Spatial and temporal variation in the composition of riverine fish communities

Ivor Growns, Karen Astles and Peter Gehrke

NSW Fisheries
P.O. Box 21, Cronulla, NSW, 2230
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SUMMARY

An understanding of spatial and temporal variation, over small and large scales, is necessary when designing a monitoring program. Knowledge of large-scale temporal variation, such as that which occurs over the duration of a monitoring program, is important to enable examination of the likelihood of detecting specific levels of environmental change. Information on small-scale temporal variation is also crucial to allow determination of the frequency of sampling and to determine whether changes in the target community or species within and between seasons may affect decisions of when to sample. It also allows an understanding of how well samples from a small number of nearby sites represent the true condition of the population or community being studied.

This study showed that small-scale spatial variation and short-term temporal variability in fish community structure is significant in the Macquarie and Namoi Rivers. However, larger scale spatial differences between rivers were the largest source of variation in the data. The interaction between temporal change and spatial variation in fish community structure, whilst statistically significant, was smaller than the variation between rivers. This suggests that although the fish communities within each river changed between sampling occasions, the underlying differences between rivers were maintained. In contrast, the strongest interaction between temporal and spatial effects occurred at the smallest spatial scale, at the level of individual sites. This means that, although the composition of the fish assemblage at a given site may fluctuate, the magnitude of these changes is unlikely to affect larger scale differences between reaches within rivers or between rivers.

Large scale temporal variation, for example between years or between periods of drought and flood, were not examined in this study. However, the results suggest that sampling at any time within a single season will be sufficient to reveal any spatial differences that may occur over large spatial scales, such as comparisons between rivers, between geographical regions, or across the entire Murray-Darling basin. Monitoring programs intended to evaluate differences in fish communities at such large spatial scales need only to sample at the scale below the level of interest. For example, where the management focus is among rivers then replicate samples should be drawn from representative reaches within rivers.

1. INTRODUCTION

Environmental impact assessment and associated monitoring can be regarded as a test of the null hypothesis that some human action has not caused a change in the environment (Fairweather 1991). Therefore, the aim in the design of such a monitoring program should be to maximise the power of the sampling program to detect changes through time. There are several obvious ways to increase the statistical power, or the ability to detect change, of a monitoring program: by increasing the number of replicated sampling sites, by increasing the duration of the sampling program or by increasing the number of samples collected over time. However, factors such as the rate of biological or ecological change and the degree of natural variation are generally beyond the control of the researcher.

An understanding of spatial and temporal variation, over small and large scales, is necessary when designing a monitoring program, to enable the statistical power of tests to be calculated (Underwood, 1994). Knowledge of large-scale temporal variation, such as that which occurs over the duration of a monitoring program, is important to enable examination of the likelihood of detecting specific levels of environmental change (Underwood, 1992). Large-scale variation in an ecological system can affect the responses observed during a monitoring program. For example, fish communities in different geographical regions may contain different species and may therefore respond differently to the same environmental factors. Information on small-scale temporal variation is also crucial to allow determination of the frequency of sampling and to determine whether changes in the target community or species within and between seasons may affect decisions of when to sample (Fairweather, 1991). It also allows an understanding of how well samples from a small number of nearby sites represent the true condition of the population or community being studied (Chapman, 1994).

Large-scale temporal and spatial variation of the structure of freshwater fish communities in New South Wales varies mainly by river type and geographical regions (Gehrke and Harris 2000). For example, slopes and lowland rivers in the North Coast region of New South Wales have a greater abundance and diversity of fish than comparable rivers in other regions. Gehrke and Harris (2000) also showed that, although annual variation in community structure was limited between years, seasonal variation in species diversity and total fish abundance reflected a lower catchability of fish in winter. However, Gehrke and Harris (2000) did not address the influence that finer scale temporal variation and hierarchical spatial scale effects have on studies of fish communities at the scale of individual rivers, where many environmental impact studies are focussed - for example the Sustainable Rivers Audit (Cullen et al. 2000).

The present project seeks to describe and evaluate the extent of small-scale temporal variation in the structure of freshwater fish community that occurs at spatial scales of site, river reach and whole of river. Different spatial scales are examined to estimate the magnitude of variation between them and hence assess their importance in contributing to overall variability.

2. METHODS

2.1. Study Site Criteria

The Namoi and Macquarie Rivers situated in the Murray-Darling basin were chosen for this study. Both rivers arise from the western slopes of the Great Dividing Range in northern New South Wales and are major tributaries of the Barwon-Darling River. Flows in the two rivers are regulated by Burrendong Dam on the Macquarie River and Keepit Dam on the Namoi River, creating similar flow regimes dominated by summer irrigation periods. The two rivers have similar faunas with abundant native fish (Gehrke and Harris 2000).

2.1.1. Survey Method

Electrofishing was selected as the least-biased method of capturing all fish species likely to be present within a designated reach (Harris and Gehrke, 1997). Electrofishing was done using a boat-mounted 7.5 kW electrofishing system. Two anodes were suspended from booms mounted on the bow of a 5 m boat with two cathodes mounted along the sides of the boat. One person operated both the controls of the electrofisher and the boat while two people at the bow dipnetted immobilised fish from the water. During this study the electrofisher was operated at between 500-1,000 volts and 3-10 amps at 60 pulses per second and 70-90% duty cycle, depending on the conductivity of the water.

2.1.2. Sampling Regime

Six survey sites were selected on each of the Namoi and Macquarie Rivers (Figure 1, Table 1). Randomly-selected paired sites were located within each of three consecutive 50 km reaches. The most upstream site on each river was established at approximately 10 km downstream of the dam. Each site was sampled on three occasions over summer and autumn 1999. Paired sites allowed local-scale variability to be assessed; reaches within rivers allowed within-river variability to be assessed, whilst the two rivers sampled enabled an assessment of large-scale variability between rivers that are geographically, geomorphologically and functionally similar. Sites were sampled approximately one month apart to assess short term variability.

