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The Ecological Effects of Structural Flood Mitigation Works on Fish Habitats and Fish Communities in the Lower Clarence River System of South-Eastern Australia

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ABSTRACT: The effects of flood mitigation structures on the quality of estuarine and freshwater fish habitats in the lower Clarence River system of south-eastern Australia were investigated. Surrounding land use, fringing vegetation, overall level of habitat disturbance, distance from the sea, salinity, and water temperature were examined and compared between four sites on natural tributary streams, four sites on channelized, flood mitigation drains gated at their mouths, and ten paired sites (five below and five above floodgates) on flood mitigation drains in this system, from mid 1988 to late 1990. Quantitative sampling of the fish fauna at each of these sites was conducted quarterly over this 2½-yr period. Juvenile fishes were sampled using netting enclosures together with application of the ichthyocide rotenone, while subadults and adults were sampled using multiple-panel gill nets. In general, fish habitats in the flood mitigation drains, and especially those above flood gates, had more intensive surrounding land uses, less natural native fringing vegetation and, overall, were more highly disturbed than those in the natural tributaries. Salinity at the various study sites was largely dependent on the pattern of seasonal (mainly summer and autumn) rainfall and distance upstream from the sea. Salinities usually differed only slightly between gated and ungated sites at similar distances from the sea, indicating that the floodgates were generally ineffective in preventing the penetration of saline river water into the drains immediately above them. These gates were, however, very effective in preventing the establishment of fringing mangrove vegetation in the drains above them. The main ecological effects of these flood mitigation works have thus been to generally degrade the overall quality of available fish habitat, particularly in terms of reductions in natural fringing vegetation (mangroves in the more estuarine-dominated areas and overhanging terrestrial trees in the more freshwater-dominated areas often being replaced by grasses and rushes), and to increase the intensity of surrounding land use (natural forest often being cleared and wetlands drained for cattle grazing and sugarcane growing), both of these factors contributing to increases in generalized aquatic habitat disturbance. Results from the study of the fish assemblages in these natural and man-altered habitats revealed the following general patterns. Highest fish species numbers and abundances occurred in the ungated natural tributaries and in drains downstream of floodgates. These habitats also contained the largest proportions of both commercial fish species and individuals as well as the majority of species and individuals with marine-estuarine affinities. Both total and commercial fish species numbers generally declined with decreasing salinity and increasing distance of the sampling sites from the sea. Even though saline waters from the main river system penetrated the majority of the floodgates during most of the study period, fish passage through these gates was found to be very restricted. Fish assemblages above such gates were generally dominated by primarily freshwater species, as compared with primarily saltwater (estuarine-marine) species below. The conversion of the great majority of small mangrove-fringed tributaries in the lower reaches of this river system into uniform floodgated drainage channels has thus resulted in the destruction of, and impeded fish access to, large areas of previously available estuarine fish nursery and feeding habitat. These drainage channels are now dominated by terrestrial-freshwater vegetation above where they are cut off from the main river channels by the floodgates, and the period of their construction has coincided with that of reported declines in fish catches in this river system. On the basis of the above findings, it is recommended that these floodgates be left fully open at all times except immediately prior to and during floods in the river system, thus facilitating the re-establishment of fringing mangrove vegetation along the banks of the artificial drains in the lower reaches, generally improving flushing and thus water quality in these drains, and allowing the establishment of primarily estuarine-marine fish communities, including more species of economic importance, in them.

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Introduction

As pointed out by Swales (1982a), "It is well established that river channel works used in land drainage schemes, carried out to alleviate flooding or improve field drainage for farming, generally have detrimental effects on the aquatic fauna through changes in the physical characteristics of the river environment." This paper describes and discusses habitat changes brought about by structural flood mitigation works (particularly channelization and flood-gating) in the tidal reaches of the lower Clarence River system of northern New South Wales (NSW), and relates the habitat differences between ungated and gated sites to the distribution and community structure of fish assemblages in natural and man-affected tributaries of this system.

Small-scale structural flood mitigation works (mainly involving the construction of drains and levee banks) have been undertaken on coastal rivers of New South Wales ever since the first agricultural settlements were established in the main river valleys of the coastal plain during the early to mid 1800s. However, it was only after a number of economically disastrous floods, which occurred around the middle of the present century, that substantial government funding was allocated for flood mitigation purposes.

Federal and state government subsidies of the costs of structural flood mitigation works carried out by the New South Wales Department of Public Works increased from a cumulative total of only ~$2 million up until 1960 to over $80 million by 1980 (Pressey and Middleton 1982). An additional 20% was contributed by constructing authorities and local councils, giving a cumulative total of almost $100 million spent over this 20-yr period. Levee banks, drainage channels, floodgates, bank stabilization and clearing works, and the alignment of river channels composed most of these works.

During the 1960s little attention was paid to the environmental effects of these flood mitigation works and no environmental impact assessments were deemed necessary prior to their construction. However, increasing environmental concern during the mid 1970s prompted the New South Wales State Pollution Control Commission (SPCC) to instruct its Technical Advisory Committee to investigate and seek submissions in relation to this problem. The results of these investigations were reported by the Commission in 1978 (State Pollution Control Commission 1978).

Although the main aims of these flood mitigation works had been ostensibly to prevent flood inundation, to guide overbank flows, and to reduce the period of inundation by floodwaters (State Pollution Control Commission 1978), the SPCC's inquiry found that in many areas these works had the primary result of draining natural coastal wetlands outside of flood periods, thus providing adjacent landowners with access to large areas of land that otherwise would have been unusable for agriculture. For example, the New South Wales State Fisheries' (1976) submission to the inquiry pointed out that "In many cases these works appear more related to irrigation, drainage and water conservation needs than to flood mitigation."

Goodrick (1970) carried out a comprehensive survey of the coastal wetlands of New South Wales and documented losses in various types of wetlands prior to 1969. These losses, which were primarily attributed to flood mitigation and associated drainage works, included 64% of the seasonal freshwater swamps and freshwater meadows, 21% of tea-tree (*Melaleuca*) swamps, 40% of reed swamps, 6% of mangrove swamps, and smaller areas of semi-permanent freshwater swamps, open fresh waters, salt meadows, and salt flats. She-oak (*Casuarina*) swamps were not surveyed. With the approximate doubling of the total cumulative expenditure on flood mitigation works in New South Wales between 1970 and 1980 (Pressey and Middleton 1982), much greater areas of coastal wetland have probably been destroyed since Goodrick's (1970) survey, though no comprehensive re-survey has subsequently been undertaken. Goodrick was mainly concerned with losses of waterfowl habitat; however, the main concerns of fisheries authorities have been losses of estuarine wetlands, particularly mangrove and salt-marsh habitats, important to fishes of commercial and recreational importance.

Possible adverse effects of structural flood mitigation works on flora and fauna that were identified by the SPCC (1978) included: "loss of habitat and disturbance of food supplies; changes in salinity through the loss of the buffering action of swamps; creation of acidic conditions in coastal bogs; loss of tidal fluctuations necessary for the survival of mangroves; loss of nutrient supplies through drainage of upstream swamps; and adverse effects of weedicides used in flood mitigation channels." With more specific regard to the concerns of fisheries authorities, the SPCC (1978) also pointed out that "The floodgating of natural tidal waterways may cause conversion of the portion of the estuary above the floodgates from salt to freshwater. This may result in the destruction of estuarine-dependent vegetation, such as mangrove swamps and weed beds, and reduces the habitat of estuarine fauna unless adequate tidal interchange can be provided." The SPCC's (1978) inquiry thus recommended "Investigation of adverse environmental impacts that have occurred or are occurring as the result of the construction or operation of existing (flood mitigation) schemes be carried out," and "of particular concern is the need for research on the ecology of the northern coastal river systems."

Water quality in the Clarence River system was subsequently investigated by the SPCC (1987), from which study it was concluded that "Flood mitigation and drainage practices . . . result in loss of aquatic habitat and produce poor water quality during low flow periods behind the gates in drains."

A number of the issues originally raised by the SPCC (1978) have since been addressed in a broader study of economically important fish populations and fisheries in the northern rivers region of New South Wales carried out by the New South Wales Fisheries Research Institute between 1987 and 1991 (Kearney 1990; Anonymous 1991), of which the present study has been a part.

With regard to this present study, structural flood mitigation works on the floodplains of the lower Clarence River system (Figs. 1 and 2) have included the straightening and dredging, or "channelizing," of natural tributary creeks to form flood mitigation drains, and the isolation of these drains from the main river system by the construction of floodgates having one-way (downstream opening) flap valves. The main stated purposes of these works have been to drain flood-prone land and to prevent the entry of floodwaters (and hopefully also tidal saline waters) from the main river channels to cultivated (mainly sugar cane) and pastoral (mainly cattle grazing) lands adjacent to this river system.

It has often been suggested by fishermen and others that the destruction of natural mangrove-fringed tributary creeks (by dredging and gating), and the subsequent draining of surrounding coastal swamps and other wetlands, may have contributed to a perceived decline in fish populations in the lower Clarence River area over the past 30 yr or so (e.g., Salisbury et al. 1980). Such a decline was thought most likely to be due to the elimination of important nursery and feeding habitats of estuarine fishes.

The importance of such estuarine habitats to fishes of economic value, and thus to fisheries, was discussed by Pollard (1976, 1981) and Copeland and Pollard (1993), who estimated that, by weight, well over half of New South Wales' total fisheries production comprised species that were estuarine-dependent at some stage of their life history. The value of mangrove creek habitats, in particular, as nursery areas for commercially and recreationally valuable fish species in New South Wales was discussed by Bell et al. (1984). Morton (1990) has discussed the importance of mangrove habitats and Morton et al. (1987, 1988) the importance of salt-marsh habitats to estuarine fishes in southern Queensland.

The main aims of the present study were to describe in some detail the differences between habitats affected and unaffected by flood mitigation and to investigate the ecological effects of some of these structural flood mitigation works on estuarine and freshwater fish communities in the lower Clarence River system, with particular emphasis on commercially and recreationally important species.

The primary aspects considered were the effects of these manmade habitat changes on water salinity and fringing vegetation, and the distribution and abundance of both estuarine and freshwater fishes. The effects were assessed by comparing gated artificial (drain) habitats and ungated natural creek habitats, and comparing habitats above and below floodgates in the drain habitat type. Further discussions of the environmental effects of flood mitigation in New South Wales can be found in Dunstan (1976), Briggs (1977), McGregor (1979), Richardson (1981), Middleton et al. (1985), Furner (1988), Graham (1989), and Pollard et al. (1991).

Materials and Methods

Sampling Area

The Clarence River, which enters the Tasman Sea on the northern coast of New South Wales at latitude 29°25'S and longitude 153°21'E (Fig. 1), is this state's largest coastal river system, having a length of ~400 km, a total catchment area of ~22,000 km^2 and an average annual discharge of ~5 million ML. Approximately 33% of the catchment area is mountainous or rugged, 33% steep to hilly, 17% undulating to hilly, and 17% mainly flat (Water Conservation and Irrigation Commission 1968). It is through the floodplain (~530 km^2) of this latter area that the tidal reaches of the lower Clarence River system meander, and in which the study area is located. These tidal reaches extend upstream as far as Copmanhurst, and during low flow periods the stretch from Copmanhurst (~110 km upstream) downstream to Harwood (~20 km upstream) is mainly fresh to brackish, and that from Harwood to the river mouth (at Yamba) is mainly estuarine to marine. Traces of salinity can at times be found in samples taken as far upstream as 60 km from the river mouth (State Pollution Control Commission 1987), and during high flow periods the fresh to brackish zone can extend downstream to the river mouth (Burgess and Woolmington 1981).

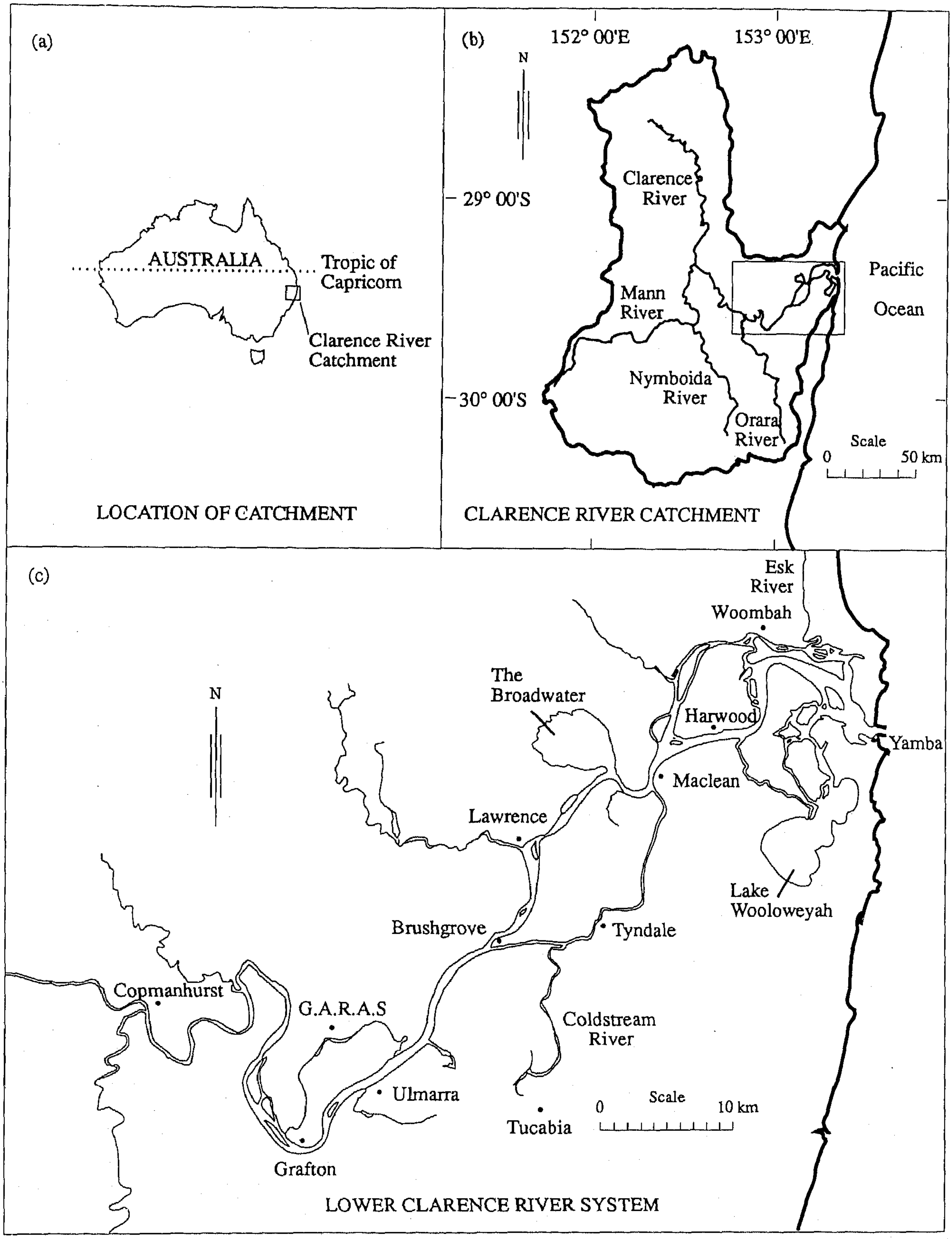

Fig. 1. The lower Clarence River system and its catchment, showing the main localities mentioned in the text.

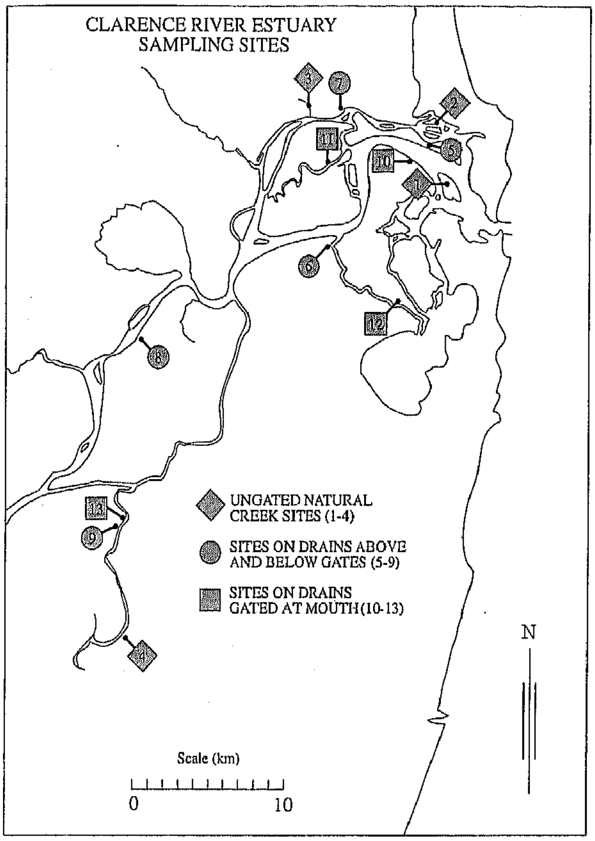

Fig. 2. The Clarence River estuary, showing the locations of the sampling sites (including the four ungated natural tributary creek sites, four sites on drains gated at their mouths, and five paired above and below gate sites) investigated during this study.

