9 The role of the natural environment and human impacts in determining biomass densities of common carp in New South Wales rivers

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Summary

The environmental factors associated with the biomass density (kg site^{-1}) of common carp (*Cyprinus carpio* L.) in rivers of New South Wales were explored. Carp were not found in any of the 20 montane sites. In inland rivers, carp were present in all sites below an altitude of ca. 500 m ASL. In coastal river systems, the distribution of carp was restricted to only six sites in an altitudinal range of 0-60 m ASL within regulated lowland rivers. All inland rivers had higher carp biomass densities than the coastal rivers. Carp biomass densities in the inland rivers were found to increase slightly ($r^2 = 0.18$) with altitude, for altitudes up 500 m ASL. These slightly higher carp biomass densities in the inland rivers were associated with an abundance of riffle habitat and coarse particles in the substratum. This unexpected association was probably the result of upstream migration of adult carp from spawning habitats, and the presence of barriers to fish dispersal including dams and natural river features. The likely spawning habitats from which adult carp migrated were lowland areas (below 200 m ASL) and water storages in mid-altitudes (200-500 m ASL).

Across New South Wales, higher carp biomass densities were associated with variables indicating human impacts, in particular the effects of dams and agriculture. Alteration of flows and water temperatures, physical barriers to fish migration, carp spawning habitat created in artificial lakes, and agricultural effects on water quality are all factors suggested as leading to higher carp biomass densities.

These results suggest that river management focused on carp spawning habitat, migration from these spawning areas, and the effects of agriculture and river regulation would be effective in reducing carp biomass densities, improving water quality and increasing native fish stocks.

INTRODUCTION

Justifications for this study

Most studies of common carp (*Cyprinus carpio* hereafter referred to as carp) and their habitat have considered only the impacts of carp at smaller scales, such as in billabongs or experimental ponds (e.g. papers cited within Taylor *et al.* 1984 and King 1995). These studies provide important information regarding the local effects of carp on water chemistry and freshwater biota, and demonstrate that the impacts of carp are partly dependent on the biomass density (kg ha^{-1}) of carp. However, additional information is required for quantifying and controlling the effects of carp in Australia. Small-scale effects of carp (e.g. increased turbidity) can be obscured by processes occurring at larger spatial scales (e.g. flow regulation or geology) (Hume *et al.* 1983; Wiens 1989). Furthermore, how the environment affects carp distribution and abundance, and ultimately the impact carp can have, has been poorly considered. To partly fill these knowledge gaps, this study describes the distribution and the kilogram-per-site biomass density of carp (carp biomass density) in relation to the physical environment associated with rivers at the catchment scale.

Carp in Australia

Carp in Australia are an alien benthic omnivorous fish species derived from the wild carp of Asia Minor and around the Caspian Sea (Balon 1974). They are widespread in southeastern Australia and can constitute most of the total fish biomass (e.g. in the Murray River, Gehrke *et al.* 1995). There are four strains of carp in Australia. The two strains of most concern to fisheries managers are the Boolara or River carp and the Koi carp (Shearer and Mulley 1978; Harris 1995; Davis 1997). Although the Boolara strain is the most abundant and widespread, the Koi strain is more abundant in some areas such as in Lake Burley Griffin (Australian Capital Territory), Lake Crescent (Tasmania), and the Shoalhaven and Richmond Rivers (New South Wales) (Shearer and Mulley 1978; Harris 1995; Davis 1997). The Prospect strain of carp has a distribution limited to Prospect Reservoir, and the Yanco strain is limited in distribution and has been genetically diluted by the Boolara strain (Shearer and Mulley 1978; Davis 1997). The four strains are not differentiated in this survey.

Environmental factors associated with carp

Although carp have been found in a wide range of habitats, optimal habitat for carp in Australia and overseas is generally considered to be low-altitude, slow-flowing waters, with access to shallow, vegetated habitat for spawning, as would be found in larger rivers or billabongs (e.g. McCrimmon 1968; Panek 1987; Rahel and Hubert 1991; Brown and Coon 1994; Brown 1996; Lyons 1996; McDowall 1996). Carp have often been found in waters that are turbid, with poor water-quality (e.g. McCrimmon 1968; Panek 1987; McDowall 1996). In addition, due to benthic feeding adaptations (Sibbing *et al.* 1986) adult carp may also be more reliant on substrata with fine aggraded particles, such as silt.

High biomass densities (kg ha^{-1}) of carp have been associated with the loss of native fish species, reduction in aquatic macrophyte abundance and deterioration of water quality; in particular an increase in turbidity (Crivelli 1983; Taylor *et al.* 1984; Fletcher *et al.* 1985; Breukelaar *et al.* 1994; Faragher and Harris 1994; Gehrke and Harris 1994; Harris 1995; King 1995; Roberts *et al.* 1995; Robertson *et al.* 1995). The association between carp biomass densities and measures of turbidity and aquatic vegetation abundance would be less significant when measured at catchment scales because larger-scale physical and ecological processes tend to obscure small-scale effects (Wiens 1989). This was demonstrated in a study within the Goulburn River catchment of north-eastern Victoria where background levels of turbidity and flow variation obscured the effects of carp on turbidity and macrophytes (Fletcher *et al.* 1985).

Some of the strongest associations likely to occur at the catchment scale are between carp and human impacts. The broad ecological tolerances of carp suggest that carp populations would thrive relative to native fish populations under human disturbance (McCrimmon 1968; Crivelli 1981; Panek 1987; Arthington *et al.* 1989; Harris 1997). Studies overseas have found that carp can become a much larger component of fish communities after disturbances in flow, damming and alteration of the stream bed (e.g. Whitley 1974 and Sparks and Starret 1975, both cited in Welcomme 1979; Hoyt and Robison 1980; Winston *et al.* 1991). Large dams may be an important component of these effects leading to increase in carp abundance. Large dams in the United States of America have had upstream and downstream effects that lead to major changes in the fish community, and an increase in carp numbers (e.g. Hoyt and Robison 1980; Winston et al. 1991). These local fish community changes due to regulation may reflect larger-scale changes favouring carp. Such large-scale effects were indicated by an Australian study (Gehrke *et al.* 1995) which found that a measure of river regulation (measuring the deviation from natural flows) was positively associated with carp-dominated fish communities. Other effects of human activities within river catchments have been associated with similar changes in fish communities. Agricultural activities have been associated with substantial reductions in flows due to irrigation, chemical enrichment, aggradation of fine sediments and changes in stream morphology (Cadwallader 1978; Rinne 1990; Koehn and O'Connor 1990; Faragher and Harris 1994; Metzeling *et al.* 1995; Brierley *et al.* 1996; Finlayson and Silburn 1996). In Australia, with these types of human impact there has been a corresponding and severe decline in native fish communities (e.g. Cadwallader 1978; Pierce 1988; Arthington *et al.* 1989; Faragher and Harris 1994; Cullen *et al.* 1996). Under these circumstances, carp would also be expected to prosper.