Electrofishing sampled all navigable habitats within the river channel. One replicate sample (or shot) consisted of two minutes of electrofisher operation covering approximately 30-40 m of river bank in approximately 1-2 m of water. Fifteen random replicate samples were taken at each site on each occasion, to be consistent with other broad-scale fish surveys being conducted by NSW Fisheries. This gave a total of 540 replicates. All fish dipnetted from the water were counted, identified to species level where possible and returned alive to the water. Fish observed to be affected by the electric field during sampling, but not caught, were also counted when they could be identified.

Table 1. The 12 survey sites on the Namoi and Macquarie Rivers sampled in February, March and May 1999 by boat electrofishing.

River system	Site	Latitude	Longitude	Nearest town
Namoi	1-Gunnedah	30°58’28	150°15’16	Gunnedah
	2-Babette’s	30°55’06	150°12’00	
	3-Broadwater No.1	30°26’56	149°56’26	Narrabri
	4-Broadwater No.2	30°24’44	149°54’28	
	5-Wee Waa	30°11’24	149°26’27	Wee Waa
	6-The Gardens	30°14’38	149°22’25	
Macquarie	7-Wellington	32°11’32	148°26’14	Wellington
	8-Wellington	32°11’38	148°28’45	
	9-Eschol No.1	32°22’33	148°40’30	Geurie
	10-Eschol No.2	32°23’55	148°38’20	
	11-Whylandra Crossing	32°33’47	148°58’34	Dubbo
	12-Dickygundi	32°32’48	148°55’42	

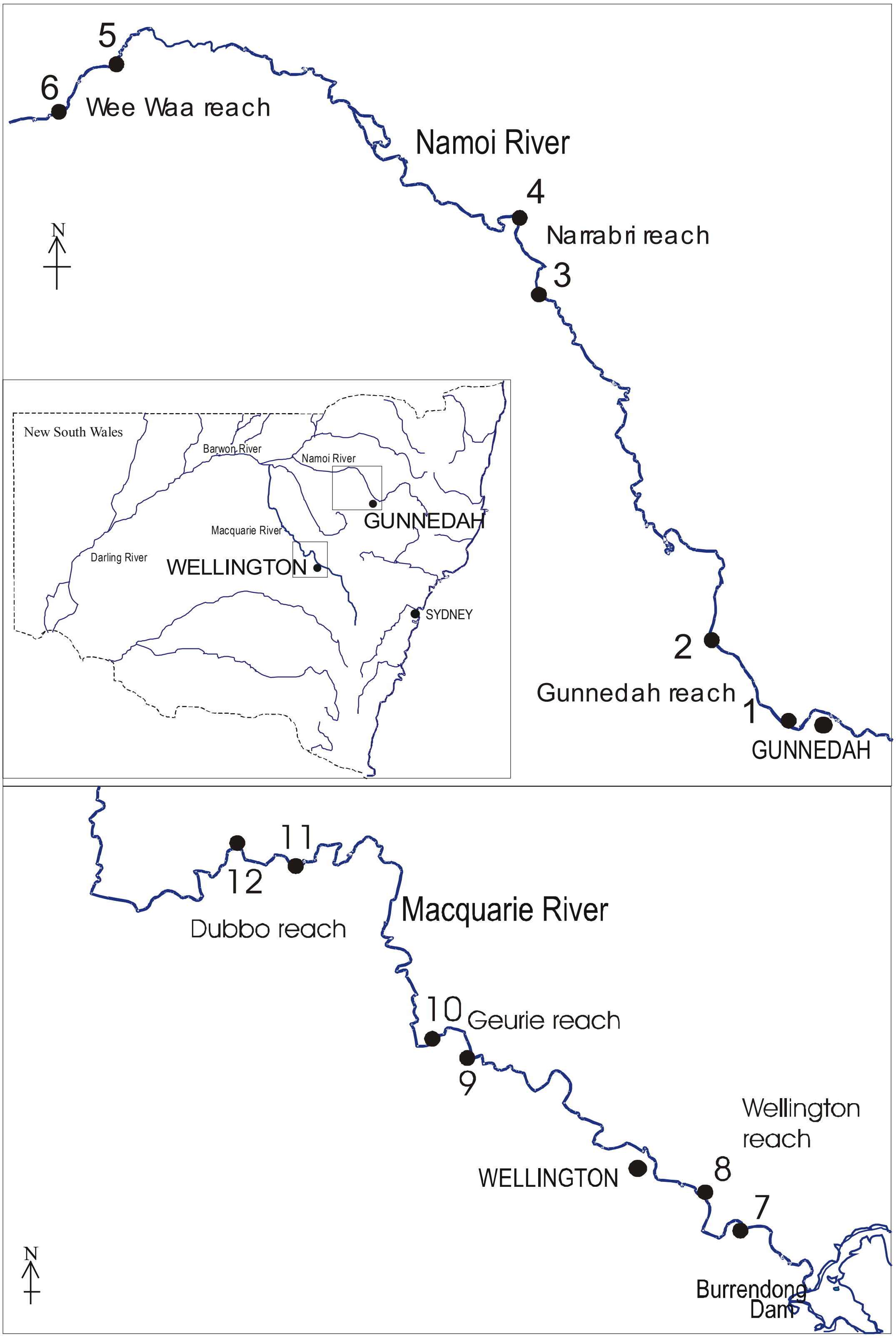

Figure 1. Locations of the 12 sites surveyed on the Namoi River (sites 1 to 6) and Macquarie River (sites 7 to 12).

2.1.3. Data analysis

Differences in community structure between sites within reaches, between reaches within rivers and between the Namoi and Macquarie rivers, on each sampling occasion and with all occasions pooled, were tested using distanced-based multivariate linear modelling (DISTLM) (Anderson, 2000). DISTLM can be used to perform an ANOVA-type analysis of main factors and the interaction terms between them in an experimental design (as shown in Table 2), based on a matrix of similarities between fish assemblages at different sites. The significance of the main factors and associations are tested using a randomisation technique. Data were log-transformed and range-standardised before analysis.

