Freshwater fish communities of the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments: a 2004 status report

Timothy Howell
Bob Creese

Industry & Investment NSW
Port Stephens Fisheries Institute
Private Bag 1, Nelson Bay NSW, 2315
Australia

Hunter - Central Rivers CMA
Project No. CRH0012
August 2010

Industry & Investment NSW
Fisheries Final Report Series
No. 126
ISSN 1837-2112

Freshwater fish communities of the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments: a 2004 status report

August 2010

Authors: Timothy D. Howell and Robert G. Creese

Published By: Industry & Investment NSW (now incorporating NSW Fisheries)

Postal Address: Cronulla Fisheries Research Centre of Excellence, PO Box 21, Cronulla, NSW

Internet: www.industry.nsw.gov.au

Cover photos: Timothy Howell. Main photo: Williams River near Salisbury. Fish photos (clockwise): eel-tailed catfish, empire gudgeon, Australian bass, Cox's gudgeon, common galaxias, long-finned eel, gambusia, goldfish, common carp, bullrout.

ISSN 1837-2112

Note: Prior to July 2004, this report series was published by NSW Fisheries as the 'NSW Fisheries Final Report Series' with ISSN number 1440-3544. Then, following the formation of the NSW Department of Primary Industries the report series was published as the 'NSW Department of Primary Industries – Fisheries Final Report Series' with ISSN number 1449-9967. The report series is now published by Industry & Investment NSW as the 'Industry & Investment NSW – Fisheries Final Report Series' with ISSN number 1837-2112.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

The following staff from I&I NSW are thanked for their contribution: Dean Gilligan for site selection following the SRA site selection process, Simon Hartley for the definition of the stream network, Antonia Creese for access to relevant data sets and producing all maps, and Tim Glasby for assistance with data analyses. Andrew Bruce, Tony Fowler, Natalie Reed, Simon Hartley and Amanda Hyde ground-truthed the stream networks and undertook much of the fieldwork and sampling for this project.

The ichthyology department of the Australian Museum provided data on holdings of threatened fish species from NSW. Peter Unmack and Tarmo Raadik provided valuable information on rare and threatened species. Tran Quynh Hoa provided useful comments on drafts of the manuscript and assisted with editing.

Funding for this Integrated Fish Monitoring project was provided by the Hunter-Central Rivers CMA and the then NSW Department of Primary Industries. Sharon Vernon from the CMA is thanked for her work in facilitating this project and for commenting on the draft report.

Abbreviations

CMA	Catchment Management Authority
IUCN	International Union for the Conservation of Nature
MDBC	Murray-Darling Basin Commission (now Murray Darling Basin Authority)
MER	Monitoring, Evaluation & Reporting (NSW government program)
NSW	New South Wales
SRA	Sustainable Rivers Audit
UHRRI	Upper Hunter River Rehabilitation Initiative
WRRP	Williams River Rehabilitation Project

NON-TECHNICAL SUMMARY

Freshwater fish communities of the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments: Status and trends

PRINCIPAL INVESTIGATORS: Timothy Howell
Bob Creese

ADDRESS: Industry & Investment NSW
Port Stephens Fisheries Institute
Taylors Beach Road, Taylors Beach
Locked Bag 1 Nelson Bay 2315
Telephone: 02 4916 3806 Fax: 02 4982 2265

OBJECTIVES:

Undertake literature reviews and fish surveys;

(1) Benchmark the current status of fish species and fish communities.
(2) Review the current status of individual fish species.
(3) Identify current threats to fish communities.
(4) Identify future research needs in terms of fish populations and their habitats.

NON TECHNICAL SUMMARY:

Fish are an integral component of aquatic ecosystems. The structure of fish assemblages provides an indication of the overall health of river systems. Further, as fish have a high public profile, they foster substantial public interest. Broad-scale fish monitoring programs offer a valuable tool for catchment management, assisting prioritisation of available management options, enabling assessment of the effectiveness of initiatives such as river rehabilitation and demonstration of these outcomes to the community.

Fish communities were sampled using a standardised electro-fishing protocol augmented with sampling with box-trap shrimp nets. Twenty-seven monitoring sites were randomly selected to benchmark the current (2004) fish community across the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments. The randomised sampling design ensures that the results can be extrapolated across all reaches in these catchments. The status of fish communities at sites and within zones was benchmarked using basic ecological parameters: species richness, total abundance, biomass, species diversity and evenness, the proportion of alien taxa and estimates of distribution.

The fish assemblages encountered in 2004 were compared to information obtained from previous surveys. This report presents the results of the most comprehensive assessment of fish species and communities ever undertaken across the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments. As such, it provides a valuable reference point for proposed monitoring of the health of riverine ecosystems under the NSW government's Monitoring, Evaluation & Reporting (MER) program.

Status of fish communities

The fish communities of all four catchments in the Hunter and Central Rivers (as they existed in 2004) are relatively healthy using the parameters tested.

Twenty-three fish species were sampled from the 27 riverine monitoring sites (11 from each of the Hunter and Manning, 3 from the Karuah and 2 from Macquarie-Tuggerah catchments). Despite this sampling effort, 76% of the freshwater fish fauna previously recorded in the Hunter catchment, 80% in the Manning, 94% in the Karuah and only 53% in the Macquarie-Tuggerah catchment were recorded in the present survey. The present survey was based on a random sampling design and therefore could not target rare species previously recorded in the catchment, and further investigation of rare species is warranted.

Fish community structure varied substantially across all four catchments, with a decrease in species richness with increasing altitude. Assessment of fish communities identified some significant differences among altitude zones. The coastal (< 50 m), lowland (50 – 200 m), slopes (200 – 400 m) and upland zones (400 – 700 m) were dominated by native fish species, while the highland zone (> 700 m) was dominated by alien fish species. The fish community in the coastal zone was characterised by a greater abundance of sea mullet and striped gudgeon than the other four zones. The significant difference between the lowland and the upland zones was predominantly driven by the higher abundance of Australian smelt and long-finned eels in the lowland zone and the absence of sea mullet in the upland zone. The highland zone differed from the lowland zone in the absence of Australian smelt and the reduced abundance of long-finned eels, and the dominance of gambusia.

With the exception of the absence of native species sampled in the highland site, the proportional abundance of native fish species in the Hunter catchment across all other altitude zones was relatively high. In the slopes and upland zones the influence of the large species common carp increased the proportion of the fish biomass which was not native. All fish species sampled in the slopes and upland zones of the Manning catchment were native. With the exception of the highland site, the proportion of native fish species across all other altitude zones was relatively high. Native species dominated the abundance in all zones except the highland, where large numbers of gambusia dominated. Gambusia, sampled at one site for each catchment, was the only alien fish species recorded in the Karuah and Macquarie-Tuggerah catchments in the present survey. Due to the relatively small size of gambusia and the few caught in comparison to the native species, gambusia contributed little to the overall total abundance or total biomass.

Current status of individual fish species

The most abundant species in the Hunter catchment in the present survey were; Australian smelt, long-finned eels, sea mullet and gambusia. Biomass was dominated by sea mullet, common carp and long-finned eels, with long-finned eels being the most widespread species. The rarest taxa were goldfish, striped gudgeon, bullrout and rainbow trout all contributing 0.1% of the total catch. The least widespread species were striped gudgeon, freshwater mullet, bullrout, rainbow trout and brown trout, each being found at only one site.

Australian smelt and long-finned eels were the two most numerous species in the Manning catchment, with long-finned eels and sea mullet dominating the total biomass. The three rarest taxa were bullrout, freshwater mullet and dwarf flat head gudgeon together contributing less than 1% of the total abundance of fish in the catchment. Long-finned eels, Cox's gudgeon and Australian smelt were the most widespread fish species in the Manning catchment.

The three most abundant fish species in the Karuah catchment were sea mullet, long-finned eels and Australian smelt. Sea mullet dominated the biomass, with significant contributions from long-finned eels, Australian bass and freshwater mullet. Australian bass, long-finned eels and freshwater mullet were found at all three sites sampled in the Karuah catchment. The two rarest taxa were bullrout and eel-tailed catfish which together accounted for less than 0.5% of all fish sampled.

Fish abundance in sites sampled in the Macquarie-Tuggerah catchment was dominated by striped gudgeon, empire gudgeon and long finned eels, with long-finned eels largely dominating the biomass. Only Australian smelt, long-finned eels and striped gudgeon were sampled at both sites in the Macquarie-Tuggerah catchment. Only one specimen of common jollytail and dwarf flat head gudgeon were recorded and, as such, were the rarest taxa.

The only species likely to be encountered in the Hunter and Central Rivers CMA area listed under the IUCN as vulnerable is the Australian Grayling. One specimen was previously identified from the Macquarie-Tuggerah catchment, representing the northerly known range of the species. Targeted sampling of Australian Grayling would be required to establish the extent of this population and determine if recovery action is required.

Another fish of great potential significance in the Hunter and Central Rivers CMA area is the Darling River hardyhead. Sampling during the late 1970's and early 1980's recorded specimens at several sites throughout the Hunter catchment. Whilst relatively common in the Darling River, the Hunter River population represents the only known coastal population. Whilst tentatively identified as this species, it is possible that this population is a separate species or sub-species. No specimens were found during the 2004 surveys and targeted sampling at sites where they have previously been recorded would help resolve the status of this taxon.

Two species of galaxids thought to be previously widespread in the highland zone of the Hunter catchment (*Galaxias olidus* and *Galaxias brevipinnus*) were not recorded in the present survey and their status is of concern. The existence of trout in the system may prevent recovery of remnant or reintroduced populations, as predation and competition by trout is believed to be substantial. Therefore, establishment of trout free waters in highland areas may be a necessity for recovery of these two species of galaxids in the Hunter catchment. Although only one specimen of common jollytail was recorded it is likely that significant populations exist in smaller coastal streams not sampled in this survey. Targeted assessment of these areas is required to assess these populations and ascertain their status in the Hunter and Central Rivers catchments.

Whilst reportedly common throughout the Murray-Darling Basin and in coastal streams north of the Hunter River, Western Carp Gudgeon have not been reported in the Manning, Karuah and Macquarie-Tuggerah catchments and have only been recorded in two sites on the Hunter River (in 1971); none were caught in the 2004 surveys. Further research needs to be conducted to ascertain the extent and status of this species in the Hunter and Central Rivers catchments.

Populations of short-finned eels have undergone a reduction in distribution and abundance in NSW. The present survey found only three specimens and targeted sampling is required to determine the extent and status of the species.

Comparison with other surveys

Ongoing sampling using a consistent standardised methodology targeting all members of the fish assemblage, is the most robust means of assessing changes in fish community structure and the status of individual species through time. Although the present study identified a higher diversity of fish species than previous surveys, it must be noted that intensity of sampling was greater, with the notable exception being the survey done in the Hunter in 1980. Previous sampling has been insufficient or unstandardised to enable rigorous assessment of changes prior to the present survey, and species richness level only can be compared. The present survey provides an excellent benchmark for future, more thorough comparisons [1].

Fish stocking

Fish stocking includes both the translocation of fish species from one area to another as well as the hatchery production and release of captive-bred fish. It is typically undertaken with the intent of either improving recreational fishing opportunities or for the conservation of endangered populations (NSWF 2003). A compilation of waterbodies and species stocked for the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments is presented.

Based on anecdotal accounts, unrecorded fish stocking has occurred in the Hunter and Central Rivers CMA area in public waters and private waters adjacent to the rivers within these systems. The extent of this undocumented stocking may be greatest in Lake Glenbawn and Lake St. Claire which are popular angling waterbodies.

One native (Australian bass), two native translocated (golden perch and silver perch) and two alien species of fish (brown trout and rainbow trout) have been and continue to be stocked as part of government sanctioned stocking programs to promote recreational fishing.

Recommendations

The recommendations of the Murray-Darling Basin Commission Native Fish Strategy (NFS) (MDBC 2003), details the most appropriate means for restoring fish populations in the inland NSW. Presently there is not a similar strategy for coastal NSW. Of the 13 goals of the NFS the following can be undertaken by the Hunter and Central Rivers CMA:

- Rehabilitation of instream and riparian vegetation.
- Improving key aspects of water quality that affect native fish.
- Improving environmental flow management.
- Reinstating fish passage at a number of key barriers.
- Contributing to the control of alien species.
- Ensuring community ownership and support.

An ongoing monitoring program is required to assess the effectiveness of each of these actions. Additional monitoring of threatened species should supplement such a program.

It is suggested that the Hunter and Central Rivers CMA:

- Supports fish sampling in the Hunter and Central Rivers catchments on a three yearly basis as a contribution to an ongoing river health assessment [1].
- Facilitates additional targeted sampling for threatened or rare fish species sites concurrently with catchment-wide sampling.
- Continues to acknowledge the need for fish monitoring activities associated with on-ground riverine rehabilitation activities.

[1] Since this report was first drafted, the NSW government's MER program has commenced. 'Fish assemblage structure' is one of the indicators being used for the Riverine Ecosystem theme of MER. Sampling for this indicator in the Hunter Central Rivers CMA area was first done in 2007/08 and will be repeated in 2010/11. It uses the same sampling protocol and stratification as described in this report, although the number of sites sampled is slightly different.

- Supports re-instatement of riparian vegetation throughout all catchments, as a way of improving fish habitats.
- Compiles long-term data sets on ecological and physical processes of interest (i.e., water extraction, de-snagging activity, thermal pollution, sedimentation, river regulation, loss of aquatic and riparian vegetation etc.) which will enable responses and prioritisation of rehabilitation activities.

KEYWORDS:

Hunter, Manning, Karuah, Macquarie-Tuggerah, freshwater fish, threatened species

1. INTRODUCTION

The health of river systems reflects the broad scale cumulative impacts of both land and aquatic management practices (MDBC 2004*a*). Fish are an integral component of aquatic ecosystems with the structure of fish assemblages providing an indication of the overall health of river systems. There are several advantages to using fish as bioassessment tools (Harris and Gehrke 1997) including:

- Fish are relatively long lived and mobile, reflecting long-term and broad spatial scale processes.
- Fish occupy higher trophic levels within stream ecosystems and in turn express impacts on lower trophic level organisms.
- Fish are easy to collect and identify as their taxonomy is well documented.
- Fish can be sampled and released alive in the field.
- The ecology and habits of fish are relatively well known.
- Fish are typically present in most waterbodies, including very small streams and polluted waters.
- Biological integrity of fish communities can be assessed easily.

Further, as fish have a very high public profile, with significant recreational, economic and social values, they foster substantial public interest (MDBC 2004*a*). This enables effective demonstration of past degradation of ecosystems, the effects of current management practices and the effectiveness of rehabilitation efforts to the wider community. A broad-scale fish monitoring program offers a valuable tool for catchment management, assisting informed prioritisation of available management options and enabling assessment of the effectiveness of initiatives such as implementation of on-ground (or in-water) remediation.

The jurisdictional area of the Hunter Central Rivers CMA (HCRCMA) contains many rivers. The three largest systems, in decreasing order of catchment area, are the Hunter system which drains directly to the ocean, the Manning system which also drains to the ocean and the Karuah which drains into Port Stephens (Figure 1.1). These three systems were the main focus of this study. Two other large coastal features in the HCRCMA area are Lake Macquarie and the Tuggerah Lakes south of Newcastle (Figure 1.1). These lake systems are fed by numerous streams, the largest of which provide substantial habitat for freshwater fish. These waterways were combined for the purposes of this study into a fourth subdivision, the Macquarie-Tuggerah catchment.

The Hunter catchment drains an area of 21,452 km^2 (Figure 2.1). The Hunter River has its source in the Mount Royal Range at an altitude of ~ 1,500 m. Major tributaries include Rouchel Brook, Pages River, Goulburn River, Glennies Creek, Wollombi Brook, Paterson River, Allyn River and Williams River. Given the extensive altitudinal and longitudinal gradients of the catchment and the range of underlying geological features, streams of the Hunter catchment are ecologically diverse.

Of the four catchments detailed in this report the Hunter catchment has had the most extensive sampling in the past. The Healthy Rivers Commission (2002) investigation of the Hunter River estimated that about 30% of native fish species had been lost. Studies conducted over the last 30 years have identified 18 native freshwater fish species and 5 alien species in the Hunter catchment (Table 6.1).

The Manning catchment drains an area of 8,176 km^2 (Figure 2.2). The Manning River has its source in the Mount Royal Range at an altitude of ~ 1,500 m. Major tributaries of the Manning River include the Gloucester, Barrington, Nowendoc and Barnard Rivers. Given the extensive altitudinal and longitudinal gradients of the catchment and the range of underlying geological features, streams of the Manning catchment are ecologically diverse.

Past sampling in the Manning catchment has been sporadic and limited in the number of sites sampled, and consequently there is limited information available. The present benchmark survey is the most intensive data collection to date. Sixteen native fish species and 4 alien species have been recorded (Table 6.2). Of particular interest is the presence of the Bellinger catfish (*Tandanus* spp), recent DNA studies have shown this to be a subspecies of the eel-tailed catfish (*Tandanus tandanus*) (Jerry 2005).

The Karuah catchment drains an area of 4,487 km^2 (Figure 2.3). The Karuah River has its source in the Barrington Tops at an altitude of ~ 1040 m. Major tributaries of the Karuah include the Branch, Ward, Mammy Johnsons Rivers Other major rivers included in the Karuah catchment include the Myall, Crawford, Wallamba, Wang Wauk, Wallingat and Coolongolook Rivers. Given the extensive altitudinal and longitudinal gradients of the catchment and the range of underlying geological features, streams of the Karuah catchment are ecologically diverse.

Much of the previous fish sampling in the Karuah was done in lower reaches near the freshwater estuarine interface. As such many of the species previously collected are not freshwater species and will not be included in this study. Sixteen endemic species and 1 alien species have been recorded in freshwater streams in this catchment (Table 6.3).

The Macquarie-Tuggerah catchment comprises several small coastal catchments covering an area of 1,577 km^2 (Figure 2.4). The major streams are the Wyong River, Ourimbah Creek and Dora Creek.

The Macquarie-Tuggerah catchment has been little studied until recently, making the present survey extremely valuable, even with only two sites surveyed. More extensive sampling is needed to fully understand the nature of the fish communities within this catchment. Presently, 14 endemic, 1 translocated and 2 alien species have been recorded.

Freshwater ecosystems are among the most threatened ecological communities on earth (Duncan and Lockwood 2001; Gleick *et al.*, 2001). Freshwater fishes are the most threatened group of vertebrate taxa with 4.4% of species threatened with extinction across the world (Groombridge and Baillie 1997). Leidy and Moyle (1998) suggest that 20% may be a more realistic figure given the scarcity of information on lesser-known taxa. The fish community of the Hunter catchment is no exception.

A number of authors have reviewed the threats posed to freshwater fish and aquatic ecosystems (Pollard and Scott 1966; Butcher 1967; Frith 1973; Cadwallader 1978; Faragher and Harris 1994; Kearney *et al*. 1999; Lintermans 2000). Most of the threats identified are relevant to fish communities in the Hunter and Central Rivers catchments. Recently, Kearney *et al*. (1999) identified six ‘major’ threats, which were (in decreasing order of priority); habitat degradation, pollution, reduced environmental flows, barriers to migration, introduced species and over-fishing. Four specific threatening processes; removal of snags from streams, the introduction of fish outside their natural range, clearing of riparian vegetation, and the installation and operation of structures which alter natural flow regimes, have been listed as key threatening processes under the *NSW Fisheries Management Act 1994*.

Table 1.1. Fish species of the Hunter and Central Rivers catchments, their conservation status, and details of the most recent records and catchments where they have been recorded (i.e., prior to 2004).

Common Name	Species Name	Conservation Status	Catchments	Most Recent Record
Native				
Australian bass	*Macquaria novemaculeata*	Abundant	M, M-T, K, H	Present study
Australian Grayling	*Prototroctes maraena*	Vulnerable	M-T	2001[Museum]
Australian smelt	*Retropinna semoni*	Abundant	M, M-T, K, H	Present study
Bullrout	*Notesthes robusta*	Abundant	M, M-T, K, H	Present study
Climbing galaxias	*Galaxias brevipinnus*	Abundant, locally threatened	M-T, H	2001[RAADIK]
Common jollytail	*Galaxias maculatus*	Abundant	M-T, K	Present study
Cox's gudgeon	*Gobiomorphus coxii*	Abundant	M, M-T, K, H	Present study
Darling River Hardyhead	*Craterocephalus amniculus*	Abundant, locally threatened	H	1980 [Museum]
Dwarf flat head gudgeon	*Philypnodon* Sp.1	Abundant	M, M-T, K, H	Present study
Empire gudgeon	*Hypseleotris compressa*	Abundant	M, M-T, K, H	Present study
Firetail gudgeon	*Hypseleotris galii*	Abundant	M, K, H	Present study
Flat head gudgeon	*Philypnodon grandiceps*	Abundant	M, M-T, K, H	Present study
Freshwater catfish	*Tandanus tandanus*	Abundant	M, K, H	Present study
Freshwater herring	*Potamalosa richmondia*	Locally abundant	M, H	Present study
Freshwater mullet	*Myxus petardi*	Abundant	M, M-T, K, H	Present study
Long-finned eel	*Anguilla reinhardtii*	Abundant	M, M-T, K, H	Present study
Mountain galaxias	*Galaxias olidus*	Abundant, locally threatened	H	2001[RAADIK]
Sea mullet	*Mugil cephalus*	Abundant	M, M-T, K, H	Present study
Short-finned eel	*Anguilla australis*	Abundant	M, K, H	Present study
Southern blue eye	*Pseudomugil signifer*	Abundant	M	Present study
Striped gudgeon	*Gobiomorphus australis*	Abundant	M, M-T, K, H	Present study
Western Carp gudgeon	*Hypseleotris klunzingeri*	Abundant, locally threatened	H	1971[Museum]
Alien				
Brown trout	*Salmo trutta*	Stocked – not self sustaining	H	Present study
Common carp	*Cyprinus carpio*	Pest	M-T, H	Present study
Gambusia	*Gambusia holbrooki*	Pest	M, M-T, K, H	Present study
Goldfish	*Carassius auratus*	Pest	M, H	Present study
Rainbow trout	*Oncorhynchus mykiss*	Stocked – not self sustaining	H	Present study
Translocated				
Golden perch	*Macquaria ambigua*	Abundant in Lake Glenbawn & Lake St. Claire	M-T, H	22/9/2004[FFRD]
Silver perch	*Bidyanus bidyanus*	Abundant in Lake Glenbawn & Lake St. Claire	H	22/9/2004[FFRD]

M – Manning Catchment, M-T – Macquarie-Tuggerah Catchment, H – Hunter Catchment, K – Karuah Catchment
Most recent record superscripts: [Museum] (Australian Museum, Sydney), [FFRD] (Freshwater Fish Research Database), [RAADIK] (Raadik pers comm. 2005).

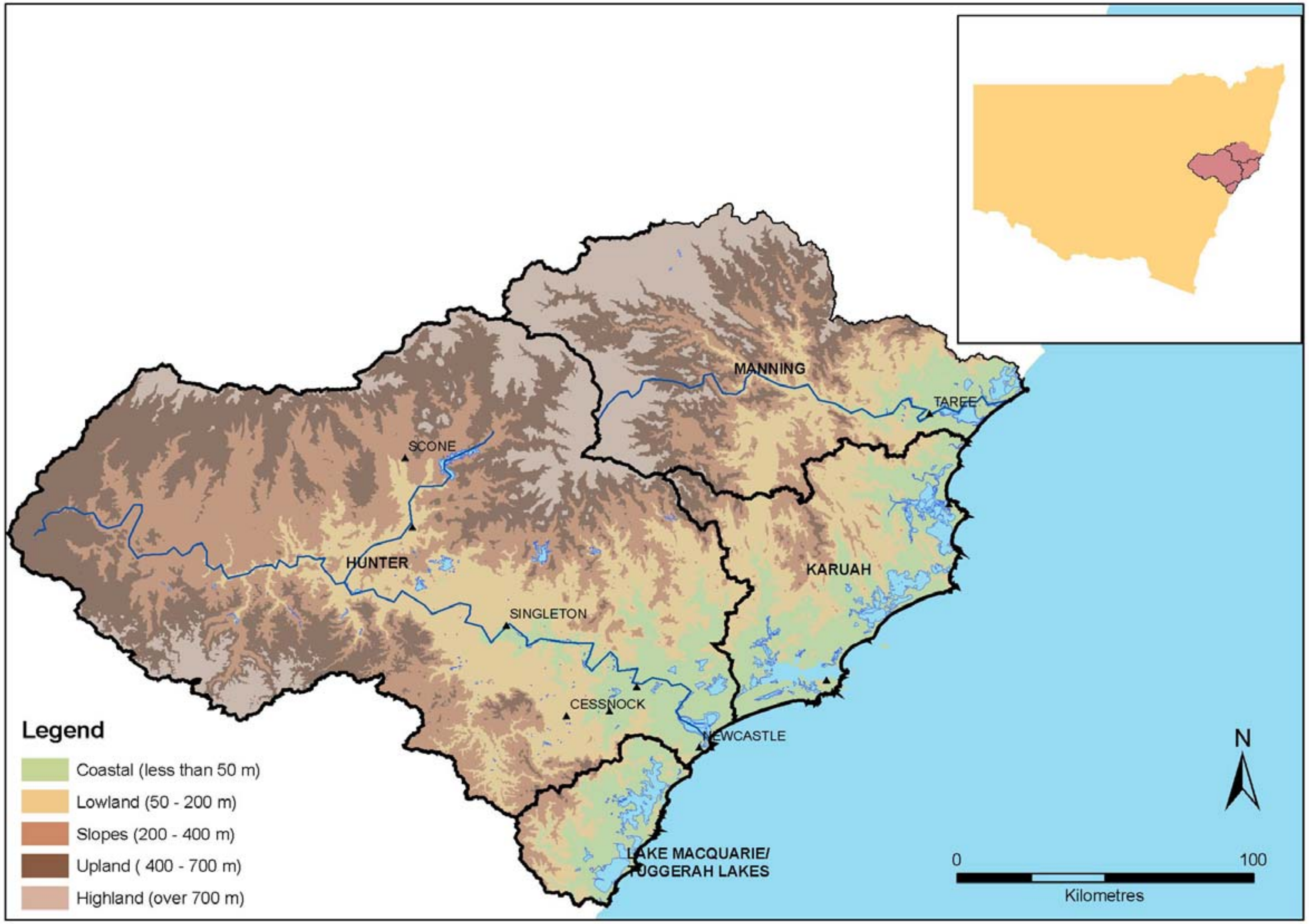

Figure 1.1. Map of the Hunter and Central Rivers catchments. The map was created using data from the NSW Department of Lands and Geoscience Australia and portrayed in geographic coordinate system GDA 1994 on Arcmap 9.1

In order to ameliorate these threatening processes, and effectively rehabilitate the freshwater aquatic community of the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments, the Hunter and Central Rivers CMA requires detailed information on the current fish community within the catchment and the relative impact each threatening process has on existing fish populations. Further, data collected in the past can be used to make inferences about the original fish community structure, and therefore provide a goal for rehabilitation activities. Lastly, data on current fish communities will enable the CMA to gauge the success or inadequacy of rehabilitation efforts through subsequent fish monitoring.

There were two main sources of historical fish data available. Statewide surveys have been periodically undertaken with no more than three sites in any of the Hunter and Central Rivers catchments. Localised sampling for a range of projects (e.g., the UHRRI near Muswellbrook) of varying sampling intensity has been done periodically. Prior to this project there had been no comprehensive sampling in the Hunter and Central Rivers catchments. The available data do not incorporate the very early periods of European settlement of the catchment, when a bulk of the catchment clearing took place, or the period coinciding with the construction of the first major irrigation storage, Glenbawn Dam. Importantly, these early periods may have been when many significant changes in fish community structure occurred.

Since the development of the standardised electrofishing sampling protocol of the NSW Rivers Survey in 1994 (Harris and Gehrke 1997), almost all fish community assessments undertaken by NSW Fisheries adopted the same standardised sampling design. This sampling protocol provides a comprehensive representation of the fish community existing at sampling sites. Further, site selection for the NSW Rivers Survey was based on a stratified random site selection process, ensuring that data collected from sites could be used to make inferences about river systems as a whole (pending sufficient site densities). Where possible, subsequent fish sampling programs utilised pre-existing sites to enable assessment of long-term trends in fish community structure. This was an important undertaking, as regular long-term monitoring sites sampled using a standardised protocol is recognised as the only means to assess change in fish communities and populations over time (Rutzoa *et al.* 1994; Lintermans 2000). However, to be effective, the number of monitoring sites must be sufficient to provide statistical power to detect change (MDBC 2004*a*), the distribution of sites must be representative of the variety of habitats existing within the catchment, and to be most useful for management purposes, surveys must be undertaken regularly in order to enable early detection of new alien species or sudden declines in native species.

The Murray-Darling Basin Ministerial Council committed in 2004 to the implementation of the SRA program (MDBC 2004*a*) in order to monitor changes in river health resulting from MDBC environmental initiatives. The present study is the first coastal equivalent and provides an example of how a standardised approach might be used to assess fish populations across the entire state. Like the SRA program, the Hunter and Central rivers catchment survey will build on the randomised site network and earlier standardised fish community surveys undertaken in NSW. Although randomly selected sites are essential for making broad-scale inferences from the data regarding river health and fish community parameters, targeted sampling of threatened species is also required in order to monitor their status through time.

This report presents data on;

- current status of fish communities in the Hunter and Central Rivers CMA area,
- current status of individual fish species,
- comparisons with other fish surveys,
- fish stocking,
- current threats to fish,
- future monitoring needs.

2. SITE SELECTION, SAMPLING PROTOCOL AND DATA MANAGEMENT

2.1. Site selection

Hunter and Central Rivers catchment maps were created using data from the NSW Department of Lands and Geoscience Australia in GDA 1994 on Arcmap 9.1. From these maps, local knowledge was used to identify the stream network considered suitable as fish habitat. All permanent and perennial streams, regulated streams and waterholes within ephemeral streams were included, whilst ephemeral streams and predominantly dry drainage streams were omitted. This stream network was then divided into five altitude zones: < 50 m (coastal zone), 50 – 200 m (lowland zone), 200 – 400 m (slopes zone), 400 – 700 m (upland zone) and > 700 m (highland zone). GIS was used to divide the stream network within each zone into 1 km long ‘potential sites’. ‘Potential sites’ were then randomly selected for each zone, and listed in order of selection.

