7 Differences in composition and structure of fish communities associated with flow regulation in New South Wales rivers

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Summary

Lowland reaches of forty rivers in New South Wales were designated as ‘regulated’, where flows were substantially modified from the natural condition by the operation of a dam upstream, or ‘unregulated’, where flows were either completely natural, or where tributary inflows created a minimally regulated flow regime despite the existence of a dam some distance upstream. Five replicate rivers of each type were selected from the North Coast, South Coast, Darling and Murray regions in the State. Fish communities in each river were sampled in summer and winter in two consecutive years using a standardised suite of gear that maximised the range of species caught at each site. Significant differences occurred in the composition of fish communities between river types, although communities in each region retained a unique regional character. The proportion of native species in the total catch was greater in unregulated rivers in all regions, ranging from 27% in the Murray region to 100% in South Coast rivers. In regulated rivers, native species made up 20% of the catch in the Murray region compared with a maximum of 99% in the North Coast. Carp, *Cyprinus carpio*, were the main alien species contributing to the changes in the proportional abundance of native species. Native species whose abundances river regulation reduced most were western carp gudgeons, *Hypseleotris* spp. bony herring, *Nematalosa erebi*, and striped gudgeons, *Gobiomorphus australis*. Fifteen native species showed some effect of river regulation on the size-structure of their populations, reflecting a confounded combination of greater recruitment success and faster growth among river types. Individual species showed positive, negative, or mixed positive and negative, effects of regulation, measured by their contribution to the fish community, species abundance, and population size-structure. Three abundant alien species and seven native species showed only positive or mixed responses, whereas thirteen native species exhibited only negative effects of river regulation. Consequently, flow regulation has reduced the resilience of New South Wales’ rivers and native fish communities to invasion by alien fish species. Experience in other regulated rivers shows that modifying the regulated flow regime can successfully rehabilitate fish communities, suggesting that similar benefits can be expected from implementing enhanced river flow objectives in New South Wales. To demonstrate more fully the ecological and economic benefits of new river flow objectives, investigations to assess the responses of fish to modified flows need to include individual, population, and community levels of organisation. Better tools are also required to measure the degree of flow regulation at individual sites.

INTRODUCTION

Regulation of stream flow by dams which impound water that would otherwise provide flow downstream is a major cause of degradation in aquatic riverine ecosystems around the world (Bain *et al.* 1988; Merron *et al.* 1993; Garcia de Jalon *et al.* 1994; Gehrke *et al.* 1995; Humphries *et al.* 1996; Zhong and Power 1996). Ecological effects of flow regulation in Australia include changes in populations of freshwater crayfish (Geddes 1990), mussels and snails (Walker 1992; Walker *et al.* 1992), fish (Cadwallader 1978; Harris 1988; Cadwallader and Lawrence 1990), and declining species diversity in fish communities (Gehrke *et al.* 1995). Apart from reducing the amount of flow in affected rivers, flow regulation also typically alters the variability of natural flow regimes on hourly, daily, monthly, seasonal, interannual, and longer time-scales. The natural fauna within a river system is adapted to natural fluctuations in environmental conditions, so that altered stability in stream flow due to river regulation may disturb environmentally-cued reproductive cycles (Ward and Stanford 1989). In this way, the altered frequency of disturbance due to either high or low flows in regulated rivers may cause a decline in species diversity as suggested by the intermediate-disturbance hypothesis (Connell 1978; Ward and Stanford 1983).

Effects of flow regulation on riverine communities may differ according to the type of shift in flow regime created by regulation. For example, rivers that are regulated principally to provide water for irrigation during seasons of low rainfall, such as the Murrumbidgee River, maintain a highly seasonal flow that is out of phase with the natural seasonal flow cycle (Merron *et al.* 1993; Walker and Thoms 1993; Gehrke *et al.* 1995). In these situations, the natural river channel is the major conduit of water for downstream use. The storage capacity of dams absorbs small to intermediate-size floods and water extraction reduces the mean annual flow volume. In contrast, rivers that are regulated to generate hydroelectricity experience highly erratic flows on a daily basis (Boon 1993; Comargo 1993; Moog 1993; Garcia de Jalon *et al.* 1994; Sear 1994; Travnichek *et al.* 1995) according to demand within the power grid. Large urban populations require a much more constant water supply, which is commonly extracted either directly from the reservoir through pipes, or by releasing water downstream to a pumping basin. In either case, downstream flows are commonly minimal and relatively stable (Ibañez *et al.* 1995; Gehrke *et al.* 1996).

In New South Wales, where rivers are regulated for all of these reasons, observed effects of flow regulation on fish communities are likely to differ among geographical regions according both to, the nature of changes to flow regimes brought about by flow regulation, and to the sensitivity of individual species and entire fish communities to departures from natural flows. This study examines differences in fish communities between regulated and unregulated rivers to identify likely effects of regulation on fish resources, and to consider ways in which partial restoration of natural flows may reverse some of these effects.

METHODS

Lowland river reaches in New South Wales were classified as either ‘regulated’, where flows were substantially modified from the natural condition by the operation of a dam upstream, or ‘unregulated’, where flows were either completely natural, or where tributary inflows create a minimally regulated flow regime despite the existence of a dam some distance upstream. The terminology adopted here differs from the legislative definitions applied by the NSW Water Act, which define regulated rivers as those rivers where flows are regulated by dams owned or operated by the Department of Land and Water Conservation. Consequently, some sites designated as regulated in this study are identified as unregulated by NSW legislation. Similarly, the definitions adopted for this study pre-date the terminology of ‘controlled’ and ‘uncontrolled’ rivers used for the purpose of setting river flow objectives for the NSW Water Reform Package announced by the Government in August 1997.

None of these simple classifications adequately reflects the continuum of river-regulation intensity in New South Wales rivers. This continuum ranges from river reaches whose flows are totally unmodified from the natural condition, to rivers whose flows are completely determined by dam releases. However, neither the methods nor the data existed during the initial stages of this project to classify lowland rivers in New South Wales according to their degree of regulation. Consequently, lowland rivers were simply classified subjectively according to whether their flows were predominantly regulated or unregulated. For this reason, river reaches nominally classified as regulated represent a range of regulated flow regimes, and conversely, nominal unregulated rivers include reaches whose flows are not modified by dams, as well as some whose flows may be altered by dam releases, extraction, or by impoundment in weirs from time to time. It was difficult to find five replicate, truly unregulated lowland rivers in the two inland regions, so that the rivers selected represent a random selection of the least-regulated rivers. For convenience throughout this report, these minimally regulated rivers are referred to as unregulated, and are compared to other regulated rivers which are, in comparison, heavily regulated. Comparisons between these river-reach types therefore indicate differences in fish communities between opposite ends of the continuum of flow regulation.

Forty river reaches were selected for this study. Sites were selected as described in Chapter 1, from rivers in the North Coast, South Coast, Darling and Murray regions in New South Wales. Lowland rivers were defined as rivers below 300 m altitude in the Murray and Darling regions, or between 40 m altitude and the upper tidal limit in coastal regions. Within each region, five replicate reaches of each river type were selected using a modified random process that avoided selecting sites that had been extensively examined in other projects by NSW Fisheries. This process also selected three sites that were highly degraded and lacked water, necessitating rejection of these sites for the purposes of this study and selection of replacement, random sites. Sites used for this analysis are shown in Figure 7.1. For a full description of these sites see Chapter 2.

Fish were caught by applying a standardised suite of quantitative sampling methods at each site, including ten 2-minute duration shots from a boat electrofisher, three fyke nets, three multimesh gill nets, and nine small-meshed wire bait traps to sample small fish species. For details of how these methods were applied and standardised, refer to Chapter 1. The unit of sampling effort used for comparisons in this study was the pooled catch from all sampling methods, including eels that were recorded as observed, to represent an estimate of the total fish community at each site. Variability and selectivity among gear types is presented separately (Chapter 10).

Sites were sampled twice yearly over two years to obtain an indication of variability in fish communities within and between years. The sample design therefore provided four factors for analysis: river type (regulated, unregulated); regions (4), years (2) and times (2). Data were analysed using a variety of techniques. Fish community data were analysed using PRIMER 4.0 (Plymouth Marine Laboratory) to perform hierarchical agglomerative classification analysis and multi-dimensional scaling (MDS) ordinations. These analyses were done at two levels, with differing degrees of pooling, to conform to the data limits in PRIMER. Primary analyses of all forty sites used catch data that were pooled over the four sampling times. Secondary analyses of ten sites within each region used data that were not pooled over times of sampling to include information on possible temporal effects of flow regulation. Species abundances were transformed to the fourth root, and similarities were calculated using the Bray-Curtis similarity measure (Bray and Curtis 1957). The fourth root transformation has the advantage that, as it is a power transformation, similarities calculated using the Bray-Curtis measure are invariant to the scale of measurement (Stephenson and Burgess, 1980). Both classification and ordination were done on similarities among sites, as determined from relative species abundances, as well as inverse analyses of similarities among species, as determined from sites in which they occurred. All classifications used the group-average linking algorithm.

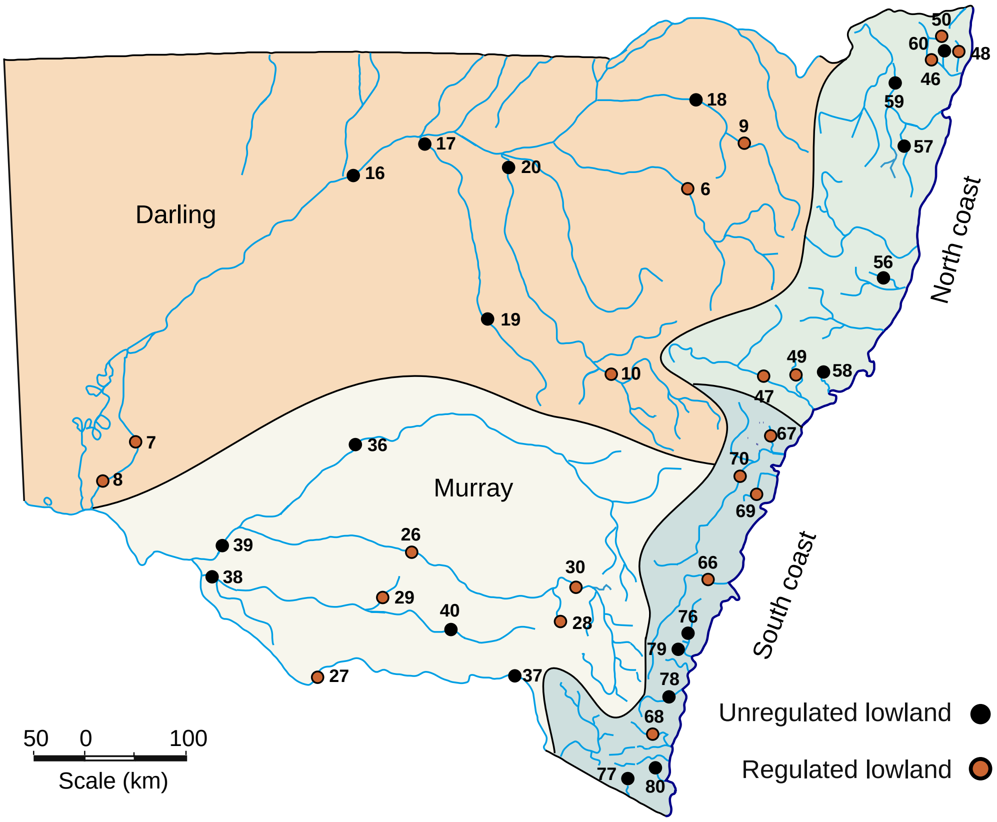

Figure 7.1 Lowland river sites sampled to determine differences between fish communitites associated with flow regulation in New South Wales rivers.

Two-way ANOSIM (ANalysis Of SIMilarities) comparisons (Clarke 1993) were done at differing strata to identify effects of flow regulation in the context of variation in fish community composition among regions, and the effects of flow regulation on fish community composition within regions over time. Permutation tests to estimate the probability of observed results used 5000 Monte Carlo randomisations for comparisons among regions, and the maximum number of 1225 randomisations for comparisons within regions over time. SIMPER (SIMilarity PERcentages) analyses were used to identify species that contribute most to the average dissimilarity between river types for each region.

Fish community variables - specifically the number of species per site, total fish abundance per site, species diversity (Shannon’s H′), and the proportion of native fish in the catch - were analysed by factorial analysis of variance. Regions, river type, years and time were used as factors to establish the importance of flow regulation in determining community structure in relation to natural spatial and temporal variation. Abundances of two species that occurred in all four regions, Australian smelt, *Retropinna semoni*, and carp, *Cyprinus carpio*, were also analysed using the four-factor model. Other species were analysed using a reduced factorial model with fewer regional treatments according to the number of regions in which each species was caught. The criterion adopted to avoid an excessive number of zero values when analysing individual species was that at least 50 individuals must have been caught during the study. Abundance data were transformed to $\log_{10}$ (x+1) to homogenise variances and to ensure that variances were independent of treatment means. Transformation was not necessary in all cases, and in a minority of cases, transformation was not successful in producing homogeneous variances (Cochran's test). However, the most consistent interpretations were achieved by applying the same transformation to all abundance data. The arc-sine transformation was used for analysing the proportion of native fish in the catch.

In addition to community composition and species abundances, the population size-structure was compared between regulated and unregulated rivers using Kolmogorov-Smirnov two-tailed tests for all species where more than 30 individuals were caught from each river type. Separate tests were done for each region.

RESULTS

A total of 27,495 fish from 51 species was recorded from lowland river reaches during this study (Table 7.1). Australian smelt was the most abundant species, followed by bony herring, *Nematalosa erebi*, western carp gudgeons, *Hypseleotris* spp., empire gudgeon, *Hypseleotris compressa*, and carp. Five species - *Carcharhinus leucas*, *Craterocephalus fluviatilis*, *Gnathanodon speciosus*, *Platycephalus fuscus* and *Redigobious macrostoma*, were caught only once, while fewer than 10 individuals were caught for an additional seven species.

Table 7.1 Quantitative summary of fish species recorded from 'unregulated' and 'regulated' lowland river sites in four geographical regions of New South Wales. Numbers indicate the sum of individuals both caught and observed during sampling.

	Species	**Darling**		**Murray**		**North Coast**		**South Coast**		**Total**
		Unreg.	Reg.	Unreg.	Reg.	Unreg.	Reg.	Unreg.	Reg.	
1	*Acanthopagrus australis*	0	0	0	0	3	8	0	0	**11**
2	*Ambassis agassizii*	1	0	0	0	7	145	0	0	**153**
3	*Ambassis nigripinnis*	0	0	0	0	212	42	0	0	**254**
4	*Anguilla australis*	0	0	0	0	0	0	1	1	**2**
5	*Anguilla reinhardtii*	0	0	0	0	246	200	211	363	**1021**
6	*Arius graeffei*	0	0	0	0	59	0	0	0	**59**
7	*Arrhamphus sclerolepis*	0	0	0	0	6	0	0	0	**6**
8	*Bidyanus bidyanus*	1	6	1	0	0	0	0	0	**8**
9	*Carassius auratus*	66	35	38	43	5	6	0	14	**207**
10	*Carcharhinus leucas*	0	0	0	0	1	0	0	0	**1**
11	*Craterocephalus fluviatilis*	0	0	0	1	0	0	0	0	**1**
12	*Craterocephalus stercusmuscarum*	466	0	0	24	0	0	0	0	**490**
13	*Cyprinus carpio*	753	241	331	519	0	127	0	41	**2013**
14	*Gadopsis bispinosus*	0	0	3	0	0	0	0	0	**3**
15	*Galaxias brevipinnis*	0	0	12	0	0	0	0	0	**12**
16	*Galaxias maculatus*	0	0	0	0	0	0	393	252	**645**
17	*Gambusia holbrooki*	143	0	0	1	19	8	0	4	**175**
18	*Gnathanodon speciosus*	0	0	0	0	0	1	0	0	**1**
19	*Gobiomorphus australis*	0	0	0	0	354	195	294	124	**967**
20	*Gobiomorphus coxii*	0	0	0	0	7	5	76	8	**96**
21	*Herklotsichthys castelnaui*	0	0	0	0	6	1	0	0	**7**
22	*Hypseleotris compressa*	0	0	0	0	1657	799	23	248	**2727**
23	*Hypseleotris galii*	0	0	0	0	9	224	0	442	**675**
24	*Hypseleotris* spp	2458	198	19	44	0	195	0	0	**2914**
25	*Leiopotherapon unicolor*	104	0	1	0	0	0	0	0	**105**
26	*Liza argentea*	0	0	0	0	27	5	0	0	**32**
27	*Maccullochella peelii*	8	17	0	0	0	0	0	0	**25**
28	*Macquaria ambigua*	94	95	23	13	0	0	0	0	**225**
29	*Macquaria colonorum*	0	0	0	0	0	8	0	1	**9**
30	*Macquaria novemaculeata*	0	0	0	0	167	216	167	525	**1075**
31	*Melanotaenia duboulayi*	0	0	0	0	120	246	0	0	**366**
32	*Melanotaenia fluviatilis*	62	42	0	2	0	0	0	0	**106**
33	*Mordacia praecox*	0	0	0	0	0	0	205	3	**208**
34	*Mugil cephalus*	0	0	0	0	330	350	35	136	**851**
35	*Myxus elongatus*	0	0	0	0	0	0	0	2	**2**
36	*Myxus petardi*	0	0	0	0	354	214	6	113	**687**
37	*Nematalosa erebi*	1843	1032	138	0	0	0	0	0	**3013**
38	*Notesthes robusta*	0	0	0	0	30	31	6	2	**68**
39	*Oncorhynchus mykiss*	0	0	10	17	0	0	0	0	**27**
40	*Perca fluviatilis*	0	188	28	56	0	0	0	0	**272**
41	*Philypnodon grandiceps*	0	4	0	0	172	109	115	223	**623**
42	*Philypnodon* sp1	0	0	0	0	18	4	85	32	**139**
43	*Platycephalus fuscus*	0	0	0	0	1	0	0	0	**1**
44	*Potamalosa richmondia*	0	0	0	0	189	212	0	1	**402**
45	*Prototroctes maraena*	0	0	0	0	0	0	33	3	**36**
46	*Pseudaphritis urvillii*	0	0	0	0	0	0	20	3	**23**
47	*Pseudomugil signifer*	0	0	0	0	66	32	0	0	**98**
48	*Redigobius macrostoma*	0	0	0	0	0	0	0	1	**1**
49	*Retropinna semoni*	4	481	143	241	3465	272	1142	529	**6277**
50	*Salmo trutta*	0	3	34	34	0	0	0	0	**71**
51	*Tandanus tandanus*	1	21	0	0	121	160	0	1	**304**
	Total	**6005**	**2363**	**781**	**995**	**7651**	**3815**	**2812**	**3073**	**27495**