Pairwise comparisons for differences in fish community composition among times were done for individual sites using ANOSIM, a non-parametric method based on rank similarities among all samples (Warwick *et al*., 1990; Clarke, 1993). The technique compares the similarity among samples within treatments with the similarity among samples between treatments. The test uses a randomisation procedure to establish a sample variance for the test statistic in which the observed value is compared with simulations under a null hypothesis. One thousand randomisations of the data were done for each comparison using the Bray-Curtis dissimilarity measure (Bray and Curtis, 1957). To reduce the chances of making a Type I error, a Bonferroni correction was applied to ANOSIM multiple comparisons by assuming that groups were significantly different at a probability of 0.005.

Species that provided the strongest discrimination between groups of sites with significantly different fish communities were identified using SIMPER analysis (Clarke, 1993). The consistency ratio (the ratio of the average to standard deviation of the dissimilarities between samples) was calculated for each species for each contrast.

The statistical model described in Table 2 was used to determine the differences in the abundance of individual fish species, total fish abundance and the number of fish species between sites, reaches, rivers and sampling occasions using analysis of deviance. Analysis of deviance was done with general linear modelling (McCullagh and Nelder 1989), with a poisson error distribution and a log link. This type of analysis is the equivalent of an analysis of variance on count data (Turak *et al.* 1999).

Table 2. Statistical model used for analysis of deviance and DISTLM.

Source of variation	Type	Degrees of freedom	Denominator for F test
Times	Fixed	2	Times x Reaches within Rivers
Rivers	Fixed	1	Reaches within Rivers
Times x Rivers	Fixed	2	Times x Reaches within Rivers
Reaches within Rivers	Random	4	Sites within Reaches within Rivers
Times x Reaches within Rivers	Mixed	8	Times x Sites within Reaches within Rivers
Sites within Reaches within Rivers	Random	6	Residual
Times x Sites within Reaches within Rivers	Mixed	12	Residual
Residual	Random	504	
Total		539	

3. RESULTS

3.1. Fish species distribution

The most abundant species caught during the project were bony herring, carp, Australian smelt and rainbowfish (Table 3). In contrast, fewer than ten individuals of freshwater catfish, silver perch, mountain galaxias and flyspecked hardyhead were caught.

Carp, Australian smelt and western carp gudgeons were present in all river reaches. However, there was considerable variation in their abundances among river reaches. Bony herring were collected only from the Namoi River, but their abundances varied considerably among reaches and between sites within reaches. Other species only recorded from the Namoi River were spangled perch and flyspecked hardyhead. Mountain galaxias was the only species collected from the Macquarie River that was not also collected from the Namoi River.

Table 3. Total abundances of each fish species recorded from 15 shots on three sampling occasions at each site within each reach.

Scientific name	Common name			Namoi						Macquarie			
		Gunnedah		Narrabri		Wee Waa		Wellington		Geurie		Dubbo	
		1	2	3	4	5	6	7	8	9	10	11	12
Bidyanus bidyanus	Silver perch	0	0	1	0	0	2	2	0	0	0	1	0
Carassius auratus	Goldfish[a]	6	2	1	4	7	7	0	0	1	0	0	2
Craterocephalus stercusmuscarum	Flyspecked hardyhead	0	0	0	0	1	0	0	0	0	0	0	0
Cyprinus carpio	Carp[a]	57	105	56	57	32	167	94	115	96	151	169	207
Galaxias olidus	Mountain galaxias	0	0	0	0	0	0	0	1	0	0	0	0
Hypseleotris spp.	Western carp gudgeons	3	0	6	0	1	0	0	1	12	1	10	3
Leiopotherapon unicolor	Spangled perch	0	0	1	0	10	7	0	0	0	0	0	0
Macquaria ambigua	Golden perch	10	10	12	10	3	50	1	0	0	0	0	0
Maccullochella peelii	Murray cod	6	4	11	9	5	1	1	0	6	1	14	17
Melanotaenia fluviatilis	Crimson-spotted rainbowfish	9	20	106	99	61	35	0	0	0	1	8	4
Nematalosa erebi	Bony herring	55	74	363	791	222	278	0	0	0	0	0	0
Perca fluviatilis	Redfin perch[a]	3	0	0	0	1	0	24	20	0	3	0	0
Philypnodon grandiceps	Flathead gudgeon	0	0	2	0	0	0	55	11	26	4	4	0
Retropinna semoni	Australian smelt	12	0	6	1	2	3	642	68	12	11	47	48
Tandanus tandanus	Freshwater catfish	0	0	1	0	0	0	0	1	0	2	0	0
Total	**Total**	**162**	**217**	**567**	**973**	**346**	**552**	**820**	**219**	**154**	**176**	**254**	**283**

[a] alien species introduced from other countries.

3.2. Fish community structure

Fish assemblages at individual sites varied significantly over time, as indicated by the significant interaction between sites and times (T x S(Re(Ri)), Table 4). In contrast, fish community structure at individual reaches (T x Re(Ri)) did not vary over time, but varied between reaches within rivers (Re(Ri)). The greatest variation in fish community structure occurred between rivers, as indicated by the large mean square. The nature of differences between rivers (T x Ri) also varied significantly over time.

Table 4. Results of distance-based linear model analysis for differences in fish community structure. * indicates p <0.05, ** p < 0.01 and *** p <0.001.