Objectives

This study of carp in New South Wales rivers first describes the differences in carp biomass density across the spatial and temporal scales covered by the NSW Rivers Survey. This determined the spatial scales that were comparable in terms of carp biomass density (e.g. all inland rivers).

To test our predictions regarding environmental conditions and carp, the presence of carp and carp biomass density were related to large-spatial-scale variables (e.g. minimum annual temperatures, catchment area, livestock densities), smaller-spatial-scale habitat description (e.g. conductivity, depth, substrate type) and long-term climatic data. More specifically, we tested whether the following environmental conditions were associated with carp and high carp biomass densities:

1. Low altitude
2. Low velocity flows
3. Large dams
4. High agricultural land use

METHODS

Field collection of data

The statistical design and sampling regime used in the NSW Rivers Survey are described in detail in Chapter 1. However, details especially relevant to this chapter are repeated here. A suite of fish-sampling techniques standardised for major habitat types were used at every site to ensure accurate representation of fish species present. The number of fish of each species was recorded for each site. For each replicate unit of gear used for fish sampling only the first ten fish of any species had their length measured. Habitat characteristics were assessed using estimates that involved a rapid, subjective grading system for features such as flow, depth, width, substrate, vegetation and observer-assessed turbidity (Table 9.1, Table 9.2). Dissolved oxygen, pH, conductivity and temperature were also measured, using a Horiba U-10 water quality meter. The region, river type, season, year, date and times of the use of each gear type were also recorded (Table 9.2).

Preparation of data for analysis

Conversion of data for analyses

Habitat variables using the rapid, subjective grading system were converted to numerical data as shown in Table 9.1. All variables used in analyses, and their abbreviations, are listed in Table 9.2.

Table 9.1 Conversion of class variables to ranked variables for statistical analysis. AFOR refers to the categories Abundant, Frequent, Occasional, Rare and Absent which were used for variables describing stream substratum, terrestrial vegetation, aquatic vegetation, substratum cover and instream habitat Refer to Table 9.2 for details of variable codes.

AFOR variables	**Level (WatLev)**	**Turbidity (OTurb)**	**Relative Flow (RelFlow)**	**Stream Velocity (WatVel)**	**Presence/absence of stream (stream) or channel (channel)**	**Value used in analyses**
Nil		Clear			Nil	0
Rare	Falling or rising	Low	Low	Slow	Present	1
Occasional	Steady	Moderate	Moderate	Moderate		2
Frequent		High	High	Fast		3
Abundant						4

Addition of environmental variables

An additional number of environmental variables in Table 9.2 were manually derived from maps. Latitude and longitude were calculated from 1:100,000 maps or directly from GPS readings, and verified using the New South Wales drainage data from the Land Information Centre's GIS (Department of Land & Water Conservation, Bathurst). Altitude (m ASL, metres above sea level) was derived from Australian Surveying and Land Information Group (AUSLIG) or Central Mapping Authority 1:100,000 maps. Catchment areas were produced by AUSLIG by plotting the New South Wales drainage layer from their GEODATA 250K topographic data and manually calculating catchment areas using a digital planimeter. Other environmental variables were derived from the most recent maps that had graphically summarised information of interest. The average annual 50% rainfall percentiles were derived from Lee and Gaffney (1986), as was rainfall variability:

Variability = ((90 percentile)-(10 percentile)) / (50 percentile)................................**Eqn. 1**

Table 9.2 Environmental variables describing the physical and vegetation characteristics, season, year and location of habitat and long-term climatic data. Potential measures of human impacts are also used. The symbols used for these variables in the analyses are shown in brackets. Variables without units were estimated using a rapid, subjective grading system. Latitude and longitude were converted to a decimal scale. * These variables were only used in Analysis of Variance.

Stream substratum	**Terrestrial vegetation**	**Aquatic vegetation**	**Substratum cover**	**Instream habitat**	**Water quality**
Bedrock (Bedrock)	Native trees (NatTree)	Sedge (Sedge)	Rock (RockCov)	Pool (PoolHab)	Conductivity (µS cm^{-1}, Conduct)
Boulder (Boulder)	Exotic trees (ExoTree)	Littoral vegetation (LittMac)	Timber (TimbCov)	Run (RunHab)	Temperature (°C, WatTemp)
Cobble (Cobble)	Shrubs (Shrubs)	Floating macrophytes (FlotMac)	Plant litter (LittCov)	Riffle (RiffHab)	pH (pH)
Gravel (Gravel)	Grass (Grass)	Submerged macrophytes (SubMac)		Stream (StrmHab)	Dissolved oxygen (mg L^{-1}, DO)
Sand (Sand)		Algae (Algae)		Channel (ChanHab)	Estimated turbidity (OTurb)
Mud/Silt (Mud)				Rapid (RapHab)	
Clay (Clay)				Undercuts (Undercut)	
Unknown (UnkSubs)					

Flow	**Site/catchment dimensions**	**Location**	**Time**	**Long-term climatic data (rainfall/ evaporation)**	**Long-term climatic data (temperatures)**
Movement of water level (WatLev)	Width (m, Width)	Region (Region)*	Year (Year)*	50% rainfall decile (mm, Rainfall)	Average maximum summer temperature (°C, Sum-max)
Estimated relative rate of flow for site (RelFlow)	Depth (m, Depth)	River type (River type)	Season* (Season)	Rainfall variability (mm, RainVar)	Average minimum winter temperature (°C,Win-min)
Estimated water velocity (Velocity)	Sampling length along site (m, Length)	Altitude (m ASL, Altitude)		Evaporation (arbitrary scale, Evapor)	Difference between Sum-max and Win-min above (°C, TempRang)
	Catchment area upstream of site (km^2, CatArea)	Latitude (Latitud)		Seasonal rainfall pattern (RainSeas)	
		Longitude (Longitud)			

	River regulation - effects of upstream water barriers	**River regulation - effects of downstream water barriers**	**Potential agricultural impacts**	**Potential human impacts**	**Stream type (channelization)**
	Height of upstream water barrier (m, UpDamHt)	Height of downstream water barrier (m, DnDamHt)	Stock density (ha/unit-stock, StockDen)	Human Population (people/ha, HumPop)	Presence of stream habitat (Stream)
	Distance of upstream water barrier (km, UpDamDis)	Distance of upstream water barrier (km, DnDamDis)	Agricultural value of land (dollars/ha, AgricVal)		Presence of channel habitat (Channel)