Composition of fish communities among regions and between river types

Classification of sites on the basis of similarities in species composition provided a clear separation of lowland rivers between inland and coastal regions (Figure 7.2). A cut-off similarity value of 55% produced six site groups consisting of predominantly South Coast sites, North Coast sites, and mixed sites from the coastal regions, and two Murray groups and one group of sites from the Darling region. Only one site, from the unregulated Wonboyn River (80R), was not classified in these groups, although it fused with sites from the remaining coastal rivers at a similarity level of 31%. There was no consistent trend for regulated and unregulated sites to form separate groups within regions. Several outlier sites were identified which did not conform to the general regional classification. The Hunter River (47R), Mangrove Creek (67R) and the Nepean River (70R) formed a mixed coastal group with greatest similarity to the South Coast group. Similarly, the Williams (49R) and Karuah (58U) rivers, also located in the North Coast region, were classified with the South Coast group. In the inland regions, the Darling River at Pooncarie (7R) and the Macquarie River at Wellington (10R) were classified with sites from the Murray region.

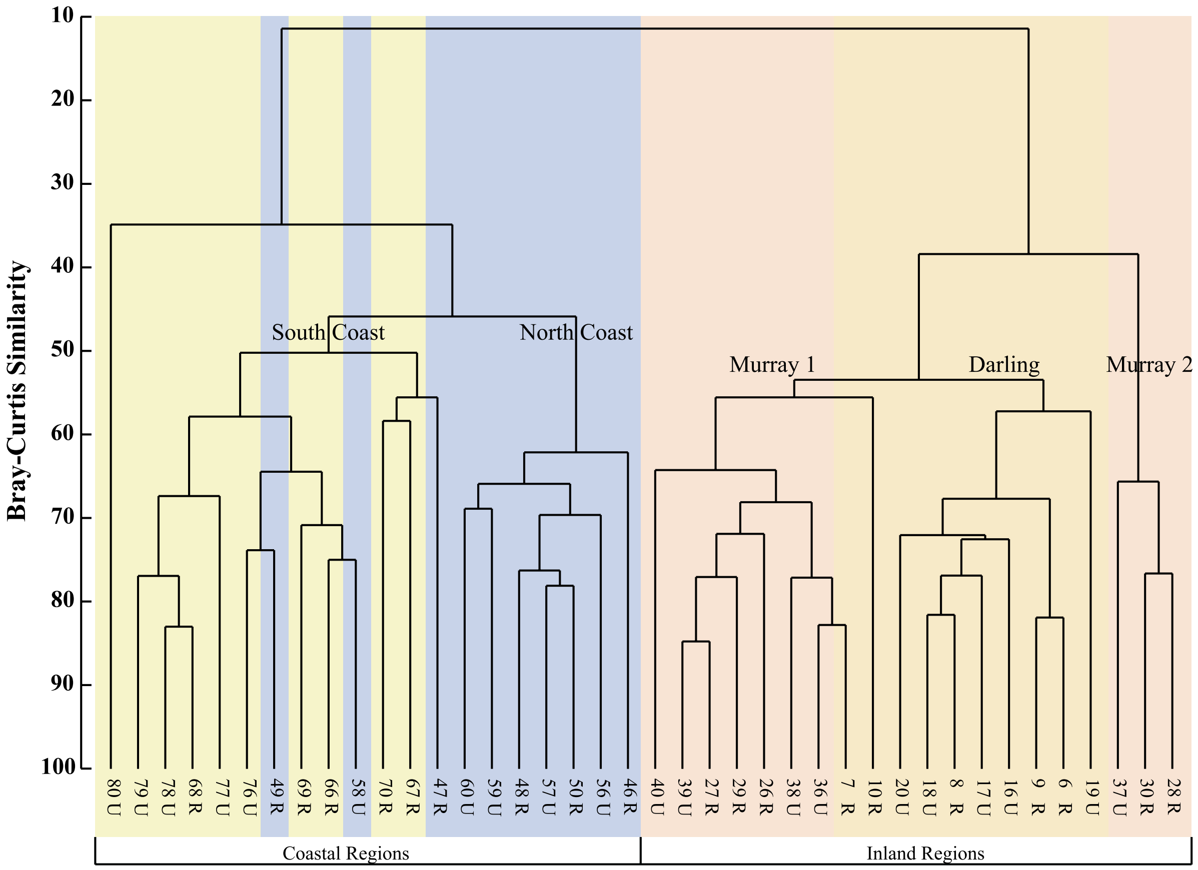

Figure 7.2 Hierarchical agglomerative classification of lowland river sites based on similarities among fish communities at each site. There is a clear seperation between sites from inland and coastal regions, and further regional separation of North Coast and South Coast, and Murray and Darling regions, but no apparent separation of sites on the basis of whether river flows are 'unregulated' (U) or 'regulated' (R). See Figure 7.1 for key to site numbers.

MDS ordination provided similar results, indicating large differences in fish communities between coastal and inland lowland rivers (Figure 7.3). Within each region, however, a degree of separation between regulated and unregulated rivers was observed. These results were confirmed by ANOSIM, which revealed significant regional effects (R = 0.861, p<0.001) and effects associated with differing degrees of flow regulation (R=0.133, p<0.05) (Table 7.2). Pairwise tests between regions indicated significant spatial differences in the fish faunas among all regions (p<0.001). Two sites are apparent as outliers from their respective groups: the Murray River at Tintaldra and the Macquarie River at Wellington.

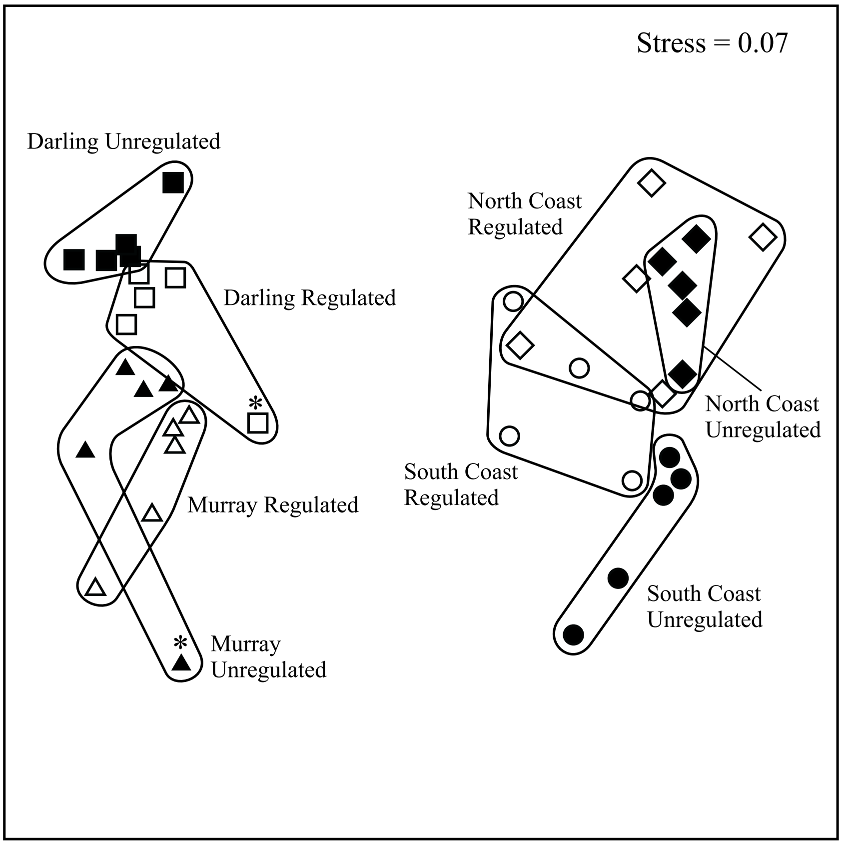

Figure 7.3 Two-dimensional MDS ordination of unregulated and regulated lowland river sites based on similarities between fish communities at each site. The distinction between communities in coastal and inland regions is obvious, while the differences between fish communities in 'unregulated' and 'regulated' rivers are significant for each region (refer to Table 7.3 for details). Outlier sites (*) are located at Tintaldra on the Murray River and on the Macquarie River at Wellington, in the Darling region.

Inverse classification and ordination indicated the presence of four species groups which reflected the regional character of species distributions (Figure 7.4). The large North Coast group of 27 species contained three subgroups, containing 17 cosmopolitan species which were caught predominantly, but not exclusively, from the North Coast region; seven uncommon species caught mostly from unregulated rivers; and three uncommon species caught mostly from regulated rivers. The remaining groups showed no subdivision associated with the degree of flow regulation between river types. A single group of five species occurred predominantly in the South Coast region, while two remaining groups contained five species that occurred only at one site in the Murray region lowland rivers, on the Murray River at Tintaldra, and 11 species that were most abundant in the Darling region, some of which also occurred in the Murray region. The similarities between these groups are shown in ordination space in Figure 7.5.

Table 7.2 Summary ANOSIM results of two-way analysis with regions and river types ('Regulated' v 'Unregulated') as factors. Catches at each site were pooled over four times of sampling, providing five spatially-replicated sites in each cell of the design. 5000 permutations were used to estimate the probabilities of Type I error associated with each comparison.

Source	**R**	**Probability**
Regulated v Unregulated Rivers	0.133	0.029
Among Regions	0.861	<0.001
Pairwise tests		
Darling v Murray	0.558	0.001
Darling v North Coast	1.000	<0.001
Darling v South Coast	1.000	<0.001
Murray v North Coast	1.000	0.001
Murray v South Coast	1.000	<0.001
North Coast v South Coast	0.636	<0.001

ANOSIM analyses within each region reveal significant spatial variation in fish communities among rivers and between regulated and unregulated rivers (Table 7.3). In all regions except the Murray, R values calculated for effects associated with flow regulation were greater than the corresponding R value for spatial variation among rivers. In the Murray region, the unregulated site on the Murray River at Tintaldra was located 125 km upstream of Hume Weir, at an altitude of 230 m, whereas the other lowland unregulated sites in this region were not above major barriers and ranged in altitude from 60 to 180 m. Thus the atypical features of this site account for the relatively large amount of variation among rivers in this region.

As indicated by the inverse classification and ordination analyses, SIMPER analysis found little evidence for the existence of different species groups in regulated and unregulated rivers in each region (Table 7.4). Values for the discriminating species ratios were low throughout, indicating little consistency within species for greater abundances in one river type or the other. This lack of consistency is also evident between regions. For example, western carp gudgeons, golden perch, *Macquaria ambigua*, goldfish, *Carassius auratus*, and carp were more abundant in unregulated rivers in the Darling region, and more abundant in regulated rivers in the Murray region. Only bony herring were consistently more abundant in unregulated rivers in both inland regions, while Australian smelt were consistently more abundant in regulated rivers.

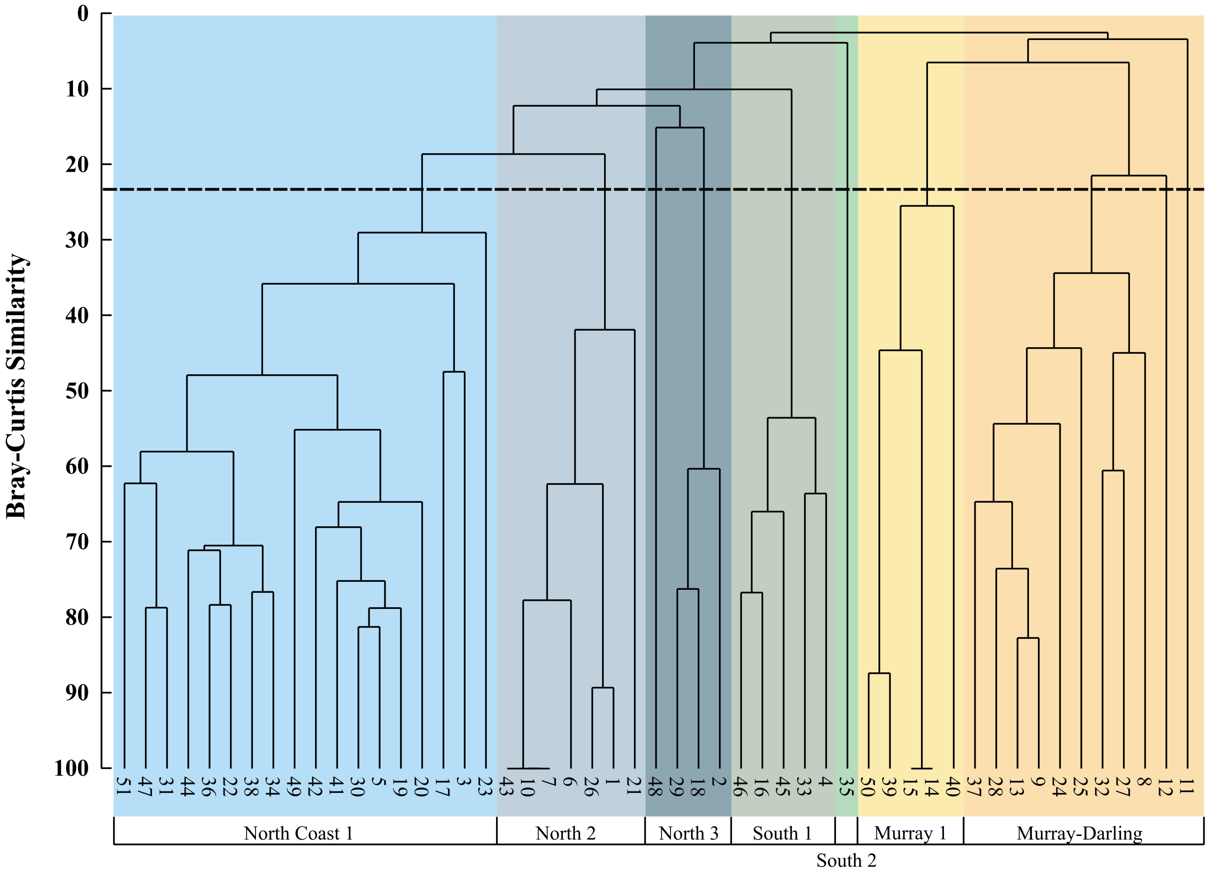

Figure 7.4 Inverse hierarchical agglomerative classification of fish species based on occurrence in lowland river sites in New South Wales. Only rare, estuarine species in the North Coast region showed any tendency to form groups based on unregulated (North Coast 2) or regulated (North Coast 3) river flows. See Table 7.1 for key to species numbers.

The greater species richness in coastal rivers meant that the percentage contributions of individual species to differences between regulated and unregulated rivers were not as large as in inland rivers. Furthermore, the low values for discriminating species ratios meant that no species consistently accounted for a large percentage of the differences in community composition between river types. Two species, Cox's gudgeon, *Gobiomorphus australis* and Australian smelt were more abundant in unregulated rivers in both regions, while Australian bass, *Macquaria novemaculeata*, and long-finned eels, *Anguilla reinhardtii*, were more abundant in regulated rivers. However, flat-headed gudgeons, *Philypnodon grandiceps*, were more abundant in unregulated rivers in the North Coast, and in regulated rivers in the South Coast region. The uncommon species that suggested the existence of different communities in regulated and unregulated North Coast rivers in the species classification and ordination contributed 2.0% or less to the percentage dissimilarity between river types, and had discriminating species ratios of 0.5 or less. Thus the groups formed by these uncommon species are more likely to represent their chance occurrence in particular river types rather than representing core members of fish communities which typically occur in either river type.