UNGATED SITES		GATED SITES	
UNGATED NATURAL CREEKS (UNPAIRED)	DRAINS BELOW GATES (PAIRED)	DRAINS GATED AT MOUTH (UNPAIRED)	DRAINS ABOVE GATES (PAIRED)
FREEBURN ISLAND	GOODWOOD ISLAND	N. PALMERS ISLAND	GOODWOOD ISLAND
NATURAL FOREST	CATTLE GRAZING	SUGARCANE FIELDS	CATTLE GRAZING
DENSE MANGROVES	FEW MANGROVES	GRASSES, RUSHES	GRASSES, RUSHES
UNDISTURBED	SL. DISTURBED	HIGH. DISTURBED	HIGH. DISTURBED
FN 5.5 16.9	GB 9.0 14.9	NG 7.5 13.0	GA 9.0 13.4
LOWER ESK RIVER	PALMERS CHANNEL	CHATSWORTH IS.	PALMERS CHANNEL
NATURAL FOREST	SUGARCANE FIELDS	SUGARCANE FIELDS	SUGARCANE FIELDS
DENSE MANGROVES	GRASSES, RUSHES	GRASSES, RUSHES	GRASSES, RUSHES
UNDISTURBED	HIGH. DISTURBED	HIGH. DISTURBED	HIGH. DISTURBED
EN 9.5 7.4	PB 19.0 9.7	TG 12.5 9.4	PA 19.0 5.2
MORORO CREEK	SHALLOW INLET	S. PALMERS ISLAND	SHALLOW INLET
CATTLE GRAZING	CATTLE GRAZING	SUGARCANE FIELDS	CATTLE GRAZING
FRING. MANGROVES	FRING. MANGROVES	GRASSES, RUSHES	GRASSES, RUSHES
SL. DISTURBED	SL. DISTURBED	HIGH. DISTURBED	HIGH. DISTURBED
MN 17.5 6.2	WB 15.5 7.5	SG 17.5 7.3	WA 15.5 4.1
	KINGS ISLAND		KINGS ISLAND
	SUGARCANE FIELDS		SUGARCANE FIELDS
	GRASSES, RUSHES		GRASSES, RUSHES
	HIGH. DISTURBED		HIGH. DISTURBED
	KB 33.5 2.0		KA 33.5 0.8
UPR COLDSTREAM R	LWR COLDSTREAM R	LWR COLDSTREAM R	LWR COLDSTREAM R
CATTLE GRAZING	CATTLE GRAZING	CATTLE GRAZING	CATTLE GRAZING
OVERHANG. TREES	OVERHANG. TREES	GRASSES, RUSHES	GRASSES, RUSHES
SL. DISTURBED	SL. DISTURBED	HIGH. DISTURBED	HIGH. DISTURBED
CN 52.5 0.2	CB 46.0 0.1	CG 45.5 0.2	CA 46.0 0.1
SURROUNDING LAND USE, FRINGING VEGETATION & LEVEL OF DISTURBANCE	KEYS ►	SITE LOCALITY SURR. LAND USE FRING. VEGETATION DISTURBANCE LEVEL	SITE LOC. CODE e.g. / DIST. FROM SEA (km) / MEAN BOT. SAL. (p.p.t.) FN 5.5 16.9

Fig. 3. Summary diagram showing site locality, surrounding land use, fringing vegetation, level of habitat disturbance, site code, distance from the sea, and mean bottom salinity for each of the 18 sampling sites. These sites are arranged into four columns (two for the unpaired sites and two for the paired sites) under two main categories (ungated sites and gated sites), and within each of these columns in order of decreasing salinity, which in all but one case (PA-PB/WA-WB) corresponds with increasing distance from the sea. (See text under Results—Habitat Characteristics of Sampling Sites, for further explanation of figure layout.)

The lower reaches of the Clarence River support the largest estuarine finfish fishery in NSW (~20% of the state's total estuarine fish catch by weight), of which ~75% is bully mullet, *Mugil cephalus* (Virgona 1992). The Clarence River area (i.e., the estuarine and adjacent coastal waters) also contributes ~40% to the state's total prawn production, mainly the school prawn, *Metapenaeus macleayi* (Montgomery and McDonall 1988).

Sampling Sites

On the basis of reconnaissance surveys and pilot fish sampling carried out during early 1988, 18 sites were selected for regular sampling between Yamba, near the Clarence River mouth, and Tucabia, ~60 km upstream on the Coldstream River tributary (Fig. 1). These sites (Fig. 2) were located on four ungated natural tributary creeks (indicated in the Results section by the site code suffix N), five flood mitigation drains gated upstream from their mouths, and sampled both below (site code suffix B) and above (site code suffix A) the floodgates, and four flood mitigation drains gated at their mouths, where they entered the main river channels, and sampled above the gates (site code suffix G).

Sampling Strategy

Habitat attributes were recorded and water-quality parameters measured in conjunction with fish sampling operations at each of the above sites during 10 quarterly sampling trips between August 1988 and November 1990. Habitat attributes recorded were surrounding land use, fringing vege-

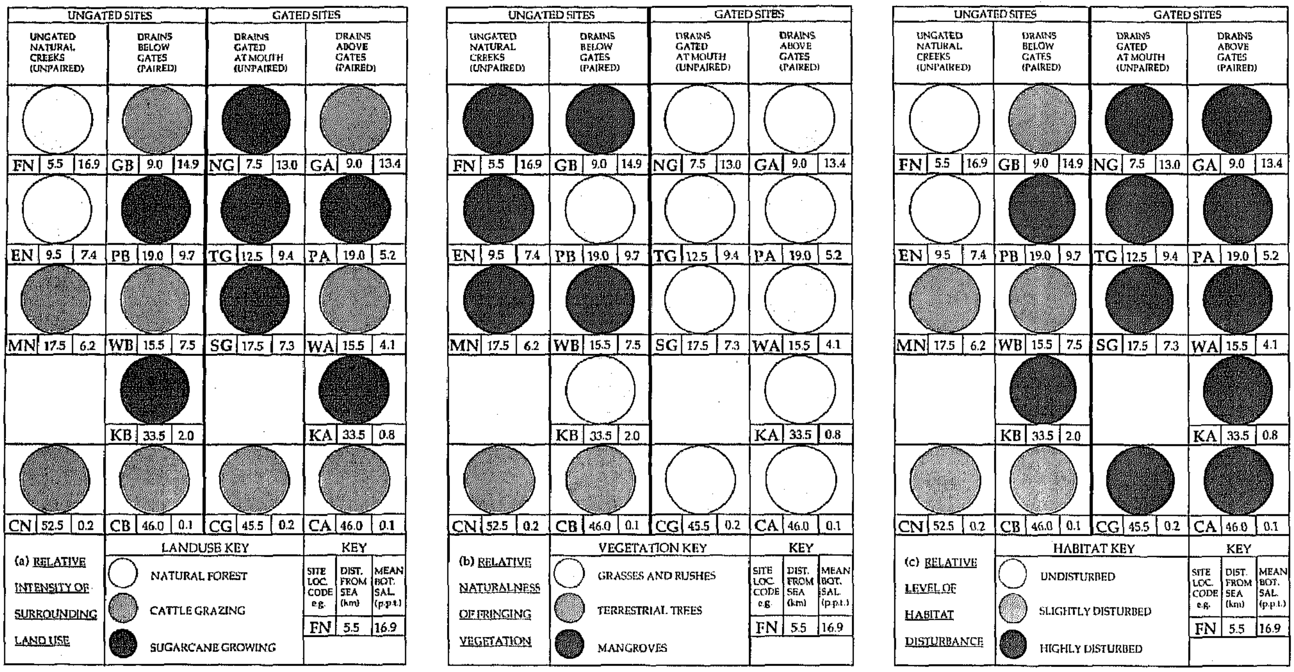

Fig. 4. Comparisons of (a) relative intensity of surrounding land use, (b) relative naturalness of fringing vegetation, and (c) relative level of habitat disturbance at the 18 sampling sites (arrangement of sites, etc., as in Fig. 3).

tation, and overall level of habitat disturbance. Water depth (to the nearest 10 cm), surface and bottom salinities (to the nearest 0.1‰), and water temperature (to the nearest 0.1°C), were measured using a Yeo-Kal Model 602 Mk II salinity-temperature meter.

Overall physical aquatic habitat disturbance at each site was estimated on a three-point scale (i.e., undisturbed < slightly disturbed < highly disturbed), based on the naturalness of the fringing vegetation (mangroves > overhanging terrestrial trees > grasses and rushes), the intensity of the surrounding land use (natural forest < cattle grazing < sugarcane fields), and the degree of channelization and the amount of natural instream cover provided by irregular and undercut banks, snags, and fallen timber, etc.

Examination of surface and bottom salinities and temperature records for each site indicated that appreciable stratification occurred only rarely during the study period, so only the bottom readings are considered in detail in the Results section.

Fish Sampling

Smaller fishes, mainly the adults of small, noneconomically useful (henceforth termed noncommercial) species and the juveniles of larger, economically useful (commercial) species, were quantitatively sampled using fine-mesh enclosure nets combined with the application of a rotenone-based ichthyocide. The enclosure nets (length ~22 m, depth ~1.5 m, stretched mesh size ~1 cm) were set perpendicularly away from the bank out to and around two 2-m long stakes placed 3.5 m toward the center of the stream, thus enclosing a bottom area of ~25 m^2. Depending upon the water depth, approximately 100 ml to 150 ml of liquid rotenone ichthyocide (Chemfish) was diluted in a 2-l plastic bag and then well mixed throughout the water column inside the enclosure. The affected fish were collected by wading and using a long-handled, fine-mesh dip net. All fish seen within the enclosure during the 30 min (in summer) to 45 min (in winter) following the appearance of the first affected fish were collected. All fish samples collected using rotenone were preserved in formalin diluted to 10% with stream or drain water. Fish samples from the rotenone stations were washed, sorted, and identified at the laboratory, and the commercial species measured (LCF to the nearest mm) and weighed (to the nearest mg wet weight). For noncommercial fish species, only the total number and total weight, and the maximum and minimum lengths, of that species present in the sample were recorded.

At three of the most upstream sites (Coldstream River sites CN, CB, and CA), and occasionally at several other sites (especially during flood periods), the enclosure nets could not be set because of excessive water depth (usually >1.5 m). On these occasions the rotenone was added and the fish collected from the bank and/or from a small dinghy, again using a long-handled dip net, from an area estimated to be that of an enclosure-net sample.

Larger fishes, mainly the adults and subadults of economically useful (i.e., commercial) species and adults of some larger noneconomically useful (i.e., noncommercial) species, were quantitatively sampled using multiple-panel, bottom-set, monofilament gill nets of incrementally increasing mesh size. These gill nets each comprised nine adjoined 10-m long panels of netting with stretched (knot to knot) mesh sizes ranging from 25 mm (1.0 in) to 127 mm (5.0 in) in 12.7 mm (0.5 in) increments. Using weights and floats at each end, these nets (which had a fishing depth of ~1.5 m) were set from either an outboard-powered punt or a small dinghy along the center of the sampling stream or drain, respectively. The soak time for these gill nets was 1.5 h.

Fish sampled by the gill nets were processed in the field as soon as possible after sampling. The genus and species codes (first three letters of their scientific names), length (length to caudal fork, or LCF, to the nearest mm) and weight (wet weight to the nearest g) were recorded for each fish. All samples, rotenone or gill net, were labelled with a unique sample identification code comprising the year, month, day, time, locality, site, and method of collecting. Data and sample identification code were recorded directly onto computer data entry forms.

Where possible, rotenone samples were collected within ~100 m above and/or below the floodgates in the flood mitigation drains, and in the upper reaches of the ungated natural tributary creeks. Gill nets were set upstream of the rotenone stations at sites above gates in drains, and downstream of them at sites below gates in drains or in ungated natural tributary creeks. On average, the water depths at the sites of the gill net sets (1.10 ± 0.41 m) were around 6 cm greater than at the sites of the rotenone stations (1.04 ± 0.38 m).

Two rotenone and two gill net samples were initially taken at each of the sampling sites in daylight hours during each sampling period. Sampling was increased to three rotenone samples at each of the three downstream natural creek sites (FN, EN, and MN, see Fig. 3) and the three downstream paired above and below gate sites (GA and GB, PA and PB, and WA and WB) from May 1989 onward. There was only room for a single gill net set on either side of the floodgate at the GA and GB sites.

In most of the results presented, only the data for the middle two years (November 1988 through August 1990) of the study were utilized in the analyses, as this was the contiguous 2-yr period having the most even pattern of rainfall over the 2.5-yr

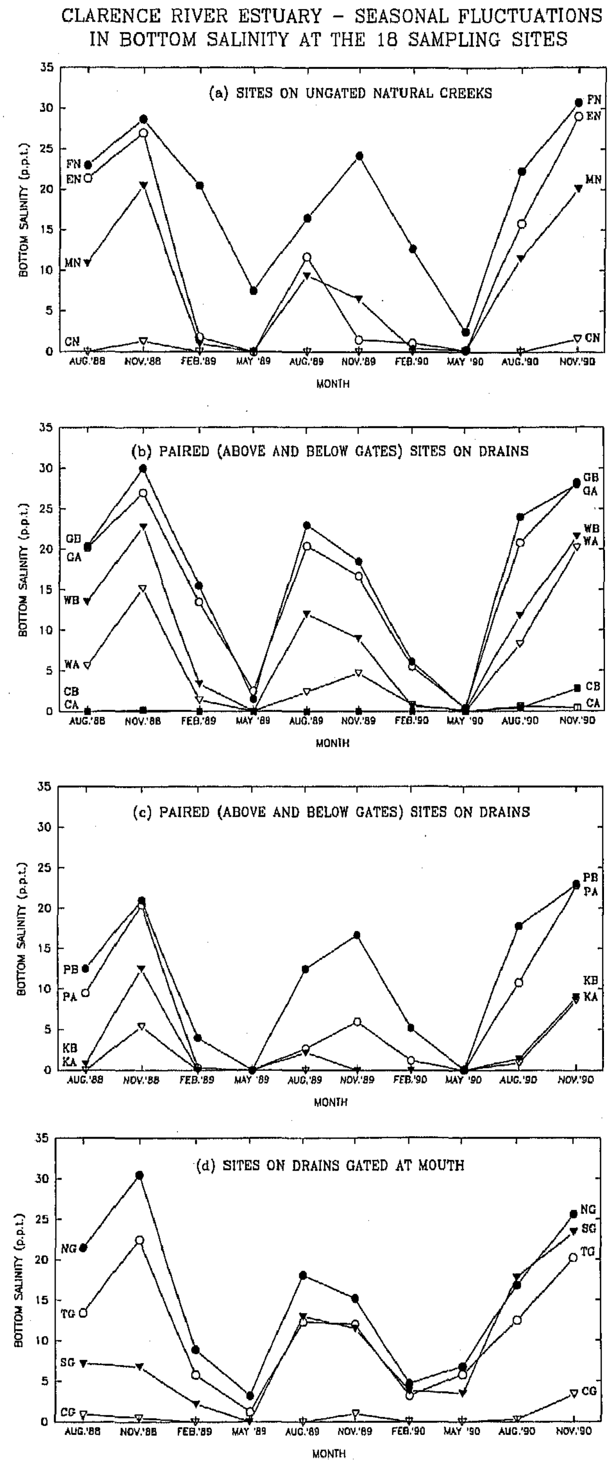

Fig. 5. Seasonal fluctuations in bottom salinity at (a) the four ungated natural creek sites, (b) three paired (above and below gates) sites on drains, (c) two paired (above and below gates) sites on drains, and (d) the four sites on drains gated at their mouths.

TABLE 1. Clarence River catchment: seasonal pattern of rainfall (mm), 1988–1990.

	Rainfall (mm)								
	Met. Dist. No. 57 Eastern North Tablelands		Met. Dist. No. 58 Upper North Coast		Clarence River Catchment			Grafton Research Station (GARAS)	
Season and Year	Actual Seasonal	Normal Seasonal	Actual Seasonal	Normal Seasonal	Actual Mean Seasonal	Normal Mean Seasonal	% Dep. from Normal	Actual Seasonal	Normal Seasonal
Summer 1988	353	419	593	548	473	484	−2	342	396
Autumn 1988	466	188	683	384	575	286	101	734	265
Winter 1988	172	123	398	201	285	162	76	237	143
Spring 1988	269	274	267	320	268	297	−10	316	255
Total 1988	1,260	1,004	1,941	1,453	1,601	1,229	30	1,629	1,054
Summer 1989	443	419	571	548	507	484	5	593	396
Autumn 1989	454	188	594	384	524	286	83	522	265
Winter 1989	61	123	93	201	77	162	−53	52	143
Spring 1989	332	274	355	320	344	297	16	320	255
Total 1989	1,290	1,004	1,613	1,453	1,452	1,229	18	1,488	1,054
Summer 1990	383	419	587	548	458	484	−5	502	396
Autumn 1990	318	188	639	384	479	286	68	442	265
Winter 1990	115	123	80	201	97	162	−40	77	143
Spring 1990	165	274	186	320	176	297	−41	101	255
Total 1990	981	1,004	1,492	1,453	1,210	1,229	−2	1,122	1,054
3-Year total	3,531	3,012	5,046	4,359	4,263	3,687	16	4,239	3,162
3-Year mean	1,177	1,004	1,682	1,453	1,421	1,229	16	1,413	1,054

study period (see Relationship between Rainfall and Salinity in the Results section).

Data Analysis

All data were entered to ASCII files using Open Access II software and then transferred to a Prime 9950 mainframe computer where they were converted to SAS (Statistical Analysis System) databases for data storage and analysis using SAS software. Two main SAS databases were created, the first (environmental database) comprising the environmental and fish catch-sampling data, and the second (biological database) the biological data on individuals of commercially and recreationally important fish species, respectively, the two databases being linked by common sample identification codes. Ordinations based on fish assemblages in the different habitats were undertaken by means of detrended correspondence analysis (DCA) using the DECORANA program of Cornell University (Hill 1979; Hill and Gauch 1980).

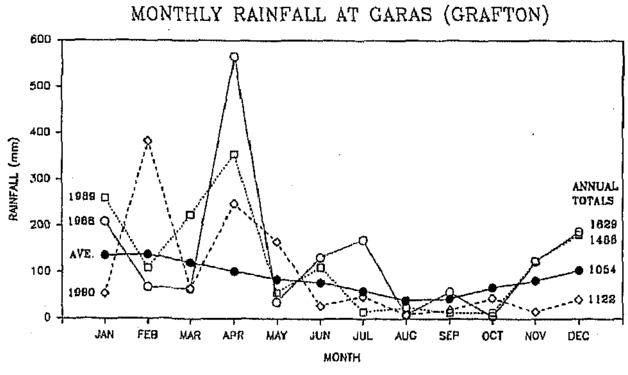

Fig. 6. Monthly rainfall at Grafton Agricultural Research and Advisory Station (GARAS) for 1988 (○), 1989 (□), and 1990 (◇), and long-term monthly averages (●).