Average maximum summer and minimum winter temperatures (°C) were derived from Anon (1974a). The difference between the average maximum summer temperature and the average minimum winter temperature (°C) was used as a measure of the range of temperature extremes. Evaporation (mm) was derived from Anon (1974b). Seasonal rainfall patterns described in Anon (1973) were used where: 1 = very marked winter precipitation; 2 = marked winter precipitation; 3 = uniform precipitation; 4 = marked summer precipitation and 5 = very marked summer precipitation. To measure the association between live-stock densities and carp biomass density (see Rinne 1990 and Owens *et al.* 1996) grazing intensity (sheep ha^{-1}) was derived from Plumb (1980a). This was calculated for cattle and sheep where 1 unit = 1 sheep ha^{-1}, where one beef beast = eight sheep, and one dairy beast = 12 sheep (equivalents used in Plumb 1980a). Variables were scored from the map as: one = 0.125 or less sheep ha^{-1}; two = 0.125-0.5 sheep ha^{-1}; three = 0.5 - 2 sheep ha^{-1} and four = 2 - 8 sheep ha^{-1}. The intensity of agricultural land use was represented using the value of agricultural land ($ ha^{-1}). This value was derived from Plumb (1982) with: zero = zero - three $ ha^{-1}; three = three - six $ ha^{-1}; six = six - 25 $ ha^{-1}; 25 = 25-50 $ ha^{-1}; 50 = 50-100 $ ha^{-1} and 100 = 100 or more $ ha^{-1}. The general effects of human populations were represented using regional human population density (persons km^{2}) and were derived from Plumb (1980b, p.4). Values were recorded as 1 = 0.03-0.3 persons km^{2}; 2 = 0.3-1.2 persons km^{2}; 3 = 1.2-5 persons km^{2}; 4 = 5-10 persons km^{2} and 5 = 10 or more persons km^{2}. The upstream and downstream effects of dams and weirs were represented by the height of the dam wall (m) and distance (km) of the nearest impoundments upstream and downstream of the site. Dam height represents the distance (m) from the stream substrate to the top of the dam or weir wall.

Calculation of carp biomass density

The conventional kilogram-per-hectare measurement used for carp (e.g. as in Roberts *et al.* 1995) was not appropriate because the sampling did not involve sampling every carp within the site, and secondly because the site was not enclosed. Carp biomass density (kg site^{-1}) was calculated for each site/time (the sample at a particular site, season and year) by:

Number of carp caught (count) x average weight of measured carp (kg)..................**Eqn. 2**

Average weight of measured carp at each site was based on the average of individually calculated fish weights for each site/time combination. Individual calculations of weight were based on fish fork lengths recorded during the NSW Rivers Survey and the length-weight regression relationship of carp collected in the study by Gehrke *et al.* (1995). This was based on 7109 carp individuals collected from the Paroo, Darling, Murrumbidgee and Murray Rivers (r^2 = 0.9881; df = 1, 7107; F = 591874.253; $p < 0.001$). The length-weight equation used was:

ln (weight (g)) = -10.813 + 3.077 ln (fork length (mm))..**Eqn. 3**

Fork length (mm) was converted into ln (weight (g)) using equation 3, and then weight (kg). This value for weight (kg) was then used in equation 2.

Analyses

The relationship between carp biomass density and habitat in New South Wales

For all analyses where a relationship with carp biomass density was tested the following expression was used to transform carp biomass density: (kg site^{-1})

'Carp biomass density' = log10 (carp biomass density (kg site^{-1}) + 2.3)..................**Eqn. 4**

This transformation increased the homogeneity of variance, as assessed by using residual plots, and the normality of the distribution as measured by the Shapiro-Wilks statistic; thereby reducing the type I error rate (SAS Institute 1990). The use of a constant in this transformation was necessary to avoid attempting to calculate a logarithm of zero at sites without carp. The constant represents the average weight of a carp in the New South Rivers Survey (2.293 kg).

Spatial and temporal scales of variation in carp biomass density

To determine the spatial and temporal scales at which most variation in carp biomass density occurs, Analyses of Variance (ANOVA) using a fully crossed and balanced design were performed (SAS Institute 1990). Temporal effects (year and season) were only analysed to check if they should be considered as confounding effects on the spatial distribution of carp biomass density. This was initially done using the factors: region, river class, year and season (see Chapter 1 for explanations of region and river class). Regions found to be not significantly different, using ANOVA and the Tukey-Kramer procedure for unplanned comparisons of means (SAS Institute 1990, hereafter collectively referred to as the Tukey-Kramer test), were pooled and the variance of carp biomass density was tested using factors: river type, year and season.

("Significant" indicates $\alpha = 0.05$ hereafter unless otherwise stated). The Tukey-Kramer test controls the rate of Type I error when comparing many treatments (e.g. river type).

The effects of large dams

The dam wall height and distance from the site of dams, both upstream and downstream, were used for all coastal-river analyses, and with the use of all correlation matrices. However, with stepwise regression and Discriminant Function Analysis (DFA, SAS Institute 1990) applied to the inland rivers data (discussed below), dam height was not used as a variable in the initial analysis, for either upstream or downstream dams, because of missing values (8 and 32 missing values out of 120 respectively).

Environmental factors associated with carp presence

To describe the environmental variables that may discriminate between sites with and without carp, stepwise DFA was used. Stepwise DFA removes autocorrelated variables from the model. Variables with a high F-value, including those removed because of autocorrelation, were used in alternative (non-stepwise) DFA models for predicting carp presence. This DFA model was tested using the cross-validation procedure for DFA in SAS (SAS Institute 1990). This runs the DFA on a subset of the data and validates the model with the rest of the data. Each prediction of a site to a group (either 'carp' or 'no carp'), using the DFA model, was calculated separately thus giving unbiased discrimination. Montane sites (sites higher than 700 m ASL) were not included in these analyses because we considered the processes that exclude carp from montane sites (e.g. migration barriers, high water velocity) could be very different to those excluding carp in lower-altitude sites.

In addition, to explore what factors may physically exclude carp in montane sites, or what makes montane habitat unsuitable for carp (e.g. lack of fine sediment), differences betwen montane and non-montane sites were tested. This involved using ANOVA and the Tukey-Kramer test 21 times so the significance level of $\alpha = 0.05$ was adjusted to $\alpha = 0.0024$ in accordance with the Dunn-Sidak correction suggested in Sokal and Rohlf (1981).