Source of variation	Degrees of freedom	Mean square	% variance explained	F
Times (T)	2	26486	10	3.2 ***
Rivers (Ri)	1	179699	65	6.8 ***
T x Ri	2	15558	6	1.9 *
Reaches within Rivers (Re(Ri))	4	26325	10	3.0 **
T x Re(Ri)	8	8172	3	1.2 ns
Sites within Reaches within Rivers (S(Re(Ri)))	6	8867	3	3.6 ***
T x S(Re(Ri))	12	6873	3	2.8 ***
Residual	504	2449	1	
Total	539	274428	100	

The fish community structure at sites within the Wellington and Dubbo reaches of the Macquarie River, and the Gunnedah and Narrabri reaches of the Namoi River, did not differ when all three temporal samples were combined (Table 5A). Over all times, there was a significant difference between sites in the Geurie reach on the Macquarie River and the Wee Waa reach on the Namoi River, but the low R value for these differences (< 0.16) indicates that community structure within these reaches remains reasonably similar over time. The sites near Wee Waa were significantly different on two sampling occasions, but the differences between the Geurie sites could not be distinguished on any particular sampling occasion.

There was no single species that contributed consistently more than an average of 20% to the dissimilarity between sites within the Wee Waa reach (Table 6A). Carp were associated with the separation of sites within this reach. However, the low consistency ratio suggests that the differences in species abundances are not consistent between the replicate samples for that reach.

There was no significant difference in fish communities between the two most upstream reaches on the Macquarie River, Wellington and Geurie, for all sampling occasions combined (Table 5B). The differences between the two most downstream reaches on the Macquarie River, Geurie and Dubbo, when significant, always had an R-value less than 0.10 suggesting that differences in community structure between reaches were small. The largest difference among river reaches along the Macquarie River, as shown by the R-value, was consistently between the upper-most and lower-most reaches, suggesting that there is a change in community structure along the river. The two species that appear to be mainly associated with the separation of reaches within the Macquarie River were carp, which were more abundant downstream (Table 3), and Australian smelt, which were more abundant upstream (Table 3, Table 6). However, a relatively high abundance of Murray cod was associated with the separation of Dubbo from the other reaches on the third sampling occasion. Consistency ratios ranged from 0.57 to 1.05 for species contributing to these differences, indicating a large degree of variation in abundances between reaches.

Table 5. Significant R values for ANOSIM contrasts in community structure at 3 spatial scales. NS indicates non significant differences between groups (p > 0.005). Differences for individual dates were tested only when the global test (all times pooled) was significant.

Contrast		All times pooled	Time 1	Time 2	Time 3
(A) Between sites within reach					
Namoi River	Gunnedah	NS			
	Narrabri	NS			
	Wee Waa	0.16	0.34	NS	0.27
Macquarie River	Wellington	NS			
	Geurie	0.08	NS	NS	NS
	Dubbo	NS			
(B) Between reaches within a river					
Namoi River	Gunnedah v Narrabri	0.06	0.12	0.11	0.09
	Gunnedah v Wee Waa	0.07	0.11	0.16	NS
	Narrabri v Wee Waa	NS			
Macquarie River	Wellington v Geurie	NS			
	Wellington v Dubbo	0.08	0.11	0.19	0.10
	Geurie v Dubbo	0.04	0.08	NS	0.08
(C) Between rivers		0.20	0.12	0.38	0.23

There was no significant difference between the downstream-most reaches of the Namoi River, the Narrabri and Wee Waa reaches, for all times combined (**Table 5**B). In contrast, the fish community at the upstream Gunnedah reach was significantly different from the two downstream reaches in the Namoi River on most sampling occasions. However, the differences in fish community structure among the Namoi River reaches never differed with an R value greater than 0.16, indicating that differences in community structure between reaches, although significant, were small. The two main species that appeared to separate the Gunnedah reach from the Narrabri and Wee Waa reaches, on most sampling occasions, were carp and bony herring, which were less abundant near Gunnedah (Table 3, Table 6B). Values of between 0.89 and 1.20 for the consistency ratio for these species suggest greater consistency in the abundance of these species within reaches than was apparent for comparisons of reaches within the Macquarie River.

The overall community structure between rivers was significantly different on all sampling occasions (Table 5C, Figure 2). The difference in community structure between rivers always had an R-value greater than or equal to the differences among river reaches within each river. This suggests that difference in community structure was greater between rivers than between reaches within any one river. However, local-scale variation within the Wee Waa reach of the Namoi River (i.e., between sites 5 and 6) was greater than the difference between rivers on the first and third sampling occasions. The two species that contributed most to the separation of the two rivers were carp and bony herring on most sampling occasions (Table 6C). Carp were more abundant in the Macquarie River, whilst bony herring were only collected from the Namoi River (Table 3).

Table 6. Species contributing more than 20% of the dissimilarity between groups in significant ANOSIM contrasts of fish community structure at 3 spatial scales. The consistency ratio is given in parentheses. NS indicates non significant differences between groups (p > 0.005).

Contrast		Time 1	Time 2	Time 3	All times
(A) Between sites within reach					
	Geurie	NS	NS	NS	*C. carpio* (0.77) *P. grandiceps* (0.73)
	Wee Waa	*C. carpio* (1.21) *M. fluviatilis* (1.11) *N. erebi* (3.14)	NS	*C. carpio* (1.3)	*C. carpio* (1.25) *M. fluviatilis* (1.05) *N. erebi* (0.98)
(B) Between reaches within river					
	Well. vs Dubb.	*R. semoni* (1.05) *C. carpio* (0.98)	*C. carpio* (1) *P. grandiceps* (0.9)	*M. peeli* (0.8) *R. semoni* (0.65)	*C. carpio* (0.83) *R. semoni* (0.77)
	Geur. vs Dubb.	*C. carpio* (1.06) *R. semoni* (0.95)	NS	*C. carpio* (0.57) *R. semoni* (0.60) *M. peeli* (0.84)	*C. carpio* (0.71) *R. semoni* (0.77)
	Gunn. vs Narr.	*C. carpio* (1.14) *N. erebi* (0.89)	*C. carpio* (1.18) *N. erebi* (1.03)	*C. carpio* (1.09) *N. erebi* (1.12)	*C. carpio* (1.01) *N. erebi* (1.10)
	Gunn. vs Wee.	*C. carpio* (1.07) *M. fluviatilis* (0.99) *N. erebi* (1.08)	*C. carpio* (1.21) *N. erebi* (1.06)	NS	*C. carpio* (1.11) *N. erebi* (1.19)
(C) Between rivers		*C. carpio* (1.02)	*C. carpio* (1.17) *N. erebi* (1.71)	*C. carpio* (1.00) *N. erebi* (1.30)	*C. carpio* (0.94) *N. erebi* (1.11)