Results

Habitat Characteristics of Sampling Sites

Figure 3 summarizes and Figs. 4 a, b and c graphically compare the nature and relative intensity of the surrounding land use, the nature and relative naturalness of the fringing vegetation, and the relative level of habitat disturbance at each of the 18 sampling sites. In each of these figures, sites are arranged into two main groups: ungated sites and gated sites. Within each group, locations are arrayed in order of decreasing salinity. The ungated sites are further subdivided into two subgroups: ungated natural creeks (unpaired) and drains below gates (paired). Likewise, the gated sites are further subdivided into two subgroups: drains gated at mouth (unpaired) and drains above gates (paired). Also shown on these figures are the site locality codes used throughout the Results section, the distances of the sampling sites from the sea (i.e., main channel distances upstream from the river mouth), and the overall mean bottom salinities at the sites over the middle 2 yr (November 1988 through August 1990) of the study. The individual sites within the four subgroupings thus can be compared vertically according to their mean salinity, and the paired and unpaired gated

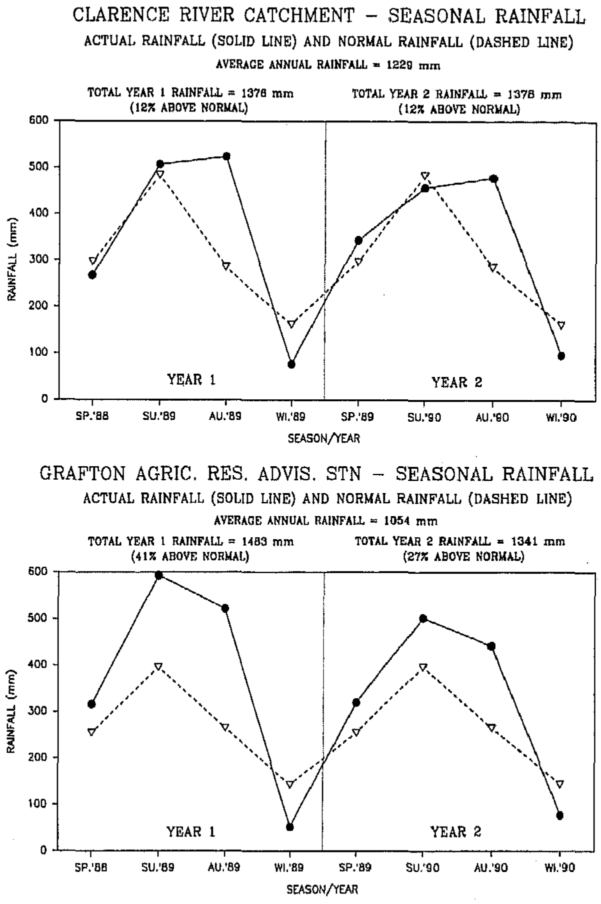

Fig. 7. Seasonal rainfall (top) over the Clarence River Catchment (CRC) and (bottom) at Grafton Agricultural Research and Advisory Station (GARAS) from spring 1988 to winter 1990 (●——●), and long-term seasonal averages (∇- - -∇).

and ungated sites of roughly similar mean salinity compared horizontally according to their degree of "gatedness." (The gradations of these sites in terms of their overall mean bottom salinity and distance from the sea are compared graphically in Figs. 11 a, b, respectively.)

A comparison of flood-mitigation-affected and flood-mitigation-unaffected fish habitats in this area has not been made previously, therefore, the main habitat characteristics of the four site categories are described in some detail below.

Ungated Natural Creek Sites

The Freeburn Island site (FN), the sampling site closest to the sea, was located in the upper reaches of a natural tributary creek draining dense mangrove forest on the south-western side of Freeburn Island, where it flows into the Freeburn Island Channel opposite the eastern end of Palmers Island (Fig. 2, site 1). Freeburn Island is relatively undisturbed by man, and the creek was fringed by dense mangroves (mainly *Aegiceras corniculatum* and *Avicennia marina,* with some *Excoecaria agallocha*). The mangrove vegetation was backed by she-oak (*Casuarina glauca*) forest; the remainder of the island is covered mainly by natural forest. Bottom salinities at this site (mean depth 0.9 m) were usually relatively high (15–30‰), especially during winter and spring (the dry season), but could be quite low (<10‰) in autumn (late wet season), especially after floods (Fig. 5a).

The lower Esk River site (EN) was located in the upper reaches of a tributary creek that enters the Woram (eastern) Channel of the Esk River delta near its confluence with the north arm of the Clarence River (Fig. 2, site 2). This creek was fringed by mangroves backed by she-oak forest and drains to the north-eastern side of Esk Island, which was mainly covered with scrub and low forest. Although usually a relatively saline (10–30‰) site (mean depth 0.6 m) in winter and spring (dry season), bottom salinities could fall to around 0–1‰ in summer and autumn (wet season), and especially during and after flooding in the (primarily fresh water) Esk River system (Fig. 5a).

The Mororo Creek site (MN) was located on a tributary creek entering the Back Channel near its junction with the north arm of the Clarence River, between the northern tip of Warregah Island and Mororo Bridge (Fig. 2, site 3). The fringing mangroves were backed by sparse she-oaks, and the surrounding land use was mainly cattle grazing. Bottom salinities at this site (mean depth 1.2 m) generally ranged from 10‰ to 20‰ in winter and spring, and fell to around 0–1‰ in summer and autumn, especially during and after flood periods (Fig. 5a).

The upper Coldstream River creek site (CN) was located on a short tributary creek entering the main Coldstream River to its east about 5 km downstream from Tucabia (Fig. 2, site 4). The fringing vegetation was mainly overhanging terrestrial trees (including camphor laurels) and the surrounding land use was cattle grazing. The water at this site (mean depth 1.7 m), which is over 50 km upstream from the sea and located on a large tributary of the main Clarence River system, was virtually fresh, though traces of salinity (~1‰) could be found during spring in drier years (Fig. 5a).

Sites on Drains Below and Above Gates

The Goodwood Island site (GB) was located below a small single floodgate on a drain flowing northward into the north arm of the Clarence River near the eastern end of Goodwood Island (Fig. 2, site 5). Fringing vegetation was scattered small

TABLE 2. Lower Clarence River system: seasonal fluctuations in bottom salinity (‰) at sampling sites, 1988–1990.

	Salinity (‰)										
	Month and Year										
Sampling Sites	August 1988	November 1988	February 1989	May 1989	August 1989	November 1989	February 1990	May 1990	August 1990	November 1990	Year 1 + Year 2[a] Mean ± SD
Natural Creeks											
FN	23.0	28.7	20.5	7.5	16.5	24.2	12.7	2.5	22.3	30.7	16.9 ± 8.8
EN	21.4	27.0	1.8	0.0	11.7	1.5	1.1	0.2	15.8	29.0	7.4 ± 9.9
MN	10.9	20.5	1.0	0.0	9.4	6.5	0.4	0.2	11.5	20.1	6.2 ± 7.3
CN	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.2 ± 0.5
Mean	13.8	19.4	5.8	1.9	9.4	8.0	3.6	7.2	12.4	20.4	8.5 ± 5.5
±SD	±10.7	±12.8	±9.8	±3.8	±6.9	±11.1	±6.1	±11.9	±9.4	±13.3	—
Below Gates											
GB	20.4	30.0	15.5	1.5	23.0	18.5	6.1	0.4	24.0	28.0	14.9 ± 11.1
PB	12.5	21.0	4.0	0.0	12.5	16.7	5.2	0.1	17.8	23.0	9.7 ± 8.3
WB	13.5	22.8	3.4	0.0	12.0	9.0	0.6	0.2	11.8	21.6	7.5 ± 8.0
KB	0.8	12.5	0.0	0.0	2.2	0.0	0.0	0.0	1.4	9.0	2.0 ± 4.3
CB	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4	2.8	0.1 ± 0.1
Mean	9.4	17.3	4.6	0.3	9.9	8.8	2.4	0.1	11.1	16.9	6.8 ± 6.0
±SD	±8.8	±11.4	±6.4	±0.7	±9.2	±8.8	±3.0	±0.2	±10.3	±10.5	—
Gated at Mouth											
NG	21.5	30.5	8.9	3.2	18.1	15.2	4.7	6.8	16.8	25.6	13.0 ± 9.0
TG	13.4	22.5	5.8	1.2	12.3	12.0	3.2	5.8	12.5	20.2	9.4 ± 6.8
SG	7.2	6.8	2.2	0.0	13.0	11.5	3.8	3.5	17.8	23.4	7.3 ± 6.2
CG	0.9	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.3	3.4	0.2 ± 0.4
Mean	10.8	15.1	4.2	1.1	10.9	9.9	2.9	4.0	11.9	18.1	7.5 ± 5.1
±SD	±8.8	±13.8	±3.9	±1.5	±7.7	±6.2	±2.0	±3.0	±8.0	±10.1	—
Above Gates											
GA	20.2	27.0	13.5	2.5	20.4	16.7	5.5	0.4	20.8	28.2	13.4 ± 9.5
PA	9.5	20.4	0.3	0.0	2.7	6.0	1.2	0.0	10.8	22.8	5.2 ± 7.2
WA	5.6	15.2	1.4	0.0	2.4	4.7	2.8	0.0	8.3	20.2	9.1 ± 5.3
KA	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.9	8.6	0.8 ± 1.9
CA	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.4	0.1 ± 0.2
Mean	7.1	13.6	3.0	0.5	5.1	5.5	1.5	0.8	8.3	16.0	4.8 ± 4.5
±SD	±8.4	±10.9	±5.9	±1.1	±8.6	±6.8	±2.3	±1.8	±8.3	±11.3	—
All sites											
Mean	10.0	16.3	43	0.9	8.7	8.0	2.5	1.1	10.8	17.7	6.9 ± 5.8
±SD	±8.6	±11.2	±6.2	±1.9	±7.9	±7.8	±3.4	±2.1	±8.4	±10.4	—

[a] Year 1 + Year 2 = core sampling period (eight samples from November 1988 to August 1990, inclusive).

mangroves, salt-couch grass (*Sporobolus virginicus*), and some rushes (*Juncus kraussii*), and the surrounding land was unused pasture land with some stands of she-oak present. Bottom salinities at this site (mean depth 0.8 m) were relatively high (15–30‰) in winter and spring, and low (0–2‰) in autumn (Fig. 5b).

The paired Goodwood Island above gate site (GA) was generally similar in terms of fringing vegetation and land use except that, instead of small mangroves, scattered small she-oak trees and clumps of rushes occurred along its grassy banks. Bottom salinities (mean depth 0.5 m) were generally similar to (<3‰ lower than) those below the floodgate (Fig. 5b).

The Palmers Channel site (PB) is located below a small, double floodgate on a drain entering Palmers Channel from the west, about 1 km from the Channel's junction with the Clarence River (Fig. 2, site 6). Fringing vegetation was mainly grasses (*Paspalum* sp.) and reeds (*Phragmites australis*), with some rushes and a few small mangroves. Surrounding land use was sugar cane growing. Bottom salinities (mean depth 1.2 m) were relatively high (10–25‰) in winter and spring, and low (0–5‰) in summer and autumn (Fig. 5c).

The paired Palmers Channel above gate site (PA) (mean depth 1.0 m) was generally similar to the below gate site except that it had no fringing mangroves but instead had a few small she-oak trees scattered amongst the grasses and rushes along its banks. Surrounding land use was also sugar cane growing. Bottom salinities could be significantly lower (i.e., up to 10‰) than below the gates during the winter and spring of some years (Fig. 5c).

The Shallow Inlet site (WB) is located below a small single floodgate on a drain flowing eastward

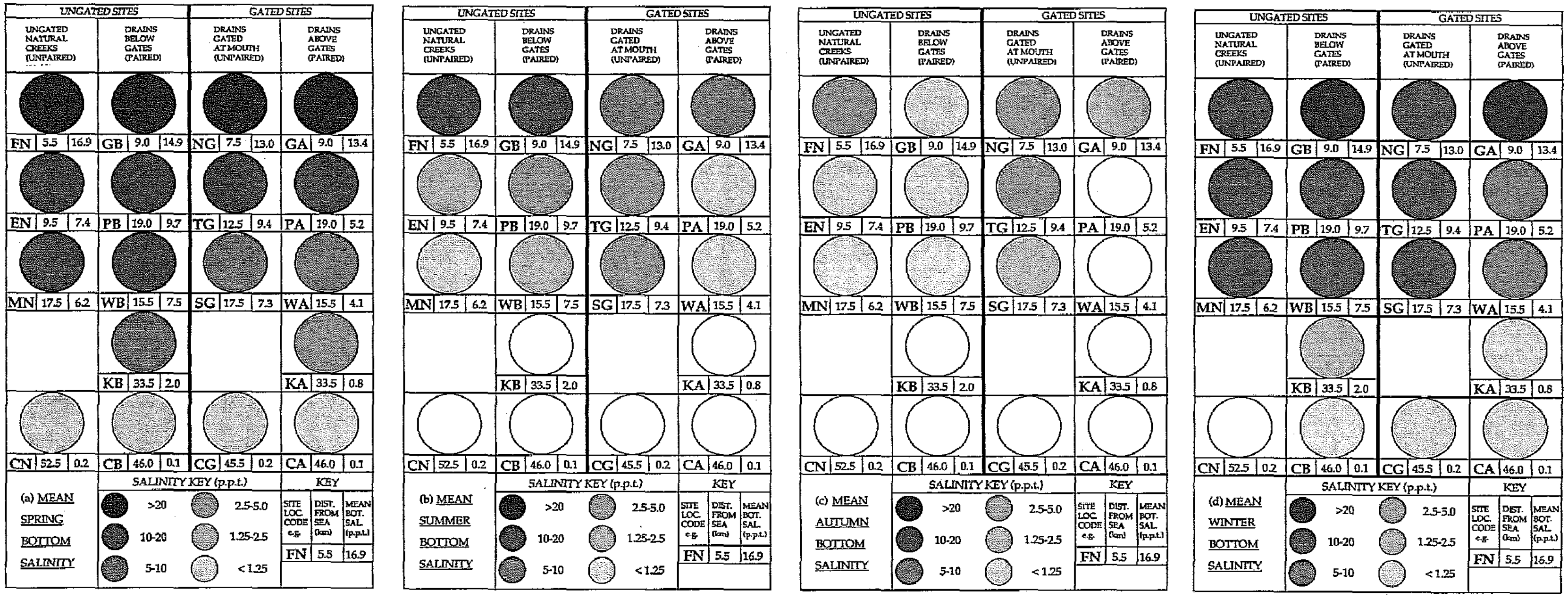

Fig. 8. Mean bottom salinities for (a) spring, (b) summer, (c) autumn, and (d) winter at the 18 sampling sites (arrangement of sites, etc., as in Figs. 3 and 4).

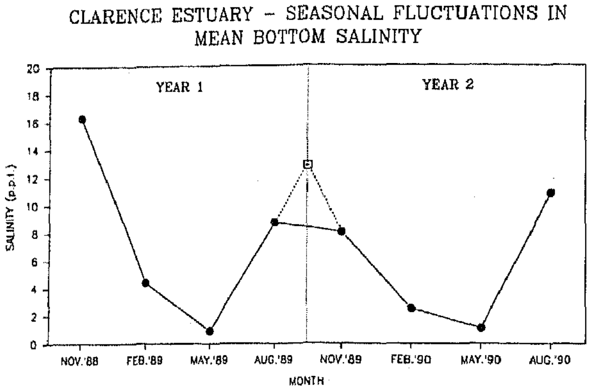

Fig. 9. Seasonal fluctuations in mean bottom salinity from November 1988 to August 1990 for all 18 sampling sites combined (peak for September–October 1989 extrapolated from trends in remaining data—see text for further explanation).

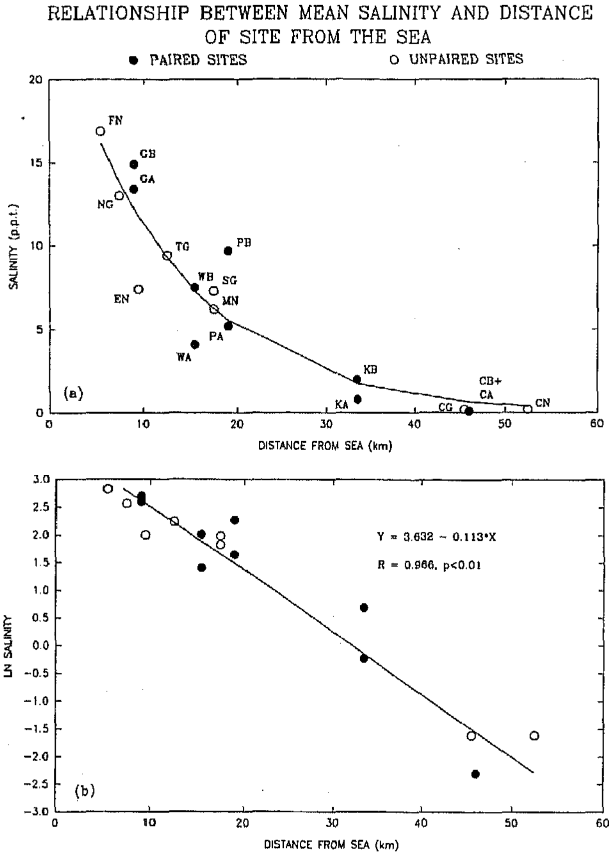

Fig. 10. Relationship between the mean bottom salinities at the sampling sites and their distances from the sea: (a) curvilinear declining exponential relationship, (b) linear logarithmic relationship.

into the head of Shallow Inlet (which enters the Clarence River's north arm), about 1 km to the west of Woombah (Fig. 2, site 7). The fringing vegetation was dense stands of mangroves (small *Aegiceras* backed by larger *Avicennia*) on the north bank, and small *Aegiceras* backed by she-oaks on the south bank. The surrounding land use was cattle grazing. Bottom salinities at this site (mean depth 0.9 m) were generally high (10–20‰) in winter and spring but dropped to 0–5‰ in summer and autumn (Fig. 5b).

The drain at the paired Shallow Inlet above gate site (WA) is about half the width of that below (i.e., 3.5 m vs 7 m). This site was fringed by rushes and pasture grasses, and submerged vegetation at times included some sea tassel (*Ruppia megacarpa*). The main surrounding land use was cattle grazing at the beginning and throughout the greater part of the study period but had changed to sugar cane growing by the end of this period. The bottom salinity at this site (mean depth 0.6 m) could be significantly lower (i.e., up to 10‰) than that at the paired below gate site, particularly during winter and spring in some years (Fig. 5b).

The Kings Island site (KB) was located below a large triple floodgate on a large drain entering the main Clarence River channel from Woodford Island opposite the southern end of Kings Island, about 3 km downstream from Lawrence (Fig. 2, site 8). The fringing vegetation was mainly reeds, grasses, and rushes, and the surrounding land use was sugar cane growing. Bottom salinities (mean depth 1.5 m) were usually fairly low (0–5‰) during most seasons but could reach 10‰ in the spring of some years (Fig. 5c).

The paired Kings Island above gate site (KA) had similar fringing vegetation, plus a few scattered she-oaks, and its submerged vegetation included the introduced water-weed *Elodea canadensis* and the native ribbonweed *Vallisneria gigantea*. The surrounding land use was sugar cane growing. Bottom salinities above the gates (mean depth 1.3 m) were also usually low but could reach 5–10‰ in the spring of some years (Fig. 5c).

The lower Coldstream River site (CB) is located below a small single floodgate on Broadmouth Gully, which enters the Coldstream River from the west about 4 km upstream from its junction with the south arm of the Clarence River (Fig. 2, site 9). Vegetation was overhanging terrestrial trees and fringing reeds, and the surrounding land use was cattle grazing. The bottom salinities (mean depth 1.8 m) usually remained close to 0‰ (Fig. 5b).