Environmental gradients over which carp biomass density varies

The habitat factors related to carp biomass density within regions, in non-montane sites, were determined using multiple stepwise regression (SAS Institute 1990). A correlation matrix, using Pearson product-moment correlations (SAS Institute 1990), was also used to identify variables significantly ($r \geq 0.3$) correlated with carp biomass density, including those variables removed because of colinearity during stepwise regression. Regions that were not significantly different in carp biomass density in the ANOVA procedures were pooled for analyses (e.g. the

Murray and Darling regions). Outliers in the regressions considered to have a disproportionate effect on the regression line, as assessed using the Cooks D statistic (SAS Institute 1990), were removed. Montane sites were not included in these analyses. As no carp were caught in them (Harris *et al.* 1995) they would have created unnecessary ‘noise’ in the analyses. The change in the average weight of carp and the carp catch along an altitudinal gradient in non-montane inland New South Wales was also tested with linear regression (SAS Institute 1990).

RESULTS

Spatial and temporal scales of variation in carp biomass density

For all of New South Wales, carp biomass density varied significantly among regions, river types and among the region-river type interactions, whereas all other interactions were non-significant (Table 9.3). Similarly, within regions only river types were significant in explaining the variance in carp biomass density (Table 9.4). Carp biomass density was higher in the inland regions compared to the coastal regions (Figure 9.1 and Figure 9.4, Table 9.5). There was no significant difference between the Murray and Darling regions, nor between the North Coast and South Coast regions (Table 9.5). Consequently, subsequent analyses treated the inland and coastal regions separately. The highest carp biomass densities for all of NSW were in mid-altitude sites (200-500 metres ASL) in inland New South Wales (Figure 9.1 and Figure 9.2, Table 9.6). For the inland rivers there were no carp in the montane river types, and no differences between other river types; whereas, for the coastal regions, regulated lowland sites had more carp than slopes sites and unregulated lowland sites. Again, no carp occurred in montane sites (Table 9.5).

Table 9.3 Differences in variance of carp biomass density in New South Wales among different spatial and temporal scales (using ANOVA). The New South Wales model had an r^2 of 0.68 (df = 63, 256; F = 8.59; p<0.001). Variables found to be significant ($\alpha = 0.05$) are shaded. df = degrees of freedom, F = F statistic, SS = sums of squares and P = probability of the difference being significant by chance alone.

Variables tested	**df**	**F**	**S S**	**P**
Region	3	33.6	84.06	0.0001
River type	3	20.6	51.70	0.0001
Region*river type	9	14.7	12.24	0.0001
Season	1	0.0	0.02	0.8838
Region*season	3	0.1	0.19	0.9058

River type*season	3	0.2	0.40	0.7560
Region*river type*season	9	0.4	0.31	0.9699
Year	1	0.3	2.42	0.1214
Region*year	3	0.2	0.42	0.7414
River type*year	3	0.3	0.63	0.5951
Region*river type*year	9	0.8	0.63	0.7675
Season*year	1	0.0	0.23	0.6322
Region*season*year	3	0.4	0.90	0.4435
River type*season*year	3	0.2	0.42	0.7414
Region*river type*season*year	9	0.5	0.40	0.9357

Table 9.4 Differences in variance of carp biomass density in inland, and coastal New South Wales among different spatial and temporal scales (using ANOVA). The inland model had an r^2 of 0.57 (df = 15, 144; F = 12.95; p<0.001). The coastal model had an r^2 of 0.24 (df = 15, 144; F = 3.06; p<0.001). Variables found to be significant ($\alpha = 0.05$) are shaded. Key: as in Table 9.3.

Variables tested	**Inland rivers**				**Coastal rivers**			
	df	F	SS	P	df	F	SS	P
River type	3	30.6	61.36	0.0001	3	3.8	14.45	0.0001
Season	1	0.0	0.02	0.8838	1	0.0	0.00	0.9575
River type*season	3	0.2	0.37	0.7750	3	0.2	0.74	0.5313
Year	1	0.5	2.85	0.0936	1	0.0	0.15	0.7007
River type*year	3	0.6	1.12	0.3438	3	0.0	0.07	0.9755
Season*year	1	0.1	0.46	0.4993	1	0.0	0.01	0.9224
River type*season*year	3	0.4	0.79	0.4988	3	0.0	0.01	0.9984

Table 9.5 Difference in carp biomass density (kg $site^{-1}$) among regions and river types in New South Wales (tested with Tukey-Kramers with ANOVA). The carp biomass densities (kg $site^{-1}$) shown are converted back from the log-transformed form of carp biomass density used in analyses. Regions or river types with the same shading were not significantly (α= 0.05) different. Key: 95% confidence = 95% confidence limits of the mean.

All of New South Wales		**Inland**		**Coastal**	
Regions	Mean carp biomass density (**kg site** $^{-1}$) (95% confidence)	River type	Mean carp biomass density (**kg site** $^{-1}$) (95% confidence)	River type	Mean carp biomass density (**kg site** $^{-1}$) (95% confidence)
Darling	9.40 (7.79 - 11.25)	Regulated lowlands	17.65 (15.27 - 20.36)	Regulated lowlands	3.07 (2.12 - 4.22)

Murray	11.89 (9.81 - 14.33)	Unregulated lowlands	18.21 (15.56 - 21.26)	Unregulated lowlands	0.0 (0.00 - 0.00)
North coast	0.56 (0.32 - 0.82)	Slopes	27.01 (21.05 - 36.79)	Slopes	0.26 (0.07 - 0.46)
South coast	0.69 (0.46 - 0.93)	Montane	0.0 (0.00 - 0.00)	Montane	0.0 (0.00 - 0.00)

Environmental factors associated with carp presence

The coastal carp sites were in the Shoalhaven River near Nowra, with Tallowa Dam upstream; a site on the Woronora River below the Woronora Dam; Mangrove Creek, which is downstream of a large dam; a site on the Nepean River downstream of four large dams; and two Hunter River sites below Glenbawn Dam. For the inland and coastal non-montane river site/times respectively, the number of site/time samples without carp were 6 site/times out of 120 (2 sites out of 30), and 102 site/times out of 120 (24 sites out of 30).

Cross-validation using the most significant variable in the models (see Table 9.6), and excluding montane sites, found inland non-carp sites could be selected with altitude with an error rate of 5.75%. In contrast, coastal non-carp sites could be selected with conductivity, agricultural value of the land or water velocity with error rates of 28.1%, 24.5% and 45.3% respectively (see Table 9.6), or using all three variables with an error rate of 20.6%. Upstream dam height was also tested, as it was significant in the coastal regression model (see below). Coastal carp sites could be selected with an error rate of 19.9% with upstream dam height, and with an error rate of 10.8% with a combination of conductivity, agricultural value of the land and upstream dam height.