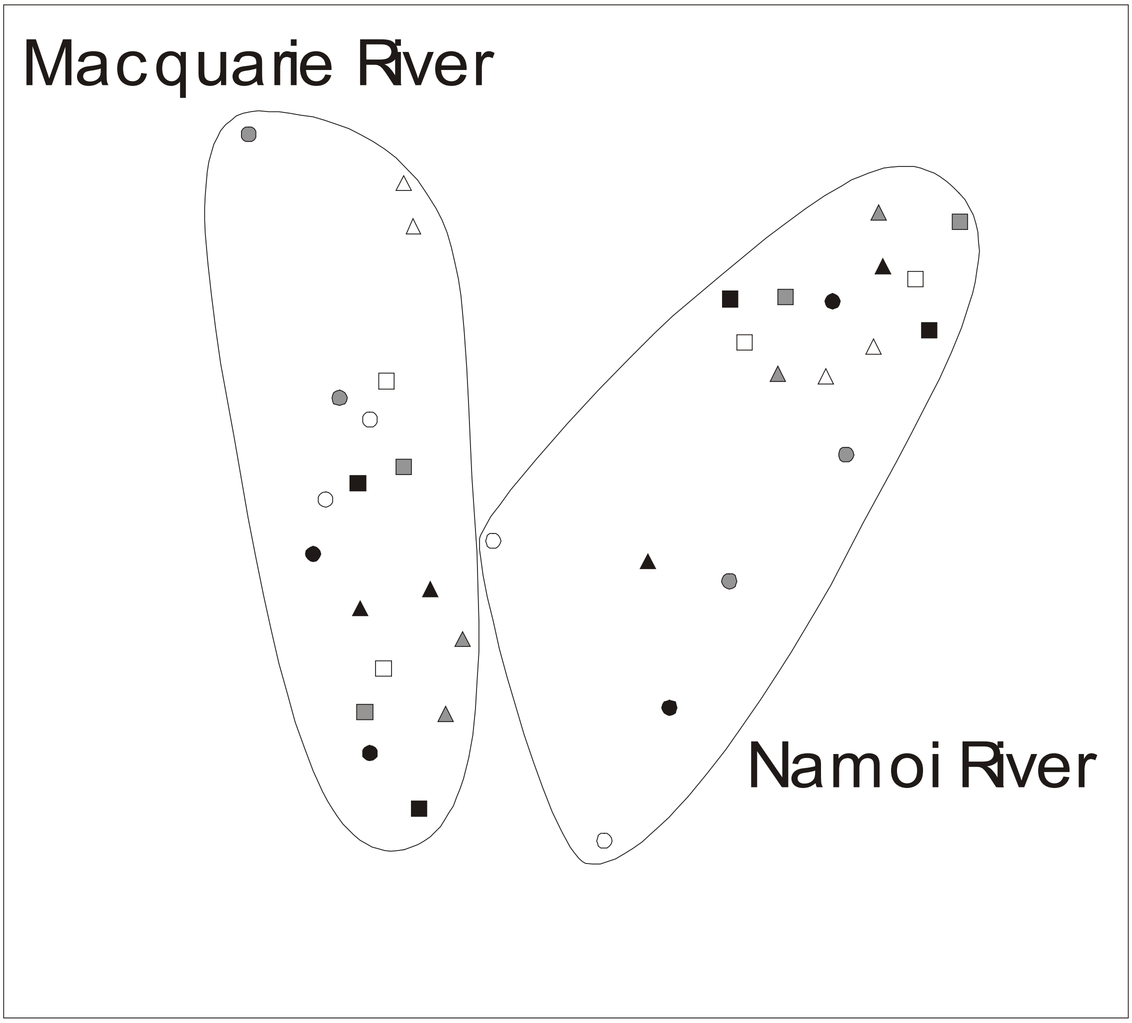

Figure 2. MDS ordination of sites (pooled replicates) showing spatial and temporal variation in fish community structure in the Macquarie and Namoi rivers. White symbols = February, grey symbols = March, black symbols = May. Circles indicate the upstream reach in each river, squares the middle reach and triangles the downstream reach.

Fish community structure differed significantly among all sampling dates at all Namoi River sites (Table 7). In addition, the first sampling occasion was significantly different from the second sampling occasion for all sites (Table 7). Community structure on the first sampling occasion was different from the third sampling occasion in only two sites on the Namoi River. At the three most upstream sites, community structure differed significantly between the second and third sampling occasions. Carp and bony herring were the species that generally contributed to differences in community structure (Table 8). The consistency ratio for bony herring between samples was generally greater than for carp, suggesting that the abundances of bony herring were less variable among samples compared to carp. Crimson-spotted rainbow fish also contributed to the differences over time for three sites, whilst golden perch contributed strongly to temporal variation at Wee Waa site 6 between the first two times.

There was no consistent pattern of differences among sampling occasions for the Macquarie River sites (Table 7). Australian smelt and carp were the species that generally contributed more than 20% to the dissimilarity among sampling occasions for the majority of sites (Table 8).

Table 7. Significant R values from ANOSIM contrasts of fish community structure at each site among sampling occasions. NS indicates non-significant differences between groups ($p > 0.005$). Differences for individual sites were tested only when the global test (all times pooled) was significant.