The paired lower Coldstream River above gate site (CA) had less overhanging fringing vegetation than the below gate site, and for most of the study period the water's surface was covered with a dense floating mat of the introduced water-fern *Salvinia molesta*. The site was generally similar to the below

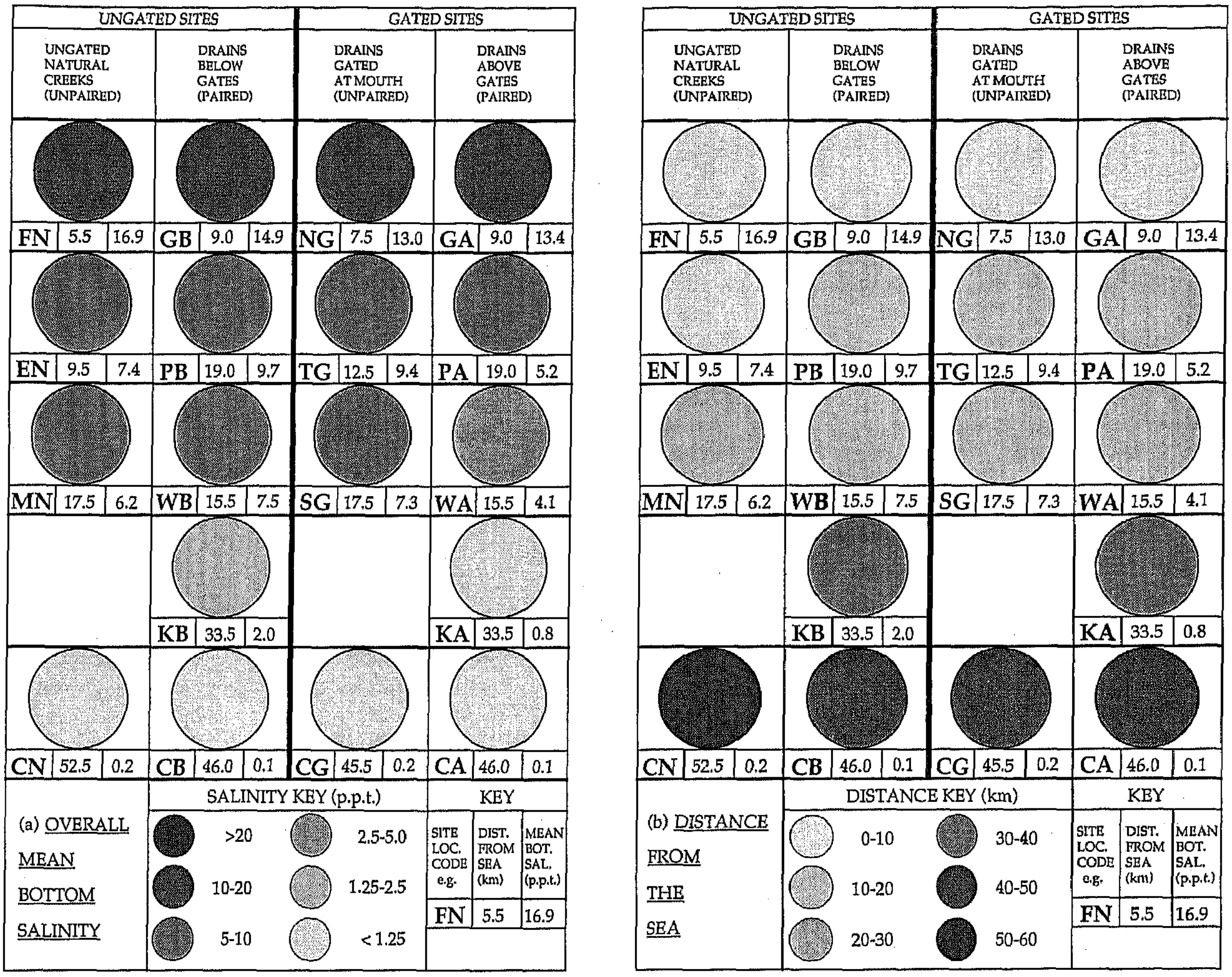

Fig. 11. (a) Overall mean bottom salinities and (b) distances from the sea of the 18 sampling sites (arrangement of sites, etc., as in Figs. 3 and 4).

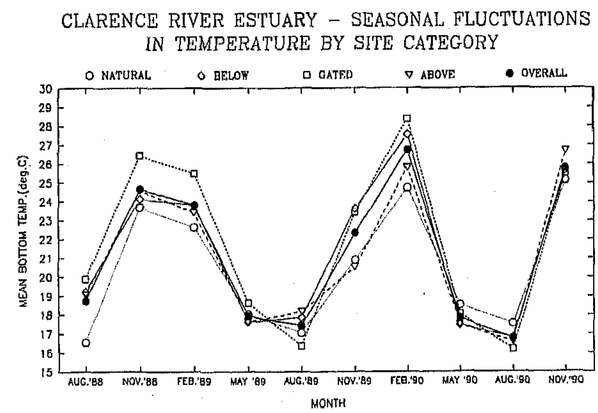

Fig. 12. Seasonal fluctuations in mean bottom temperatures for each of the four site categories and for the 18 sampling sites combined.

gate site in terms of land use. Bottom salinities (mean depth 1.7 m) generally approached 0‰ (Fig. 5b).

Sites on Drains Gated at Their Mouths

The north Palmers Island site (NG) is on a drain running inland from the north-eastern shore of Palmers Island opposite Goodwood Island. The drain is gated (three large floodgates) at its mouth where it enters the main Clarence River channel (Fig. 2, site 10). Fringing vegetation was grasses and rushes and a few she-oaks, and the surrounding land use was sugar cane growing. Submerged vegetation was mainly sea tassel. Bottom salinities above the gates (mean depth 0.9 m) were generally high (~15–30‰) in winter and spring and lower (5–10‰) in summer and autumn (Fig. 5d).

TABLE 3. Lower Clarence River system: seasonal fluctuations in bottom temperature (°C) at sampling sites, 1988–1990.

Sampling Sites	Temperature (°C)										
	Month and Year										
	August 1988	November 1988	February 1989	May 1989	August 1989	November 1989	February 1990	May 1990	August 1990	November 1990	Year 1 + Year 2[a] Mean ± SD
Natural Creeks											
FN	14.4	25.3	22.7	20.0	18.0	19.1	23.8	19.0	17.6	25.7	20.7 ± 2.7
EN	17.5	22.8	23.5	18.8	16.9	—	—	18.5	22.0	24.6	20.4 ± 2.5
MN	17.3	21.9	22.8	15.3	17.5	—	23.7	17.4	15.7	26.4	19.2 ± 3.3
CN	17.0	24.7	21.5	18.0	15.8	22.7	26.7	19.2	14.8	23.8	20.4 ± 3.9
Mean	16.6	23.7	22.6	18.0	17.0	20.9	24.7	18.5	17.5	25.1	20.4 ± 2.8
±SD	±1.3	±1.4	±0.7	±1.7	±0.8	±1.8	±1.4	±0.7	±2.8	±1.0	—
Below Gates											
GB	19.0	23.8	25.5	17.5	22.5	—	—	16.7	16.6	25.0	20.4 ± 3.6
PB	23.5	24.2	24.8	17.5	17.5	24.0	26.1	16.6	17.4	27.7	21.0 ± 3.8
WB	18.0	23.5	23.2	16.5	14.2	—	26.6	17.3	20.3	25.0	20.2 ± 4.1
KB	17.6	24.1	21.0	18.1	16.5	23.5	28.5	18.0	14.5	24.4	20.5 ± 4.3
CB	18.0	25.0	24.5	18.5	18.6	23.4	29.0	18.7	15.2	26.1	21.6 ± 4.3
Mean	19.2	24.1	23.8	17.6	17.9	23.6	27.6	17.5	16.8	25.6	21.1 ± 3.9
±SD	±2.2	±8.5	±1.6	±0.7	±2.7	±0.3	±1.2	±0.8	±2.0	±1.2	—
Gated at Mouth											
NG	20.4	24.0	24.5	19.5	15.7	24.2	29.0	16.6	16.6	27.0	21.3 ± 4.5
TG	18.4	28.5	26.6	19.0	17.7	23.6	28.5	18.0	15.0	25.0	22.1 ± 5.0
SG	21.8	27.8	24.4	17.5	15.5	21.5	27.0	19.2	17.2	25.5	21.3 ± 4.4
CG	19.0	25.4	26.5	18.5	16.5	24.5	29.0	18.4	15.9	24.5	21.8 ± 4.3
Mean	19.9	26.4	25.5	18.6	16.3	23.5	28.4	18.0	16.2	25.5	21.6 ± 4.6
±SD	±1.4	±1.8	±1.1	±0.7	±0.9	±1.2	±0.8	±0.9	±0.8	±0.9	—
Above Gates											
GA	21.6	24.8	25.0	17.5	23.5	—	—	16.7	17.0	25.2	20.8 ± 3.7
PA	23.0	26.4	23.2	17.7	16.8	19.6	24.0	16.6	16.9	33.0	20.2 ± 3.6
WA	18.8	24.5	23.7	16.3	16.6	—	24.0	17.9	18.4	27.6	20.2 ± 3.4
KA	17.1	24.6	20.7	18.5	16.0	22.5	26.8	18.0	15.2	23.0	20.3 ± 4.0
CA	14.8	22.5	24.5	18.2	18.0	19.5	28.4	18.2	15.4	24.6	20.6 ± 4.0
Mean	19.1	24.6	23.4	17.6	18.2	20.5	25.8	17.5	16.6	26.7	20.5 ± 3.4
±SD	±3.0	±1.2	±1.5	±0.8	±2.7	±1.4	±1.8	±0.7	±1.2	±3.5	—
All sites											
Mean	18.7	24.7	23.8	17.9	17.4	22.3	26.7	17.8	16.8	25.8	20.9 ± 3.6
±SD	±2.4	±1.6	±1.6	±1.1	±2.2	±1.9	±2.0	±1.0	±1.9	±2.1	—

[a] Year 1 + Year 2 = core sampling period (eight samples from November 1988 to August 1990, inclusive).

The Chatsworth Island site (TG) is located on a drain near the south-eastern corner of Chatsworth Island. The drain has three large floodgates where it enters the Serpentine Channel (Fig. 2, site 11). Its fringing vegetation was mainly grasses with a few rushes, and the surrounding land use was sugar cane growing. Bottom salinities (mean depth 0.9 m) ranged from 10‰ to 20‰ in winter and spring, to around 1–5‰ in summer and autumn (Fig. 5d).

The south Palmers Island site (SG) is on a drain, located near the southern end of Palmers Island. Three large floodgates are located where the drain flows into the southern part of Palmers Channel, about three quarters of the way from the main river channel toward Lake Wooloweyah (Fig. 2, site 12). Mean depth of this site was 0.8 m. Fringing vegetation and land use were generally similar to those at the Chatsworth Island site (TG). The seasonal salinity regime was also similar to that at TG, except during the first two sampling periods (August and November 1988), when salinity was much lower (Fig. 5d).

The lower Coldstream River site (CG) is located on a drain, which has three large floodgates at its mouth, where it enters the Coldstream River from the west (just north of Broadmouth Gully), about 3 km from its confluence with the south arm of the Clarence River (Fig. 2, site 13). Fringing vegetation and surrounding land use were similar to those at TG and SG. Bottom salinity (mean depth 0.9 m) was usually very low (0–5‰) (Fig. 5d).

Relationship Between Rainfall and Salinity

The Clarence River Catchment (CRC) encompasses the northern half of the inland New South Wales Meteorological District No. 57—Eastern Northern Tablelands (ENT) and the southern half

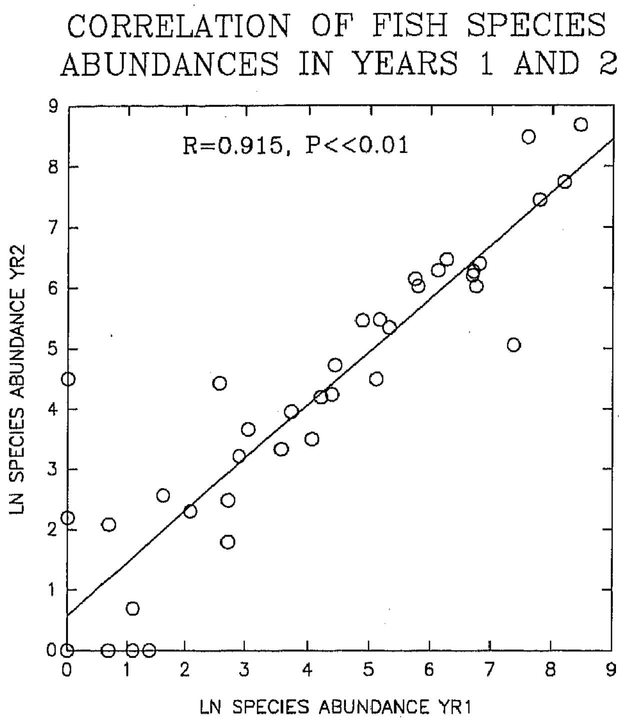

Fig. 13. Correlation between total fish species abundances over the two core years (years 1 and 2) of the study period. (Data transformed to x + 0.0001 to allow for effects of zero occurrences in log-log regression.)

of the coastal District No. 58—Upper North Coast (UNC), therefore, the best estimates of seasonal rainfall patterns over the catchment were obtained by averaging the rainfall figures for these two districts (Bureau of Meteorology 1988, 1989, 1990). The seasonal rainfall figures for the two districts and the estimated seasonal averages for the catchment are given in Table 1 for the three-calendar-year period 1988–1990, inclusive. From these figures it can be seen that District 58 (UNC) had a normal (i.e., long-term average) annual rainfall (1,453 mm), which was around 450 mm (or 45%) higher than that for District 57 (ENT) (1,004 mm). For the actual rainfalls over the 3-yr period, this percentage difference (43%) was quite similar (i.e., there was considerably more rainfall nearer the coast). The estimated mean annual rainfalls over the entire Clarence River Catchment (CRC) were 30% higher than normal in 1988, 18% higher in 1989, and 1.5% lower in 1990, or on average 16% higher over the entire 3-yr period.

To choose the two most comparable contiguous 1-yr periods (i.e., two "core" years) in terms of "normal" CRC rainfall over the total 2.5-yr (August 1988–November 1990) field study, the three possible contiguous 2-yr periods from winter (August) 1988 to autumn (May) 1990, spring (November) 1988 to winter (August) 1990, and summer (February) 1989 to spring (November) 1990, were compared. Of these, the middle 2-yr period (spring 1988 through winter 1990) proved to be the most consistent, the annual rainfalls over the 2 yr being 1,376 mm (spring 1988–winter 1989) and 1,378 mm (spring 1989–winter 1990). In both years these annual rainfall figures were 12% higher than the average normal annual rainfall of 1,229 mm calculated for the catchment as a whole.

Monthly rainfall records obtained from the Grafton Agricultural Research and Advisory Station (GARAS) for the years 1988–1990 inclusive were similarly converted to seasonal totals (Table 1). Seasonal rainfall figures for GARAS, which is located ~10 km to the north of Grafton (Fig. 1), compared quite closely with the estimated figures for the Clarence River Catchment (CRC) as a whole (i.e., they were generally higher than those for ENT and lower than those for UNC). The mean annual rainfall at GARAS over this 3-yr period was 1,413 mm (compared with CRC 1,421 mm, ENT 1,177 mm, and UNC 1,682 mm), which was 34% higher than the long-term annual GARAS average of 1,054 mm (compared with CRC 1,229 mm, ENT 1,004 mm, and UNC 1,453 mm). Monthly rainfalls at GARAS are plotted in Fig. 6, from which it can be seen that the highest rainfalls occurred in April (autumn) 1988 and 1989 and in February (summer) 1990. In general, the overall pattern of rainfall at GARAS was similar in 1988 and 1989.

Major floods in the lower Clarence River (7 m peaks at Grafton) were recorded in early and late April 1989; during 1990, peaks of 3–4 m were recorded in early February and early and late April, with a smaller peak in late May. Significant flooding had also occurred prior to the study period, in early April and early July 1988 (New South Wales Department of Public Works 1989, 1990). These flood peaks are closely correlated with the monthly rainfall patterns for these years (shown in Fig. 6). According to Karmouche and McCarthy (1977) there had been more than 70 major floods in the Clarence River system since 1839, 40 of which were considered medium to severe.

Seasonal rainfall over the two core years of the study period for the entire catchment (CRC) and at GARAS, together with the normal rainfall patterns for CRC and GARAS, are shown in Figs. 7a, b, respectively. It can be seen that the normal seasonal rainfall pattern in both cases is extremely symmetrical, with a distinct peak in summer and a distinct trough in winter. It can also be seen that the seasonal rainfall pattern at GARAS closely followed that for the CRC as a whole over this 2-yr

TABLE 4. List of all species collected during the entire study period, showing their name codes, economic status, salinity status, and numbers and frequencies of occurrence in the samples.

Family Genus and Species	Name Code	Economic Status	Salinity Status	Total No. in (10) Quarterly Samples	Frequencies of Occurrence in Samples
FISHES					
Carcharhinidae					
Carcharhinus leucas	CAR LEU	C	S	1	1
Elopidae					
Elops machnata	ELO MAC	C	S	10	3
Megalops cyprinoides	MEG CYP	C	S	4	4
Anguillidae					
Anguilla australis	ANG AUS	C	F	171	70
Anguilla reinhardtii	ANG REI	C	F	247	110
Clupeidae					
Herklotsichthys castelnaui	HER CAS	C	S	100	9
Potamalosa richmondia	POT RIC	C	F	186	44
Retropinnidae					
Retropinna semoni	RET SEM	N	F	2	2
Galaxiidae					
Galaxias maculatus	GAL MAC	N	F	2	2
Cyprinidae					
Carassius auratus[a]	CAR AUR	N	F	1	1
Ariidae					
Arius graeffei	ARI GRA	C	F	94	21
Plotosidae					
Euristhmus lepturus	EUR LEP	C	S	1	1
Tandanus tandanus	TAN TAN	C	F	1	1
Hemiramphidae					
Arrhamphus sclerolepis	ARR SCL	C	S	4	1
Hyporhamphus regularis	HYP REG	C	S	1	1
Belonidae					
Tylosurus gavialoides	TYL GAV	C	S	1	1
Poeciliidae					
Gambusia holbrooki[a]	GAM HOL	N	F	4,180	196
Melanotaeniidae					
Melanotaenia doublayi	MEL DUB	N	F	2	2
Pseudomugilidae					
Pseudomugil signifer	PSE SIG	N	F	1,540	96
Syngnathidae					
Vanacampus margaritifer	VAN MAR	N	S	1	1
Scorpaenidae					
Centropogon australis	CEN AUS	N	S	7	2
Notesthes robusta	NOT ROB	N	F	18	12
Platycephalidae					
Platycephalus fuscus	PLA FUS	C	S	75	52
Ambassidae					
Ambassis agassizi	AMB AGA	N	F	350	79
Ambassis jacksoniensis	AMB JAC	N	S	674	66
Ambassis marianus	AMB MAR	N	S	8,226	131
Percichthyidae					
Macquaria colonorum	MAC COL	C	F	3	3
Macquaria novemaculeata	MAC NOV	C	F	20	11

TABLE 4. Continued.