The montane streams, which had no carp, had a small width and depth when compared to rivers at other sites. These streams also had large particle sizes dominating the substratum (they were low in mud and clay), little timber cover and an abundance of riffle and rapid habitat (see Table 9.7).

Table 9.6 Environmental variables related to differences between carp and non-carp sites in New South Wales (excluding montane sites) selected using Discriminant Function Analysis. Longitude, conductivity and water level (italicised) were removed from the models because of autocorrelation. Refer to Table 9.2 for an explanation of variable codes.

Inland				**Coastal**			
Variable	**r^2**	**F**	**P**	**Variable**	**r^2**	**F**	**P**
Altitude (m)	0.27	43.3	0.0001	Conduct (μS cm^{-1})	0.31	51.9	0.0001
Win-min	0.22	32.0	0.0001	AgricVal (\$ ha^{-1})	0.12	15.3	0.0002
Longitud	0.22	33.1	0.0001	WatLev	0.07	9.1	0.0032
HumPop	0.13	16.5	0.0001	TempRang (ºC)	0.06	7.2	0.0084
Latitud	0.09	11.8	0.0008	Evapor (mm)	0.10	12.0	0.0008
Longitud	0.01	1.4	0.2323	Longitud	0.11	13.7	0.0003
Rainfall (mm)	0.07	8.9	0.0035	RainSeas	0.08	10.3	0.0017

DnDamDis (km)	0.07	8.5	0.0043	*WatLev*	0.01	0.7	0.4227
				Latitud	0.05	5.6	0.0199
				Conduct(μ*S cm*$^{-1}$)	0.03	3.2	0.0774
				StockDen (unit-stock ha^{-1})	0.04	5.2	0.0244

Environmental gradients over which carp biomass density varies

Site altitude was the variable most strongly correlated with carp biomass densities in the inland regions (stepwise regression and correlation table, Table 9.8 and Table 9.9). The regression model excluded observations with no carp as these site values - all of which are above 500 m ASL - each had a Cook's D value of 0.038. These values had a disproportionate effect on the regression line, as carp biomass density was progressively higher with altitude up to about 500 m, beyond which there was only one site with carp (at 600 m, Figure 9.1 and Figure 9.2). The change in carp biomass density along this altitudinal gradient can be explained by larger average carp weights ($r^2 = 0.20$; df = 1, 111; F = 27.93; $p<0.001$) and not a larger carp catch ($r^2 = 0.001$; df = 1, 111; F = 0.13; $p>0.05$) with higher altitudes in non-montane sites up to 500 m ASL (Figure 9.3). The height of downstream dams was the next most correlated variable with carp biomass density (Table 9.8, Figure 9.2). The highest carp biomass densities were in mid-altitude sites above dams or weirs (Table 9.10). High carp biomass density sites also had more riffle habitat, and had a substratum with more coarse particles (boulders, gravel and rocks) but fewer fine particles such as clay. These habitats also had smaller catchment areas upstream and lower average winter minimum temperatures, lower evaporation and higher rainfall (Table 9.9).

Table 9.7 Environmental factors describing the physical habitat of montane sites versus non-montane sites. Shaded variables are those significantly different at α =0.0024 (which corrects for the increased type I error rate with multiple tests). NS = not significantly different at α =0.05.

Variable	**Mean (95% confidence)**	
	Non-montane sites	**Montane sites**
Boulder	NS	
Cobble	NS	
Bedrock	1.25 (1.07 - 1.43)	1.81 (1.45 - 2.17)
Gravel	1.60 (1.40 - 1.80)	2.13 (1.81 - 2.45)
Sand	1.96 (1.76 - 2.16)	2.36 (2.04 - 2.68)
Mud	2.30 (2.10 - 2.50)	1.68 (1.34 - 2.02)
Clay	1.05 (0.85 - 1.25)	0.30 (0.08 - 0.52)
RockCov	1.89 (1.69 - 2.09)	2.38 (2.06 - 2.70)
TimbCov	2.72 (2.60 - 2.84)	1.65 (1.41 - 1.89)
PlantLitt	NS	
Undercut	1.60 (1.46 - 1.74)	2.03 (1.79 - 2.27)
RunHab	0.97 (0.79 - 1.15)	1.51 (1.17 - 1.85)
RiffHab	1.23 (1.05 - 1.41)	1.85 (1.59 - 2.11)
RapHab	0.18 (0.10 - 0.26)	0.75 (0.47 - 1.03)
PoolHab	NS	
StrmHab	NS	

ChanHab	NS	
Width (m)	26.40 (24.40 - 28.40)	8.19 (6.47 - 9.91)
Depth (m)	1.59 (1.45 - 1.73)	1.01 (0.87 - 1.15)

In the coastal rivers carp biomass density was most correlated with conductivity (Table 9.9 and Table 9.11). Catchment area, height of upstream dams, distance to upstream dams and turbidity were all also positively correlated with carp biomass density (Table 9.9). All coastal sites where carp were caught were within 0 to 60 m ASL (Figure 9.4).

Table 9.8 Environmental variables that enable prediction of carp biomass density in the inland rivers using multiple stepwise regression excluding sites at which no carp were caught. The regression model had an r^2 of 0.41 (df = 5, 107; F = 18.47; p<0.001) . The +/- symbols on the partial r^2 indicate that carp biomass density was either higher (+) or lower (-) with high values of the environmental variable (all partials were positive). Refer to Table 9.2 for an explanation of variable codes.

Environmental variable	**Partial r^2**	**F**	**P**
Altitud (m)	0.18	23.6	0.0001
Sedge	-0.07	10.1	0.0019
ExoTree	-0.06	9.3	0.0029
Evapor (mm)	-0.05	8.9	0.0034
WatLev	0.05	9.6	0.0025

Table 9.9 Environmental variables correlated with carp biomass density (kg site $^{-1}$) in inland and coastal rivers. Only variables with an r greater than or equal to 0.3, and significant at $\alpha = 0.05$ are shown. The +/- symbols on the r indicate that carp biomass density was either higher (+) or lower (-) with high values of the environmental variable. Refer to Table 9.2 for an explanation of variable codes.