The random site selection procedure used for the SRA was followed (see MDBC 2004*b*) for selection of monitoring sites in the Hunter and Central Rivers catchments. Following power analysis of pilot SRA data, the minimum number of sites required to adequately characterise the fish community of a zone in the MDBC was identified as seven sites (MDBC 2004*a*). The balance of sites in each zone was then selected from the randomly generated list of ‘potential sites’. This procedure was used as a guide, but adjusted for the Hunter and Central Rivers CMA area to give a more proportionate representation of zones within the catchments. Table 2.1 shows the distribution of sampling sites selected within each altitude zone for each catchment. Sampling site locations are mapped on Figures 2.1 – 2.4 with site details given in Table 2.2.

Table 2.1. Distribution of sampling sites within each altitude zone.

Altitude	Hunter	Manning	Karuah	Macquarie-Tuggerah	Total
0 – 50	2	2	2	2	8
50 – 200	3	3	1		7
200 – 400	3	3			6
400 – 700	2	2			4
> 700	1	1			2
Total	**11**	**11**	**3**	**2**	**27**

Table 2.2. Randomly selected riverine monitoring sites.

Site name	Latitude	Longitude	DLWC bsin name	Waterbody name	Altitude zone	Altitude (m)
Dungog	-32.4	151.8	Hunter River Basin	Williams River	0 – 50	40
Elderslie	-32.6	151.3	Hunter River Basin	Hunter River	0 – 50	10
Bonnington	-32.3	151.5	Hunter River Basin	Allyn River	50 – 200	100
Control site	-32.3	151.7	Hunter River Basin	Williams River	50 – 200	110
Olive Pool	-32.3	150.8	Hunter River Basin	Hunter River	50 – 200	125
Bickham	-31.8	150.9	Hunter River Basin	Pages River	200 – 400	390
Barton Vale	-32.2	150.3	Hunter River Basin	Merriwa River	200 – 400	210
Cassilis	-32	150.2	Hunter River Basin	Krui River	200 – 400	355
Naracoorte	-31.9	151.3	Hunter River Basin	Hunter River	400 – 700	420
Whissonsett	-31.8	151.1	Hunter River Basin	Isis River	400 – 700	410
Stewarts Brook	-31.9	151.4	Hunter River Basin	Polblue Creek	> 700	1240
Middle site	-32.4	152.2	Karuah River Basin	Myall River	0 – 50	2
Stroud	-32.5	152	Karuah River Basin	Karuah River	0 – 50	20
Pikes Crossing	-32.3	152	Karuah River Basin	Mammy Johnsons River	50 – 200	80
Yarramalong	-33.2	151.3	Mac-Tuggerah Lakes	Wyong River	0 – 50	20
Pambula	-33.1	151.4	Mac-Tuggerah Lakes	Dora Creek	0 – 50	2
Eastbank	-31.8	152.3	Manning River Basin	Dingo Creek	0 – 50	35
Karaak Flat	-31.9	152.3	Manning River Basin	Manning River	0 – 50	18
Forbesdale	-32	151.9	Manning River Basin	Barrington River	50 – 200	140
Doon Ayre	-31.9	152.1	Manning River Basin	Gloucester River	50 – 200	60
Bretti Reserve	-31.8	151.9	Manning River Basin	Barnard River	50 – 200	98
Black Rock	-32	151.8	Manning River Basin	Barrington River	200 – 400	200
Cooplacurripa	-31.6	151.9	Manning River Basin	Cooplacurripa River	200 – 400	240
Terrabanella	-31.5	152.1	Manning River Basin	Rowleys River	200 – 400	200
Barry	-31.6	151.3	Manning River Basin	Barnard River	400 – 700	530
Glen Ward	-31.8	151.6	Manning River Basin	Manning River	400 – 700	450
Linda Downs	-31.5	151.7	Manning River Basin	Nowendoc River	> 700	840

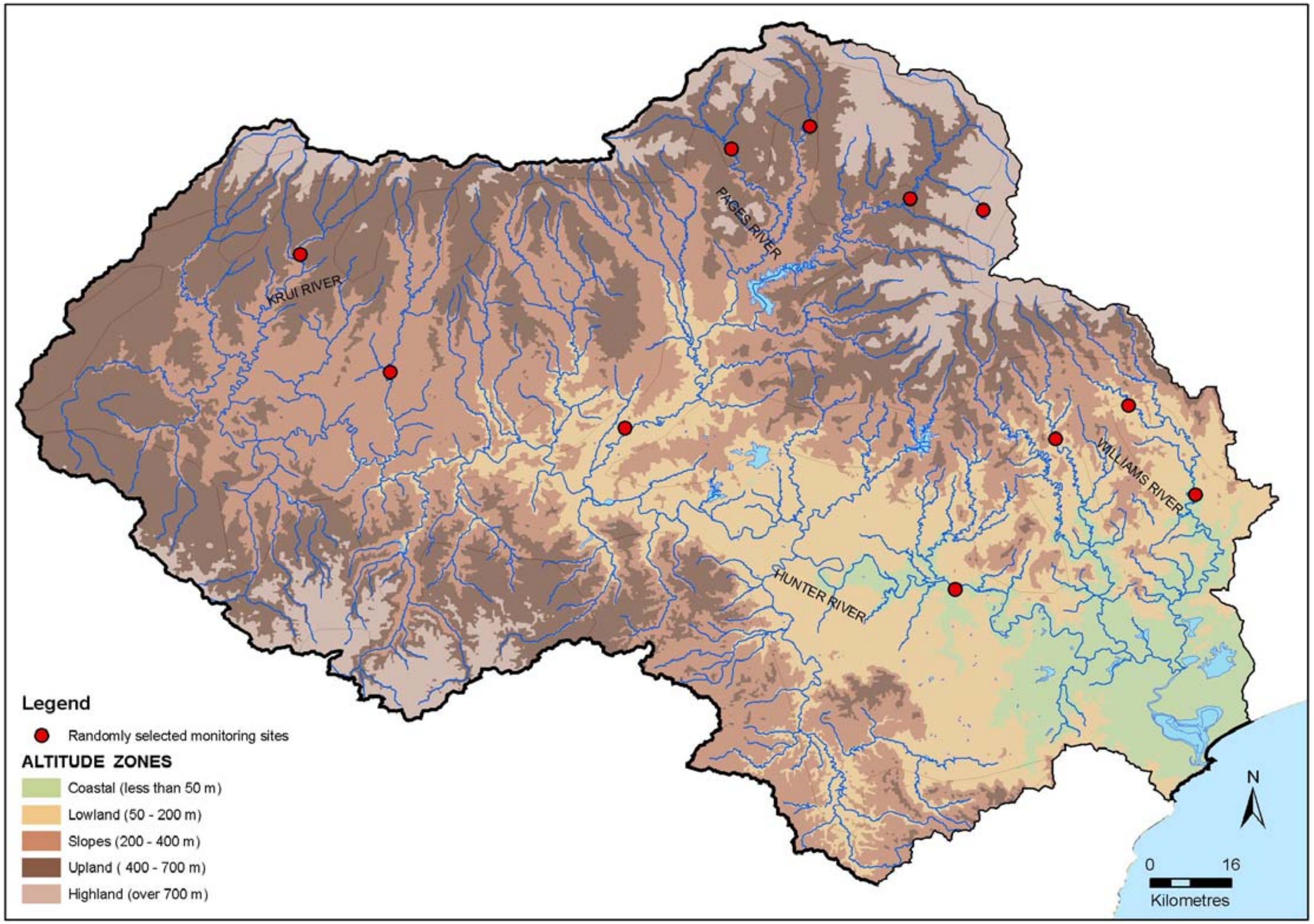

Figure 2.1. Locations of randomly selected monitoring sites (red) in the Hunter catchment. The stream network is derived from the AUSLIG 1: 250,000 and NLWRA stream networks, but reaches not providing fish habitat (ephemeral streams and drainage lines) are omitted. The catchment was divided into five zones based on altitude (as undertaken for the MDBCs SRA program) for the purposes of analysing spatial structure in fish community variables.

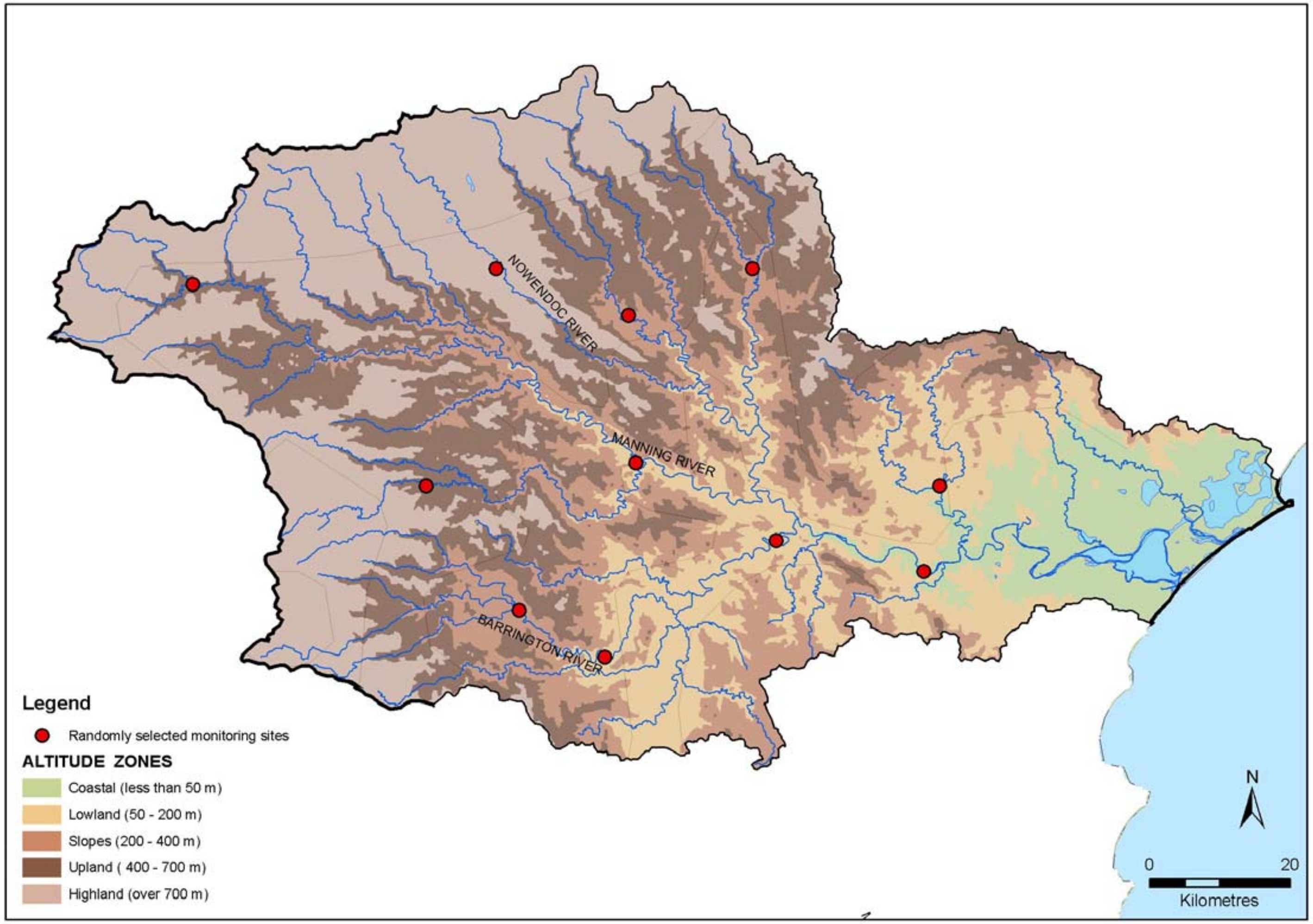

Figure 2.2. Locations of randomly selected monitoring sites (red) in the Manning catchment. The stream network is derived from the AUSLIG 1: 250,000 and NLWRA stream networks, but reaches not providing fish habitat (ephemeral streams and drainage lines) are omitted. The catchment was divided into five zones based on altitude (as undertaken for the MDBCs SRA program) for the purposes of analysing spatial structure in fish community variables.

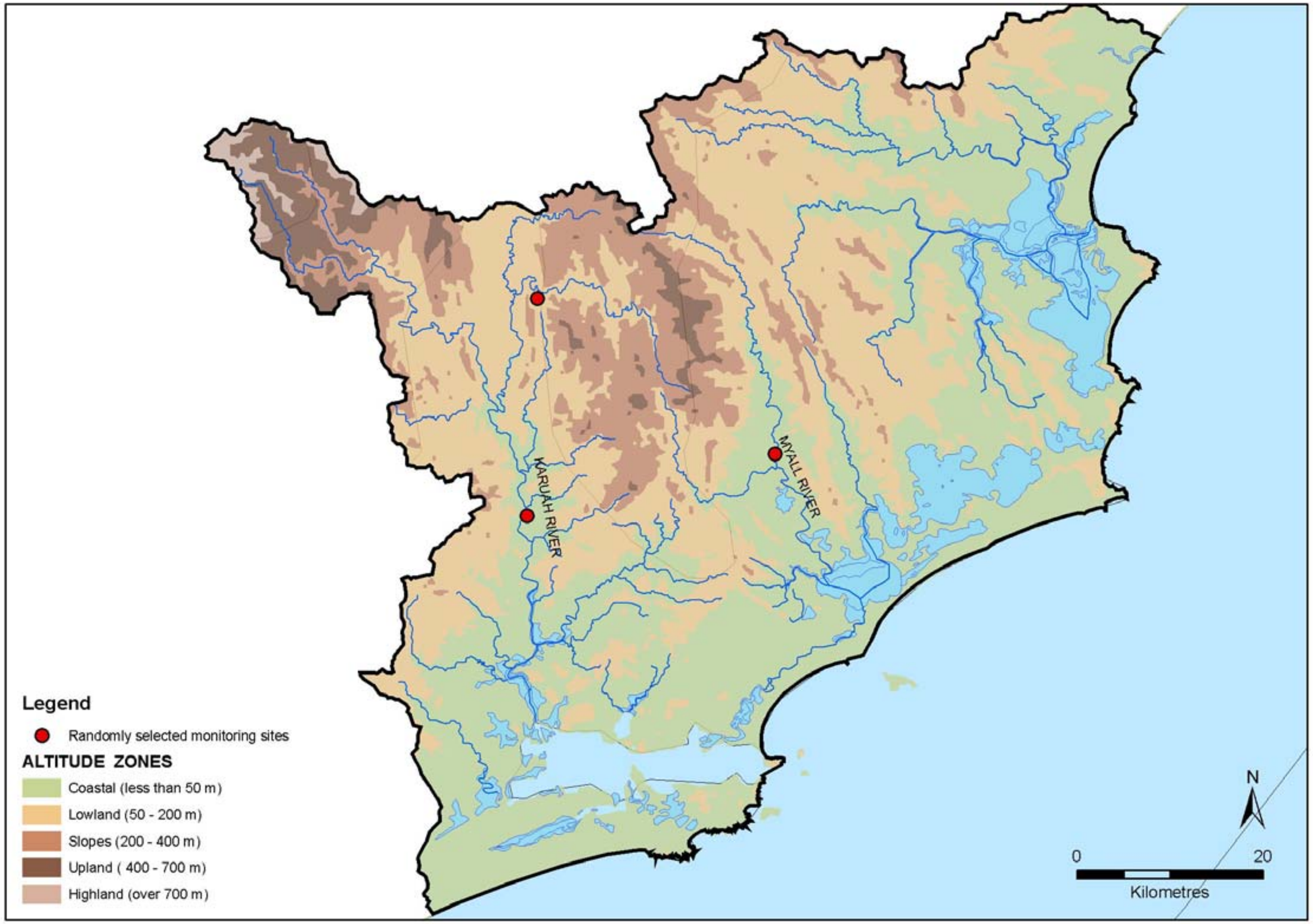

Figure 2.3. Locations of randomly selected monitoring sites (red) in the Karuah catchment. The stream network is derived from the AUSLIG 1: 250,000 and NLWRA stream networks, but reaches not providing fish habitat (ephemeral streams and drainage lines) are omitted. The catchment was divided into five zones based on altitude (as undertaken for the MDBCs SRA program) for the purposes of analysing spatial structure in fish community variables.

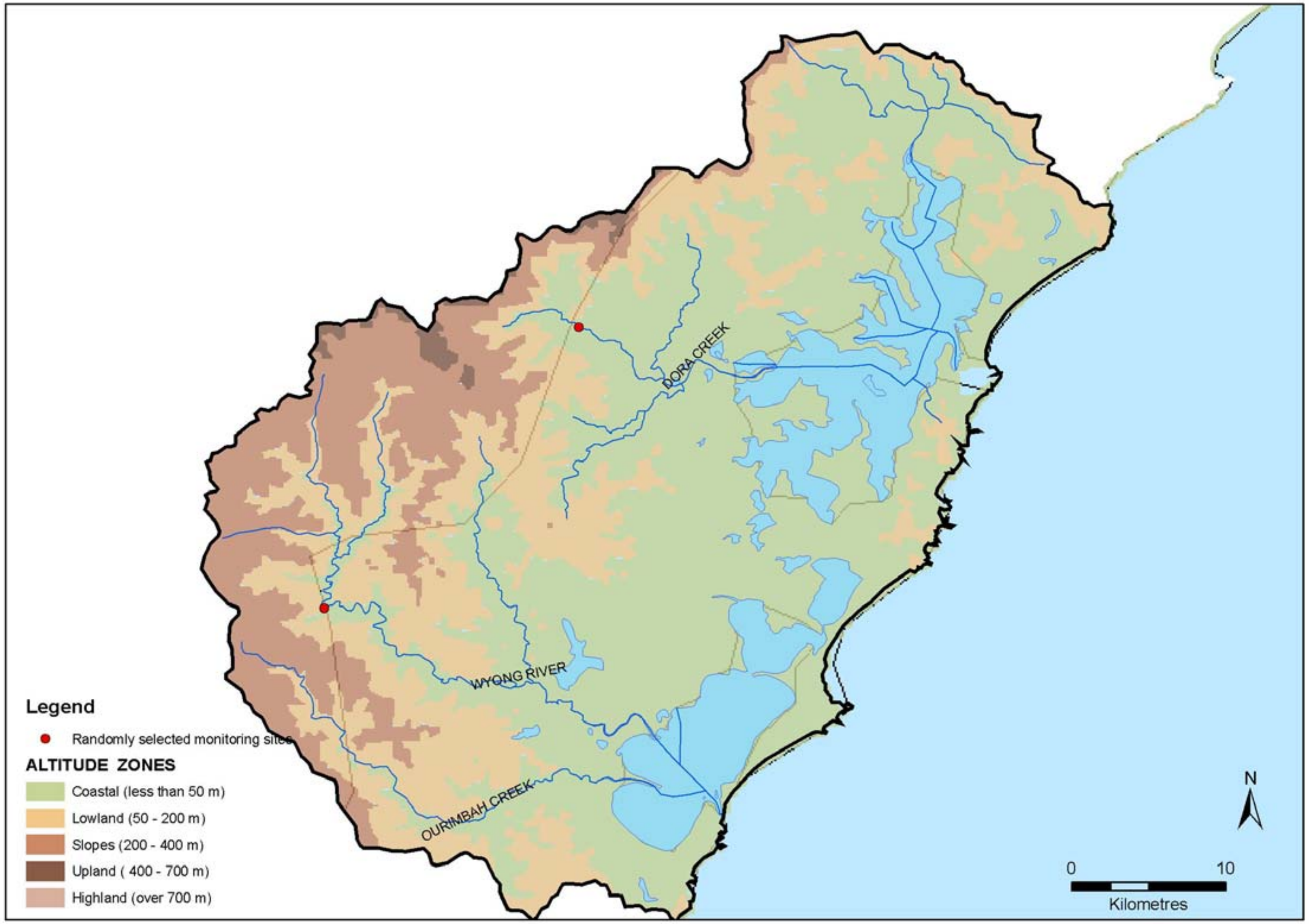

Figure 2.4. Locations of randomly selected monitoring sites (red) in the Macquarie-Tuggerah catchment. The stream network is derived from the AUSLIG 1: 250,000 and NLWRA stream networks, but reaches not providing fish habitat (ephemeral streams and drainage lines) are omitted. The catchment was divided into five zones based on altitude (as undertaken for the MDBCs SRA program) for the purposes of analysing spatial structure in fish community variables.

2.2. Sampling procedure

2.2.1. Sampling sites

The sampling procedure for riverine sites was based on standardised boat and/or backpack electrofishing in addition to 10 unbaited shrimp traps as developed for the SRA program (MDBC 2004*b*).

Either large boat (7.5 kW Smith-Root model GPP 7.5 H/L) or small boat (2.5 kW Smith-Root model GPP 2.5 H/L) electrofishing was undertaken depending on the size of the stream. In streams wider than 15 m, the larger electrofishing boats were used. Smaller streams were sampled using the smaller boat. Boats were used to sample all navigable habitats (waters deeper than ~ 0.75 m). A backpack electrofisher (400 W Smith-Root model 12) was used to sample non-navigable (but wadeable) habitats such as riffles and runs.

Boat operations consisted of 90 seconds of electrofishing (power on). Each operation was undertaken using intermittent electrofishing, with a ~10 second application of power followed by a ~10 second pause and advance of approximately 5 m. This protocol minimises the 'herding' of fish. As a further prevention of herding, each operation was undertaken on alternate banks. For streams > 5m wide, at least two 'mid-stream' shots were undertaken. For streams < 5 m wide, where the electric field covered the entire stream width, a greater spacing was used between operations to prevent herding and the boat progressed in a zig-zag fashion between banks. Each operation took an average of three minutes to complete.

Backpack operations consisted of 150 seconds of electrofishing (power on). Each operation was undertaken using intermittent electrofishing, with the backpack used to fish all areas accessible to the stationary operators (1.5 – 2 m radius). Following electrofishing of that area, the operators moved ~3 m and repeated the process. In streams > 10 m wide, electrofishing was undertaken along both banks. In smaller streams, operators progressed in a zig-zag fashion in an upstream direction. Each operation took an average of five minutes to complete.

The number of boat and/or backpack operations undertaken was dependent on the proportional availability of each habitat type within the 1 km sampling sites. Sites which were totally navigable by boat were sampled using 12 boat electrofishing operations. Conversely, sites with no navigable habitat were sampled using 8 backpack electrofishing operations. For sites which had both navigable and non-navigable habitats, a combination of both boat and backpack electrofishing was used. In these circumstances, the number of boat and backpack operations undertaken was dependent on the proportional availability of navigable and non-navigable habitat within the sampling site.

During each operation, dip-netters removed all electrofished individuals and placed them in an aerated live-well (boat fishing) or bucket (backpack fishing). All individuals that could not be dip-netted but could be positively identified were recorded as observed. All electrofishing was undertaken during daylight hours.

In addition to electrofishing, 10 un-baited commercially available concertina-type shrimp traps were set. Traps were set for a minimum period of two hours whilst electrofishing was being undertaken. Data from each of the 10 traps were recorded as a separate operation.

At the completion of each operation (including both electrofishing and shrimp traps), captured individuals were identified, counted, measured and observed for externally visible parasites, wounds, diseases etc. before being released. All taxa were recorded to species level where possible. Specimens of the genera *Hypseleotris*, *Gobiomorphus* and *Anguilla* were recorded as ‘spp’ unless operators were absolutely confident of their identification. In the case of difficult identifications, specimens were photographed and/or preserved in 70% ethanol for later laboratory identification. Length measurements to the nearest millimetre were taken as fork length for species with forked tails and total length for other species. Where large catches of a species occurred, only a sub-sample of individuals were measured and examined for each gear type. The sub-sampling procedure consisted of measuring all individuals in each operation until at least 50 individuals had been measured. Once this had happened, the remainder of individuals in that operation were measured, but any individuals of that species from subsequent operations of that gear type were only counted. Sub-sampling for health status involved careful observation of one side (usually the left) of every fish that was measured. The numbers of parasites, wounds etc. observed were recorded for each individual assessed.

2.2.2. Habitat assessment

In addition to fish sampling data, a habitat assessment and water quality analysis was undertaken at each site. Habitat values for riparian and instream vegetation, substratum, mesohabitat (pool, run, riffle, rapid), and instream cover variables were scored using an AFOR scale (Abundant, Frequent, Occasional, or Rare) for the site as a whole.

Water quality parameters; temperature (^{o}C), dissolved oxygen (mg/L), pH, and conductivity (µS/cm) were measured using a Horiba U10 water quality meter. Turbidity was measured using either the Horiba U10 water quality meter or secchi disk. Three replicate measurements of each parameter were made at 20 cm below the surface in addition to one replicate ‘depth profile’, where parameters were assessed at 1 m intervals between the surface and substratum (only possible for turbidity using the Horiba instrument).

2.3. Data entry and quality assurance

Data were entered onto standard data-sheets by the senior operator at the completion of each operation. Data recorded included fish variables (as described above), electrofishing settings, sampling time (real time plus electrofishing time), average depth, average stream width, mesohabitat sampled and distance travelled in the operation.

Data were then transferred directly into I&I NSW’s Freshwater Fish Research Database. Within this data storage system, data were first entered into intermediate tables by technical staff. The data were then run through a series of 50 range-checks to identify any outliers and inconsistencies in data recording. All potential errors were referred to the senior operator responsible for data collection at that site for confirmation and/or correction. The corrected intermediate tables were then appended into the database for storage.

3. STATUS OF FISH COMMUNITIES OF THE HUNTER, MANNING, KARUAH AND MACQUARIE-TUGGERAH CATCHMENTS IN 2004

3.1. Introduction

Fish communities are co-occurring populations of individual fish species within habitats. Changes in fish communities are driven by a range of interactions within the ecosystem. A number of studies have attributed changes in fish community composition to natural processes such as increasing species diversity and habitat variability progressively downstream within river systems (Rahel and Hubert 1991; Paller 1994; Gehrke and Harris 2000). However, human induced catchment disturbance also plays a role in driving fish community structure (Connell 1978; Ward and Stanford 1983; Puckridge *et al.* 1998). In addition, direct interactions between members of the fish community such as predation, interspecific competition, intraspecific competition, direct interactions with other aquatic organisms and indirect interactions through broader ecosystem processes also affect fish community structure. The combined effects of each of these processes governs the species composition and relative abundances of species within the community. Given the large catchment area of the Hunter and Central Rivers catchments, their extensive altitudinal range and underlying geological features, consequent range of habitats, and spatial variation in the level and type of human disturbance, the composition of fish communities occurring at sites are unlikely to be consistent throughout the catchment.

The structure of fish communities is expected to be similar in areas that contain similar habitat types which have been exposed to similar disturbances. These include both natural events such as bushfires and fish kills resulting from heavy rainfall following a prolonged dry period, as well as human induced disturbances such as, construction of barriers to fish passage, river regulation, de-snagging, introduction of alien fish and fish kills resulting from pollution. As a result, it can be hypothesised that identification of patterns in fish community structure would lead to identification of areas of habitat which require similar management or rehabilitation activities (Gehrke and Harris 2000).

Once the distribution of fish communities has been identified within the catchment, basic ecological parameters such as species richness, total abundance, biomass, species diversity and evenness, the proportion of alien taxa and estimates of recruitment can then be used assess temporal changes in community status. Further, the status of fish communities in least-disturbed habitats can be used to set management targets for rehabilitation of those that have been disturbed.

3.2. Methods

3.2.1. Site selection and sampling procedures

Site selection and sampling followed the protocols and procedures outlined in chapter 2. All 27 sites were included in the assessment of bio-zonation within the catchment and to benchmark the 2004 fish communities in each catchment and make statements about community condition in each altitude zone.

3.2.2. *Data analysis*

Data from all operations at a site (boat electrofishing, backpack electrofishing and shrimp-traps) were combined for analysis. Data were not standardised to catch-per-unit-effort as the same standardised sampling was undertaken at all sites.

Biomass per site was estimated from length-weight relationships presented in the literature (MDBC 2004*a*, Pease 2004, Pusey *et al.* unpublished, Harris 1987, Froese & Pauly 2003). An established length-weight relationship for freshwater mullet (*Myxus petardi*) could not be found, so estimates were based on sea mullet (*Mugil cephalus*). The weight of each measured individual was estimated using these relationships. The weight of unmeasured and observed individuals was estimated using the average weight of all measured individuals for that gear type at that site. In the small number of instances where a species was only observed at a site, the average weight of individuals measured for that gear type in that zone was used.

To examine bio-zonation of fish communities throughout the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments, multivariate analyses were undertaken using PRIMER 5.2.2 (Plymouth Marine Laboratory). Similarity matrices were created using the Bray-Curtis similarity index (Bray and Curtis 1957) for un-standardised abundance data from the 27 monitoring sites. As there was a wide spread in values, data were fourth root transformed to equalise the contribution of rare and common taxa. Data were plotted using both a hierarchical agglomerative classification analysis (which uses a group-average linking algorithm) and multi-dimensional scaling (MDS) ordinations in two dimensions. ANOSIM (ANalysis Of SIMilarities) (Clarke 1993) was used to test differences in fish community structure across altitude zones. Permutation tests to estimate the probability of the observed results used 5000 randomisations. Where significant differences were identified, SIMPER (SIMilarity PERcentages) analyses were used to identify the species contributing most to dissimilarities.

Total species richness, total abundance, total biomass, Shannon's diversity and evenness indices, proportion native species, proportion native abundance and proportion native biomass were calculated for each site and the average within each zone was calculated in order to provide a benchmark of the current fish communities. Proportion of total catch and proportion of total biomass were also estimated for each individual species within each zone.

Shannon's diversity index was calculated (based on the abundance of each species) for each site, using the following formula (Begon *et al.* 1990):

$$\text{diversity } H = - \Sigma\, P_i \ln P_i$$

where the P_i is the proportion of the ith species and ln is $\log_e$. The associated evenness index was calculated as:

$$\text{evenness } J = H / \ln S$$

where S is the species richness at that site.