		Contrast			
		Time 1 v 2	Time 1 v 3	Time 2 v 3	All Times pooled
Namoi River	Gunnedah site 1	0.16	NS	0.19	0.12
	Gunnedah site 2	0.38	NS	0.33	0.26
	Narrabri site 3	0.38	NS	0.33	0.15
	Narrabri site 4	0.34	0.31	NS	0.26
	Wee Waa site 5	0.35	NS	NS	0.18
	Wee Waa site 6	0.43	0.25	NS	0.27
Macquarie River	Wellington site 7				NS
	Wellington site 8	NS	0.19	NS	0.14
	Geurie site 9				NS
	Geurie site 10				NS
	Dubbo site 11				NS
	Dubbo site 12	0.29	0.40	NS	0.27

Table 8. Species contributing more than 20% of the dissimilarity between groups in significant ANOSIM contrasts offish community structure at each site among sampling occasions. The ratio of mean percentage contribution to the standard deviation is indicated in parentheses. NS indicates non-significant differences between groups (p > 0.005). Species names summarised as the first three letters of the genus and species names.

		Contrast		
		Time 1 vs time 2	Time 1 vs time 3	Time 2 vs time 3
Namoi River	Gunnedah site 1	*C. carpio* (1.13) *N. erebi* (1.22)	NS	*C. carpio* (1.08) *N. erebi* (1.03)
	Gunnedah site 2	*C. carpio* (0.96) *N. erebi* (0.93)	NS	*C. carpio* (0.96) *N. erebi* (1.08)
	Narrabri site 3	*C. carpio* (1.18) *N. erebi* (0.85)	NS	*M. fluviatilis* (1.36) *N. erebi* (1.50)
	Narrabri site 4	*C. carpio* (1.05) *M. fluviatilis* (1.24) *N. erebi* (1.83)	*C. carpio* (1.13) *M. fluviatilis* (1.25) *N. erebi* (1.80)	NS
	Wee Waa site 5	*N. erebi* (2.83)	NS	NS
	Wee Waa site 6	*C. carpio* (1.08) *M. ambigua* (1.66) *M. fluviatilis* (1.10)	*C. carpio* (1.02) *M. fluviatilis* (1.11)	NS
Macquarie River	Wellington site 7			
	Wellington site 8	NS	*C. carpio* (0.95) *P. grandiceps (*0.71) *R. semoni* (0.69)	NS
	Geurie site 9			
	Geurie site 10			
	Dubbo site 11			
	Dubbo site 12	*C. carpio* (0.93) *R. semoni* (1.33)	*C. carpio* (0.92) *R. semoni* (1.38)	-

3.3. Differences in species abundance among sites

The interactions between time and site within river reaches (T x S(Re(Ri)), Table 9 and between time and river reach within rivers (T x Re(Ri)), Table 9) were not significant for the number of species, total abundance or abundance of any individual species except carp. This suggests that, apart from the abundance of carp, differences in the abundance of species between sites within river reaches, or among river reaches within rivers, were relatively constant over time. The interaction between time and rivers (T x Ri, Table 9) was not significant for any variable except the number of species (Table 9), suggesting that the difference in the average number of species between rivers changed between sampling occasions.

There were significant differences in the abundances of four out of ten species (carp, western carp gudgeons, golden perch and flathead gudgeons) between sites within reaches (S(Re(Ri)), Table 9). F-values for the differences between sites within reaches for all these species, except for flathead gudgeons, were larger than the differences among reaches within rivers, suggesting that these species have patchy distributions at a local scale within the Namoi and Macquarie rivers. There were large differences in the abundance of these fish species between sites within some reaches (Table 3, Figure 3b, f, d and g respectively).

Abundances of goldfish and crimson-spotted rainbowfish differed significantly between rivers (Table 9). Bony herring were only present in the Namoi River and the percentage of variance explained by the difference in the abundance of golden perch and flathead gudgeon between rivers was greater than other sources of variation. The total number of goldfish, crimson-spotted rainbowfish, bony herring and golden perch caught was greater in the Namoi River (Table 3, Figure 3c, d and e). Only the abundance of flathead gudgeon was greater in the Macquarie River (Figure 3g). The abundances of Murray cod and Australian smelt were similar between rivers (Table 3).

The number of species, total fish abundance and the abundances of carp, goldfish, bony herring, golden perch and Murray cod differed significantly between sampling occasions (Table 9). The mean number of species recorded, mean total fish abundance and abundance of each of these five fish species were lower on the first sampling occasions compared to the March and May sampling occasions (Figure 4). The abundances of bony herring, golden perch and Murray cod were similar on the March and May sampling occasions. Carp and goldfish were most abundant during May.

Table 9. Significant F values from analyses of deviance for spatial (Ri = rivers, Re = reaches and S = sites) and temporal (T) differences in number of species, total abundance and the abundance of individual species. * indicates $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$.

Source of variation	Degrees of freedom	Variable											
		Number of Species	Total abundance	Carp	Goldfish	Western carp gudgeons	Bony herring †	Crimson-spotted rainbow fish	Golden perch	Murray cod	Australian smelt	Flathead gudgeon	Redfin perch
T	2	15.3***	6.1*	48.2***	20.1***		10.9**		13.4***	14.1***			
R	1	38.1***		30.1***	23.3***	5.6*		23.5***	131.0***			86.2***	13.3***
Re(Ri)	4	27.0***		9.7***					18.3***			41.1***	52.8***
S(Re(Ri))	6	3.9*		28.8***		14.1***			37.7***			39.3***	
T x Ri	2	25.1***											
T x Re(Ri)	8												
T x S(Re(Ri))	12			5.6*									

