclean (June 2001), and for the Project Review meeting in Grafton (October 2003). Specific activities targeting recreational angling groups included talks to four recreational angling groups within identified acid sulfate soil catchments.

8.3. Local landholders in the Clarence river floodplain

Local landholders in the Clarence river floodplain involved with the research project were always contacted prior to a field trip, to discuss our planned date and time for sampling their sites. In addition, we always tried to meet the landholders in person when in the field, to discuss findings from the last and current field trip. Landholders were further kept up-to-date through distribution of Fisheries NSW and CFP newsletters containing articles on our project.

One-to-one meetings were held with 11 of the (then) 12 landowners involved with the research project in the Clarence river floodplain in 2000 and 2001. The objectives of these meetings were: (i) to inform individual landowners about our research findings in their particular drainage system, and, (ii) to gain information relating to the long term (i.e. since construction) and short term (i.e. since last sampled) history of their drainage system. Landowners were given a summary of information relevant to their drainage system to date in the form of 2-3 A4 pages, including graphs and pictures. Meetings generally lasted 1/2 – 2 hrs, depending on the availability and interest of the landowner. Additional meetings are scheduled to take place in 2004 to present the final report and final results.

Finally, we invited all landholders involved to a thank-you BBQ during our last field trip.

8.4. Scientific and general community

The scientific community was kept informed about our project through eight seminars, six presentations at national and international conferences, and two articles in internationally refereed journals (others are planned).

The general community was kept informed about our project through the media, including twelve articles in local newspapers, three radio interviews, and two segments on TV.

8.5. Development of guidelines for floodgate specifications and management

A new set of guidelines entitled '*Guidelines for managing floodgate and drainage systems on coastal floodplains*' has been produced as a result of collaborative research between NSW Fisheries (this project) and NSW Agriculture ("*Hydrologic effects of floodgate management on coastal agriculture*", DAN 13). During the process of developing the guidelines, the Floodgate Guidelines Working Party met seven times (Table 8.1d). This Working Party included members of NSW Fisheries, NSW Agriculture, Clarence Floodplain Project, Department of Land and Water Conservation, and the Clarence River Fish Coop. The Working Party requested feedback on various draft versions from the CFP and the RDC bodies, and comments and suggestions were subsequently integrated into a new draft. A draft of this document was distributed to key stakeholders in May 2003 and feedback was integrated into a final draft. This new draft guidelines document was presented at a project review meeting in Grafton in October 2003. Senator Judith Troeth launched the new set of guidelines in Grafton in January 2004.

8.6. Discussion

The Joint Communication Strategy worked well. We believe we were successful in communicating effectively with both landholders and fishers, as they frequently commented upon the project, noting the 'courteous and helpful manner' in which our team presented itself. Both commercial and recreational fishers clearly appreciated the opportunity to be informed of research relevant to their local fisheries. Nevertheless, often we did not receive any feedback from commercial fishers, making it difficult to assess whether our communication had been effective or not.

Meetings with landholders also appeared to be useful from the perspective of the landowners. With the exception of one landowner, all viewed the information presented as highly informative and useful. They appreciated the time and effort invested in keeping them abreast of developments. All parties benefited from the opportunity to discuss issues relating to drainage systems examined, and the topic of acid sulfate drainage and flood mitigation techniques in general. From the perspective of the project, these meetings were very useful, providing valuable information about the drainage systems studied and local area, as well as further improving communication between landowners and NSW Fisheries. The largest benefit, however, was in providing an opportunity to illustrate the ill-effects of unmanaged floodgates on their property in a non-threatening circumstance.

Finally, to improve future extension and communication strategies for similar projects, we recommend that these strategies should include an evaluation component. This would ensure that communication and extension strategies are effective and efficient, and that on-ground change will result from the research projects. An evaluation of the effectiveness of the new set of guidelines would provide a first step in that direction.

Table 8.1. Extension and communication activities undertaken during and after the conclusion of the project. Specific communication activities as outlined in the Communication Strategy (Appendix 6), and activities in addition to those in the Strategy are given as a) presentations, b) articles, c) media coverage, and d) various (incl. meetings).

Table 8.1a. **Presentations**

Year	Date	Responsible	Event
2000	Jun-16	FK & MB	Technical report to FRDC and CFP steering committee
	Aug-07	MB	Hunter Native Fish (NFA)
	Aug-10	MB	Australian Society for Fish Biology, Annual Conference, Albury (poster)
	Aug-18	FK	The Way Forward on Weirs (Inland Rivers Network) (poster)
	Aug-25	MB	Clarence River Basscatch
	Sep-01	FK	Port Stephens Fisheries Centre, NSW Fisheries, Taylors Beach
	Sep-15	MB	Macleay River Basscatch
	Sep-13	MB	Clarence River FCA
	Nov. 12	FK	Set prawn pocket net draw – Maclean
	Nov-13	MB	Grafton Districts Anglers Club
	Dec-15	FK	Technical report to FRDC and CFP steering committee
2001	Feb-08	FK	Port Stephens Acid Sulfate Soils Local Action Committee, Raymond Terrace
	Feb-22	FK	Estuarine General MAC meeting, Cronulla
	Mar-02	FK	Estuarine Prawn Trawl MAC meeting, Cronulla
	Apr-08	FK	Aquatic Ecology & Media Training Workshop, Grafton
	May-01	FK	University of Newcastle, CIVL 459 Environmental Engineering Design, Newcastle
	June 22/23	FK	Community Forum, Maclean
	June 26/27	FK	Technical report to FRDC and CFP steering committee
	Aug-14	FK	FRDC Board, PSFC Taylors Beach
	Aug-30	FK	ASSMAC Meeting No. 35, Grafton
	Sept.-27	FK	Australian Society for Fish Biology, Annual Conference, Bunbury
	Dec-11	AB	Improving the Quality of Drainage Water from NSW Canelands meeting, Harwood
2002	Feb-08	AB	Technical report to FRDC and CFP steering committee, Maclean
	Feb-14	FK	School of Environmental and Applied Sciences, Griffith University, Gold Coast Campus
	Mar-05	FK	Northern Fisheries Centre, Queensland Department of Primary Industries, Cairns
	Mar-07	FK	Australian Institute of Marine Science, Townsville
	Mar-08	FK	Davies Laboratories, CSIRO Sustainable Ecosystems, Townsville
	Mar-12	FK	Long Pocket Laboratories, CSIRO Sustainable Ecosystems, Indooroopilly
	May-06	FK	University of Newcastle, MARI 3330 Marine Fish and Fisheries, Ourimbah
	Jul-01	AB	Presentation to landholders and Millers Forest Progress Assoc., Hunter R
	Aug-13	AB	NSW Fisheries Floodgate Design Workshop, Ballina
	Aug 25-30	FK	5th International Acid Sulfate Soil Conference, Tweed Heads (poster and talk)
	Sept 18-19	FK & AB	Technical report to FRDC and CFP steering committee
2003	March	FK	Cleveland Laboratories, CSIRO Marine Research, Cleveland
	July	FK	Australian Marine Sciences Association, Annual Conference
	August	FK	School of Biological Sciences, Flinders University, Adelaide
	October	FK	Project review meeting, Grafton

FK = Frederieke Kroon, AB = Andrew Bruce, MB = Matt Barwick

Table 8.1b. **Articles**

Year	Date	Responsible	Newsletter / Magazine / Journal
2000	May	FK	CFP newsletter - research edition
	May	FK	ASSAY newsletter
	June	FK	OOC Jottings (newsletter of Office of Conservation, NSW Fisheries)
	July	FK	ASSAY newsletter
	August	FK	OOC Jottings (newsletter of Office of Conservation, NSW Fisheries)
	October	MB & FK	The Queensland Fishermen
	December	FK	OOC Jottings (newsletter of Office of Conservation, NSW Fisheries)
2001	January	FK	R&D News (newsletter FRDC)
	March	FK & MB	Fisheries NSW - Official journal of NSW Fisheries
	July	HS & FK	WetlandLink Bulletin (*Issue 2, Volume 3*)
	August	FK	CFP newsletter
	September	RD & FK	Section on FRDC 1998/215 in "*Coastal Ecological Floodplain*" Manual; Ocean Watch Australia and NHT.
	September	FK	OOC Jottings (newsletter of Office of Conservation, NSW Fisheries)
	December	FK	ASSAY newsletter
2002	March	FK, SJ & RL	CFP newsletter - research edition
	March	FK	The Queensland Fishermen
	May	FK	Provided summary of research outcomes and issues for SoE report 2003 ('Improvements to Fish Passage')
	June	AB	"Here, there and every weir", NSW Fish Passage Update (newsletter)
	August	FK	Wetlands Alive (*Vol. 6, No. 1*)
	August	AB	Proceedings of the NSW Fisheries Floodgate design and modification workshop
	Autumn	FK	The Jacana (newsletter of Wetland Research and Conservation, University of Sydney)
	October	FK	R&D News (newsletter FRDC)
2003	September	FK & GH	Limnology and Oceanography: Methods (*Vol. 1, pp 39-44*)

FK = Frederieke Kroon, AB = Andrew Bruce, MB = Matt Barwick, GH = Graham Housefield, HS = Heather Shearer, SC = Scott Johnston, RL = Rob Loyd, RD = Roberta Dixon

Table 8.1c. Media Coverage

Year	Date	Responsible	Newspaper, radio and TV
2000	Jun-24	CFP	The Daily Examiner
	Jul-05	CFP	The Daily Examiner
	Jul-27	FK	The Daily Examiner
	Jul-27	FK	ABC North Coast – radio
	Jul-28	FK	Lower Clarence Review
	Aug-03	FK	Coastal Views
	Aug-12	FK	ABC Radio National "A Country Breakfast"
	Nov-10	FK & SJ	The Daily Examiner
	Nov-17	FK & SJ	Lower Clarence Review
	Nov-23	FK & SJ	Coastal Views
	Dec-05	SJ	The Daily Examiner
2001	June	AC & FK	Prime TV, Coffs Harbour
	Jun-25	AC	The Daily Examiner
	Jul-06	FK	Lower Clarence Review
	Jul-19	FK	Coastal Views
	Dec-18	FK	ABC North Coast (Rural Report, possibly Country Hour on ABC National)
2002	Jan-08	FK & GH	NBN News (Tamworth, Mid North Coast, North Coast, Central Coast and Newcastle)

FK = Frederieke Kroon, GH = Graham Housefield, SC = Scott Johnston, AC = Alan Cibilic
CFP = Clarence Floodplain Project

Table 8.1d. Various (incl. meetings)

Year	Date	Responsible	Meeting, workshop, etc.
2000	Sept. 20	FK	Meeting - Mike Hayes (Project Officer) and Phil March (Oceanwatch Chairman) at Yarrahapinni
	Nov. 1-6	MB	One-on-one meetings with Clarence river landholders involved
	Nov.	FK & MB	Meeting - Floodgate Guidelines Working Party (w/ PH, PS, AC, and SJ)
2001	January	FK	NSW Tide charts handed out to all five landholders on Blanches drain
	February	FK, MB & GH	Meeting - Fish passage and sluicegate design (w/ AC)
	Mar-23	MB	Meeting - Yarrahapinni Trust: boat trip around Yarrahapinni broadwater after the 2nd flood
	April	FK & MB	Hand-out and mail-out of copies of "Fisheries NSW" to all twelve Clarence river landholders involved
	Apr-03	FK	Meeting - Floodgate Guidelines Working Party (w/ PH, PS, AC & SJ)
	Apr-04	FK & MB	Meeting - Communication Strategy (w/ AC and SJ)
	May	FK & MB	Hand-out and mail-out of fifty A3 posters to Fish Coops in coastal NSW & QLD
	May-17	FK, MB & GH	Present at official opening of Yarrahapinni floodgate
	May-20	FK	Hand-out of copies of water quality results collected so far to all five landholders on Blanches drain
	May-23	FK	Meeting - Floodgate Guidelines Working Party (w/ PH, PS, AC & SJ)
	May-29	FK	Workshop - Macleay River Catchment Acid Sulfate Soils Remediation Projects Review - Kempsey
	May	AC & FK	Mail-out invitations to Community Forum to Clarence River Fishermens Co-op Ltd), and all 12 Clarence river landholders involved
	Jul-22	FK	NSW Tide chart handed out to landholder on Taloumbi radial drain #5
	Aug-15	CFP	Meeting - Blanches Drain Management Plan
	Aug-23	FK	NSW Tide chart mailed out to landholder on Carrols drain
	Aug-29	FK	Meeting - Floodgate Guidelines Working Party (w/ SJ, TK & RL)
	Sept-17/18	TK	Poster and hand-outs at Public Display, Yamba Shopping Fair (Landcare Grafton / Clarence River Fish Co-op)
	Dec	AB	One-on-one meetings with Clarence river landholders involved
	Nov-22	FK & AB	Meeting - Floodgate Guidelines Working Party (w/ PH, PS, AC, RL, TK, & SJ)
	Dec-04	FK	Field Day Manning river (w/ Bob Smith)
2002	Jan-17	TK	Poster at Environmental Education Day (Clarence River Fishermen's Co-op Ltd), as part of CoastCare Annual Summer Festival
	Feb-7	AB	Meeting with Liquid Level tidal floodgate designer, Kempsey
	Mar-6	AB & GH	Meeting with DLWC Morpeth re. installation of a tidally operating floodgate in Hunter river
	Mar-27	AB & FK	Meeting with DLWC Morpeth re. installation of a tidally operating floodgate in Hunter river
	April	AB	Mail-out invitations to "thank-you" BBQ to all thirteen Clarence river landholders involved
	May-16	AB	Meeting - Floodgate Guidelines Working Party (w/ PH, PS, AC, RL, TK, & SJ)
	May-17	FK, AB & GH	BBQ for all Clarence river landholders, CFP, Clarence Fishing Coop, and NSW Fisheries personnel involved
	March - July	AB	Meetings and consultations with DLWC, landholders and Greg Breckell re. installation of tidally operating floodgate in Hunter river
	Jul-1	AB	Meeting - Millers Forest Progress Association re. installation of a tidally operating floodgate in Hunter river
	Aug-13	AB	NSW Fisheries Floodgate Design Workshop, Ballina
	Sept-16	AB	Meeting with Hastings Council re tidally operated floodgates in Hastings River
2003	Mar-5	AB	Meeting with Hunter River landowners re tidally operating floodgate
	May-27	FK, BP & AB	Meeting with SCU PhD student and supervisors re tidal operated floodgate research needs

FK = Frederieke Kroon, AB = Andrew Bruce, MB = Matt Barwick, GH = Graham Housefield, BP = Bruce Pease, SC = Scott Johnston, AC = Alan Cibilic, RL = Rob Loyd, TK = Natasha Keys, PH = Peter Haskins, PS = Peter Slavich
CFP = Clarence Floodplain Project

Table 8.2. Extension and communication activities for FRDC 1998 / 215 during (2000 - 2002) and beyond the duration of (2003) the project. Number in between brackets refers to activities targetted at commercial and recreational fishers.

Year	Presentations	Articles	Media coverage	Various	Total
2000	11 (6)	7 (2)	11	3 (0)	32 (8)
2001	10 (3)	6 (3)	5	21 (2)	42 (8)
2002	11 (0)	8 (4)	1	11 (1)	26 (4)
2003	4 (1)	1 (0)	0	2 (0)	7 (1)
Total	36 (10)	22 (9)	17	33 (2)	107 (21)

9. GENERAL DISCUSSION

The implementation of flood mitigation schemes affects fish passage to once seasonally flooded areas used in feeding and breeding (Welcomme, 1979; Pollard and Hannan, 1994), and removes spatial and temporal variation in environmental conditions (Chapter 3). Previous studies have demonstrated that an increase in the permeability of a tidal barrier may facilitate a change in coastal floodplain habitats from freshwater to estuarine, as well as allowing passage of fish and invertebrates (e.g. Gibbs *et al.*, 1997). Few data, however, are available on the precise relationships between fish and invertebrate recruitment and the opening size or opening regime of these tidal barriers. For example, whilst Pollard and Hannan (1994) suggested that the gates be left open permanently except in times of flood, it is at these times that many species migrate to the flooded margins for growth and reproduction (Welcomme, 1979).

In this study, we examined the relationship between recruitment of migratory and non-migratory fish and invertebrate species and the opening size of, and the frequency and timing of the opening of tidal barriers. Our results from the Clarence river floodplain show that an increase in opening frequency of floodgates resulted in a significant increase in species richness and diversity in managed systems (Chapter 4). The increase in total number of all species and total number of commercial species, including species such as yellowfin bream (*Acanthopagrus australis*), southern herring (*Herklotsichthys castelnaui*), sandy sprat (*Hyperlophus vittatus*), flat-tailed mullet (*Liza argenta*), sea mullet (*Mugil cephalus*), and school prawn (*Metapenaeus macleayi*), indicates that fish passage does improve with **frequent** and **regular** opening of floodgates. These results are corroborated by the fact that five different types of tidally operated floodgates, which open frequently and regularly with the tidal cycle, improved fish passage into gated drainage systems (Appendix 8). In contrast, species richness and diversity did not increase with increased opening times of floodgates (Chapter 4). Our results also suggest that fish passage is not improved with the installation of a mini-sluicegate on a floodgate, or with the installation of vertical lift-gates (Chapter 4). However, it should be noted that the effectiveness of these structures was only examined on a single drainage system each. In the Macleay floodplain, species assemblages in Yarrahapinni Broadwater changed significantly after floodgate openings in 2001 and 2002, and became similar to those in reference drainage systems (Appendix 4). In all cases, juveniles of commercially and recreationally significant species moved into drainage systems with opened floodgates, regardless of whether the system was a modified natural creek or a man-made drain.

Using size frequency data of commercially and recreationally significant species captured in the Clarence river floodplain, we further examined whether there are particular times or seasons when barriers to recruitment would have the greatest impact (Chapter 5). It appears that an increase in the frequency of floodgate closures and of acid sulfate discharge during the high rainfall season (late summer and early autumn) may impact on the recruitment of fewer commercially significant species than similar conditions during winter and spring. This is because most of the commercially significant species are ocean spawners that recruit primarily during low rainfall conditions in winter and spring. Nevertheless, results from our laboratory experiments suggest that even low concentrations of sulfuric acid have the potential to affect migration of juveniles of these species in the field (Chapter 7). Thus, floodgate closure periods should be minimised at all times of the year to reduce impacts on the recruitment of non-commercial estuary spawning species, as well as the potential mortality of juveniles and adults of commercially significant species trapped behind these barriers for extended periods. Floodgates should remain open and disturbance of acid sulfate soils should be minimised during the critical, low-rainfall, winter period to ensure that recruitment of commercially significant species to estuarine habitats is maintained and enhanced.

Opening of floodgates by itself does not appear to be sufficient to maintain and enhance improvement of fish passage into managed drainage systems. While floodgate opening improves water and habitat quality in managed drainage systems (Chapter 4), and may return some of the natural spatial and temporal heterogeneity, our results indicate that the major water quality variables of concern are still the elevated concentrations of nutrients (Chapter 3, 4). To reduce the input of nutrients into the waterways, best land management practices, including reduced and / or more effective and efficient use of fertilizers, as well as fencing off waterways and riparian restoration, should be implemented and adhered to. In addition, the major habitat quality variables of concern in managed gated systems are the absence of mangroves and sea grass (Chapter 4). Both mangroves and seagrass were consistently more abundant at reference sites than at managed gated sites, due to the long exclusion of tidal water and mangrove seeds by floodgates. This would have had a significant impact on the composition of species assemblages present. Management of riparian zones, including restoration of riparian vegetation, can have multiple objectives (RipRap, 2003). These projects aim to at least halt, and preferably reverse the impacts of clearing on stream ecology, and are generally promoted to limit in-stream primary production, provide a buffer strip for the trapping of sediment, nutrients and contaminants, prevent bank erosion, and provide habitat and food sources for aquatic organisms. The economic benefits resulting from these functions can include good water quality and nursery habitat for important fisheries species.