3.3. Results

3.3.1. Hunter and Central Rivers catchments

3.3.1.1. Catch data

Twenty-two fish species were sampled from the 27 monitoring sites (Table 3.1). During the survey 73% of the freshwater fish fauna previously recorded in the Hunter catchment (19 of 26), 80% in the Manning (16 of 20), 94% in the Karuah (16 of 17) but only 53% in the Macquarie-Tuggerah catchment (9 of 17) were recorded. The present survey did not include targeting rare species previously recorded in the catchment, and further investigation of rare species is required.

The most abundant species across all four catchments (Table 3.1) were Australian smelt (30.6%), long-finned eels (18.9%) and sea mullet (10.2%). Biomass (Table 3.2) was largely dominated by sea mullet (36.5%), long-finned eels (24.3%) and common carp (17.4%), although common carp were found only in the Hunter catchment in the present survey.

3.3.1.2. Spatial structure of fish communities within the Hunter and Central Rivers catchments

Classification analysis of abundance data from the 27 sites demonstrated substantial spatial variability in fish community structure across the catchments, as indicated by the deep branching pattern resulting from low similarities among sites (Figure 3.1). Further, the classification analysis demonstrated that there are relatively few associations (clusters) of sites at higher levels of similarity suggesting limited discrete biozonation across the catchments (Figure 3.1).

The only easily interpretable patterns were for five significantly different clusters separated at < 40% similarity. The most dissimilar site was Stewarts Brook on Barrington Tops with no similarity to any other site due to the presence of brown trout and rainbow trout which were not recorded elsewhere. The next divergence separated a group of 2 sites (Naracoorte and Cassilis in the upland zone of the Hunter catchment) dominated by common carp, eel-tailed catfish and flat head gudgeon. The next cluster included two sites (Middle site on the Karuah River and Pambula on Dora creek, both in the coastal zone) which were dominated by long-finned eels, gambusia, striped gudgeon and empire gudgeon. The site at Linda Downs on the upper Manning River was distinguished by the dominance of long-finned eels and gambusia. The final cluster, which included all the remaining sites, contained a wide range of species, but was distinguished by the dominance of long-finned eels, Cox's gudgeon and Australian smelt. Although subsequent breakdown of the fish community was possible, the results became more ambiguous and harder to interpret.

Table 3.1. Numbers of fish sampled for each catchment in 2004 (for scientific names see Table 1.1).

Species	**Manning (11 sites)**	**Macquarie-Tuggerah Lakes (2 sites)**	**Karuah (3 sites)**	**Hunter (11 sites)**	**Total Catch (27 sites)**
Native fish species					
Anguilla spp	81	-	-	1	82
Australian bass	9	2	43	65	119
Australian smelt	546	10	62	563	1181
Bullrout	6	-	1	1	8
Common jollytail	-	1	-	-	1
Cox's gudgeon	139	11	9	106	265
Dwarf flat head gudgeon	3	1	16	6	26
Eel-tailed catfish	20	-	1	47	68
Empire gudgeon	22	20	40	12	94
Fire-tail gudgeon	-	-	17	-	17
Flat head gudgeon	25	-	42	101	168
Freshwater herring	143	-	-	6	149
Freshwater mullet	2	-	15	3	20
Gobiomorphus spp	9	-	-	-	9
Hypseleotris spp	3	-	3	1	7
Long-finned eel	350	20	79	280	729
Southern blue-eye	11	-	-	-	11
Sea mullet	161	-	91	142	394
Short-finned eel	-	-	1	2	3
Striped gudgeon	90	27	30	1	148
Alien fish species					
Brown trout	-	-	-	5	5
Common carp	-	-	-	53	53
Gambusia	118	2	28	131	279
Goldfish	17	-	-	1	18
Rainbow trout	-	-	-	1	1
Total	**1755**	**94**	**478**	**1528**	**3855**

Table 3.2. Biomass (grams) of fish sampled for each catchment in 2004.

Species	Manning (11 sites)	Macquarie-Tuggerah Lakes (2 sites)	Karuah (3 sites)	Hunter (11 sites)	Total Catch (27 sites)
Native fish species					
Anguilla spp	11,499	-	-	77	11,576
Australian bass	7,837	73	10,353	20,622	38,885
Australian smelt	714	26	50	1,156	1,946
Bullrout	3,902	-	172	705	4,779
Common jollytail	-	1	-	-	1
Cox's gudgeon	1,129	170	117	1,137	2,553
Dwarf flat head gudgeon	3	2	6	5	16
Eel-tailed catfish	18,672	-	1,679	29,796	50,147
Empire gudgeon	68	74	95	29	266
Fire-tail gudgeon	-	-	6	-	6
Flat head gudgeon	76	-	72	129	277
Freshwater herring	27,744	-	-	643	28,387
Freshwater mullet	1,468	-	7,980	1,015	10,463
Gobiomorphus spp	112	-	-	-	112
Hypseleotris spp	1	-	1	1	3
Long-finned eel	94,707	4,620	17,893	58,992	176,212
Southern blue-eye	12	-	-	-	12
Sea mullet	96,755	-	38,091	129,450	264,296
Short-finned eel	-	-	78	312	390
Striped gudgeon	498	485	312	12	1,307
Alien fish species					
Brown trout	-	-	-	210	210
Common carp	-	-	-	126,381	126,381
Gambusia	27	1	3	46	77
Goldfish	5,750	-	-	377	6,127
Rainbow trout	-	-	-	63	63
Total	**270,974**	**5,452**	**76,908**	**371,158**	**724,492**

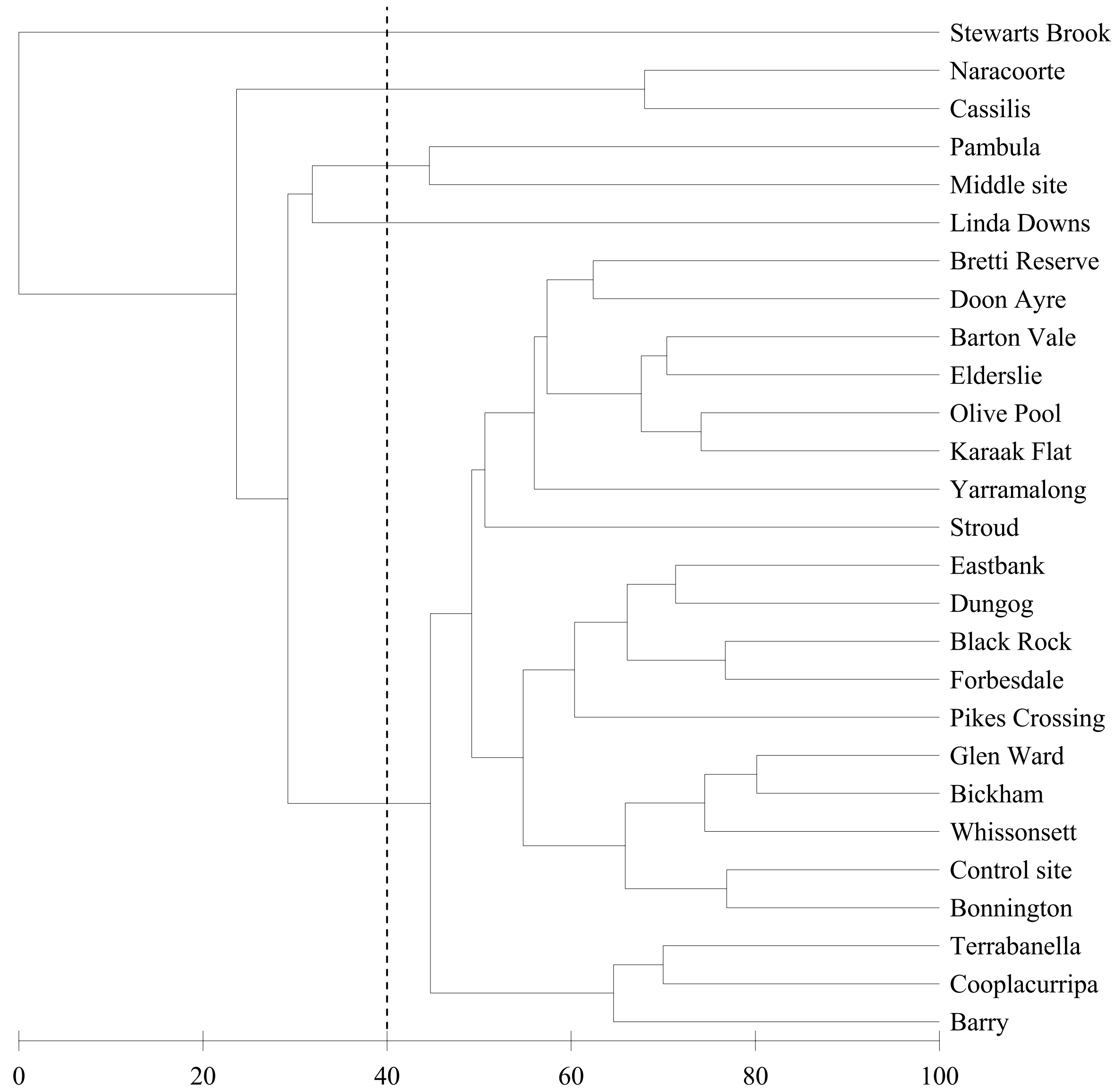

Figure 3.1. Bray-Curtis classification analysis of all sites in the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments based on similarities calculated from abundance data. The 40% similarity level was used to interpret the similarity of fish communities.

3.3.1.3. Analysis of altitude zones

Comparison of the fish community over the pre-determined altitude zones using ANOSIM identified significant differences between fish communities (Global $R \approx 0.359$, $p < 0.0001$). The coastal zone was significantly different from the lowland ($R = 0.181$, $p = 0.035$), slopes ($R = 0.45$, $p = 0.001$), upland ($R = 0.608$, $p = 0.002$) and highland zones ($R = 0.931$, $p = 0.022$). The lowland zone was significantly different from the upland ($R = 0.357$, $p = 0.027$) and highland zones ($R = 0.925$, $p = 0.028$), but not from the neighbouring slopes zone ($R = 0.122$, $p = 0.121$). The slopes zone was not significantly different from the upland ($R = -0.095$, $p = 0.74$) and highland zones ($R = 0.688$, $p = 0.071$), and the upland zone was not significantly different from the highland zone ($R = 0.5$, $p = 0.133$). Multi-dimensional scaling illustrates the relationships and also highlights a substantial increased variability in fish communities with increasing altitude (Figure 3.2). This pattern is evidenced in the scatter of sites within each zone increasing from lowland zone, where the fish community at each site was very similar and hence tightly clustered, to the upland zone where each of the four sites had a very different fish community and the sites are broadly scattered. The relatively high variability in the coastal zone is most likely attributed to the range of catchments included in this analysis. As the cluster analysis (Figure 3.1) shows, Stewarts Brook, in the highland zone, was very different from all the other sites and was excluded from the multi-dimensional scaling (Figure 3.2).

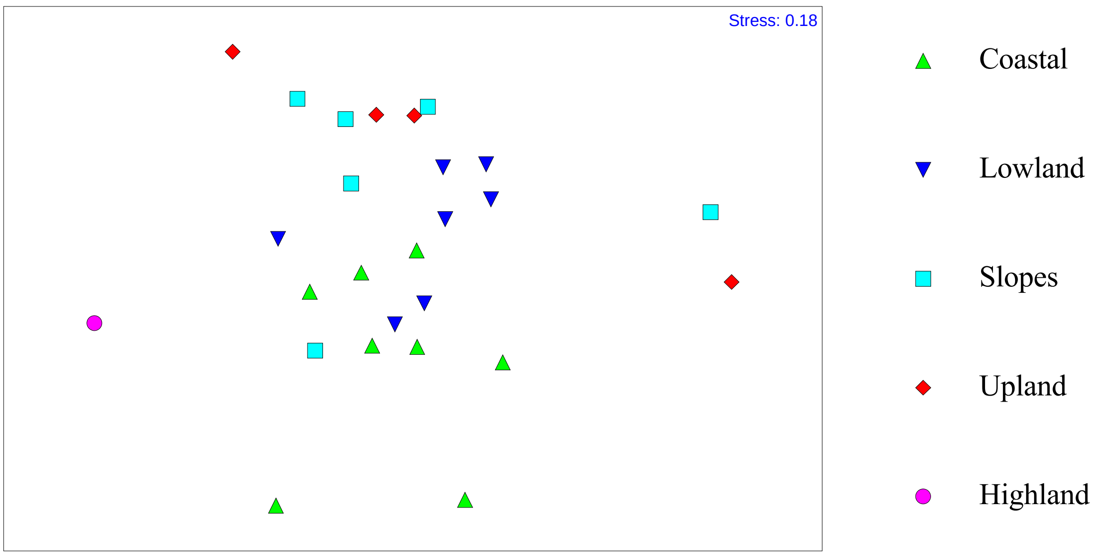

Figure 3.2. MDS ordination of fish community data from sites in the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments. Sites are separated into one of five categories based on altitude zones of: coastal (< 50 m), lowland (50 – 200 m), slopes (200 – 400 m), upland (401 – 700 m) and highland (> 700 m).

Table 3.3. Contributions of species to the dissimilarity between fish assemblages in different zones. The consistency ratio indicates the consistency with which each species discriminates between zones, with larger values indicating greater consistency. The cumulative % column indicates the cumulative contribution of each species to the average dissimilarity between zones. The average dissimilarity (D%) is expressed as a percentage ranging from 0 (identical) to 100 (totally dissimilar).

Species	**Mean Abundance**		**Consistency ratio**	**Cum. %**	**D %**
	Coastal	Lowland			71.15
Australian smelt	15.63	93.43	1.39	31.29	
Long-finned eel	16.63	50.29	1.4	46.42	
Sea mullet	23.38	16.43	1.04	56.85	
Gambusia	5.5	11.86	0.53	63.61	
Freshwater herring	3	14.29	0.82	70.02	
	Coastal	Slopes			76.24
Australian smelt	15.63	50.17	1.16	22.72	
Sea mullet	23.38	15.33	1.11	37.21	
Long-finned eel	16.63	31.83	0.96	49.68	
Flat head gudgeon	5.38	15.83	0.49	60.01	
Striped gudgeon	15.13	0	1	67.07	
Australian bass	9.75	0	0.65	72.19	
	Coastal	Upland			79.85
Australian smelt	15.63	25.25	0.89	20.19	
Sea mullet	23.38	0	1.07	35.12	
Cox's gudgeon	6.25	16.75	0.97	46.76	
Striped gudgeon	15.13	0	1.06	56.17	
Long-finned eel	16.63	11.25	1.02	63.97	
Australian bass	9.75	1.5	0.75	71.19	
	Coastal	Highland			93.83
Gambusia	5.5	52.5	1.02	26.58	
Sea mullet	23.38	0	0.95	40.97	
Long-finned eel	16.63	5	1.06	51.71	
Striped gudgeon	15.13	0	0.94	61.26	
Australian smelt	15.63	0	0.91	70.39	
	Lowland	Upland			75.32
Australian smelt	93.43	25.25	1.53	34.68	
Long-finned eel	50.29	11.25	1.52	52.78	
Sea mullet	16.43	0	0.67	61.51	
Cox's gudgeon	15.57	16.75	1.29	68.8	
	Lowland	Highland			92.95
Australian smelt	93.43	0	1.56	31.69	
Gambusia	11.86	52.5	1	49.7	
Long-finned eel	50.29	5	1.48	67.43	

The fish community in the coastal zone was characterised by a greater abundance of sea mullet and striped gudgeon than in the other four zones (Tables 3.3). The significant difference between the lowland and the upland zones was predominantly driven by the higher abundance of Australian smelt and long-finned eels in the lowland zone and the absence of sea mullet in the upland zone (Table 3.3). The highland zone differed from the lowland zone in the absence of Australian smelt and the reduced abundance of long-finned eels, and the dominance of gambusia.

Across all sites in the Hunter and Central Rivers catchments there was a significant decrease ($P < 0.0001$) in species richness with increased altitude (Figure 3.3). The species sampled in each of the four zones in the Hunter and Central Rivers catchments are shown in Table 3.4. The coastal, lowland, slopes and upland zones were dominated by native fish species while the highland zone was dominated by alien fish species (Table 3.4).

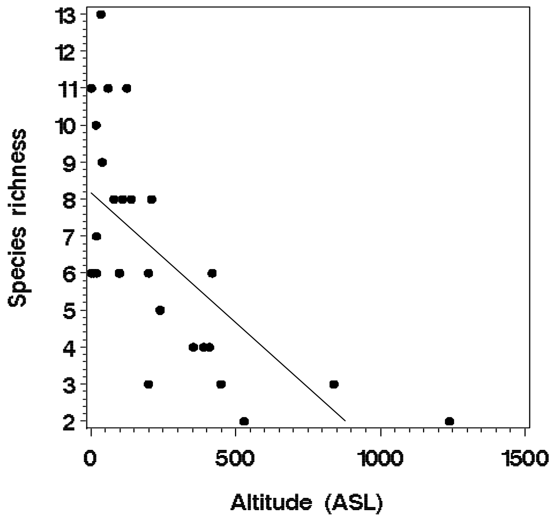

Figure 3.3. Relationship between species richness and altitude across all catchments in the Hunter and Central Rivers catchments. $R^2 = 0.45$.

Table 3.4. Presence/absence of fish species in each altitudinal zone. Presence of fish sampled from randomly selected monitoring sites is indicated by •.

Species	Coastal	Lowland	Slopes	Upland	Highland
Native species					
Anguilla spp		•	•	•	•
Australian bass	•	•		•	
Australian smelt	•	•	•	•	
Bullrout	•	•			
Common jollytail	•				
Cox's gudgeon	•	•	•	•	
Eel-tailed catfish	•	•	•	•	
Empire gudgeon	•	•	•		
Fire-tail gudgeon	•				
Flat head gudgeon	•	•	•	•	
Freshwater herring	•	•	•		
Freshwater mullet	•	•			
Gobiomorphus spp			•	•	
Hypseleotris spp	•	•	•		
Long-finned eel	•	•	•	•	•
Southern blue-eye	•	•			
Dwarf flat head gudgeon	•	•	•		
Sea mullet	•	•	•		
Short-finned eel	•	•		•	
Striped gudgeon	•	•			
Alien species					
Brown trout					•
Common carp		•	•	•	
Gambusia	•	•	•		•
Goldfish		•	•		•
Rainbow trout					•

Table 3.5. Fish community parameters estimated from data collected from 27 randomly selected riverine monitoring sites within the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments.

Site Name	Catchment	Waterbody	Altitude zone	Species Richness	Total abundance	Total Biomass (kg)	Shannon's *H*	Shannon's *J*	Proportion native species	Proportion native abundance	Proportion native biomass
Dungog	Hunter River Basin	Williams River	0 – 50	9	128	19.009	1.63	0.74	1	1	1
Elderslie	Hunter River Basin	Hunter River	0 – 50	6	63	2.692	1.39	0.77	0.83	0.9	0.99
Bonnington	Hunter River Basin	Allyn River	50 – 200	6	260	50.161	1.26	0.7	0.83	0.99	0.99
Control site	Hunter River Basin	Williams River	50 – 200	8	339	22.107	0.99	0.48	1	1	1
Olive Pool	Hunter River Basin	Hunter River	50 – 200	11	184	28.578	1.73	0.72	0.82	0.55	0.54
Barton Vale	Hunter River Basin	Merriwa River	200 – 400	8	218	142.621	1.52	0.73	0.63	0.72	0.85
Bickham	Hunter River Basin	Pages River	200 – 400	4	126	0.54	0.82	0.59	1	1	1
Cassilis	Hunter River Basin	Krui River	200 – 400	4	128	64.819	0.78	0.56	0.75	0.83	0.02
Naracoorte	Hunter River Basin	Hunter River	400 – 700	5	27	37.23	1.44	0.81	0.8	0.56	0.2
Whissonsett	Hunter River Basin	Isis River	400 – 700	4	49	3.128	1.13	0.81	1	1	1
Stewarts Brook	Hunter River Basin	Polblue creek	> 700	2	6	0.273	0.45	0.65	0	0	0
Middle site	Karuah River Basin	Myall River	0 – 50	11	255	48.937	2.13	0.89	0.91	0.89	0.99
Stroud	Karuah River Basin	Karuah River	0 – 50	7	77	16.996	1.42	0.73	1	1	1
Pikes Crossing	Karuah River Basin	Mammy Johnsons River	50 – 200	8	146	10.973	1.36	0.66	1	1	1
Pambula	Mac-Tuggerah Lakes	Dora Creek	0 – 50	6	21	2.351	1.52	0.85	0.83	0.9	0.99
Yarramalong	Mac-Tuggerah Lakes	Wyong River	0 – 50	6	73	3.1	1.66	0.93	1	1	1
Eastbank	Manning River Basin	Dingo Creek	0 – 50	13	186	14.321	2.03	0.79	0.92	0.99	0.99
Karaak Flat	Manning River Basin	Manning River	0 – 50	10	144	34.59	1.84	0.8	0.9	0.95	0.99
Bretti Reserve	Manning River Basin	Barnard River	50 – 200	6	140	71.112	1.47	0.82	1	1	1
Doon Ayre	Manning River Basin	Gloucester River	50 – 200	11	318	52.612	1.86	0.78	0.91	0.95	0.89
Forbesdale	Manning River Basin	Barrington River	50 – 200	8	229	20.939	1.52	0.73	0.89	0.98	0.99
Black Rock	Manning River Basin	Barrington River	200 – 400	6	174	34.338	1.26	0.71	1	1	1
Cooplacurripa	Manning River Basin	Cooplacurripa River	200 – 400	5	198	20.246	0.88	0.55	1	1	1
Terrabanella	Manning River Basin	Rowleys River	200 – 400	3	45	5.128	0.92	0.84	1	1	1
Barry	Manning River Basin	Barnard River	400 – 700	2	91	8.244	0.69	0.99	1	1	1
Glen Ward	Manning River Basin	Manning River	400 – 700	3	110	1.038	0.46	0.42	1	1	1
Linda Downs	Manning River Basin	Nowendoc River	> 700	3	121	8.405	0.44	0.4	0.33	0.12	0.99

3.3.2. 2004 benchmark of fish communities in individual catchments

3.3.2.1. Fish communities of the Hunter catchment

Fish community parameters for individual monitoring sites in the Hunter catchment are presented in Table 3.5. Nineteen fish species were sampled from 11 sites in the Hunter catchment, of which 14 were native species and 5 alien species (Table 3.1). Species richness in the Hunter catchment averaged 6.2 ± 0.8 species per sampling site. Eleven species recorded at the sampling site in the Allyn River increased the average for the lowland zone, and there was a large variation between sites in the upland zone (Figure 3.4).

Whilst highly variable, average numbers of individuals steadily decreased with increasing altitude (Figure 3.5). The average abundance of fish per site in the Hunter catchment was 139 ± 31 individuals. There was much variation in biomass between altitude zones and between sites, but there was a consistently higher biomass in sites within the lowland zone (Figure 3.6). The lowland zone was characterised by the abundance of the larger species, sea mullet and Australian bass (refer section 4.3.1). Abundance was dominated by native fish species (Figure 3.7), but common carp was the second highest contributor to total biomass due to the large size of this species (Figure 3.8).

Average fish diversity across the whole catchment, estimated using Shannon's diversity index (*H*), was low (*H* = 1.2) (Figure 3.9). Seventy-three percent of the fish sampled throughout the catchment belonged to four species; Australian smelt, long-finned eels, sea mullet and gambusia (refer section 4.3.1). The proportions are very different when calculated for biomass as two of these species are relatively small. With biomass, common carp and sea mullet dominated the total fish biomass sampled in the survey (refer section 4.3.1). There were no discernable trends in species evenness which varied between altitudes in the Hunter catchment (Figure 3.10).

All fish species sampled in the coastal zone of the Hunter catchment were native. With the exception of the absence of native species sampled in the highland site, the proportion of native fish species across all other altitude zones was relatively high (90%) (Figure 3.11). Abundance of native fish species was high across altitude zones with the exception of the highland, and exhibited variability in the lowland and upland zones (Figure 3.12). The increased variability in the proportion of biomass contributed by native species in the slopes and upland zones (Figure 3.13) is largely driven by common carp in some of those sites (refer section 4.3.1).

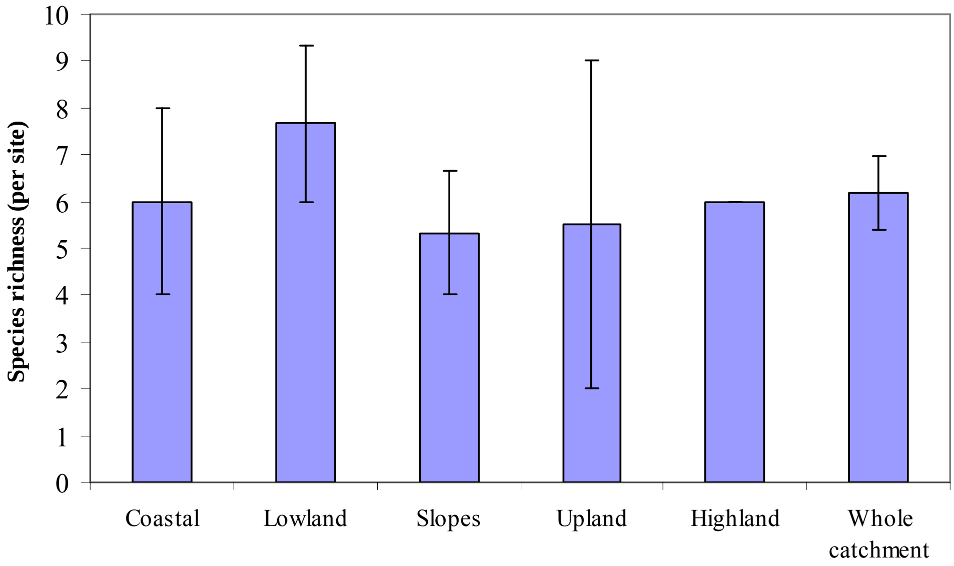

Figure 3.4. Average species richness at sites in each of the five altitude zones and the whole Hunter catchment. Error bars represent the standard error.

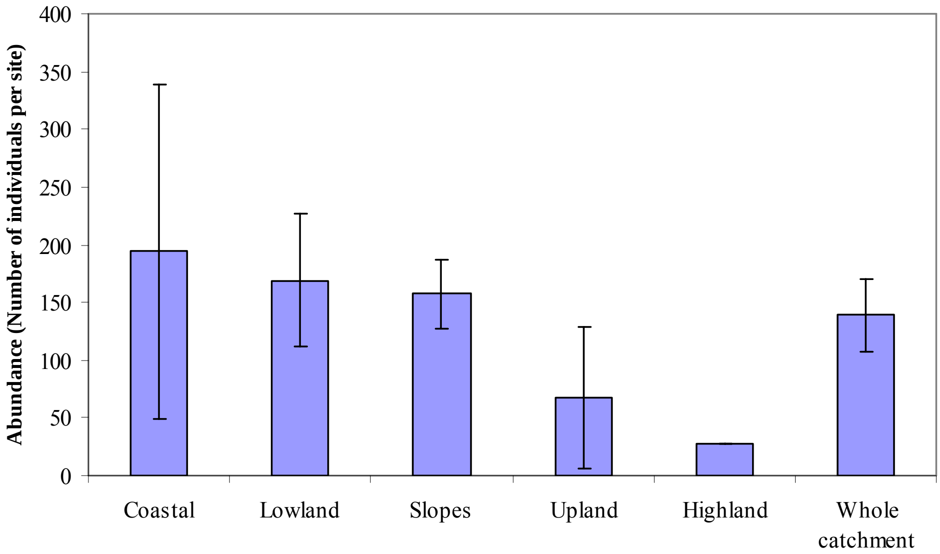

Figure 3.5. Average number of individuals at sites in each of the five altitude zones and the whole Hunter catchment. Error bars represent the standard error.

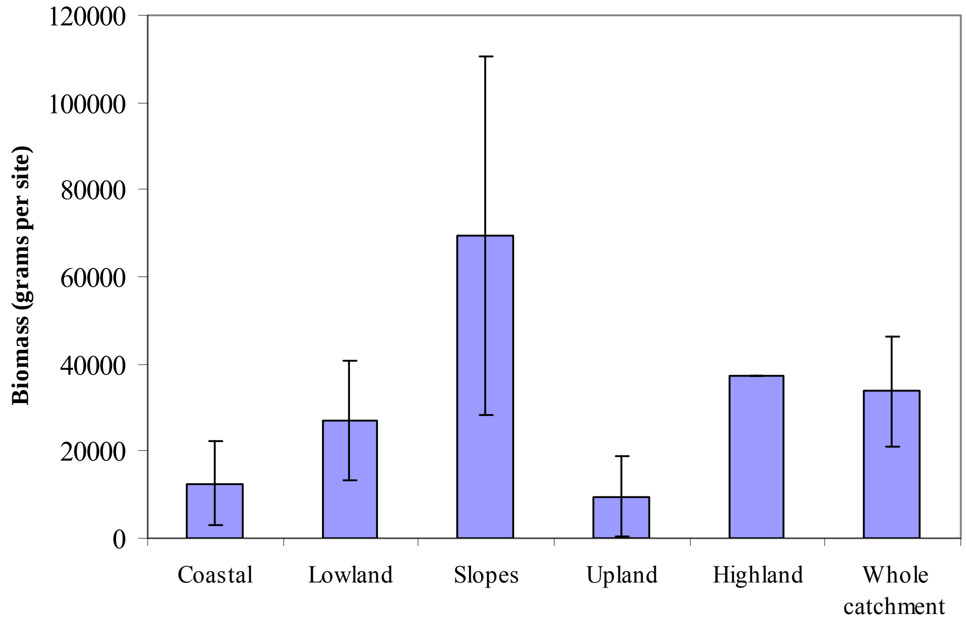

Figure 3.6. Average total biomass at sites in each of the five altitude zones and the whole Hunter catchment. Error bars represent the standard error.