Family Genus and Species	Name Code	Economic Status	Salinity Status	Total No. in (10) Quarterly Samples	Frequencies of Occurrence in Samples
Sillaginidae					
Sillago ciliata	SIL CIL	C	S	1	1
Pomatomidae					
Pomatomus saltatrix	POM SAL	C	S	26	16
Sparidae					
Acanthopagrus australis	ACA AUS	C	S	454	108
Rhabdosargus sarba	RHA SAR	C	S	1	1
Gerreidae					
Gerres subfasciatus	GER SUB	C	S	49	29
Monodactylidae					
Monodactylus argenteus	MON ARG	C	S	6	5
Girellidae					
Girella tricuspidata	GIR TRI	C	S	10	8
Mugilidae					
Liza argentea	LIZ ARG	C	S	1,357	147
Mugil cephalus	MUG CEP	C	E	1,888	279
Mugil georgii	MUG GEO	C	S	91	5
Myxus elongatus	MYX ELO	C	S	4	2
Myxus petardi	MYX PET	C	F	33	16
Eleotridae					
Butis butis	BUT BUT	N	S	1	1
Gobiomorphus australis	GOB AUS	N	F	11,780	334
Hypseleotris compressa	HYP COM	N	F	7,296	240
Hypseleotris gallii	HYP GAL	N	F	1,303	108
Philypnodon grandiceps	PHI GRA	N	F	946	146
Philypnodon species	PHI SPE	N	F	263	65
Gobiidae					
Arenigobius bifrenatus	ARE BIF	N	S	11	7
Arenigobius frenatus	ARE FRE	N	S	3	3
Bathygobius kreffti	BAT KRE	N	S	1	1
Cryptocentroides cristatus	CRY CRI	N	S	2	2
Favonigobius exquisitus	FAV EXQ	N	S	13	3
Favonigobius tamarensis	FAV TAM	N	S	149	51
Gobiopterus semivestita	GOB SEM	N	S	2,192	76
Mugilogobius paludis	MUG PAL	N	S	1,865	145
Mugilogobius stigmaticus	MUG STI	N	S	1	1
Pseudogobius olorum	PSE OLO	N	S	1,542	131
Redigobius macrostoma	RED MAC	N	S	503	91
Taenioididae					
Taenioides mordax	TAE MOR	N	S	3	3
Soleidae					
Synaptura nigra	SYN NIG	C	S	7	7
Monacanthidae					
Meuschenia trachylepis	MEU TRA	C	S	1	1
Tetraodontidae					
Marilyna pleurosticta	MAR PLE	N	S	66	29
DECAPOD CRUSTACEANS					
Penaeidae					
Metapenaeus bennettae	MET BEN	C	S	6	2
Metapenaeus macleayi	MET MAC	C	S	2,493	99
Penaeus plebejus	PEN PLE	C	S	17	5
Portunidae					
Scylla serrata	SCY SER	C	S	13	10

[a] Introduced species.

TABLE 5. Abundances and frequencies of occurrence of fish species in the samples during the two core years (years 1 and 2) of the study period. Name codes are given in Table 4.

Name Code	Year 1[a] Number	Year 1[a] Frequency	Year 2 Number	Year 2 Frequency	Year 1 + 2 Number	Year 1 + 2 Frequency
GOB AUS	4,721	139	5,870	154	10,591	293
HYP COM	2,002	102	4,807	119	6,809	221
AMB MAR	3,634	58	2,300	47	5,934	105
GAM HOL	2,426	87	1,711	88	4,137	175
GOB SEM	1,592	35	157	23	1,749	58
MUG CEP	905	111	601	110	1,506	221
PSE OLO	817	57	528	54	1,345	111
PSE SIG	803	45	494	37	1,297	82
HYP GAL	853	53	413	48	1,266	101
LIZ ARG	525	61	644	64	1,169	125
MUG PAL	456	66	538	59	994	125
PHI GRA	310	59	466	64	776	123
AMB JAC	326	29	414	32	740	61
RED MAC	203	42	209	43	412	85
ACA AUS	173	44	238	51	411	95
AMB AGA	131	32	235	46	366	78
PHI SPE	164	45	89	16	253	61
ANG REI	84	39	112	52	196	91
POT RIC	80	23	69	14	149	37
ANG AUS	67	28	66	34	133	62
HER CAS	13	4	84	3	97	7
FAV TAM	42	23	52	23	94	46
ARI GRA	58	6	33	12	91	18
MUG GEO	1	1	90	4	91	5
PLA FUS	36	22	28	23	64	45
MAR PLE	21	10	39	14	60	24
GER SUB	18	9	25	15	43	24
MYX PET	15	9	12	4	27	13
POM SAL	15	8	6	5	21	13
NOT ROB	5	5	13	6	18	11
MAC NOV	8	4	10	5	18	9
GIR TRI	2	2	8	6	10	8
ELO MAC	1	1	9	2	10	3
CEN AUS	7	2	—	—	7	2
SYN NIG	4	4	1	1	5	5
MON ARG	3	3	2	2	5	5
ARE BIF	3	2	2	2	5	4
MEG CYP	3	3	1	1	4	4
ARR SCL	4	1	—	—	4	1
MAC COL	2	2	1	1	3	3
TAE MOR	—	—	3	3	3	3
FAV EXQ	1	1	1	1	2	2
GAL MAC	1	1	1	1	2	2
RET SEM	1	1	1	1	2	2
CRY CRI	2	2			2	2
MEL DUB	2	2			2	2
BAT KRE	1	1			1	1
BUT BUT	1	1			1	1
CAR AUR	1	1			1	1
EUR LEP	1	1			1	1
MYX ELO	1	1			1	1
MEU TRA	1	1			1	1
CAR LEU			1	1	1	1
HYP REG			1	1	1	1
MUG STI			1	1	1	1
RHA SAR			1	1	1	1
SIL CIL			1	1	1	1
TAN TAN			1	1	1	1
TYL GAV			1	1	1	1
VAN MAR			1	1	1	1
Total number of fish	20,607	1,289	20,330	1,298	40,927	2,587
Number of species	51		50		60	

[a] Year 1 totals adjusted upward to give equal numbers of samples to year 2.

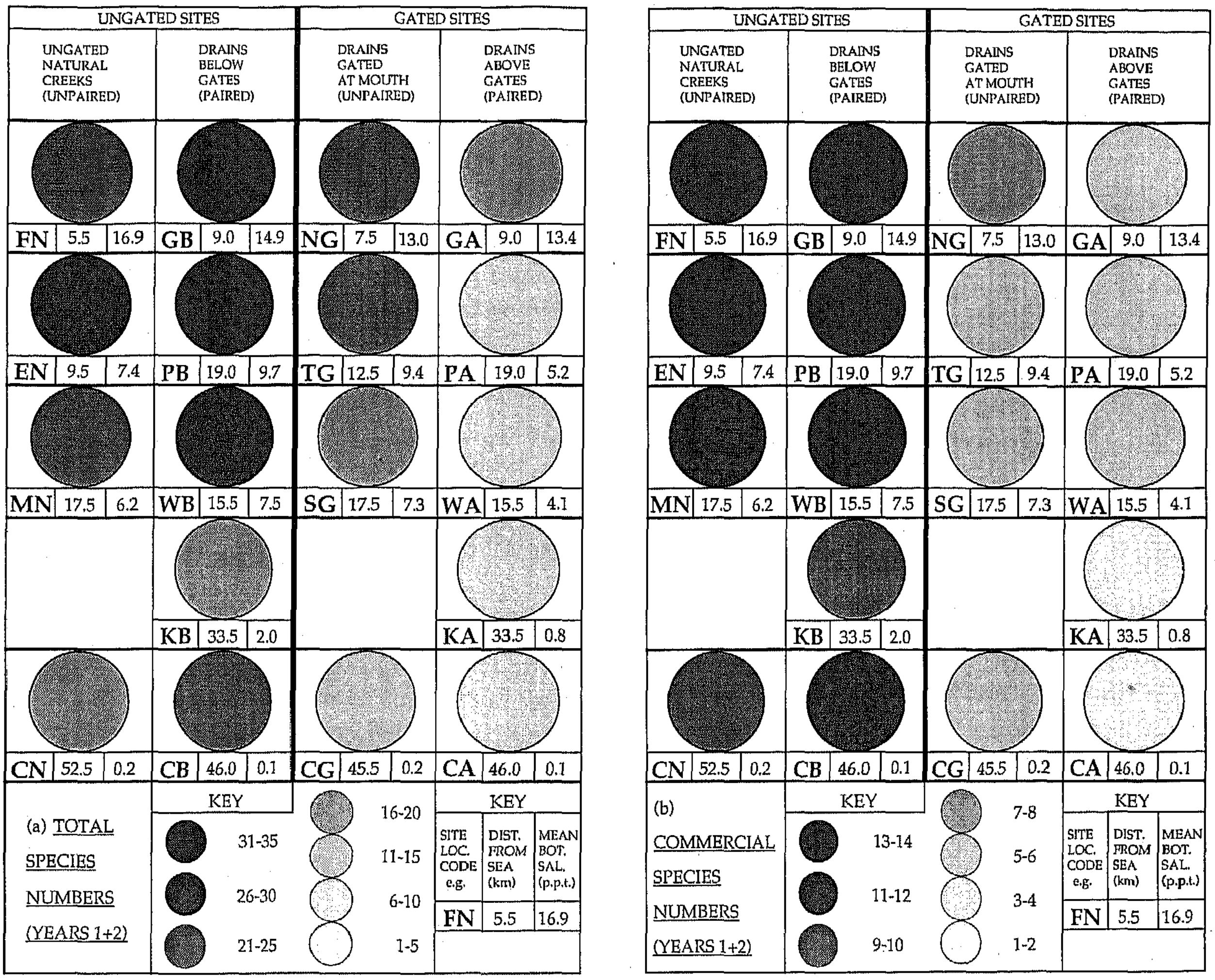

Fig. 14. (a) Total fish species numbers and (b) commercial fish species numbers sampled at the 18 sampling sites over the two core years of the study period (arrangement of sites, etc., as in Figs. 3 and 4).

period from spring 1988 through winter 1990 (henceforth referred to as the core sampling period, or years 1 and 2 in the tables). Figure 7a shows clearly that, over this 2-yr period selected for data averaging, the majority of the excess rainfall in the CRC as a whole fell in the autumns of both years, with slight deficits occurring in the two winters.

The seasonal fluctuations in bottom salinity at the various sampling sites (Table 2, Figs. 5a–d) have the general pattern of spring peaks and autumn troughs, reflecting the inverse of the general pattern of rainfall over the study period. Highest salinities (28–31‰) were found at site FN each November, and lowest salinities (0‰) at many of the more upstream sites, particularly during May. The overall mean patterns of salinity at these sites for each season are compared graphically in Figs. 8a–d.

The close relationship between rainfall and salinity can be seen by comparing Figs. 7a and 9. The average bottom salinity for all 18 sampling sites (Fig. 9) fluctuated inversely with respect to seasonal rainfall for CRC (which provided a closer comparison to these salinity data than seasonal rainfall at GARAS, Fig. 7b). A lag of approximately 1 month between the fluctuations in catchment rainfall and mean salinity was evident. As the mean seasonal salinities shown in Fig. 9 are the products of spot measurements at the sampling sites, rather than integrated measures as in the case of the rainfall figures, the likely position of the 1989 winter-spring peak in salinity (which was missed between the quarterly sampling periods) has been extrap-

UNGATED SITES								GATED SITES							
UNGATED NATURAL CREEKS (UNPAIRED)				DRAINS BELOW GATES (PAIRED)				DRAINS GATED AT MOUTH (UNPAIRED)				DRAINS ABOVE GATES (PAIRED)			
RT	7.9	88.9	288	RT	7.9	106.1	48	RT	7.2	69.6	123	RT	5.6	85.6	50
GT	3.3	104.6	3028	GT	1.8	7.1	667	GT	1.3	8.0	3156	GT	0.4	1.3	71
RC	2.1	28.8	100	RC	1.9	18.0	14	RC	1.1	3.6	87	RC	0.5	4.8	27
GC	2.5	22.9	2333	GC	1.8	5.4	652	GC	1.2	8.0	3156	GC	0.3	1.3	68
FN	5.5	16.9		GB	9.0	14.9		NG	7.5	13.0		GA	9.0	13.4	
RT	6.3	71.2	5	RT	9.2	75.8	61	RT	6.6	55.9	75	RT	5.5	114.7	166
GT	3.2	8.0	1040	GT	2.8	46.4	1644	GT	0.9	12.8	3930	GT	0.5	2.8	434
RC	1.3	4.8	37	RC	2.4	9.2	29	RC	0.5	0.9	41	RC	1.0	2.1	89
GC	2.9	7.6	1036	GC	2.3	8.6	1275	GC	0.9	12.8	3930	GC	0.5	2.8	434
EN	9.5	7.4		PB	19.0	9.7		TG	12.5	9.4		PA	19.0	5.2	
RT	5.8	161.7	91	RT	7.6	276.5	150	RT	7.5	101.9	123	RT	5.5	165.6	149
GT	2.4	7.1	1781	GT	3.1	20.1	1988	GT	1.1	6.6	1325	GT	0.2	1.0	50
RC	1.3	1.6	4	RC	1.8	5.1	65	RC	1.3	7.9	51	RC	1.1	2.1	44
GC	2.2	6.9	1767	GC	2.8	14.3	1928	GC	0.9	6.3	1290	GC	0.2	1.0	50
MN	17.5	6.2		WB	15.5	7.5		SG	17.5	7.3		WA	15.5	4.1	
				RT	4.6	89.4	12					RT	4.1	97.6	52
				GT	2.1	8.8	2093					GT	0.3	0.3	182
				RC	0.2	1.5	1					RC	0.3	0.1	0.2
				GC	2.1	8.8	2093					GC	0.3	0.3	182
				KB	33.5	2.0						KA	33.5	0.8	
RT	6.1	93.9	24	RT	6.5	95.0	58	RT	4.7	78.9	183	RT	2.6	29.1	7
GT	1.6	4.1	1301	GT	2.7	10.6	4225	GT	0.4	1.1	404	GT	0	0	0
RC	1.8	3.1	10	RC	1.6	9.3	14	RC	0.6	1.0	73	RC	0.5	0.5	1
GC	1.5	3.9	1291	GC	2.4	9.5	4220	GC	0.4	1.0	402	GC	0	0	0
CN	52.5	0.2		CB	46.0	0.1		CG	45.5	0.2		CA	46.0	0.1	

MEAN TOTAL AND COMMERCIAL SPECIES NOS, ABUNDANCES & BIOMASSES BY SITE AND METHOD

KEY			
METHODS & STATUS	SPECIES NOS	ABUNDANCES	BIOMASSES

KEY	
RT	ROT. STN TOTAL
GT	GILL NET TOTAL
RC	ROT. STN COMM.
GC	GILL NET COMM.

KEY		
SITE LOC. CODE e.g.	DIST. FROM SEA (km)	MEAN BOT. SAL. (ppt)
FN	5.5	16.9

Fig. 15. Mean numbers, abundances and biomasses of total (T) and commercial (C) fish species from the rotenone station (R) and gill net (G) samples taken at the 18 sampling sites over the two core years of the study period (arrangement of sites, etc., as in Figs. 3 and 4).

olated from the remaining data and added to the figure (dotted lines).

Relationship Between Salinity and Distance Upstream

In Fig. 10a the mean bottom salinity at each sampling site over the two core years of the study is plotted against the distance of that site upstream from the sea. These two parameters show a strongly negative correlation ($r = -0.966$, $p < 0.01$) when the natural log of salinity is plotted against distance from the sea (Fig. 10b). The overall mean bottom salinities and distances from the sea of the various sites are compared graphically in Figs. 11a and b.

From both Figs. 10a and 11a it can be seen that, overall, the floodgates are ineffective in preventing saline water from entering the drains above them. For the paired (below and above gates) sites, the approximate average salinity differences over sampling years 1 and 2 were as follows: GB and GA 1.5‰, WB and WA 3.5‰, PB and PA 4.5‰, KB and KA 1.0‰, and CB and CA 0‰.

Water Temperature

Based on spot measurements of seasonal bottom water temperatures, all sites showed the expected pattern of summer maxima and winter minima, closely paralleling seasonal air temperature changes at these shallow water (average depth ~1 m) sites.

The lowest bottom water temperatures recorded during the study were between 14°C and 15°C (in August) and the highest between 29°C and 33°C (in February and November). Combined mean seasonal bottom water temperatures for each of the site categories (natural creek, gated at mouth, below gates, and above gates) were compared over the two core years of the study period (Fig. 12, Table 3). None of the site categories differed significantly from the others or from the overall mean, although mean seasonal bottom temperatures at the natural creek sites were the lowest and least variable (20.4 ± 2.8°C), and those at the sites on drains gated at their mouths were the highest and most variable (21.6 ± 4.6°C).

As mentioned above, temperature and salinity stratification were both relatively rare during the study period. Minor exceptions occurred, especially during spring, when rainwater running into some of the creeks and drains formed a colder, fresher layer over the warmer, saline water beneath (e.g., on six occasions when the surface water was 1°C to 3°C colder than the bottom water, and the bottom water was 5–10‰ more saline than the surface water). On another 13 occasions there was a layer of surface water that was 3–4°C warmer than the bottom water but with no significant (i.e., <5‰) salinity difference.

Fish Community Structure

Table 4 lists fish and crustacean species found at one or more of the 18 sampling sites during the entire 2.5-yr study period, and gives their name codes (as used in subsequent tables); their economic status (i.e., commercial or noncommercial species); their salinity status (i.e., primarily saltwater species—generally estuarine-marine dwelling as adults, primarily freshwater species—generally freshwater dwelling as adults, or euryhaline species—equally well adapted to saline or freshwater habitats as adults); their total numbers in the samples; and their frequencies of occurrence in the samples.

TABLE 6. *t*-tests for significant differences between mean numbers of species in both rotenone station and gill net samples from gated versus ungated sites shown in Fig. 15.