Analysis of variance of fish community variables revealed a significant main effect among regions for species richness, Shannon's diversity, total abundance and the proportion of native fish in the total catch (p<0.001, Table 7.5). Main effects associated with river regulation were only detected for the proportion of native fish in the total catch (p<0.05) where the proportional abundance of native fish was greater in unregulated rivers than in regulated rivers. The significant region*river type interaction (p<0.01) for total abundance reflects the greater abundance of fish in unregulated rivers in the Darling and North Coast regions, with greater abundances in regulated rivers in the Murray and South Coast regions (Figure 7.6).

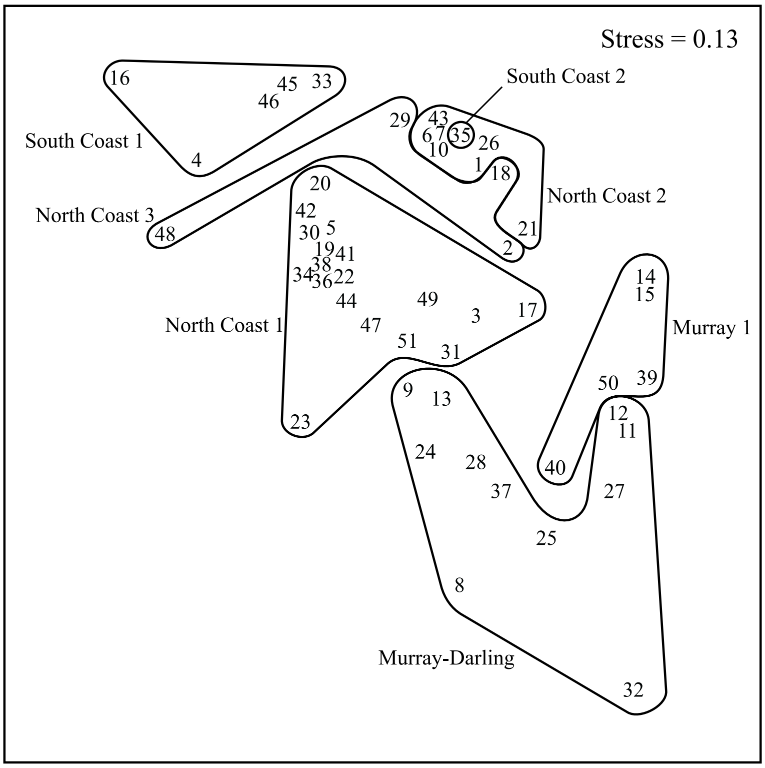

Figure 7.5 Two-dimensional MDS ordination of fish species in regulated and unregulated lowland rivers in New South Wales. Species groups follow the regional distributions with no distinct separation between species occurring in 'unregulated' or 'regulated' rivers, except for species in South Coast 2, North Coast 3 (regulated) and North Coast 2 (unregulated). See Table 7.1 for key to species numbers.

Distribution of species among regions and between river types

Both species recorded in all four regions, carp and Australian smelt, had significant regional effects (p<0.001) and region*river type interactions (p<0.001 and p<0.05) (Table 7.5). Carp were most abundant in regulated rivers in all regions except the Darling region, where unregulated rivers contained most carp (Figure 7.5). The complete absence of carp from unregulated rivers in the South Coast region contributed greatly to the strength of the region*river type interaction. The region*river type interaction for Australian smelt shows that in both coastal regions, unregulated rivers had higher abundances than regulated rivers, but the situation was reversed in the inland regions.

Table 7.3 Summary ANOSIM results of two-way analyses with sites and river types ('Regulated' v 'Unregulated') as factors, and four samples as replicates in time. Separate analyses were done for each region. 5000 permutations were used to estimate the probabilities of Type I error associated with each comparison.

Source	**R**	**Probability**
Darling		
Regulated v Unregulated	0.719	<0.001
Among Rivers	0.573	<0.001
Murray		
Regulated v Unregulated	0.350	<0.001
Among Rivers	0.484	<0.001
North Coast		
Regulated v Unregulated	0.723	<0.001
Among Rivers	0.679	<0.001
South Coast		
Regulated v Unregulated	0.704	<0.001
Among Rivers	0.699	<0.001

The only abundant species collected from the Darling and Murray regions that showed any significant effects between regulated and unregulated rivers was bony herring (Table 7.6), which was less abundant in regulated rivers (Figure 7.7). In contrast six coastal species, striped gudgeons (*Gobiomorphus australis*), Cox's gudgeons, empire gudgeons (*Hypseleotris compressa*), firetailed gudgeons (*Hypseleotris galii*), Australian bass and freshwater mullet (*Myxus petardi*), showed either significant differences in abundance between regulated and unregulated rivers, or significant region*river type interactions (Table 7.6). Both striped gudgeons and Cox's gudgeons were more abundant in unregulated rivers, while firetail gudgeons and Australian bass were more abundant in regulated rivers. Both empire gudgeons and freshwater mullet were more abundant in unregulated rivers in the North Coast region, but more abundant in regulated rivers in the South Coast region.

Of the eight species that were abundant in only one region (Table 7.7), only Pacific blue-eyes, *Pseudomugil signifer*, collected from the North Coast region, showed any effect of river regulation, in the form of a river type*year interaction. Pacific blue-eyes were more abundant in unregulated rivers in the first year, and in regulated rivers in the second year.

Table 7.4 Species contributing to differences in fish communities between 'regulated' and 'unregulated' rivers within each region, as determined by SIMPER analysis. Mean dissimilarity values indicate the magnitude of differences between communities in unregulated and regulated rivers in each region. Ratio values indicate the consistency of each species in discriminating between communities in each river type, with larger ratios indicating greater consistency. The percent column indicates the average contribution of each species to differences between river types.

Species	**Mean Abundance**		**Consistency ratio**	**Percent**	**Cumulative %**
	Unregulated	Regulated			
		Darling region mean dissimilarity = 49.9			
Hypseleotris spp	114.3	9.9	1.2	16.1	16.1
Nematalosa erebi	68.5	28.0	1.5	14.7	30.8
Macquaria ambigua	4.5	4.5	1.2	9.5	40.3
Retropinna semoni	0.2	18.8	0.9	8.7	49.0
Carassius auratus	3.2	1.8	1.2	8.3	57.3
Leiopotherapon unicolor	5.2	0.0	1.0	7.6	64.8
Melanotaenia fluviatilis	2.9	1.5	0.9	6.8	71.7
Cyprinus carpio	25.9	8.5	1.3	5.5	77.1
		Murray region mean dissimilarity = 51.9			
Retropinna semoni	6.1	9.0	1.1	16.3	16.3
Carassius auratus	1.9	1.9	1.0	12.3	28.7
Perca fluviatilis	1.1	2.7	1.1	12.0	40.6
Macquaria ambigua	1.1	0.5	1.0	10.7	51.3
Nematalosa erebi	5.0	0.0	0.7	9.0	60.3
Salmo trutta	0.7	1.6	0.7	8.9	69.2
Hypseleotris spp	0.9	2.2	0.8	7.9	77.1
Cyprinus carpio	12.7	16.2	1.4	7.8	84.9
		North Coast region mean dissimilarity = 47.4			
Hypseleotris compressa	77.9	34.2	1.4	10.9	10.9
Mugil cephalus	12.1	13.8	1.2	6.6	17.5
Potamalosa richmondia	7.3	10.1	1.2	6.3	23.8
Gobiomorphus australis	16.7	8.1	1.3	6.3	30.0
Retropinna semoni	12.1	3.5	1.2	6.0	36.2
Melanotaenia duboulayi	4.8	10.1	1.1	6.0	42.2
Myxus petardi	16.7	8.1	1.1	5.5	47.7
Philypnodon grandiceps	7.1	5.4	1.3	5.5	53.2
Tandanus tandanus	5.9	7.5	1.1	4.9	58.0
Anguilla reinhardtii	12.3	10.1	1.2	4.3	62.3
Notesthes robusta	1.2	1.2	1.2	3.8	66.1
Pseudomugil signifer	3.2	1.6	0.9	3.8	69.9
Macquaria novemaculeata	7.9	9.9	1.3	3.7	73.6
		South Coast region mean dissimilarity = 57.4			
Retropinna semoni	19.3	15.0	1.2	8.8	8.8
Macquaria novemaculeata	7.4	24.8	1.1	8.5	17.3
Galaxias maculatus	17.8	5.1	1.2	8.0	25.3
Philypnodon grandiceps	5.3	11.2	1.2	7.9	33.2
Gobiomorphus australis	13.5	6.0	1.3	7.7	40.1
Cyprinus carpio	0.0	1.9	1.1	6.1	47.0
Gobiomorphus coxii	3.5	0.3	1.2	5.8	52.7

Population size structure

In the Darling region, all species abundant in both unregulated and regulated rivers had significantly different population size-structures ($p<0.001$) between river types (Table 7.8), reflecting the greater abundance of juveniles in unregulated rivers for all species (Figure 7.8), both native and alien, except for crimson-spotted rainbowfish, *Melanotaenia fluviatilis*. This result suggests higher recruitment success in unregulated rivers in the Darling region.

Table 7.5 Summary of four-way analyses of variance for fish community variables and abundant species collected from all four regions. Treatment effects are abbreviated R - region (fixed), T - ‘unregulated’ versus ‘regulated’ river types (fixed), Y - year (random), S - sampling occasion (fixed). Only F-values and probabilities are given. *p<0.05, **p<0.01, ***p<0.001.

Effect	**Degrees of freedom**	**Species Richness**	**Shannon Diversity**	**Total Abundance**	**Proportion of Nati Species**	***Cyprinus carpio***	***Retropinna semoni***
R	3	81.445***	40.357***	26.511***	167.872***	100.017***	7.079***
T	1	0.851	F<0.001	0.683	6.079*	4.388*	0.005
R*T	3	1.317	0.888	4.346**	0.484	6.412***	3.941**
Y	1	F<0.001	0.016	0.377	2.211	5.787*	0.238
R*Y	3	0.993	0.947	0.778	1.216	2.164	0.078
T*Y	1	0.441	0.304	0.432	0.140	1.351	0.001
R*T*Y	3	0.580	0.770	0.420	0.206	0.882	0.950
S	1	5.109*	0.870	7.908**	0.174	0.861	0.708
R*S	3	0.799	0.769	0.861	0.049	1.300	0.135
T*S	1	2.068	1.786	0.722	0.076	4.112*	0.002
R*T*S	3	0.249	1.127	0.073	0.517	0.921	0.084
Y*S	1	0.968	0.078	1.293	1.576	0.051	5.725*
R*Y*S	3	2.041	0.246	1.321	1.343	0.234	0.829
T*Y*S	1	1.564	0.730	0.610	0.274	0.302	0.852
R*T*Y*S	3	1.024	0.936	0.150	0.402	0.528	0.369
Residual	128						

The situation was reversed in the Murray region, where all three species showing a significant difference in population size structure contained a greater proportion of small individuals in regulated rivers. These species, goldfish, carp and redfin perch, *Perca fluviatilis*, are all alien species. The only abundant native species in this region, Australian smelt, showed no significant difference in size structure between river types.

Seven species in the North Coast region displayed different population size structures between river types. Empire gudgeons, striped mullet, *Mugil cephalus*, freshwater mullet, freshwater herring, *Potamalosa richmondia*, and Pacific blue-eyes, had larger mean lengths in regulated rivers (Figure 7.9). Unregulated rivers contained a large proportion of juvenile striped mullet less than 150 mm, as well as a large number of individuals longer than 250 mm. In comparison, regulated rivers displayed a single mode around 300 mm in the length distribution for this species. For freshwater mullet, both regulated and unregulated rivers contained a detectable class of juvenile fish, but the regulated rivers contained a particularly high abundance of individuals larger than 350 mm. The remaining two species with different population size-structures between river types in the North Coast region were Australian bass and Australian smelt. Both species displayed larger mean lengths in unregulated rivers than in regulated rivers.

Seven species in the South Coast region displayed different population size-structures between river types. Long-finned eel populations in unregulated rivers appeared truncated, with few individuals greater than 625 mm, whereas over 40% of individuals from regulated rivers were larger than 625 mm. Although the lengths of eels were only estimated by the observer without bringing them into the boat, the difference in length distributions is so large and so significant that it clearly reflects a real difference in the size structure of populations between regulated and unregulated rivers. Four small species, the common jollytail, *Galaxias maculatus*, striped gudgeons, empire gudgeons and Australian smelt also differed in length distributions between river types with larger mean lengths in regulated rivers. These species appear to have had greater recruitment success in unregulated rivers rather than attaining greater length in regulated rivers. The two remaining species with different size distributions between river types, Australian bass and flatheaded gudgeons, both had similar proportions of juveniles in unregulated and regulated rivers, but the proportion of individuals larger than mean length was greater in unregulated rivers.

Observed effects of river regulation on fish community composition, species abundance and population size-structure are summarised in Table 7.9, with an assessment of whether effects are positive or negative for each species. Five species, consisting of one alien species and four species native to coastal regions, showed only positive effects of increased flow regulation. In contrast, eight species native to coastal regions and five native inland species showed only negative effects of increased flow regulation. A further four species recorded from all four regions showed both positive and negative effects of increased river regulation that varied among regions. No effect of increased regulation was observed for six species, while the remaining 23 species were not recorded in sufficient numbers to detect any effect of flow regulation.

Thus, unregulated rivers in the Darling region appear to contain larger numbers of fish than regulated rivers, with a greater abundance of small individuals than in regulated rivers. In contrast, fish abundances were generally greater in regulated rivers in the Murray region, with a higher proportion of juveniles also in regulated reaches. In both coastal regions, Australian bass were uniformly more abundant in regulated rivers, but with larger individuals in unregulated rivers. Populations of remaining species in both coastal regions tended to have greater proportions of large individuals in regulated rivers with approximately equal numbers of species being more abundant in either unregulated or regulated rivers.

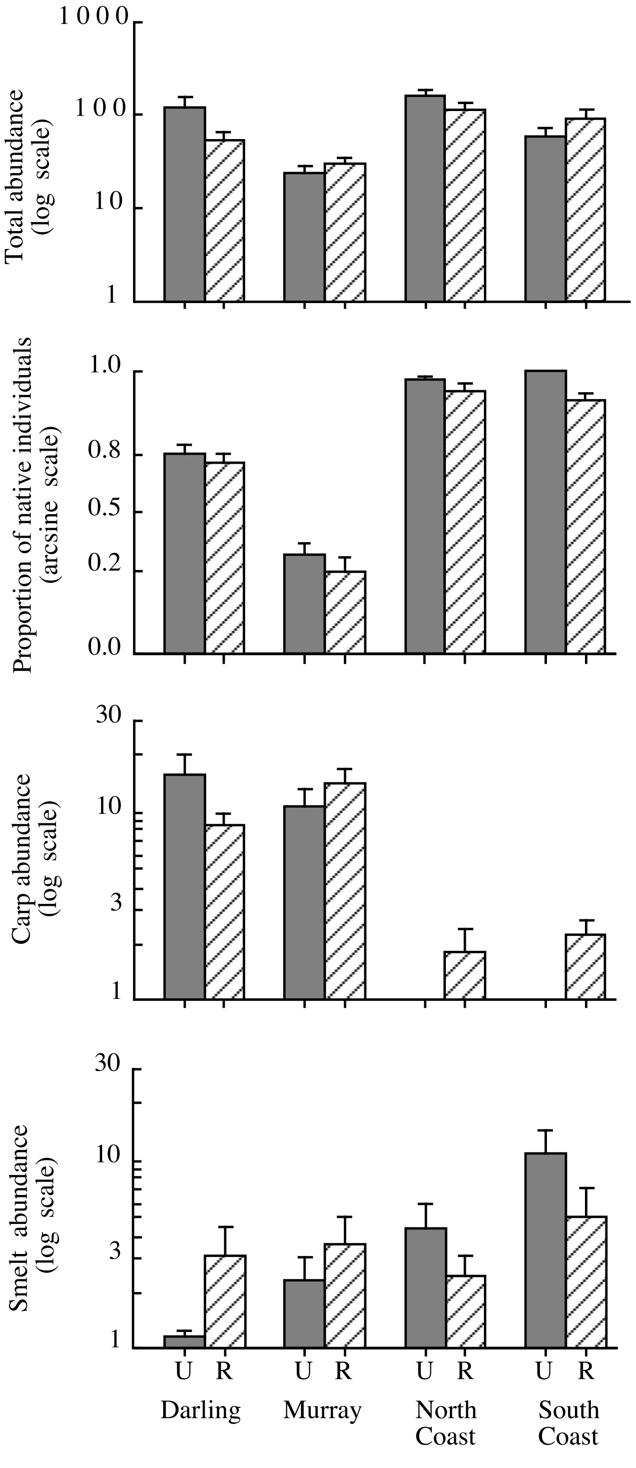

Figure 7.6 Mean values Ò s.e. for community variables and fish species showing significant interactions between river type (U='Unregulated', R= 'Regulated') and regions.

Table 7.6 Summary of four-way analyses of variance for species that were abundant in two regions only. Treatment effects are abbreviated R - region (fixed), T - 'unregulated' versus 'regulated' river types (fixed), Y - year (random), S - sampling occasion (fixed). Only F-values and probabilities are given. *p<0.05, **p<0.01, ***p<0.001.