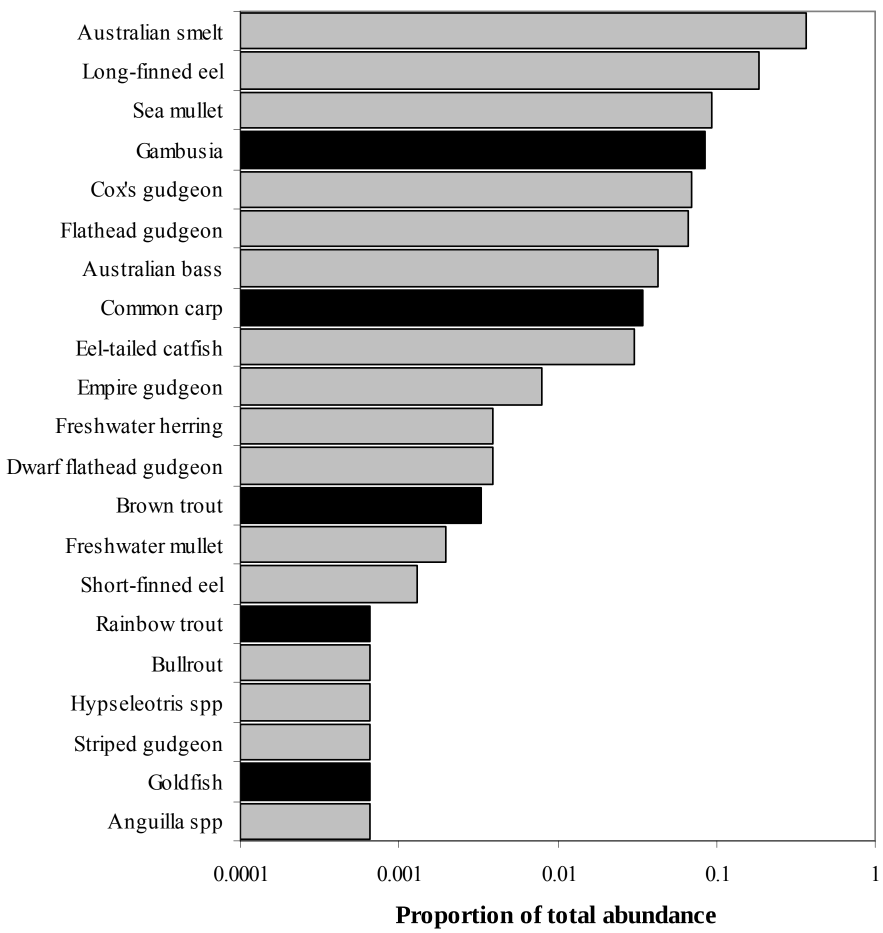

Figure 3.7. Proportion of each species in the total number of individuals (log_{10} scale) sampled throughout the Hunter catchment. Black: Alien species. Grey: Native species.

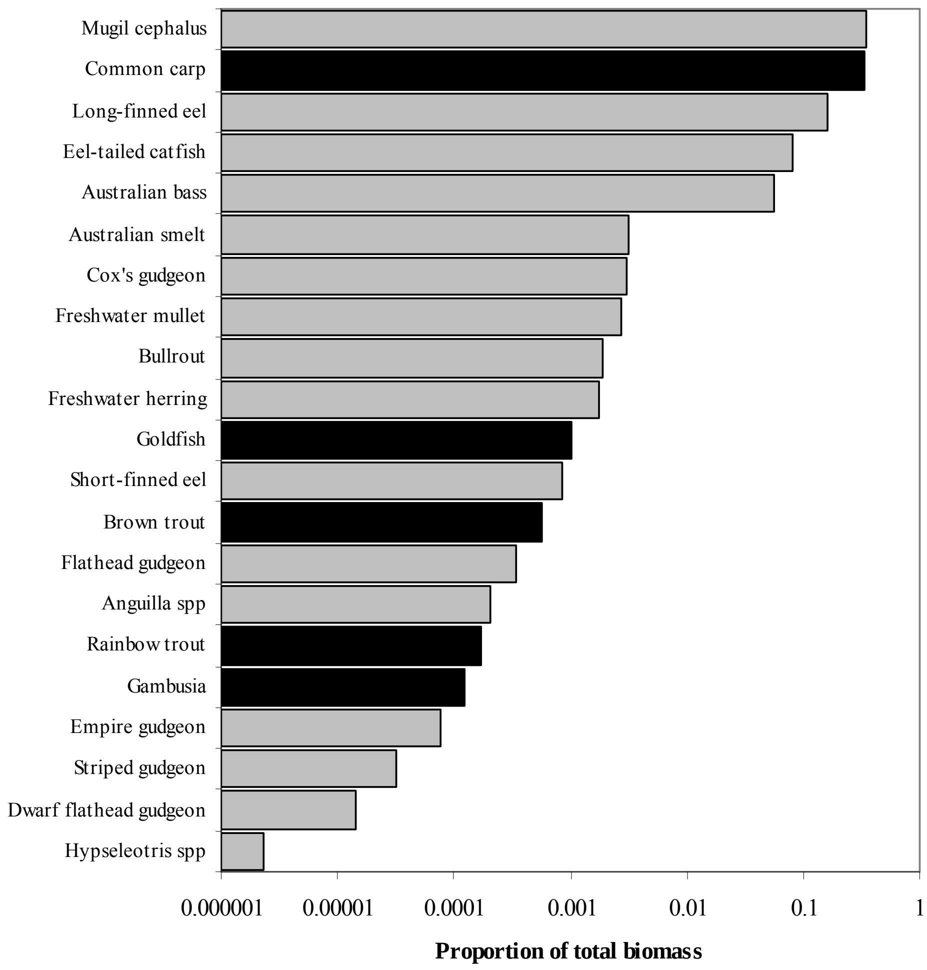

Figure 3.8. Proportion of each species in the total biomass (log_{10} scale) sampled throughout the Hunter catchment. Black: Alien species. Grey: Native species.

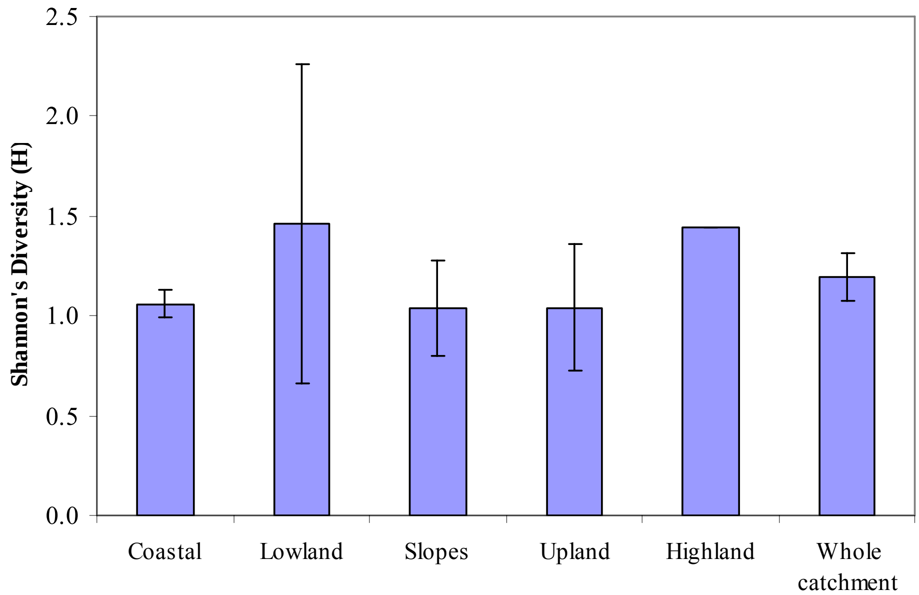

Figure 3.9. Average Shannon's diversity (*H*) at sites in each of the five altitude zones and the whole Hunter catchment. Error bars represent the standard error.

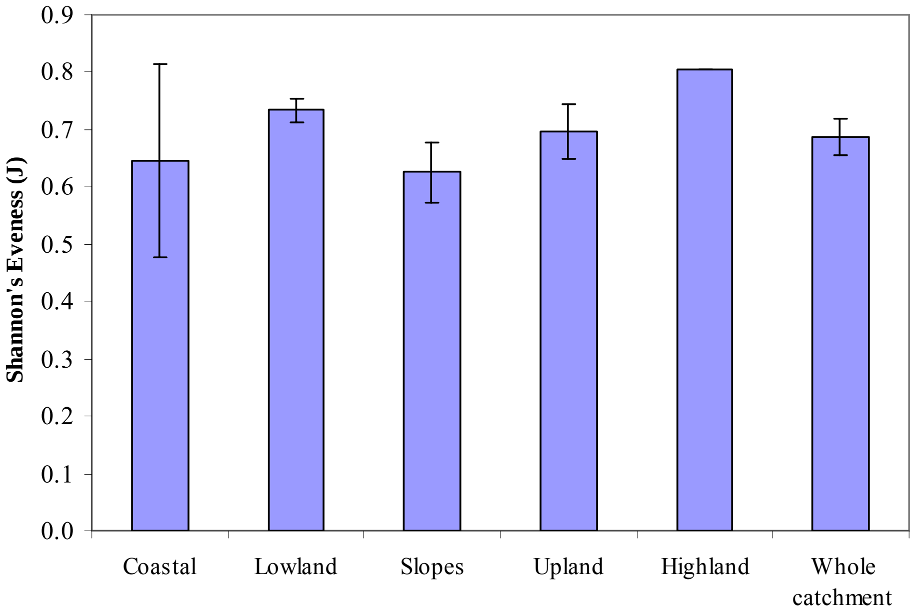

Figure 3.10. Average Shannon's evenness (*J*) at sites in each of the five altitude zones and the whole Hunter catchment. Error bars represent the standard error.

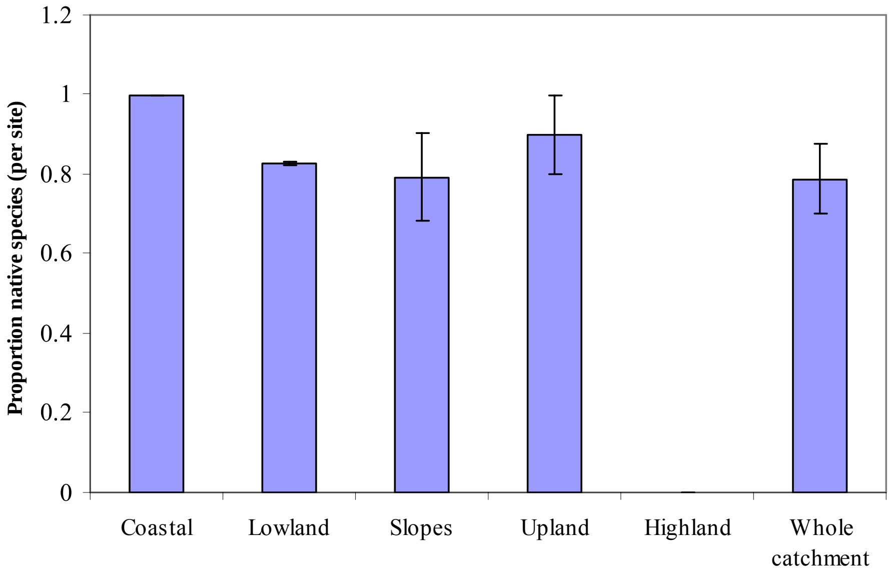

Figure 3.11. Average proportion of species richness which are native at sites in each of the five altitude zones and the whole Hunter catchment. Error bars represent the standard error.

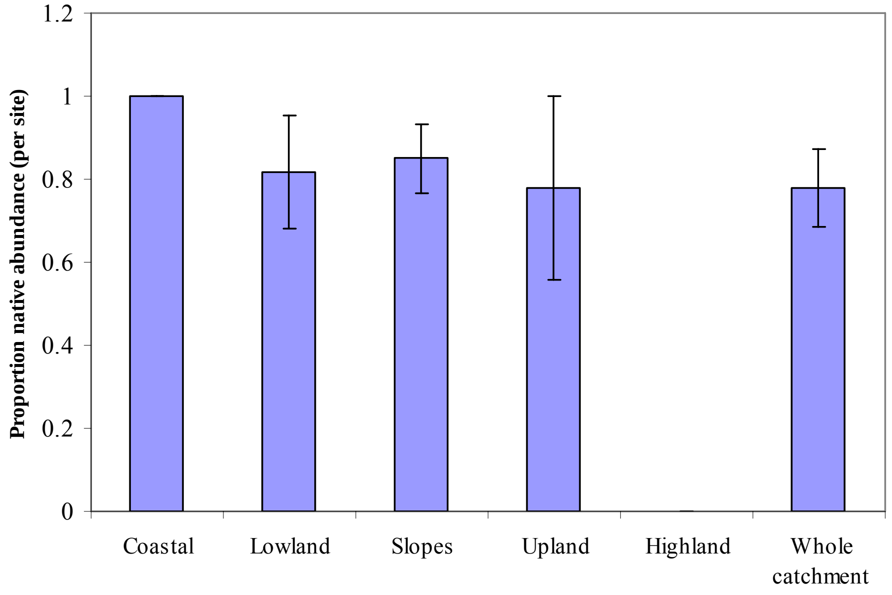

Figure 3.12. Average proportion of total abundance which are native at sites in each of the five altitude zones and the whole Hunter catchment. Error bars represent the standard error.

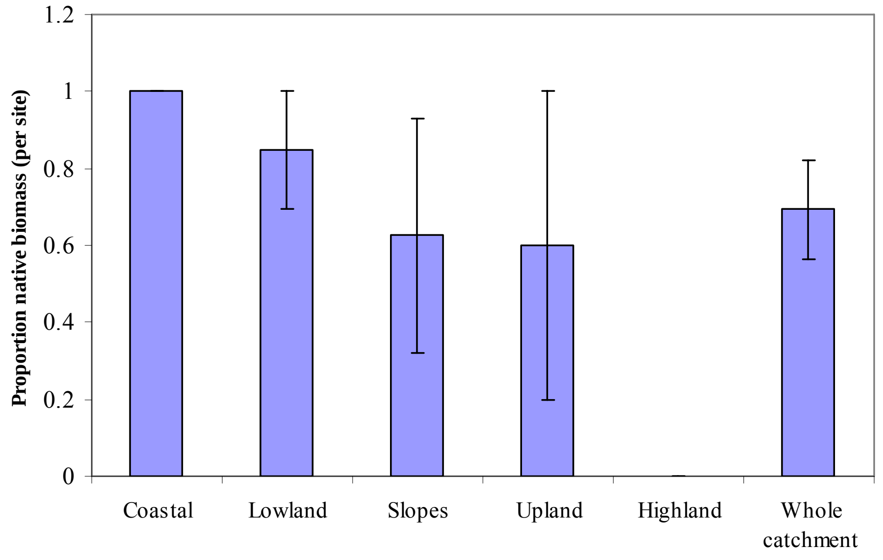

Figure 3.13. Average proportion of total biomass contributed by native species in each of the five altitude zones and the whole Hunter catchment. Error bars represent the standard error.

3.3.2.2. *Fish communities of the Manning catchment*

Fish community parameters for individual monitoring sites in the Hunter catchment are presented in Table 3.5. Sixteen fish species were sampled from 11 sites in the Manning catchment, of which 14 were native species and 2 alien (Table 3.1). Species richness in the Manning catchment averaged 6.4 ± 0.3 species per sampling site. There was a steady decrease in species richness with increasing altitude (Figure 3.14).

Total abundance and biomass of fish increased from the coastal to the lowland zone after which abundance decreased with increasing altitude (Figures 3.15 and 3.16). The average abundance of fish per site in the Manning catchment was 160 ± 22 individuals. These trends are largely explained by the abundance of a small species (Australian smelt) and several large species (sea mullet, freshwater herring and long-finned eels) (refer section 4.3.2). Abundance and biomass were dominated by native species (Figures 3.17 and 3.18).

Average fish diversity across the whole catchment, estimated using Shannon's diversity index (H), was low (H = 1.2) (Figure 3.19). Seventy-five percent of the fish sampled throughout the Manning catchment belonged to four species: Australian smelt, long-finned eels, freshwater mullet and freshwater herring (refer section 4.3.2).

As Shannon's diversity decreased with increasing altitude, evenness became more variable with increasing altitude (Figure 3.20).

All fish species sampled in the slopes and upland zones of the Manning catchment were native. With the exception of the highland site, the proportion of native fish species across all other altitude zones was relatively high (91%) (Figure 3.21). Native species dominated the abundance in all zones except the highland (Figure 3.22), where, large numbers of gambusia in the highland zone dominated the total abundance. Alien fish species contributed little to the total biomass across all altitude zones (Figure 3.23).

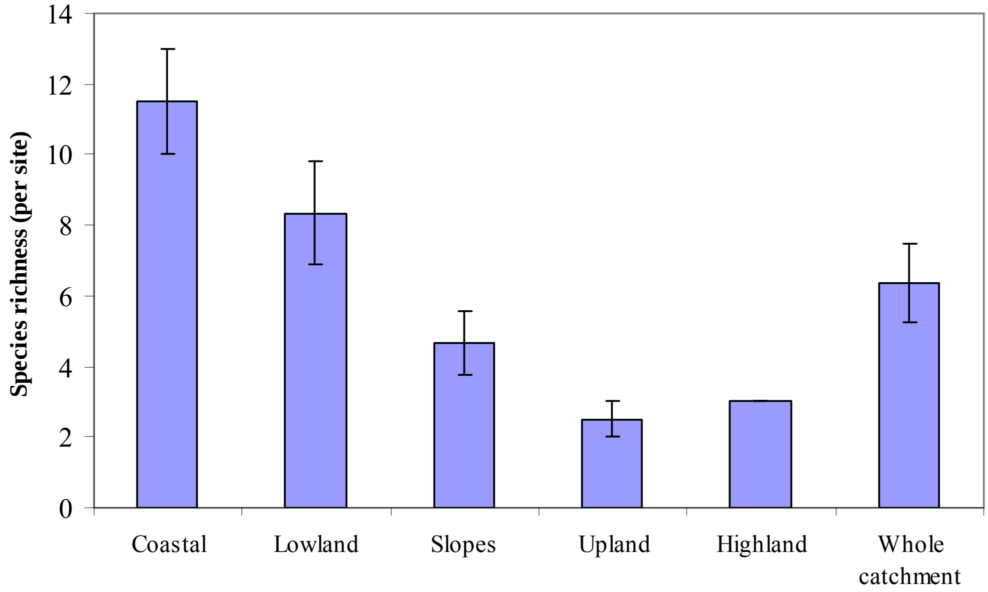

Figure 3.14. Average species richness at sites in each of the five altitude zones and the whole Manning catchment. Error bars represent the standard error.

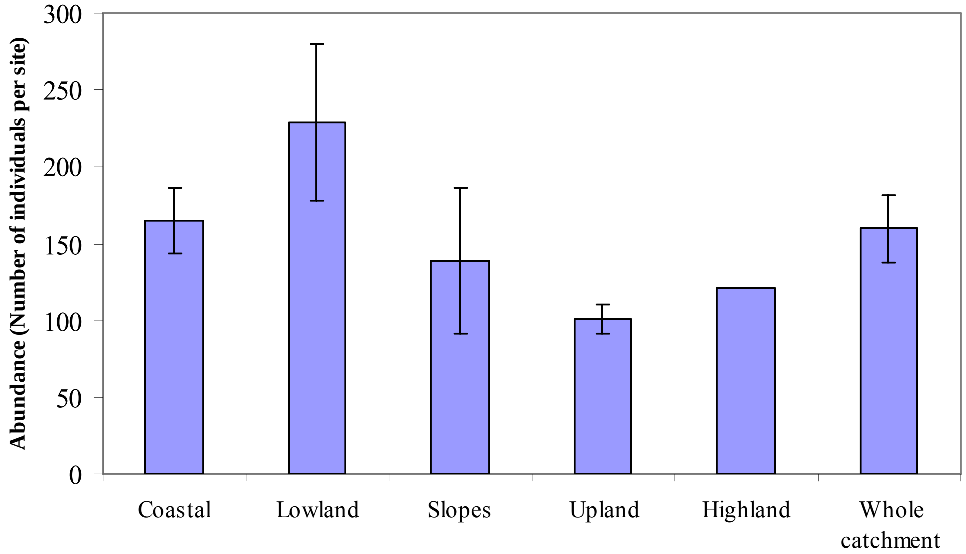

Figure 3.15. Average number of individuals at sites in each of the five altitude zones and the whole Manning catchment. Error bars represent the standard error.

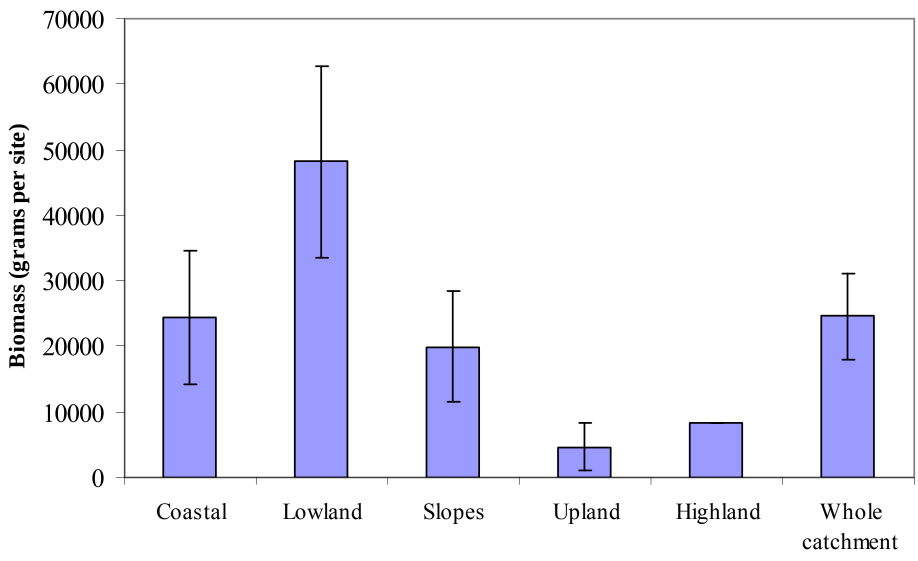

Figure 3.16. Average total biomass at sites in each of the five altitude zones and the whole Manning catchment. Error bars represent the standard error.

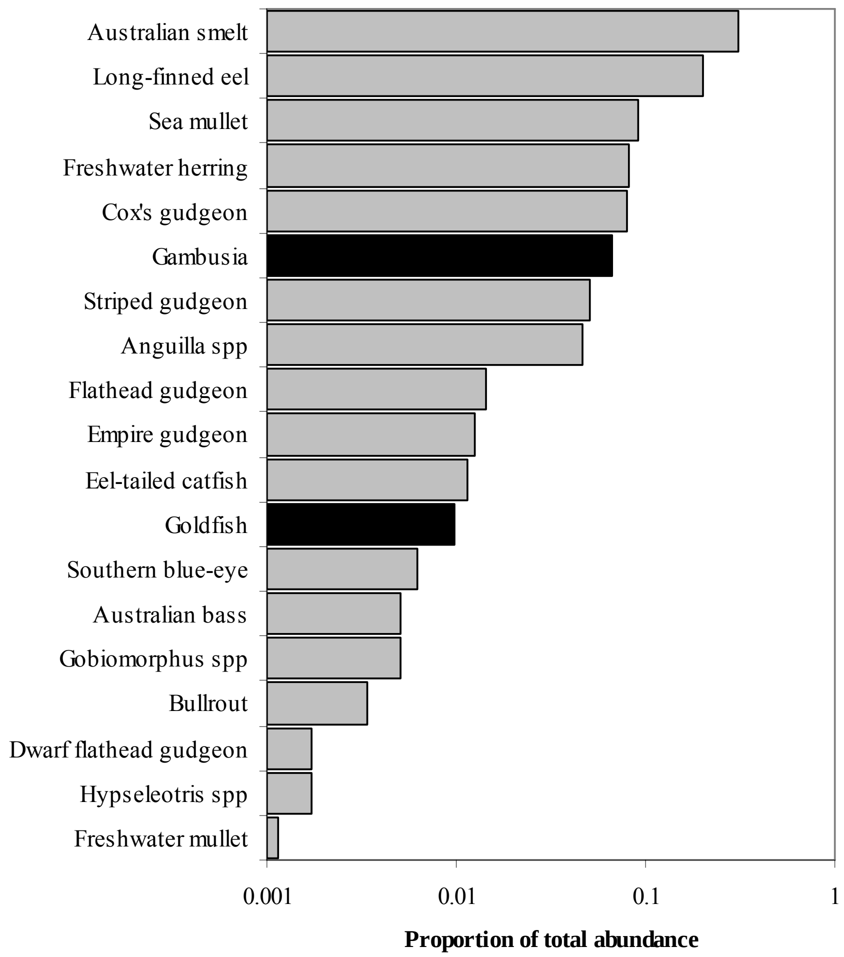

Figure 3.17. Proportion of each species in the total number of individuals (log_{10} scale) sampled throughout the Manning catchment. Black: Alien species. Grey: Native species.

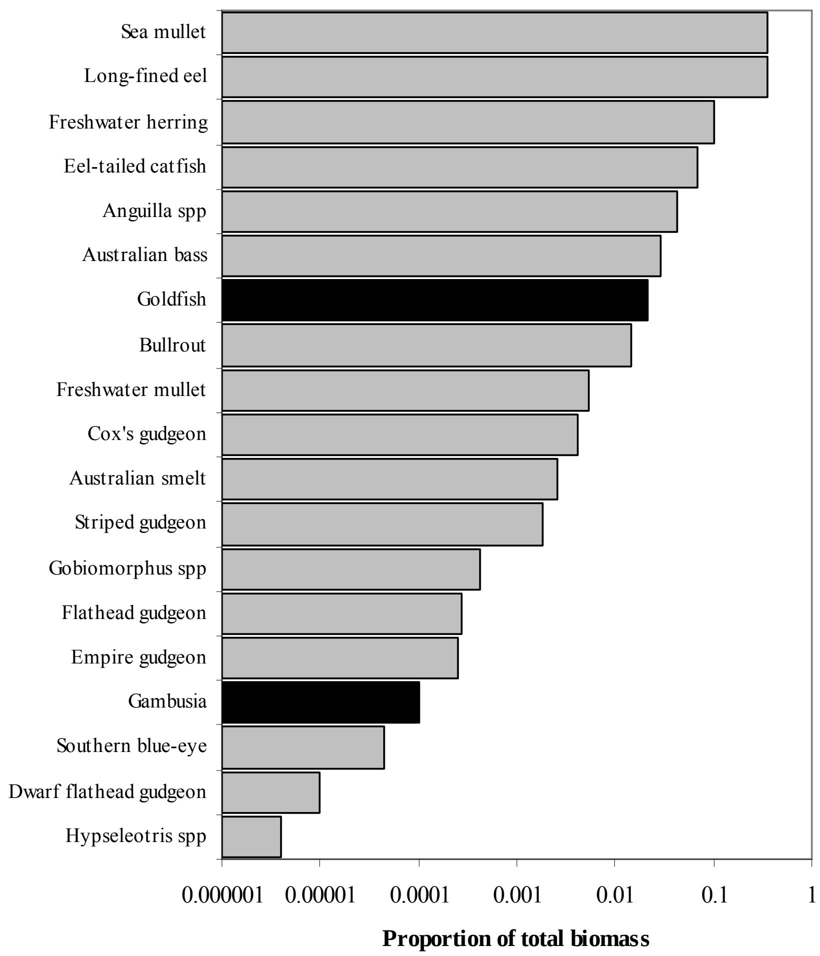

Figure 3.18. Proportion of each species in the total biomass (log_{10} scale) sampled throughout the Manning catchment. Black: Alien species. Grey: Native species.

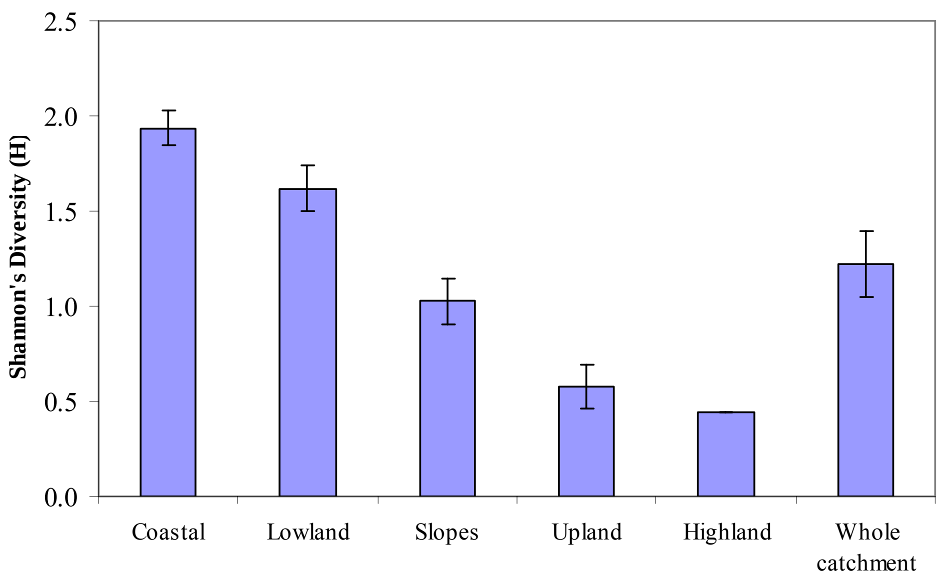

Figure 3.19. Average Shannon's diversity (*H*) at sites in each of the five altitude zones and the whole Manning catchment. Error bars represent the standard error.