Site/Sample Parameters[a]	Mean	±SD	95% C.L.	Site/Sample Parameters[a]	Mean	±SD	95% C.L.	Signif.* ($p < 0.05$)
	Ungated Sites				Gated Sites			
Natural Creeks				Gated at Mouth				
RS.T.Spp.Nos.	6.53	0.81	1.29	RS.T.Spp.Nos.	6.50	1.09	1.73	N.S.
GN.T.Spp.Nos.	2.63	0.69	1.09	GN.T.Spp.Nos.	0.93	0.33	0.53	*
RS.C.Spp.Nos.	1.63	0.34	0.54	RS.C.Spp.Nos.	0.88	0.33	0.53	N.S.
GN.C.Spp.Nos.	2.28	0.51	0.81	GN.C.Spp.Nos.	0.85	0.29	0.46	*
Below Gates				Above Gates				
RS.T.Spp.Nos.	7.16	1.54	1.92	RS.T.Spp.Nos.	4.66	1.17	1.45	N.S.
GN.T.Spp.Nos.	2.50	0.48	0.59	GN.T.Spp.Nos.	0.28	0.17	0.21	*
RS.C.Spp.Nos.	1.58	0.74	0.92	RS.C.Spp.Nos.	0.68	0.31	0.39	N.S.
GN.C.Spp.Nos.	2.28	0.33	0.41	GN.C.Spp.Nos.	0.26	0.16	0.20	*
Total Ungated				Total Gated				
RS.T.Spp.Nos.	6.88	1.31	1.07	RS.T.Spp.Nos.	5.48	1.46	1.19	N.S.
GN.T.Spp.Nos.	2.56	0.58	0.48	GN.T.Spp.Nos.	0.57	0.41	0.33	*
RS.C.Spp.Nos.	1.60	0.60	0.49	RS.C.Spp.Nos.	0.77	0.34	0.27	*
GN.C.Spp.Nos.	2.28	0.42	0.34	GN.C.Spp.Nos.	0.52	0.37	0.30	*

[a] Key to sample parameters: RS. = rotenone station, GN. = gill net, T.Spp.Nos. = total species numbers, C.Spp.Nos. = commercial species numbers. * $t_{0.05(3)} = 3.182$; $t_{0.05(4)} = 2.776$.

Overall, 61 fish species (47,790 individuals) were sampled, of which 30 were classified as commercial and 31 as noncommercial species. Thirty-nine species were classified as primarily saltwater, 21 as primarily freshwater, and only one as euryhaline. Although a number of the smaller noncommercial species showed strong evidence of being euryhaline, not enough was known about their life histories and salinity tolerances to classify them definitively as such, so they were classified as either primarily saltwater or primarily freshwater species for the purposes of this study (salinity classifications based on Merrick and Schmida 1984; Hutchins and Swainston 1986; Allen 1989; Paxton et al. 1989). The single commercial species classified as euryhaline, the bully mullet *Mugil cephalus,* as an adult lives with equal facility in a wide variety of both freshwater and saltwater habitats in eastern Australia, at salinities ranging from 0‰ to >35‰. In view of the importance of this particular species in the fish community and fisheries of the lower Clarence River system (see Virgona 1992), it was considered necessary to distinguish it from other "temporarily" euryhaline commercial species such as the catadromous percichthyid basses and anguillid eels, which move from fresh to saline habitats primarily during their spawning migrations.

The most numerically abundant families overall were the Eleotridae or gudgeons (comprising six species), the Ambassidae or glass perchlets (three species) and the Gobiidae or gobies (11 species), amongst the noncommercial group; and the Mugilidae or grey mullets (five species), Sparidae or sea breams (two species) and Anguillidae or eels (two species) amongst the commercial group. The introduced mosquitofish, *Gambusia holbrooki* (Poeciliidae), was the fourth most abundant individual species overall, after two of the gudgeons and a glass perchlet.

Although the sampling techniques used were designed specifically to catch finfishes, a number of commercially important decapod crustaceans (four species, 2,529 individuals) were also caught; these are listed at the bottom of Table 4. Dominant amongst these was the school prawn, *Metapenaeus macleayi* (Penaeidae).

When the finfish totals for years 1 and 2 only of the study period are considered (Table 5), it can be seen that the relative abundances of the various species over the two separate core sampling years (Fig. 13) were highly correlated ($r = 0.915$). The actual overall total numbers of individuals caught and total frequencies of occurrence during each year were also very similar (Table 5). Overall, 60 fish species (51 in year 1 and 50 in year 2) were sampled during this 2-yr core period, 38 of which were classified as primarily saltwater, 21 as primarily freshwater, and one as a euryhaline species. Of the 30 commercial species sampled over this period, 21 were saltwater, 8 freshwater, and 1 euryhaline. The only major differences between the 2 yr were in the relative abundances of the goby *Gobiopterus semivestita* (an order of magnitude greater in the first year) and the mullet *Mugil georgii* and herring *Herklotsichthys castelnaui* (both greater in the second year, primarily due to single large schools being captured). Amongst the more numerically abundant species, the gudgeon *Hypseleotris compressa* was about 2½ times as abundant in the second year compared with the first year.

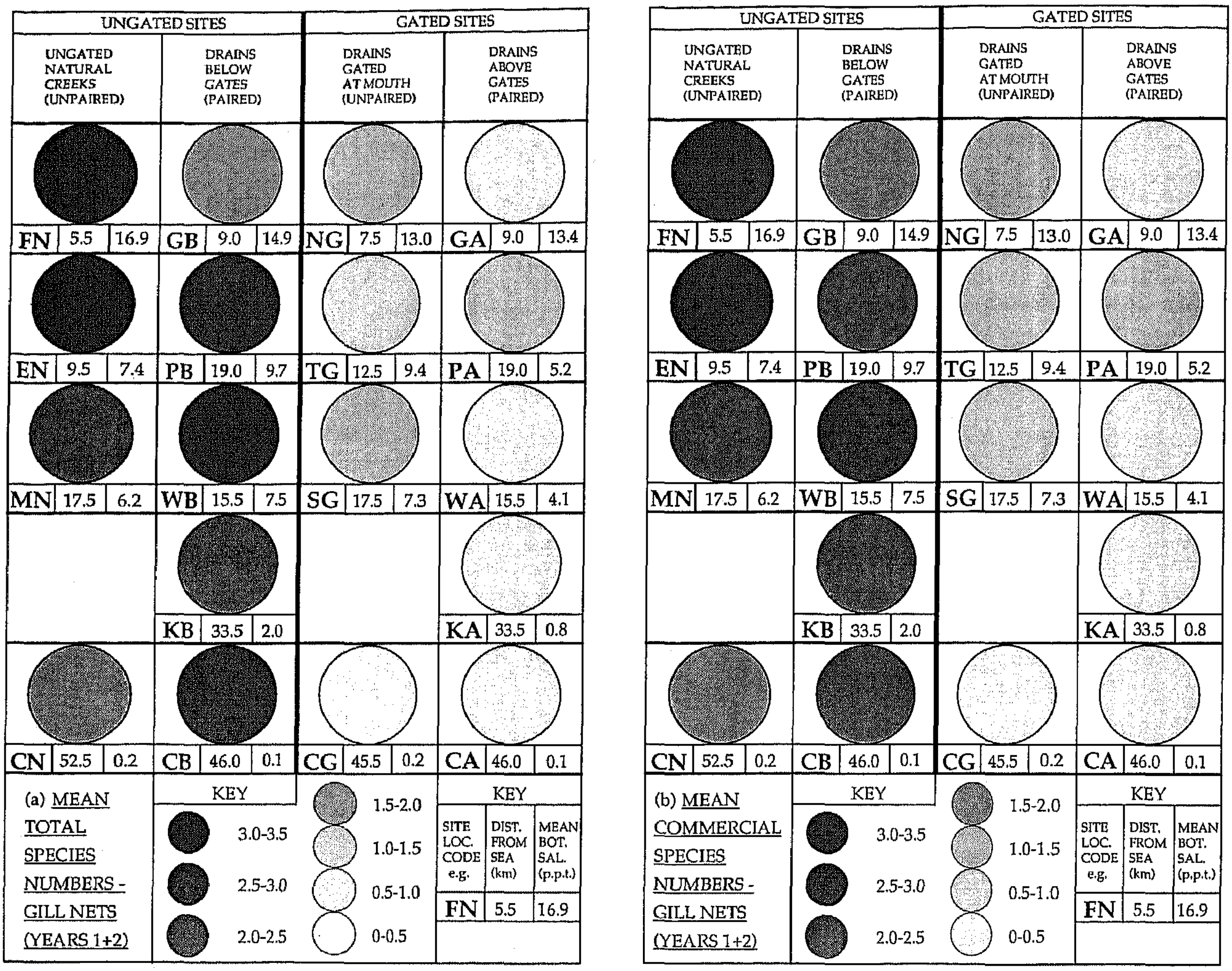

Fig. 16. (a) Mean total species numbers, and (b) mean commercial species numbers, from the gill net samples taken at the 18 sampling sites over the two core years of the study period (arrangement of sites, etc., as in Figs. 3 and 4).

Comparisons of Fish Community Parameters at Sites

The total numbers of all fish species and of commercial fish species sampled (by all methods) at each of the 18 sites over the 2-yr core sampling period are compared in Figs. 14a, b. Total species numbers were higher in the ungated versus the equivalent gated sites, including both the ungated natural creeks versus drains gated at their mouths, and the paired drains below gates versus drains above gates. There was also a general pattern of higher species numbers at those sites that were more saline and closer to the sea (see next section), particularly in the case of the gated sites.

Figure 15 summarizes mean total (T) and mean commercial (C) fish species numbers, abundances, and biomasses for the rotenone station (R) and gill net (G) samples taken at each site over the 2-yr core sampling period. Mean total and mean commercial fish species numbers from the two sampling methods at the gated versus the ungated sites were compared by *t*-test (Table 6). Mean total and mean commercial fish species numbers in the gill net samples were significantly higher ($p < 0.05$) in both the ungated natural creeks versus the drains gated at their mouths, and in the drains below gates versus the drains above gates, as well as in all of the ungated versus the gated sites combined (see graphical comparisons in Figs. 16a, b). In the rotenone station samples, mean commercial fish species numbers were also significantly higher ($p < 0.05$) in the ungated versus the gated sites overall (Fig. 17). Each of the remaining combinations of sites sampled using rotenone had

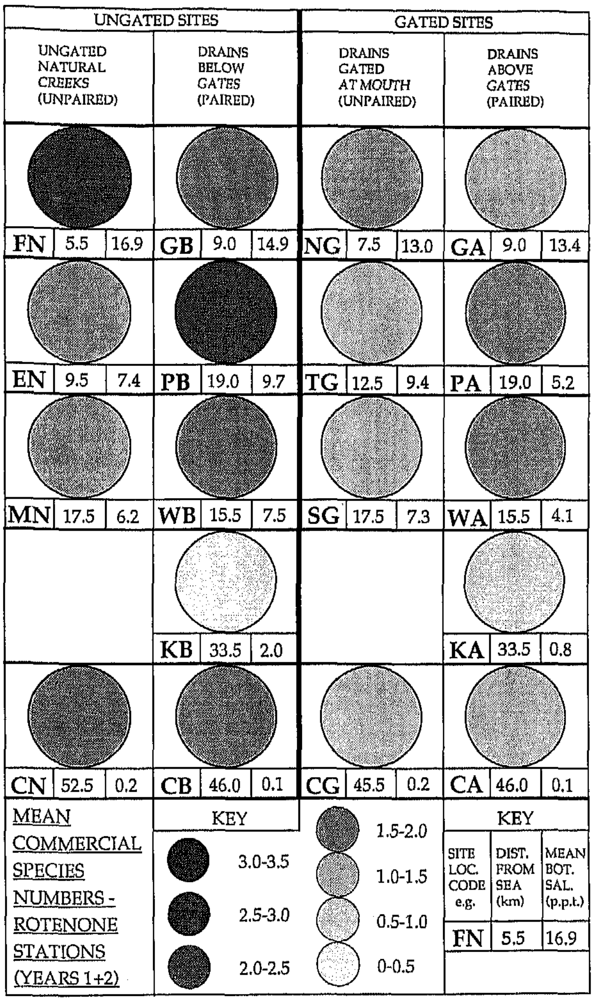

Fig. 17. Mean commercial species numbers from the rotenone station samples taken at the 18 sampling sites over the two core years of the study period (arrangement of sites, etc., as in Figs. 3 and 4).

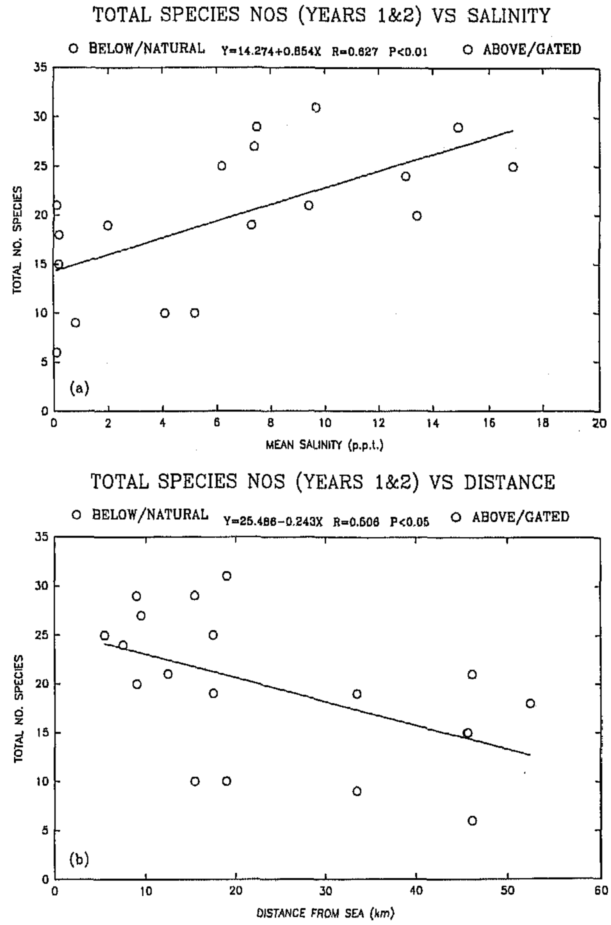

Fig. 18. Correlations between total species numbers and (a) mean site salinity and (b) distance from the sea for the 18 sampling sites combined.

higher mean total and commercial fish species numbers in the ungated than the gated sites, though these differences were not significant. In all cases, mean abundances (Fig. 15) were greater in the ungated versus the gated sites, but again these differences were not significant. Mean biomasses (Fig. 15) showed no significant patterns in the ungated versus the gated sites.

Relationships Between Fish Species Numbers, Salinity, and Distance From the Sea

Correlations between fish species numbers (total and commercial) sampled and the mean bottom salinities and distances from the sea at each of the 18 sampling sites over the 2-yr core sampling period (eight quarterly samples) were plotted. The correlation between total species number and mean site salinity ($r = 0.627$; $p < 0.01$; Fig. 18a) was greater than that between total species number and distance from the sea ($r = -0.506$, $p < 0.05$; Fig. 18b) for the 18 sampling sites plotted together. Commercial species numbers, however, were not significantly correlated with either mean site salinity or distance from the sea for the sites considered together (plots not shown).

When data were plotted separately for the nine ungated and the nine gated sites over this 2-yr core sampling period, however, the correlation was marginally greater for total species numbers against distance from the sea ($r = -0.791$, $p < 0.05$, Fig. 19a) than against salinity ($r = 0.700$, $p < 0.05$, Fig. 19b) for the ungated sites. The reverse was true for the gated sites (salinity $r = 0.840$, $p < 0.01$, Fig. 19b; distance $r = -0.664$, $p > 0.05$, N.S., Fig. 19a). Correlations for commer-

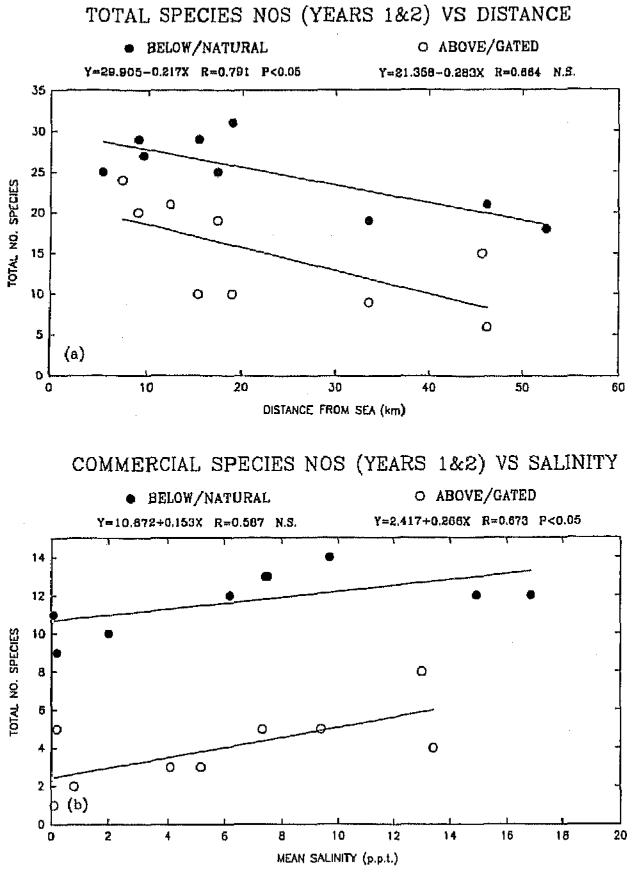

Fig. 19. Correlations between total species numbers and (a) distance from the sea and (b) mean site salinity for the nine ungated and nine gated sites plotted separately.

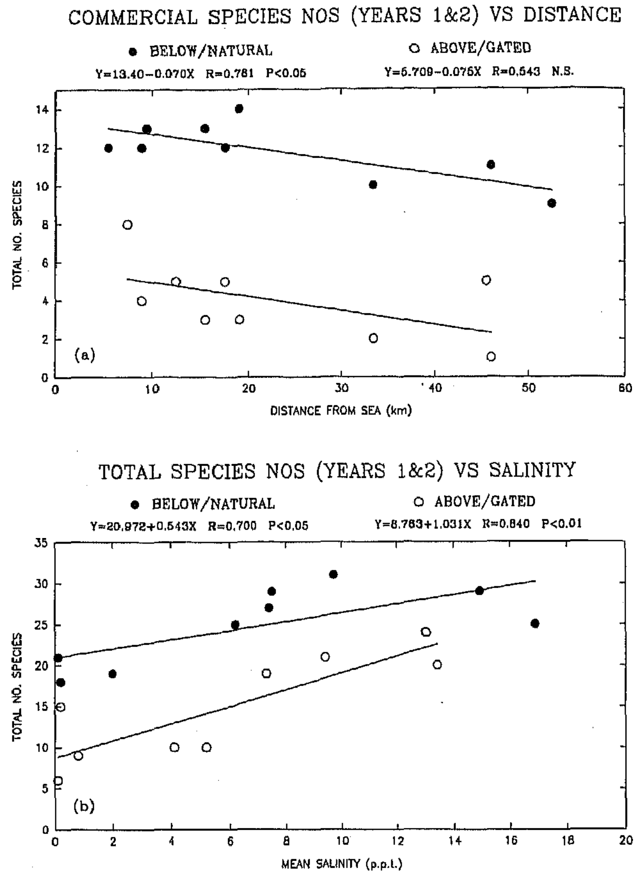

Fig. 20. Correlations between commercial species numbers and (a) distance from the sea and (b) mean site salinity for the nine ungated and nine gated sites plotted separately.

cial species numbers were significant for ungated sites with distance ($r = -0.761$, $p < 0.05$, Fig. 20a) and gated sites with salinity ($r = 0.673$, $p < 0.05$, Fig. 20b). Each of the above correlations calculated for the 2-yr core sampling period (eight quarterly samples) was greater than when calculated for the entire 2.5-yr sampling period (10 quarterly samples) (plots not shown).