		Darling - Murray					**North Coast - South Coast**										
Effect	**Degrees freedom**	***Carassius auratus***	***Hypseleotris spp***	***Macquaria ambigua***	***Nematalosa erebi***	***Perca fluviatilis***	***Anguilla reinhardtii***	***Gobiomorphus australis***	***Gobiomorphus coxii***	***Hypseleotris compressa***	***Hypseleotris galii***	***Macquaria novemaculeata***	***Mugil cephalus***	***Myxus petardi***	***Notesthes robusta***	***Philypnodon grandiceps***	***Philypnodon spp***
R	1	0.886	19.246***	17.512***	65.192***	5.826*	0.314	2.163	13.779***	28.079***	0.004	1.271	20.178***	36.717***	24.783***	0.562	8.287**
T	1	0.984	0.555	1.771	10.990**	2.553	0.005	7.658**	11.818***	2.424	6.360*	5.992*	0.274	0.220	0.837	0.828	0.565
R*T	1	0.536	1.627	0.108	0.328	0.264	0.045	1.658	10.879***	8.612**	0.440	7.186**	2.203	11.699**	0.057	3.412	0.139
Y	1	0.289	0.033	1.502	0.063	2.670	0.057	0.518	3.704	0.026	0.212	0.699	0.022	0.014	1.815	0.001	1.050
R*Y	1	0.650	0.002	0.003	0.082	0.241	0.247	0.452	4.480*	0.928	0.177	<0.001	0.724	0.047	0.452	0.537	3.375
T*Y	1	0.015	0.000	0.506	0.004	0.562	0.009	0.172	7.127**	0.497	0.183	0.044	0.649	0.012	0.144	1.841	1.552
R*T*Y	1	0.306	0.614	0.802	0.001	0.155	0.265	0.102	1.951	0.313	0.151	0.049	0.136	0.117	0.087	0.746	0.188
S	1	0.702	2.178	0.138	5.746*	0.692	0.801	0.281	2.151	2.808	0.315	0.455	0.961	0.021	0.521	1.195	0.019
R*S	1	0.276	0.235	0.942	5.107*	0.470	3.111	0.027	0.276	0.036	0.251	0.413	0.011	0.880	0.521	0.003	0.453
T*S	1	0.035	0.013	0.008	2.559	0.351	0.200	0.244	0.521	0.643	0.280	0.065	0.795	0.326	0.860	0.666	<0.001
R*T*S	1	1.539	0.108	0.894	2.139	0.857	0.390	0.028	0.012	0.360	0.219	0.787	0.940	0.134	0.179	0.302	0.694
Y*S	1	0.120	0.291	1.386	5.332*	0.246	0.459	0.138	3.707	0.136	0.663	0.439	<0.001	0.201	0.043	0.174	0.415
R*Y*S	1	0.252	0.571	0.098	0.198	1.093	0.680	1.583	4.857*	0.164	1.663	0.040	0.250	1.395	2.429	0.514	3.304
T*Y*S	1	0.227	0.119	0.125	3.505	0.014	1.224	0.007	1.393	0.146	0.045	0.083	0.258	1.637	0.080	0.296	0.031
R*T*Y*S	1	0.026	0.602	0.236	<0.001	0.185	0.026	0.406	0.431	0.812	0.473	0.308	0.301	0.439	2.669	0.001	1.690
Residual	64																

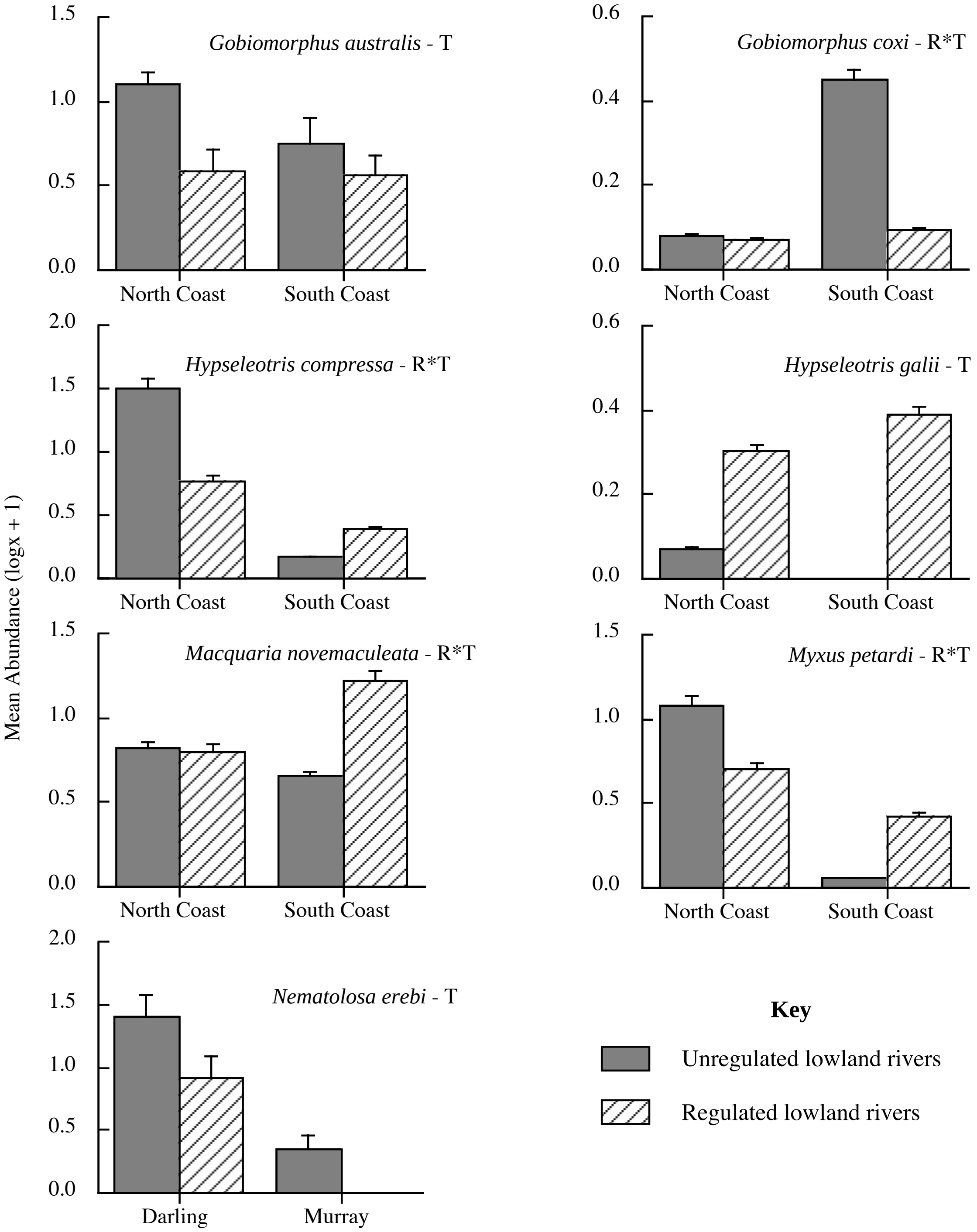

Figure 7.7 Mean abundance Ò s.e. for species showing significant effects of river type (T), or region*river type interactions (R*T). n=20

Table 7.7 Summary of three-way analyses of variance for species that were abundant in only one region. Treatment effects are abbreviated T -'unregulated' versus 'regulated' river types (fixed), Y - year (random), S - sampling occasion (fixed). Only F-values and probabilities are given. *p<0.05, **p<0.01, ***p<0.001.

		Darling	**Murray**	**North Coast**						**South Coast**
Effect	Degrees of freedom	*Melanotaenia fluviatilis*	*Salmo trutta*	*Ambassis agassizii*	*Ambassis nigripinnis*	*Melanotaenia duboulayi*	*Potamalosa richmondia*	*Pseudomugil signifer*	*Tandanus tandanus*	*Galaxias maculatus*
T	1	0.098	0.951	0.161	0.692	0.027	0.134	0.316	2.264	4.138
Y	1	0.681	0.077	1.839	0.164	0.058	0.597	0.316	0.084	0.005
T*Y	1	0.406	0.514	0.161	0.002	0.327	0.368	13.712***	0.023	0.005
S	1	0.002	0.394	1.839	5.667*	1.857	11.222**	1.992	0.028	3.551
T*S	1	0.433	0.035	0.161	0.692	0.959	0.614	2.816	0.539	0.053
Y*S	1	0.815	0.607	1.839	0.164	1.373	0.510	6.549	0.513	1.851
T*Y*S	1	0.815	0.115	0.161	0.002	0.129	0.601	1.992	0.206	2.551
Residual	32									

Table 7.8 Population size structure comparisons using Kolmogorov-Smirnov tests between ‘unregulated’ and ‘regulated’ rivers for abundant species in each region. *p<0.05, **p<0.01, ***p<0.001.

Species	**Unregulated**		**Regulated**		χ^2
	Mean Length	N	Mean Length	N	
Darling Region					
Carassius auratus	125	55	179	35	36.95***
Cyprinus carpio	251	378	344	173	71.58***
Hypseleotris spp	32	229	35	155	17.65***
Macquaria ambigua	232	85	292	90	23.93***
Melanotaenia fluviatilis	56	57	44	30	32.06***
Nematalosa erebi	116	757	158	448	101.00***
Murray Region					
Carassius auratus	167	36	129	32	17.42***
Cyprinus carpio	365	232	343	283	8.01*
Perca fluviatilis	174	21	113	48	18.49***
Retropinna semoni	48	102	44	164	6.87 ns
North Coast Region					
Gobiomorphus australis	74	273	75	141	4.09 ns
Hypseleotris compressa	47	510	49	189	8.02*
Macquaria novemaculeata	264	150	239	195	14.99**
Melanotaenia duboulayi	41	86	42	118	3.77 ns
Mugil cephalus	246	227	274	237	24.93***
Myxus petardi	279	300	310	147	40.88***
Philypnodon grandiceps	54	141	54	84	2.25 ns
Potamalosa richmondia	137	144	164	148	68.67***
Pseudomugil signifer	27	71	29	30	12.75**
Retropinna semoni	47	106	39	63	32.82***
Tandanus tandanus	370	116	352	149	3.77 ns
South Coast Region					
Anguilla reinhardtii	415	48	611	67	16.39***
Galaxias maculatus	66	82	71	76	7.85*
Gobiomorphus australis	67	210	71	106	13.24**
Hypseleotris compressa	50	23	57	110	15.37***
Macquaria novemaculeata	227	138	177	455	55.25***
Philypnodon grandiceps	64	76	56	132	11.79**
Philypnodon sp	36	61	35	31	1.87 ns
Retropinna semoni	43	318	50	142	29.41***

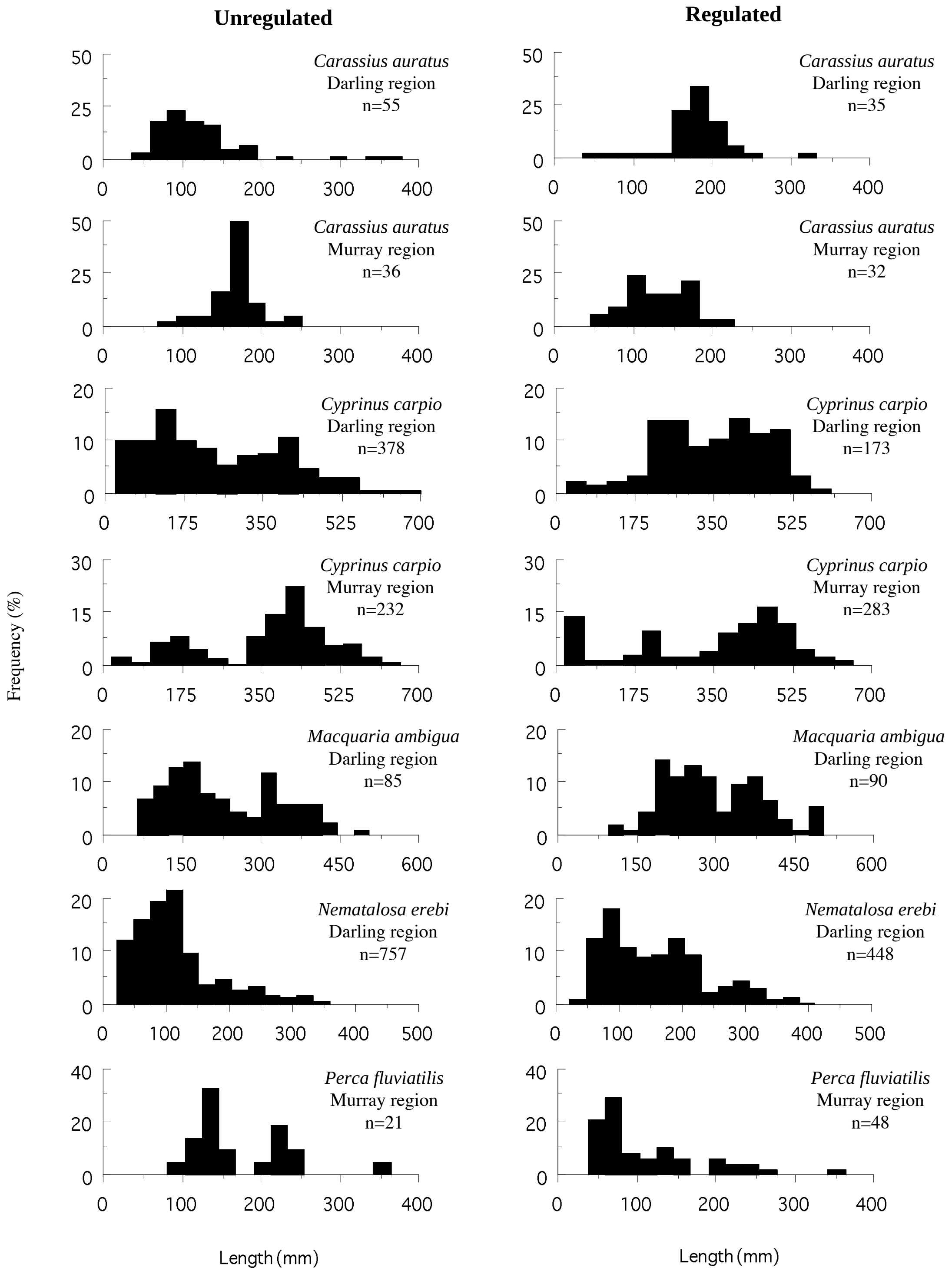

Figure 7.8 Length-frequency distributions for selected species in the Murray and Darling regions with significantly different population size structures ($p<0.05$) between 'unregulated' and 'regulated' river types (Kolmogorov-Smirnov test).

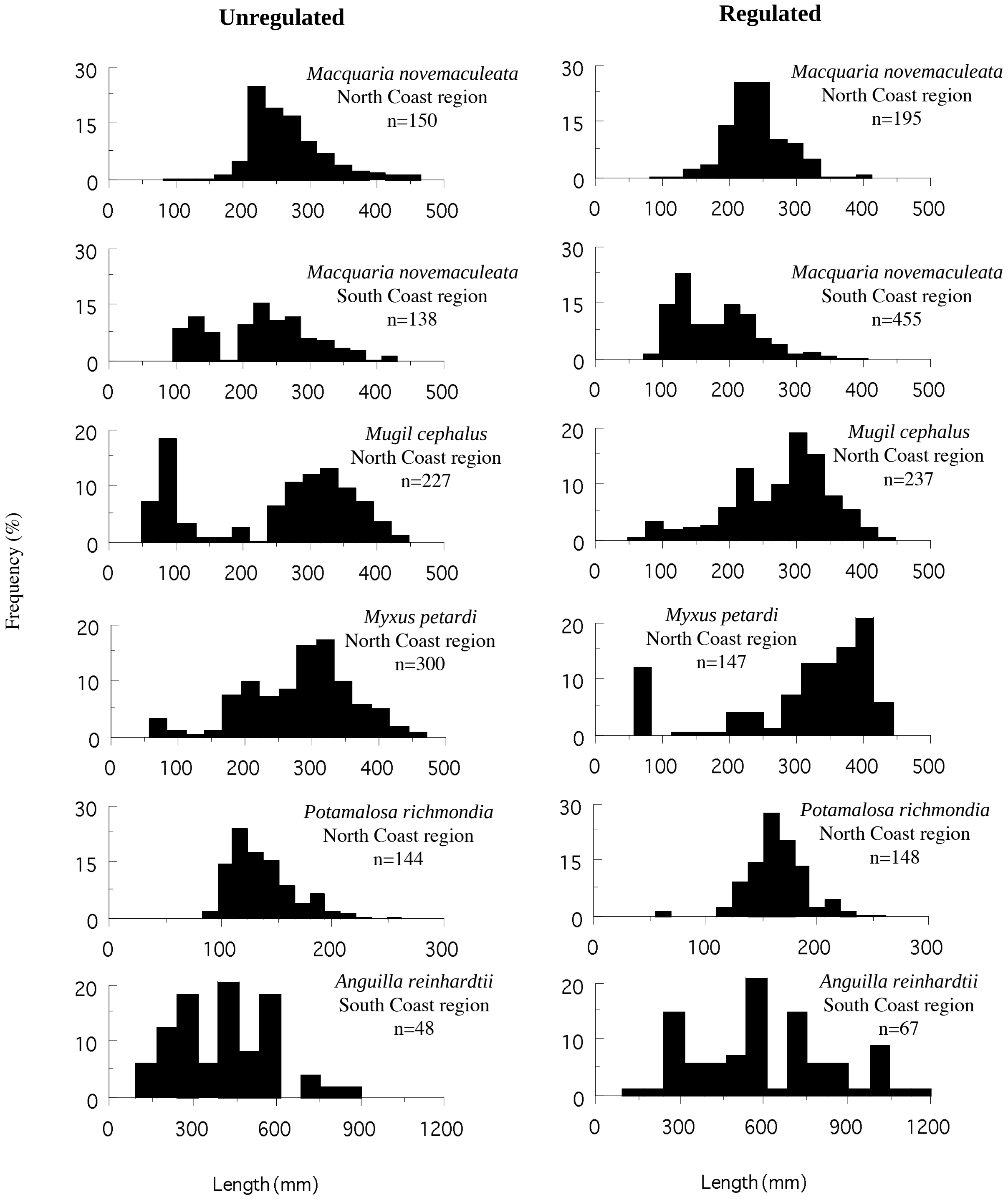

Figure 7.9 Length-frequency distributions for selected species in the North Coast and South Coast regions with significantly different population size structures ($p<0.05$) between unregulated and regulated river types (Kolmogorov-Smirnov test).