Inland		**Coastal**	
Environmental variable	**r**	**Environmental variable**	**r**
Altitude (m)	0.42	Conduct (µS cm^{-1})	0.70
DnDamHt (m)	0.39	CatArea (km^2)	0.52
Win-min	-0.36	UpDamHt (m)	0.49
RocCov	0.35	UpDamDis (km)	0.36
Evapor (mm)	-0.35	Turb	0.35
Gravel	0.31	DnDamHt (m)	-0.33
RiffHab	0.31		
Rainfall (mm)	0.31		
Boulder	0.30		
Clay	-0.30		
CatArea (km^2)	-0.30		

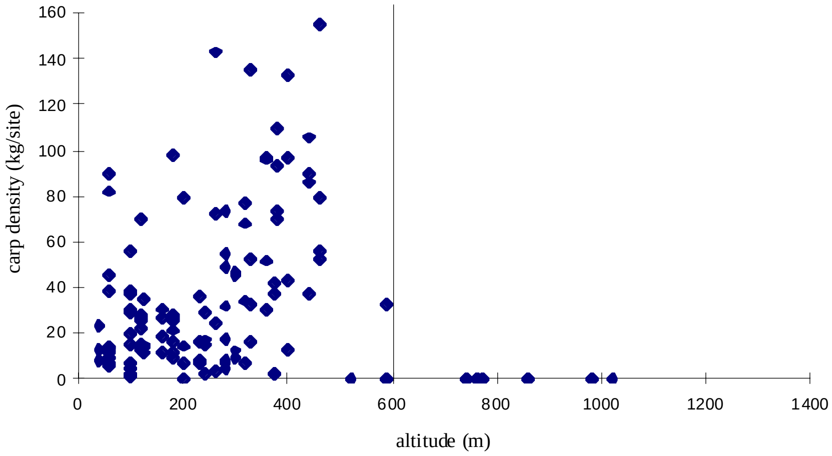

Figure 9.1 Carp biomass density (kg site^{-1}) in relation to altitude for all sites in inland New South Wales. A possible threshold, possibly representing environmental conditions unsuitable for carp, is shown starting at 600 m.

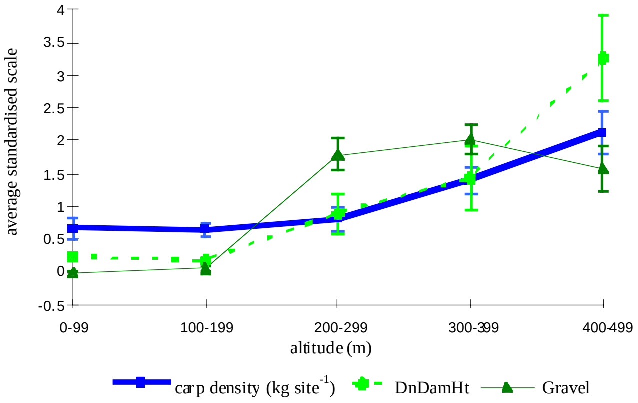

Figure 9.2 Means of carp biomass density (kg site^{-1}), downstream dam height (m, DnDamHt) and abundance of gravel (Gravel) in the substratum of the inland rivers at different categories of altitude in sites where carp were caught. Means of variables for each altitude category were divided by the overall mean for that variable so relative trends could be illustrated. Error bars indicate 95% confidence limits of the means.

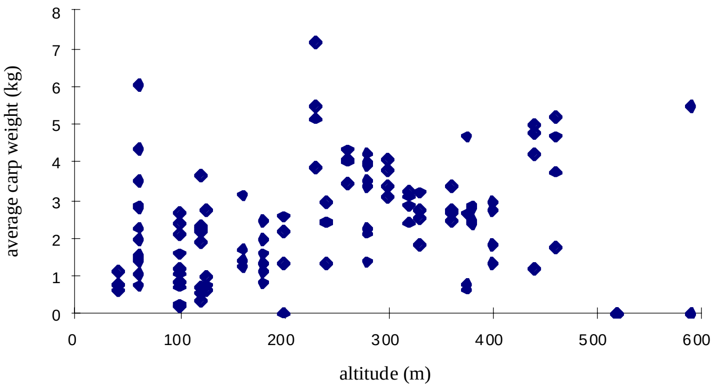

Figure 9.3 Change in the average weight of carp (kg, calculated from lengths) with altitude for non-montane rivers in inland New South Wales.

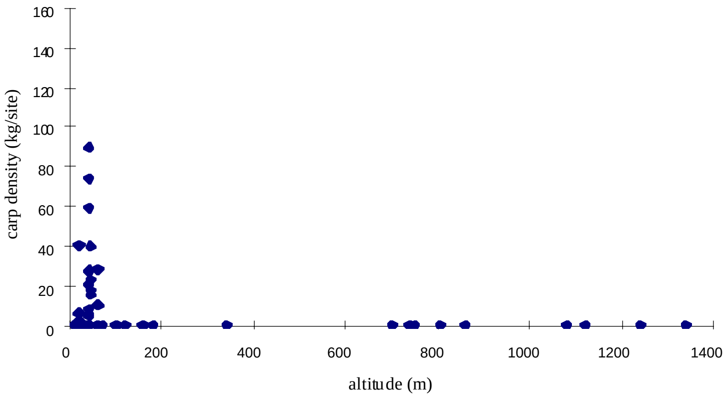

Figure 9.4 Carp biomass density (kg site^{-1}) in relation to altitude for all sites in coastal New South Wales.