Relationship Between Salinity Status and Species Occurrence

Figures 21a, b, c and Figs. 22a, b, c show the proportion of mean species numbers, abundances, and biomasses of commercial and noncommercial fishes caught in the gill net and rotenone station samples, according to their salinity status.

For the gill net samples (which comprised primarily adults and subadults of commercial species), species numbers, abundances and biomasses of primarily saltwater fishes were proportionally greatest in the six ungated downstream sites (i.e., those <20 km from the sea), while those of primarily freshwater fishes were proportionally greatest in the three ungated upstream sites (i.e., those >30 km from the sea). Few freshwater, and even fewer saltwater, fishes were caught in gill net samples from the gated sites, which were dominated by the euryhaline bully mullet. No fish were caught in the gill nets at the furthest upstream, and least saline, gated site (CA).

The rotenone station samples were comprised primarily of small noncommercial species and the juveniles of larger commercial species. In all cases, the proportion of noncommercial species was higher in the rotenone samples than in the gill net samples, with the majority of the primarily saltwater species again occurring in the more downstream ungated sites. Primarily freshwater species again dominated the more upstream ungated sites, but in this case, also all of the (upstream and downstream) gated sites. The euryhaline commercial category (i.e., juvenile bully

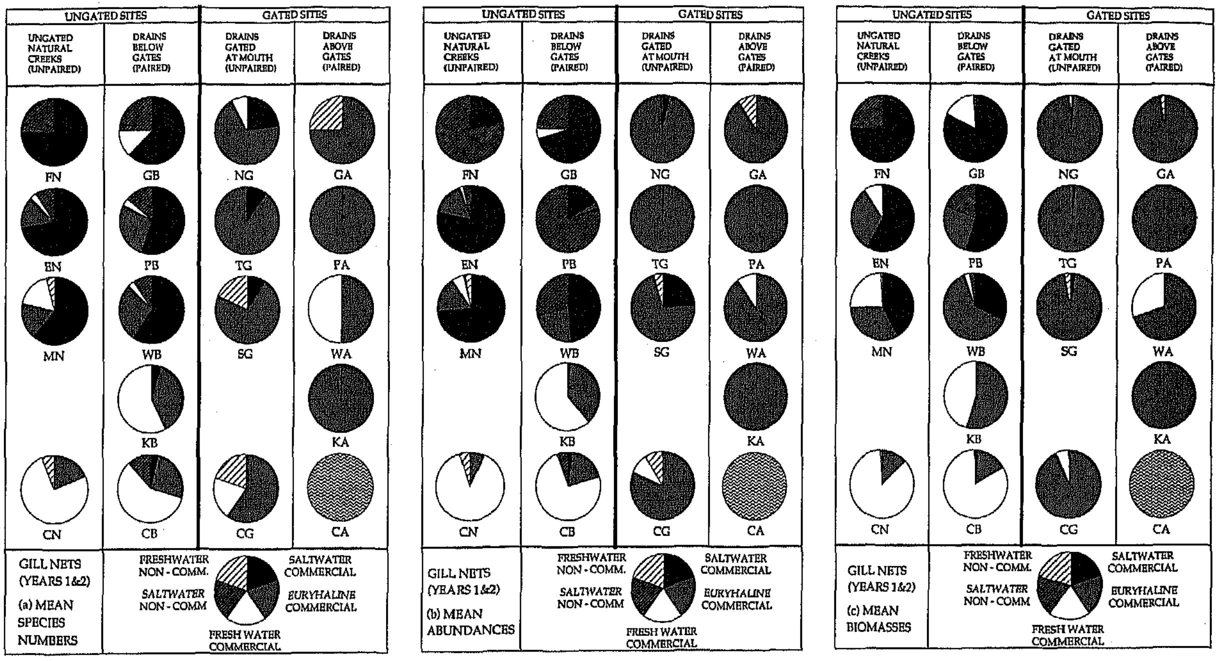

Fig. 21. (a) Mean species numbers, (b) mean abundances, and (c) mean biomasses of commercial and noncommercial saltwater, freshwater, and euryhaline fish species in the gill net samples taken at the 18 sampling sites over the two core years of the study period (arrangement of sites, etc., as in Figs. 3 and 4).

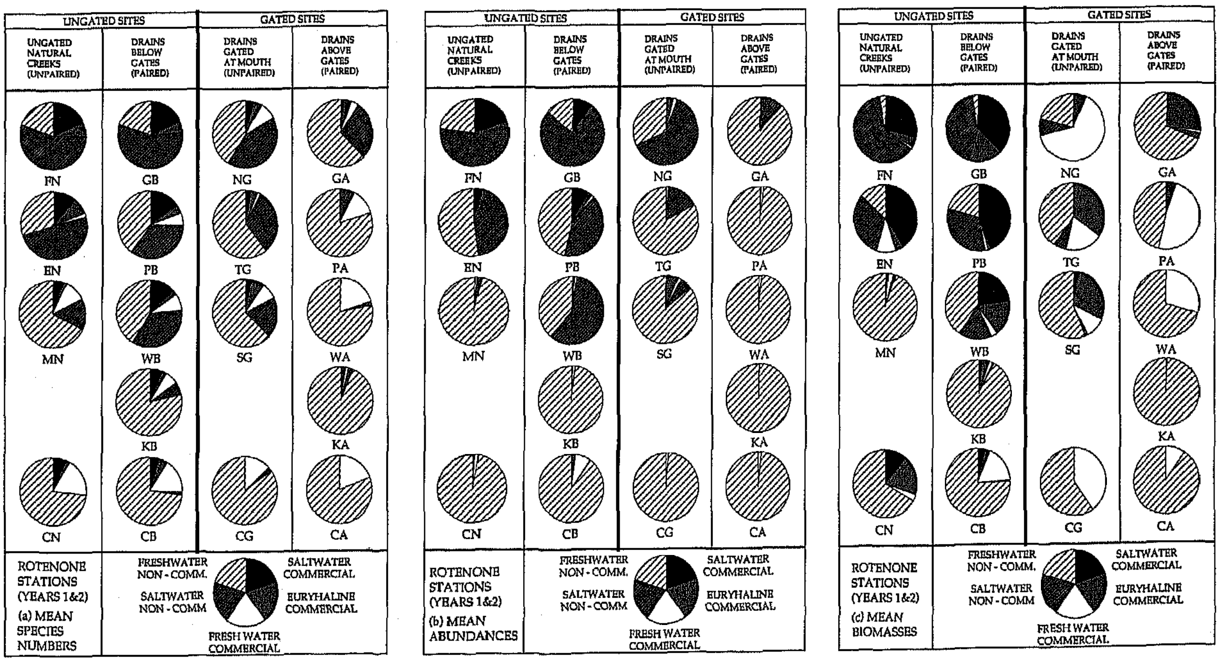

Fig. 22. (a) Mean species numbers, (b) mean abundances, and (c) mean biomasses of commercial and noncommercial saltwater, freshwater, and euryhaline fish species in the rotenone station samples taken at the 18 sampling sites over the two core years of the study period (arrangement of sites, etc., as in Figs. 3 and 4).

TABLE 7. Dominant fish species in gill net and rotenone station samples. Name codes are given in Table 4.

Category and Name Code	Main Life-History Stage[a]	Dominance Rank[b]	No. Occ. Sites	Frequency in Samples	Total Number	Economic Status[c]
Gill Net Samples						
Salt water						
Commercial Species						
LIZ ARG	A, SA	1	7	62	563	C
PLA FUS	A	2	7	40	57	C, A
GER SUB	SA	3	5	17	30	C
ACA AUS	A, SA	4	6	15	20	C, A
POM SAL	J	5	6	11	19	C, A
HER CAS	SA	6	2	5	93	A
MUG GEO	SA	7	1	5	91	C
Noncommercial Species						
AMB MAR	A, SA	1	7	34	2,025	F
Euryhaline						
Commercial Species						
MUG CEP	A, SA	1	15	135	712	C
Fresh water						
Commercial Species						
POT RIC	A, SA	1	7	35	141	A
ARI GRA	A	2	6	18	91	C
MYX PET	A	3	4	13	27	A
MAC NOV	A	4	3	9	18	A
MAC COL	A	5	3	3	3	A
TAN TAN	A	6	1	1	1	A
Noncommerical Species						
NOT ROB	A	1	3	4	6	V
Rotenone Station Samples						
Salt water						
Commercial Species						
ACA AUS	J	1	12	71	346	C, A
LIZ ARG	J	2	8	55	546	C
GER SUB	J	3	4	7	13	C
GIR TRI	J	4	2	5	7	C, A
SYN NIG	J	5	4	5	5	C
MON ARG	J	6	3	4	4	C
PLA FUS	J	7	1	4	6	C, A
Noncommercial Species						
AMB MAR	SA	1	7	64	3,872	F
PSE OLO	J-A	2	5	102	1,263	F
MUG PAL	J-A	3	6	117	961	F
GOB SEM	J-A	4	6	53	1,714	F
AMB JAC	SA	5	7	55	658	F
RED MAC	J-A	6	6	78	375	F
FAV TAM	J-A	7	5	43	89	F
MAR PLE	A, SA	8	4	20	55	F
Euryhaline						
Commercial Species						
MUG CEP	J	1	15	80	733	C
Fresh water						
Commercial Species						
ANG REI	J	1	16	86	189	C
ANG AUS	J	2	13	56	122	C
POT RIC	J	3	2	2	8	A

TABLE 7. Continued.

Category and Name Code	Main Life-History Stage[a]	Dominance Rank[b]	No. Occ. Sites	Frequency in Samples	Total Number	Economic Status[c]
Noncommerical Species						
GOB AUS	J-A	1	18	268	9,860	F
HYP COM	J-A	2	17	199	6,391	F
GAM HOL	J-A	3	18	160	3,700	I
HYP GAL	J-A	4	12	94	1,130	F
PHI GRA	J-A	5	14	115	723	F
PSE SIG	J-A	6	8	73	1,205	F
AMB AGA	SA	7	12	68	323	F
PHI SPE	J-A	8	11	50	199	F

[a] J = juvenile, SA = subadult, A = adult, J-A = juvenile to adult.

[b] Dominance rank based on mulitple of following three columns.

[c] C = commercial, A = angling, F = forage, V = venomous, P = poisonous, I = introduced.

mullet) was not dominant at any of the sites, tending to occur more in the downstream sites (both gated and ungated). The proportionately higher biomasses (Fig. 22c) when compared with the abundances (Fig. 22b) of commercial species in the rotenone station samples are due to the few larger specimens of these species captured, the weights of which were often one or more orders of magnitude greater than those of the majority of the catch, which comprised small juveniles.

With regard to the breakdown by species of these different salinity status categories (Table 7), in the gill net samples the saltwater commercial category comprised primarily flat tail mullet (*Liza argentea*), dusky flathead (*Platycephalus fuscus*), silver biddy (*Gerres subfasciatus*), yellowfin bream (*Acanthopagrus australis*) and tailor (*Pomatomus saltatrix*), with occasional schools of southern herring (*Herklotsichthys castelnaui*) and fantail mullet (*Mugil georgii*). The saltwater noncommercial category comprised almost exclusively the marine glass perchlet (*Ambassis marianus*). The euryhaline commercial category, as mentioned earlier, comprised exclusively the bully mullet (*Mugil cephalus*).

The freshwater commercial category comprised primarily freshwater herring (*Potamalosa richmondia*), fork-tailed catfish (*Arius graeffei*), freshwater mullet (*Myxus petardi*) and Australian bass (*Macquaria novemaculeata*), with occasional estuary perch (*Macquaria colonorum*) and eel-tailed catfish (*Tandanus tandanus*). The freshwater noncommercial category comprised almost exclusively the bullrout (*Notesthes robusta*), with occasional large gudgeons (*Gobiomorphus australis* and *Hypseleotris compressa*) also being present.

In the rotenone station samples (Table 7), the saltwater commercial category again comprised mainly yellowfin bream, flat tail mullet, and silver biddy, together with luderick (*Girella tricuspidata*), black sole (*Synaptura nigra*), silver batfish (*Monodactylus argenteus*) and dusky flathead (all primarily juveniles). The saltwater noncommercial category comprised mainly two species of glass perchlets (Ambassidae), five small species of gobies (Gobiidae), and a toadfish (*Marilyna pleurosticta*). The euryhaline commercial category again comprised exclusively (mainly juvenile) bully mullet.

The freshwater commercial category comprised almost exclusively two species of eels (Anguillidae, mainly small elvers) and juvenile freshwater herring; and the freshwater noncommercial category was mainly a variety (five species) of gudgeons (Eleotridae), the introduced mosquitofish (*Gambusia holbrooki*), the blue-eye (*Pseudomugil signifer*), and the olive glass perchlet (*Ambassis agassizi*).

Ordination of Sites by Species Rank Abundances

The rank abundances of the species at each site in the gill net and rotenone station samples over the two core years of the study period are presented in Tables 8 and 9. These rank abundances were inverted (by subtracting each rank value from that of the lowest rank for that site and adding 1), and the resulting data analyzed using a multivariate pattern analysis ordination (detrended correspondence analysis, DCA).

The ordination of sites in the gill net samples (i.e., the predominantly larger fish species and individuals) is shown in Fig. 23. The order of sites along the horizontal axis (axis I) of this ordination generally appeared to reflect the sites' mean bottom salinity and distance from the sea (salinity and distance were highly negatively correlated—Spearman's rank correlation $r_s = -0.909$, $p < 0.0001$; see also Fig. 10b); therefore, rank correlations between site order and each of these two variables were calculated. These analyses showed site order to be significantly correlated with salinity ($r_s = 0.682$, $p < 0.01$) and distance ($r_s = -0.617$; $p < 0.01$).

With regard to the vertical axis (axis II), the lower site grouping shown in Fig. 23a comprises all of the ungated sites (unpaired sites on natural creeks plus paired sites on drains below gates), and the upper site grouping comprises all of the gated sites (unpaired sites on drains gated at their mouths plus paired sites on drains above gates; site CA is not included as no fish were caught in the gill nets throughout the sampling period). Axis II of this ordination thus shows the generally strong effect of the floodgates on the composition of the fish assemblages above and below them.

When only the ungated sites (lower group) are

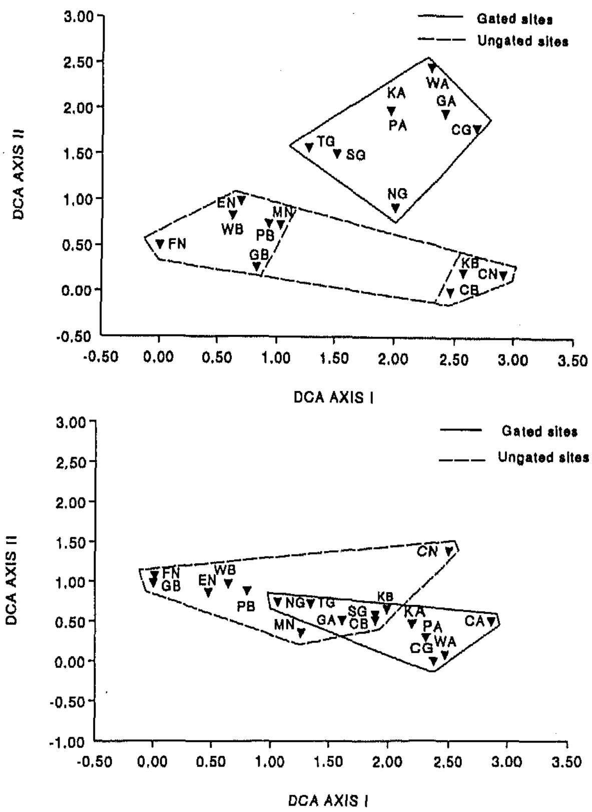

Fig. 23. Ordination (Detrended Correspondence Analysis) of sites based on rank abundances of fish species present in (top) the gill net samples and (bottom) the rotenone station samples, over the two core years of the study period.

considered, the effects (from left to right) of decreasing salinity (Spearman's rank correlation $r_s = 0.817$, $p < 0.01$) and increasing distance from the sea ($r_s = -0.900$, $p < 0.001$) on the fish assemblages at each site are apparent (axis I); in this case, distance has the stronger influence. No such significant effect of salinity ($r_s = 0.360$, N.S.) or distance upstream ($r_s = -0.450$, N.S.) is present for the gated sites (upper group). Thus axis I represents a transition of the fish assemblages present at the ungated sites from a primarily saltwater, downstream community to a primarily freshwater, upstream one.

In summary, axis II shows the effects of the floodgates in creating a community above them that is basically different from that of both the downstream and upstream ungated sites. This is not surprising when it is considered that the extremely euryhaline bully mullet (*Mugil cephalus*) comprised by far the greatest proportions of the gill net catches at all of the gated sites (Table 8, Figs. 21a–c). As might be expected, the two distinct groupings (to the far left and far right of axis I) amongst the ungated sites comprise assem-

TABLE 8. Relative abundances of fish species (numbers and ranks) in the gill net samples (two replicates per site) at the 18 sampling sites over the two core years of the study period. Name codes are given in Table 4.

	Ungated Sites																	
	FN		EN		MN		CN		GB		PB		WB		KB		CB	
Name Code	No.	Rk[a]	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.
MUG CEP			29	1	8	2	7	2			33	2	44	1	41	2	9	3
LIZ ARG	104	1	7	2	38	1			21	1	39	1	28	2				
POT RIC					1	7	16	1	2	4					46	1	32	2
AMB MAR	5	2	2	6					13	2	29	3	6	5			5	4
ARI GRA							6	3									53	1
PLA FUS	3	3	4	3	7	3					7	4	8	3	1	5	2	5
POM SAL	2	6	1	8	1	7			3	3	4	5	3	6	1	5		
GER SUB	2	6	7	2	2	5			2	4			1	7				
ACA AUS	3	3	1	8	3	4			1	6	2	6	1	7				
HER CAS	3	3											8	3				
MAC NOV					1	7	1	5							7	3	1	6
MYX PET							5	4							4	4		
HYP COM							1	5										
MYX ELO			3	5														
NOT ROB					2	5	1	5										
MEG CYP																		
MAR PLE	2	6																
AMB AGA			2	6														
ELO MAC											1	7						
MEU TRA																		
MUG GEO	1	9																
GOB AUS																		
ANG REI																		
GIR TRI			1	8														
Total no. species	9		10		9		7		6		7		8		6		6	
Total no. individuals	125		57		63		37		42		115		99		100		102	
No. commercial species	7		8		8		5		5		6		7		6		5	
No. commercial individuals	118		53		61		35		29		86		93		100		97	

[a] No. = number. Rk = rank.

blages dominated by predominantly saltwater and predominantly freshwater fish species, respectively (Figs. 21a–c).