The potential effectiveness of rehabilitating certain environmental variables can first be examined using the fluviarium system described in Chapter 5. This system can be used or modified to study behavioural responses of aquatic biota to a wide variety of environmental variables, including water quality, habitat quality, or combinations of two or more environmental variables. For example, the presence of suitable habitat may alleviate strong avoidance behaviour to low acid levels, as has been shown for zinc avoidance by fathead minnows (*Pimephales promelas*) (Korver and Sprague, 1989). The choice of (combination of) variables is limitless, but is dictated by the nature of the problem under investigation. In any choice experiment, however, it is vital to know the values of the studied variable in the field to ensure that the experiment reflects choices that may be encountered in the field.

In Australia, preference – avoidance responses are most likely a significant component of the life histories of native aquatic fauna, in particular of migrating and catadromous species. For example, at least 50% of commercial and recreational target species undertake migrations to and from the sea during their life cycles (Kailola *et al.*, 1993). Water quality variables that may affect migration of aquatic fauna include temperature (e.g. Aziz and Greenwood, 1981; McKinnon and Gooley, 1998), suspended sediments (e.g. Prosser *et al.*, 2001), turbidity (e.g. Blaber and Blaber, 1980), pesticide (e.g. Davies *et al.*, 1994) and herbicide concentrations (Moore *et al.*, 2003), and discharges of sulfuric acid and associated (trace-) metals in acid sulfate soil areas (Roach, 1997; Cook *et al.*, 2000; Preda and Cox, 2001). Of these, preference – avoidance responses to temperature (Astles *et al.*, 2003), and to sulfuric acid (Chapter 7) have been now documented in Australian species.

Behavioural studies conducted with the fluviarium system can complement LD_{50} studies. LD_{50} trials provide valuable information regarding the physiological tolerances of species to certain substances, however, they do not provide information on a species' behaviour in response to these substances. A combination of laboratory studies, including preference-avoidance experiments and LD_{50} trials, as well as field observations on natural populations and environmental variables, will provide a solid combination of scientifically sound data for sustainable management of aquatic ecosystems.

Our results suggest that opening of floodgates can be an avenue to manage exotic species, such as *Gambusia holbrooki* (Chapter 4, Appendix 4) The results from both the Clarence and Macleay floodplains showed that opening floodgates reduces the relative abundance and biomass *G. holbrooki* in managed systems compared to gated systems. Hence, opening floodgates should be considered as an effective manner of reducing the numbers of *G. holbrooki*, and other exotic species such as *Poecilia reticulata*, *Poecilia latipinna*, *Xiphophorus helleri*, *Xiphophorus maculatus*, and *Oreochromis mossambicus*, and their detrimental impact on native fish fauna. For *G. holbrooki*, this includes predation on the eggs and adults of *H. galli* and *Pseudomugil signifer*

(Ivantsoff and Aarn, 1999), and its impact on the breeding success of *P. signifer* with concerns raised about the conservation of the species in the presence of *G. holbrooki* (Howe *et al*., 1997).

The identification, during this study, of key ecological species within reference and gated drainage systems can be helpful in assessing the health of drainage systems. The two native gudgeons, *Hypseleotris compressus* and *Phylipnodon grandiceps*, and the exotic *G. holbrooki* were consistently more abundant and had greater biomasses in gated drainage systems. In contrast, the school prawn *Metapenaeus macleayi* was consistently more abundant and had greater biomass in reference drainage systems. Hence, the relative abundance of these species in gated systems may provide a useful indicator for land managers to assess the success of any management of floodgated drainage systems on their properties. Such monitoring, for example, could easily be used in conjunction with automated tide gates which showed considerable promise in our preliminary trials.

10. RECOMMENDATIONS & IMPLICATIONS

10.1. Recommendations

- To improve and maintain fish passage and water quality in gated drainage systems, floodgates (i.e. one-way downstream opening flapgates) should be opened on a frequent and regular basis throughout the year.

- To prevent lost of valuable recruits to coastal fisheries (both commercial and recreational), the regime of opening of floodgates should be maintained once it has commenced.

- To ensure that recruitment of commercially significant species to estuarine habitats is maintained and enhanced, floodgates should remain open and disturbance of acid sulfate soils should be minimised during the critical, low-rainfall, winter period.

- Closure periods should be minimised at all times of the year, to reduce (i) impacts on the recruitment of non-commercial estuary spawning species, and (ii) the potential mortality of juveniles and adults of commercially significant species trapped behind closed floodgate and / or acid sulfate soil discharge barriers for extended periods.

- To further improve fish passage and water quality in gated drainage systems, particularly if the drainage system itself is going to be fish habitat, additional measures should be taken including (i) reduction of nutrient input, (ii) removal of grasses and rushes, and, (iii) rehabilitation of mangroves and seagrass.

- Significant effort should go into implementation and adherence of best land management practices to reduce nutrient input into coastal drainage systems, including reduced and / or more effective and efficient use of fertilizers, fencing off water courses, and rehabilitation of riparian vegetation.

- To improve and maintain fish passage into gated drainage systems, as well as to minimise the risk of saline overtopping, installation of automated systems, as opposed to floodgates that need to be managed manually by winches, is desirable.

- The effectiveness and design of automated floodgates, to improve fish passage and water quality should be examined in more detail. Well-designed, tide-actuated gates should be robust in construction, require little maintenance, and be able to control water levels inside drainage systems by having fully adjustable opening and closing heights.Of particular importance are design improvements that would enhance passage of additional species that are considered significant food sources (e.g. *Acetes sibogae australis*) for commercially significant species.

- If automated systems are not an option, appropriate incentives for landowners should be put in place to promote frequent and regular opening of floodgates.

- The potential to improve fish passage using either mini-sluice gates or vertical liftgates requires further assessment, to examine whether the structures themselves or other factors prevented the expected improvements in fish passage.

- Opening of floodgates results in a decrease in abundance and biomass of the exotic *Gambusia holbrooki*, and should be considered as an option to reduce the distribution of this, and other exotic species in coastal floodplains.

- Opening of floodgates results in a decrease in abundance of grasses and rushes, and should be considered as an option to manage aquatic weeds in gated drainage systems.

- The identification of key ecological species within reference and gated drainage can assist in assessing the health of drainage systems. The relative abundance of native gudgeons and exotic species like *Gambusia holbrooki* in gated systems may be a good way for land managers to assess the success of their management of floodgated drainage systems.

- Acid sulfate discharge in coastal floodplains should be minimised. Laboratory work on juvenile of commercial fish and prawn species suggest that chronic, low levels of acid sulfate discharge may affect migration behaviour in the field, which could have potential effects on stock sizes. The results suggest that chronic pH levels in coastal watercourses should not drop below 6.5, which corresponds to the ANZECC trigger levels for pH (6.5 – 8.0) for slightly disturbed ecosystems in southeast Australia.

- The impact of other water quality variables, such as total phosphorus, phosphate, and total nitrogen, on ecosystem patterns and processes critical to successful recruitment and survival of commercially and recreationally significant species should be examined.

- To ensure that restoration and rehabilitation activities for fish nursery habitat along the east coast of Australia are most effective from a fisheries perspective, a desktop study should be conducted compiling all available information on spatial and temporal recruitment patterns of commercially and recreationally significant species. This should include information on their dependency on riverine habitats and ecological processes, as well as a gap analysis.

- Restoration and rehabilitation activities of fish nursery habitat should focus on the most appropriate habitat from a fisheries point of view, as opposed to focussing on areas where landholders are willing to cooperate, although obviously the two are not necessarily mutually exclusive. To this effect, a whole-of-catchment view should be taken to restoration and rehabilitation activities, to ensure that benefits to water quality and fish passage are maximised through improvements in land-use practice and innovation in landscape planning and management.

- To ensure that communication and extension strategies are effective and efficient, these strategies should include an evaluation component. An evaluation of the effectiveness of the new set of guidelines would provide a first step in that direction.

10.2. Benefits

Primary beneficiaries of this research are the commercial and recreational sectors of the fishing industry who benefit from:

- an increase in the level of restoration and total area of fish habitats and hence the enhancement of fish and invertebrate stocks;
- increased knowledge of the functioning of the complex of fish and invertebrate habitats in coastal floodplains and wetlands;
- the provision of information to develop habitat / ecosystem management plans which will complement management plans providing an ecological sustainable development (ESD) approach for key estuarine fish and invertebrate stocks.

Secondary beneficiaries are the community in general and other user groups who gain increased amenity from the restored coastal floodplains and wetlands. Farmers will benefit from the management of the tidal barriers in conjunction with the development of the improved wet pasture plant species (project funded separately to this fisheries project), which will increase the productivity of the grazed areas.

10.3. Intellectual property

No patentable inventions or processes have been developed as part of this project. All results are being published in relevant scientific articles and other public domain literature.

10.4. Further development

Fish passage

Our results show that active management of floodgates improves fish passage. However, these improvements in fish passage quickly disappear when floodgates have not been opened for prolonged periods of time. This is often the case as landholders managing floodgates are not always present or have time to open and / or close floodgates. Juveniles of species that recruited into drainage systems with managed floodgates disappear from these systems when these floodgates are closed again. It is currently unknown whether this is due to migration out of the drainage system, or to mortality related to a sudden decrease in water quality. If the latter is the case, the cure may be worse than the disease, and valuable recruits will be lost to the fisheries. Hence, management of floodgates should be maintained once it has commenced. To improve and maintain fish passage, installation of automated systems, as opposed to floodgates that need to be managed manually by winches, is desirable. If automated systems are not an option, appropriate incentives for landowners should be put in place to promote frequent and regular opening of floodgates.

Saline overtopping

Most landholders open and close their floodgates based on information provided by tide-charts. In coastal floodplains, most of the drained agricultural land is below high tide level; opening floodgates always carries the risk of overtopping this land with saline water. Given that tidal heights are not always predicted accurately, and are affected by local weather conditions, this is a real and serious risk to the landholder. An additional problem with vertical lift gates is that they are difficult to open and close with strong currents. This means that landholders may not always be able to close these types of gates when required, again increasing the risk of saline overtopping. To minimise this risk, installation of automated systems that open and close automatically with the tide, as opposed to floodgates that need to managed manually by winches, is desirable.

Mini-sluicegate

While the mini-sluicegate at Dennys Gully did not improve fish passage, this may be due to some particular characteristic of Dennys Gully itself, and not the mini-sluicegate. To test this option, it would be desirable to test a mini-sluicegate at another location; this is significant, as these gates have been proposed as the “answer to all our problems”. Therefore, before more mini-sluicegates are installed, it is important to thoroughly examine their potential (or lack thereof) to improve fish passage. CRCC has a second mini-sluicegate ready to be installed at a floodgated drainage system in the Clarence River (Rob Lloyd, Manager Clarence Floodplain Project, pers. comm.).

Vertical liftgates

While the vertical liftgate at Marsh Drain did not improve fish passage, this may be due to some particular characteristic of Marsh Drain itself, and not the vertical liftgate. To test this option, it would be desirable to test a vertical liftgate at another location. Given the difficulties with opening and closing vertical lift gates with strong currents, they may not be installed in too many additional locations. However, if they are their potential (or lack thereof) to improve fish passage should be thoroughly examined.

Tidal floodgates

All five tidal floodgates examined appeared to successfully allow fish passage into gated drainage systems. While this is a promising result, the effectiveness and design of these automated systems to improve fish passage and water quality should be examined in more detail. Of particular importance are design improvements that would enhance passage of additional species that are considered significant food sources (e.g. *Acetes sibogae australis*) for juveniles and adults of a number of commercially significant species present in managed gated drainage systems.

Water quality

Concentrations of nutrients in coastal, gated drainage systems were much more strongly associated with the composition of species assemblages than acid sulfate soil by-products. Whilst this does not eliminate acid sulfate soil by-products as potentially having a significant impact on aquatic ecosystem health (e.g. Chapter 7; Johnston *et al.*, 2003), it does indicate that more effort should go into implementation and adherence of best land management practices to reduce nutrient input, including reduced and / or more effective and efficient use of fertilizers, as well as fencing off water courses and rehabilitation of riparian vegetation.

Coastal floodplain rehabilitation

Restoration and rehabilitation activities of fish nursery habitat should focus on the most appropriate habitat from a fisheries point of view, as opposed to focussing on areas where landholders are willing to cooperate, although obviously the two are not necessarily mutually exclusive. To this effect, a whole-of-catchment view should be taken to restoration and rehabilitation activities, to ensure that benefits to water quality and fish passage are maximised through improvements in land-use practice and innovation in landscape planning and management.

10.5. Staff

Name	Role
Frederieke Kroon	Research Scientist (Principal Investigator)
Matt Barwick	Fisheries Technician Grade 3 / Advisory Officer (initial stages)
Andrew Bruce	Fisheries Technician Grade 3 / Advisory Officer (final stages)
Graham Housefield	Fisheries Technician Grade 2
Tony Fowler *	Fisheries Technician Grade 1 (Casual)
Chris Gallen *	Fisheries Technician Grade 1 (Casual)
Brooke McCartin *	Fisheries Technician Grade 1 (Casual)
Kris Pitman *	Fisheries Technician Grade 1 (Casual)

* part time

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APPENDICES

Appendix 1. Species abundance at reference and gated drainage systems in the lower Clarence river floodplain.

Class/Order/Family	Genus and species	Common name	Minimum length (mm)	Maximum length (mm)	Total number	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully [#]	Harwoods Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
CLASS CHONDRICHTHYES																		
Order Myliobatidiformes																		
Dasyatididae	Dasyatis fluviorum	Estuary stingray	1,220	1,220	1							1						
Dasyatididae	*Dasyatis* spp.	Unidentified stingray	310	310	1												1	
CLASS ACTINOPTERYGII																		
Order Anguilliformes																		
Anguillidae	*Anguilla australis*	Short-fin eel*	48.3	297	17	5			4		1		2					5
	Anguilla reinhardtii	Long-fin eel*	53.2	1,500	41	9	6	16	1	1	2	1	2					3
Order Atheriniformes																		
Atherinidae	*Atherinosoma microstoma*	Small-mouth hardyhead	18	19.4	2												2	
Melanotaeniidae	*Melanotaenia duboulayi*	Duboulay's rainbowfish	12.5	49.4	100	23			56							4		17
Poeciliidae	*Gambusia holbrooki*	Mosquitofish	5.2	44	19,159	3,073	4,003	897	576	45	4,253	42	4,737	6	120	385		1,022
Pseudomugilidae	*Pseudomugil signifer*	Southern blue-eye	8.1	32.6	3,773	9	621	18	365	269	141	85		1,101	445	29	690	
Order Beloniformes																		
Belonidae	*Tylosurus gavialoides*	Stout longtom*	153	153	1									1				
Hemiramphidae	*Hyporhamphus regulatus*	River garfish*	27.2	110.8	14					5				3		4		2
	Arrhamphus sclerolepis	Snub-nosed garfish	19	165	46					2			1	23			20	
Order Clupeiformes																		
Clupeidae	*Herklotsichthys castelnaui*	Southern herring*	8.7	111.8	168						1	8		32	1	126		
	Hyperlophus vittatus	Sandy sprat*	18	52.1	86		5					58		4	1	11	3	4
Elopidae	*Megalops cyprinoides*	Oxeye herring*	325	325	1			1										
Engraulidae	*Engraulis australis*	Australian anchovy*	42.9	42.9	1												1	
Order Osmeriformes																		
Retropinnidae	*Retropinna semoni*	Australian smelt	29.3	35.5	3													3
Order Perciformes																		
Apogonidae	*Siphamia roseigaster*	Silver siphonfish	21.3	46.9	42							35		7				
Blenniidae	*Omobranchus anolius*	Oyster blenny	44.3	44.3	1												1	
Carangidae	*Caranx* spp.	Unidentified trevally*	49	49	1									1				
Chandidae	Ambassis agassizii	Olive perchlet	11.5	43.9	801	276	42	2	81		1	29	3	15	10	19	304	19
	Ambassis jacksoniensis	Port Jackson glassfish	9.1	62.4	5,361	1	316	37	2	86	1	1,057	157	771	329	293	2,311	
	Ambassis marianus	Ramsay's glassfish	8.5	81.2	4,537	18	79	39		16	7	2,579	54	341	780	221	403	
	Ambassis spp.	unidentified glassfish	7.5	35.4	1,053	6	6	14	1	45	4	86	1	64	268	347	211	

Class/Order/Family	Genus and species	Common name	Minimum length (mm)	Maximum length (mm)	Total number	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully [#]	Harwoods Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
Cyprinidae	Carassius auratus	Goldfish	12.2	154	14	1			1							12		
Gerreidae	*Gerres subfasciatus*	Silver biddy*	8.8	110.2	793		3	11			78	135	1	250	51	10	254	
Girellidae	*Girella tricuspidata*	Blackfish*	12.5	23.5	22		2					2			1		17	
	Microcanthus strigatus	Stripey	11.2	14.8	2							1					1	
Gobiidae	*Afurcagobious tamarensis*	Tamar River goby	9.8	51.3	1,950	8	256	31			59	372	4	902	42	2	274	
	Arenigobius bifrenatus	Bridled goby	16.2	73.8	80			18				28		6			28	
	Arenigobius frenatus	Half-bridled goby	17.8	74.9	22			2						3			17	
	Arenigobius spp.	unidentified gobies	24.3	71.2	27												27	
	Butis butis	Crimson-tipped gudgeon	32.1	79.3	2									1	1			
	Cryptocentrus critatus	Oyster goby	16.3	69.4	12												12	
	Favonigobius exquisites	Exquisite sand-goby	12.7	49.8	685			22		2	5	76		127			453	
	Glossogobius biocellatus	Estuary goby	16.4	56.2	32		1					17		14				
	Gobiomorphus australis	Striped gudgeon	6.5	90.2	18,399	1,660	1,958	782	5,492	2,012	1,373	782	985	68	1,133	693		1,461
	Gobiopterus semivestitus	Glass goby	2.7	78.6	2,663	4	105	7	1	12	510	806	166	247	173	255	371	6
	Hypseleotris compressus	Empirefish	10	211.3	90,114	19,075	1,576	8,961	11,393	8,559	4,586	6,543	19,196	14	420	3,685	43	6,063
	Hypseleotris galii	Firetailed gudgeon	11.3	36.8	3,468	2,298	208	5	244	18	3	15	170		17	52	2	436
	Hypseleotris klunzingeri	Western carp gudgeon	42.4	42.4	1			1										
	Mugilogobius platynotus	Mangrove goby	7.6	53.6	160		7	4			124	3	2	2	5		13	
	Pandaculus lidwilla	Dwarf goby	9.4	28.4	63		1	6				1		1	4	16	34	
	Philypnodon grandiceps	Flathead gudgeon	7.8	69	16,766	845	10,995	84	1242	203	139	93	353	121	657	1,729	6	299
	Philypnodon sp.1	Dwarf flathead gudgeon	5.4	67.5	4,254	30	3,684	1	1		3	6	256		22	211	2	38
	Pseudogobius olorum	Blue-spot goby	1.3	40.7	10,736	24	3,760	293		2	1,886	411	11	662	901	18	2,768	
	Redigobius macrostoma	Large-mouth goby	10.6	37.5	1,498		221	7		49	376	115		143	415	25	147	
	Taenioides purpurascens	Eel goby	69.1	99.7	2		1					1						
	Juvenile Gobiidae	Juvenile goby/gudgeon	6.2	12.9	266		251								12			3
Monodactylidae	*Monodactylus argenteus*	Silver batfish	12.3	51.6	72		8			2	1	30		20	8		3	
Mugilidae	*Liza argentea*	Flat-tail mullet*	6.1	150.4	2,913	2	17	1	3	4		514		1,255	397	48	672	
	Mugil cephalus	Sea mullet*	16.9	360	1,018	214	221	1	101	24	5	50		226	36	23	115	2
	Myxus petardi	Freshwater mullet*	83	374	4				4									
Pomatomidae	*Pomatomus saltatrix*	Tailor*	19.8	102.4	50							3		4	5		38	
Scatophagidae	*Scatophagus argus*	Spotted scat	8.1	33.1	4							3		1				
	Selenotoca multifasciata	Striped scat	15.8	43.6	9					1		2		1	5			
Sillaginidae	*Silago ciliata*	Sand whiting*	63	63.5	2												2	
Sparidae	*Acanthopagrus australis*	Yellow-finned bream*	5.3	270	882	1	119	8		2	3	223		224	66	5	231	
	Rhabdosargus sarba	Tarwhine*	7.6	58.1	214		1				1	43		15	6	3	145	
Sphyraenidae	*Sphyraena obtusata*	Striped seapike*	133.6	133.6	1									1				