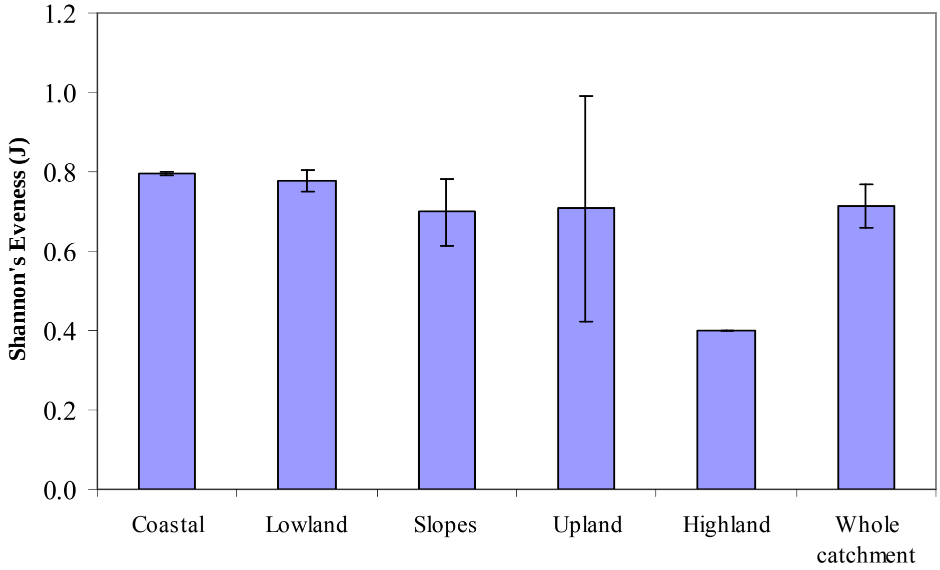

Figure 3.20. Average Shannon's evenness (*J*) at sites in each of the five altitude zones and the whole Manning catchment. Error bars represent the standard error.

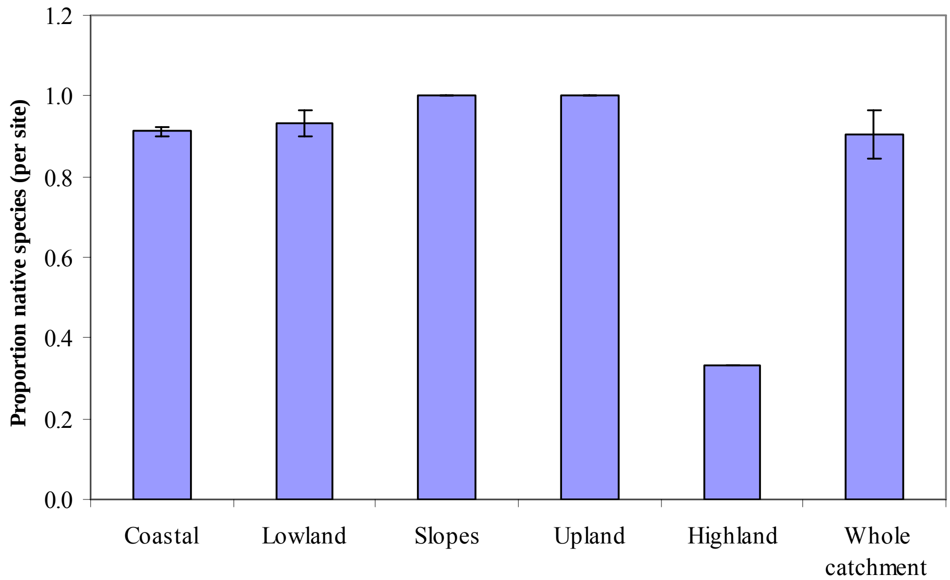

Figure 3.21. Average proportion of species richness which are native at sites in each of the five altitude zones and the whole Manning catchment. Error bars represent the standard error.

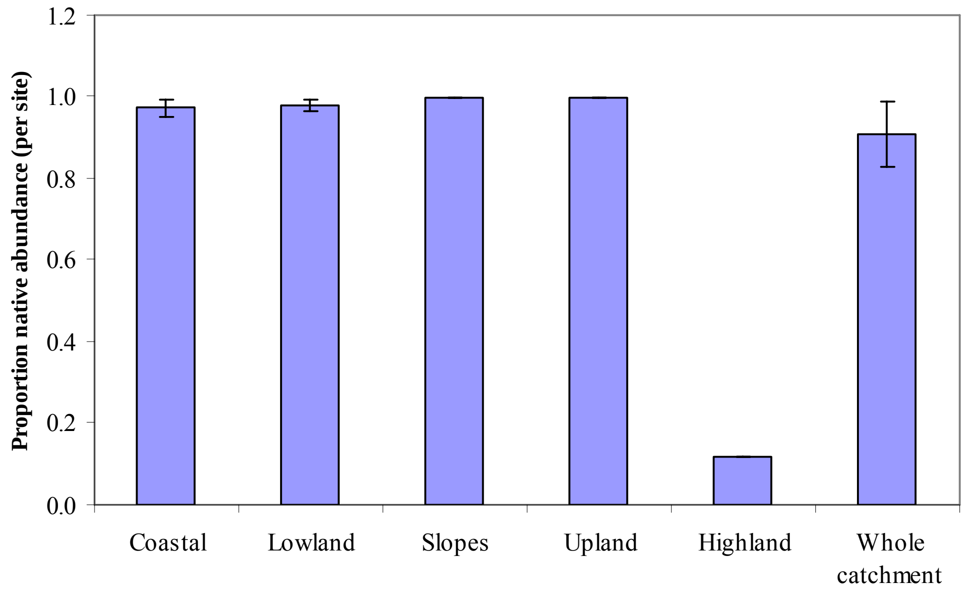

Figure 3.22. Average proportion of total abundance which are native at sites in each of the five altitude zones and the whole Manning catchment. Error bars represent the standard error.

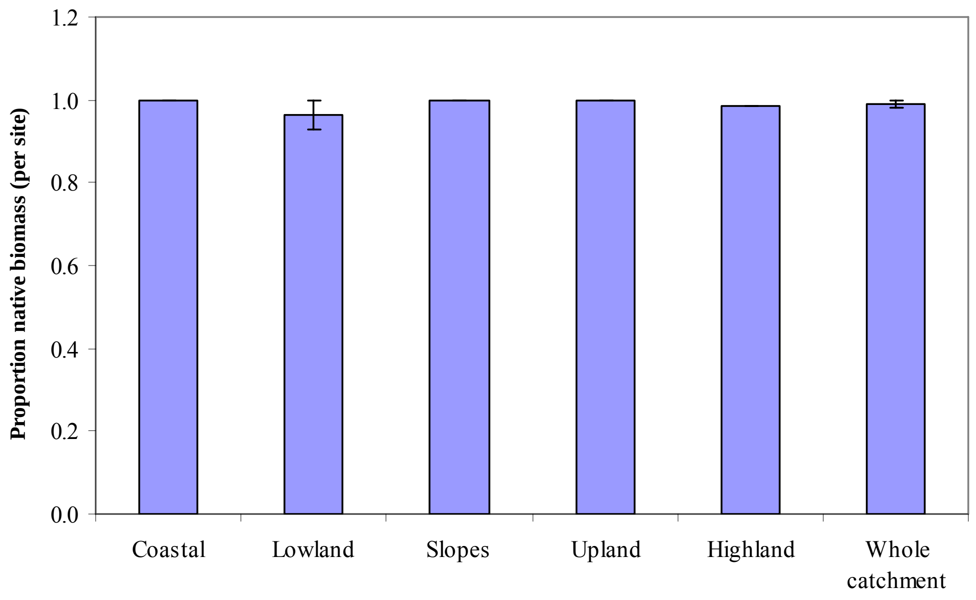

Figure 3.23. Average proportion of total biomass which is contributed by native fish in each of the five altitude zones and the whole Manning catchment. Error bars represent the standard error.

3.3.2.3. Fish communities of the Karuah catchment

Fish community parameters for individual monitoring sites in the Hunter catchment are presented in Table 3.5. Sixteen fish species were sampled from 3 sites in the Karuah catchment, of which 15 were native species and 1 alien (Table 3.1). Species richness in the Karuah catchment averaged 8.7 ± 0.6 species per sampling site. While species richness was higher in the coastal zone, there was some variation between sites (Figure 3.24).

The average abundance of fish per site in the Karuah catchment was 159 ± 52 individuals. The most abundant species was sea mullet, but long-finned eels, Australian smelt, Australian bass, flat head gudgeon and empire gudgeon were also relatively abundant. Abundance of both large and small fish (sea mullet, empire gudgeon and flathead gudgeon) at the Myall River sampling site dominated the variation between the coastal and lowland zones for all analyses (Figures 3.25 – 3.26, 3.29 – 3.33). The biomass (Table 3.2) was dominated by sea mullet and long-finned eels, with Australian bass, freshwater mullet and eel-tailed catfish also making significant contributions. The only alien species recorded, gambusia, did not contribute a significant proportion to total number of individuals (Figure 3.27) or total biomass (Figure 3.28).

Average fish diversity across the whole catchment, estimated using Shannon's diversity index (*H*), was higher in the Karuah catchment (*H* = 1.6) (Figure 3.29) than in the Hunter and Manning catchments (both *H* = 1.2). This is reflected in the broader spread of abundance between species in the Karuah in comparison to the Hunter and Manning catchments (refer sections 4.3.1 – 4.3.3).

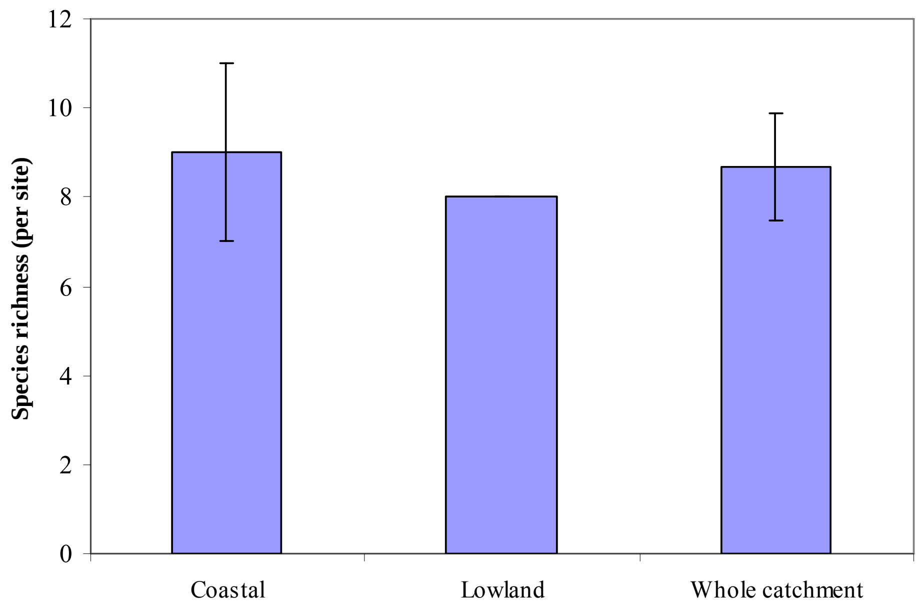

Figure 3.24. Average species richness at sites in both of the two altitude zones and the whole Karuah catchment. Error bars represent the standard error.

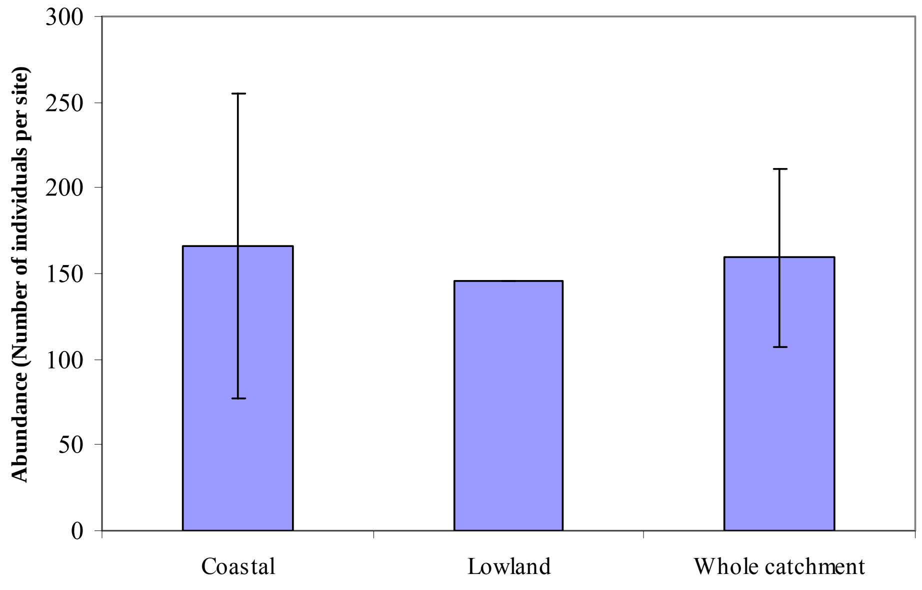

Figure 3.25. Average number of individuals at sites in both of the two altitude zones and the whole Karuah catchment. Error bars represent the standard error.

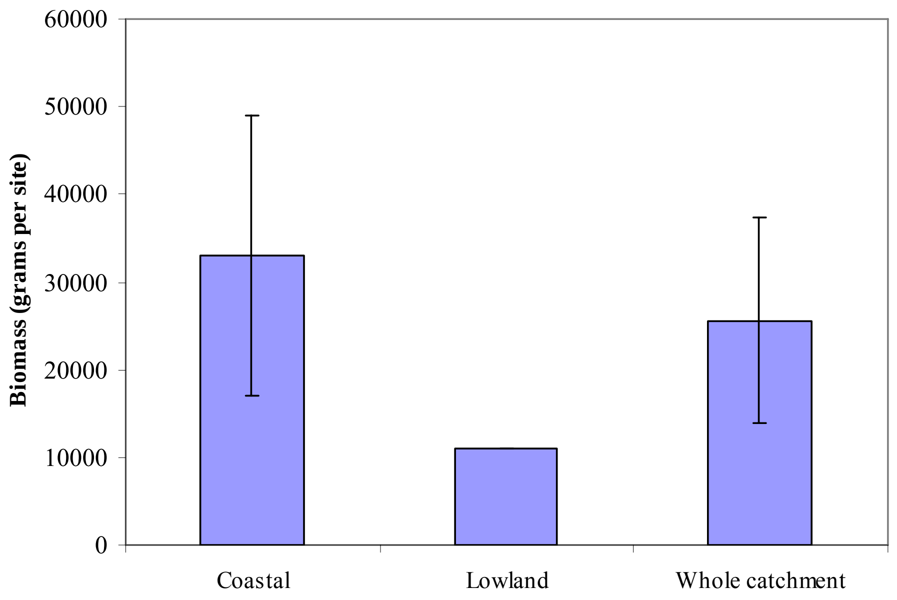

Figure 3.26. Average total biomass at sites in both of the two altitude zones and the whole Karuah catchment. Error bars represent the standard error.

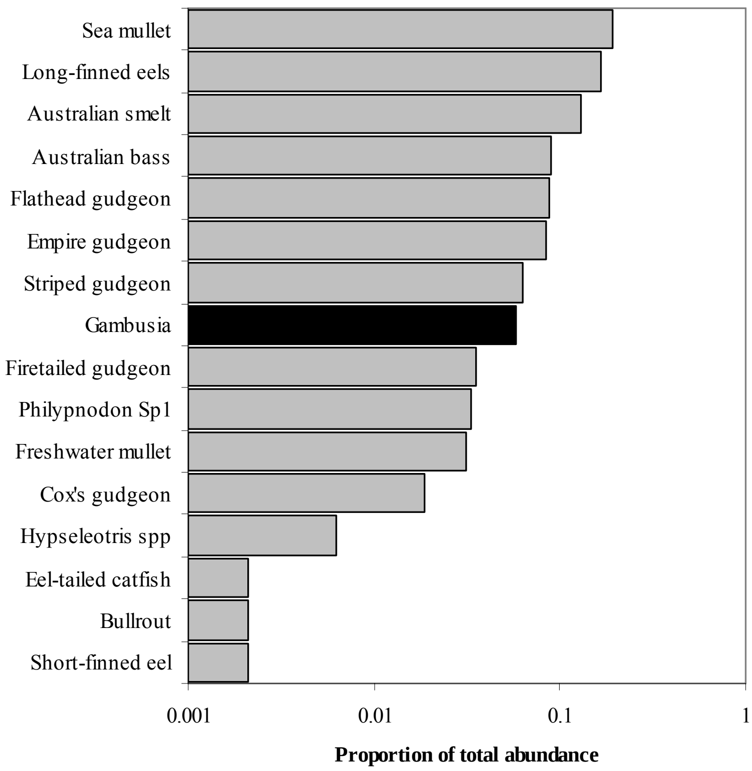

Figure 3.27. Proportion of each species in the total number of individuals (log_{10} scale) sampled throughout the Karuah catchment. Black: Alien species. Grey: Native species.

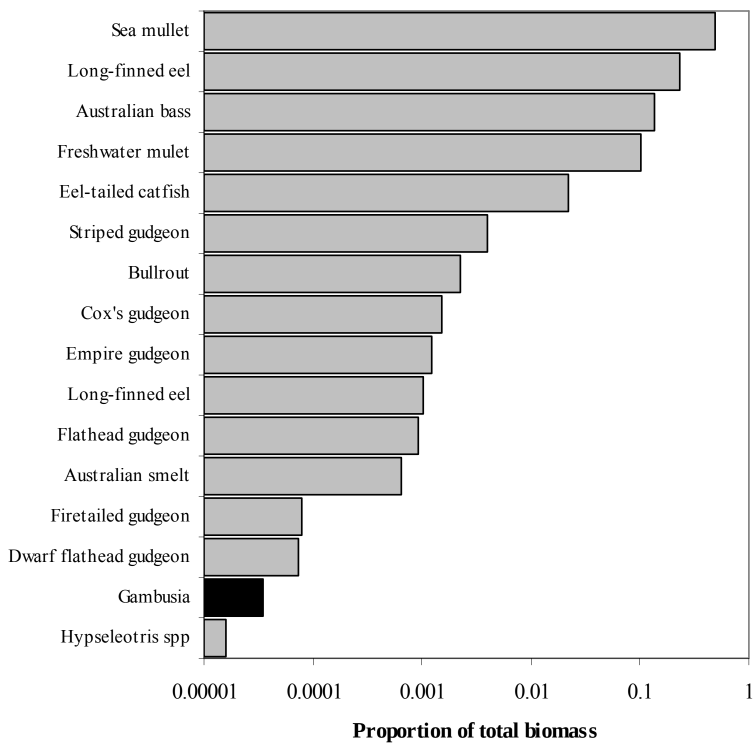

Figure 3.28. Proportion of each species in the total biomass (log_{10} scale) sampled throughout the Karuah catchment. Black: Alien species. Grey: Native species.

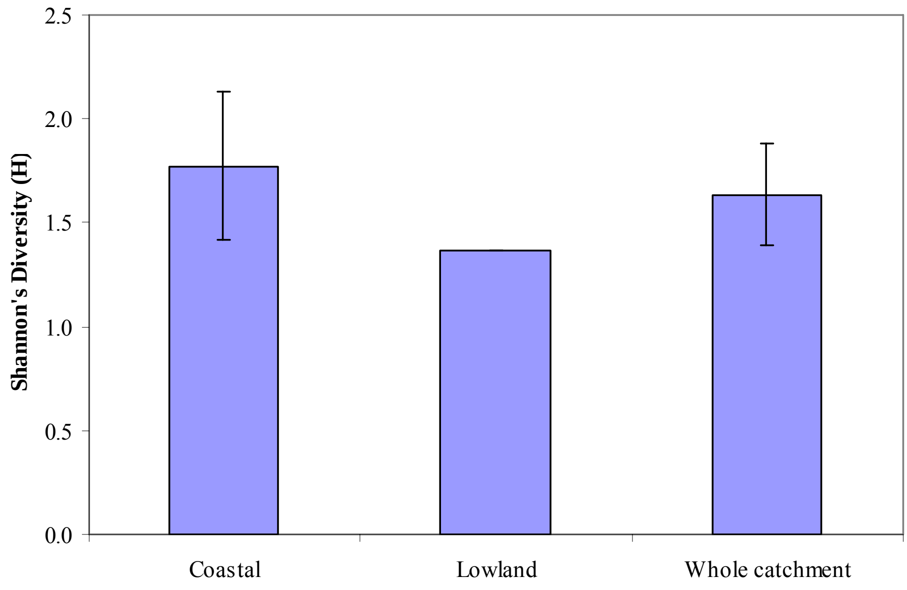

Figure 3.29. Average Shannon's diversity (*H*) at sites in both of the two altitude zones and the whole Karuah catchment. Error bars represent the standard error.

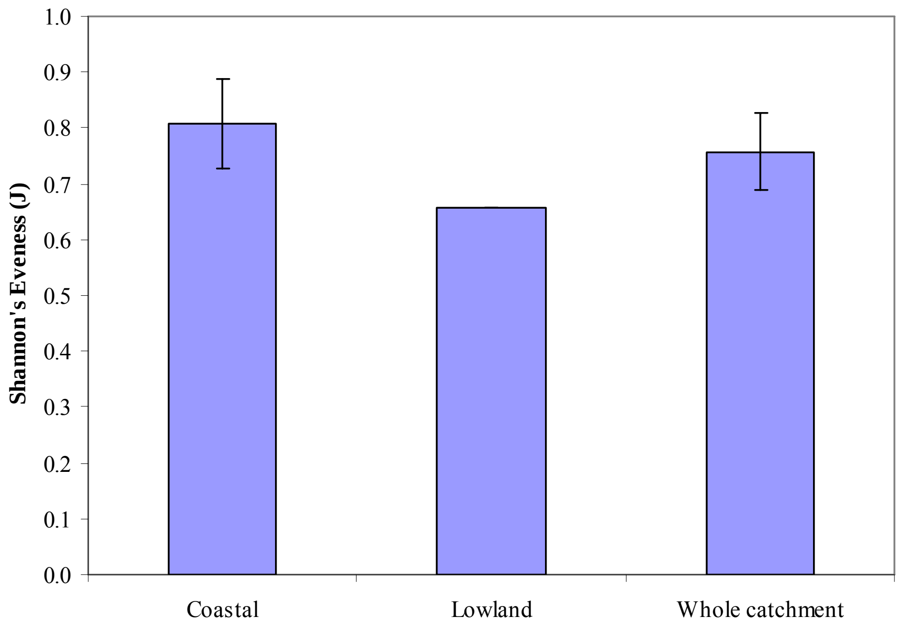

Figure 3.30. Average Shannon's evenness (*J*) at sites in both of the two altitude zones and the whole Karuah catchment. Error bars represent the standard error.

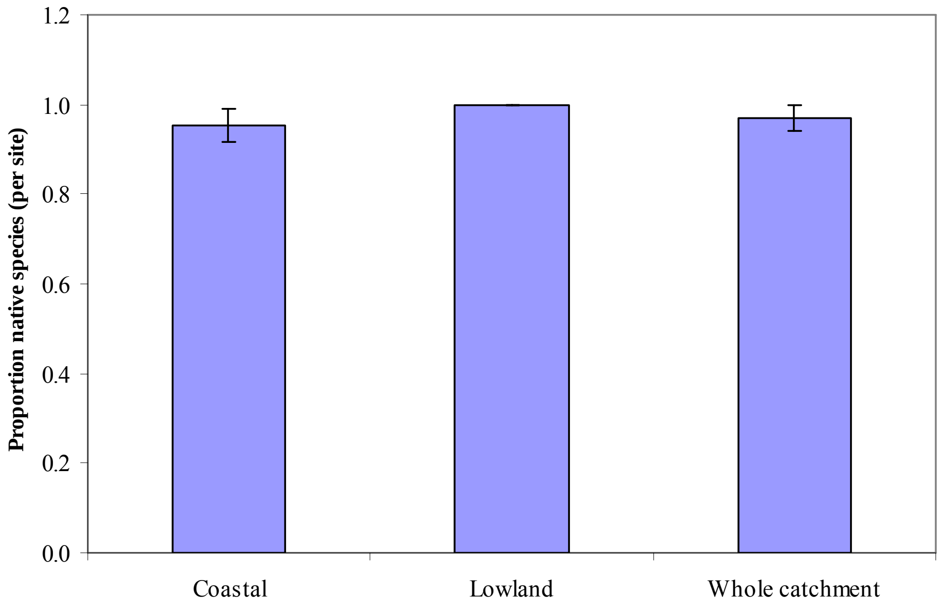

Figure 3.31. Average proportion of species richness which are native at sites in both of the two altitude zones and the whole Karuah catchment. Error bars represent the standard error.

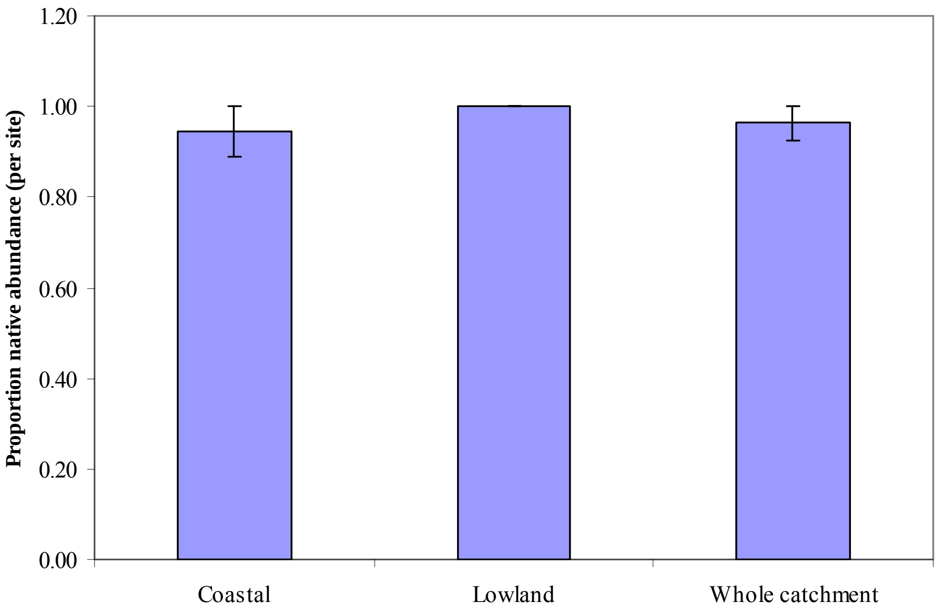

Figure 3.32. Average proportion on total abundance which are native at sites in both of the two altitude zones and the whole Karuah catchment. Error bars represent the standard error.

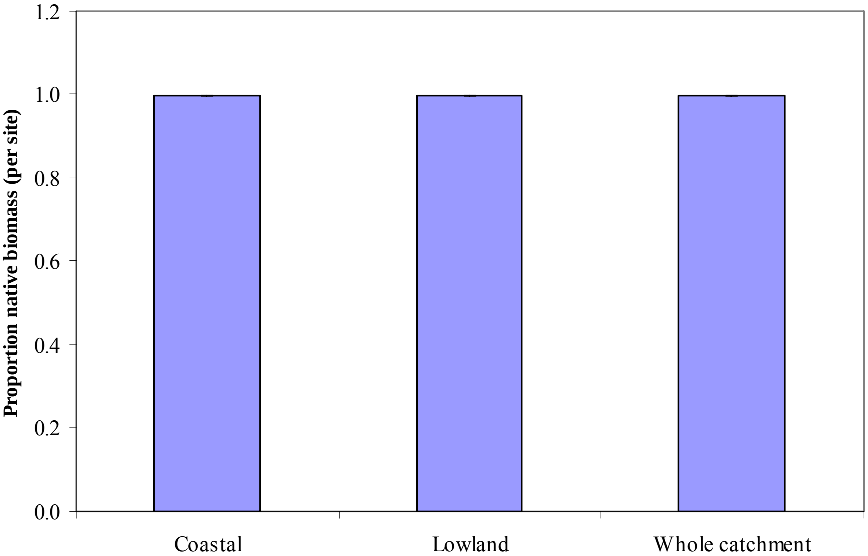

Figure 3.33. Average proportion of total biomass contributed by native fish in both of the two altitude zones and the whole Karuah catchment. Error bars represent the standard error.

3.3.2.4. Fish communities of the Macquarie-Tuggerah catchment

Fish community parameters for individual monitoring sites in the Hunter catchment are presented in Table 3.5. Nine fish species were sampled from 2 sites in the Macquarie-Tuggerah catchment, of which 8 were native and 1 was alien (Table 3.1). Six fish species were sampled at both sites in the Macquarie-Tuggerah catchment.

The average abundance of fish in the two sampling sites was 47 ± 26 individuals which was far lower than the Hunter, Manning and Karuah catchments (Table 3.6). Abundance and biomass were dominated by native fish species in Macquarie-Tuggerah catchment. The most abundant species were striped gudgeon, empire gudgeon and long-finned eels, with Cox's gudgeon and Australian smelt also relatively abundant (refer section 4.3.4). The biomass was dominated by long-finned eels, with striped gudgeon and Cox's gudgeon also making significant contributions (refer section 4.3.4).

Average fish diversity across the whole catchment, estimated using Shannon's diversity index (H), was relatively high (H = 1.6) (Table 3.6). This is reflected in the broad spread of abundance between species in the Macquarie-Tuggerah catchment (refer section 4.3.4). The catchment was dominated by native fish species (Table 3.6). Gambusia was the only alien species caught in the present survey and contributed little to total abundance (Figure 3.34) or total biomass (Figure 3.35).

Given the low percentage of fish caught in 2004 compared to those previously recorded and the range of coastal stream types within this catchment, more intensive sampling is required to adequately benchmark fish communities in the Macquarie-Tuggerah catchment. This is highlighted by the concurrent sampling done for another project in which five species not recorded in the present survey were caught at one site on the lower Wyong River (refer Table 6.4).

Table 3.6. Fish community parameters for the Macquarie-Tuggerah catchment, both sites located in the coastal zone (0 – 50).