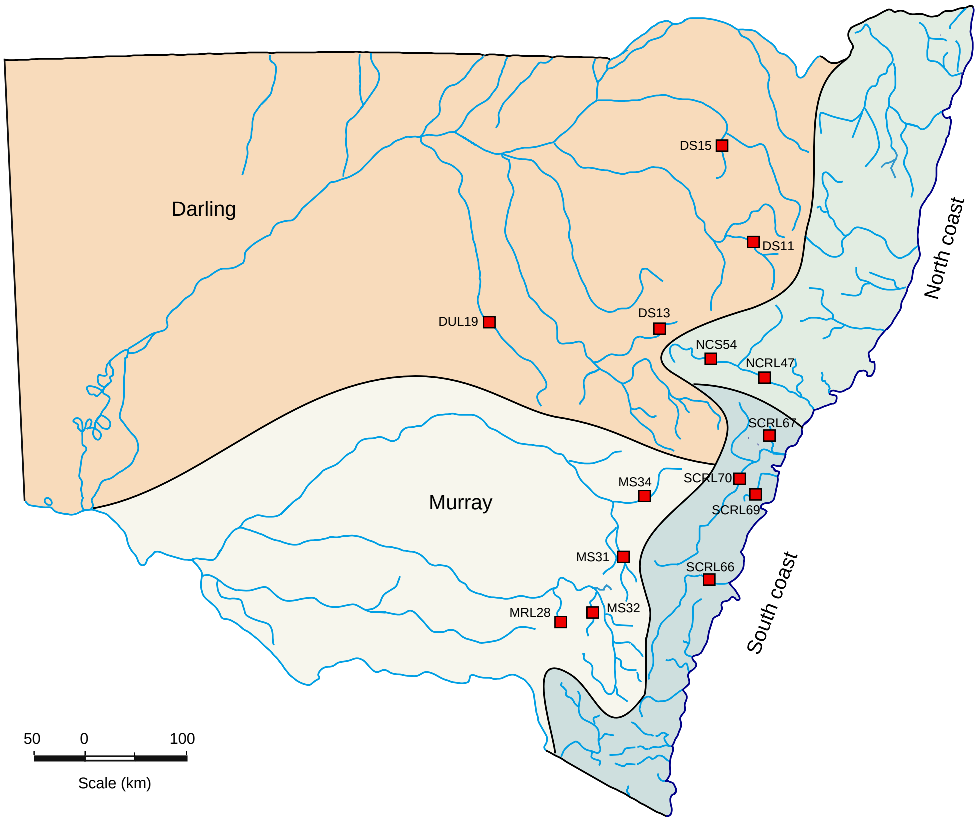

Figure 9.5 The NSW Rivers Survey sites where the highest carp biomass densities (kg site^{-1}) were recorded in New South Wales. The coastal sites marked represent the only sites where carp were found. The inland sites marked represent the eight sites (out of 40) which had carp densities above 90 kg site^{-1}.

Table 9.10 The eight inland sites (out of 40) that had carp densities above 90 kg site^{-1} and the wall height (m) and distance (km) of the closest upstream and downstream dams. Each site was sampled four times so a biomass density greater than 90 kg site-1 could occur more than once. '?' indicates that the value was unknown.

Site code	Carp biomass density (kg site $^{-1}$)	River	Dam upstream	Distance from site (km)	Wall height (m)	Dam downstream	Distance from site (km)	Wall height (m)
MS31	155.3	Lachlan	None			Wyangala	95	82
MRL28	142.7	Tumut	Blowering	20	30	Berembed weir	500	3
DS11	135.6	Peel	Keepit	18	55	Paradise weir	32	?
DS13	96.7/132.4	Talbragar	None			Narromine weir	150	4
MS32	109.4/93.6	Goodradigbee	None			Burrinjuck	25	80
DUL19	97.7	Bogan	None			Nyngan Weir	10	3
DS15	96.0/96.5	Horton	None			Tareelaroi	115	?
MS34	105.5	Abercrombie	None			Wyangala	53	82

Table 9.11 Environmental variables that enable prediction of carp biomass density in the coastal rivers (excluding montane sites) using multiple stepwise regression. The regression model had an r^2 of 0.74 (df = 9, 110; F = 34.4; p<0.001) . The +/- symbols on the partial r^2 indicate that carp biomass density was either higher (+) or lower (-) with high values of the environmental variable (all partials were positive). Agricultural value of the land (italicised) was removed from the model because of autocorrelation. Refer to Table 9.2 for an explanation of variable codes.

Environmental variable	**Partial r^2**	**F**	**P**
Conduct (µS cm^{-1})	0.49	113.6	0.0001
UpDamHt (m)	0.11	30.9	0.0001
CatArea (km^2)	0.03	10.1	0.0019
AgricVal ($ ha^{-1})	0.03	8.7	0.0039
DnDamHt (m)	0.02	6.6	0.0113
DnDamDis (km)	-0.02	6.6	0.0113
AgricVal ($ ha^{-1})	0.01	3.0	0.0841
Algae	-0.02	7.6	0.0068
UpDamDis (km)	-0.01	4.5	0.0357
pH	-0.01	5.2	0.0247
Depth (m)	-0.01	4.1	0.0448

DISCUSSION

General patterns in carp distribution and density

Spatial scales of variation in carp biomass density

At the largest scale in this study - the State of New South Wales as a whole - the most obvious patterns were that the inland rivers had many more sites with carp and had much higher carp biomass densities. Carp were present at all sites below 500 m ASL in the inland rivers, and were found in sites up to 600 m ASL (Figure 9.1). In contrast, only six of the 40 coastal sites had carp and these were all found within 0 to 60 m ASL (Figure 9.4).

How big were the carp biomass densities?

A very coarse estimate of what the carp biomass densities may indicate in terms of kilograms per hectare can be derived from the calibration experiment on the Bogan River (Chapter 3). The first day's sampling, equivalent to one river survey sample, yielded 30.1 kg site^{-1}. The density estimate from a subsequent five days' sampling the same site is 147 kg site^{-1}, equivalent to 609.5 kg ha^{-1}; (values from Dennis Reid, NSW Fisheries Research Institute). It is very unlikely that a simple linear relationship to generalise between the biomass density of the carp caught and the actual biomass density of carp can be accurately used because of variation in catch efficiency due to factors such as fish size, habitat variation, etc. At least for the Bogan River site, catch efficiency (i.e. the ratio of Rivers Survey biomass density, 30.1 kg site^{-1}, to total estimated biomass density, 609.5 kg ha^{-1}) was approximately 1:20. Assuming there was a similar catch efficiency in the Lachlan River site (Table 9.10) where the highest carp biomass density was recorded during the NSW Rivers Survey, the carp were at a biomass density of about 3144 kg ha^{-1}.

Environmental factors associated with carp presence and carp biomass densities

The importance of slow-flowing habitat

One of the principal findings of this study is that carp are strongly associated with the lower altitudes of New South Wales (Figure 9.1 and Figure 9.4). Similarly, large spatial scale research on fish communities in North America has found carp to predominantly occupy lower altitudes (e.g. Rahel and Hubert 1991; Brown and Coon 1994; Lyons 1996). Comparisons between numerous general observations or research results across different altitudes also suggest that carp predominantly occupy low altitudes in Australia (Brown 1996; McDowall 1996) and in North America (McCrimmon 1968; Panek 1987). Lowland sites provide breeding habitat in the form of floodplains, backwaters, shallow river edges and billabongs, all of which are more prevalent in low altitude sites (Warner 1987; Schumm 1988). These lowland habitats would also be subject to fewer periodic or episodic high-velocity flows. The high biomass densities of carp in the inland rivers can be partly explained by the greater availability of lowland habitat that provides suitable slow-flowing spawning grounds and nursery areas for carp. For most of their length the inland rivers are dominated by low-gradient, low-velocity habitat at low altitudes (Warner 1987). In contrast, the coastal rivers have very short sections with low gradients (Warner 1987).

The absence of carp from the 20 montane sites sampled may have been due to the lack of access to slow-flowing habitat. The montane streams are characterised by small channels, high gradients, frequent rapids and riffles, large substrate particles and few deep areas (Table 9.7). They are erosive zones rather than the depositional floodplain habitats favoured by carp. These streams would have little habitat in which carp could spawn or take refuge from high flows. The combination of these unsuitable conditions and the presence of barriers, both natural (waterfalls) and artificial (dams and weirs), blocking upstream dispersal from the original lower-Murray source of Boolara carp in the inland rivers (Davis 1977) would have excluded carp from many montane sites.