Class/Order/Family	Genus and species	Common name	Minimum length (mm)	Maximum length (mm)	Total number	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully [#]	Harwoods Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
Order Pleuronectiformes																		
Bothidae	*Pseudorhombus jenysii*	Small-toothed flounder*	32.8	130.5	3							1		2				
Soleidae	*Synaptura nigra*	Black sole*	59	95.6	3							1					2	
Order Salmoniformes																		
Galaxiidae	*Galaxias maculatus*	Common jollytail	24.9	37.8	21				1									20
Order Scorpaeniformes																		
Platycephalidae	*Platycephalus fuscus*	Dusky flathead*	34.9	410	7		1					3		2	1			
Scorpaenidae	*Centropogon australis*	Fortescue	10.4	175.9	23					2		2		4	2		13	
	Notesthes robusta	Bullrout	15.6	212	7		1		3			1			2			
Order Tetraodontiformes																		
Monacanthidae	*Meuschenia trachylepis*	Yellow-finned leatherjacket*	18.1	18.1	1		1											
Tetraodontidae	*Tetractenos glaber*	Smooth toadfish	28.3	137.2	26							13		1			12	
	Tetractenos hamiltoni	Common toadfish	65.1	75.4	2												2	
TOTAL FISH					192,503	27,582	28,476	11,269	19,572	11,361	13,563	14,277	26,101	6,686	6,336	8,226	9,651	9,403
CLASS AMPHIBIA																		
Order Anura		tadpoles			25											13		12
CLASS ARACHNIDA																		
Order Aranaea																		
Lycosidae	*Lycosa* spp.	Wolf spider			5	1	1		2							1		
Tetragnathidae					2							1		1				
CLASS BRANCHIOPODA																		
Sub-order Conchostraca		clam shrimps			26											23		3
CLASS COPEPODA		copepods			18						18							
CLASS MALACOSTRACA																		
Order Amphipoda																		
		amphipods			45		10	7			20			8				
Melitidae	*Allorchestes compressa*	Sand flea	14.3	14.3	1											1		
	Melita plumulosa				280		35	1			244							
Order Decapoda																		
Alpheidae	*Alpheus* spp.		3.4	9.9	22							3					19	
Atyidae	Caridina indistincta		1.4	8.1	996	425	7	1	413	17		57	11		7	21		37
	Caridina nilotica				1,841	19	15	46	19	1,476	9	33	1	82	134	5	2	
	Paratya australiensis		2	4.8	3				2						1			
Grapsidae	*Australoplax tridentata*		4.9	7.1	2						1	1						
	Paragrapsus laevis	Shore crab	10.9	10.9	1							1						
	Parasesarma erythrodactyla		3	11.2	17		1	1			1			3	4		7	
	Sesarma erythrodactyla	Marsh crab	6.5	6.5	1						1							
Hymenosomatidae	*Amarinus* spp.	Spider crab			332	8	166	28		2	16	76	6	13	9	5	3	

Class/Order/Family	Genus and species	Common name	Minimum length (mm)	Maximum length (mm)	Total number	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully [#]	Harwoods Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
Palaemonidae	*Macrobrachium cf novaehollandiae*	Long-armed shrimp	2.2	23.4	625	2	17	129		10	21	195	14	42	157	25	13	
	Palaemon debilis		1.1	21.9	24,406	35	331	1,492	14	18	6,673	5,359	68	2,085	485	15	7,829	2
	Metapenaeus bennettae	Greasy back prawn*	3.9	22.8	17	2	1	10			1		1	1			1	
	Metapenaeus macleayi	School prawn*	0.4	27.5	12,462	77	186	425	355	110	93	5,703	20	3,632	1,446	128	268	19
	Penaeus esculentus	Tiger prawn*	4.3	16.2	12		1					9		1			1	
	Penaeus plebejus	King prawn*	1.8	24.2	339	1	5	7			52	97	1	36		2	138	
Portunidae	*Portunus pelagicus*	Blue swimmer crab*	6.7	7	2									2				
	Thalamita crenata		12.7	21.7	2												2	
Sergestidae	*Acetes sibogae australis*		1.1	10.7	425,972	4	16,576	12,525		144	13	259,931	3,695	68,031	63,288	1,546	219	
Order Isopoda																		
	Catoessa ambassae				128		7			2		2		3	8		106	
Cirolanidae					65											64	1	
Sphaeromatidae	*Cymodetta* spp.	Pill bug			1,431		79	171		86	440	5	448	160	14	9	16	3
Order Mysidacea		opposum shrimps			32		22	1				5	1			3		
CLASS BIVALVIA																		
Order Mytiloida																		
Mytilidae	*Xenostrobus securis*				205		24				166		13	2				
Order Veneroida																		
Corbiculidae	*Corbicula australis*				244		232				12							
Mactricidae	*Spisula trigonella*	Trough shell			35		4					20	7	4				
Semelidae	*Theora fragilis*				3							3						
Trapeziidae	*Fluviolanatus subtortus*				2,414	385	710	375	17	33	327	3	353	6	27	173	1	4
CLASS CEPHALOPODA																		
Idiosepiidae	*Idiosepius* spp.	Pygmy squid			14		2							5	1		6	
CLASS CIRRIPEDIA		barnacles																
	Tesseropora rosea				4			3						1				
CLASS GASTROPODA																		
Order Archaeopulmonata																		
Ellobiidae	*Ophicardelus ornatus*				2									1		1		
Super-order Hypsogastropoda																		
Littorinidae	*Bembicium auratum*				2												2	
Nassaridae	*Nassarius burchardi*	Dog whelk			40		19				15	5		1				
	Nassarius jonassi				14		3				3	2		5			1	
Amphibolidae	*Salinator fragilis*				163	1		27		2	129			4				
Haminoeidae	*Haminoea* sp.1				1						1							
Planorbidae	*Glyptophysa gibbosa*				39	26		1	3	3					1			5
CLASS TURRITELLIDAE																		
Order Sorbeoconcha																		
Batillariidae	*Batillaria australis*				2												2	

Class/Order/Family	Genus and species	Common name	Minimum length (mm)	Maximum length (mm)	Total number	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully [#]	Harwoods Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
Thiaridae	*Melanoides* spp.	Screwshell			579	2			1	1	36		539					
CLASS HIRUDINEA		leeches																
	Hirudinae spp.				2													2
CLASS POLYCHAETA																		
Nereididae	*Ceratonereis aequisetis*				210		0	23			171	0				16		
Orbiniidae	*Scoloplos simplex*				22						21	1						
CLASS INSECTA																		
Order Coleoptera																		
Dytiscidae		diving beetle			280	14		2		3	24	1	135			4		97
Haliplidae		crawling water beetle			13	12												1
Order Diptera																		
Stratiomyidae	*Odontomyia* spp.	soldierfly larvae			2		1				1							
		soldier-flies			1			1										
Tipulidae		fly larvae (maggot)			5						4							1
Order Hemiptera																		
Belostomatidae	*Diplonychus* spp.	Giant water bug			109	18		9	19	1	2	5	5			2		48
Corixidae		lesser water boatmen			1,711	749	17	34	1	9	3	2	1		3	75		817
Geridae	*Limnogonus* spp.	Pond skater			23	4				1				4			14	
Naucoridae		creeping water bug			63	58				3			1					1
Notonectidae		water boatmen			55	5	8			14	2					23		3
Order Mecoptera																		
Nannochoristidae					4													4
Order Odonata																		
Anisopteran		dragonfly larvae			148	21		1	43	12	7		7		1	21	1	34
Zygoptera		damselfly larvae			130	16	20	12	11	15	26		10		1	15		4
TOTAL INVERTEBRATES					475,626	1,885	18,500	15,332	900	1,962	8,553	271,520	5,337	74,133	65,587	2,178	8,652	1,086
TOTAL NUMBER					**668,154**	**29,467**	**46,976**	**26,601**	**20,472**	**13,323**	**22,116**	**285,797**	**31,438**	**80,819**	**71,923**	**10,417**	**18,303**	**10,500**

* commercially harvested species
[r] reference sites
[#] seines hauled below gates at Denny Gully have been excluded from totals

Appendix 2. Species biomass at reference and gated drainage systems in the lower Clarence river floodplain.

Scientific name	Total weight (g)	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully #	Harwood's Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
*Acanthopagrus australis**	2672.0	0.1	1,696.0	88.9		0.2	28.9	179.4		392.0	115.2	1.3	170.0	
Acetes sibogae australis	26,302.3	0.1	1,123.5	639.2		26.6	4.2	16,469.0	422.1	4,224.8	3,160.8	215.1	16.9	
Afurcagobious tamarensis	568.8	2.8	176.8	18.0			30.8	81.1	0.9	177.3	18.4	0.3	62.4	
Allorchestes compressa	0.1											0.1		
Alpheus spp.	4.0							0.8					3.2	
Amarinus spp.	33.5	0.6	14.1	2.1		2.8	7.4	4.5	0.6	0.6	0.3	0.3	0.2	
Ambassis agassizii	279.5	123.1	11.9	2.8	37.7		1.0	13.6	1.8	16.6	1.7	5.9	50.7	12.7
Ambassis jacksoniensis	3,511.7	0.2	301.4	23.0	0.8	55.8	0.3	812.6	25.4	560.0	112.7	336.1	1,283.4	
Ambassis marianus	14,421.6	13.7	247.4	30.3		20.3	1.3	11,077.5	34.3	1,210.7	709.4	455.9	620.8	
Ambassis spp.	67.9	0.8	0.8	1.1	0.2	6.6	0.6	6.0	0.1	4.2	16.8	13.9	16.8	
Amphipoda species	0.7		0.1	0.1			0.4			0.1				
Anguilla australis	46.2	2.6			2.1		0.3		1.7					39.5
Anguilla reinhardtii	23,722.3	1,353.6	6,423.2	13,431.7	0.9	0.9	400.3	200.0	1,909.5					2.2
Anisopteran species	18.8	1.9		1.1	6.4	1.9	0.6		0.3		0.2	1.8	0.2	4.4
Arenigobius bifrenatus	120.7			35.0				15.7		6.5			63.5	
Arenigobius frenatus	37.6			9.3						1.1			27.2	
Arenigobius spp.	61.2												61.2	
Arrhamphus sclerolepis	504.4					110.6			0.1	97.8			295.9	
Atherinosoma microstoma	0.2												0.2	
Australoplax tridentata	0.2						0.1	0.1						
Batillaria australis	4.0												4.0	
Bembicium auratum	0.4												0.4	
Butis butis	8.5					0.5				7.5	0.5			
Caranx spp.*	3.0									3.0				
Carassius auratus	290.9	148.1			142.3							0.5		
Caridina indistincta	78.4	29.6	0.4	0.1	34.8	1.9		6.7	0.7		0.6	0.7		2.9
Caridina nilotica	101.5	0.5	0.3	1.2	1.8	88.0	0.1	2.8	0.1	2.4	4.1	0.1	0.1	
Catoessa ambassae	1.4		0.1			0.1		0.1		0.1	0.1		0.9	
Centropogon australis	150.0					0.7		0.1		139.1	0.3		9.8	
Ceratonereis aequisetis	17.2		0.4	0.6			15.6	0.3				0.3		

Scientific name	Total weight (g)	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully #	Harwood's Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
Conchostracom species	2.0											1.9		0.1
Copepoda species	0.1						0.1							
Corbicula australis	2.3		2.2				0.1							
Corixidae species	50.5	20.3	0.4	0.4	0.1	0.3	0.1	0.1	0.1		0.1	2.2		26.4
Cryptocentrus critatus	25.4												25.4	
Cymodetta spp.	7.2		0.1	2.5		0.3	2.5	0.1	1.2	0.1	0.1	0.1	0.1	0.1
Dasyatis fluviorum	1,600.0							1,600						
Dasyatis spp.	2,000.0												2,000	
Diplonychus spp.	13.6	2.0		2.4	1.8	0.2	0.4	0.3	0.4			0.2		5.9
Dytiscidae species	9.3	0.3		0.1		0.3	0.6	0.1	3.2			0.1		4.6
*Engraulis australis**	0.5												0.5	
Favonigobius exquisites	195.4			3.0		0.3	4.6	20.8		33.4			133.3	
Fly larvae (maggot)	0.5						0.3							0.2
Fluviolanatus subtortus	142.0	20.7	31.6	16.7	0.3	0.6	41.6	0.8	24.2	0.3	1.3	3.4	0.3	0.2
Galaxias maculatus	4.3				0.2									4.1
Gambusia holbrooki	2,795.9	523.0	520.1	130.9	158.4	8.2	615.1	9.3	636.5	1.5	23.4	45.5		124.0
Gerres subfasciatus	1,596.3		1.6	4.7			30.7	98.3	0.1	763.5	210.5	0.2	486.7	
*Girella tricuspidata**	3.4		0.6					1.2			0.2		1.4	
Glossogobius biocellatus	30.5		1.1					8.0		21.4				
Glyptophysa gibbosa	4.4	2.2		0.2	0.2	1.3					0.4			0.1
Gobiidae species	2.5		2.3								0.1			0.1
Gobiomorphus australis	4,541.2	584.3	632.9	147.5	1,025	381.4	718.8	138.1	248.7	5.9	176.1	130.6		351.9
Gobiopterus semivestitus	239.8	0.4	6.7	0.3	0.1	0.6	69.7	82.5	12.2	19.8	10.1	15.1	22.0	0.3
Haliplidae species	0.4	0.3												0.1
Haminoea sp1	0.6						0.6							
*Herklotsichthys castelnaui**	470.4					176.7	0.1	49.6		180.7	0.9	62.4		
Hirudinae spp.	0.3													0.3
*Hyperlophus vittatus**	29.4		1.2					14.7		0.5	0.4	10.5	1.6	0.5
*Hyporhamphus regulatus**	16.8					1.0				0.6		1.2		14.0
Hypseleotris compressus	26,313.0	5,773.1	941.5	2,753.9	2,864.8	2,173.4	1,903.9	1,109.0	5,743.6	1.5	264.5	895.1	7.2	1,881.5
Hypseleotris galii	586.9	397.5	23.5	0.6	51.9	5.4	0.3	1.8	18.2		2.1	5.9	0.3	79.4
Hypseleotris klunzingeri	1.2			1.2										
Idiosepius spp.	2.1		0.9							0.7	0.2		0.3	
Isopod species	1.1											1.0	0.1	

Scientific name	Total weight (g)	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully #	Harwood's Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
Limnogonus spp.	0.4	0.1				0.1				0.1			0.1	
*Liza argentea**	7,482.3	69.3	126.9	50.1	10.4	228.0		983.4		4,083.2	648.5	177.3	1,105.2	
Lycosa spp.	0.8	0.4	0.2		0.1							0.1		
Macrobrachium cf *novaehollandiae*	498.5	6.2	33.3	147.4		7.4	24.5	132.1	7.8	15.4	95.4	12.4	16.6	
*Megalops cyprinoides**	600.0			600.0										
Melanoides spp.	94.4	0.1			0.1	0.1	3.2		90.9					
Melanotaenia duboulayi	49.3	16.3			17.4							0.2		15.4
Melita plumulosa	0.8		0.1	0.1			0.6							
*Metapenaeus bennettae**	39.0	6.2	1.4	25.8			0.4		0.1	0.1			5	
*Metapenaeus macleayi**	5,447.4	39.7	402.6	362.9	230.5	59.8	75.4	2,156.2	36.4	843.2	918.4	172.0	70.9	79.4
*Meuschenia trachylepis**	0.1		0.1											
Microcanthus strigatus	0.2							0.1					0.1	
Monodactylus argenteus	95.9		2.9			11.8		34.8		34.0	7.7		4.7	
*Mugil cephalus**	5,426.9	114.3	4,240	21.1	135.9	25.0	86.6	42.5		109.8	527.1	58.2	60.7	5.7
Mugilogobius platynotus	18.5		4.4	2.1			8.6	0.1	0.1	0.3	0.1		2.8	
Mysidia spp	0.5		0.3					0.1	0.1					
*Myxus petardi**	2,759.0				2,750.0	9.0								
Nassarius burchardi	5.2		3.2				1.3	0.6		0.1				
Nassarius jonassi	1.9		0.3				1.3	0.1		0.1			0.1	
Naucoridae species	1.7	0.8				0.4								0.5
Notonectidae species	1.3	0.1	0.4			0.2	0.1					0.4		0.1
Notesthes robusta	1,002.5		0.1		735.3			107.6			159.5			
Odontomyia spp.	0.2		0.1				0.1							
Omobranchus anolius	1.1												1.1	
Ophicardelus ornatus	0.2									0.1		0.1		
Palaemon debilis	2,812.5	3.5	72.4	112.1	1.1	2.5	878.2	641.3	10.8	167.3	56.6	0.6	865.8	0.3
Pandaculus lidwilla	4.1		0.1	0.6				0.1		0.2	0.6	1.7	0.8	
Paragrapsus laevis	0.9							0.9						
Parasesarma erythrodactyla	5.8		0.4	0.1			0.5			2.1	1.4		1.3	
Paratya australiensis	0.1										0.1			
*Penaeus esculentus**	14.2		0.4					13.3		0.4			0.1	
*Penaeus plebejus**	134.6	6.4	18.2	37.1			46.3	6.4	0.1	1.8		6.6	11.7	

Scientific name	Total weight (g)	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully #	Harwood's Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
Philypnodon grandiceps	6,879.3	339.8	4,396.4	31.6	517.5	202.7	135.4	24.2	97.2	21.8	310.9	715.2	1.5	85.1
Philypnodon sp1.	658.3	12.8	567.8	0.1	1.5		3.4	0.4	27.4		2.3	36.6	0.1	5.9
*Platycephalus fuscus**	696.9		0.6					493.7		201.2	1.4			
*Pomatomus saltatrix**	108.0							27.9		38.7	35.7		5.7	
*Portunus pelagicus**	0.3									0.3				
Prawn bodies	67.9	0.6	1.0	1.0	3.3			37.1		23.5			1.4	
Pseudogobius olorum	2,123.3	6.0	978.6	37.8		0.6	387.8	59.8	0.5	73.4	152.0	2.7	424.1	
Pseudomugil signifer	583.1	0.2	133.6	2.0	35.4	53.7	20.5	11.7		133.4	81.4	3.4	107.8	
*Pseudorhombus jenysii**	53.3							19.7		33.6				
Redigobius macrostoma	320.2		52.6	1.1		31.1	109.9	7.8		9.7	79.0	10.3	18.7	
Retropinna semoni	0.7													0.7
*Rhabdosargus sarba**	142.7		0.3				0.2	1.3		12.1	12.2	0.6	116.0	
Salinator fragilis	7.3	0.1		1.1		0.2	5.8			0.1				
Scatophagus argus	5.3							2.7		2.6				
Scoloplos simplex	1.2						1.1	0.1						
Selenotoca multifasciata	13.1					3.4		2.9		1.1	5.7			
Sesarma erythrodactyla	0.2						0.2							
Shrimp bodies	6.0	2.5	0.8	0.8	0.9			0.2		0.6			0.1	0.1
*Silago ciliata**	7.0												7.0	
Siphamia roseigaster	39.8							31.5		8.3				
*Sphyraena obtusata**	17.8									17.8				
Spisula trigonella	5.0		0.8					1.1	3.0	0.1				
Stratiomyidae species	0.1			0.1										
*Synaptura nigra**	32.8							9.5					23.3	
Tadpole species	3.2											1.2		2.0
Taenioides purpurascens	4.6		3.3					1.3						
Tesseropora rosea	2.1			0.1						2.0				
Tetractenos glaber	1,229.1							290.5		52.0			886.6	
Tetractenos hamiltoni	28.0												28.0	
Tetragnatha spp	0.2							0.1		0.1				
Thalamita crenata	2.9												2.9	
Theora fragilis	0.1							0.1						
*Tylosurus gavialoides**	3.7									3.7				
Xenostrobus securis	124.6		1.0				121.2		2.2	0.2				

Scientific name	Total weight (g)	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream [r]	Dennys Gully #	Harwood's Drain	James Creek [r]	Marshes Drain	Morroro Creek [r]	Sandy Creek [r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
Zygoptera species	1.5	0.1	0.4	0.1	0.1	0.1	0.3		0.1		0.1	0.1		0.1

commercially harvested species
[r] reference sites
[#] seines hauled below gates at Denny Gully have been excluded from totals

<u>Appendix 3.</u> Water quality and habitat quality variables at reference and gated drainage systems in the lower Clarence River floodplain.