Parameter	Value
Species richness (per site)	6 ± 0
Species abundance (per site)	47 ± 26
Species biomass (per site)	2725 ± 375
Species diversity	1.59 ± 0.07
Species evenness	0.89 ± 0.04
Proportion native species	0.89 ± 0.08
Proportion native abundance	0.95 ± 0.05
Proportion native biomass	0.99 ± 0.0002

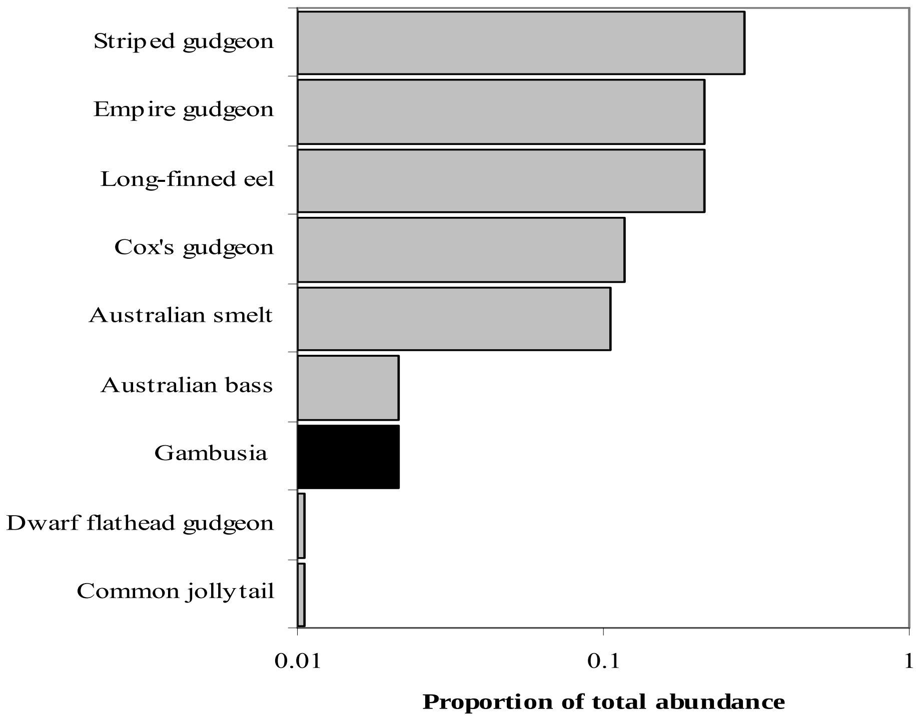

Figure 3.34. Proportion of each species in the total number of individuals (log_{10} scale) sampled at 2 sites in the Macquarie-Tuggerah catchment. Black: Alien species. Grey: Native species.

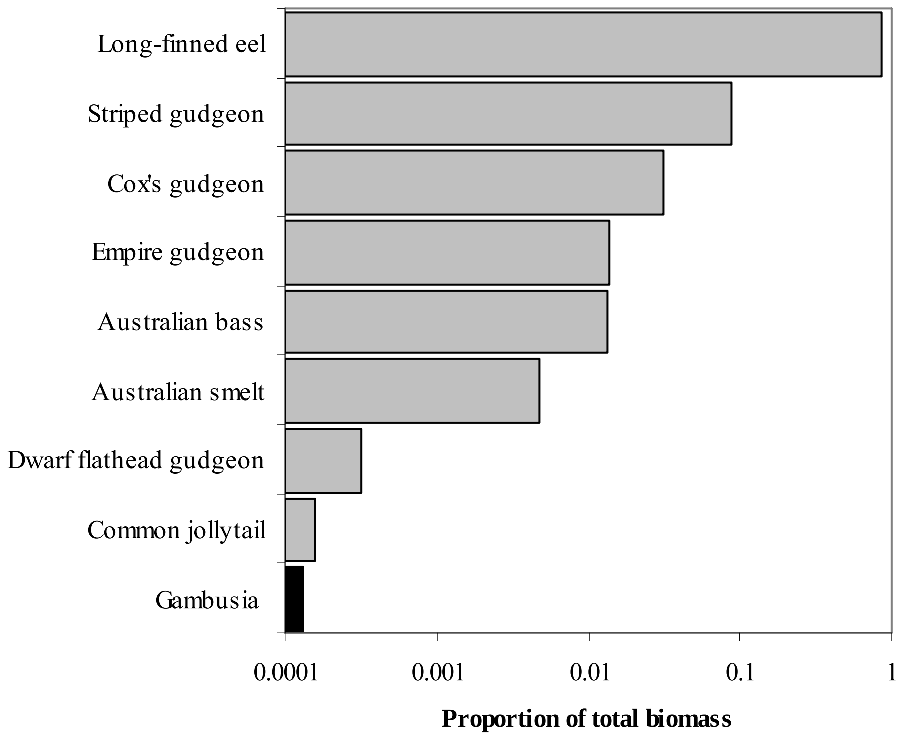

Figure 3.35. Proportion of each species in the total biomass (log_{10} scale) sampled at 2 sites in the Macquarie-Tuggerah catchment. Black: Alien species. Grey: Native species.

4. STATUS OF INDIVIDUAL SPECIES OF THE HUNTER, MANNING, KARUAH AND MACQUARIE-TUGGERAH CATCHMENTS IN 2004

4.1. Introduction

Although assessments of fish community structure are informative for definition of management zones and fish community health, the status of individual components of the fish communities, its species, is also of management interest. For example, if a decline in species richness is observed, it is necessary to identify which species are being lost.

Three aspects of an individual species' status are their abundance within the ecosystem, how widespread or restricted their distribution is and the level of recruitment within the population. Changes in these three parameters provide invaluable data for understanding the underlying mechanisms governing the status of the population. For instance, an increase in the abundance of a species suggests that habitat condition has improved for adults of that species, or an increase in recruitment suggests that suitable spawning cues and rearing habitats are being created. However, the most useful information would be gained from situations where only one of the three parameters changed whilst the other two remained stable. Changes in abundance alone would indicate changes in the habitat condition for adult fish, changes in recruitment alone would indicate changes in spawning cues and/or rearing habitats and changes in distribution alone would indicate restricted dispersal or localised disturbances.

Species could be considered secure only if all three of these factors remain stable through time or increased. However, if any one of these factors declined significantly, that species could be considered at risk. This report benchmarks the former two parameters, but further research needs to be conducted to estimate sizes of fish at one year old (or at sexual maturity for short lived species) to enable future estimates of recruitment.

4.2. Methods

Site selection and sampling followed the protocols and procedures outlined in chapter 2. All data from the 27 monitoring sites were used to benchmark the current status of fish species in each altitude zone for each catchment. Abundance was calculated as both the proportion of individuals and the proportion of total biomass of the sample. Each of these is presented separately. The distribution of each species was calculated as the proportion of sites at which that species was sampled.

4.3. Results and discussion

4.3.1. Hunter catchment

The four most abundant species throughout the Hunter catchment were Australian smelt, long-finned eels, sea mullet and gambusia accounting for 73% of total abundance (Table 4.1). However, there was substantial variation amongst zones, and none of these species were recorded in the highland zone. The rarest taxa were goldfish, striped gudgeon, bullrout and rainbow trout all contributing 0.1% of the total catch.

Australian smelt and Gambusia, which contributed 37% and 8.6% of the total abundance respectively, together contributed to less than 0.1 % of the total biomass due to their small size. Sea mullet (35%), common carp (34%) and long-finned eels (16%) largely dominated the total biomass in the Hunter catchment (Table 4.2), with log-finned eels being recorded in four of the five altitude zones.

The most widespread species was long-finned eels, occurring at 82% of sites sampled and being found in every zone except the highland zone (Table 4.3). The next most widespread species were Australian smelt and Cox's gudgeon, both occurring at 73% of sites and sampled from all zones, except the highland zone. The least widespread species were striped gudgeon, freshwater mullet, bullrout, rainbow trout and brown trout, each being found at only one site (Table 4.3). The one sampling site from the highland zone was totally dominated by brown trout and rainbow trout.

Table 4.1. Proportion of each species in the total catch within altitude zones in the Hunter catchment.

Altitude Zone	Coastal	Lowland	Slopes	Upland	Highland	Totals	Rank (total)
Native species							
Anguilla spp	0	0	0	0.013	0	0.001	16
Australian bass	0.22	0.022	0	0.079	0	0.043	7
Australian smelt	0.225	0.48	0.294	0.066	0	0.368	1
Bullrout	0	0.001	0	0	0	0.001	16
Cox's gudgeon	0.079	0.088	0.008	0.237	0	0.069	5
Dwarf flat head gudgeon	0.005	0.006	0	0	0	0.004	11
Eel-tailed catfish	0	0.034	0.032	0.066	0	0.031	9
Empire gudgeon	0.01	0.005	0.013	0	0	0.008	10
Flat head gudgeon	0	0.001	0.201	0.066	0	0.066	6
Freshwater herring	0.021	0.003	0	0	0	0.004	11
Freshwater mullet	0.016	0	0	0	0	0.002	14
Hypseleotris spp	0	0	0.002	0	0	0.001	16
Long-finned eel	0.236	0.221	0.083	0.303	0	0.183	2
Sea mullet	0.152	0.029	0.191	0	0	0.093	3
Short-finned eel	0	0.001	0	0.013	0	0.001	15
Striped gudgeon	0.005	0	0	0	0	0.001	16
Alien Species							
Brown trout	0	0	0	0	0.833	0.003	13
Common carp	0	0.008	0.074	0.158	0	0.035	8
Gambusia	0.031	0.1	0.1	0	0	0.086	4
Goldfish	0	0	0.002	0	0	0.001	16
Rainbow trout	0	0	0	0	0.167	0.001	16

Table 4.2. Proportion of each species in the total biomass within altitude zones in the Hunter catchment.

Altitude Zone	Coastal	Lowland	Slopes	Upland	Highland	Totals	Rank (total)
Native species							
Anguilla spp	0	0	0	0.002	0	< 0.001	15
Australian bass	0.32	0.096	0	0.099	0	0.056	5
Australian smelt	0.003	0.007	0.002	< 0.001	0	0.003	6
Bullrout	0	0.007	0	0	0	0.002	9
Cox's gudgeon	0.005	0.006	< 0.001	0.008	0	0.003	7
Dwarf flat head gudgeon	< 0.001	< 0.001	0	0	0	< 0.001	20
Eel-tailed catfish	0	0.256	0.003	0.082	0	0.08	4
Empire gudgeon	< 0.001	< 0.001	< 0.001	0	0	< 0.001	18
Flat head gudgeon	0	< 0.001	< 0.001	0.001	0	< 0.001	14
Freshwater herring	0.015	0.003	0	0	0	0.002	10
Freshwater mullet	0.047	0	0	0	0	0.003	8
Hypseleotris spp	0	0	< 0.001	0	0	< 0.001	21
Long-finned eel	0.426	0.41	0.027	0.068	0	0.159	3
Sea mullet	0.183	0.082	0.563	0	0	0.349	1
Short-finned eel	0	0.002	0	0.003	0	0.001	12
Striped gudgeon	0.001	0	0	0	0	< 0.001	19
Alien species							
Brown trout	0	0	0	0	0.77	< 0.001	13
Common carp	0	0.129	0.402	0.737	0	0.341	2
Gambusia	< 0.001	< 0.001	< 0.001	0	0	< 0.001	17
Goldfish	0	0	0.002	0	0	0.001	11
Rainbow trout	0	0	0	0	0.23	< 0.001	16

Table 4.3. Proportion of sites within altitude zones across the Hunter catchment in which each species was sampled.

Altitude Zone	Coastal	Lowland	Slopes	Upland	Highland	Totals	Rank (total)
Native species							
Anguilla spp	0	0	0	0.5	0	0.091	14
Australian bass	0.5	1	0	0.5	0	0.455	5
Australian smelt	1	1	0.667	0.5	0	0.727	2
Bullrout	0	0.333	0	0	0	0.091	14
Cox's gudgeon	1	1	0.667	0.5	0	0.727	2
Dwarf flat head gudgeon	0.5	0.333	0	0	0	0.182	11
Eel-tailed catfish	0	1	0.667	1	0	0.636	4
Empire gudgeon	0.5	0.333	0.333	0	0	0.273	9
Flat head gudgeon	0	0.333	0.333	0.5	0	0.273	9
Freshwater herring	0.5	0.333	0	0	0	0.182	11
Freshwater mullet	0.5	0	0	0	0	0.091	14
Hypseleotris spp	0	0	0.333	0	0	0.091	14
Long-finned eel	1	1	1	0.5	0	0.818	1
Sea mullet	1	0.333	0.333	0	0	0.364	6
Short-finned eel	0	0.333	0	0.5	0	0.182	11
Striped gudgeon	0.5	0	0	0	0	0.091	14
Alien species							
Brown trout	0	0	0	0	1	0.091	14
Common carp	0	0.333	0.667	0.5	0	0.364	6
Gambusia	0.5	0.667	0.333	0	0	0.364	6
Goldfish	0	0	0.333	0	0	0.091	14
Rainbow trout	0	0	0	0	1	0.091	14

4.3.2. Manning catchment

Australian smelt (31%) and long-finned eels (21%) were the two most numerous species in the Manning catchment (Table 4.4). While both species were found in the lower four altitude zones, long-finned eels were also sampled in the highland zone. A second group of fish species (sea mullet, freshwater herring, Cox's gudgeon, gambusia and striped gudgeon) accounted for 37% of the total abundance but there was a substantial variation amongst altitude zones (Table 4.4). The three rarest taxa were bullrout, freshwater mullet and dwarf flat head gudgeon together contributing less than 1% of the total abundance of fish in the catchment (Table 4.4).

Total biomass in the Manning catchment was dominated by sea mullet (36%) and long-finned eels (35%) (Table 4.5). Freshwater herring (10%) and eel-tailed catfish (7%) had the third and fourth highest biomass (Table 4.5). These four species together contributed 88% of the total biomass, although there was some variation among altitude zones.

Long-finned eel was the most widespread fish species occurring at all sites sampled (Table 4.6) in the Manning catchment. The next most widespread species was Cox's gudgeon occurring at all sites except in the highland zone (Table 4.6). Australian smelt occurred in 82% of all sites sampled, but was not sampled in the highland zone (Table 4.6). Freshwater mullet and bullrout were the two least widespread species, being only sampled at one site each.

Table 4.4. Proportion of each species in the total catch within altitude zones in the Manning catchment.

Altitude Zone	Coastal	Lowland	Slopes	Upland	Highland	Totals	Rank (total)
Native species							
Anguilla spp	0	0.023	0.077	0.144	0.033	0.046	8
Australian bass	0.018	0.004	0	0	0	0.005	14
Australian smelt	0.218	0.313	0.392	0.478	0	0.311	1
Bullrout	0.018	0	0	0	0	0.003	16
Cox's gudgeon	0.067	0.048	0.085	0.244	0	0.079	5
Dwarf flat head gudgeon	0.003	0.001	0.002	0	0	0.002	17
Eel-tailed catfish	0	0.022	0.012	0	0	0.011	11
Empire gudgeon	0.021	0.022	0	0	0	0.013	10
Flat head gudgeon	0.012	0.03	0	0	0	0.014	9
Freshwater herring	0.061	0.142	0.061	0	0	0.081	4
Freshwater mullet	0.006	0	0	0	0	0.001	19
Gobiomorphus spp	0	0	0.007	0.03	0	0.005	14
Hypseleotris spp	0.009	0	0	0	0	0.002	17
Long-finned eel	0.127	0.187	0.358	0.104	0.083	0.199	2
Sea mullet	0.203	0.133	0.005	0	0	0.092	3
Southern blue-eye	0.021	0.006	0	0	0	0.006	13
Striped gudgeon	0.191	0.039	0	0	0	0.051	7
Alien species							
Gambusia	0.024	0.007	0	0	0.868	0.067	6
Goldfish	0	0.022	0	0	0.017	0.01	12

Table 4.5. Proportion of each species in the total biomass within altitude zones in the Manning catchment.

Altitude Zone	**Coastal**	**Lowland**	**Slopes**	**Upland**	**Highland**	**Totals**	**Rank (total)**
Native species							
Anguilla spp	0	0.039	0.052	0.242	0.056	0.042	5
Australian bass	0.11	0.017	0	0	0	0.029	6
Australian smelt	0.003	0.003	0.002	0.007	0	0.003	11
Bullrout	0.08	0	0	0	0	0.014	8
Cox's gudgeon	0.003	0.001	0.004	0.061	0	0.004	10
Dwarf flat head gudgeon	< 0.001	< 0.001	< 0.001	0	0	0	18
Eel-tailed catfish	0	0.087	0.101	0	0	0.069	4
Empire gudgeon	< 0.001	< 0.001	0	0	0	0	15
Flat head gudgeon	< 0.001	< 0.001	0	0	0	0	14
Freshwater herring	0.058	0.122	< 0.001	0	0	0.102	3
Freshwater mullet	0.03	0	0	0	0	0.005	9
Gobiomorphus spp	0	0	< 0.001	0.008	0	0	13
Hypseleotris spp	< 0.001	0	0	0	0	0	19
Long-finned eel	0.127	0.227	0.695	0.683	0.929	0.35	2
Sea mullet	0.583	0.462	0.024	0	0	0.357	1
Southern blue-eye	< 0.001	< 0.001	0	0	0	0	17
Striped gudgeon	0.006	0.001	0	0	0	0.002	12
Alien species							
Gambusia	< 0.001	< 0.001	0	0	0.003	0	16
Goldfish	0	0.039	0	0	0.012	0.021	7

Table 4.6. Proportion of sites within altitude zones across the Manning catchment in which each species was sampled.

Altitude Zone	Coastal	Lowland	Slopes	Upland	Highland	Totals	Rank (total)
Native species							
Anguilla spp	0	0.333	0.667	0.5	1	0.455	6
Australian bass	1	0.667	0	0	0	0.364	7
Australian smelt	1	1	1	0.5	0	0.818	3
Bullrout	0.5	0	0	0	0	0.091	17
Cox's gudgeon	1	1	1	1	0	0.909	2
Dwarf flat head gudgeon	0.5	0.333	0.333	0	0	0.273	10
Eel-tailed catfish	0	0.333	0.333	0	0	0.182	13
Empire gudgeon	1	0.333	0	0	0	0.273	10
Flat head gudgeon	0.5	0.333	0	0	0	0.182	13
Freshwater herring	1	1	0.333	0	0	0.545	4
Freshwater mullet	0.5	0	0	0	0	0.091	17
Gobiomorphus spp	0	0	0.667	0.5	0	0.273	10
Hypseleotris spp	0.5	0	0	0	0	0.091	17
Long-finned eel	1	1	1	1	1	1	1
Sea mullet	1	0.667	0.667	0	0	0.545	4
Southern blue-eye	0.5	0.333	0	0	0	0.182	13
Striped gudgeon	1	0.667	0	0	0	0.364	7
Alien species							
Gambusia	1	0.333	0	0	1	0.364	7
Goldfish	0	0.333	0	0	1	0.182	13

4.3.3. Karuah catchment

The three most abundant fish species in the Karuah catchment were sea mullet (19%), long-finned eels (16%) and Australian smelt (13%) (Table 4.7). However, there was substantial variation in the presence/absence within altitude zones and variation of abundance between the two zones. Australian bass (9%) and flat head gudgeon (9%) were also abundant throughout the catchment (Table 4.7). Although abundant, empire gudgeon (8%) were only recorded in the coastal zone (Table 4.7). The two rarest taxa were bullrout and eel-tailed catfish which together accounted for less than 0.5% of all fish sampled.

Sea mullet (50%) dominated the biomass in the Karuah catchment (Table 4.8). Together, long-finned eels (23%), Australian bass (14%) and freshwater mullet (10%) accounted for most of the remaining biomass (Table 4.8).

Australian bass, long-finned eels and freshwater mullet were found at all three sites sampled in the Karuah catchment (Table 4.9). Cox's gudgeon, empire gudgeon, flat head gudgeon and sea mullet were all recorded in two of the three sites (Table 4.9). The remaining species were only recorded at one site each in the present survey.

Table 4.7. Proportion of each species in the total catch within altitude zones in the Karuah catchment.

Altitude Zone	Coastal	Lowland	Totals	Rank (total)
Native species				
Australian bass	0.084	0.103	0.09	4
Australian smelt	0	0.425	0.13	3
Bullrout	0	0.007	0.002	14
Cox's gudgeon	0.006	0.048	0.019	12
Dwarf flat head gudgeon	0.048	0	0.033	10
Eel-tailed catfish	0.003	0	0.002	14
Empire gudgeon	0.12	0	0.084	6
Fire-tail gudgeon	0.051	0	0.036	9
Flat head gudgeon	0.117	0.021	0.088	5
Freshwater mullet	0.039	0.014	0.031	11
Hypseleotris spp	0	0.021	0.006	13
Long-finned eel	0.078	0.363	0.165	2
Sea mullet	0.274	0	0.19	1
Short-finned eel	0.003	0	0.002	14
Striped gudgeon	0.09	0	0.063	7
Alien species				
Gambusia	0.084	0	0.059	8

Table 4.8. Proportion of each species in the total biomass within altitude zones in the Karuah catchment.

Altitude Zone	Coastal	Lowland	Totals	Rank (total)
Native species				
Australian bass	0.108	0.295	0.135	3
Australian smelt	0	0.005	0.001	12
Bullrout	0	0.016	0.002	7
Cox's gudgeon	< 0.001	0.009	0.002	8
Dwarf flat head gudgeon	< 0.001	0	0	14
Eel-tailed catfish	0.025	0	0.022	5
Empire gudgeon	0.001	0	0.001	9
Fire-tail gudgeon	< 0.001	0	0	13
Flat head gudgeon	0.001	< 0.001	0.001	11
Freshwater mullet	0.109	0.072	0.104	4
Hypseleotris spp	0	< 0.001	0	16
Long-finned eel	0.171	0.603	0.233	2
Sea mullet	0.578	0	0.495	1
Short-finned eel	0.001	0	0.001	10
Striped gudgeon	0.005	0	0.004	6
Alien species				
Gambusia	< 0.001	0	0	15

Table 4.9. Proportion of sites within altitude zones across the Karuah catchment in which each species was sampled.

Altitude Zone	Coastal	Lowland	Totals	Rank (total)
Native species				
Australian bass	1	1	1	1
Australian smelt	0	1	0.333	8
Bullrout	0	1	0.333	8
Cox's gudgeon	0.5	1	0.667	4
Dwarf flat head gudgeon	0.5	0	0.333	8
Eel-tailed catfish	0.5	0	0.333	8
Empire gudgeon	1	0	0.667	4
Fire-tail gudgeon	0.5	0	0.333	8
Flat head gudgeon	0.5	1	0.667	4
Freshwater mullet	1	1	1	1
Hypseleotris spp	0	1	0.333	8
Long-finned eel	1	1	1	1
Sea mullet	1	0	0.667	4
Short-finned eel	0.5	0	0.333	8
Striped gudgeon	0.5	0	0.333	8
Alien species				
Gambusia	0.5	0	0.333	8

4.3.4. Macquarie-Tuggerah catchment

Fish abundance in sites sampled in the Macquarie-Tuggerah catchment was dominated by striped gudgeon (29%), empire gudgeon (21%) and long finned eels (21%) (Table 4.10). While Cox's gudgeon (12%) and Australian smelt (11%) were also relatively abundant, only one specimen of both common jollytail and dwarf flat head gudgeon were recorded (Table 4.10).

Biomass in the Macquarie-Tuggerah catchment was largely dominated by long-finned eels (85%) (Table 4.11). Australian smelt, common jollytail, flat head gudgeon and gambusia contributed to less than 0.1% of the total biomass (Table 4.11).

Only Australian smelt, long-finned eels and striped gudgeon were sampled at both sites in the Macquarie-Tuggerah catchment (Table 4.12). The remaining species were only found at one site each.

Table 4.10. Proportion of each species in the total catch within altitude zones in the Macquarie-Tuggerah catchment.

Altitude Zone	**Coastal**	**Rank**
Native species		
Australian bass	0.021	6
Australian smelt	0.106	5
Common jollytail	0.011	8
Cox's gudgeon	0.117	4
Dwarf flat head gudgeon	0.011	8
Empire gudgeon	0.213	2
Long-finned eel	0.213	2
Striped gudgeon	0.287	1
Alien species		
Gambusia	0.021	6

Table 4.11. Proportion of each species in the total biomass within altitude zones in the Macquarie-Tuggerah catchment.

Altitude Zone	**Coastal**	**Rank**
Native species		
Australian bass	0.013	5
Australian smelt	0.005	6
Common jollytail	0	8
Cox's gudgeon	0.031	3
Dwarf flat head gudgeon	0	7
Empire gudgeon	0.014	4
Long-finned eel	0.848	1
Striped gudgeon	0.089	2
Alien species		
Gambusia	0	9

Table 4.12. Proportion of sites within altitude zones across in the Macquarie-Tuggerah catchment in which each species was sampled.

Altitude Zone	Coastal	Rank
Native species		
Australian bass	0.5	4
Australian smelt	0.5	4
Common jollytail	0.5	4
Cox's gudgeon	0.5	4
Dwarf flat head gudgeon	0.5	4
Empire gudgeon	1	1
Long-finned eel	1	1
Striped gudgeon	1	1
Alien species		
Gambusia	0.5	4

5. POTENTIALLY THREATENED FISH SPECIES

5.1. Introduction

Although the process of random site selection is essential in order to make catchment-wide or zone-wide statements about the status of fish communities and populations, randomisation is inadequate for monitoring the status of threatened species. This is because populations of threatened species are, by definition, rare and usually only occur as discrete isolated populations. Through chance, selecting a moderate number of sampling sites over an area as large as the Hunter Central Rivers catchments is likely to miss many or most isolated threatened species populations. As a result, the targeted sampling of known threatened species populations will be required in future to assess changes in their status through time.

Two species identified as potentially threatened (Morris *et al.* 2001), eel-tailed catfish and freshwater herring, were relatively abundant and widespread in both the Hunter and Manning catchments in the present survey. The seven species not present or extremely low in abundance in the present survey were Australian grayling, Darling River hardyhead, western carp gudgeon, mountain galaxias, climbing galaxias, common galaxias and the short-finned eel.

5.2. Fish species at risk

5.2.1. Australian grayling

Figure 5.1. The vulnerable Australian grayling (*Prototroctes maraena*). Photo: Rudie Kuiter.

Australian grayling is widespread but relatively uncommon in coastal streams of south-eastern Australia (Allen 2002). Australian grayling has been listed as 'Vulnerable' by the IUCN due to definite decline in numbers across its distribution.

A single specimen found in the Macquarie-Tuggerah catchment in 1999 extended the northerly range of the species (Australian Museum). Targeted assessment for both fish larvae and adults is required to assess the status of the Australian grayling population in the Macquarie-Tuggerah catchment.

5.2.2. Darling River hardyhead

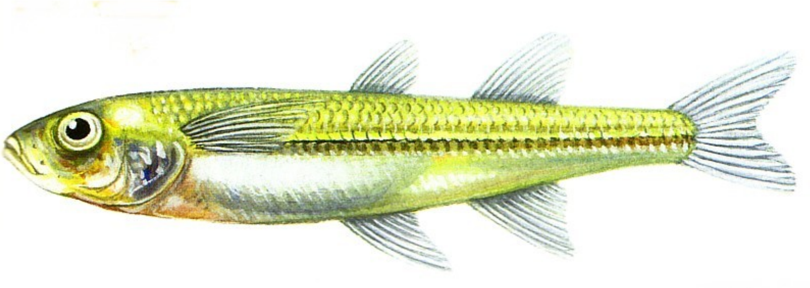

Figure 5.2. The potentially threatened Darling River hardyhead (*Craterocephalus amniculus*). Illustration: Jill Ruse.

Darling River hardyhead is relatively common within a restricted area in the upper reaches of the Darling River (Allen 2002). Specimens of Darling River hardyhead caught in several streams within the Hunter catchment in the late 1970's and early 1980's are tentatively called *Craterocephalus amniculus*, but may prove to be a separate undescribed species. Waterbodies in which they were recorded are Hunter, Goulburn and Pages rivers and Glennies and Bowmans Creeks (Australian Museum, Battaglene 1985). Targeted sampling at sites where they have been previously recorded is required to assess the current status of the population and monitor any changes.

5.2.3. Western carp gudgeon

Figure 5.3. The potentially threatened western carp gudgeon (*Hypseleotris klunzingeri*). Photo: Gunther Schmida.

Although very common throughout the Murray-Darling basin and in coastal streams towards the Queensland border, there are few records from the Hunter River and none from the other Hunter and Centrals Rivers catchments. The only two documented records from the Hunter River in 1971 were both in the Hunter River, near Lake Liddell and the town of Muswellbrook (Australian Museum). Targeted sampling at both of these two sites and other potential sites is required.

5.2.4. Mountain galaxias

Figure 5.4. The potentially threatened mountain galaxias (*Galaxias olidus*). Photo: Rudie Kuiter.

Mountain galaxias is widely distributed in streams draining both sides of the Great Dividing Range from South Australia to southern Queensland. Whilst locally abundant in some areas of Australia, the taxonomy of mountain galaxias is uncertain with recent research suggesting that it may actually be a species complex (Raadik 2001). The earliest record of mountain galaxias in the Hunter and Central Rivers catchments was from Omadale Brook in 1909 (Australian Museum), but specimens have been found in more recent times in Oaky Creek, Hunter River near Hunter Vale and Moonan Flat, Moonan Creek, Stewarts Creek and the Isis River (Battaglene 1985, Raadik, T.A. 2005, pers. comm.). Targeted sampling at sites where they have been previously recorded is required to assess the current status of the population and to monitor changes over time. Results of targeted sampling may require that careful consideration is given to streams stocked with trout, as trout are thought to eat and compete with mountain galaxias.

5.2.5. Climbing galaxias

Figure 5.5. The potentially threatened climbing galaxias (*Galaxias brevipinnis*). Photo: Neil Armstrong.

Climbing galaxias are distributed in coastal streams from Kangaroo Island in South Australia to the Hunter catchment in NSW (Allen 2002, Raadik 2005). Although locally abundant in some areas of Australia, in NSW fragmented populations remain in only a few suitable habitats (Morris *et al.* 2001). Climbing galaxias have only been recorded from Hunter and Macquarie-Tuggerah catchments, which are at the northern extent of the recorded distributional range of the species. Specimens have been found in Ourimbah Creek in the Macquarie-Tuggerah catchment in 1906 and again in 1995 (Australian Museum records). Populations have also been found in Jerusalem Creek in the Hunter catchment (Raadik 2005). Similarly to the mountain galaxias, recent research suggests that *G. brevipinnus* may actually be a species complex (Raadik 2001). Targeted sampling at sites where they have been previously recorded is required to assess the current status of the population and to monitor changes over time. Results of targeted sampling may require that careful consideration be given to streams stocked with trout, as trout are thought to eat and compete with mountain galaxias.

5.2.6. Common jollytail

Figure 5.6. The potentially threatened common jollytail (*Galaxias brevipinnis*). Photo: Timothy Howell.