Table 7.9 Summary of species showing effects of increased flow regulation in analyses of fish communities (SIMPER), species abundances (ANOVA) and population size structures (Kolmogorov-Smirnov). ● indicates effect observed; ○ indicates no effect observed;? indicates species caught in insufficient numbers, or catches too variable to determine sensitivity to flow regulation. The two right-most columns indicate whether observed effects are positive or negative for each species.

Species	**Tolerance (T)**	**Level of Effect**			**+ive**	**-ive**
	Intolerance (I)	**Community**	**Abundance**	**Population**		
Positive effects only						
Anguilla reinhardtii	T	●	o	●	●	o
Hypseleotris galii	T	o	●	?	●	o
Macquaria novemaculeata	I	●	●	●	●	o
Melanotaenia duboulayi	I	●	o	o	●	o
Perca fluviatilis	T	●	o	●	●	o
Positive and negative effects						
Carassius auratus	T	●	o	●	●	●
Cyprinus carpio	T	●	●	●	●	●
Philypnodon grandiceps	T	●	o	●	●	●
Retropinna semoni	T	●	●	●	●	●
Potamalosa richmondia	I	●	o	●	●	●
Negative effects only						
Arius graeffei	I	o	●	?	?	●
Galaxias maculatus	I	●	o	●	o	●
Gobiomorphus australis	T	●	●	●	o	●
Gobiomorphus coxii	T	o	●	?	o	●
Hypseleotris compressa	T	●	●	●	o	●
Hypseleotris spp.	T	●	o	●	?	●
Leiopotherapon unicolor	T	o	●	o	o	●
Macquaria ambigua	I	●	o	●	o	●
Melanotaenia fluviatilis	I	●	o	●	o	●
Mugil cephalus	I	●	o	●	o	●
Myxus petardi	I	●	●	●	o	●
Nematalosa erebi	I	●	●	●	o	●
Pseudomugil signifer	T	●	●	●	o	●
No observed effect						
Ambassis agassizi	I	o	o	?	o	o
Ambassis nigripinnis	I	o	o	?	o	o
Notesthes robusta	I	●	o	?	o	o
Philypnodon sp1	T	o	o	o	o	o
Salmo trutta	I	o	o	o	o	o
Tandanus tandanus	I	●	o	o	o	o
Insufficient data						
Acanthopagrus australis	T	o	?	?	?	?
Anguilla australis	T	o	?	?	?	?
Arramphus sclerolepis	I	o	?	?	?	?
Bidyanus bidyanus	I	o	?	?	?	?
Carcharhinus leucas	I	o	?	?	?	?
Craterocephalus fluviatilis	I	o	?	?	?	?
Craterocephalus stercusmuscarum	I	o	?	?	?	?
Gadopsis bispinosus	T	o	?	?	?	?
Galaxias brevipinnis	T	o	?	?	?	?
Gambusia holbrooki	T	o	?	?	?	?
Gnathanodon speciosus	I	o	?	?	?	?
Herklotsichthys castelnaui	T	o	?	?	?	?
Liza argentea	T	o	?	?	?	?
Maccullochella peelii	I	o	?	?	?	?
Macquaria colonorum	I	o	?	?	?	?
Mordacia praecox	T	o	?	?	?	?
Myxus elongatus	I	o	?	?	?	?
Oncorhynchus mykiss	I	o	?	?	?	?
Platycephalus fuscus	T	o	?	?	?	?
Prototroctes maraena	I	o	?	?	?	?
Pseudaphritis urvillii	I	o	?	?	?	?
Redigobius macrostoma	T	o	?	?	?	?

DISCUSSION

The different terminology used to define river flow regimes in New South Wales reflects recent advances in understanding of the effects of river management, and the continuing need for quantitative tools to better measure the ways in which flows are manipulated. A simple dichotomy according to whether flow regimes are influenced by dams was the only practical approach for rivers in New South Wales when this study was initiated. Since then, a number of measures have been developed to quantify and categorise hydrological changes in rivers. The Annual Proportional Flow Deviation (Gehrke *et al.* 1995) uses actual and modelled monthly flow data to estimate changes in flow volume and seasonality from the natural condition. A more comprehensive suite of measures is provided by Richter *et al.* (1996), covering monthly flows, annnual extremes, timing of flows, frequency and duration of high and low flows, and the rate and frequency of changes in flow. These and other similar methods enable comparisons between hydrologically-similar rivers at a finer level of resolution than was possible during the present study. But unfortunately, these methods cannot yet be applied to many of the rivers in New South Wales. Continued development of suitable tools for measuring flow regimes is required to enable future studies to improve understanding of ecological responses to changes in flow.

Effects of flow regulation on riverine fish have been closely studied in recent years, at levels ranging from responses of individual fish, through population-level changes to changes in the composition and structure of fish communities. Reported effects include reduced abundance of fish larvae (Scheidegger and Bain 1995), suppressed growth rates (Weisberg and Burton 1993), altered community structure (Bain *et al.* 1988; Kinsolving and Bain 1993) and reduced species diversity (Gehrke *et al.* 1995).

Fish communities in New South Wales rivers show substantial differences in species composition between reaches where flows are highly regulated and reaches which retain a predominantly natural, minimally-regulated flow regime. At the same time, fish communities in all four regions investigated in this study displayed a regional identity, irrespective of whether flows in a given river were regulated or unregulated. The existence of a regional identity might be encouraging from the point of view that the basic structure of riverine fish communities is still intact despite various environmental disturbances. However, the regional pattern also supports a contrary perspective that contemporary fish communities in lowland rivers simply reflect the degree of disturbance since European settlement within the four regions studied.

Different reasons may exist between coastal and inland regions for the differences in fish communities between regulated and unregulated rivers. In both the Darling and Murray regions, rivers are regulated predominantly to provide a secure supply of water for irrigation, with flood mitigation, town water supply and hydroelectric power generation accounting for relatively small proportions of the total flow. Flows in these rivers retain a strong seasonal pattern that is out of phase with the natural flow cycle, with a reduced mean annual flow volume and increased stability (Merron *et al.* 1993; Walker and Thoms 1993; Gehrke *et al.* 1995; Imbert and Stanford 1996). In contrast, regulated rivers in the North Coast and South Coast regions are mostly regulated to provide town water supplies. Some exceptions occur, such as the Hunter and Richmond rivers, which provide flows for irrigation as well as town water supplies. Rivers regulated for town water supplies may exhibit a suppressed seasonal cycle with reduced annual flows and increased flow stability (Ibañez *et al.* 1995; Gehrke *et al.* 1996). Therefore the main difference in flow regime between rivers regulated for irrigation purposes and those regulated for town water supplies is the degree of seasonal change. Consequently, the ecological impacts of flow regulation in the rivers in this study are likely to differ qualitatively from impacts in rivers regulated for generating hydroelectricity, where flows are erratic and variable on a daily time scale (e.g. Bain *et al.* 1988; Garcia de Jalon *et al.* 1994).

Fish communities in both inland and coastal regions had a lower proportional abundance of native species in highly regulated rivers, or conversely, a greater proportional abundance of alien species. The nature and degree of flow regulation lie on a continuum of disturbance to river ecosystems (Connell 1978; Ward and Stanford 1983; Gehrke *et al.* 1995), ranging from reduced flow variability in rivers regulated for irrigation or town water supply to increased flow variability in rivers regulated to generate hydroelectricity. Both extremes disrupt equilibrium processes in aquatic ecosystems, and allow habitat generalist species to increase in abundance while habitat specialists decline (e.g. Bain *et al.* 1988; Gehrke *et al.* 1995), leading to a reduction in species diversity. Successful alien species are commonly habitat generalists that become established following human disturbance, especially when the pre-existing fauna is depauperate (Ross 1991). In New South Wales, carp, goldfish, gambusia and redfin perch are all alien species with generalist habitat requirements, and which thrive in disturbed habitats. For example, carp occurred in regulated rivers only in both the North Coast and South Coast regions. In contrast, many native species have specialist flow requirements that influence recruitment success (Harris and Gehrke 1994). Thus by increasing the stability of river flows and reducing the frequency of natural disturbance, river regulation disadvantages fluvial specialist species while favouring generalist species.

It is surprising then that this study detected no differences in species diversity or species richness between regulated and unregulated rivers. This outcome may result from the replacement of sensitive native species with alien species (Minckley and Meffe 1987; Welcomme 1994) in regulated rivers, creating relatively small changes in species diversity and richness when compared with the large amount of spatial variation in this study. Under these circumstances, the proportion of native fish in samples provides a more sensitive indicator of changes in fish communities than species richness or diversity. In contrast, Gehrke *et al.* (1995) found a highly significant reduction in diversity with increasing flow regulation in the Murray-Darling River system. The reason for the different results between these two studies may lie in the larger amount of spatial and temporal replication in the present study, and the quantitative approach to measuring the degree of regulation in the former study.

Differing abilities among species to tolerate disturbance is an important attribute in assessing the impact of river regulation on fish communities. The species collected in this study have been nominally classified as either tolerant or intolerant of habitat degradation (Chapter 6, Harris 1995). In the context of river regulation as a form of degradation, tolerance and intolerance may be loosely equated with broad categories of macrohabitat generalists and fluvial specialists as defined by Kinsolving and Bain (1993). The effects of flow regulation on individual species, the level at which effects were observed, and species tolerance classifications are summarised in Table 7.9. Species fall into five groups based on whether they exhibited differences between highly regulated and minimally regulated rivers that were positive only (from the species' perspective), those exhibiting both positive and negative responses, species that were affected in a negative way by river regulation, species that exhibited no effects of flow regulation, and those species that were caught in numbers that were either too low or too variable to detect an effect.

Five species showed positive effects of river regulation in terms of their contribution to fish communities, species abundance or size distributions. Long-finned eels, firetailed gudgeons and redfin perch are all tolerant species, whereas Australian bass and eastern rainbowfish are intolerant. However, Australian bass are classified as intolerant mainly because they are a migratory species that becomes locally extinct upstream of major dams and weirs. As this investigation is restricted to nominally unregulated rivers and reaches downstream of major barriers to migration, Australian bass are much more tolerant of conditions in these habitats than their classification suggests. Thus the species showing positive effects are predominantly tolerant. Notably, no native species in the inland regions showed any positive effects of river regulation.

Another five species showed both positive and negative effects. For example, carp were more abundant and showed stronger recruitment in minimally regulated rivers in the Darling region, but did not occur in unregulated rivers in coastal regions. Of these species, only freshwater herring are classified as intolerant, again because of their migratory habits and their record of local extinction above dams and weirs. Thus the only species occurring in inland regions that showed any positive response to river regulation were the alien species redfin perch, goldfish and carp, and one tolerant native species, Australian smelt.

Thirteen native species - six tolerant and seven intolerant of disturbance - showed only negative effects of river regulation on community composition, species abundance or population size structure. The clearest example from this group is given by bony herring in inland regions, which contributed more to fish communities in unregulated rivers than regulated rivers, was more abundant in unregulated rivers, and demonstrated stronger recruitment of smaller juvenile fish in unregulated rivers. It is noteworthy that no alien species exhibited only negative effects of regulation.

A further six species showed no effect of river regulation, while 22 species were caught in insufficient numbers to determine the magnitude or direction of any effect. Some of these species are known to be particularly sensitive to flow regulation. For example, successful recruitment of silver perch and Murray cod is influenced by inundation of floodplain habitats during late spring and early summer. Silver perch in particular appear to be sensitive to flow regulation and other catchment disturbances as their populations have declined dramatically in the last 50 years (Mallen-Cooper 1993). Conversely, Murray cod which exhibited low recruitment in the Lower Murray River for 10-15 years (Rohan 1989) have since shown strong recruitment in years where natural or manipulated overbank flows have occurred (Bryan Pierce *pers comm*). It is likely that future study may find that other uncommon species are also sensitive to river regulation.

Many species in the present study displayed differences in population size-structure between river types. These results are consistent with the findings of Weisberg and Burton (1993), who found that growth rates of white perch (*Morone americana*) were greater after introducing a minimum environmental flow in the Susquehanna River, because of an increase in prey abundance (Weisberg *et al.* 1990). Length distributions of New South Wales species do not suggest enhanced growth in unregulated rivers by attainment of greater maximum size than in regulated rivers. Rather, a greater abundance of juveniles was observed in unregulated rivers for goldfish, carp, golden perch and bony herring from the Darling region, Australian bass, striped mullet and freshwater herring from the North Coast region, and long-finned eels from the South Coast region. The abundance of juveniles of these species in unregulated rivers supports earlier suggestions that recruitment success is higher in unregulated rivers (Harris and Gehrke 1994; Gehrke *et al.* 1995). The basis for this hypothesis stems from the Flood-Pulse Concept (Junk *et al.* 1989; Bayley 1995), whereby floods play a critical role in the productivity of floodplain river ecosystems by boosting the input of nutrients and organic material as flood waters spill out over the floodplain. In the lowland reaches of a river, the period of inundation may be relatively long so that the productivity contributed by floodplain habitats greatly exceeds inputs from upstream. In regulated rivers, the frequency of high flows is reduced, so that the contribution of the floodplain to food production in the river is likely to be less than in similar unregulated rivers. Thus the greater abundance of juvenile fish in unregulated rivers suggests greater recruitment success in these rivers through enhanced productivity.

In the Murray region, only alien species showed a difference in population size-structure between river types. For goldfish, carp and redfin perch, juveniles were more abundant in regulated rivers than in unregulated rivers, suggesting that recruitment of these species is favoured by the more stable conditions in regulated rivers in this region.

The cause of these differences between fish communities in regulated and unregulated rivers in New South Wales is not simply the degree to which flow is regulated in different rivers. The real problem is likely to be much more complex, based on a combination of catchment-scale changes on a time-scale of 50 to 100 years, of which flow regulation is only one form of disturbance. Therefore, while river regulation can be shown to have detrimental effects on riverine fish communities, it does not necessarily follow that fish communities and river health can be fully restored simply by re-establishing elements of the natural flow regime. However, examples of recovery of fish communities in regulated rivers provide encouraging evidence that improved flow regimes are a tangible component of restoring river health.

The Tallapoosa River in Alabama is regulated by a hydroelectric dam. Under normal operations when flows ranged from 0 to 225 $m^3 s^{-1}$ on a daily basis, only eight generalist species of fish occurred 3 km downstream of the dam (Travnichek *et al.* 1995). However, one year after the introduction of a minimum flow of 34 $m^3 s^{-1}$, the number of species increased to 19, with total fish abundance increasing more than five-fold. Additionally, 12 of the 19 species were classified as fluvial specialists. The fish assemblage 37 km downstream of the dam changed from being dominated by generalist species previously, to a dominance by fluvial specialists after a minimum flow regime had been established. Thus the enhanced flow regime created a modified fish assemblage that more closely reflected the species composition of a riverine system.

Beyond changes in the composition of fish communities, enhanced flows in regulated rivers may also improve the trophic structure of riverine food webs, resulting in enhanced condition, growth and food consumption of fish. Before 1982, the Conowingo Hydroelectric Dam in Maryland operated with a minimum off-peak release of 3 $m^3 s^{-1}$. Four years after commencing a minimum release of 142 $m^3 s^{-1}$, white perch, yellow perch (*Perca flavescens*) and channel catfish (*Ictalurus punctatus*) all showed an increase in consumption of trichopterans and chironomids, and a decline in the proportion of fish with empty stomachs (Weisberg and Burton 1993). Growth of white perch in particular was improved by the enhanced flow regime, with length increases of up to 38% in the first year class. The condition of all three species, measured as fish weight at a given length, also increased significantly, indicating a trophically-driven physiological benefit to individual fish from the enhanced flow regime (Weisberg and Burton 1993), in addition to the community-scale benefits identified by Travnichek *et al.* (1995).