Table A3.1. Clarence River sites water quality.

		Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream[r]	Dennys Gully	Harwoods Drain	James Creek[r]	Marshes Drain	Morroro Creek[r]	Sandy Creek[r]	Taloumbi # 5	Thorny Creek[r]	Wants Drain
Depth (cm)	Mean	77	93	80	107	76	51	94	90	109	68	127	68	127
Temp (^{0}C)	Mean	22.1	22.0	23.1	20.8	23.3	23.1	21.6	21.9	21.5	22.2	22.1	23.3	19.9
	Minimum	13.0	13.0	12.9	11.7	18.0	16.5	15.3	14.2	15.7	14.5	14.9	15.8	11.9
	Maximum	30.7	28.4	30.9	28.9	26.8	31.0	28.3	29.2	29.3	29.7	31.1	34.9	26.7
DO (mg/L)	Mean	5.7	6.6	7.4	4.6	8.5	9.7	5.7	5.0	5.9	6.1	5.5	7.0	3.5
	Minimum	0.0	0.1	0.0	1.3	6.0	0.4	0.0	0.0	4.0	2.9	0.7	0.2	0.1
	Maximum	10.6	13.3	16.3	8.5	11.2	18.4	9.0	10.0	8.3	9.0	9.3	11.0	7.0
pH	Mean	6.4	7.4	7.5	6.4	7.9	7.7	7.3	7.4	7.2	7.0	6.8	7.6	6.3
	Minimum	4.4	5.5	5.6	5.2	7.3	6.1	5.6	6.4	5.9	3.6	5.2	5.2	4.7
	Maximum	7.3	8.6	8.7	8.8	8.9	9.4	8.2	8.8	8.2	8.1	8.0	8.5	7.4
Salinity (g/L)	Mean	4.8	16.4	16.5	2.0	4.8	16.4	11.4	11.6	18.0	10.3	14.6	29.2	2.2
	Minimum	0.0	0.2	0.2	0.1	3.1	0.1	0.0	0.0	0.7	0.0	0.1	10.5	0.2
	Maximum	12.2	26.6	28.7	5.2	6.8	27.4	20.5	28.0	25.2	18.3	35.6	36.4	5.1

[r] reference sites

Table A3.2. Clarence River sites mean levels of chemical stressors and toxicants.

	Blanches Drain	Carrolls Drain	Carrs Drain	Cold-stream[r]	Dennys Gully	Harwoods Drain	James Creek[r]	Marshes Drain	Morroro Creek[r]	Sandy Creek[r]	Taloumbi # 5	Thorny Creek[r]	Wants Drain
Conductivity (dS/m)	6.00	18.70	18.21	3.00	6.28	18.67	13.89	12.92	18.93	13.03	14.55	35.19	3.36
Total dissolved solids (mg/L)	4078	12718	12386	2039	4270	12695	9443	8263	12874	8862	9892	23931	2285
Total phosphorous (mg/L)	0.092	0.115	0.366	0.024	0.035	0.134	0.036	0.231	0.023	0.030	0.017	0.021	0.045
Phosphate (mg/L)	0.013	0.047	0.221	0.007	0.007	0.059	0.009	0.130	0.005	0.006	0.004	0.006	0.005
Total nitrogen (mg/L)	0.942	0.725	1.282	0.696	0.311	0.716	0.424	1.403	0.318	0.387	0.930	0.277	0.994
Total Kjeldahl nitrogen (mg/L)	0.870	0.656	1.250	0.644	0.309	0.663	0.403	1.296	0.300	0.370	0.821	0.261	0.949
Nitrate (mg/L)	0.059	0.062	0.018	0.049	0.003	0.051	0.018	0.083	0.015	0.014	0.095	0.016	0.044
Nitrite (mg/L)	0.011	0.007	0.005	0.003	0.001	0.002	0.002	0.022	0.003	0.002	0.013	0.001	0.002
Ammonia (mg/L)	0.195	0.068	0.081	0.050	0.004	0.128	0.041	0.227	0.012	0.017	0.163	0.061	0.083
Total aluminium (mg/L)	0.123	0.061	0.068	0.061	0.008	0.057	0.045	0.078	0.056	0.069	0.123	0.051	0.059
Dissolved aluminium (mg/L)	0.022	0.012	0.027	0.015	0.006	0.015	0.024	0.042	0.015	0.028	0.070	0.005	0.037
Total iron (mg/L)	1.597	0.309	2.100	0.673	0.020	0.196	0.669	0.688	0.196	0.364	0.479	0.120	0.572
Dissolved iron (mg/L)	0.888	0.112	1.202	0.132	0.008	0.064	0.508	0.495	0.083	0.170	0.272	0.037	0.217

[r] reference sites

Table A3.3. Clarence River sites mean habitat variables. The proportional contribution of each substratum and vegetation type was quantified by ranking on a 5-point scale, corresponding to absent (0), uncommon (1), common (2), abundant (3) and very abundant (5).

	Blanches Drain	Carrolls Drain	Carrs Drain	Coldstream[r]	Dennys Gully	Harwoods Drain	James Creek[r]	Marshes Drain	Morroro Creek[r]	Sandy Creek[r]	Taloumbi # 5	Thorny Creek [r]	Wants Drain
Width (m)	8.8	8.9	10.5	6.7	5.7	9.5	5.3	4.4	15.0	11.7	9.9	12.8	10.0
Mud (0-5)	3.5	3.7	3.7	4.0	3.3	3.7	3.7	3.4	4.0	3.2	2.9	4.0	4.0
Sand (0-5)	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.7	2.1	0.1	0.0
Fine gravel (0-5)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Gravel (0-5)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Cobble (0-5)	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.7	0.0	0.4	0.0	0.0	0.0
Boulders (0-5)	0.5	0.0	0.5	0.0	1.6	0.5	0.0	1.7	0.1	1.5	0.0	0.1	0.1
Bedrock (0-5)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
Leaf litter (0-5)	0.6	0.4	0.3	1.2	0.5	0.3	1.3	0.9	1.2	1.5	0.2	1.0	0.5
Seagrass (0-5)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0
Water Lillies (0-5)	0.7	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	2.8
Grasses and Rushes (0-5)	2.3	0.7	0.8	3.0	2.0	2.1	0.2	2.7	0.4	0.5	3.0	0.0	1.4
Mangroves (0-5)	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	2.0	2.0	0.1	4.0	0.0
Overhanging terrestrial trees (0-5)	0.0	0.0	0.0	1.5	0.7	0.0	2.0	1.4	1.3	2.1	0.7	0.2	0.0
Filamentous algae (0-5)	0.2	0.7	1.0	0.3	0.3	2.3	0.0	0.5	0.0	0.1	0.1	0.0	0.4
Large woody debris (0-5)	0.0	0.1	0.4	3.8	0.3	0.0	0.4	0.3	0.4	1.4	0.4	0.8	0.0
Small woody debris (0-5)	0.2	0.5	0.8	3.0	0.8	0.4	0.9	1.0	1.0	2.2	0.8	1.7	0.2
Undercut bank (0-5)	1.2	1.0	1.5	0.8	0.7	0.8	0.7	1.2	1.1	2.0	1.8	0.0	0.8
Exposed rootmasses (0-5)	0.0	0.1	0.0	0.5	0.0	0.0	2.8	0.1	0.9	1.5	0.0	2.1	0.0
Riparian cover (%)	0.0	0.0	0.0	9.2	0.0	0.0	58.8	5.6	8.1	26.0	1.5	9.2	0.0

[r] reference sites

Appendix 4. The effectiveness of Floodgate management in improving fish passage and water and habitat quality in the Macleay river, NSW.

Introduction

The movement of estuarine fishes past floodgates can be effected by either opening the floodgates permanently or by managing them, i.e. opening and closing them more often (Chapter 4). During the time of the Clarence River study, an opportunity arose to examine the response of fish assemblages in a different system – the Yarrahapinni Broadwater on the Macleay river estuary (Figure A4.1). The area was closed off from the main estuary through construction of levee banks, drainage channels and floodgates in 1971 (Tulau and Naylor, 1999).

In 1996 and 1997, the community upstream from the closed floodgates was dominated by freshwater species such as gudgeons, blue-spot gobies, southern blue-eye and G*ambusia*, while very few commercially or recreationally important species were collected. In constrast, the downstream community was diverse and dominated by several commercial species (Gibbs *et al.*, 1999). These authors considered that the differences were most likely due to gates acting as physical barriers to fish passage, but that reduced water and habitat degradation in Yarrahapinni Broadwater may also have been important.

The floodgates at Yarrahapinni Broadwater were officially opened in May 2001, but most of the dropboards were still in place until later that year and water movement continued to be restricted. In fact, the floodgates were never completely opened, and some dropboards remained in place during the preliminary sampling that we were able to do. Our sampling involved only a spatial comparison rather than the 'before and after' comparison that had been done in the Clarence system (Chapter 4).

Methods

Macleay River

The Macleay river (30° 52'S, 153° 01'E) is situated on the mid-north coast of NSW, with a catchment area of about 11,385 km^2 (Roy *et al.*, 2001). The entrance of the Macleay river is approximately 40 km downstream by water from Kempsey, and is bordered by South West Rocks on the south. Major sub-catchments in the Macleay's floodplain include the Clybucca river and Spencers Creek. This study was conducted in the river's lower reaches between Jerseyville and South West Rocks (Figure A4.1; Table A4.1a).

Sampling sites

Four sampling sites were selected in April 2001: three drainage systems without floodgates (i.e. reference drainage systems), and one drainage system with floodgates (i.e. gated drainage system). The floodgates at the gated system comprised one-way (downstream opening) flap valves. Catchment-related parameters (distance to river mouth and catchment area) of these drainage systems were estimated in the laboratory by reference to published topographic maps (1:50,000 and 1:100,000) of the areas (Table A4.1b). All reference and gated sites have a high acid sulfate soil potential (Table A4.1b), as determined from DLWC's acid sulfate soil risk maps.

The three reference drainage systems were (see also Figure A4.1, A4.2a; Table A4.1a, b):

Option 2 is situated in the Clybucca creek area and enters Clybucca Creek from the east, 11 km from the mouth of the Macleay river. The creek drains a catchment of approximately 0.5 km^2 and is bordered by mangroves. The catchment is used for cattle grazing.

Option 3 is situated in the Clybucca creek area and enters Clybucca Creek from the west, 12 km from the mouth of the Macleay river. The creek drains a catchment of approximately 6.5 km^2 and is bordered by mangroves. The catchment is used for cattle grazing.

Pelican Island is situated on Pelican Island and enters the main Macleay river from the south-east, 8 km from the mouth of the Macleay river. The creek drains a catchment of approximately 1.7 km^2, and is bordered by mangroves on the southern side. The catchment is used for cattle grazing.

Information on the gated system (Figure A4.1, A4.2b; Table A4.1a, b) is from Tulau and Naylor (1999) unless otherwise noted.

Yarrahapinni Broadwater is situated in the Anderson Inlet area and enters the Clybucca Creek from the north-west, 8 km from the mouth of the Macleay river. Prior to closing, the large estuarine wetland comprised 84 ha of mangroves, 339 ha of saltmarshes, and large areas of seagrasses and shallow mudflats (SWC, 1997). The area was closed off from the main estuary through construction of levee banks, drainage channels and floodgates with 5 box culverts in 1971. Most of the area is SEPP 14 wetland.

Opening regimes of gated drainage system

The Yarrahapinni Trust, in consultation with Kemspsey Shire Council, managed the opening of floodgates on Yarrahapinni Broadwater. We asked the Yarrahapinni Trust to keep detailed records of number of gates opened, date and time of opening and closing, as well as anything else considered noteworthy and relevant to this project. Unfortunately, despite frequent requests, these records were never passed on to us and may have been lost forever with the passing of Mike Hayes. Given that the floodgates were open during each one of our field trips, we considered that this gated site met the criteria for a “managed” system, as used in Chapter 4.

Sampling methods

Samples were collected on 3 occasions: November 2001, March 2002 and May 2002. Quantification of fish and invertebrate asseblages and of water and habitat quality followed the procedures described in Chapter 2. In general, Option 2 and Option 3 were sampled around high slack tide, and Pelican Island around low slack tide. Data analyses also followed the same procedures as used in the Clarence River (see Chapter 4).

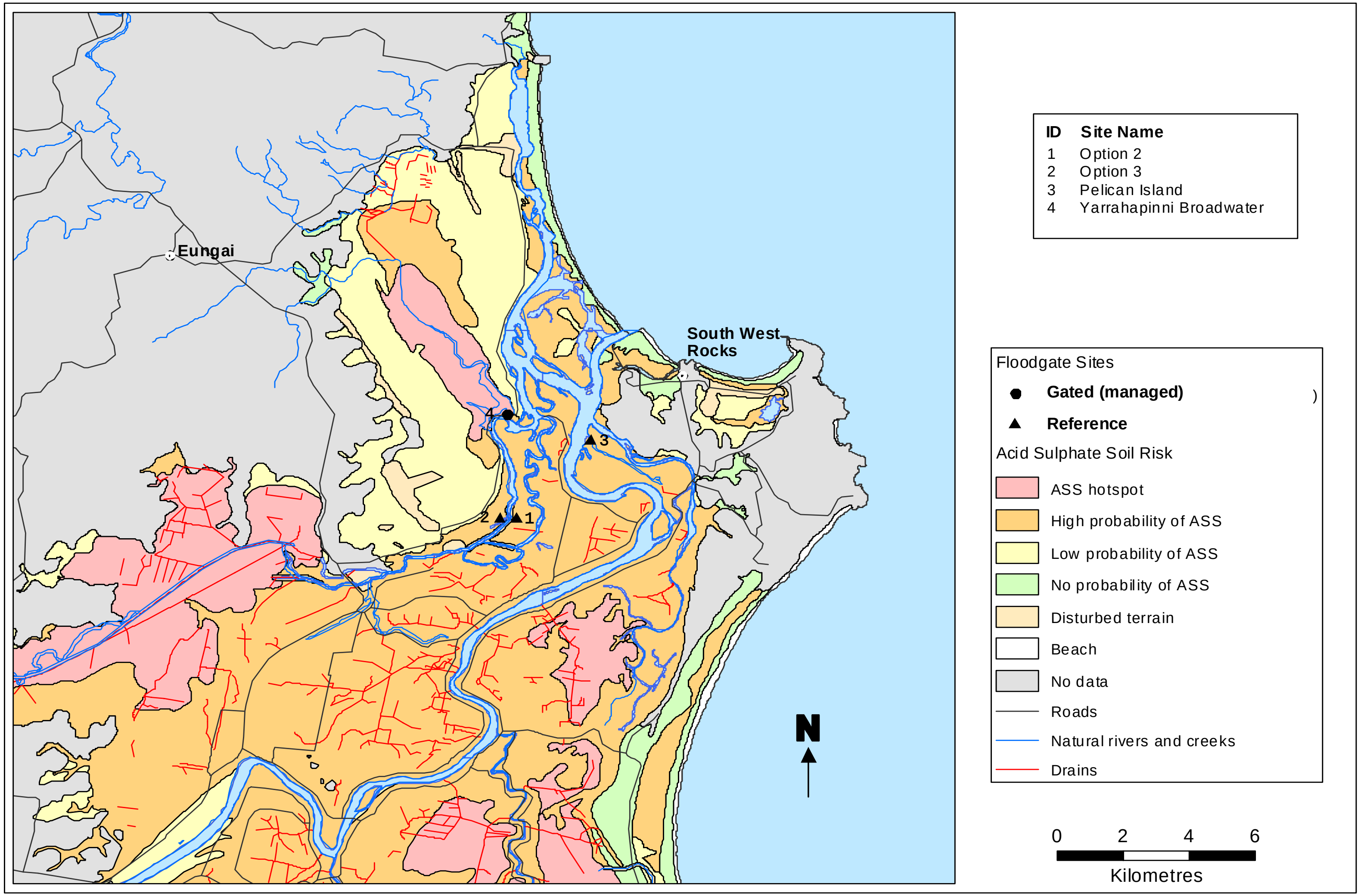

Figure A4.1. Sampling sites on the Macleay river floodplain, showing the four sites sampled during this project.

Table A4.1. Sampling sites at the Macleay river floodplains. (a) Northings and Eastings were were taken from CMA 1:25000 topographic maps (+ 50m). (b) Distance from mouth and catchment area were estimated using published topographic maps, and depth of pyritic level was obtained from DIPNR and Kempsey Shire Council.

a.

MACLEAY RIVER	NAME	LOCATION	ACCOUNT #	OPENINGS	Area 1 North	Area 1 East	Area 2 North	Area 2 East
REFERENCE (OPEN)								
Option 2	**n/a**	Clybucca Creek	**n/a**	**n/a**	**65 78 200**	**(56) 04 99 200**	**65 78 200**	**(56) 04 99 250**
Option 3	**n/a**	**Clybucca Creek**	**n/a**	**n/a**	**65 78 200**	**(56) 04 99 050**	**65 78 100**	**(56) 04 99 000**
Pelican Island	**n/a**	**Pelican Island**	**n/a**	**n/a**	**65 80 700**	**(56) 05 01 250**	**65 80 650**	**(56) 05 01 300**
GATED (MANAGED)								
Yarrahapinni Broadwater	**Yarrahapinni Broadwater**	**Andersons Inlet**		**Flapgate**	**65 81 500**	**(56) 04 99 050**	**65 81 600**	**(56) 04 99 050**

b.

MACLEAY RIVER	DISTANCE FROM MOUTH (KM)	DRAINAGE AREA (KM^2)	DEPTH OF PYRITIC LEVEL (M)
REFERENCE (OPEN)			
Option 2	**11**	**0.5**	**0**
Option 3	**12**	**6.5**	**0**
Pelican Island	**4**	**1.7**	**0**
GATED (MANAGED)			
Yarrahapinni Broadwater	**8**	**55.8**	**0-1**

(i)

(ii)

(iii)

Figure A4.2a. Reference sampling sites on the Macleay river floodplain, (i) Option 2, (ii) Option 3, and (iii) Pelican Island.

(i)

(ii)

(iii)

(iv)

Figure A4.2b. The ‘gated’ sampling site on the Macleay river floodplain at Yarrahapinni Broadwater, (i) showing the general setting, (ii) a close-up with gates closed, (iii) a close-up with gates open, and (iv) one of the two sampling areas.

Results

A total of 96 seines were collected in the Macleay river during this study, resulting in a total catch of 68 taxa (41 fish and 27 invertebrate taxa), 33.946 individuals (16,472 fish and 17,474 invertebrates), and a combined weight of approximately 10.3 kg (8.1 kg fish and 2.2 kg invertebrates). Of these, 20 taxa (29%) were of economic importance (16 fish species and 4 invertebrates), accounting for 3,762 (11.1%) of the individuals (2,052 fish and 1,710 invertebrates) and approximately 4.7 kg (45.6%) of the weight (4.4 kg fish and 0.3 kg invertebrates). Total numbers of individuals and biomass per species are presented for the 4 sites in Tables A4.9 and A4.10, and water quality data are given in Table A4.11.

Species assemblages (abundance data)

Non-metric multidimensional scaling showed that samples collected at a single site were generally located together within one sample occasion (Figure A4.3), indicating the similarity between these samples and supporting our experimental design and the results from our pilot study. However, the ordinations did not show clear separations between abundance assemblages of reference and managed drainage systems across the three sampling occasions. All three ordinations were good representations of the data, with stress levels ranging from 0.03 to 0.05. Nested ANOSIM revealed that, across all three sampling occasions, species assemblages based on abundance did not differ significantly between reference and managed drainage systems (Table A4.2).

SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species assemblages (based on abundance) between treatments, explained 56.7% to 66.58% of average dissimilarity between treatments (Table A4.3). For the three sampling occasions, sixteen species out of the 68 taxa collected were most important in contributing to the total average dissimilarity in species abundance assemblages between treatments. Four of these sixteen species (*Ambassis jacksoniensis*, *Ambassis spp.*, *Metapenaeus macleayi*, and *Palaemon debilis*) consistently contributed to these dissimilarities. *Ambassis jacksoniensis* and *P. debilis* were consistently more abundant in the reference drainage systems, while *M. macleayi* was more abundant in Yarrahapinni Broadwater two out of the three sampling occasions. Across the three sampling occasions, *M. macleayi* was the only commercially signficant species contributing to the total average dissimilarities.

BIOENV revealed that various combinations of 8 out of the 47 water and habitat quality variables best described the biotic patterns shown in the nMDS ordinations (Table A4.4; Figure A4.3). On two sampling occasions, the combination of three environmental variables involved both water quality and habitat quality variables. The correlations between the combination of three environmental variables and the biotic patterns shown in the nMDS ordinations (Figure A4.3) ranged from 0.703 to 0.885 (Table A4.4). Nutrients contributed to the combinations of environmental variables two times; nitrate twice and phosphate once. Large and small woody debris each contributed to the combinations of environmental variables once. Acid sulfate soil discharge by-product did not contribute to any of these combinations of environmental variables.

Species assemblages (biomass data)

Non-metric multidimensional scaling showed that samples collected at a single site were generally located together within one sample occasion (Figure A4.4), indicating the similarity between these samples and supporting our experimental design and the results from our pilot study. However, the ordinations did not show clear separations between biomass assemblages of reference and managed drainage systems across the three sampling occasions. All three ordinations were good representations of the data, as shown by the stress levels ranging from 0.02 to 0.06. Nested ANOSIM revealed that, across all three sampling occasions, species assemblages based on biomass did not differ significantly between reference and managed drainage systems (Table A4.5).

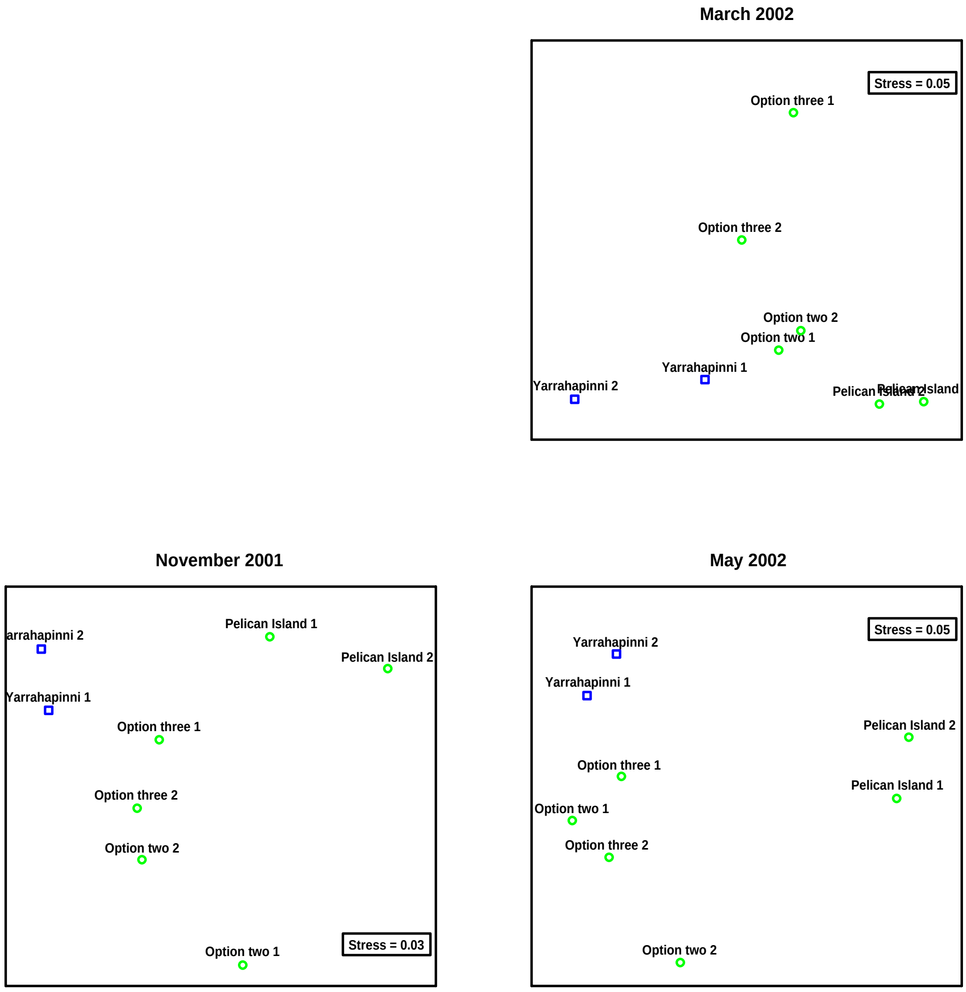

Figure A4.3. Macleay river. Non-metric multidimensional scaling (nMDS) ordinations of species assemblages (based on abundance data) on each of the three sampling occasions in the Macleay river floodplain. The ordinations are based on log (x+1) transformed abundances and Bray-Curtis similarities. Green open symbols are reference drainage systems and open square symbols are managed, gated drainage systems.

Table A4.2. Summary of two-way nested ANOSIM tests examining differences among species assemblages (based on abundance data) between treatments (reference vs managed drainage systems) for the three sampling occasions in the lower Macleay river floodplain.

Month	Source of variation	Permutations	Global R	Significance level
Nov. 2001	Treatment	4	0.333	0.50
	Location (Treatment)	15	0.722	0.06
Mar. 2002	Treatment	4	0.333	0.75
	Location (Treatment)	15	1	0.06
May 2002	Treatment	4	0.111	0.50
	Location (Treatment)	15	0.778	0.13

SIMPER revealed that the first ten species that contributed to the total average dissimilarities in species assemblages (based on biomass) between treatments, explained 61.1% to 73.98% of average dissimilarity between treatments (Table A4.6). For the three sampling occasions, eighteen species out of the 68 taxa collected were most important in contributing to the total average dissimilarity in species abundance assemblages between treatments. Three of these species (*Ambassis jacksoniensis*, *Metapenaeus macleayi*, and *Palaemon debilis*) consistently contributed to these dissimilarities. Biomass of *A. jacksoniensis* and *P. debilis* was consistently greater in the reference drainage systems, while biomass of *M. macleayi* was greater in Yarrahapinni Broadwater two out of the three sampling occasions. Across the three sampling occasions, three commercial species contributed to the total average dissimilarities, namely *Acanthopagrus australis*, *Liza argentea*, and *M. macleayi*.

BIOENV revealed that various combinations of 8 out of the 47 water quality and habitat quality variables best described the biotic patterns shown in the nMDS ordinations (Table A4.7; Figure A4.4). On two out of three sampling occasions, the combination of three environmental variables involved both water quality and habitat quality variables. The correlations between the combination of three environmental variables and the biotic patterns shown in the nMDS ordinations (Figure A4.4) ranged from 0.710 to 0.918 (Table A4.7). Nutrients contributed to the combinations of environmental variables two our three times; nitrate twice and phosphate once. Large and small woody debris each contributed to the combinations of environmental variables once. Only once did an acid sulfate soil discharge by-product (dissolved iron) contribute to these combinations of environmental variables.

Water quality and ANZECC guidelines

Several water quality variables measured in the reference and managed drainage systems during the three field trips from November 2001 to May 2002 did not conform to ANZECC guidelines (2000) (Table A4.8). However, the frequency with which values did not conform to ANZECC guidelines in reference and managed systems did not differ significantly for any of the chemical stressors or toxicants (Table A4.8).

Table A4.3. SIMPER results showing the species ranked in decreasing order of importance (1-10 only) that contributed to the total average dissimilarity in species assemblages (based on abundance data) between treatments (reference vs managed drainage systems). Percentage of average dissimilarity between treatments for each sampling occasion, and percentages of cumulative contribution by first ten species to dissimilarity are given. Numbers in bold indicate species that were more abundant in reference sites, and species in red indicate species significant for commercial and/or recreational fisheries.

Reference vs Managed	**2001**	**2002**	
	Nov	**March**	**May**
Average dissimilarity	56.62%	66.58%	57.20%
Acetes sibogae australis	3	1	
Afurcagobious tamarensis		10	9
Ambassis jacksoniensis	10	2	2
Ambassis marianus	8		
Ambassis spp	6	3	4
Arrhamphus sclerolepis		9	
Favonigobius exquisites		6	10
Gambusia holbrookii			7
Gerres subfasciatus		5	
Gobiomorphus australis	4		
Hypseleotris compressus	1		8
Metapenaeus macleayi	7	8	3
Palaemon debilis	2	4	5
Pseudogobius olorum	5	7	
Pseudomugil signifer	9		6
Redigobius macrostoma			1
Cumulative contribution	71.37%	69.32%	71.99%

Table A4.4. BIOENV results showing sets of three environmental variables that best describe the biotic patterns shown in the nMDS ordinations of species assemblages (based on abundance data) (Figure 3) for the three sampling occasions in the lower Macleay river floodplain. ** indicates that environmental variable was more common or present at higher concentrations at reference sites. The correlation coefficient (Spearman), based on the similarity matrices of both the biotic and abiotic data, is given for each sampling occassion.

	2001	**2002**	
	Nov	**March**	**May**
Correlation coefficient	**0.885**	**0.760**	**0.703**
Dissolved oxygen (surface)	*		
Phosphate (mg/L P)		**	
Nitrate (mg/L N)	**	**	
Sand		*	
Leaf litter			*
Filamentous algae			**
Large woody debris			**
Small woody debris	*		

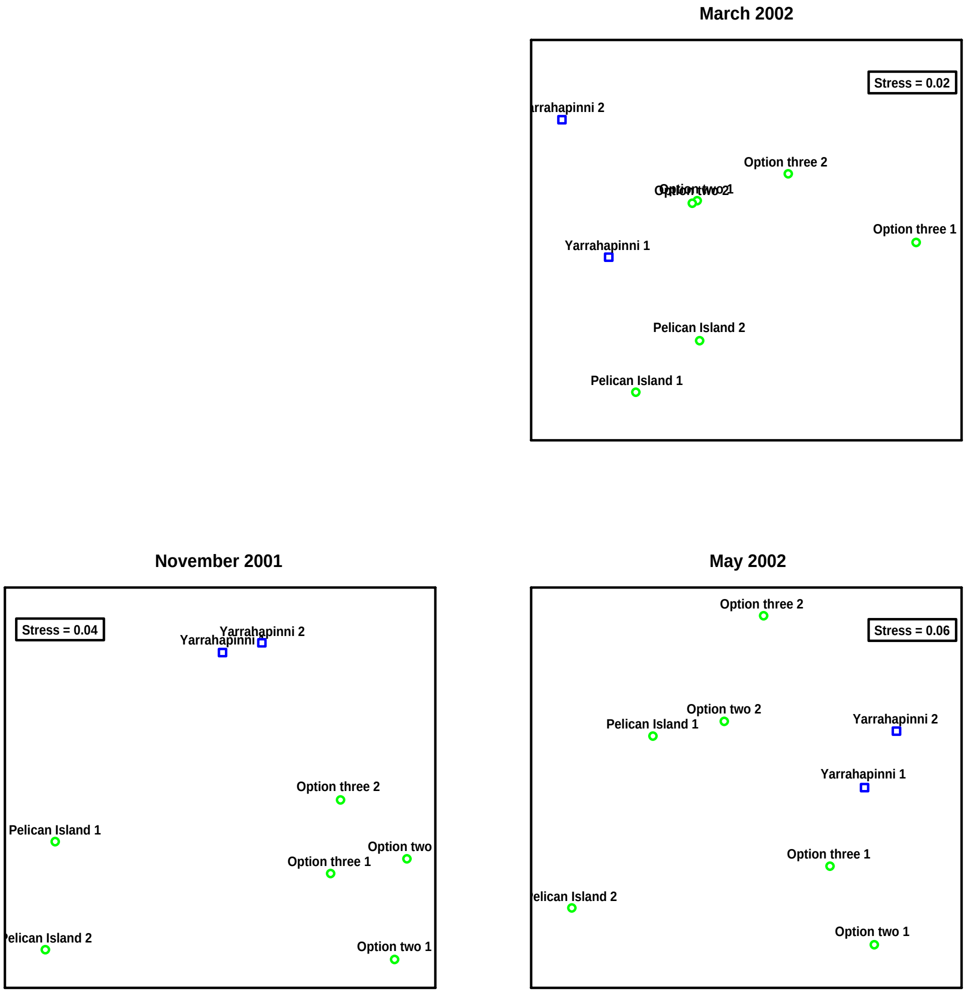

Figure A4.4. Macleay river. Non-metric multidimensional scaling (nMDS) ordinations of species assemblages (based on biomass data) on each of the three sampling occasions in the Macleay river floodplain. The ordinations are based on log (x+1) transformed abundances and Bray-Curtis similarities. Green open symbols are reference drainage systems and open square symbols are managed, gated drainage systems.

Table A4.5. Summary of two-way nested ANOSIM tests examining differences among species assemblages (based on biomass data) between treatments (reference vs managed drainage systems) for the three sampling occasions in the lower Macleay river floodplain.

Month	Source of variation	Permutations	Global R	Significance level
Nov. 2001	Treatment	4	0.111	0.75
	Location (Treatment)	15	0.722	0.06
Mar. 2002	Treatment	4	-0.111	0.75
	Location (Treatment)	15	0.667	0.06
May 2002	Treatment	4	-0.111	0.50
	Location (Treatment)	15	0.389	0.20

Table A4.6. SIMPER results showing the species ranked in decreasing order of importance (1-10 only) that contributed to the total average dissimilarity in species assemblages (based on biomass data) between treatments (reference vs managed drainage systems) for the three sampling occasions in the lower Macleay river floodplain. Percentage of average dissimilarity between treatments for each sampling occasion, and percentages of cumulative contribution by first ten species to dissimilarity are given. Numbers in bold indicate species that were more abundant in reference sites, and species in red indicate species significant for commercial and/or recreational fisheries.

Reference vs Managed	**2001**	**2002**	
	Nov	**March**	**May**
Average dissimilarity	**61.05%**	**73.88%**	**63.83%**
Acanthopagrus australis		5	
Acetes sibogae australis	**3**	1	
Afurcagobious tamarensis		8	3
Ambassis jacksoniensis	**9**	**6**	**2**
Ambassis marianus	6	3	
Ambassis spp			**10**
Arrhamphus sclerolepis		**10**	
Favonigobius exquisites			8
Gambusia holbrookii			9
Gerres subfasciatus	**5**	**2**	
Gobiomorphus australis	4		
Hypseleotris compressus	1		6
Liza argentea		**7**	**5**
Metapenaeus macleayi	**8**	4	4
Palaemon debilis	**2**	**9**	**7**
Pseudogobius olorum	7		
Pseudomugil signifer	**10**		
Redigobius macrostoma			1
Cumulative contribution	**60.97%**	**66.90%**	**76.27%**

Table A4.7. BIOENV results showing sets of three environmental variables that best describe the biotic patterns shown in the nMDS ordinations of species assemblages (based on biomass data) (Figure 4) for the three sampling occasions in the lower Macleay river floodplain. ** indicates that environmental variable was more common or present at higher concentrations at reference sites. The correlation coefficient (Spearman), based on the similarity matrices of both the biotic and abiotic data, is given for each sampling occasion.

	2001	**2002**	
	Nov	**March**	**May**
Correlation coefficient	**0.918**	**0.644**	**0.710**
Dissolved oxygen (surface)	*		
Phosphate (mg/L P)		**	
Nitrate (mg/L N)	**	**	
Dissolved iron (mg/L)		**	
Leaf litter			*
Filamentous algae			**
Large woody debris			**
Small woody debris	*		

Table A4.8. Results of χ^2 tests comparing the frequencies that water quality values did not conform to ANZECC guidelines (2000) in reference and managed drainage systems. Trigger values are given for lowland rivers and streams for (i) physical and chemical stressors for south-east Australia (including NSW and south-east Queensland) for slightly disturbed ecosystems, and, (ii) toxicants at 95% level of protection (ANZECC, 2000). Numbers in red indicate significant difference between expected and observed frequencies.

November 2001 - May 2002	**Trigger values (ANZECC, 2000)**	**Reference drainage systems**	**Managed drainage system**	χ^2	**p**
a. Physical and chemical stressors					
pH $_{(s)}$	6.5 - 8.0	2 / 9	1 / 3	0.15	0.70
pH $_{(b)}$	6.5 - 8.0	2 / 9	0 / 3	0.80	0.37
Total phosphoros (mg/L P)	0.05 mg P/ l	1 / 9	0 / 3	0.36	0.55
Phosphate (mg/L P)	0.02 mg P/L	1 / 9	0 / 3	0.36	0.55
Total nitrogen (mg/L N)	0.5 mg N/L	0 / 9	0 / 3	n/a	n/a
Turbidity (NTU)	6-50 NTU	4 / 9	2 / 3	0.44	0.37
DO $_{(s)}$ (mg/L)	5.0 mg/L	2 / 9	0 / 3	0.80	0.37
DO $_{(b)}$ (mg/L)	5.0 mg/L	2 / 9	0 / 3	0.80	0.37
b. Toxicants					
Total aluminium (mg/L)	0.05 mg/L (pH>6.5)	2 / 9	0 /3	0.80	0.37
Ammonia (mg/L N)	0.9 mg N/L	0 / 9	0 /3	n/a	n/a
Nitrate (mg/L N)	0.7 mg N/L	0 / 9	0 /3	n/a	n/a

Discussion

Species assemblages, based on abundance and biomass, in the reference and managed gated drainage systems in the Macleay river floodplain did not clearly separate (Figure A4.3, A4.4). In addition, ANOSIM results showed that treatment effects were not significant (Table A4.2, A4.5). This indicates that the species assemblages in Yarrahapinni Broadwater were similar to those in the reference drainage systems. Furthermore, similar numbers of commercially and recreationally signficant species were collected in Yarrahapinni Broadwater and reference drainage systems, including yellowfin bream (*Acanthopagrus australis*), flat-tail mullet (*Liza argentea*) and school prawn (*Metapenaeus macleayi*). These results are strikingly different from Gibbs *et al*. (1999), who found that the upstream community was dominated by freshwater fish and invertebrate species, while very few commercially or recreationally important species were collected. These results strongly suggest that the floodgate openings in 2001 and 2002 resulted in a significant change in species assemblages in the Yarrahapinni Broadwater. This supports that, with active floodgate management (i.e opening and closing of gates), juvenile fish and invertebrates will utilise floodgated drainage systems.

Our results suggest that opening of floodgates can be an avenue to manage exotic species, such as *Gambusia holbrooki* (see also Chapter 4). The results from the SIMPER analysis (Table A4.3, A4.6) show that *G. holbrooki* contributed to the dissimilarity in species assemblages between reference and managed drainage systems. While *G. holbrooki* was still more common and present at higher biomass in Yarrahapinni Broadwater than in the reference drainage systems (Tables A4.9, 4.10), numbers had significantly decreased compared to Gibbs *et al.* (1999). These results suggest that opening floodgates reduces the relative abundance and biomass *G. holbrooki* in managed systems compared to gated systems. Opening floodgates should be considered as an effective manner of reducing the numbers of *G. holbrooki*, and it's detrimental impact on native fish fauna.

The combinations of environmental variables that best described the biotic patterns shown in the six nMDS ordinations were never strongly correlated with those biotic patterns, and varied from trip to trip (Table A4.4, A4.7; Figure A4.3, A4.4). In addition, the frequency that values did not conform to ANZECC guidelines in both systems did not differ significantly for any of the chemical stressors or toxicants (Table A4.8). Moreover, water quality in Yarrahapinni Broadwater in general was similar to that in the three reference drainage systems (Table A4.11). In contrast, Gibbs *et al.* (1999) found that both salinity and pH levels were generally lower in Yarrahapinni Broadwater than at reference sites. These results strongly suggest that the floodgate openings in 2001 and 2002 resulted in a significant improvement in water quality in the Yarrahapinni Broadwater, and became similar to that in reference drainage systems. This supports the contention that, with active floodgate management (i.e opening and closing of gates), water quality will improve in floodgated drainage systems.