† - analysis done on Namoi River data only

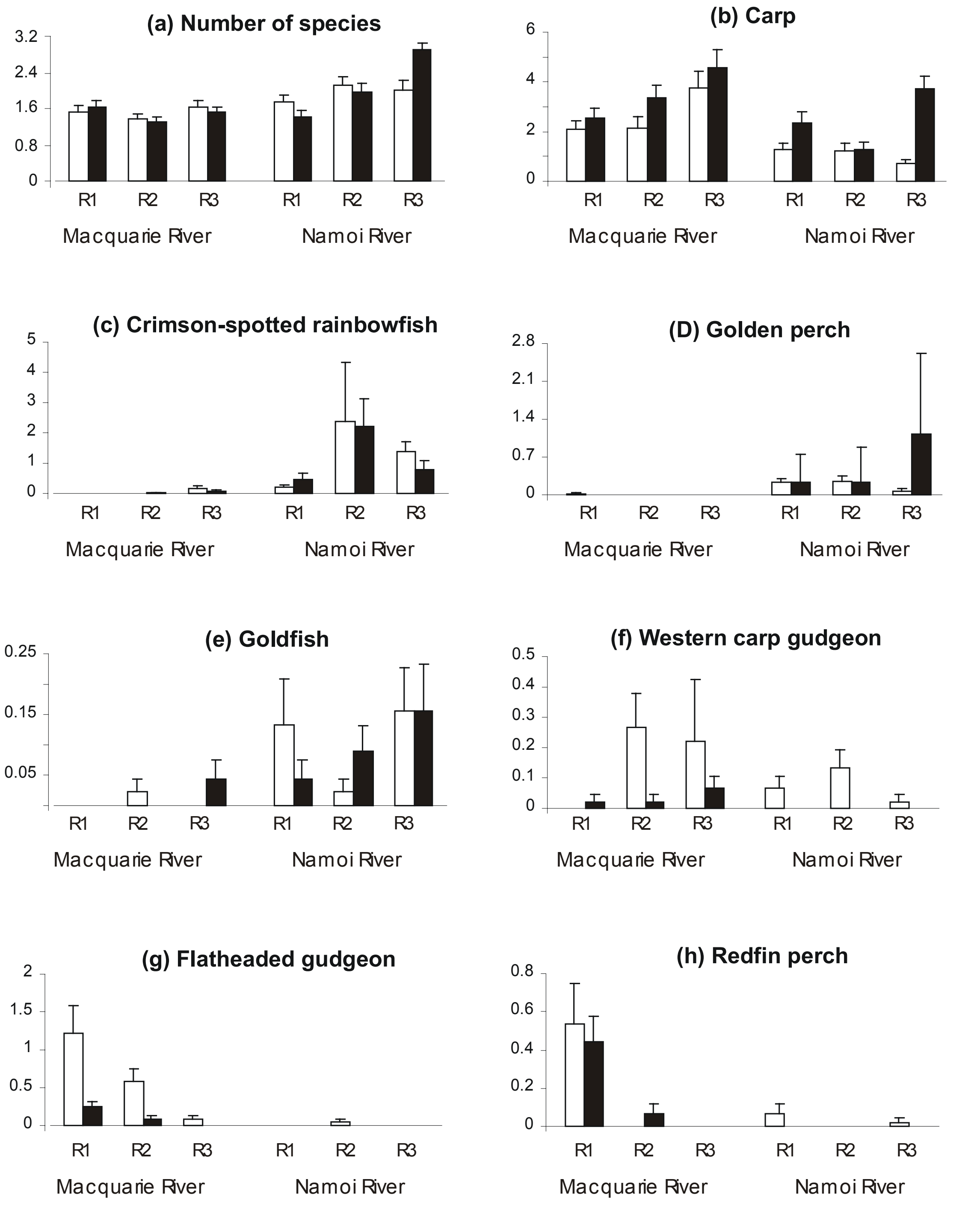

Figure 3. Mean number (+ S.E.) of species (a) and abundance of seven fish species (b to h) per electrofishing shot at each site within each river reach (R1 upstream to R3 downstream). Black and white bars indicate paired sites within each river reach.