The distribution of the common jollytail in Australia extends from Adelaide through to southern Queensland, Tasmania and south Western Australia (Allen 2002). Whilst very common in some areas, it has experienced a recent decline in places it was once common in NSW. Whilst only one specimen of common jollytail was sampled in the present survey, it is likely that populations are more restricted to smaller coastal streams not covered in this survey. To assess the status of the common jollytail, targeted sampling in areas where they are believed to be abundant is required.

5.2.7. Short-finned eel

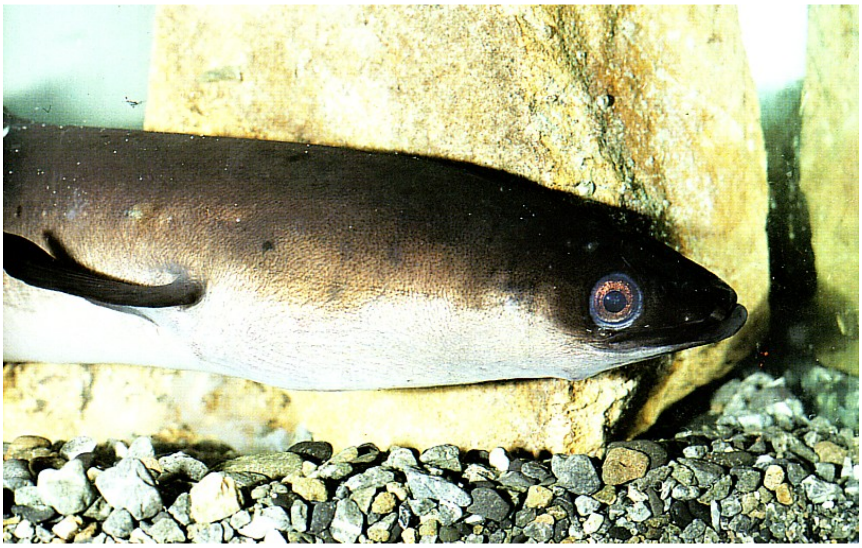

Figure 5.7. The potentially threatened short-finned eel (*Anguilla australis*). Photo: Robert McDowall.

The short-finned eel is common across much of its range from Mt Gambia in South Australia through to the Richmond River in NSW. Whilst it is more common in waterbodies without long-finned eels, it has experienced a reduced distribution and abundance in the northern part of its range (Morris *et al.* 2001). Three short-finned eels were sampled in the Hunter and Karuah catchments in the present study, although some of the eels only identified to genus in the Manning River may have been short-finned eels. Targeted sampling at sites where they have been previously recorded is required to assess the current status of the population and monitor any changes.

6. COMPARISONS WITH PREVIOUS FISH SAMPLING

6.1. Introduction

Ongoing sampling using a consistent standardised sampling methodology, which targets all members of the fish community (as far as is possible), is the most robust method of assessing changes in fish community structure and the status of individual species through time (Brown 1992, Rutzoa *et al.* 1994). Long term and regular surveys also enable early detection of the introduction and spread of new pest species such as the release of various aquarium fish into Australian rivers (Lintermans 2000).

Until the present study, fish sampling throughout the Hunter and Central Rivers catchments has been sporadic and limited, which limits the capacity to assess changes over time. The NSW Rivers survey (Harris and Gehrke 1997) included four sites in the Hunter catchment, two sites in the Manning catchment and one site in the Karuah catchment and all but two of these sites were sampled in the present survey. This study provides a standardised sampling baseline covering a range of altitude zones for future assessment of fish communities in the Hunter and Central Rivers catchments.

6.2. Results and discussion

6.2.1. Hunter catchment

There have been three previous fish surveys covering a range of sites in the Hunter catchment. In 1980, a survey of 22 sites was done in the Hunter catchment to assess the potential impact of a number of proposed dams (Battaglene 1985). Sites were selected on the basis of being located at possible dam locations as well as being downstream of possible dam sites. The survey used a broad range of sampling gears and intensity, but was largely focused in the upland zone. As such, it can only be used to compare the presence and absence of fish species in the Hunter catchment with the present study. Fourteen species were found in both surveys (Table 6.1). Sampling in Glenbawn Dam in the 1980 survey found golden perch and silver perch (Table 6.1). Targeted sampling in the present survey and the continued angling popularity and fish stocking records for Glenbawn Dam suggest that the status of both of these translocated native fish species has not changed significantly. The absence of Darling River hardyhead in the present survey is of concern (refer section 5.2.2). Although not sampled in the 1980 survey, dwarf flat head gudgeon were caught in all subsequent fish surveys (Table 6.1). Of the five species recorded in the present study that were not found in 1980, brown trout, rainbow trout and common carp are alien. Brown and rainbow trout are widely stocked for recreational angling and there are no records of self-sustaining populations. Common carp are of concern, as they were not recorded in 1983 (Llewellyn 1983) but were recorded in the NSW River survey in 1996. In the present study, common carp were one of the largest contributors to the total biomass of all fish sampled.

The 1983 fish survey of the Hunter catchment (Llewellyn 1983) sampled from four sites in the coastal and lowland zones and failed to record ten species caught in the present survey. However, mountain galaxias, which is potentially threatened (refer section 5.2.4), was recorded.

All species listed from the 1996 fish survey (Harris and Gehrke 1997), in which three sites were located in the coastal and lowland zones, were sampled in the present survey. Two of the fish species sampled in the present survey (brown trout and rainbow trout) were not recorded in the

1996, which did include sampling in the highland zone. Of the remaining two species not recorded in the 1996 fish survey, the short-finned eel is a potentially threatened species (refer section 5.2.7).

Table 6.1. Fish species recorded in past surveys in the Hunter catchment (1 = present, 0 = absent).

Species	Present survey	1996 survey	1983 survey	1980 survey
Native species				
Australian bass	1	1	0	1
Australian smelt	1	1	1	1
Bullrout	1	1	1	1
Cox's gudgeon	1	1	0	1
Darling River hardyhead	0	0	0	1
Dwarf flat head gudgeon	1	1	1	0
Eel-tailed catfish	1	1	1	1
Empire gudgeon	1	0	0	1
Flat head gudgeon	1	1	1	1
Freshwater herring	1	1	1	1
Freshwater mullet	1	1	0	0
Long-finned eel	1	1	0	1
Mountain galaxias	0	0	1	0
Sea mullet	1	1	1	1
Short-finned eel	1	0	0	1
Striped gudgeon	1	1	0	1
Translocated native species				
Golden perch	0	0	0	1
Silver perch	0	0	0	1
Alien species				
Brown trout	1	0	0	0
Common carp	1	1	0	0
Gambusia	1	1	1	1
Goldfish	1	1	1	1
Rainbow trout	1	0	0	0
Total	**19**	**15**	**10**	**17**

6.2.2. Manning catchment

In both the previous surveys of the Manning catchment (Llewellyn 1983, Harris and Gehrke 1997) only two sites were sampled. However, the 1996 survey recorded all the same species as the present study (Table 6.2). In contrast, only two species were recorded in the 1983 survey (Llewellyn 1983), of which gambusia is an alien species.

Table 6.2. Fish species recorded in past surveys in the Manning catchment (1 = present, 0 = absent).

Species	Present survey	1996 survey	1983 survey
Native species			
Australian bass	1	1	0
Australian smelt	1	1	0
Bullrout	1	1	0
Cox's gudgeon	1	1	0
Dwarf flat head gudgeon	1	1	1
Eel-tailed catfish	1	1	0
Empire gudgeon	1	1	0
Flat head gudgeon	1	1	0
Freshwater herring	1	1	0
Freshwater mullet	1	1	0
Long-finned eel	1	1	0
Sea mullet	1	1	0
Southern blue-eye	1	1	0
Striped gudgeon	1	1	0
Alien species			
Gambusia	1	1	1
Goldfish	1	1	0
Total	**16**	**16**	**2**

6.2.3. Karuah catchment

Previous fish surveys have included only one site in the Karuah catchment, and sampling gear and intensity varied significantly. All species previously recorded in past surveys were sampled in the present survey with the addition, in the present survey, of dwarf flat head gudgeon and eel-tailed catfish (Table 6.3).

Table 6.3. Fish species recorded in past surveys in the Karuah catchment (1 = present, 0 = absent).

Species	Present survey	1996 survey	1983 survey
Native species			
Australian bass	1	1	0
Australian smelt	1	1	0
Bullrout	1	1	0
Cox's gudgeon	1	1	0
Dwarf flat head gudgeon	1	0	0
Eel-tailed catfish	1	0	0
Empire gudgeon	1	1	0
Fire-tail gudgeon	1	1	1
Flat head gudgeon	1	1	0
Freshwater mullet	1	1	1
Long-finned eel	1	1	1
Southern blue-eye	1	0	1
Sea mullet	1	1	0
Short-finned eel	1	0	1
Striped gudgeon	1	1	0
Alien species			
Gambusia	1	0	1
Total	**16**	**11**	**6**

6.2.4. Macquarie-Tuggerah Catchment

The present study represents the first survey of the Macquarie-Tuggerah catchment. Whilst two sites were selected for sampling following the procedure outlined in section 2.1, a third site sampled concurrently for another project highlights the need for more intensive sampling within this catchment. Six of the eleven species caught at the one site for the 'daughterless carp' project were not found in the two sites sampled in the present survey. Conversely, four of the nine species recorded in the present survey were not recorded from the 'daughterless carp' sampling site. These results indicate that the level of sampling in the Macquarie-Tuggerah catchment in this survey was insufficient to adequately ascertain the status of current fish assemblages.

Table 6.4. Fish species recorded in the present survey and a concurrent project (Daughterless carp) in the Macquarie-Tuggerah catchment in 2004 (1 = present, 0 = absent).

Species	**Present survey**	**Daughterless Carp (2004)**
Native species		
Australian bass	1	1
Australian smelt	1	1
Bullrout	0	1
Common jollytail	1	0
Cox's gudgeon	1	0
Dwarf flat head gudgeon	1	0
Empire gudgeon	1	1
Flat head gudgeon	0	1
Freshwater mullet	0	1
Long-finned eel	1	1
Sea mullet	0	1
Striped gudgeon	1	1
Translocated native species		
Golden perch	0	1
Alien species		
Common carp	0	1
Gambusia	1	0
Total	**9**	**11**

7. FISH STOCKING IN THE HUNTER AND CENTRAL RIVERS CATCHMENTS: 2001 - 2004

7.1. Introduction

Fish stocking includes both the translocation of fish from one area into another as well as the hatchery production and release of captive bred fish. It is typically undertaken with the intent of either improving recreational fishing opportunities or for the conservation of endangered populations (NSWF 2003).

Despite much debate among fisheries managers and scientists, stocking fish is considered by the public as an important tool in achieving sustainable recreational fisheries (NSWF 2003). Management of stocking activities was assumed by the NSW government in 1960 (NSWF 2003). Native fish breeding programs did not begin until 1961 with the opening of the Narrandera Fisheries Centre. Lake Glenbawn and Lake St. Claire are renowned angling waters and an important part of local economies.

Stocking data were accessed from the NSW fish stocking database. It does not contain data regarding early translocation of native species, the unauthorised stocking of angling species, the deliberate liberation of alien species such as goldfish and common carp, or the illegal introduction of aquarium fishes.

7.2. Results and discussion

One native species (Australian bass), two translocated native species (golden perch and silver perch) and two alien species (brown trout and rainbow trout) are presently stocked throughout the Hunter and Central Rivers catchments annually.

All five species are stocked into waterbodies in the Hunter catchment. The majority of the stocked fish which are native species (Australian bass, golden perch and silver perch) are stocked into man-made impoundments, whilst the trout are stocked in the upper reaches and tributaries of the Hunter River (Table 7.1).

Stocking of fish in the Manning catchment is dominated by the release of rainbow trout into the upper reaches and tributaries of the Manning River (Table 7.2). Brown trout are also stocked in the upper Manning and Barnard Rivers (Table 7.2).

There is limited stocking of fish in the Karuah and Macquarie-Tuggerah catchments. In the Karuah catchment, Australian bass are stocked in both the Myall and Crawford Rivers, while rainbow trout are stocked in the upper reaches of the Myall River (Table 7.3). The Wyong River and Ourimbah Creek, stocked with Australian bass, are the only waterbodies currently stocked with fish in the Macquarie-Tuggerah catchment (Table 7.4).

Table 7.1. Streams and dams stocked in the Hunter catchment between 2001 and 2004. Waterbodies stocked are indicated with a ●.

Waterbody	Australian Bass	Golden perch	Silver perch	Brown trout	Rainbow trout
Backwater Creek	-	-	-	-	●
Carters Brook	-	-	-	●	●
Dartbrook Creek	-	-	-	-	-
Davis Creek	-	-	-	-	-
Glenbawn Dam	●	●	●	-	●
Lake St. Claire	●	●	●	-	-
Hunter River	●	-	-	-	●
Keans Creek	-	-	-	-	-
Lake Liddell	●	-	-	-	-
Lostock Dam	●	-	-	-	-
Moonan Brook	-	-	-	-	●
Moonan Brook	-	-	-	-	-
Omadale Brook	-	-	-	-	●
Paddys Creek	-	-	-	-	●
Pages river	-	-	-	-	-
Polblue Creek	-	-	-	-	●
Pourmalong Creek Dam	●	-	-	-	-
Rouchel Brook	-	-	-	-	-
Stewarts Brook	-	-	-	●	●
Telarah lagoon	●	-	-	-	-
Thompsons Creek	-	-	-	-	-
Tubrabucca Creek	-	-	-	-	●
Warrabrook Wetlands	●	-	-	-	-
Wybong Creek	-	-	-	●	-

Table 7.2. Streams and dams stocked in the Manning catchment between 2001 and 2004. Waterbodies stocked are indicated with a ●.

Waterbody	Brown trout	Rainbow trout
Manning River	●	●
Barnard River	●	●
Pigna Barney Creek	-	●
Barrington River	-	●
Dilgry River	-	●
Gloucester River	-	●
Kerripit Creek	-	●
Kholwha Creek	-	●
Moppy Creek	-	●
Tomalla Creek	-	●
Back Creek	-	●
Tuggalo River	-	●
Backwater Creek	-	●
Lingera Creek	-	●
Long Swamp Creek	-	●
Tomalla Creek	-	●
Sheepstation Creek	-	●
Nowendoc River	-	●

Table 7.3. Streams stocked in the Karuah catchment between 2001 and 2004. Waterbodies stocked are indicated with a ●.

Waterbody	Australian bass	Rainbow trout
Crawford River	●	-
Myall River	●	-
Myall River	-	●

Table 7.4. Streams stocked in the Macquarie-Tuggerah catchment between 2001 and 2004. Waterbodies stocked are indicated with a ●.

Waterbody	Australian bass
Ourimbah Creek	●
Wyong River	●

8. GENERAL DISCUSSION AND RECOMMENDATIONS

This report presents the results of the most detailed assessment of fish species and communities ever undertaken across the Hunter and Central Rivers catchments [2]. The randomised and representative sampling design ensures that the results collected can be extrapolated across all reaches of the catchment. Data presented here serve three purposes:

(1) To benchmark the current status of fish species and fish communities.
(2) To enable future analyses to determine trends in fish species and communities.
(3) To provide data-sets suitable for undertaking analysis of the relative impacts of a broad range of processes.

Twenty-three fish species were sampled from the 27 riverine monitoring sites (11 from each of the Hunter and Manning, 3 from the Karuah and 2 from Macquarie-Tuggerah catchments). Despite this sampling effort, 76% (19 species) of the freshwater fish fauna previously recorded in the Hunter catchment, 80% (16 species) in the Manning, 94% (16 species) in the Karuah and only 53% (9 species) in the Macquarie-Tuggerah catchment were recorded in the present survey. The present survey was based on a random sampling design and therefore could not target rare species previously recorded in the catchment, and further investigation of rare species is warranted.

Fish community structure varied substantially across all four catchments, with a decrease in species richness with increasing altitude. Assessment of fish communities identified some significant differences between altitude zones. The coastal, lowland, slopes and upland zones were dominated by native fish species, while the highland zone was dominated by alien fish species. The fish community in the coastal zone was characterised by a greater abundance of sea mullet and striped gudgeon than the other four zones. The significant difference between the lowland and the upland zones was predominantly driven by the higher abundance of Australian smelt and long-finned eels in the lowland zone and the absence of sea mullet in the upland zone. The highland zone differed from the lowland zone in the absence of Australian smelt and the reduced abundance of long-finned eels, and the dominance of gambusia.

With the exception of the absence of native species sampled in the highland site, the proportional abundance of native fish species in the Hunter catchment across all other altitude zones was relatively high (90%). In the slopes and upland zones, the influence of large common carp increased the proportion of the biomass which was not native species. All fish species sampled in the slopes and upland zones of the Manning catchment were native. With the exception of the highland site, the proportion of native fish species across all other altitude zones was very high (91%). Native species dominated the abundance in all zones except the highlands, where large numbers of gambusia were very abundant. Gambusia was the only alien fish species recorded in the Karuah and Macquarie-Tuggerah catchments in the present survey. Due to the relatively small size of gambusia and the low numbers caught in comparison to the native species, gambusia contributed little to the overall total abundance or total biomass.

---

[2] Since this report was first drafted, the NSW government's MER program has commenced. 'Fish assemblage structure' is one of the indicators being used for the Riverine Ecosystem theme of MER. Sampling for this indicator in the Hunter Central Rivers CMA area was first done in 2007/08 and will be repeated in 2010/11. It uses the same sampling protocol and stratification as described in this report, although the number of sites sampled is slightly different.

The most abundant species in the Hunter catchment in the present survey were: Australian smelt, long-finned eels, sea mullet and gambusia. Biomass was dominated by sea mullet, common carp and long-finned eels, with long-finned eels being the most widespread species. The rarest taxa were goldfish, striped gudgeon, bullrout and rainbow trout all contributing 0.1% of the total catch. The least widespread species were striped gudgeon, freshwater mullet, bullrout, rainbow trout and brown trout, each being found at only one site.

Australian smelt and long-finned eels were the two most numerous species in the Manning catchment, with long-finned eels and sea mullet dominating the total biomass. The three rarest taxa were bullrout, freshwater mullet and dwarf flat head gudgeon together contributing less than 1% of the total abundance of fish in the catchment. Long-finned eels, Cox's gudgeon and Australian smelt were the most widespread fish species in the Manning catchment.

The three most abundant fish species in the Karuah catchment were sea mullet, long-finned eels and Australian smelt. Sea mullet dominated the biomass, with significant contributions from long-finned eels, Australian bass and freshwater mullet. Australian bass, long-finned eels and freshwater mullet were found at all three sites sampled in the Karuah catchment. The two rarest taxa were bullrout and eel-tailed catfish which together accounted for less than 0.5% of all fish sampled.

Fish abundance in sites sampled in the Macquarie-Tuggerah catchment was dominated by striped gudgeon, empire gudgeon and long finned eels, with long-finned eels largely dominating the biomass. Only Australian smelt, long-finned eels and striped gudgeon were sampled at both sites in the Macquarie-Tuggerah catchment. One specimen of both common jollytail and dwarf flat head gudgeon only were recorded and, as such, they were the rarest taxa.

While the present study identified a higher diversity of fish species than previous surveys, it must be noted that intensity of sampling was greater, with the notable exception being the survey done in the Hunter in 1980. Previous sampling has been insufficient to enable rigorous assessment of changes prior to the present survey, and species richness levels only can be usefully compared. The present survey provides an excellent benchmark for future, more thorough comparisons [3].

One native (Australian bass), two native translocated (golden perch and silver perch) and two alien species of fish (brown trout and rainbow trout) have been, and continue to be, stocked as part of government sanctioned stocking programs to promote recreational fishing.

8.1. Recommendations

The Native Fish strategy for the Murray Darling Basin has identified 13 objectives:

(1) Repair and protect key components of aquatic and riparian habitats.
(2) Rehabilitate and protect the natural functioning of wetlands and floodplain habitats.
(3) Improve key aspects of water quality that affect native fish.
(4) Modify flow regulation practices.
(5) Provide adequate passage for native fish.
(6) Devise and implement recovery plans for threatened native fish species.

[3] Since this report was first drafted, the NSW government's MER program has commenced. 'Fish assemblage structure' is one of the indicators being used for the Riverine Ecosystem theme of MER. Sampling for this indicator in the Hunter Central Rivers CMA area was first done in 2007/08 and will be repeated in 2010/11. It uses the same sampling protocol and stratification as described in this report, although the number of sites sampled is slightly different.

(7) Create and implement management plans for other native fish species and communities.
(8) Control and manage alien fish species.
(9) Protect native fish from threats of disease and parasites.
(10) Manage fisheries in a sustainable manner.
(11) Protect native fish from the adverse effects of translocation and stocking.
(12) Ensure native fish populations are not threatened from aquaculture.
(13) Ensure community and partner ownership and support for native fish management.

These objectives are likely to be equally relevant to coastal catchments and can be achieved through utilisation of CMA resources. Actions such as rehabilitation of instream woody habitats and riparian vegetation, rehabilitation of wetlands, elimination of thermal pollution, improvement of environmental flows, reinstatement of fish passage at a number of barriers, and measures to control alien species are all worthy of consideration. Involving the community in such actions would ensure their ongoing ownership of, and support for, the fish resources in the CMA area.

8.1.1. Aquatic habitat rehabilitation

Key components of aquatic and riparian habitat include home sites, spawning sites, shade, shelter from excessive water velocities, shelter from predators, feeding sites and a variety of water depths. Further, each species may utilise a range of habitats at different life stages. Riverine habitats have been degraded by riparian clearing, de-snagging, loss of wetlands, alienation of the floodplain, bank erosion and sedimentation (Cadwallader 1978, Faragher and Harris 1994, Finlayson *et al.* 1994, Abernethy and Rutherford 1999, Kearney *et al.* 1999, Treadwell *et al.* 1999, MDBC 2004*a*). Rehabilitation of aquatic habitats requires actions such as rehabilitation and protection of riparian zones, re-snagging, erosion control and de-silting. Projects such as the UHRRI near the town of Muswellbrook and the WRRP are promoting such actions and are crucial in helping to understand and learn from reach-scale processes in river rehabilitation.

8.1.2. Reducing thermal pollution

The release of cold hypolimnetic water from the base of dams, termed thermal pollution, such as that released from Glenbawn Dam and Lake St. Claire, is one of the most significant threatening processes in regulated catchments (Cadwallader 1978, Koehn and O'Connor 1990, Faragher and Harris 1994, Koehn *et al.* 1995, Kearney *et al.* 1999, Lugg 1999, Koehn 2001). Thermal pollution impacts on fish populations by preventing seasonal warming to critical spawning temperatures, temperature shock to eggs and larvae following sudden high volume releases, inhibited activity, growth, and disease resistance, reduced eggs and larval survival and delayed maturity (Koehn 2001). Measures to reduce the severity of hypolimnectic flows and factor in crucial timing in relation to fish life stage requirements in planned releases could improve conditions for fish communities.

8.1.3. Improving environmental flow management

Regulation of flows through controlled release from storages and water extraction have vastly changed the hydrology of river systems, causing widespread degradation (Cadwallader 1978, Bain *et al.* 1988, Kinsolving and Bain 1993, Weisberg and Burton 1993, Faragher and Harris 1994, Welcomme 1994, Gehrke *et al.* 1999, Kearney *et al.* 1999). The ecological needs of fish communities can run counter to the needs of water users who depend on reliable and predictable water supplies (MDBC 2004). The major aspects of the flow regime modified by river regulation include (Finlayson *et al.* 1994; Maheshwari *et al.* 1995):

- Reduced flow downstream of irrigation areas.
- Reversed seasonal flow regime.
- Reduced duration of flow peaks.
- Reduced frequency of flow peaks, particularly small to medium high flow events.

8.1.4. Reinstating fish passage

Barriers such as dams, weirs and regulators are known to impede the migration of fish and prevent the completion of their lifecycles (Cadwallader 1978, Faragher and Harris 1994, Kearney *et al.* 1999, Thorncraft and Harris 2000). The NSW Weirs policy aims to halt and, where possible, reduce and remove the environmental impact of weirs on streams. The most effective way of achieving this is by the removal of un-utilised structures. Where this is not possible, construction of a well designed fishway allowing passage of all species and size classes of fish in the community is a viable alternative.

8.1.5. Controlling alien species

Given the great impact of alien fish on riverine ecosystems, the control of pest fish is also a high priority for rehabilitating fish communities. Apart from the freshwater pests program of the Invasive Animals CRC (IA CRC), and its flagship 'daughterless carp' project, little is being done to control pest fish species. However support of the IA CRC's freshwater pests program is likely to result in the most cost-effective means of addressing the need for pest fish control for all pest fish species in the catchment.

8.1.6. Fostering community ownership and support

Lastly, education of the community and the fostering of community support for riverine ecosystems are also critical in the long-term rehabilitation of the fish community of the Hunter and Central Rivers catchments. As fish are hidden underwater, the community understanding of issues relating to fish is often less than for more visible terrestrial ecosystems. Further, the community's perception of fish assemblages is drawn entirely from the status of recreationally important species, with little consideration given to the majority of less familiar species. An ongoing fish monitoring program is required in order to fill that knowledge gap. Rehabilitation projects such as the UHRRI near Muswellbrook provide an excellent opportunity not only to examine the effectiveness of rehabilitation but to also educate and encourage community ownership of the region's rivers.

8.2. Ongoing monitoring requirements

8.2.1. General

Data presented in this report, particularly the trends in monitoring data and stocking records' lend themselves to detailed analyses of the response of fish communities to long-term changes in threatening processes such as the degree of river regulation, the cumulative number of fish passage barriers, the degree of thermal pollution, the amount of de-snagging, the effectiveness of fish stocking, the response of fish populations to various flow parameters etc. However, although illustrative, a uni-variate approach assessing each threatening process in isolation is inadequate for teasing apart the many inter-related influences of fish populations. A detailed review and compilation of all available data, followed by a detailed multi-variate analytical approach is required in order to provide detailed and accurate information on the relative threats posed by a range of processes affecting fish communities. This approach would allow the development of models of the response of fish populations to implementation of the range of rehabilitation activities suggested above. In order to make these analyses possible, data on parameters related to each of these threatening processes needs to be compiled and made available. Such a model would provide a useful tool with which the CMA could use to develop the most cost-effective recovery options for fish communities in the Hunter and Central Rivers catchments.

8.2.2. Potentially threatened species

Although the process of random site selection is essential to make catchment-wide or zone-wide statements about the status of fish communities and populations, randomisation is inadequate for monitoring the status of threatened species. Targeted sampling of these species is required to assess changes in their status through time. The seven species not present or extremely low in abundance in the present survey were Australian grayling, Darling River hardyhead, western carp gudgeon, mountain galaxias, climbing galaxias, common galaxias and the short-finned eel.

The only species likely to be encountered in the Hunter and Central Rivers CMA area listed under the IUCN as vulnerable is the Australian Grayling. One specimen was previously identified from the Macquarie-Tuggerah catchment, representing the northerly known range of the species. Targeted sampling of Australian Grayling would be required to establish the extent of this population and determine if recovery action is required.

Another fish of great potential significance in the Hunter Central Rivers CMA area is the Darling River hardyhead. Sampling during the late 1970’s and early 1980’s recorded specimens at several sites throughout the Hunter catchment. Whilst relatively common in the Darling River, the Hunter River population represents the only known coastal population. Whilst tentatively identified as this species, it is possible that this population is a separate species or sub-species. No specimens were found during the 2004 surveys and targeted sampling at sites where they were previously recorded would help resolve the status of this taxon.

Two species of galaxids thought to be previously widespread in the highland zone of the Hunter catchment (*Galaxias olidus* and *Galaxias brevipinnus*) were not recorded in the present survey and their status is of concern. The existence of trout in the system may prevent recovery of remnant or reintroduced populations, as predation and competition by trout is believed to be substantial. Although only one specimen of common jollytail was recorded, it is likely that significant populations exist in smaller coastal streams not sampled in this survey. Targeted assessment of these areas is required to assess these populations and ascertain their status in the Hunter and Central Rivers catchments.

Whilst reportedly common throughout the Murray-Darling Basin and in coastal streams north of the Hunter River, Western Carp Gudgeon have not been reported in the Manning and have only been recorded in two sites on the Hunter River (in 1971); none were caught in the 2004 surveys. Further research needs to be conducted to ascertain the extent and status of this species in the Hunter and Central Rivers catchments.

Populations of short-finned eels have undergone a reduction in distribution and abundance in NSW. The present survey found only three specimens and targeted sampling is required to determine the extent and status of the species.

9. REFERENCES

Abernethy, B. and Rutherfurd, I.D., 1999. Guidelines for stabilising stream banks with vegetation. Technical report 99/10, CRC for Hydrology, Melbourne.

Allen, G.R., Midgley. 2002, S.H. and Allen, M., 2002. Field guide to the freshwater fishes of Australia. CSIRO publishing, Melbourne.

Battaglene, S., 1985. Preliminary study of the fish resources of the Hunter Valley. Division of Fisheries, New South Wales Department of Agriculture.

Begon, M., Harper, J.L. and Townsend, C.R., 1990. *Ecology: Individuals, Populations and Communities*. Blackwell Scientific Publications, Melbourne.

Bray, J.R. and Curtis, J.T., 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs* **27:** 325–349.

Butcher, A.D., 1967. A changing aquatic fauna in a changing environment. *IUCN Publications, New Series* **9:** 197–218.

Cadwallader, P.L., 1978. Some causes of the decline in range and abundance of native fish in the Murray-Darling River system. *Proceedings of the Royal Society of Victoria* **90:** 211–224.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* **18:** 117–143.

Connell, J.H., 1978. Diversity in tropical rainforests and coral reefs. *Science* **199:** 1302–1310.

Duncan, J.R. and Lockwood, J.L., 2001. Extinction in a field of bullets: a search for causes in the decline of the world's freshwater fishes. *Biological Conservation* **102:** 97–105.

Faragher, R.A. and Harris, J.H., 1994. The historical and current status of freshwater fish in New South Wales. *Australian Zoologist* **29:** 166–176.

Finlayson, B.L., Gippel, C.J. and Brizga, S.O., 1994. Effects of reservoirs on downstream aquatic habitat. *Water* **21:** 15–20.

Frith, H.J., 1973. *Wildlife Conservation*. Angus and Robertson, Sydney.