Opening of floodgates in the Clarence river floodplain resulted in significant improvements in habitat quality in managed drainage systems, including the disappearance of waterlillies, and grasses and rushes due to tidal influx (Chapter 4). As expected (SWC, 1997), the opening of one floodgate at Yarrahapinni Broadwater resulted in die-back of rushes and *Casuarina glauca* swampforest in the lower marsh (pers. obs.). In the Clarence, our results incidate that grasses and rushes are a significant habitat quality component, frequently associated with the differences between species assemblages present in gated and reference drainage systems (Table A4.4, A4.7). Consequently, the die-back of rushes as a result of floodgate opening in Yarrahapinni has most likely affected species assemblages present. For example, this may be by limiting the spawning substrate available for abundant species such as *Hypseleotris compressus*, *Philypnodon grandiceps*, and *P. sp.* (Larson and Hoese, 1996), thereby limiting their ability to complete their life cycle within drainage systems. Nevertheless, additional habitat quality components will need to be addressed to restore species assemblages to compositions resembling more closely those in reference drainage systems (Table A4.3, A4.6, A4.9, A4.10). This would be particularly important if Yarrahapinni Broadwater itself is going to provide a role as fish nursery habitat again. The results of the BIOENV analyses in the Clarence river (Table A4.4, A4.7) indicate that restoration of mangroves and seagrass are the prime candidates. Continued opening of floodgates at Yarrahapinni Broadwater is expected to result in the lower marsh areas being replaced by mangrove and saltmarsh (SWC, 1997). From a fisheries perspective, it is therefore of great concern that, in February 2004, the floodgates at Yarrahapinni Broadwater have been closed again for at least a year (Simon Walsh, NSW Fisheries, pers. comm.).

Table A4.9. Species abundance at reference and gated drainage systems in the lower Macleay river floodplain.

Class/Order/Family	Genus and species	Common name	Total number	Minimum length (mm)	Maximum length (mm)	Option three [r]	Option two [r]	Pelican Island [r]	Yarrahapinni broadwater
CLASS ACTINOPTERYGII									
Order Atheriniformes									
Poeciliidae	*Gambusia holbrooki*	Mosquitofish	42	16.4	31.5	3	2		37
Pseudomugilidae	*Pseudomugil signifer*	Southern blue-eye	588	10.6	30.3	411	134	4	39
Order Beloniformes									
Belonidae	*Tylosurus gavialoides*	Stout longtom*	1	590.0	590.0	1			
Hemiramphidae	*Arrhamphus sclerolepis*	Snub-nosed garfish	7	62.2	78.7	6	1		
	Hyporhamphus regulatus	River garfish*	1	48.2	48.2	1			
Order Clupeiformes									
Clupeidae	*Herklotsichthys castelnaui*	Southern herring*	63	57.4	103.5	12	50		1
	Hyperlophus vittatus	Sandy sprat*	92	22.9	32.7	1		91	
Engraulidae	*Engraulis australis*	Australian anchovy*	1	26.0	26.0			1	
Order Osmeriformes									
Retropinnidae	*Retropinna semoni*	Australian smelt	1	24.2	24.2			1	
Order Perciformes									
Carangidae	*Scomberoides* spp.	Queenfish*	1	36.0	36.0	1			
Chandidae	Ambassis jacksoniensis	Port Jackson glassfish	6,218	9.4	52.3	776	2,948	1,534	960
	Ambassis marianus	Ramsay's glassfish	762	12.3	71.3	83	396	45	238
	Ambassis spp.	unidentified glassfish	2,076	5.9	22.3	53	623	1,154	246
Gerreidae	Gerres subfasciatus	Silver biddy*	108	13.3	84.5	23	70	9	6
	Girella tricuspidata	Blackfish*	6	14.3	80.3	2	1	2	1
Gobiidae	*Afurcagobious tamarensis*	Tamar River goby	588	11.1	47.9	287	153	2	146
	Arenigobius bifrenatus	Bridled goby	21	17.4	71.5			17	4
	Arenigobius frenatus	Half-bridled goby	4	15.2	26.9			4	
	Arenigobius spp.	unidentified gobies	4	27.5	41.1	2			2

Class/Order/Family	Genus and species	Common name	Total number	Minimum length (mm)	Maximum length (mm)	Option three [r]	Option two [r]	Pelican Island [r]	Yarrahapinni broadwater
	Favonigobius exquisites	Exquisite sand-goby	1,116	11.3	40.2	84	20	925	87
	Glossogobius biocellatus	Estuary goby	5	25.1	46.7	1		3	1
	Gobiomorphus australis	Striped gudgeon	331	13.0	36.0	26	1		304
	Gobiopterus semivestitus	Glass goby	64	13.6	21.5	30	29	3	2
	Hypseleotris compressus	Empirefish	930	13.5	46.5	11	25		894
	Mugilogobius platynotus	Mangrove goby	11	16.2	31.6	2	2	4	3
	Pandaculus lidwilla	Dwarf goby	18	9.6	13.1	15	3		
	Pseudogobius olorum	Blue-spot goby	932	10.8	32.0	44	123	294	471
	Redigobius macrostoma	Large-mouth goby	568	8.3	27.8	188	22	59	299
Monodactylidae	*Monodactylus argenteus*	Silver batfish	2	13.5	32.1		1		1
Mugilidae	*Liza argentea*	Flat-tail mullet*	1,579	2.5	144.5	507	200	608	264
	Mugil cephalus	Sea mullet*	88	21.0	86.6	20	66		2
Pomatomidae	*Pomatomus saltatrix*	Tailor*	6	21.6	120.5	2	1	3	
Scatophagidae	*Scatophagus argus*	Spotted scat	4	9.4	14.8		3		1
Sillaginidae	*Silago ciliata*	sand whiting*	8	15.7	109.7	2	4	1	1
Sparidae	*Acanthopagrus australis*	Yellow-finned bream*	194	11.8	82.4	76	11	60	47
	Rhabdosargus sarba	Tarwhine*	7	23.2	51.8	3	2		2
Order Pleuronectiformes									
Bothidae	*Pseudorhombus jenysii*	Small-toothed flounder*	3	23.0	116.3			1	2
Order Scorpaeniformes									
Platycephalidae	*Platycephalus fuscus*	Dusky flathead*	3	27.7	137.4		1	2	
Scorpaenidae	*Centropogon australis*	Fortescue	5	6.7	14.6	1		4	
Order Tetraodontiformes									
Monacanthidae	*Meuschenia trachylepis*	Yellow-finned leatherjacket*	1	42.1	42.1				1
Tetraodontidae	*Tetractenos hamiltoni*	Common toadfish	13	24.2	95.0			13	
TOTAL FISH			16,472			2,674	4,892	4,844	4,062
CLASS ARACHNIDA									
Order Araneae									
Tetragnathidae	*Tetragnatha* spp.		1						1

Class/Order/Family	Genus and species	Common name	Total number	Minimum length (mm)	Maximum length (mm)	Option three [r]	Option two [r]	Pelican Island [r]	Yarrahapinni broadwater
CLASS MALACOSTRACA									
Order Decapoda									
Alpheidae	*Alpheus* spp.		31	1.6	9.6	7	2	9	13
Atyidae	Caridina nilotica		1	3.1	3.1				1
Grapsidae	*Australoplax tridentata*		1	4.5	4.5		1		
	Parasesarma erythrodactyla		6	4.3	8.8	1	5		
Hymenosomatidae	*Amarinus* spp.	Spider crab	3	6.9	8.5				3
Palaemonidae	*Macrobrachium cf novaehollandiae*	Long-armed shrimp	37	2.8	19.9	7	1	8	21
	Palaemon debilis		6,315	1.4	15.2	1,314	352	4,488	161
Penaeidae	*Metapenaeus bennettae*	Greasy back prawn*	4	3.3	29.8	1			3
	Metapenaeus macleayi	School prawn*	1,586	1.3	16.6	698	243	34	611
	Penaeus plebejus	King prawn*	118	1.7	13.9	8	4	62	44
	Portunus pelagicus	Blue swimmer crab*	2	5.2	15.4			2	
Portunidae	*Thalamita crenata*		1	29.5	29.5			1	
	Acetes sibogae australis		9,182	1.1	9.1	55	4	6,189	2,934
Sergestidae									
Order Isopoda	*Catoessa ambassae*		30			3	13	1	13
	Cymodetta spp.	Pill bug	4				2		2
Sphaeromatidae									
CLASS BIVALVIA									
Order Mytiloida									
Mytilidae	*Xenostrobus securis*		1						1
Mactricidae	*Spisula trigonella*	Trough shell	2					1	1
Tellins	*Tellina deltoidalis*		1					1	
Trapeziidae	*Fluviolanatus subtortus*		1			1			
CLASS CEPHALOPODA									
Idiosepiidae	*Idiosepius* spp.	Pygmy squid	4	6.4	6.4			2	2
CLASS GASTROPODA									
Super-order Hypsogastropoda									

Class/Order/Family	Genus and species	Common name	Total number	Minimum length (mm)	Maximum length (mm)	Option three [r]	Option two [r]	Pelican Island [r]	Yarrahapinni broadwater
Littorinidae	*Bembicium auratum*		1						1
Nassaridae	*Nassarius burchardi*	Dog whelk	40					29	11
	Nassarius jonassi		37					34	3
CLASS POLYCHAETA	*Ceratonereis aequisetis*		2				1		1
Nereididae	*Prionospio* spp.		2						2
Spionidae									
CLASS INSECTA									
Order Hemiptera									
Geridae	*Limnogonus* spp.	Pond skater	61			3	27	28	3
TOTAL INVERTEBRATES			17,485			2,099	662	1,0889	3,835
TOTAL NUMBER			**33,946**			**4,772**	**5,547**	**15,733**	**7,894**

* commercially harvested species
[r] reference sites

Table A4.10. Species biomass at reference and gated drainage systems in the lower Macleay river floodplain.

Scientific name	Total weight (g)	Option Two [r]	Option Three [r]	Pelican Island [r]	Yarrahapinni Broadwater
*Acanthopagrus australis**	213.7	36.9	29.1	56.0	91.7
Acetes sibogae australis	1,108.6	0.1	5.9	778.4	324.2
Afurcagobious tamarensis	107.8	23.2	47.9	0.4	36.3
Alpheus spp.	6.9	0.3	0.3	1.1	5.2
Amarinus spp.	0.6				0.6
Ambassis jacksoniensis	1,700.2	841.3	139.6	454.2	265.1
Ambassis marianus	442.1	132.3	15.9	150.6	143.3
Ambassis spp.	150.2	46.3	2.1	88.8	13.0
Arenigobius bifrenatus	24.2			22.6	1.6
Arenigobius frenatus	0.6			0.6	
Arenigobius spp.	3.5		1.2		2.3
Arrhamphus sclerolepis	14.2	1.7	12.5		
Australoplax tridentata	0.1	0.1			
Bembicium auratum	0.2				0.2
Caridina nilotica	0.1				0.1
Catoessa ambassae	0.4	0.1	0.1	0.1	0.1
Centropogon australis	0.4		0.1	0.3	
Ceratonereis aequisetis	0.2	0.1			0.1
Cymodetta spp.	0.2	0.1			0.1
Engraulis australis	0.1			0.1	
Favonigobius exquisites	173.8	2.1	8.9	148.2	14.6
Fluviolanatus subtortus	0.1		0.1		
Gambusia holbrooki	10.1	0.1	0.5		9.5
Gerres subfasciatus	202.9	101.1	76.0	19.9	5.9
*Girella tricuspidata**	23.5	19.6	2.5	0.3	1.1
Glossogobius biocellatus	3.3		1.7	1.4	0.2
Gobiomorphus australis	42.5	0.1	1.5		40.9
Gobiopterus semivestitus	4.0	2.2	1.4	0.3	0.1
*Herklotsichthys castelnaui**	791.5	574.3	213.6		3.6
*Hyperlophus vittatus**	18.0		0.1	17.9	
*Hyporhamphus regulatus**	0.6		0.6		
Hypseleotris compressus	158.5	4.9	1.0		147.7
Idiosepius spp.	0.2			0.1	0.1
Limnogonus spp.	0.4	0.1	0.1	0.1	0.1
*Liza argentea**	2,777.7	976.1	891.8	81.4	828.4
Macrobrachium cf novaehollandiae	55.1	0.3	0.4	3.6	50.8
*Metapenaeus bennettae**	12.9		0.1		12.8
*Metapenaeus macleayi**	281.4	28.5	121.6	1.9	129.4
*Meuschenia trachylepis**	1.7				1.7
Monodactylus argenteus	1.9	0.2			1.7
*Mugil cephalus**	167.6	75.9	66.4		25.3
Mugilogobius platynotus	1.8	0.5	0.3	0.1	0.9
Nassarius burchardi	3.2			2.2	1.0
Nassarius jonassi	1.3			1.3	
Palaemon debilis	661.0	27.7	117.3	486.1	29.9
Pandaculus lidwilla	0.7	0.1	0.6		
Parasesarma erythrodactyla	1.1	0.9	0.2		
*Penaeus plebejus**	11.3	0.1	0.3	3.5	7.4
*Platycephalus fuscus**	27.1	0.2		26.9	
*Pomatomus saltatrix**	56.5	29.2	9.6	17.7	
*Portunus pelagicus**				1.9	
Prawn bodies*	0.8	0.5	0.1		0.2
Prionospio spp.	0.1				0.1
Pseudogobius olorum	154.9	16.9	6.4	50.0	81.6

Scientific name	**Total weight (g)**	**Option Two ʳ**	**Option Three ʳ**	**Pelican Island ʳ**	**Yarrahapinni Broadwater**
Pseudomugil signifer	88.5	15.9	60.9	0.3	11.4
*Pseudorhombus jenysii**	32.4			5.7	26.7
Redigobius macrostoma	68.7	1.0	15.7	13.7	38.3
Retropinna semoni	0.1			0.1	
*Rhabdosargus sarba**	18.2	9.6	5.4		3.2
Scatophagus argus	0.7	0.6			0.1
Scomberoides spp.*	0.3		0.3		
*Silago ciliata**	27.9	0.1	27.0	0.4	0.4
Spisula trigonella	0.3			0.1	0.2
Tellina deltoidalis	0.1			0.1	
Tetractenos hamiltoni	236.6			236.6	
Tetragnatha spp.	0.1				0.1
Thalamita crenata	17.9			17.9	
*Tylosurus gavialoides**	250.0		250.0		
Xenostrobus securis	0.1				0.1

* commercially harvested species
ʳ reference sites

Table A4.11. Water quality and habitat quality variables at reference and gated drainage systems in the lower Macleay river floodplain. [r] = reference sites.

(i) Water quality

		Option three [r]	Option two [r]	Pelican Island [r]	Yarrahapinni broadwater
Depth (cm)	Mean	111	93	120	214
Temp (^{0}C)	Mean	23.2	23.2	23.8	22.9
	Minimum	18.8	19.3	20.3	20.3
	Maximum	27.0	26.0	26.5	26.3
DO (mg/L)	Mean	6.8	6.7	7.2	6.8
	Minimum	4.5	4.3	5.6	4.8
	Maximum	9.2	8.9	8.7	9.9
pH	Mean	7.5	7.5	8.1	8.0
	Minimum	7.0	7.1	7.7	7.6
	Maximum	7.9	8.0	8.5	8.9
Salinity (g/L)	Mean	28.6	29.1	30.1	32.6
	Minimum	18.3	20.2	0.5	28.7
	Maximum	36.6	36.8	36.4	36.3

(ii) Mean levels of chemical stressors and toxicants.

	Option three [r]	Option two [r]	Pelican Island [r]	Yarrahapinni broadwater
Conductivity (dS/m)	28.24	27.90	32.70	29.82
Total dissolved solids (mg/L)	19202	18972	22234	20281
Total phosphorous (mg/L)	0.016	0.019	0.043	0.016
Phosphate (mg/L)	0.004	0.005	0.015	0.005
Total nitrogen (mg/L)	0.348	0.353	0.230	0.217
Total Kjeldahl nitrogen (mg/L)	0.325	0.325	0.224	0.209
Nitrate (mg/L)	0.022	0.028	0.006	0.008
Nitrite (mg/L)	0.001	0.002	0.001	0.001
Ammonia (mg/L)	0.023	0.033	0.009	0.024
Total aluminium (mg/L)	0.079	0.030	0.010	0.026
Dissolved aluminium (mg/L)	0.023	0.008	0.003	0.005
Total iron (mg/L)	0.098	0.018	0.027	0.017
Dissolved iron (mg/L)	0.032	0.004	0.002	0.003

(iii) Habitat variables. The proportional contribution of each substratum and vegetation type was quantified by ranking on a 5-point scale, corresponding to absent (0), uncommon (1), common (2), abundant (3) and very abundant (5).

	Option three [r]	**Option two** [r]	**Pelican Island** [r]	**Yarrahapinni broadwater**
Width (m)	15.4	11.8	29.0	28.9
Mud (0-5)	3.8	4.0	4.0	3.8
Sand (0-5)	0.4	0.0	0.0	1.3
Fine gravel (0-5)	0.0	0.0	0.0	0.0
Gravel (0-5)	0.1	0.0	0.0	0.0
Cobble (0-5)	0.1	0.0	0.0	0.0
Boulders (0-5)	0.3	0.1	0.0	0.1
Bedrock (0-5)	0.0	0.0	0.0	0.0
Leaf litter (0-5)	1.1	0.9	0.6	1.0
Seagrass (0-5)	0.0	0.0	0.0	0.0
Water Lillies (0-5)	0.0	0.0	0.0	0.0
Grasses and Rushes (0-5)	0.3	0.9	0.3	0.3
Mangroves (0-5)	3.4	2.6	2.4	0.5
Overhanging terrestrial trees (0-5)	0.0	0.4	0.1	3.1
Filamentous algae (0-5)	0.1	0.1	0.0	0.0
Large woody debris (0-5)	0.1	0.1	0.5	0.1
Small woody debris (0-5)	0.4	0.3	0.6	1.0
Undercut bank (0-5)	0.1	0.5	0.1	0.0
Exposed rootmasses (0-5)	1.4	1.6	2.1	0.3
Riparian cover (%)	6.9	3.8	1.3	1.3

Appendix 5. Tide-actuated floodgates

Introduction

Active floodgate management improved water quality and fish passage, but these gains disappeared if the floodgates were not regularly opened (Chapter 4). An automated system of restricted floodgate opening would be a more desirable alternative to improve both water quality and fish passage than systems requiring manual operation.

Tide-actuated, flow-controled gates for flood mitigation drainage systems came on the market in 2001, mid-way through this FRDC project. These gates open and close automatically with the tide, but still allow the main floodgate to operate normally in flood conditions. They have the advantage that they do not have to be managed by the landholder, they minimise the risk of saline overtopping, but they still provide regular and frequent exchange of water. A number of these gates have since been installed in various locations in NSW and QLD. Hastings Council in NSW, for example, has been closely involved with the development of tide-actuated floodgates and have an increasing number of gates fitted to drainage systems in their region since 2001.

To ensure that fish passage is improved and maximised with the installation of automated tidal gates, it is important that the different designs are thoroughly evaluated. This was not feasible as part of this FRDC project. However, given the promising nature of these gates for improvement of fish passage, a preliminary evaluation was considered useful to examine whether fish and invertebrate species would use these structures to migrate into gated drainage systems.

Here, we present a preliminary assessment of the effectiveness of existing, tidally-operated floodgates in the Maria and Camden Haven rivers near Port Macquarie on the mid-north coast of NSW, as well as the changes to fish and invertebrate populations following the installation of a tidally-operated modification to a Hunter River floodgate. We examined two different designs for their effectiveness in improving fish passage and water quality. The two manufacturers of these tide-actuated floodgates obviously believe that their designs provide better opportunities for fish passage than standard floodgates. Anectodal reports from Hastings Council support this. The preliminary trials described here were designed to test whether these claims could be more rigorously investigated using field sampling.

Methods

Two different designs for tide-actuated floodgates were examined:

Design 1: Armon Engineering based in Kempsey produces a floodgate which uses a float to operate a smaller window gate within the main floodgate (Figure A5.1). The water level at which the window is opened and closed is adjusted by altering the height of the float. Gates can be made from steel, stainless steel or aluminium, with window sizes up to 900 mm x 900 mm. Approximately 50 Armon Engineering tide-actuated gates are presently operating in NSW and Qld.