These examples, both from the United States of America, indicate clearly that rehabilitation of fish communities in regulated rivers is possible by modifying the regulated flow regime. Although both cases involve erratic flow releases from hydroelectric dams, at the opposite end of the disturbance frequency continuum from irrigation releases, it appears reasonable to expect that similar improvements in the composition of fish communities and in the condition of fish might follow the introduction of enhanced river flow objectives in New South Wales. Therefore, to demonstrate more fully the ecological and economic benefits of new river flow objectives, investigations to assess the responses of fish to modified flow regimes need to include individual and population-scale responses in addition to the broader composition of fish communities. Furthermore, quantitative methods, such as the Annual Proportional Flow Deviation (Gehrke *et al.* 1995), Indicators of Hydrologic Alteration (Richter *et al.* 1996), or similar techniques are urgently required to strengthen comparisons between rivers subjected to differing degrees and types of flow regulation.

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8 Alien fish species from the New South Wales Rivers Survey

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Summary

Alien species are defined as those species introduced from overseas and now established in the wild. Of the 11 species which have been recorded from New South Wales rivers, six were captured during the current survey for a total of 5,103 individuals, or 18.4% of the total fish catch.

The species captured were brown trout, *Salmo trutta,* rainbow trout, *Oncorhynchus mykiss,* redfin perch, *Perca fluviatilis,* gambusia, *Gambusia holbrooki*, goldfish, *Carassius auratus*, and common carp, *Cyprinus carpio*. This chapter deals with the first five of these species, with carp being considered separately in Chapter 9.

Alien fish showed significant differences in abundance among regions and among river types with a highly significant region*river type interaction. Catches were also lower in winter months than in summer. Rivers in the Darling region contained the highest number of alien species but the Murray region had the highest proportion of individuals belonging to alien species (57.5%). In comparison the Darling (25.1%), North Coast (8.7%) and South Coast (9.1%) had lower proportions of alien species in the total catch. Distributions of each of the alien species captured during the survey could be explained by temperature tolerance and habitat attributes.

INTRODUCTION

Alien species are defined as those species introduced from overseas and now established in the wild. The term was used (Harris 1995a) to distinguish between alien species and introduced species (native species established outside their natural distribution) and feral species (domestic fish escaped to the wild).

There are 11 alien species listed as occurring in New South Wales freshwater habitats which came into New South Wales as both deliberate and accidental introductions. These species have been identified recently by Harris (1995b). They are yellowfin goby, *Acanthogobius flavimanus,* goldfish, *Carassius auratus,* common carp, *Cyprinus carpio*, gambusia, *Gambusia holbrooki,* rainbow trout, *Oncorhynchus mykiss,* redfin perch, *Perca fluviatilis,* brown trout, *Salmo trutta,* Atlantic salmon, *Salmo salar,* brook trout, *Salvelinus fontinalis,* tench, *Tinca tinca,* and oriental weatherloach, *Misgurnus anguillicaudatus.*

METHODS

Methods describing the sampling design, fish collection, site selection and data management are found in Chapter 2. A descriptive analysis was found to portray the data most informatively. Four-factorial analysis of variance was used to assess the variability in alien fish distributions among regions and river types and between times of sampling and years of the survey. Regions, river types and time of sampling were treated as fixed factors, with years as a random factor. Analyses for the alien species included common carp although data on this species are analysed in more detail separately (Chapter 9). Only the data on fish actually caught, rather than those observed, were analysed.

RESULTS

Analysis of alien fish data

Of the 11 possible alien species which have been recorded from New South Wales rivers, only six were captured during the survey. The total catch of the six alien species during the survey was 5,103 fish (18.4% of the total catch) and included *Salmo trutta*, *Oncorhynchus mykiss*, *Perca fluviatilis*, *Gambusia holbrooki*, *Cyprinus carpio* and *Carassius auratus* (Table 8.1). Analysis of variance of alien fish abundance pooled for all species (log (x+1) transformed) showed highly significant main effects among regions (p<0.001) and less significant differences among river types (p<0.05) with a highly significant region * river type interaction (p<0.001) (Table 8.2). This interaction showed that the pattern of distribution of these species among river types varied among the four ecological regions of the survey (see below). The time of sampling was also a significant effect (p<0.05) with winter samples showing lower abundances of alien species than those in summer, indicating greater catchability of alien species at warmer temperatures. There were no significant differences in alien fish abundance between the two years of the survey. Actual numbers of the six alien species captured in the four survey periods is shown in Table 8.3.

Rivers in the Darling region contained the highest number (6) of alien fish species captured. However the Murray region had the highest proportion of alien fish individuals (57.5%) (Table 8.1). In comparison the Darling (25.1%), North Coast (8.7%) and South Coast (9.1%) had lower proportions of alien species in the total catch.

Alien species accounted for 41.7% (5 of 12) of the number of fish species collected from the montane rivers. The comparative figure for the slopes sites was 14.6% (6 of 41) and for the unregulated and regulated river sites the contribution of alien species were 13% (6 of 46) and 13.6% (6 of 44) respectively. The contribution of the aliens to the total catch of individuals of all species was highest in the montane sites, followed by the slopes sites. The corresponding contribution of aliens in the unregulated and regulated lowland rivers sites was lower at approximately 10% (Table 8.1, Figure 8.2).

Distribution of alien species.

Those species predicted but not captured were yellowfin goby, *Acanthogobius flavimanus,* Atlantic salmon, *Salmo salar,* brook trout, *Salvelinus fontinalis,* tench, *Tinca tinca,* and oriental weatherloach, *Misgurnus anguillicaudatus*. The numbers of each of the alien species captured in each of the four survey periods is shown in Table 8.3. The inland drainages had the highest number of alien species, with both the Murray and the Darling regions containing carp and all five other species.

Table 8.1 Summary of the abundances by region and river type of the six alien species caught during the NSW Rivers Survey.

Region / River Type	*Carassius auratus*		*Cyprinus carpio*		*Gambusia holbrooki*		*Oncorhynchus mykiss*		*Perca fluviatilis*		*Salmo trutta*		Total aliens	Total Catch in Rivers Survey	Aliens as % of total catch
	Total	% of catch	Total	% of catch	Total	% of catch	Total	% of catch	Total	% of catch	Total	% of catch			
Darling, Montane	44	7.0	0	0.0	181	28.7	5	0.8	41	6.5	111	17.6	382	630	60.6
Darling, Slopes	129	5.6	380	16.5	339	14.7	2	0.1	79	3.4	2	0.1	931	2305	40.4
Darling, Unregulated Lowland	63	1.3	517	10.8	113	2.4	0	0.0	0	0.0	0	0.0	693	4808	14.4
Darling, Regulated Lowland	35	2.1	170	10.3	0	0.0	0	0.0	143	8.7	3	0.2	351	1647	21.3
Total Darling	**271**	**2.9**	**1067**	**11.4**	**633**	**6.7**	**7**	**0.1**	**263**	**2.8**	**116**	**1.2**	**2357**	**9390**	**25.1**
Murray, Montane	5	1.3	0	0.0	27	7.1	33	8.7	20	5.3	18	4.8	103	378	27.2
Murray, Slopes	18	2.9	347	56.1	2	0.3	20	3.2	37	6.0	7	1.1	431	619	69.6
Murray, Unregulated Lowland	37	6.1	254	41.8	0	0.0	9	1.5	21	3.5	14	2.3	335	607	55.2
Murray, Regulated Lowland	37	5.2	324	45.6	1	0.1	15	2.1	53	7.5	31	4.4	461	711	64.8
Total Murray	**97**	**4.2**	**925**	**40.0**	**30**	**1.3**	**77**	**3.3**	**131**	**5.7**	**70**	**3.0**	**1330**	**2315**	**57.5**
North Coast, Montane	4	0.4	0	0.0	577	62.2	1	0.1	0	0.0	0	0.0	582	927	62.8
North Coast, Slopes	123	5.2	8	0.3	44	1.8	0	0.0	0	0.0	0	0.0	175	2385	7.3
North Coast, Unregulated Lowland	5	0.1	0	0.0	19	0.5	0	0.0	0	0.0	0	0.0	24	3853	0.6
North Coast, Regulated Lowland	6	0.2	75	2.6	8	0.3	0	0.0	0	0.0	0	0.0	89	2852	3.1
Total North Coast	**138**	**1.4**	**83**	**0.8**	**648**	**6.5**	**1**	**0.0**	**0**	**0.0**	**0**	**0.0**	**870**	**10017**	**8.7**
South Coast, Montane	1	0.2	0	0.0	356	66.2	10	1.9	26	4.8	86	16.0	479	538	89.0
South Coast, Slopes	1	0.1	0	0.0	0	0.0	1	0.1	0	0.0	11	0.7	13	1595	0.8
South Coast, Unregulated Lowland	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	1577	0.0
South Coast, Regulated Lowland	13	0.6	37	1.6	4	0.2	0	0.0	0	0.0	0	0.0	54	2310	2.3
Total South Coast	**15**	**0.2**	**37**	**0.6**	**360**	**6.0**	**11**	**0.2**	**26**	**0.4**	**97**	**1.6**	**546**	**6020**	**9.1**
Total for Montane	54	2.2	0	0.0	1141	46.1	49	2.0	87	3.5	215	8.7	1546	2473	62.5
Total for Slopes	271	3.9	735	10.6	385	5.6	23	0.3	116	1.7	20	0.3	1550	6904	22.5
Total for Unregulated Lowland	105	1.0	771	7.1	132	1.2	9	0.1	21	0.2	14	0.1	1052	10845	9.7
Total for Regulated Lowland	91	1.2	606	8.1	13	0.2	15	0.2	196	2.6	34	0.5	955	7520	12.7
Total alien species	**521**	**1.9**	**2112**	**7.6**	**1671**	**6.0**	**96**	**0.3**	**420**	**1.5**	**283**	**1.0**	**5103**	**27742**	**18.4**

Table 8.2 Four-factorial analysis of variance for the alien species abundance data indicating significant interaction with region and type of river.

	DF	F-Value	P-Value
Region	3	74.128	<.0001
Type	3	2.757	0.0429
Region * Type	9	9.450	<.0001
Year	1	2.348	0.1267
Region * Year	3	0.768	0.5127
Type * Year	3	1.614	0.1865
Region * Type * Year	9	0.613	0.7860
Time	1	5.101	0.0248
Region * Time	3	0.159	0.9241
Type * Time	3	0.442	0.7234
Region * Type * Time	9	0.610	0.7879
Year * Time	1	0.110	0.7409
Region * Year * Time	3	0.731	0.5341
Type * Year * Time	3	0.519	0.6697
Region * Type * Year * Time	9	0.201	0.9939
Residual	256		

Table 8.3 Numbers of alien fish individuals caught in each survey round.

Species	Survey 1	Survey 2	Survey 3	Survey 4	Total
Carassius auratus	113	169	121	118	521
Cyprinus carpio	555	753	360	443	2112
Gambusia holbrooki	87	851	374	359	1671
Oncorhynchus mykiss	42	16	9	29	96
Perca fluviatilis	33	292	29	66	420
Salmo trutta	82	80	52	69	283

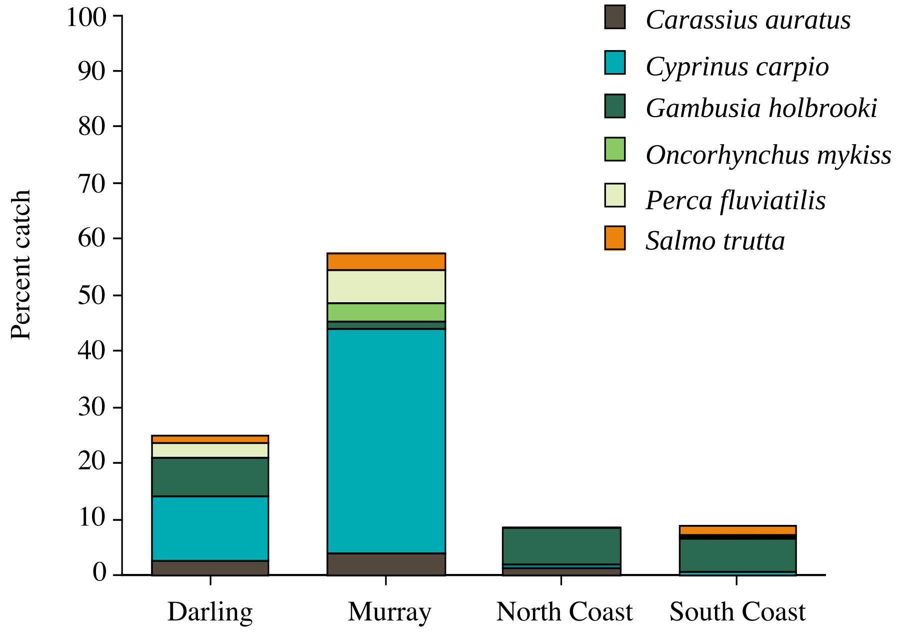


Figure 8.1 Alien fish as a percentage of total Rivers Survey catch for each region

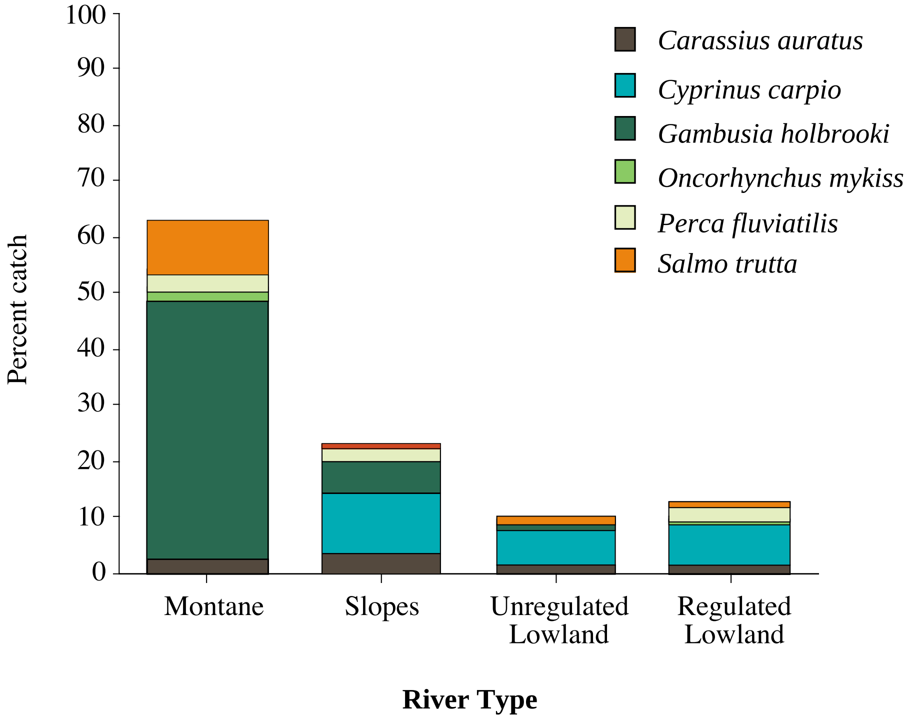
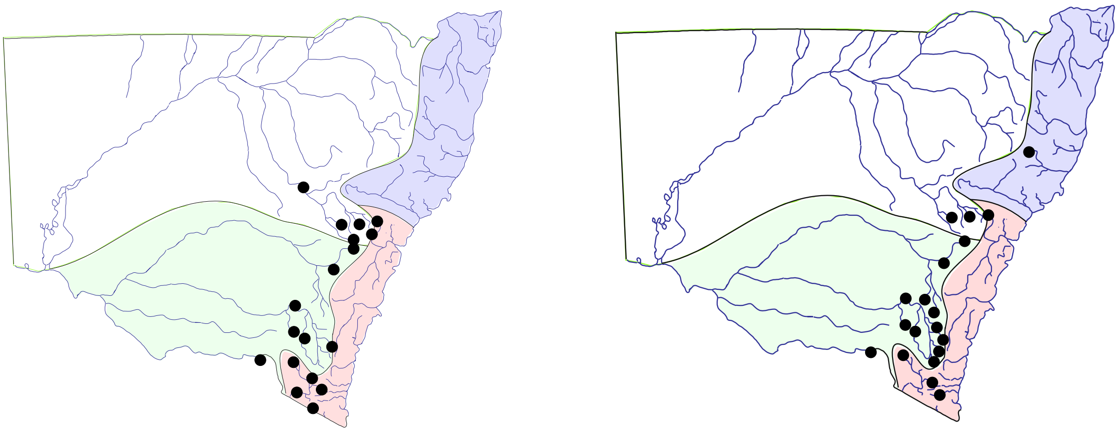
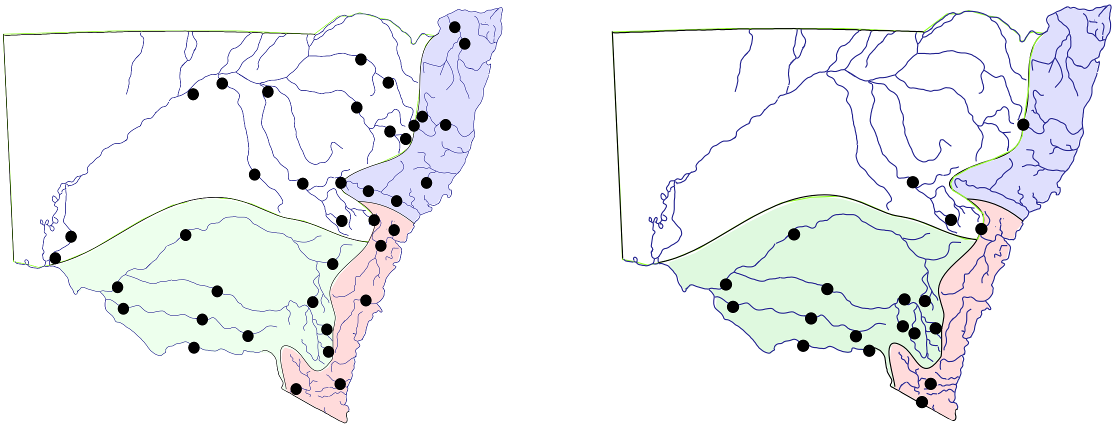