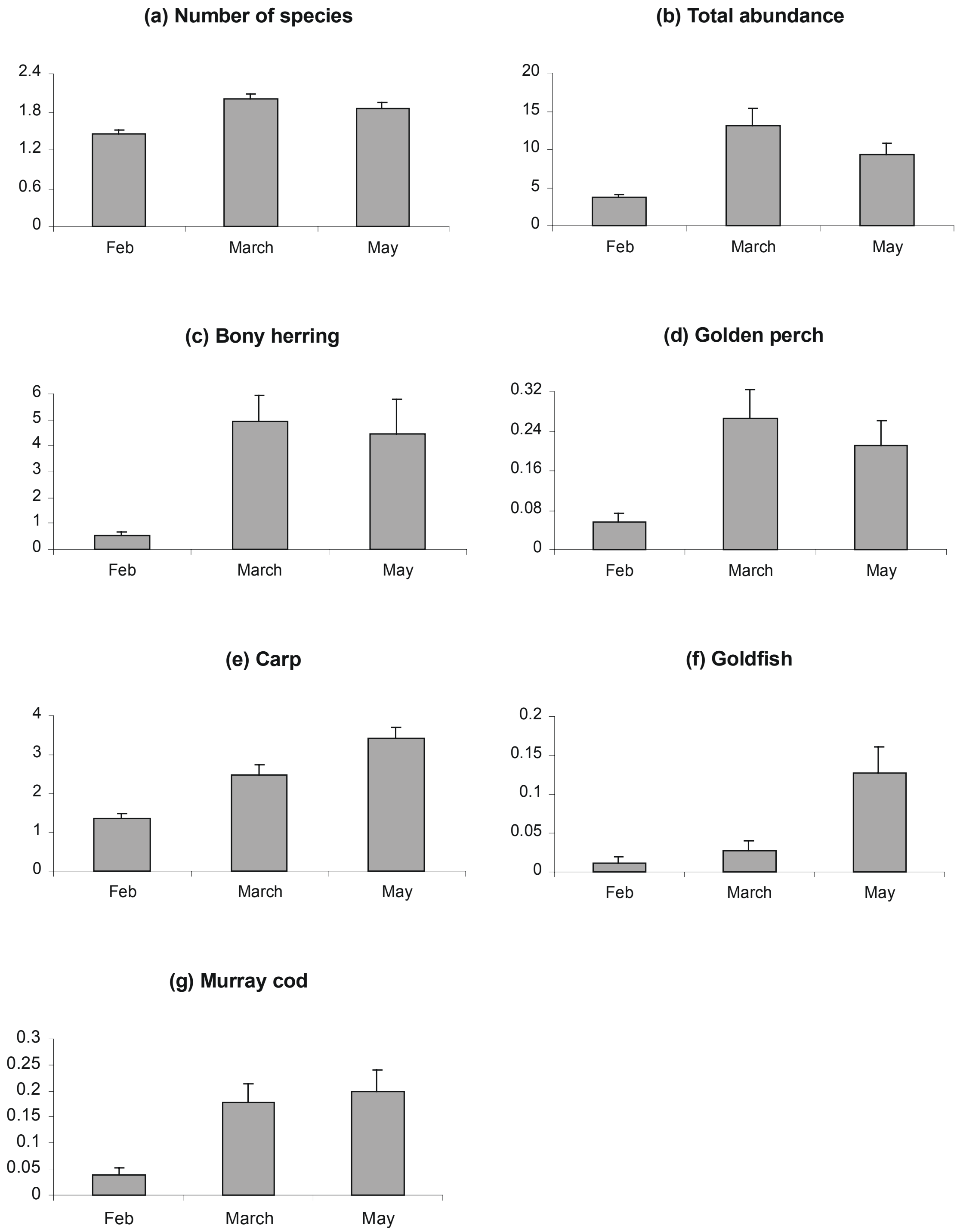

Figure 4. Mean number (+ S.E.) of species (a), total fish abundance (b) and abundance of five fish species (c-g) per electrofishing shot on each sampling occasion from both rivers.

4. DISCUSSION

4.1. Sources of variation in fish communities

We have demonstrated that small-scale spatial variation and short-term temporal variability in fish community structure is significant in the Macquarie and Namoi Rivers. However, larger scale spatial differences between rivers were the largest source of variation in the data. Spatial variation in fish community structure appeared to be similar between sites within reaches and among reaches within rivers. Carp and bony herring were the main species associated with the differences between rivers. However, the abundances of goldfish, western carp gudgeons, crimson-spotted rainbowfish, golden perch, flathead gudgeons and redfin perch also differed between rivers (Figure 4). Consequently, the differences between rivers were mostly larger than the differences among reaches or between sites within reaches. These results are similar to Gehrke and Harris (2000) who demonstrated that the composition of riverine fish communities varied among ecoregions and river types in New South Wales but showed little seasonal or annual variation.

The largest difference among sampling occasions in the present study was between the first and second sampling occasions in the Namoi River and appeared to have resulted from localised differences in the abundances of carp and bony herring. In contrast, there was no consistent pattern in the differences in community structure among other sampling occasions at other sites. This suggests that fish community structure within lowland rivers is relatively constant over one to three month time periods, although there may be short-term variation in the abundances of individual species. The short-term patterns in the abundances of individual species may be associated with different movement patterns. For example, Murray cod undergo a relatively short-distance spawning migration in late winter to early summer but there are differences in their movement patterns between rivers and under different river flow conditions (Koehn and Nicol 1998). In contrast, the same study showed that carp and golden perch are generally more mobile than Murray cod and can show abrupt large-scale movements. In contrast to the temporal changes in the abundances of these larger fish species, the smaller fish species in the present study (flathead gudgeon, western carp gudgeon, Australian smelt and crimson-spotted rainbowfish) did not exhibit any significant temporal changes in abundance.

The interaction between temporal change and spatial variation in fish community structure, although statistically significant, was smaller than the variation between rivers. This suggests that although the fish communities within each river changed between sampling occasions, the underlying differences between rivers were still detectable. Similarly, the differences among reaches within rivers were consistent over time. In contrast, the strongest interaction between temporal and spatial effects occurred at the smallest spatial scale, at the level of individual sites. This means that, although the composition of the fish assemblage at a given site may fluctuate, the magnitude of these changes is unlikely to affect larger scale differences between reaches within rivers or between rivers. These results suggest that sampling at any time within a single season will be sufficient to show spatial differences that occur over large spatial scales, such as comparisons between rivers, between geographical regions, or across the entire Murray-Darling basin.

4.2. Implications for monitoring programs

The results of this study have implications for the design of future monitoring programs. The relatively small to medium-scale spatial variation in fish communities within and among reaches, compared to the large differences between rivers, suggests that a small number of sampling sites may be used to effectively describe the variation between rivers or between reaches within a river.

This recommendation is supported by studies that show that the structure of fish communities in coastal and inland rivers in south-eastern Australia is influenced by environmental factors on small geographic scales, such as habitat structure (Koehn *et al.* 1994) changes in riparian vegetation (Growns *et al.* 1997, Growns *et al.* 2003), sewage pollution (Growns *et al.* 1998) or river regulation (Gehrke *et al.* 1999, Humphries and Lake 2000, Gehrke *et al.* 2001). Therefore, sampling of riverine fish communities should be stratified within river reaches, or geomorphologically distinct river regions. Monitoring programs intended to evaluate changes in fish communities at large spatial scales, such as entire river basins, between regions within a basin or between individual rivers, need only sample at the scale immediately below the level of interest. For example, where the management focus is on differences among rivers, then replicate samples should be drawn from representative reaches within rivers.

The lack of consistent small-scale temporal variability shown during the present study and the limited variation in fish communities between years shown in other studies (Gehrke and Harris 2000) suggests that fish communities in lowland rivers are relatively stable over time. This property of fish communities can be used to advantage when assessing responses of rivers to different management scenarios. Subsequent to our study, two large scale projects (the Integrated Monitoring of Environmental Flows program initiated under the Water Reform Process in NSW and the Sustainable Rivers Audit under development for the Murray Darling Basin) are using fish as a primary indicator of ecological change in river systems.

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