Design 2: Australian Aqua Services based in Wauchope have designed a semi-floating pipe system fitted with an adjustable ballast attachment (Figure A5.2). As the tide rises, the mouth of the pipe rises above the water level and cuts off further inflow. Pipes can be made in a range of sizes and from a variety of materials including translucent or internally light reflective.

Sampling sites

Four sites with tidally-operated floodgates were chosen from within the Hastings Council region, one in the Camden Haven River and three in the Maria River catchment (Table A5.1). These sites were chosen to be fitted with tide-actuated floodgates by Hastings Council on the basis that they had chronic acid discharges and low pH. Few fish had been observed above any of the floodgates prior to gate modifications (Thor Aaso, Hastings Council, pers. comm.).

Rossglen Drain (CH 5.6R) is situated on the Camden Haven River near Kew. Two 900 mm-diameter circular floodgates are fitted at the mouth of the drain. When not actively managed, the drain continually discharged acid water of pH 3.5-5.5 (Hastings Council, 2002a). A 500 mm wide x 300 mm high tide-actuated Armon Engineering gate was installed in the western floodgate in July 2001 (Figure A5.3), and a retention weir built in September 2002 to contain acid 300 m upstream of the gate. Only one acid discharge event has occurred since September 2002, and regular water quality monitoring has shown the drain to have a pH of above 6.5 (Hastings Council, unpublished data).

Oceana Tea Tree Drain (MR 22.2L) is situated on the Maria River 13 km upstream of its junction with the Hastings River. The drain is fitted with three 2.3 m x 2.3 m floodgates. Australian Aqua Services installed a 2 m x 0.6 m tide-actuated pipe system to the centre floodgate in August 2001 (Figure A5.2), which is set to allow tidal exchange for tides reaching up to 0.35 m AHD. Dropboards are also installed on the upstream side of the floodgate culverts, set with a crest height of 0.2 m AHD.

Kentwell Farm Drain (MR 23.0L) is situated on the Maria River 1km upstream of Oceana Tea Tree. The drain is fitted with three 2.3 m x 2.3 m floodgates. Dropboards were added on the upstream side of the floodgate culverts to raise water levels in the drain to 0.2 m, and two 500 mm wide x 300 mm high tide-actuated Armon Engineering gates were installed in November 2001 (Figure A5.4), resulting in a large reduction in aquatic weeds for 1.2 km within the drain, and raising of the drain's average pH from 3 to 7 (Hastings Council, unpublished data). A major acid discharge event in April 2002 dropped the drain pH to 4, but it rapidly returned to above 6 through tidal flushing over the following weeks.

Fernbank Ck Drain (FC 10.4R) discharges into Fernbank Creek 700 m upstream of the junction with the Hastings River. Two 1170 mm x 1255 mm square floodgates are fitted. A 500 mm wide x 300 mm Armon Engineering gate was installed in March 2002 (Figure A5.5) and set to close once drain water levels rise above 0.5 m AHD, and a dropboard weir was built 320 m upstream of the gate set at a crest height of +0.3m AHD. Spot pH measurements from March to December 2003 have been above 6 (Hastings Council, unpublished data).

There were no pre-existing tide-actuated floodgates on the Hunter river. Discussions were held with landowners and the Miller's Forest Progress Association, and potential sites for installation were examined along the Hunter River between Fullerton Cove and Morpeth. A site at Greenways Creek was chosen, with nearby Purgatory Creek acting as the reference site (see Table A5.1).

Greenways Creek (Gate 7.480) is situated midway between Hexham and Raymond Terrace. Six 2.3 m x 2.3 m floodgates are fitted to box culverts across the creek mouth. A 600 mm wide x 800 mm high tide-actuated Armon Engineering gate was installed in the eastern box culvert in October 2002 (Figure A5.6) by DIPNR's Hunter Valley Flood Mitigation Group.

Purgatory Creek (Gate 2.030) is located near Hexham, 16 km from the mouth of the Hunter River. Three pipe culverts are fitted with 1.8 m diameter floodgates 230 m upstream from the mouth of the creek, but the section of creek between these gates and the junction with the Hunter River is clear of obstructions, with natural tidal flow and is lined with mangroves (Figure A5.7).

Figure A5.1. Float-operated floodgate manufactured by Armon Engineering. Upper: gate position at low tide, Lower: gate position at high tide.

Figure A5.2. Tide-actuated floodgate manufactured by Australian Aqua Services, shown here installed at Oceana Tea Tree.

Figure A5.3. Tide-actuated floodgate at Rossglen Drain.

Table A5.1. Tide-actuated gate sampling sites. Drain/gate reference numbers are identifying codes used by Hastings Council for Camden Haven and Maria River flood mitigation systems and by DIPNR for Hunter River structures. Northings and Eastings were were taken from CMA 1:25000 topographic maps (+ 50 m). Distance from mouth and catchment area were estimated using published topographic maps, and depth of pyritic level was obtained from Hastings, Maitland City, and Newcastle City Councils.

SITE NAME	DRAIN/GATE REF. NO.	CATCHMENT	GATE TYPE	NORTHING	EASTING	DISTANCE FROM MOUTH (km)	DRAINAGE AREA (km^2)	DEPTH OF PYRITIC LEVEL (m)
Rossglen	CH 5.6R	Camden Haven River	Armon Engineering	64 97 200	(56) 04 74 050	12	0.3	0
Oceana Tea Tree	MR 22.2L	Maria River	Aust. Aqua Services	65 30 500	(56) 04 84 200	21	6	0-1
Kentwell Farm	MR 23.0L	Maria River	Armon Engineering	65 31 700	(56) 04 84 100	22	6	0-1
Fernbank Ck	FC 10.4R	Maria River	Armon Engineering	65 24 800	(56) 04 85 500	10	1	0-1
Greenways Ck	Gate 7.480	Hunter River	Armon Engineering	63 71 200	(56) 03 77 700	21	15	0-1
Purgatory Ck	Gate 2.030	Hunter River	No gate	63 67 950	(56) 03 76 450	16	6	0-1

Figure A5.4. Tide-actuated floodgates at Kentwell Farm.

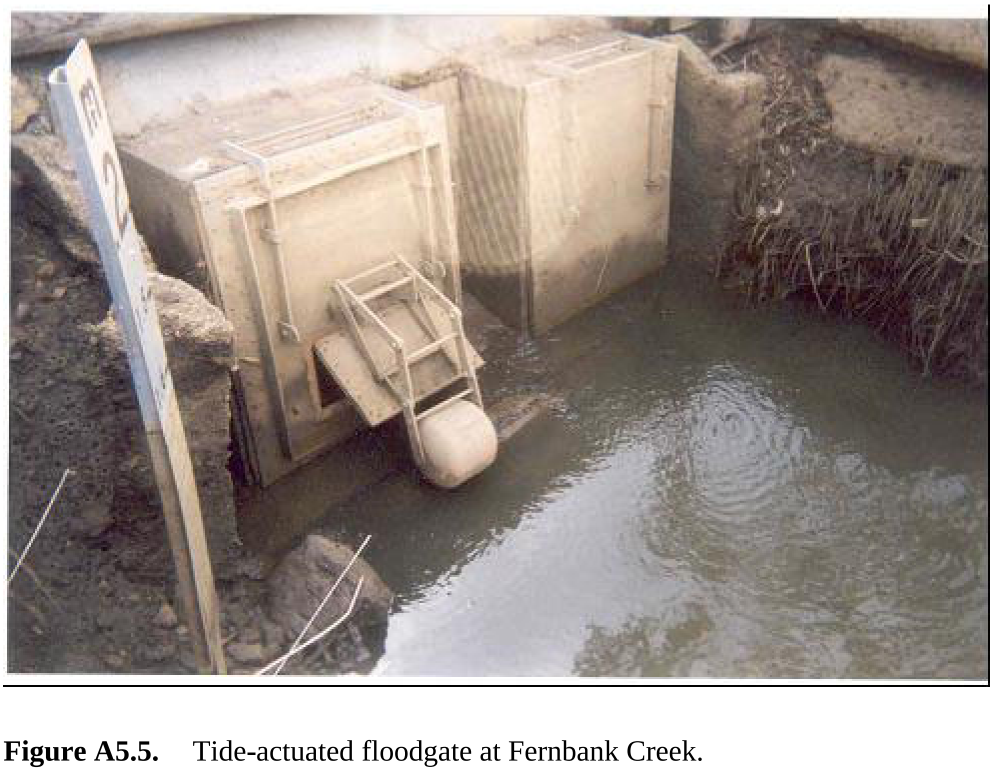

Figure A5.5. Tide-actuated floodgate at Fernbank Creek.

Figure A5.6. Tide-actuated floodgate at Greenways Creek in the Hunter catchment.

Figure A5.7. Purgatory Creek, the reference site in the Hunter Catchment.

Sampling methods

Sites in the Camden Haven and Maria rivers were sampled only once, in February 2003. Sites in the Hunter river were sampled five times from September 2002 to January 2003, twice before the installation of the tide-actuated gate, and three times afterwards.

Quantification of fish and invertebrates, and water and habitat quality followed the procedures described in Chapter 2, with the following exceptions:

a) All sites were sampled below the floodgates as well as above them.

b) Four seines were hauled in each of these two areas. However, due to the limited depth and scarcity of suitable habitat at 3 sites (Rossglen, Kentwell Farm and Greenways creek), there was insufficient space downstream for four hauls and only two could be done.

c) Only fish and crustacea were recorded; all individuals were identified in the field, counted and released alive at the point of capture. No weights were recorded.

d) Specimens that could not be quickly identified to species level were recorded at the highest possible classification. For example, very small tarwhine and bream that could not be separated were recorded as “unidentified sparidae”.

e) No water samples were collected for nutrient and metal analysis.

Results

Problems with the field sampling design, most notably the inability to get adequate replicates below three of the five floodgates examined, meant that the data could not be statistically examined. Further, the sampling in the Maria and Camden Haven rivers had spatial replicates but no temporal component, whereas the sampling in the Hunter river had replication at the temporal scale but not the spatial scale. For these reasons, the preliminary results are presented as combined totals and only general inferences are drawn from the two data sets.

Camden Haven and Maria rivers

In total, 15,243 individuals (4,996 fish and 10,247 crustaceans), comprising of 34 taxa (27 fish and 7 crustacea taxa) were caught from the four Camden Haven and Maria rivers sites during the single sampling event (Table A5.2). These consisted of 11 commercial (9 fish and 2 crustacean) and 23 non-commercial (18 fish and 5 crustacean) species.

The number of species recorded was similar above and below each gate except perhaps at Rossglen where 16 species were caught below the gate but only 10 above it (Table A5.3). Numbers of individual per species varied greatly between sites, as well as above and below the floodgates at each site (Table A5.2). However, *Acetes* shrimp (*Acetes sibogae australis*) comprised greater than 75% of the total catch numbers below floodgates at two of the four sites, while few individuals of this species were recorded from above any of the gates. When excluding *Acetes* shrimp from the totals, the remaining catches were greater above the floodgates than below at three of the four sites (Table A5.3). Again, the only site where the catch was greater downstream of the gate was Rossglen.

Hunter river

Over the five sampling occasions, 32 species (23 fish and 9 crustacean) were collected from Greenways Creek before installation of the tide-actuated gate. Of these, nine were commercially harvested species (7 fish and 2 crustacean). Catches were dominated by the non-commercial *Acetes* shrimp which made up over 92% of the total catch of 181, 161 individuals (Table A5.4). They comprised 66% of the total catch numbers below the floodgate and 98% of the catch at the ungated, reference site, but not a single specimen was caught above the gate. Before the installation of the tide-actuated floodgate, the total number of species recorded was similar above and below the gate and at the reference site (Table A5.5), but individual numbers were 27 times higher below the gate than above. If *Acetes* shrimp are removed from the total catch, total numbers of individuals caught below the gate were still nine times greater than above it (Table A5.5). Flat-tailed mullet (*Liza argentea*), glassfish (*Ambassis* spp.) and glass gobies (*Gobiopterus semivestitus*) were also abundant below the gate but rare or absent from catches above it (Table A5.4).

A total of 34 species (25 fish and 9 crustacean), including 12 commercially harvested species (9 fish and 3 crustacean) were collected from Greenways creek after installation of the tide-actuated gate (table A5.4). Again, species richness was similar similar above and below the gate and at the reference site, and the total numbers of individuals caught was only four times higher below the gate than above it (Table A5.5). *Acetes* shrimp still made up 94% of the total catch at the reference site and 92% of the catch below the modified floodgate, but they now also comprised 37% of the catch above the floodgate. Flat-tailed mullet, glassfish and glass gobies were still more abundant below the gate than above it after the installation, but total numbers of fish and crustaceans caught (excluding *Acetes* shrimp) were now greater above the gate than below it (Table A5.4). Commercial and recreational species such as luderick (*Girella tricuspidata*), yellow-finned bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*), sea mullet (*Mugil cephalus*) and school prawns (*Metapenaeus macleayi*) were now common above the gate.

Water quality

Water quality was very similar above and below each of the four floodgates investigated in the Camden Haven and Maria rivers (Table A5.6). Mean water temperatures ranged from 24.2 ^{0}C below the Fernbank Ck gate to 26 ^{0}C above the Rossglen gate, and salinity varied from 27.2 g/L below the Tea Tree gate to 35.5 g/L above the Fernbank Ck gate (Table A5.6). A faulty dissolved oxygen probe made D.O. readings unreliable.

Before installation of the new gate on Greenways creek in the Hunter catchment, mean water temperatures across all sampling sites varied between 18.9 ^{0}C and 19.9 ^{0}C (Table A5.7). Surface salinity averages were 13.5 g/L above the gate and 19.3 ppt below it, while salinity averages at the bottom of the water column were 16.0 g/L above the gate and 20.0 g/L below it. Average salinities at the control site were 18.8 g/L at the surface and 22.9 g/L near the sediment. After gate installation, mean water temperatures across all sampling areas varied between 24.7 ^{0}C and 27.1 ^{0}C (Table A5.7). Surface salinity averages at Greenways creek were 16.4 g/L above the gate and 17.9 g/L below it, while salinity averages at the bottom of the water column were 18.3 ppt above the gate and 17.2 g/L below it. Average salinities at the control site were 25.7 g/L at the surface and 27.4 g/L near the sediment.

Table A5.2. Species abundance above and below Camden Haven and Maria Rivers tidally operated floodgates.

Class/Order/Family	Genus and species	Common Name	Fernbank Ck		Kentwell Farm		Tea Tree		Rossglen	
			above gate	below gate	above gate	below gate #	above gate	below gate	above gate	below gate #
CLASS ACTINOPTERYGII										
Order Anguilliformes										
Anguillidae	*Anguilla reinhardtii*	Long-fin eel*			1	1				
Order Atheriniformes										
Pseudomugilidae	*Pseudomugil signifer*	Southern blue-eye	61		1,563	10	653	152	108	179
Order Clupeiformes										
Clupeidae	*Herklotsichthys castelnaui*	Southern herring*		10		2		11		
Order Perciformes										
Chandidae	*Ambassis* spp.	Glassfish		138	26	23	6	31		14
Gerreidae	*Gerres subfasciatus*	Silver biddy*				4	12	4		
Gobiidae	*Afurcagobious tamarensis*	Tamar River goby	48	50	17	25	2	86		1
	Arenigobius bifrenatus	Bridled goby	1	7				1		1
	Favonigobius exquisites	Exquisite sand-goby						1		
	Gobiomorphus australis	Striped gudgeon	187		9		34	16	56	4
	Gobiopterus semivestitus	Glass goby	59	27	138	1	58	17		
	Hypseleotris compressus	Empirefish	8		4				3	
	Mugilogobius paludis	Mangrove goby	43		2					
	Pandaculus lidwilla	Dwarf goby		2						1
	Philypnodon grandiceps	Flathead gudgeon	4	1	2	3	106	2	14	11
	Philypnodon sp.	Dwarf flathead gudgeon							5	17
	Pseudogobius olorum	Blue-spot goby	189	73	45	10	34	41	4	2
	Redigobius macrostoma	Large-mouth goby	13	13	25	6	109	110		10
Monodactylidae	*Monodactylus argenteus*	Silver batfish			1	1	12			
Mugilidae	*Liza argentea*	Flat-tail mullet*	1	44	2	18		45	9	23
	Mugil cephalus	Sea mullet*	4		4	1	4	0		
Sparidae	*Acanthopagrus australis*	Yellow-finned bream*		10		1	11	6		1
	Rhabdosargus sarba	Tarwhine*					12			
Girellidae	*Girella tricuspidata*	Blackfish/Luderick*					1	3		
Pomatomidae	*Pomatomus saltatrix*	Tailor*		7						
Scatophagidae	*Selenotoca multifasciata*	Striped scat		2			3	1		
	Scatophagus argus	Spotted scat			1					

			Fernbank Ck		Kentwell Farm		Tea Tree		Rossglen	
Class/Order/Family	**Genus and species**	**Common Name**	**above gate**	**below gate**	**above gate**	**below gate #**	**above gate**	**below gate**	**above gate**	**below gate #**
Order Scorpaeniformes										
Scorpaenidae	*Centropogon australis*	Fortescue						1		
CLASS MALACOSTRACA										
Order Decapoda										
Grapsidae	*Parasesarma erythrodactyla*	Crab	3		1					2
Hymenosomatidae	*Amarinus* spp.	Spider crab	2		4		6	1	1	
	Macrobrachium spp.	Long-armed shrimp	26	52	140	13	60	57	6	41
Palaemonidae	*Palaemon debilis*	unnamed shrimp	1,422	467	40	138	331	224	54	75
	Metapenaeus macleayi	School prawn*		44				10		
	Penaeus plebejus	King prawn*						3		
Sergestidae	*Acetes sibogae australis*	unnamed shrimp	3	3,042	42	29	6	3,777		125
TOTAL NUMBER			2,074	3,989	2,067	286	1,460	4,600	260	507

reduced sampling due to restricted space (see Methods section)
* commercially harvested species

Table A5.3. Camden Haven and Maria Rivers sites catch summary.

	Fernbank Ck		**Kentwell Farm**		**Tea Tree**		**Ross Glen**	
	above gate	**below gate**	**above gate**	**below gate***	**above gate**	**below gate**	**above gate**	**below gate***
Total numbers	2,074	3,989	2,067	286	1,460	4,600	260	507
Acetes shrimp	3	3,042	42	29	6	3,777	0	125
Total minus *Acetes* shrimp	2,071	947	2,025	257	1,454	823	260	382
Adjusted totals #	2,071	947	2,025	514	1,454	823	260	764
Number of fish species	12	13	15	14	15	18	7	12
Number of crustacean species	5	4	5	3	4	6	3	4
Total number of species	17	17	20	17	19	23	10	16

* reduced sampling due to restricted space (see Methods section).
# below gate catches (minus *Acetes* shrimp) doubled to estimate relative abundances under similar sampling to above gate area.

Discussion

In general, as large an opening as possible is most likely best for maximum improvements in fish passage and water quality. Fish and invertebrate passage is thus most likely improved through the large gate we installed on the Hunter river than through the smaller gates used on the Maria and Camden Haven rivers. However, in situations where over-topping is a high risk and the size of the opening needs to be restricted to reduce the speed of water inflow in case of gate failure or jamming, a narrow but tall opening shape is likely to result in better fish passage than a wide but short opening of the same area.

On the larger Armon Engineering gate installed at Greenways Creek, the position of the floats restricts the maximum angle that the gate can open (Figure A5.8), and on a rising tide the incoming water pressure slams the gate shut early, significantly reducing the time that the gate is open and the volume and height of tidal water that enters the drainage system. Half filling the floats with water adds extra weight that helps to hold the gates open longer against incoming water pressure, and a possible further improvement would be to redesign the gate with the floats mounted to each side of the internal flap instead of in front of it, allowing it to open much wider. Light aluminium floodgates open sooner and wider than heavy steel gates with runout flow, even with tide-actuated devices fitted (Figure A5.8), resulting in faster draining of inundated land following floods. The larger entrance size and reduced current flow improves fish passage as well.