Figure 8.2 Alien fish as a percentage of total Rivers Survey catch for each river type



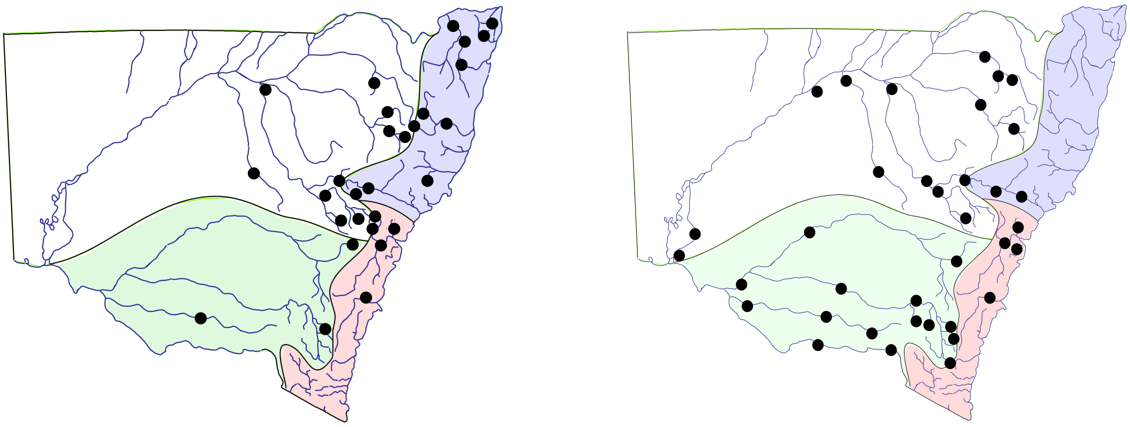
Salmo trutta

Oncorhynchus mykiss



Carassius auratus

Perca fluviatilis



Gambusia holbrooki

Cyprinus carpio

Figure 8.3 Capture sites for the six alien species, the 80 Rivers Survey sites are listed in Chapter 1.

Abundance by species

Brown trout *(Salmo trutta)*

A total of 283 brown trout was captured at 18 sites with montane and slopes sites yielding 83% of the captures. Brown trout contributed 8.7% of the total catch in the montane sites (Table 8.1). This species was found in all regions excepting the North Coast and was restricted to the upper reaches of rivers in the other regions. This is reflected in their altitudinal distribution (Figure 8.4) indicating that 10 of the 18 sites at which this species was found were over 600 m above sea level. Lower-altitude sites from which brown trout were captured were in rivers flowing from a high altitude and which have relatively low water temperatures (e.g. Murray River at Tintaldra) or below storages releasing cold water (e.g. Macquarie River at Wellington, Tumut River at Tumut).

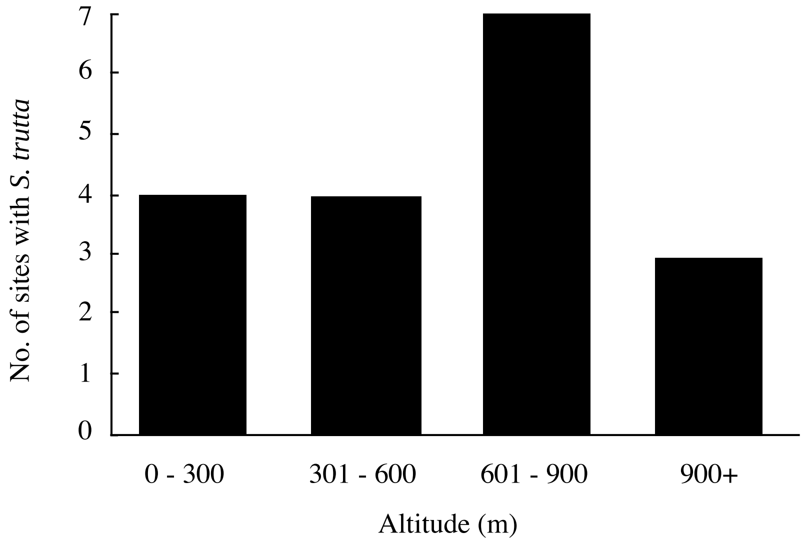


Figure 8.4 Altitudinal distribution of brown trout captured during the survey

Rainbow trout *(Oncorhynchus mykiss)*

A total of 96 rainbow trout was captured at 19 sites. Catches were confined to the upper reaches of rivers with 75% of the fish taken from montane and slopes sites (Figure 8.2) The prevalence of rainbow trout in montane and slopes sites is reflected in the altitudinal distribution with 15 of the 19 capture sites being above 300 m altitude, and are thus cooler or are below storages releasing cold water.

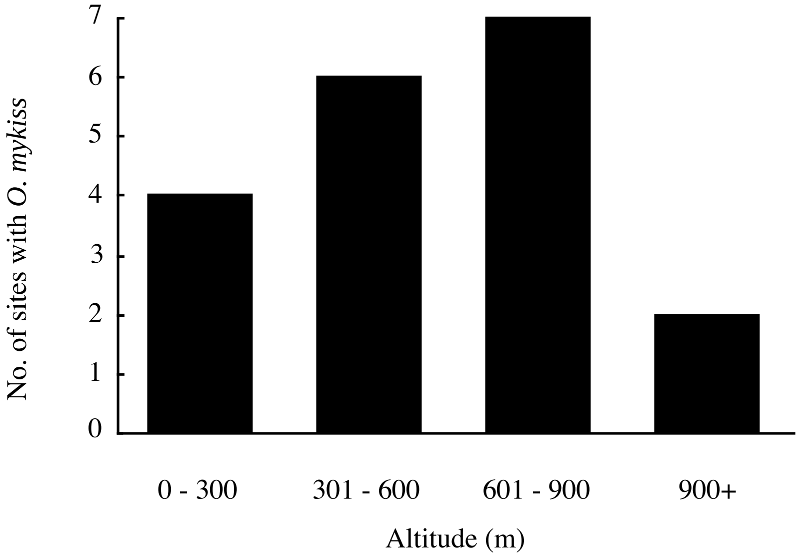


Figure 8.5 Altitudinal distribution of rainbow trout captured during the survey

Goldfish *(Carassius auratus)*

A total of 521 goldfish was captured at 39 sites which were widely distributed among ecological regions and river types (Table 8.1). Most fish were captured in the Darling region and the least in the South Coast region. Sites in slopes and lowland river types contributed 89.6% of the fish captured. The low abundance of goldfish in montane sites is reflected in their altitudinal range, with 87.2% of individuals collected at altitudes below 600 m.

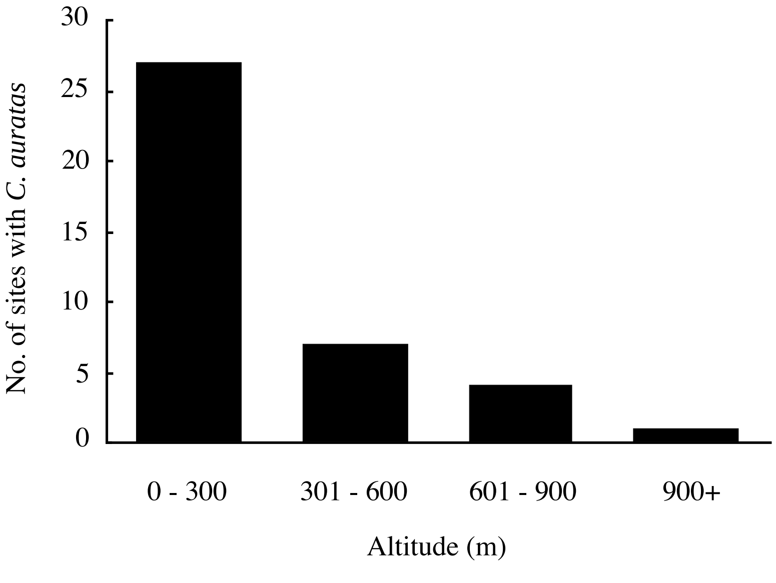


Figure 8.6 Altitudinal distribution of goldfish captured during the survey.

Redfin perch *(Perca fluviatilis)*

A total of 420 redfin perch was captured during the study with 70% of captures occurring in the second survey round (Table 8.3). Redfin perch were recorded from 20 of the 80 sites sampled, with only seven sites having captures of 10 or more specimens over the two sampling years. Of the six alien species captured during the study, redfin perch were the fourth most abundant. The site on the Macquarie River below Burrendong Dam had the highest abundance of redfin perch with a total of 143 captured, of which 136 were captured during the second survey. Their abundance was temporally highly variable.

This species was mainly found in the inland drainages with the widest distribution occurring in the Murray region. They were recorded from four higher-altitude sites in the Darling region and from two sites in the upper reaches of the Snowy River system in the South Coast region but were not recorded from the North Coast region (Figure 8.1).

Redfin perch were recorded in all four river types but were proportionally more abundant in the montane streams, which had low species diversity and fish numbers. They were found at altitudes ranging from 60 to 1,020 m with the majority of these sites being below 300 m (Figure 8.7).

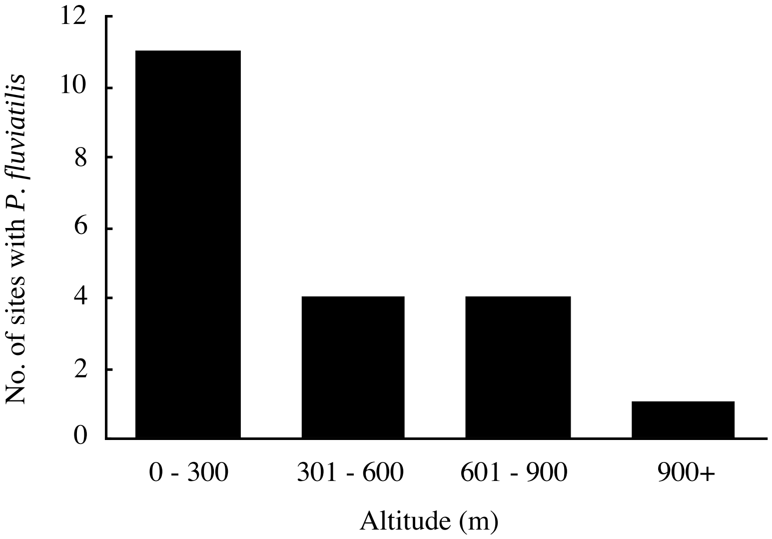


Figure 8.7 Altitudinal distribution of redfin perch captured during the survey.

Gambusia *(Gambusia holbrooki)*

A total of 1,671 gambusia was captured during the study with approximately 50% of this number caught during the second survey round in the summer of 1994-95. A further 3,367 gambusia (estimated numbers) were observed but not captured. Gambusia were recorded at 27 of the 80 survey sites, with six sites having captures or observations of more than 50 specimens.

Gambusia were most widely distributed in the Darling and North Coast regions with their presence recorded at only four sites in the South Coast and two sites in the Murray regions (Figure 8.1) They were recorded in all four river types but were proportionally higher in abundance in the montane streams, particularly in the two coastal drainages. A surprisingly low number of gambusia were recorded in the Murray region, contributing only 77 of the total of 1671 fish captured in this drainage. Gambusia were found at altitudes ranging from 20 to 1120 m, but the majority of sites where gambusia were recorded were below 300 m (Figure 8.8)

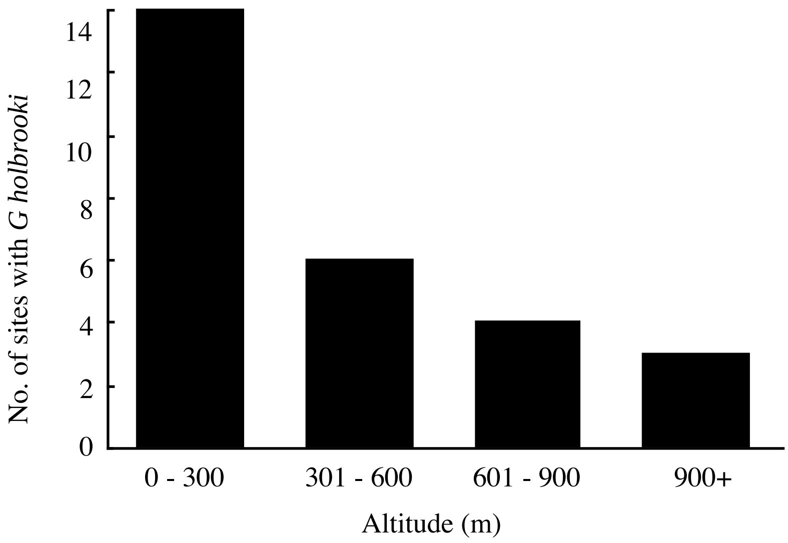


Figure 8.8 Altitudinal distribution of gambusia captured during the survey.

The majority of gambusia (1121 individuals) were caught by electrofishing with either boat or backpack gear. Gee traps captured 32.7% of this species (547 individuals). None were caught in panel nets and only three were caught in fyke nets.

Effect of gear type on captures

The type of gear used was highly influential in the capture of the various alien fish species and the effect of gear type is the subject of a separate chapter in this report (Chapter 10). It should be remembered that not all the gear types were used at each site, depending on the river type in which each site was classified. Captures of alien species by the various gear types are listed in Table 8.4.

Table 8.4 Capture of the alien species by gear type.

Species	Boat electrofishing	Backpack Pool	Backpack Riffle	Fyke	Gee trap	Panel
Carassius auratus	361	33	26	26	5	58
Cyprinus carpio	1722	0	46	130	19	197
Oncorhynchus mykiss	26	10	31	6	0	23
Perca fluviatilis	233	22	33	56	4	74
Gambusia holbrooki	130	386	566	3	547	0
Salmo trutta	32	84	82	16	0	69

DISCUSSION

Elliott (1981) defines criticial temperature ranges for fish species as “the ranges over which a significant disturbance in the normal behaviour of a fish may occur.” Differences in thermal regime between studies may lead to a degree of overlap between critical and optimum temperature ranges for species referred to in the following discussion.

Brown trout *(Salmo trutta)*

Distribution, habitat preferences and thermal tolerance

Brown trout distribution was largely influenced by the low-temperature preference of the species, with 76% of captures recorded from the montane sites and 7.1% from slopes sites. Capture sites were largely (78%) over 300 m in altitude (Figure 8.4). Elliott (1981) gave the following ranges for brown trout temperature preferences: optimum range 4-19˚C, lower critical range 0-4˚C and upper critical range 19-30˚C. A narrower temperature range of 1-10˚C for spawning and egg survival has been reported for this species. The lower and upper lethal temperatures for eggs are about 0˚C and greater than 13˚C. As occurs in other species the critical limits for spawning and egg development are narrower than for adult survival (Elliott 1981) and in brown trout this precludes their distribution outside the cooler streams.

The recorded abundance of brown trout may have been enhanced by stocking. This species is an important recreational species but it is stocked in limited numbers in New South Wales (180,000 in 1995). The species has established breeding populations over a wide range of suitable habitat within the state.

Impacts of brown trout on other fish species

The decline of populations of the mountain galaxiid *Galaxias olidus* has been attributed to predation by brown trout (Frankenburg 1966; Tilzey 1976; Fletcher 1979; 1986; Jackson and Williams 1980). Furthermore, Fletcher (1979) found similarities in the diets of both species, suggesting an overlap in their diets. During the present study brown trout were captured at 18 sites. At 8 (44%) of these sites *G. olidus* were also captured, indicating that at least in some situations these species can coexist.

Jackson (1978) showed that for sympatric populations of brown trout and river blackfish, *Gadopsis marmoratus,* although their diets were similar, coexistence was possible because each species occupied different habitats. It is also probable that brown trout can eliminate invertebrate species by predation (Fletcher 1979; Williams 1974). Williams (1974) found that brown trout predation most likely caused the decline of the Tasmanian mountain shrimp *Anaspides tasmaniae* and Fletcher (1979) demonstrated a decline in invertebrates after brown trout were introduced to a stream where *G. olidus* also occurred. Trout may also impact riparian fauna species as they have been reported to prey on small reptiles (Lintermans 1992; Rutzou *et al.* 1994).