A similar ordination resulting from analysis of the rotenone station samples (i.e., the predominantly smaller fish species and individuals) is shown in Fig. 23b. There was no clear separation on the vertical axis (II) of the gated and ungated sites, although the former were generally displaced toward the right (i.e., less saline, upstream) side of the ordination (axis I). The patterns for each of the ungated *and* gated sites showed strong effects of decreasing salinity (r_s = 0.867, $p < 0.01$, and r_s = 0.800, $p < 0.01$, respectively), and particularly of increasing distance from the sea (r_s = −0.950, $p < 0.0001$, and r_s = −0.867, $p < 0.01$, respectively), from the left to the right of axis I. Grouped together, the 18 sites showed an intermediate but more significant correlation with salinity (r_s = 0.824, $p < 0.0001$), and a lesser but intermediately significant correlation with distance from the sea (r_s = −0.748, $p < 0.001$). Overall, there were thus less distinct differences between the downstream high-salinity and upstream low-salinity assemblages amongst these smaller fishes from the rotenone station samples compared with the larger fishes from the gill net samples.

Summary Conclusions and Discussion

The overall physical quality of fish habitat, particularly in terms of fringing bank vegetation, generally decreased with the increasing intensity of surrounding land use that accompanied structural flood mitigation works (i.e., channelization and floodgating) in tributaries of the lower Clarence River system.

Mean seasonal rainfall over the Clarence River Catchment was usually highest during the aquatic summer period (i.e., the three peak water temperature months centered around February) and lowest in the winter period (centered around August). During the middle two core years of the study period, overall annual catchment rainfalls were ~12% higher than normal (much higher than normal in the autumns of both years and slightly lower in the winters). Heavier than normal rainfalls resulted in major floods in the lower

TABLE 8. Extended.

Gated Sites																			
NG		TG		SG		CG		GA		PA		WA		KA		CA		Total Sites	
No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.
74	1	67	1	74	1	11	1	8	1	19	1	15	1	15	1			454	1
4	2			25	2													266	2
						1	2											98	3
																		60	4
																		59	5
																		32	6
																		15	7
																		14	8
		1	2															12	9
																		11	10
																		10	11
1	4																	10	11
1	4							2	2									4	13
																		3	14
																		3	14
3	3																	3	14
																		2	17
																		2	17
																		1	19
1	4																	1	19
																		1	19
						1	2											1	19
												1	2					1	19
																		1	19
6		2		2		3		2		1		2		1		0		24	
84		68		99		13		10		19		16		15		0		1,064	
5		2		2		2		1		1		2		1		0		18	
83		68		99		12		8		19		16		15		0		992	

Clarence River system in and around the autumns of both 1989 and 1990.

Mean bottom salinities at the study sites showed spring peaks and autumn troughs, and were inversely related to the seasonal pattern of catchment rainfall, with a lag of approximately 1 mo. Salinity generally decreased in a negative exponential relationship with the distance of the study sites from the sea. Salinities usually differed only slightly between gated and ungated sites (including paired sites below and above floodgates) at similar distances from the sea, except during the winters and springs of some years, when salinities above some of the gates were lower.

Water temperatures throughout the system were generally highest around February and lowest around August, and were, on average, only slightly higher and more variable in some of the gated versus the ungated sites.

Overall, 60 fish species were sampled during the two year core period of the study (51 in the first year and 50 in the second), of which 38 were classified as primarily saltwater, 21 as primarily freshwater, and only one as euryhaline. Of these 60 species, 30 were classified as being of some economic value (i.e., commercial species), of which 21 were primarily saltwater, eight primarily freshwater, and one a euryhaline species. With respect to the paired below and above gate sites, overall total species numbers present over the two year core period of the study were in all cases higher below the gates than above them.

Overall total numbers of commercial species present over this period were in all cases higher in all of the ungated versus the gated sites. Both mean total and mean commercial fish species numbers in the gill net samples were significantly higher both in ungated natural creeks versus drains gated at their mouths, and in drains below gates versus drains above gates. Mean commercial fish species numbers in the rotenone station samples were significantly higher in the total ungated versus the total gated sites. Both total and commercial species numbers present at the various sites generally declined with both decreasing salinity and increasing distance from the sea.

In terms of species numbers, abundances, and biomasses, saltwater (commercial and noncommercial) fishes generally dominated the gill net samples from the ungated sites closest to (i.e.,

TABLE 9. Relative abundances of fish species (numbers and ranks) in the rotenone station samples (two replicates per site) at the 18 sampling sites over the *two core years of the study period*.

	Ungated Sites																	
	FN		EN		MN		CN		GB		PB		WB		KB		CB	
Name Code	No.	Rk[a]	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.
GOB AUS	45	6	130	2	735	1	15	3	16	7	173	1	249	1	216	1	107	2
GAM HOL	3	12	3	12	1	10	50	1	2	15	21	6	7	10	21	4	197	1
HYP COM	1	14	26	6	67	3	9	4	1	18	4	15	1	14	26	3	8	7
PSE SIG	164	1	210	1	110	2			4	13	14	9	53	2	7	6	2	9
HYP GAL					1	10	22	2					1	14	40	2	2	9
MUG PAL	91	4	33	5	24	4			31	6	11	11	17	6				
PSE OLO	22	8	49	4					124	2	23	5	38	4				
AMB MAR	3	12	68	3	1	10			82	3	100	2	13	8	1	11	3	8
MUG CEP	113	3	6	10	1	10	4	5	60	5	6	13	41	3	2	9	9	5
PHI GRA			3	12	7	6	3	6	2	15	76	3	32	5	16	5	9	5
AMB JAC	42	7	23	7	4	8			135	1			7	10	1	11		
LIZ ARG	122	2	14	9	2	9	1	10	8	11	7	12	1	14				
PHI SPE					11	5					1	19	1	14			1	12
GOB SEM	4	10	3	12	1	10			79	4	16	8	17	6				
RED MAC			6	10					9	10	37	4	6	12				
AMB AGA							2	7			4	15			3	8	2	9
ACA AUS	46	5	18	8					10	9	20	7	8	9				
ANG REI					5	7	1	10			2	17	5	13	2	9	29	3
ANG AUS					1	10					12	10	1	14	4	7	13	4
FAV TAM	4	10							7	12	5	14	1	14				
MAR PLE	13	9	1	16					1	18								
FAV EXQ	1	14							11	8								
POT RIC															1	11		
CEN AUS																		
SYN NIG									3	14			1	14				
MON ARG	1	14	2	15							1	19						
ARE BIF									2	15								
ARE FRE																		
NOT ROB							1	10									1	12
PLA FUS											2	17						
MEL SPL							2	7										
HER CAS							2	7										
MYX ELO											1	19						
BUT BUT																		
BAT KRE																		
CRY CRI									1	18								
EUR LEP	1	14																
CAR AUR																		
GIR TRI	1	14																
Total no. species	18		16		15		12		20		21		20		13		13	
Total no. individuals	677		595		971		112		588		536		500		340		383	
No. commercial species	5		4		4		4		4		8		6		4		3	
No. commercial individuals	283		40		9		8		81		51		57		9		51	

[a] No. = number. Rk = rank.

<20 km upstream from) the sea, freshwater commercial species the ungated sites furthest from (i.e., >30 km upstream from) the sea, and the single euryhaline commercial species, the bully mullet (*Mugil cephalus*), the gated sites in both the downstream and upstream areas.

Saltwater (smaller noncommercial and juvenile commercial) fishes generally dominated the rotenone station samples from the ungated downstream sites, and freshwater (smaller noncommercial) species the remainder of the sites (including the ungated upstream and particularly all of the gated sites), in terms of species numbers, abundances, and biomasses. Juveniles of the euryhaline bully mullet were a much less significant component of the fish fauna in the rotenone station samples at most sites compared with the adults in the gill net catches.

The dominant species comprising the primarily saltwater commercial fish component included adult and juvenile flat-tail mullet, dusky flathead, and yellowfin bream; and juvenile silver biddy, tai-

TABLE 9. Extended.

Gated Sites																		Total Sites	
NG		TG		SG		CG		GA		PA		WA		KA		CA			
No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.	No.	Rk.
127	1	54	3	124	2	50	2	156	2	248	1	40	4	332	1			2,817	1
76	2	105	1	342	1	19	4	240	1	229	2	585	1	177	2	86	1	2,164	2
45	5	14	7	41	3	131	1	126	3	116	3	91	3	165	3			872	3
		4	12					34	5									602	4
3	12					25	3	21	6	4	6	283	2	54	4	75	2	531	5
64	3	3	13					98	4									372	6
56	4	26	6	2	11			1	10									341	7
4	10	11	8	4	8			1	10					3	6			294	8
2	14			6	7			2	8	3	8							255	9
4	10	75	2	9	6	2	6	2	8					1	8			241	10
		1	15															213	11
																		155	12
2	14	50	4	29	4	5	5	3	7	10	5	22	5	3	6	1	5	139	13
8	8	7	9															135	14
28	6	28	5	3	10			1	10									118	15
		7	9	13	5					59	4	2	8	8	5	2	3	102	16
																		102	16
3	12			4	8	2	6	1	10	4	6	8	6			2	3	68	18
		1	15			1	8			1	9	8	6					42	19
13	7	2	14															32	20
1	16																	16	21
																		12	22
		6	11															7	23
7	9																	7	23
1	16																	5	25
																		4	26
1	16	1	15															4	26
1	16	1	15															2	28
																		2	28
																		2	28
																		2	28
																		2	28
																		1	33
1	16																	1	33
		1	15															1	33
																		1	33
																		1	33
						1	8											1	33
																		1	33
20		19		11		9		13		9		8		8		5		39	
477		397		577		236		686		674		1,039		743		166		9,667	
3		2		2		3		2		3		2		0		1		13	
6		7		10		4		3		8		16		0		2		645	

lor, and luderick. The primarily freshwater commercial fish component was dominated by adult and juvenile freshwater herring; adult fork-tailed catfish, freshwater mullet, and Australian bass; and juvenile long- and short-finned eels. The euryhaline commercial fish component comprised exclusively the bully mullet.

The saltwater noncommercial fish component comprised mainly several species of gobies, glass perchlets, and a toadfish; and the freshwater noncommercial fish component mainly several species of gudgeons, the introduced mosquitofish, the blue-eye, the olive glass perchlet, and the bullrout.

Ordination of the sampling sites by species rank abundances in the gill net samples (larger fishes) showed a strong effect of "gatedness" on the compositions of the fish assemblages. There was also a strong effect of salinity and distance upstream for the assemblages in the ungated, but not the gated sites, the latter being in all cases dominated by the euryhaline bully mullet (*Mugil cephalus*). Ordination of the sampling sites by species rank abundances in the rotenone station samples (smaller fishes) showed no significant effect of gatedness on the compositions of the fish assemblages, but there was again a strong but gradual effect of salinity and distance upstream on not only the assemblages in the ungated sites but also in the gated sites.

Amongst the probable adverse effects of structural flood mitigation works on aquatic flora and fauna suggested by the SPCC (1978) was the loss of mangroves. Indeed, there has been a virtually complete, and seemingly permanent, loss of mangroves above the floodgates due to greatly reduced tidal penetration into these habitats. However, the SPCC's (1978) proposition that this "destruction of estuarine vegetation, such as mangrove swamps" is primarily caused by the "conversion of the portion of the estuary above the floodgates from salt to freshwater" is not supported by the present results. As pointed out above, most of the floodgates in the lower reaches of the Clarence River system were surprisingly ineffective in preventing the ingress of salt water into the drains above them over the longer term. However, the more general statement that the construction of such structural flood mitigation works "reduces the habitat of estuarine fauna unless adequate tidal interchange can be provided" (SPCC 1978) is supported. Increasing tidal interchange would not only allow increased ingress of saline estuarine water but also ingress of the propagules (e.g., mangrove seeds and seedlings, the larvae of estuarine invertebrates, and the juveniles of estuarine fishes) of a wide variety of estuarine flora and fauna (see also Furner 1988).

E. Scribner (New South Wales Fisheries Research Institute, personal communication), who studied water quality in the lower Clarence River system, noted that no floodgate that he observed was ever a perfect seal; all leaked at least slightly on the rising tide, allowing some river water into the floodplain channel above it.

Although the majority of the floodgates had little effect over most of the study period in keeping saline water out of the drains above them, they were very effective in preventing the establishment of fringing mangrove vegetation in the drains above them and also in preventing access past them of both primarily estuarine-marine fish species and some migratory freshwater species such as the Australian bass, *Macquaria novemaculeata*. The fish fauna above them was often dominated by one small freshwater species of no economic value (the introduced mosquitofish, *Gambusia holbrooki*) and also by the adults of the euryhaline bully mullet, *Mugil cephalus*.

There is very little published literature on the ecological effects, and particularly the effects on fishes, of estuarine flood mitigation works in general. Literature is available, however, on the effects of similar channelization works on fishes in freshwater stream environments; this literature has been reviewed by Swales (1982b). In North America in particular, Swales found that stream channelization works generally resulted in lower fish biomasses, abundances, and species numbers in the channelized habitats versus those in natural streams (Swales 1982b, Table 1). The results of the present study agree with these general findings, although in the Clarence River the effects of channelization on fish habitats are compounded by the effects of the floodgates on fish passage.

Very few studies have been carried out on the fish faunas of flood mitigation drains anywhere in Australia. One such study was conducted by Graham (1989), who sampled the channelized but ungated Newrybar flood mitigation drain using gill nets. (The Newrybar drain enters the upper reaches of North Creek, a tributary of the Richmond River system, about 70 km north-northeast of the Clarence River mouth.) Five sites on this drain were sampled at distances ranging from 10 km (salinity ~14‰) to 18 km (salinity <1‰) upstream from the confluence of North Creek with the lower Richmond River. The bully mullet (*M. cephalus*) was found to be by far the most numerically dominant species at all of these sites. Other species caught included Australian bass (*M. novemaculeata*), bullrout (*N. robusta*), dusky flathead (*P. fuscus*), estuary perch (*M. colonorum*), and mulloway (*Argyrosomus hololepidotus*, family Sciaenidae), in that order. Smaller fishes captured in this drain using small seine and dip nets included mainly the marine glass perchlet (*A. marianus*), mosquitofish (*G. holbrooki*), and striped gudgeon (*G. australis*). Decapod crustaceans captured in the seine and dip net samples included the mud crab (*S. serrata*) and both the school prawn (*M. macleayi*) and the greasyback prawn (*M. bennettae*).

McGregor (1979) sampled the fish fauna above and below flood mitigation gates in Ironbark Creek, a small tributary of the Hunter River system, which is located around 400 km to the south-southwest of the Clarence River mouth, using gill nets and seines. The floodgates at this site are usually left partially open, but McGregor sampled above and below them during periods when they were both partially open and fully closed. He found that, even with the gates partially open, several predominantly estuarine-marine species (*P. fuscus*, *A. hololepidotus*, *R. sarba* and *G. tricuspidata*) commonly found below the gates were not found above them. Even with some tidal exchange (~15%), there was a marked reduction in both fish species numbers and abundances above compared with below the gates. The results from the seine net samples showed only a marginal improvement in the movement of juvenile fishes from below to immediately above the gates when these were partially opened. In general, *M. cephalus* dominated the gill net catches above the gates (occurring together with a few *L. argentea, Acanthopagrus australis, G. subfasciatus,* and *P. saltatrix*). The latter species, followed by *M. cephalus, P. fuscus, A. hololepidotus,* and *L. argentea,* were dominant in the gill net catches from below the gates.

In an ongoing study of the effects of these Ironbark Creek floodgates on the fish community above them (M. Shepherd, Macquarie University, North Ryde, New South Wales, personal communication), this assemblage was compared with that in a nearby ungated mangrove-fringed natural tributary of this system (Mosqueto Creek) by means of gill net, seine net, and rotenone sampling. Shepherd found that, amongst the commercial species present, the natural creek was dominated by *L. argentea, Acanthopagrus australis, M. cephalus, G. subfasciatus,* and *P. fuscus,* while the gated creek was dominated by *M. cephalus, Acanthopagrus australis, G. subfasciatus, Anguilla reinhardtii,* and *Anguilla australis,* in that order. The smaller noncommercial species in the samples from the ungated creek habitat were dominated by a number of species of primarily estuarine-marine gobies (Gobiidae), together with the blue-eye (*P. signifer*), two species of glass perchlets (*Ambassis* spp.), and a gudgeon (Eleotridae). The noncommercial species assemblage in the gated creek was dominated by several species of primarily freshwater-brackishwater gudgeons, the mosquitofish (*G. holbrooki*), two gobies, and a glass perchlet.

The species compositions of the fish assemblages in these gated and ungated habitats in both of the above studies showed close similarities with those found during the present study in the Clarence River area.

Also with regard to the north coast of New South Wales, Middleton et al. (1985) noted that the local production of oysters, finfish, and prawns had all shown declines between the mid 1950s and the late 1970s, corresponding with the period of construction and completion of many flood mitigation structures in the Macleay River area (located ~200 km to the south-southwest of the Clarence River mouth). A study to determine the effects on the fish community of the removal of a major set of floodgates at Yarrahappini Broadwater on this river system (see Smith 1986) is presently underway (M. Shepherd, personal communication).

In the Belmore River, another tributary of the Macleay system, Richardson (1981) studied the effects of floodgates on water quality and the fish community. The release of poor-quality, deoxygenated water from above these gates, compounded by low pH conditions after flooding, resulted in a massive fish kill in this river system in March 1978. Eighteen out of the 22 species involved (including 14 commercial species) were prominent amongst the catches taken from the Clarence River tributaries during the present study. In the light of her overall findings, Richardson (1981) recommended that "the controlling authorities should only approve these structures for the strict purpose of mitigating floods, and (thus) attempt to minimise disturbance to the ecological balance of the estuaries and wetlands."

In response to the many environmental problems experienced with structural flood mitigation works over the years, New South Wales Fisheries has developed a set of estuarine habitat management guidelines in relation to such activities. The current guidelines are outlined in Pollard et al. (1991). The most pertinent of these recommendations in the context of this study are that channelization of natural creeks and streams should be avoided, and that existing floodgates should be kept open at all times other than during floods so as to allow for normal outflow of runoff and the natural ebb and flow of tides.

In conclusion, suggested management of fish habitats above the floodgates in tributaries of the lower Clarence River system, aimed at improving both the overall quality of these habitats and thus the fish communities utilizing them, should leave the gates fully open at all times except immediately prior to and during floods in the main river system, as suggested by Pollard et al. (1991). This tactic will allow fringing mangrove vegetation to re-establish along the banks of the artificial drains in the lower reaches of this river system, generally improve flushing and thus water quality in these drains, and allow the establishment of primarily estuarine-marine fish communities, including species of economic importance, and also migratory freshwater species such as the Australian bass. The rehabilitation of these artificial flood mitigation drain environments as suitable nursery habitats for juveniles and feeding habitats for adults and subadults of such economically useful fishes should have overall beneficial effects on the recreational and commercial fisheries of the lower Clarence River system.

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