Acetes shrimp were found in high abundance at mid-estuary reference sites in the Clarence River (James Creek, Morroro Creek and Sandy Creek; see Appendix 1) and Hunter River (Purgatory Creek; Table A5.4). They are probably important food items for many commercial fish species including yellow-finned bream and flat-tail mullet (Pease *et al.*, 1981b; Ballagh, 2002). Their virtual absence from un-managed, gated sites in the Clarence River, but subsequent appearance in reasonable numbers in three drains following lifting of the gates (Table 4.3, Appendix 1) suggests they can colonise these areas if other conditions such as water quality and habitat are suitable. However, very few *Acetes* shrimp were found above any of floodgates in the Camden Haven and Maria Rivers compared to below two of the gates (Table A5.2). This may indicate that the actual gates on these two drains are less than optimal for allowing upstream passage.

In the Hunter, higher numbers of *Acetes* shrimp were recorded above the floodgate after gate modification (Table A5.4), but they were still ten times less abundant than below the gate. The Armon gate on the Hunter River is over three times larger than the ones on the Maria and Camden Haven rivers and nearly twice the size of the one at Oceana Tea Tree, and it also covers a much greater portion of the water column. It is therefore likely that movement of *Acetes* shrimp through the gate is improved by the reduced current resulting from the increased area of the gate aperture and the greater depth coverage.

All pH readings recorded above and below the gates in the Camden Haven, Maria and Hunter rivers, and from the Hunter river reference site, conformed to ANZECC guidelines for lowland rivers and streams in south-east Australia for slightly disturbed ecosystems (2000) (Tables A5.6, A5.7). The four sites in the hastings catchment were fitted with tide-actuated floodgates by because they all had chronic acid discharges with pH as low as 3 (Hastings Council, 2001a; 2001b; 2002a; 2002b). Water quality monitoring since the installations has shown average pH in the drains rising to 7 (Hastings Council, unpublished data). Readings taken during the present study showed virtually identical temperature, pH and salinity above and below the gates (Table A5.6).

Water quality in Greenways Creek prior to the modified gate installation was good, possibly due to its large catchment area allowing substantial flushes following rainfall, and several leaky floodgates (Table A5.7). Readings of pH and temperature were very similar above and below the gate. Mean salinity values above the gate were approximately 4-5 g/L higher than below, but following gate installation they more closely resembled the outside readings. Higher salinity water is more effective at buffering acid discharges than fresher water. As this water is also more dense and may form a salt wedge at the bottom of the water column, it makes sense to have gate openings as close to the channel base as possible.

Generally accepted criteria for definition of effective, freshwater fishways are that they should be able to “pass 90% of each migratory life stage of each species, and pass fish for 95% of migration flows or 50% of tailwater levels until drown-out, whichever is the greater” (Mallen-Cooper, 1992, 2000). For estuarine tidal floodgates in locations needing improved fish passage, comparable criteria could be that they should be able to “pass 90% of each life stage of each species present outside of the floodgate, and pass fish for 50% of each ebb and flood tidal cycle”.

The limited number of sites and sampling that could be undertaken during this preliminary assessment limited our ability to analyse and interpret the data. However, together with the results and analyses from the Clarence river detailed in the main body of the report, as well as the monitoring by Hastings Council, it can be concluded that both designs of tide-actuated floodgates are successful at improving water quality and allowing better passage for fish and invertebrates, and are a vast improvement over the standard floodgate. However, it is likely that the designs can be developed further to provide even better passage, with the aim of allowing as wide as possible a diversity of species and size classes to negotiate floodgate barriers as are attempting to do so.

Table A5.4. Species abundance at Hunter River sites before and after installation of tidally operated floodgate.

			Before gate installation			After gate installation		
			Greenways Ck		Purgatory Ck [r]	Greenways Ck		Purgatory Ck [r]
Class/Order/Family	**Genus and species**	**Common Name**	**above gate**	**below gate [#]**	**no gate**	**above gate**	**below gate [#]**	**no gate**
CLASS ACTINOPTERYGII								
Order Anguilliformes								
Anguillidae	*Anguilla reinhardtii*	Long-fin eel*	1			2		
Order Atheriniformes								
Poeciliidae	*Gambusia holbrookii*	Mosquitofish					1	
Pseudomugilidae	*Pseudomugil signifer*	Southern blue-eye			1	2		
Order Clupeiformes								
Clupeidae	*Hyperlophus vittatus*	Sandy sprat*					3	33
Order Perciformes								
Chandidae	*Ambassis marianus*	Ramsay's glassfish		2				
	Ambassis spp.	Glassfish		1,041	186	2	114	55
Gerreidae	*Gerres subfasciatus*	Silver biddy*						1
Girellidae	*Girella tricuspidata*	Blackfish/Luderick*	8	4	8	42		2
Gobiidae	*Afurcagobious tamarensis*	Tamar River goby	8	6	5	129	69	173
	Arenigobius bifrenatus	Bridled goby	7	2	8	72	23	793
	Arenigobius frenatus	Half-bridled goby						5
	Favonigobius exquisites	Exquisite sand-goby	1	2	2	5	2	15
	Gobiomorphus australis	Striped gudgeon	61			23		
	Gobiopterus semivestitus	Glass goby	21	3,746	199	43	452	156
	Hypseleotris compressus	Empirefish	34	1		33	1	
	Mugilogobius paludis	Mangrove goby	6	3	4	7	1	4
	Philypnodon grandiceps	Flathead gudgeon	154	23	13	653	29	31

Class/Order/Family	Genus and species	Common Name	Before gate installation: Greenways Ck above gate	Before gate installation: Greenways Ck below gate #	Before gate installation: Purgatory Ck r no gate	After gate installation: Greenways Ck above gate	After gate installation: Greenways Ck below gate #	After gate installation: Purgatory Ck r no gate
	Philypnodon sp.	Dwarf flathead gudgeon				1		
	Pseudogobius olorum	Blue-spot goby	24		14	150	3	319
	Redigobius macrostoma	Large-mouth goby	89	13	28	182	2	59
Mugilidae	*Liza argentea*	Flat-tail mullet*		320	122	65	248	827
	Mugil cephalus	Sea mullet*	1	34	88	18	10	62
		Unidentified juv. mullet		39	318			
Pomatomidae	*Pomatomus saltatrix*	Tailor*					4	6
Scatophagidae	*Scatophagus argus*	Spotted scat						1
Sparidae	*Acanthopagrus australis*	Yellow-finned bream*	50	60	34	51		36
	Rhabdosargus sarba	Tarwhine*	60	128	47	29		16
		unidentified sparidae			427			
Order Salmoniformes								
Galaxiidae	*Galaxias maculatus*	Common jollytail		5				
Order Pleuronectiformes								
Paralichthyidae	*Pseudorhombus jenynsii*	Small-tooth flounder*						2
Order Scorpaeniformes								
Scorpaenidae	*Centropogon australis*	Fortescue		2		5	2	
Order Tetraodontiformes								
Monacanthidae	*Meuschenia trachylepis*	Yellowfin Leatherjacket*	3	14		1		1
Tetraodontidae	*Tetractenos glaber*	Smooth toadfish	20	23	8	19	4	1
CLASS MALACOSTRACA								
Order Decapoda								
Atyidae	*Caridina* spp.	unidentified shrimp	4					
Grapsidae	*Parasesarma erythrodactyla*	un-named crab	9	4		43	3	3

Class/Order/Family		Genus and species	Common Name	Before gate installation: Greenways Ck above gate	Before gate installation: Greenways Ck below gate #	Before gate installation: Purgatory Ck r no gate	After gate installation: Greenways Ck above gate	After gate installation: Greenways Ck below gate #	After gate installation: Purgatory Ck r no gate
			unidentified crab			1			
	Palaemonidae	*Macrobrachium* spp.	Long-armed shrimp	4	9	2	6	1	3
		Palaemon debilis	un-named shrimp	55	522	32	170	31	571
			unidentified shrimp	20					
	Penaeidae	*Metapenaeus bennettae*	Greasy-back prawn*			1	2		3
		Metapenaeus macleayi	School prawn*	21		23	128	17	146
		Penaeus plebejus	King prawn*	1		2	16	1	7
			unidentified prawns	4		4			
	Sergestidae	*Acetes sibogae australis*	un-named shrimp		11,856	92,966	1,114	11,202	49,526
TOTAL NUMBER				666	17,859	94,543	3,013	12,223	52,857

reduced sampling due to restricted space (see Methods section)
r reference site
* commercially harvested species

Table A5.5. Hunter river sites catch summary.

	Before gate installation			After gate installation ^		
	Greenways Ck		Purgatory Ck [r]	Greenways Ck		Purgatory Ck [r]
	above gate	below gate*	no gate	above gate	below gate*	no gate
Total numbers	666	17,859	94,543	3,013	12,223	52,857
Acetes shrimp		11,856	92,966	1,114	11,202	49,526
Total minus *Acetes* shrimp	666	6,003	1,577	1,899	1,021	3,331
Number of fish species	17	20	18	22	17	22
Number of crustacean species	8	4	8	7	6	7
Total number of species	25	24	26	29	23	29

^ sites were sampled twice prior to gate installation and tree times after installation.
* reduced sampling due to restricted space (see Methods section).

Table A5.6. Mean water quality readings at Camden Haven and Maria Rivers sites.

		Fernbank Ck		Kentwell Farm		Tea Tree		Ross Glen	
		above gate	below gate	above gate	below gate*	above gate	below gate	above gate	below gate*
Depth (cm)		40	92	40	137	58	72	33	33
Temp (^{0}C)	Top	25.6	24.6	24.9	25.8	25.6	25.1	26.0	25.6
	Bottom	25.5	24.2	25.0	25.1	25.6	25.1	26.0	25.6
PH	Top	7.4	7.4	7.1	7.4	7.4	7.4	7.5	7.2
	Bottom	7.3	7.2	7.1	7.3	7.4	7.3	7.5	7.2
Salinity (ppt)	Top	35.5	35.2	29.8	28.6	29.2	27.2	34.2	34.2
	Bottom	35.5	35.3	29.8	30.2	29.2	28.4	34.2	34.2

* reduced sampling due to restricted space (see Methods section)

Table A5.7. Mean water quality readings at Hunter River sites.

		Before gate installation			After gate installation		
		Greenways Ck		Purgatory Ck [r]	Greenways Ck		Purgatory Ck [r]
		above gate	below gate*	no gate	above gate	below gate*	no gate
Depth (cm)		72	126	118	87	79	86
Temp (^{0}C)	Top	19.9	19.3	19.5	25.4	25.3	24.7
	Bottom	19.5	19.2	18.9	25.6	27.1	25.9
pH	Top	8.0	7.9	7.8	8.0	8.0	7.9
	Bottom	7.9	7.9	7.9	7.9	8.0	7.8
Salinity (ppt)	Top	13.5	19.3	18.8	16.4	17.9	25.7
	Bottom	16.0	20.0	22.9	18.3	17.2	27.4

* reduced sampling due to restricted space (see Methods section)
[r] reference site

Figure A5.8. Differences in opening size during an outflow between a standard steel floodgate and an aluminium gate fitted with a tide-actuated internal gate.

Appendix 6. Joint communication strategy outline.

NSW Agriculture & NSW Fisheries

Floodgate and Acid Drainage Research Projects

Joint Communications Strategy

- Amended August 2000 -

BACKGROUND

NSW Agriculture & NSW Fisheries Floodgate and Acid Drainage Research Projects will both be conducted largely in the Clarence Valley coastal floodplain and share a number of common sites.

Funded by Research and Development Corporations (Land and Water Resources, Fisheries, Sugar), ASSMAC, and the relevant state government department, the research projects are supported locally by Clarence River Council's Clarence Floodplain Project (CFP) which also receives funding from the Natural Heritage Trust, Department of Land and Water Conservation, ASSMAC, and industry sponsorship.

The two research projects are designed to determine the impacts of changed management of floodgates on: water quality, agricultural production, ground water, and fish passage and recruitment. By sharing common sites, projects will be cost-efficient and have the opportunity to integrate information. This will maximise outcomes to the beneficiaries.

The thrust of the research is to contribute to real on-ground change. It is expected that the findings will improve the management of floodgates, not only at the research sites, but also have more general application. In this way, environmental improvements are anticipated, as is the maintenance of agricultural production.

To facilitate research progress, the funding groups requested that the CFP Steering Committee adopt the role of intermediary reporting body, that is, that the research projects report to the funding bodies through the CFP. The CFP Steering Committee accepted this role to ensure a close association with the research, local adoption of the findings, and to assist, at the local level, with the seamless implementation of the research. The CFP also guaranteed that required pre-research preparation would occur, such as the establishment of floodgate management regimes and installation of the required equipment.

IMPLEMENTING THE RESEARCH FINDINGS

For on-ground change to result from the research projects, the research findings must be made available, in an appropriate format, to various audiences. These include:

- funding partners (the R&D Corporations and ASSMAC)
- the CFP Steering Committee
- technical and advisory groups
- industry groups
- government agencies
- volunteer drain management committees

- potential drain management volunteers
- landowners adjoining drainage systems
- the general community

Implementation of the findings will, to a large degree, be dependent on their effective communication to a wide audience.

COMMUNICATIONS STRATEGY

Cost-effective communications that result in on-ground change and meet the needs of all audiences, should have the following characteristics:
1. Strategically planned
2. One combined communications strategy to encompass both research projects
3. Involve a variety of formats
4. Continue beyond the duration of the research projects

PROPOSAL

The CFP Steering Committee recommends adoption of the communications strategy as described.

However, the CFP has identified resource limitations as an issue of concern. It is the understanding of the CFP that, for communications, NSW Agriculture and NSW Fisheries have limited amounts within the research budgets. The R & D Corporations, via LWRRDC, have previously offered some assistance to the CFP in order to offer local field days. Suitable publications and interpretive / educational displays may require additional funding.

To remedy this, the CFP Steering Committee proposes that:

1. **That the strategy detailed above be adopted as the joint communications strategy for both research projects, to be delivered as an integrated package with the assistance of the CFP.**
2. **That additional assistance is requested from the Research funding bodies to offer one field day or Congress annually (total 2).**
3. **That additional funding is sought from appropriate sources to offer the identified extension elements at completion of the research projects.**

STAGE 1: SPECIFIC COMMUNICATIONS DURING PROJECTS

ITEM	PERIOD/NUMBER	RESPONSIBILITY	AUDIENCE	PROGRESS
Reporting to the CFP Steering Committee according to details in the project applications, generally every 12 months.	Dec - 00, 01, 02, 03	CFP, NSW Agric team, NSW Fisheries team.	CFP Steering committee	2000 - June & December 2001 -
Reporting to the funding bodies & peers, and the CFP Steering Committee, Generally a full day (after the CFP Steering Com meeting) and will be followed by a site tour on the second day.	June - 01, 02, 03	CFP, all	Funding bodies, professional peers, & CFP Steering Committee	2000 - June 2001 -
Letters direct to members of drain management committees at research sites, including introduction letters, research updates, and invitations to site visits and workshops / field days.	as relevant	CFP to coordinate	Drain management committee volunteer members	
Face to face meetings with drain management committees at research sites - with both individual members and small groups, to discuss access, research needs, findings, application of results	as relevant	CFP to coordinate initially. All teams will be involved.	Drain management volunteers	
General floodgate management workshop / Field day – annually, targetting volunteer management committees with additional invitations to agency staff, industry representatives, CFP	May/June in 2001 & 2002	Planning to begin in March. All teams involved.	Drain management volunteers	
A bus trip to various sites will be organised at least once throughout the project.	Annually in April or May	CFP	Drain management volunteers	
Local floodgate management workshop at Blanches and Moloneys Drainage systems, for the volunteer landowner drain managers	October 2001	NSW Agric Team / CFP / all	Local drain management volunteers	
Local floodgate management workshop, for volunteer landowners managers at each research drainage site, as findings indicate the need to review management practices. Sites are Carrolls Drain, Wants Drain, Dennys Gully, and perhaps others.	Expected once or twice during the projects	CFP, NSW Agric team, NSW Fisheries team.	Landowners & farmers generally	
Local newspaper articles – 2 per year for each research project	4 per year Oct / May - Agric April / Nov - Fisheries	NSW Agric team, NSW Fisheries team.	General community	

ITEM	PERIOD/NUMBER	RESPONSIBILITY	AUDIENCE	PROGRESS
State and national media coverage - attempt once per year to coincide with significant events - eg general field days / research announcement / technical workshop etc	1 attempt per year	CFP, NSW Agric team, NSW Fisheries team.	General community	
CFP News – Special Research editions To include information on best practice floodgate and drainage system management where possible	I per year, approx May	CFP, NSW Agric team, NSW Fisheries team.	General community	
CFP News, regular editions – update articles once per year	At least 1 per year, eg Sept /Oct	CFP, NSW Agric team, NSW Fisheries team.	General community	
Presentations to local technical committee (eg agency specialists, industry representatives, volunteer management committee executive members) and other technical committees (eg ASSMAC technical committee, Environment committee of NSW Cane Growers etc, Clarence Estuary Management Committee) via CFP steering committee - half way into the project and at the end	At least once for each committee (total 4 to 8); End 2001/ 2002	Individual research teams	As specified	
Joint or individual project presentations direct to the relevant Industry executive groups or general meetings, eg Clarence Cane Growers Assoc (including Environment committee of NSW Cane Growers), NSW Farmers Association; Clarence Fishermen's Cooperative	At least once for each group, as invited (total 3 to 6) End 2001/ 2002	Individual research teams	As specified	
General Clarence floodplain science and management Congress, to include seminars, presentations and workshops, showcasing the latest developments in the research and action fields. Presentations will be requested from: research teams, universities, ASSMAC, Govt agencies, fishing ind, cane ind, other ind, Councils, etc.	1 each in 2001, 2002, and thereafter reviewed for annual offering.	CFP to coordinate.	General public	

STAGE 2: SPECIFIC COMMUNICATIONS ELEMENTS AT COMPLETION

Note completion dates: NSW Fisheries Project - 31/12/02; NSW Agriculture - 31/06/04

ITEM	PERIOD/NUMBER	RESPONSIBILITY	AUDIENCE	PROGRESS
Static permanent high profile interpretive display, including text, photos, findings, interpretation of the problems and benefits of management options, and recognition for funding bodies and other contributors. The display would be in full colour, protected from weather, eg with a roof and protective plastic. An example of a suitable location is Ferry Park, Maclean, on the Pacific Highway, a stopping place for travellers (tourist information centre, café/ restaurant, coach rest stop), and locals (floating jetty, art gallery, restaurant). Two or more duplicate displays for mobile use.	At least one permanent, 2 mobile duplicates.	CFP to seek funding eg from ASSMAC, R&D Corps, CASSP	General public	
Published guide to floodgate management, possibly a double-sided booklet, colour plates, Fisheries one end, Agriculture the other. Essentially a "How To" guide, summarising the key findings and management recommendations regarding practical floodgate management. (Note different completion dates for the two research projects; may need to be separate booklets)	Initial print run of 4,000	CFP to seek additional funding eg from ASSMAC, R&D Corps, CASSP, EPA Trust	Drain managers, lay audience, general public	

Other titles in this series:

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No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. Final Report to Fisheries Research and Development Corporation. Project No. 96/139.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters. Final Report to Fisheries Research and Development Corporation. Project No. 94/024.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales. Final Report to Fisheries Research and Development Corporation. Project No. 95/151.

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No. 6 Allan, G.L. and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. Final Report to Fisheries Research and Development Corporation. Project No. 93/120-03. 237pp + appendices.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. Final Report to Fisheries Research and Development Corporation. Project No. 93/120. 54pp + appendices.

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No. 9 Nell, J.A., McMahon, G.A. and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. Final Report to Cooperative Research Centre for Aquaculture. Project No. D.4.2. 25pp.

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No. 11 Watford, F.A. and Williams, R.J., 1998. Inventory of estuarine vegetation in Botany Bay, with special reference to changes in the distribution of seagrass. Final Report to Fishcare Australia. Project No. 97/003741. 51pp.

No. 12 Andrew, N.L., Worthington D.G., Brett, P.A. and Bentley N., 1998. Interactions between the abalone fishery and sea urchins in New South Wales. Final Report to Fisheries Research and Development Corporation. Project No. 93/102.

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