Rainbow trout *(Oncorhynchus mykiss)*

As with brown trout, rainbow trout were largely confined to the upper reaches of the rivers surveyed, with 75% of capture records being from montane or slope sites. Those sites below 600 m altitude were on rivers emanating from high altitudes or received cool water from large dams upstream, so that water temperature influenced the distributional pattern. Elliott (1981) gave the optimum range for rainbow trout as 10-22°C, the lower critical range 0-9°C and the upper critical range as 19-30°C. The spawning temperature lies in the range 4-19°C and the lower and upper lethal temperatures for eggs are about 0°C and above 20°C. Large-scale stocking of this species takes place throughout suitable locations and it is an important recreational species. During 1995, 350,000 rainbow trout were released from the NSW Fisheries hatchery at Jindabyne and fish were also released from the Ebor hatchery.

Effects of rainbow trout on other species

Although rainbow trout have not been as strongly linked to predation on smaller fish species as brown trout, their presence has been shown to affect invertebrates, particularly zooplankton, in both size and species composition (Galbraith 1967; Brooks 1968). Lintermans and Rutzou (1990) found that rainbow trout and *G. olidus* had almost mutually exclusive distributions in the upper Cotter River catchment in the ACT indicating that rainbow trout are similar to brown trout in their impacts on this galaxiid. Although of the 19 sites at which rainbow trout were captured during the present study, 9 (47.4%) of these sites were also inhabited by

G. olidus indicating that cohabitation is possible. They have also been reported as preying on small reptiles (Lintermans 1992; Rutzou *et al.* 1994).

Epizootic Haematopoietic Necrosis Virus also has also been recorded from cultured rainbow trout and translocation of redfin perch and salmonids poses a risk of the disease spreading to native fish as some native species have been shown to be highly susceptible to the virus (Langdon 1990).

Goldfish *(Carassius auratus)*

Goldfish were widely distributed, largely (86.8%) at sites below 600 m altitude. Only five of the capture sites were in the montane rivers. Cyprinids such as goldfish are eurythermic (Elliott 1981), and therefore have a generalised distribution in New South Wales. Goldfish have an optimal temperature near 27˚C, a lower critical range of 0-17˚C and an upper critical range of 27-42˚C. Spawning temperatures are in the range of 5-19˚C (Billard *et al.* 1981). It is also a fish of slower-flowing waters and pools and can survive low oxygen concentrations (McDowall 1996a).

Goldfish have been present as wild populations in Australia for many decades but few deterimental impacts have been recorded. However, this may simply reflect the lack of research directed at this species.

Effects of goldfish on other fish species

Goldfish ulcer disease (GUD) is a bacterial disease of goldfish and is caused by an atypical strain of *Aeromonas salmonicida*. The disease was first isolated from a goldfish farm in Victoria in 1974 (Rowland and Ingram 1991; Trust *et al.* 1980). Since then outbreaks have occurred at warmwater fish hatcheries in New South Wales and Victoria (Whittington *et al.* 1987). Rowland and Ingram (1991) stated that fingerlings of Murray cod, *Maccullochella peelii*, golden perch, *Macquaria ambigua,* and silver perch, *Bidyanus bidyanus,* are resistant to GUD but that salmonids are highly susceptible. This has obvious implications for the valuable aquaculture industry based on salmonids and possibly for the major recreational fisheries exploiting salmonid fish in the wild.

Redfin perch *(Perca fluviatilis)*

Distribution, habitat preferences and thermal tolerance

The majority of sites where redfin perch were recorded were in the slopes or lowland rivers. This is in accordance with the reported distribution of this species in Tasmania (Weatherley 1974), Victoria (Cadwallader and Backhouse 1983), and Britain (Weatherley 1963b). The preference of redfin perch for slower, lowland streams and backwaters is well documented, as is their general avoidance of steep, rapidly flowing streams (Weatherley 1963b; 1977; Lake 1971). This avoidance of the faster-flowing erosional streams explains to a large degree the absence of redfin from many of the montane streams sampled during this survey. These fast-water habitats with their lack of suitable spawning sites provide an effective barrier to natural colonisation from downstream reaches (Weatherley and Lake 1967; Weatherley 1977). Redfin perch were occasionally found in montane streams and this is most probably as a result of human intervention, with redfin being moved from one water body to another by unthinking anglers (Lintermans *et al.* 1990a). Redfin perch can certainly survive the low winter water temperatures of upland environments provided suitable slow-flowing or lentic environments are available, with populations thriving in Blowering Reservoir on the Tumut River. Temperature requirements for spawning are low compared to most native fish species, with spawning usually occurring in early spring when water temperatures reach 11 to 12°C. Eggs are laid in long strands usually amongst aquatic macrophyte beds with breeding often occurring in the slower backwaters or billabongs off the main channel. This reproductive strategy enables redfin perch to survive in the colder montane impoundments and in slow-flowing rivers of the tablelands.

Whilst habitat preferences are thought to largely determine the upstream limits of redfin distribution, it is thermal tolerance which is believed responsible for limiting the distribution of the species in lowland habitats. Redfin perch are not present throughout most of the Darling drainage, the exceptions being some upland rivers in the Orange area and a population in the upper reaches of the Gwydir River. The redfin population in the Macquarie River below Burrendong Dam is probably able to persist because of the cold-water releases from Burrendong. Weatherley (1963a) found the upper thermal limit of redfin perch to be 30-31°C which explains their absence from much of the lower Darling where temperatures commonly reach 30°C during summer.

Impacts of redfin perch on other fish species

Information on the impacts of redfin on other fish species is often speculative and anecdotal, even though the species has been established in Australia for over 100 years. Reported impacts include predation and introduction of disease. Redfin perch are predominantly carnivorous, consuming a wide variety and size-range of organisms. In a study in south-western Australia, Pen and Potter (1992) found that as redfin perch increased in size, their diet shifted from predominantly planktonic Crustacea to benthic invertebrates, and decapod crustaceans in larger fish. However, they noted that all size groups of redfin perch fed on two small native fish species, *Edelia vittata* and *Bostockia porosa*, with native fish remains comprising up to 17 % of the stomach volume of redfin. Pen and Potter (1992) concluded that under extreme conditions, such as when a marked depletion occurs, in alternative food sources that the presence of redfin perch could pose a threat to the conservation of native fish species. Hutchinson (1991) presented circumstantial distributional evidence to suggest that redfin perch has eliminated *E. vittata* from part of the Murray River system in Western Australia. The capacity of redfin perch to rapidly populate stable bodies of water and form large populations of stunted individuals is well documented (Cadwallader and Backhouse 1983; Lintermans *et al.* 1990a). Under these conditions both males and females can reach reproductive maturity when less than 100 mm long (Lintermans unpublished data). Such high-density populations could suppress or perhaps even eliminate populations of small native fish. Anecdotal evidence from Lake Burley Griffin in Canberra indicates that numbers of western carp gudgeon, (*Hypseleotris klunzingeri)* numbers have increased dramatically following a marked reduction in redfin perch abundance due to an outbreak of disease (Lintermans unpubl. data).

Cadwallader (1978) suggested that the introduction of redfin perch has had an adverse effect on native fish species, with small, weed-inhabiting species such as pygmy perch, rainbowfish and carp gudgeons suggested as being most at risk (Cadwallader and Backhouse 1983). Dietary studies on redfin perch in the Canberra region have shown that they eat substantial numbers of western carp gudgeon as well as gambusia and other redfin perch. Harris *et al.* (unpublished data) showed that survival of golden perch, *Macquaria ambigua*, and silver perch, *Bidyanus bidyanus*, juveniles of about 30 mm length was significantly lower in impoundment's containing redfin perch. Predation by redfin perch on trout has also been cited as a cause for the decline of several trout fisheries in south-eastern Australia. Baxter *et al.* (1985) found that redfin perch predation on stocked trout fingerlings was high, with 35% of redfin perch captured within 48 hours of trout stocking having trout in their stomach. The incidence of redfin perch predation was still high six weeks after stocking, with 12% of redfin perch captured having trout in their stomach. Moy (1974) found that after a release of brown trout averaging 7.5 cm in length, 90 percent of redfin perch captured had been feeding on the newly liberated trout. However after releasing rainbow trout of 20 cm average length, there were no trout found in redfin perch stomachs. Obviously trout of the larger size were able to evade redfin perch predation, but as most stocking of both native fish and trout involves fish of 5 - 10 cm, redfin perch predation is an issue that needs to be considered. Where threatened fish species are being stocked, the presence of large numbers of redfin may play a substantial part in the ultimate success or failure of the reintroduction.

The greatest potential threat to native fish stocks from redfin perch is the introduction of the disease Epizootic Haematopoietic Necrosis Virus (EHNV). This virus, unique to Australia, was first isolated in 1985 from redfin perch (Langdon *et al.* 1986). EHN is characterised by sudden high mortalities of fish displaying necrosis of the renal haematopoietic tissue, liver, spleen and pancreas (Langdon and Humphrey 1987). Experimental work by Langdon (1989a,b) demonstrated that the threatened species Macquarie perch, *Macquaria australasica,* was one of several species which are extremely susceptible to EHN. Macquarie perch were held in aquaria and exposed to EHNV in water, with all fish in two trials dying within five days. It has now been suggested that the dramatic decline of Macquarie perch in Lake Eildon in Victoria may have been related to EHNV and redfin perch (Langdon 1989b), with predation and competition also suggested as contributing factors (Cadwallader and Rogan 1977). Other species that were highly susceptible to EHNV were silver perch, *Bidyanus bidyanus*, mountain galaxias, *Galaxias olidus,* and the alien gambusia. Murray cod, *Maccullochella peelii,* were less susceptible but able to act as a carrier of the disease, as were rainbow trout (Langdon 1989b).

The spread of EHNV has been aided by the relatively resistant characteristics of the virus and it can be readily transmitted from one geographical location to another on nets, fishing lines, boats and other equipment. Langdon (1989b) found that the virus retained its infectivity after being stored dry for 113 days. Once EHNV has been recorded from a water body it is considered impossible to eradicate it.

Gambusia *(Gambusia holbrooki)*

Gear selectivity and sampling bias

Gambusia are not susceptible to capture in panel and fyke nets due to their small size and ability to pass through the mesh. The high relative success of electrofishing for sampling gambusia has been noted in other studies. Lintermans (1995) found that of four gear types used (gill nets, fyke nets, bait traps, electrofishing) in the Murrumbidgee and Molonglo Rivers near Canberra, the only method which sampled gambusia was electrofishing. However, even electrofishing does not sample gambusia efficiently as seen from the low ratio of captured to observed fish evident at many sites in the current study. Gambusia are often found in slow-flowing areas at the edge of waterbodies in water depths of 10 cm or less. In the current study these habitats would only be thoroughly sampled by backpack electrofishing, as boat electrofishing could often not access these shallow water habitats effectively. Backpack electrofishing of pools was only carried out in montane river types so the lower occurrence of gambusia in the lowland and slopes rivers could be partly associated with sampling problems. The relative inefficiency of electrofishing in sampling small fish is well known (Cowx and Lamarque 1990), although the use of higher pulse frequencies can increase efficiency somewhat. However the risk of causing injury to larger fish also increases with higher frequencies and so was not acceptable for this study. The abundance data for this species are therefore not considered a reliable estimate of population size.

Distribution, habitat preferences and thermal tolerance

The number of sites in the Murray region which contained gambusia (two sites) was surprisingly low as this species was previously reported to be widespread in this drainage (Llewellyn 1983; Cadwallader and Backhouse 1983; Lintermans unpubl. data).

Gambusia were distributed relatively evenly amongst the four river types, with the lowland category containing the largest number of capture sites (Figure 8.2), and avoid fast-flowing water

(Arthington *et al.* 1986; McDowall 1996a; Lintermans unpublished data). One reason for this avoidance of fast-flowing water is that the predatory efficiency of gambusia decreases dramatically with increasing water flow (Ravichandra Reddy and Pandian 1974). Gambusia are eurythermal, thriving in suitable habitats at a wide range of water temperatures. The reported thermal maximum for the species varies from 37°C (Cadwallader and Backhouse 1983) to about 44°C (McDowall 1996a; Lloyd 1984) with individuals acclimated to higher temperatures and cyclic temperature regimes having higher maximum temperature tolerance (Otto 1973, 1974). Gambusia can also withstand temperatures just above freezing (0.5°C) and survive in ice-covered waters (Lloyd 1984; Otto 1973; Meffe *et al.* 1983) with the species recorded from Three Mile Dam in the Snowy Mountains of New South Wales at an altitude of 1460 m (Lintermans unpublished. data). This wide temperature tolerance, coupled with tolerance of low oxygen tension and salinities more than twice seawater, enables gambusia to survive in a wide variety of stream environments (Arthington *et al.* 1986; Lloyd 1984).

Impacts of gambusia on other fish species

Gambusia have been implicated in the decline in abundance or range of 35 fish species worldwide (Lloyd 1990) with circumstantial evidence that several Australian native fish species have been impacted. Lloyd and Walker (1986) considered that the apparent decline of purple-spotted gudgeon, *Mogurnda adspersa,* in the lower Murray River may be associated with the spread of gambusia. Similarly they found that pygmy perch, *Nannoperca australis,* had declined and now only occurred in two streams, where gambusia were absent. Similar overlapping distributional patterns have been recorded for gudgeons, hardyheads and some rainbowfish in southeastern Queensland (Arthington *et al.* 1986). The impacts of alien species are often difficult to separate from the impacts of habitat degradation as alien species are often found in disturbed habitats (Arthington 1991; Arthington *et al.* 1983, 1990).

The mechanisms by which gambusia impact native species are varied and include direct competition for resources, interference competition, and predation. Gambusia are an adaptable, generalist predator and feed on a wide range of both terrestrial and aquatic organisms. (McDowall 1996b; Lloyd 1984). Arthington *et al.* (1986) concluded that overlap in the diets of gambusia and firetail gudgeon, *Hypseleotris galii,* may be important in periods of food scarcity. Gambusia with their high reproductive rate and extended breeding season may swamp suitable habitats with juveniles and deplete food supplies before *H. galii* populations can build up (Arthington *et al.* 1986). Crimson-spotted rainbowfish, *Melanotaenia fluviatilis,* and hardyheads, *Craterocephalus* spp., may also be affected by gambusia in the same way (Arthington *et al.* 1986).

Interference competition occurs when gambusia denies other species access to a particular resource, generally through aggressive behaviour (Schoenherr 1981). Aggressive behaviour in gambusia often involves chasing and fin nipping (Lloyd 1986; Barlow *et al.* 1990; Myers 1965, McDowall 1996a) which can lead to secondary bacterial or fungal infections (Meffe 1983), and eventually death (Meffe *et al*. 1983). Schoenherr (1981) discussed a behavioural hierarchy in which gambusia females are dominant and aggressive, resulting in increased mortality rates and reduced fecundity of the Gila topminnow, *Poeciliopsis occidentalis.* This reduction in survival of adult female Gila topminnows was attributed to increased physiological stress due to aggression from gambusia (Schoenherr 1981).

Gambusia are also known to prey upon the eggs and fry of other fish species (Schoenherr 1981), with Meffe (1985) calculating that a single female gambusia could consume the entire annual production of fry of the Gila topminnow. Meffe (1985) concluded that even a low predation rate on fry could have a significant impact if the target species has low fecundity or if the predator is abundant.

Species expected but not captured

The six alien species recorded for New South Wales but not captured during the current survey are yellowfin goby, roach, Atlantic salmon, brook trout, tench and oriental weatherloach. The absence of each species from the survey can be explained by either habitat preferences, very small populations or extremely limited distributions. The yellowfin goby, an import from Asia presumed to have entered Australia via ballast water from ships, typically inhabits estuaries of major ports and has been captured from upper estuarine limits in the Hawkesbury River, New South Wales (Harris 1995a).

The two salmonid species, brook trout and Atlantic salmon, are maintained in the wild by stocking and are released in only a limited number of sites, mostly in impoundments, which the current survey did not sample. Oriental weatherloach is a popular aquarium fish which was first detected in the wild in 1984 in both Victoria and the Australian Capital Territory. (Allen 1984; Lintermans *et al*. 1990b). This species is abundant but only in localised populations (Lintermans and Burchmore 1996), and was not detected during this survey. Tench and roach have only rarely been recorded in New South Wales (Llewellyn 1983), occurring in small numbers and with restricted distributions.

Ecological consequences of alien fish species

Alien species are more likely to be successful in disturbed habitats and to occupy broad ecological niches (Arthington *et al,* 1990; Courtenay and Hensley 1980; Harris 1995b; Ross 1991). Apart from the two trout species, which thrive in headwater streams because of available niches and because there are often no large competing predatory species other than eels (Harris 1995), the alien species found during this survey largely occupy disturbed ecosystems. The habitats have been altered in many ways including flow regulation by weirs and dams altering both the flow and temperature regimes.

The impacts of alien species on the native fish and invertebrates are many and can include food competition, predation, space competition, habitat disturbance and their role as disease vectors (Harris 1995a; Fletcher 1986; Cadwallader 1996). They have also been implicated in extinctions of fish species. Miller *et al.* (1989) showed that for a range of extinct North American fish species the most common cause of extinction was habitat loss but the effects of introduced species were responsible for the demise of 68% of 40 taxa now extinct. Alien fish species may also be impacting other faunal groups such as invertebrates and amphibians. Predation by trout on tadpoles of the endangered spotted tree frog *Littoria spenceri* is considered a major threat to this species (G. Gillespie, personal communication). Predation by gambusia on eggs and lavae probably threatens other aquatic taxa, especially amphibians.

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