Froese, R. and Pauly, D. 2003. Fishbase. ICLARM, Manilla, Philippines. www.fishbase.org.

Gehrke, P.C., Astles, K.L. and Harris, J.H., 1999. Within-catchment effects of flow alteration on fish assemblages in the Hawkesbury-Nepean River system, Australia. *Regulated Rivers: Research and Management* **15:** 181–198.

Gehrke, P.C. and Harris, J.H., 2000. Large scale patterns in species richness and composition of temperate riverine fish communities, south-eastern Australia. *Marine and Freshwater Research* **51:** 165–182.

Gippel, C.J., O'Neill, I.C. and Finlayson, B.L., 1992. The hydraulic basis of snag management. Centre for Environmental Applied Hydrology, University of Melbourne.

Gleick, P.H., Singh, A. and Shi, H., 2001. *Threats to the Worlds Freshwater Resources*. Pacific Institute for Studies in Development, Environment and Security. Oakland, California.

Groombridge, B. and Baillie, J., 1997. 1996 IUCN Red list of threatened animals. IUCN Gland, Switzerland and Cambridge, UK.

Harris, J.H. and Gehrke, P.C., 1997. *Fish and Rivers in Stress: The NSW Rivers Survey*. NSW Fisheries, Cronulla.

Harris, J.H. 1987. Growth of Australian Bass *Macquaria novemaculeata* (Perciformes: Percichthyidae) in the Sydney Basin. *Australian Journal of Marine and Freshwater Science* **38**: 351–361.

Healthy Rivers Commission, 2002. Independent Inquiry into the Hunter River, Final Report. Healthy Rivers Commission. May 2002.

Jerry, D.R., 2005. Electrophoretic evidence for the presence of *Tandanus tandanus* (Pisces: Plotosidae) immediately north and south of the Hunter River, New South Wales. *Proceedings of the Linnean Society of New South Wales.* **126:** 121–124.

Kearney, R.E., Davis, K.M. and Beggs, K.E., 1999. Issues affecting the sustainability of Australia's freshwater fisheries resources and identification of research strategies. Project No. 97/142. Final report, May 1999.

Kingsford, R.T., 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology* **25:** 109–127.

Kinsolving, A.D. and Bain, M.B., 1993. Fish assemblage recovery along a riverine disturbance gradient. *Ecological Applications* **3:** 531–544.

Koehn, J.D., 2001. Ecological impacts of cold water releases on fish and ecosystem processes. Pages 7–11 in B. Phillips (ed.), *Thermal pollution of the Murray-Darling Basin waterways*. World Wildlife Fund for Nature, Australia.

Koehn, J.D., Doeg, T.J., Harrington, D.J. and Milledge, G.A., 1995. The effects of Dartmouth Dam on the aquatic fauna of the Mitta Mitta River. Report to the Murray-Darling Basin Commission, Canberra.

Koehn, J.D. and O'Connor, W.G. 1990. Threats to Victorian freshwater native fish. *Victorian Naturalist* **107:** 5–12.

Lake, J.S., 1971. Freshwater fishes and rivers of Australia. Nelson, Melbourne.

Lake, P.S., 1982. The relationship between freshwater fish distribution, stream drainage area and stream length in some streams of south-east Australia. *Bulletin of the Australian Society for Limnology* **8:** 31–37.

Leidy, R.A. and Moyle, P.B., 1998. Conservation status of the world's freshwater fish fauna: an overview. Pages 187–227 in P. L. Fieldler and P. M. Karieva (eds), *Conservation Biology: For the Coming Decade*, 2nd edition. Chapman and Hall, New York.

Lintermans, M., 2000. Recolonization by the mountain galaxias *Galaxias olidus* of a montane stream after the eradication of rainbow trout (*Oncorhynchus mykiss*). *Marine and Freshwater Research* 51: 799–804.

Llewellyn, L.C., 1983. The distribution of fish in New South Wales. Australian Society for Limnology, Special Publication No. 7.

Lugg, A., 1999. Eternal winter in our rivers: Addressing the issue of cold water pollution. NSW Fisheries, Nowra.

Maheshwari, B.L., Walker, K.F. and McMahon, T.A., 1995. Effects of regulation on the flow regime of the river Murray, Australia. *Regulated Rivers: Research and Management* **10:** 15–38.

McDowall, R.M., 2003. Impacts of introduced salmonids on native galaxiids in New Zealand upland streams: A new look at an old problem. *Transactions of the American Fisheries Society* **132:** 229–238.

Morris, S.A., Pollard, D.A., Gehrke, P.C. and Pogonoski, J.J., 2001. Threatened and potentially threatened freshwater fishes of coastal New South Wales and the Murray-Darling Basin. Report to Fisheries Action Program and World Wide Fund for Nature by NSW Fisheries, Cronulla.

Murray-Darling Basin Commission, 2003. Native Fish Strategy for the Murray-Darling Basin 2003–2013. Murray-Darling Basin Commission, Canberra.

Murray-Darling Basin Commission, 2004*a*. Fish theme pilot audit technical report – Sustainable Rivers Audit. Murray-Darling Basin Commission, Canberra.

Murray-Darling Basin Commission, 2004*b*. Murray Darling Basin Initiative, Sustainable Rivers Audit, Fish sampling protocol manual (Draft – version of August 2004). Murray-Darling Basin Commission, Canberra.

NSW Water Resources Council, 1991. Water facts. NSW Water Resources Council.

Paller, M.H., 1994. Relationships between fish assemblage structure and stream order in South Carolina coastal plain streams. *Transactions of the American Fisheries Society* **123:** 150–161.

Pease, B.C. (Ed), 2004. Description of the biology and an assessment of the fishery for adult longfinned eels in NSW. Final Report to Fisheries Research and Development Corporation. NSW Department of Primary Industries – Fisheries Final Report Series No. 69. 167pp.

Pollard, D. and Scott, T.D., 1966. River and reef. Pages 112–134 in A.J. Marshall (ed.), *The Great Extermination*. Heinemann, London.

Puckridge, J.T., Sheldon, F., Walker, K.F. and Boulton, A.J., (1998). Flow variability and the ecology of large rivers. *Marine and Freshwater Research* **49:** 55–72.

Raadick, T., 2001. When is a mountain galaxias not a mountain galaxias? *Fishes of Sahul.* **15(4):** 785–789.

Raadik, T., 2005. Dorrigo plateau – a biodivisity “hot-spot” for galaxids. *Fishes of the Sahul.* **19(1):** 98–107.

Rutzou, T.V., Rauhala, M.A. and Ormay, P.I., 1994. The fish fauna of the Tidbinbilla River catchment. Technical report No. 7, ACT Parks and Conservation Service, Canberra.

Rahel, F.J. and Hubert, W.A., 1991. Fish assemblages and habitat gradients in a Rocky Mountain – Great Plains stream: biotic zonation and additive patterns of community change. *Transactions of the American Fisheries Society* **120:** 319–332.

Thorncraft, G. and Harris, J.H., 2000. Fish passage and fishways in New South Wales: A status report. Technical report 1/2000 of the Cooperative Research Centre for Freshwater Ecology, Canberra.

Treadwell, S., Koehn, J.D. and Bunn. S., 1999. Large woody debris and other aquatic habitat. Pages 79–96 in S. Lovett and P. Price (eds), *Riparian land management, Technical Guidelines Volume 1: principles of sound management*. Land and water Resources research and Development Corporation, Canberra.

Ward, J.V. and Stanford, J.A., 1983. The intermediate disturbance hypothesis: an explanation for biotic diversity patterns in lotic ecosystems. Pages 347–356 in T.D. Fontaine III and S.M. Bartell (eds), *Dynamics of Lotic Ecosystems*. Ann Arbor Science, Michigan.

Weisberg, S.B. and Burton, W.H., 1993. Enhancement of fish feeding and growth after an increase in minimum flow below the Conowingo Dam. *North American Journal of Fisheries Management* **13:** 103–109.

Welcomme, R.L., 1994. The status of large river habitats. Pages 11–20 in I.G. Cox (ed.), *Rehabilitation of Freshwater Fisheries.* Fishing News Books, Oxford.

Other titles in this series:

ISSN 1440-3544 (NSW Fisheries Final Report Series)

No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales.

No. 4 Pethebridge, R., Lugg, A. and Harris, J., 1998. Obstructions to fish passage in New South Wales South Coast streams. 70pp.

No. 5 Kennelly, S.J. and Broadhurst, M.K., 1998. Development of by-catch reducing prawn-trawls and fishing practices in NSW's prawn-trawl fisheries (and incorporating an assessment of the effect of increasing mesh size in fish trawl gear). 18pp + appendices.

No. 6 Allan, G.L. and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. 237pp + appendices.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. 54pp + appendices.

No. 8 Heasman, M.P., O'Connor, W.A. and O'Connor, S.J., 1998. Enhancement and farming of scallops in NSW using hatchery produced seedstock. 146pp.

No. 9 Nell, J.A., McMahon, G.A. and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. 25pp.

No. 10 Nell, J.A. and Maguire, G.B., 1998. Commercialisation of triploid Sydney rock and Pacific oysters. Part 1: Sydney rock oysters. 122pp.

No. 11 Watford, F.A. and Williams, R.J., 1998. Inventory of estuarine vegetation in Botany Bay, with special reference to changes in the distribution of seagrass. 51pp.

No. 12 Andrew, N.L., Worthington D.G., Brett, P.A. and Bentley N., 1998. Interactions between the abalone fishery and sea urchins in New South Wales.

No. 13 Jackson, K.L. and Ogburn, D.M., 1999. Review of depuration and its role in shellfish quality assurance. 77pp.

No. 14 Fielder, D.S., Bardsley, W.J. and Allan, G.L., 1999. Enhancement of Mulloway (*Argyrosomus japonicus*) in intermittently opening lagoons. 50pp + appendices.

No. 15 Otway, N.M. and Macbeth, W.G., 1999. The physical effects of hauling on seagrass beds. 86pp.

No. 16 Gibbs, P., McVea, T. and Louden, B., 1999. Utilisation of restored wetlands by fish and invertebrates. 142pp.

No. 17 Ogburn, D. and Ruello, N., 1999. Waterproof labelling and identification systems suitable for shellfish and other seafood and aquaculture products. Whose oyster is that? 50pp.

No. 18 Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P. and Walford, T.R., 2000. Sampling estuarine fish species for stock assessment. Includes appendices by D.J. Ferrell, B.C. Pease, T.R. Walford, G.N.G. Gordon, C.A. Gray and G.W. Liggins. 194pp.

No. 19 Otway, N.M. and Parker, P.C., 2000. The biology, ecology, distribution, abundance and identification of marine protected areas for the conservation of threatened Grey Nurse Sharks in south east Australian waters. 101pp.

No. 20 Allan, G.L. and Rowland, S.J., 2000. Consumer sensory evaluation of silver perch cultured in ponds on meat meal based diets. 21pp + appendices.

No. 21 Kennelly, S.J. and Scandol, J. P., 2000. Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery. 43pp + appendices.

No. 22 Williams, R.J., Watford, F.A. and Balashov, V., 2000. Kooragang Wetland Rehabilitation Project: History of changes to estuarine wetlands of the lower Hunter River. 82pp.

No. 23 Survey Development Working Group, 2000. Development of the National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. (Volume 1 – 36pp + Volume 2 – attachments).

No.24 Rowling, K.R and Raines, L.P., 2000. Description of the biology and an assessment of the fishery of Silver Trevally *Pseudocaranx dentex* off New South Wales. 69pp.

No. 25 Allan, G.L., Jantrarotai, W., Rowland, S., Kosuturak, P. and Booth, M., 2000. Replacing fishmeal in aquaculture diets. 13pp.

No. 26 Gehrke, P.C., Gilligan, D.M. and Barwick, M., 2001. Fish communities and migration in the Shoalhaven River – Before construction of a fishway. 126pp.

No. 27 Rowling, K.R. and Makin, D.L., 2001. Monitoring of the fishery for Gemfish *Rexea solandri*, 1996 to 2000. 44pp.

No. 28 Otway, N.M., 1999. Identification of candidate sites for declaration of aquatic reserves for the conservation of rocky intertidal communities in the Hawkesbury Shelf and Batemans Shelf Bioregions. 88pp.

No. 29 Heasman, M.P., Goard, L., Diemar, J. and Callinan, R., 2000. Improved Early Survival of Molluscs: Sydney Rock Oyster (*Saccostrea glomerata*). 63pp.

No. 30 Allan, G.L., Dignam, A and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 1. R&D Plan.

No. 31 Allan, G.L., Banens, B. and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 2. Resource Inventory and Assessment. 33pp.

No. 32 Bruce, A., Growns, I. and Gehrke, P., 2001. Woronora River Macquarie Perch Survey. 116pp.

No. 33 Morris, S.A., Pollard, D.A., Gehrke, P.C. and Pogonoski, J.J., 2001. Threatened and Potentially Threatened Freshwater Fishes of Coastal New South Wales and the Murray-Darling Basin. 177pp.

No. 34 Heasman, M.P., Sushames, T.M., Diemar, J.A., O'Connor, W.A. and Foulkes, L.A., 2001. Production of Micro-algal Concentrates for Aquaculture Part 2: Development and Evaluation of Harvesting, Preservation, Storage and Feeding Technology. 150pp + appendices.

No. 35 Stewart, J. and Ferrell, D.J., 2001. Mesh selectivity in the NSW demersal trap fishery. 86pp.

No. 36 Stewart, J., Ferrell, D.J., van der Walt, B., Johnson, D. and Lowry, M., 2001. Assessment of length and age composition of commercial kingfish landings. 49pp.

No. 37 Gray, C.A. and Kennelly, S.J., 2001. Development of discard-reducing gears and practices in the estuarine prawn and fish haul fisheries of NSW. 151pp.

No. 38 Murphy, J.J., Lowry, M.B., Henry, G.W. and Chapman, D., 2002. The Gamefish Tournament Monitoring Program – 1993 to 2000. 93pp.

No. 39 Kennelly, S.J. and McVea, T.A. (Ed), 2002. Scientific reports on the recovery of the Richmond and Macleay Rivers following fish kills in February and March 2001. 325pp.

No. 40 Pollard, D.A. and Pethebridge, R.L., 2002. Report on Port of Botany Bay Introduced Marine Pest Species Survey. 69pp.

No. 41 Pollard, D.A. and Pethebridge, R.L., 2002. Report on Port Kembla Introduced Marine Pest Species Survey. 72pp.

No. 42 O'Connor, W.A, Lawler, N.F. and Heasman, M.P., 2003. Trial farming the akoya pearl oyster, *Pinctada imbricata*, in Port Stephens, NSW. 170pp.

No. 43 Fielder, D.S. and Allan, G.L., 2003. Improving fingerling production and evaluating inland saline water culture of snapper, *Pagrus auratus*. 62pp.

No. 44 Astles, K.L., Winstanley, R.K., Harris, J.H. and Gehrke, P.C., 2003. Experimental study of the effects of cold water pollution on native fish. 55pp.

No. 45 Gilligan, D.M., Harris, J.H. and Mallen-Cooper, M., 2003. Monitoring changes in the Crawford River fish community following replacement of an effective fishway with a vertical-slot fishway design: Results of an eight year monitoring program. 80pp.

No. 46 Pollard, D.A. and Rankin, B.K., 2003. Port of Eden Introduced Marine Pest Species Survey. 67pp.

No. 47 Otway, N.M., Burke, A.L., Morrison, NS. and Parker, P.C., 2003. Monitoring and identification of NSW Critical Habitat Sites for conservation of Grey Nurse Sharks. 62pp.

No. 48 Henry, G.W. and Lyle, J.M. (Ed), 2003. The National Recreational and Indigenous Fishing Survey. 188 pp.

No. 49 Nell, J.A., 2003. Selective breeding for disease resistance and fast growth in Sydney rock oysters. 44pp. (Also available – a CD-Rom published in March 2004 containing a collection of selected manuscripts published over the last decade in peer-reviewed journals).

No. 50 Gilligan, D. and Schiller, S., 2003. Downstream transport of larval and juvenile fish. 66pp.

No. 51 Liggins, G.W., Scandol, J.P. and Kennelly, S.J., 2003. Recruitment of Population Dynamacist. 44pp.

No. 52 Steffe, A.S. and Chapman, J.P., 2003. A survey of daytime recreational fishing during the annual period, March 1999 to February 2000, in Lake Macquarie, New South Wales. 124pp.

No. 53 Barker, D. and Otway, N., 2003. Environmental assessment of zinc coated wire mesh sea cages in Botany Bay NSW. 36pp.

No. 54 Growns, I., Astles, A. and Gehrke, P., 2003. Spatial and temporal variation in composition of riverine fish communities. 24pp.

No. 55 Gray, C. A., Johnson, D.D., Young, D.J. and Broadhurst, M. K., 2003. Bycatch assessment of the Estuarine Commercial Gill Net Fishery in NSW. 58pp.

No. 56 Worthington, D.G. and Blount, C., 2003. Research to develop and manage the sea urchin fisheries of NSW and eastern Victoria. 182pp.

No. 57 Baumgartner, L.J., 2003. Fish passage through a Deelder lock on the Murrumbidgee River, Australia. 34pp.

No. 58 Allan, G.L., Booth, M.A., David A.J. Stone, D.A.J. and Anderson, A.J., 2004. Aquaculture Diet Development Subprogram: Ingredient Evaluation. 171pp.

No. 59 Smith, D.M., Allan, G.L. and Booth, M.A., 2004. Aquaculture Diet Development Subprogram: Nutrient Requirements of Aquaculture Species. 220pp.

No. 60 Barlow, C.G., Allan, G.L., Williams, K.C., Rowland, S.J. and Smith, D.M., 2004. Aquaculture Diet Development Subprogram: Diet Validation and Feeding Strategies. 197pp.

No. 61 Heasman, M.H., 2004. Sydney Rock Oyster Hatchery Workshop 8 – 9 August 2002, Port Stephens, NSW. 115pp.

No. 62 Heasman, M., Chick, R., Savva, N., Worthington, D., Brand, C., Gibson, P. and Diemar, J., 2004. Enhancement of populations of abalone in NSW using hatchery-produced seed. 269pp.

No. 63 Otway, N.M. and Burke, A.L., 2004. Mark-recapture population estimate and movements of Grey Nurse Sharks. 53pp.

No. 64 Creese, R.G., Davis, A.R. and Glasby, T.M., 2004. Eradicating and preventing the spread of the invasive alga *Caulerpa taxifolia* in NSW. 110pp.

No. 65 Baumgartner, L.J., 2004. The effects of Balranald Weir on spatial and temporal distributions of lower Murrumbidgee River fish assemblages. 30pp.

No. 66 Heasman, M., Diggles, B.K., Hurwood, D., Mather, P., Pirozzi, I. and Dworjanyn, S., 2004. Paving the way for continued rapid development of the flat (angasi) oyster (*Ostrea angasi*) farming in New South Wales. 40pp.

ISSN 1449-9967 (NSW Department of Primary Industries – Fisheries Final Report Series)

No. 67 Kroon, F.J., Bruce, A.M., Housefield, G.P. and Creese, R.G., 2004. Coastal floodplain management in eastern Australia: barriers to fish and invertebrate recruitment in acid sulphate soil catchments. 212pp.

No. 68 Walsh, S., Copeland, C. and Westlake, M., 2004. Major fish kills in the northern rivers of NSW in 2001: Causes, Impacts & Responses. 55pp.

No. 69 Pease, B.C. (Ed), 2004. Description of the biology and an assessment of the fishery for adult longfinned eels in NSW. 168pp.

No. 70 West, G., Williams, R.J. and Laird, R., 2004. Distribution of estuarine vegetation in the Parramatta River and Sydney Harbour, 2000. 37pp.

No. 71 Broadhurst, M.K., Macbeth, W.G. and Wooden, M.E.L., 2005. Reducing the discarding of small prawns in NSW's commercial and recreational prawn fisheries. 202pp.

No. 72. Graham, K.J., Lowry, M.B. and Walford, T.R., 2005. Carp in NSW: Assessment of distribution, fishery and fishing methods. 88pp.

No. 73 Stewart, J., Hughes, J.M., Gray, C.A. and Walsh, C., 2005. Life history, reproductive biology, habitat use and fishery status of eastern sea garfish (*Hyporhamphus australis*) and river garfish (*H. regularis ardelio*) in NSW waters. 180pp.

No. 74 Growns, I. and Gehrke, P., 2005. Integrated Monitoring of Environmental Flows: Assessment of predictive modelling for river flows and fish. 33pp.

No. 75 Gilligan, D., 2005. Fish communities of the Murrumbidgee catchment: Status and trends. 138pp.

No. 76 Ferrell, D.J., 2005. Biological information for appropriate management of endemic fish species at Lord Howe Island. 18 pp.

No. 77 Gilligan, D., Gehrke, P. and Schiller, C., 2005. Testing methods and ecological consequences of large-scale removal of common carp. 46pp.

No. 78 Boys, C.A., Esslemont, G. and Thoms, M.C., 2005. Fish habitat and protection in the Barwon-Darling and Paroo Rivers. 118pp.

No. 79 Steffe, A.S., Murphy, J.J., Chapman, D.J. and Gray, C.C., 2005. An assessment of changes in the daytime recreational fishery of Lake Macquarie following the establishment of a 'Recreational Fishing Haven'. 103pp.

No. 80 Gannassin, C. and Gibbs, P., 2005. Broad-Scale Interactions Between Fishing and Mammals, Reptiles and Birds in NSW Marine Waters. 171pp.

No. 81 Steffe, A.S., Murphy, J.J., Chapman, D.J., Barrett, G.P. and Gray, C.A., 2005. An assessment of changes in the daytime, boat-based, recreational fishery of the Tuross Lake estuary following the establishment of a 'Recreational Fishing Haven'. 70pp.

No. 82 Silberschnieder, V. and Gray, C.A., 2005. Arresting the decline of the commercial and recreational fisheries for mulloway (*Argyrosomus japonicus*). 71pp.

No. 83 Gilligan, D., 2005. Fish communities of the Lower Murray-Darling catchment: Status and trends. 106pp.

No. 84 Baumgartner, L.J., Reynoldson, N., Cameron, L. and Stanger, J., 2006. Assessment of a Dual-frequency Identification Sonar (DIDSON) for application in fish migration studies. 33pp.

No. 85 Park, T., 2006. FishCare Volunteer Program Angling Survey: Summary of data collected and recommendations. 41pp.

No. 86 Baumgartner, T., 2006. A preliminary assessment of fish passage through a Denil fishway on the Edward River, Australia. 23pp.

No. 87 Stewart, J., 2007. Observer study in the Estuary General sea garfish haul net fishery in NSW. 23pp.

No. 88 Faragher, R.A., Pogonoski, J.J., Cameron, L., Baumgartner, L. and van der Walt, B., 2007. Assessment of a stocking program: Findings and recommendations for the Snowy Lakes Trout Strategy. 46pp.

No. 89 Gilligan, D., Rolls, R., Merrick, J., Lintermans, M., Duncan, P. and Kohen, J., 2007. Scoping knowledge requirements for Murray crayfish (*Euastacus armatus*). Final report to the Murray Darling Basin Commission for Project No. 05/1066 NSW 103pp.

No. 90 Kelleway, J., Williams. R.J. and Allen, C.B., 2007. An assessment of the saltmarsh of the Parramatta River and Sydney Harbour. 100pp.

No. 91 Williams, R.J. and Thiebaud, I., 2007. An analysis of changes to aquatic habitats and adjacent land-use in the downstream portion of the Hawkesbury Nepean River over the past sixty years. 97pp.

No. 92 Baumgartner, L., Reynoldson, N., Cameron, L. and Stanger, J. The effects of selected irrigation practices on fish of the Murray-Darling Basin. 90pp.

No. 93 Rowland, S.J., Landos, M., Callinan, R.B., Allan, G.L., Read, P., Mifsud, C., Nixon, M., Boyd, P. and Tally, P., 2007. Development of a health management strategy for the Silver Perch Aquaculture Industry. 219pp.

No. 94 Park, T., 2007. NSW Gamefish Tournament Monitoring – Angling Research Monitoring Program. Final report to the NSW Recreational Fishing Trust. 142pp.

No. 95 Heasman, M.P., Liu, W., Goodsell, P.J., Hurwood D.A. and Allan, G.L., 2007. Development and delivery of technology for production, enhancement and aquaculture of blacklip abalone (*Haliotis rubra*) in New South Wales. 226pp.

No. 96 Ganassin, C. and Gibbs, P.J., 2007. A review of seagrass planting as a means of habitat compensation following loss of seagrass meadow. 41pp.

No. 97 Stewart, J. and Hughes, J., 2008. Determining appropriate harvest size at harvest for species shared by the commercial trap and recreational fisheries in New South Wales. 282pp.

No. 98 West, G. and Williams, R.J., 2008. A preliminary assessment of the historical, current and future cover of seagrass in the estuary of the Parramatta River. 61pp.

No. 99 Williams, D.L. and Scandol, J.P., 2008. Review of NSW recreational fishing tournament-based monitoring methods and datasets. 83pp.

No. 100 Allan, G.L., Heasman, H. and Bennison, S., 2008. Development of industrial-scale inland saline aquaculture: Coordination and communication of R&D in Australia. 245pp.

No. 101 Gray, C.A and Barnes, L.M., 2008. Reproduction and growth of dusky flathead (*Platycephalus fuscus*) in NSW estuaries. 26pp.

No. 102 Graham, K.J., 2008. The Sydney inshore trawl-whiting fishery: codend selectivity and fishery characteristics. 153pp.

No. 103 Macbeth, W.G., Johnson, D.D. and Gray, C.A., 2008. Assessment of a 35-mm square-mesh codend and composite square-mesh panel configuration in the ocean prawn-trawl fishery of northern New South Wales. 104pp.

No. 104 O'Connor, W.A., Dove, M. and Finn, B., 2008. Sydney rock oysters: Overcoming constraints to commercial scale hatchery and nursery production. 119pp.

No. 105 Glasby, T.M. and Lobb, K., 2008. Assessing the likelihoods of marine pest introductions in Sydney estuaries: A transport vector approach. 84pp.

No. 106 Rotherham, D., Gray, C.A., Underwood, A.J., Chapman, M.G. and Johnson, D.D., 2008. Developing fishery-independent surveys for the adaptive management of NSW's estuarine fisheries. 135pp.

No. 107 Broadhurst, M., 2008. Maximising the survival of bycatch discarded from commercial estuarine fishing gears in NSW. 192pp.

No. 108 Gilligan, D., McLean, A. and Lugg, A., 2009. Murray Wetlands and Water Recovery Initiatives: Rapid assessment of fisheries values of wetlands prioritised for water recovery. 69pp.

No. 109 Williams, R.J. and Thiebaud, I., 2009. Occurrence of freshwater macrophytes in the catchments of the Parramatta River, Lane Cove River and Middle Harbour Creek, 2007 – 2008. 75pp.

No. 110 Gilligan, D., Vey, A. and Asmus, M., 2009. Identifying drought refuges in the Wakool system and assessing status of fish populations and water quality before, during and after the provision of environmental, stock and domestic flows. 56pp.

ISSN 1837-2112 (Industry & Investment NSW – Fisheries Final Report Series)

No. 111 Gray, C.A., Scandol. J.P., Steffe, A.S. and Ferrell, D.J., 2009. Australian Society for Fish Biology Annual Conference & Workshop 2008: Assessing Recreational Fisheries; Current and Future Challenges. 54pp.

No. 112 Otway, N.M. Storrie, M.T., Louden, B.M. and Gilligan, J.J., 2009. Documentation of depth-related migratory movements, localised movements at critical habitat sites and the effects of scuba diving for the east coast grey nurse shark population. 90pp.

No. 113 Creese, R.G., Glasby, T.M., West, G. and Gallen, C., 2009. Mapping the habitats of NSW estuaries. 95pp.

No. 114 Macbeth, W.G., Geraghty, P.T., Peddemors, V.M. and Gray, C.A., 2009. Observer-based study of targeted commercial fishing for large shark species in waters off northern New South Wales. 82pp.

No. 115 Scandol, J.P., Ives, M.C. and Lockett, M.M., 2009. Development of national guidelines to improve the application of risk-based methods in the scope, implementation and interpretation of stock assessments for data-poor species. 186pp.

No. 116 Baumgartner, L., Bettanin, M., McPherson, J., Jones, M., Zampatti, B. and Kathleen Beyer., 2009. Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murray-Darling Basin. 47pp.

No. 117 Astles, K., West, G., and Creese, R.G., 2010. Estuarine habitat mapping and geomorphic characterisation of the Lower Hawkesbury river and Pittwater estuaries. 229pp.

No. 118 Gilligan, D., Jess, L., McLean, G., Asmus, M., Wooden, I., Hartwell, D., McGregor, C., Stuart, I., Vey, A., Jefferies, M., Lewis, B. and Bell, K., 2010. Identifying and implementing targeted carp control options for the Lower Lachlan Catchment. 126pp.

No. 119 Montgomery, S.S., Walsh, C.T., Kesby, C.L and Johnson, D.D., 2010. Studies on the growth and mortality of school prawns. 90pp.

No. 120 Liggins, G.W. and Upston, J., 2010. Investigating and managing the *Perkinsus*-related mortality of blacklip abalone in NSW. 182pp.

No. 121 Knight, J., 2010. The feasibility of excluding alien redfin perch from Macquarie perch habitat in the Hawkesbury-Nepean Catchment. 53pp.

No. 122 Ghosn, D., Steffe, A., Murphy, J., 2010. An assessment of the effort and catch of shore and boat-based recreational fishers in the Sydney Harbour estuary over the 2007/08 summer period. 60pp.

No. 123 Rourke, M. and Gilligan, D., 2010. Population genetic structure of freshwater catfish (*Tandanus tandanus*) in the Murray-Darling Basin and coastal catchments of New South Wales: Implications for future re-stocking programs. 74pp.

No. 124 Tynan, R., Bunter, K. and O'Connor, W., 2010. Industry Management and Commercialisation of the Sydney Rock Oyster Breeding Program. 21pp.

No. 125 Lowry, M., Folpp, H., Gregson, M. and McKenzie, R., 2010. Assessment of artificial reefs in Lake Macquarie NSW. 47pp.

No. 126 Howell, T. and Creese, R., 2010. Freshwater fish communities of the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments: a 2004 status report. 93pp.