In spite of the importance of low-velocity flows to carp spawning, conditions indicating low energy flows were not consistently associated with high carp biomass densities. The highest carp biomass densities were found in association with conditions indicating high-energy flows (coarse substrate) in mid-altitude sites in the inland rivers, and yet carp in the coastal rivers were found in association with high conductivity and low altitudes which suggest low-energy flows (Table 9.9 and Table 9.11). Conductivity is a coarse measure of chemical richness (Welcomme 1979), and therefore can be higher at low flows because salts leaching into the stream from the water table become more concentrated (Lawrence *et al.* 1981; Metzeling *et al.* 1995). Velocity was not a significant variable (Table 9.2, Table 9.8 - Table 9.11) possibly because critical high flows detrimental to carp were poorly represented over time, as only four measurements were taken per site, two during a drought, and field sampling was scheduled to avoid floods. Furthermore, within the lowland reaches of both the inland and coastal rivers, breeding sites of carp would have largely been in the slow-flowing backwaters and billabongs, which were not sampled. However, these limitations in sampling do not explain the conflicting results between the coastal and inland rivers. These conflicting results could be expected if adults from self-sustaining carp populations were able to migrate into high-altitude, high-energy flow habitat. For the inland rivers the breeding populations of carp may have been within the lower altitudes (below 200 m ASL) or in downstream water storages (Table 9.10) Low carp recruitment at high altitudes was indicated by the small proportion of fish less than 1kg above an altitude of 200 m ASL (Figure 9.3), suggesting also that the dense carp populations found in mid-altitude sites consist of adult fish recruiting from downstream reaches and migrating upstream. Carp length-frequency distributions for the Darling River, Bogan River and Little River **(**Chapter 2**)** also show clear increases in average size with increasing altitude. The higher altitude populations would have resulted from the strong upstream migration that has been documented for adult carp (Mallen-Cooper *et al.* 1995). These results indicate that viable high biomass density carp populations of high biomass density do not require the conditions associated with low-energy flows and fine substrata if they are maintained by migration from downstream breeding populations.

Human impacts and carp

The human impact most clearly indicated as an effect on carp in this study was flow regulation. The heights of dam (or weir) walls in New South Wales, upstream of coastal sites, and downstream of inland sites, were positively correlated with carp biomass densities (Table 9.8, Table 9.9, Table 9.11, Figure 9.2). In addition, carp were only found in regulated lowland rivers in the coastal region (Figure 9.5). Large larger dams usually result in greatly altered flow variability and, for sites downstream of most dams, summer water temperatures are suppressed (Cadwallader 1978; Faragher and Harris 1984). Such changes in flow and temperature are suitable for adult carp but not for native fish (Harris 1997; Gehrke *et al.* 1995, Chapter 4). The direction (upstream or downstream) of the carp sites relative to these dams reflected the location of higher carp biomass densities. Large-biomass populations were in higher altitudes (200-500 m ASL) in the inland rivers both upstream and downstream of large dams (Table 9.10) but only in the lower altitudes of the coast. The positive correlation between coastal carp biomass densities and distance from upstream dams (Table 9.9) is likely to be an artefact of natural barriers to upstream migration of carp, and associated with the scarcity of regulated reaches in coastal lowland rivers and their invariable occurrence near sea level.

This association between large dams and carp was more evident in the inland rivers, probably reflecting a greater impact. As well as having more habitat area which supports carp, the flows of major inland rivers are also more intensely modified to provide water for irrigation, as opposed to the coastal dams which are mainly for municipal water supply (Chapter 7). These results also reflected the association between fish communities dominated by carp and the more-regulated inland New South Wales rivers found by Gehrke *et al.* (1995). In the inland rivers, dams have prevented upstream migration of native fish, thereby affecting fish-community composition in the mid-altitudes (Mallen-Cooper *et al.* 1995; Harris and Mallen-Cooper 1994). Large carp biomass densities would have resulted from carp travelling upstream and congregating beneath dams such as Keepit Dam and Blowering Dam (Table 9.10). The passage of migrating carp may also have been blocked by natural barriers such as waterfalls. Inland rivers upstream of many dams are also suitable for carp (e.g. sites in Table 9.10). Upstream of dams, where the largest carp biomass densities occurred (Figure 9.2), abundant carp populations breeding in water storages may also have affected upstream fish communities. Dam construction in the United States of America led to increases in carp numbers in the storages of these dams (Hoyt and Robison 1980; Winston *et al.* 1991). These American carp populations are said to proliferate in impoundments and then move upstream in large numbers (Winston *et al.* 1991). Artificial lakes such as Lake Burley Griffin in the Australian Capital Territory that have a high proportion of carp in the fish catch (Lintermans 1996) may also supplement carp biomass densities in inflowing rivers by upstream migration.

The relative importance of natural effects and human impacts is difficult to discern for the coastal rivers, as carp populations, conditions indicating low-energy flows (low altitude and higher conductivity), rivers with large upstream dams, and greater agricultural use were all found along a narrow coastal strip (Table 9.9, Table 9.11). The more important human impacts are also not clear, In the six coastal sites in which carp were present the agricultural value of land was high and the upstream dams were large. The high conductivities also give some indication of water quality in coastal carp habitats. These rivers could be chemically enriched by reduced or naturally low flows which can lead to a greater mixing of salts with the water table (Lawrence et al. 1981; Metzeling et al. 1995). High conductivity could also indicate increased input of sediments and dissolved solids from catchment modification associated with agriculture. A greater chemical richness could also result from other human activities. For example, nutrient loading from human treated sewage affects the Hawkesbury-Nepean River and has caused a marked change in the fish community and increased carp abundance (Pollard et al. 1994).

It is possible that flow regulation and agriculture played a more equal role in affecting carp biomass densities than this study indicates. The association between areas of high agricultural value and high carp biomass densities may also have been found in the inland rivers if adult carp were unable to migrate upstream from spawning sites. Agricultural land use and the resulting ecological effects have been often been documented for southeastern Australia (Cadwallader 1978; Koehn and O'Connor 1990; Faragher and Harris 1994; Metzeling *et al*. 1995; Brierley *et al*. 1996; Finlayson and Silburn 1996; Ogden 1996). These disturbances generally lead to a decline in native species and an increase in alien species such as carp (Harris 1997; Arthington *et al*. 1989).

CONCLUSION

This study indicates that carp were suited by conditions that existed before European settlement, but also that flow regulation and activities associated with agricultural land use lead to higher carp biomass densities. The association with flow regulation was more evident in the inland rivers, where carp are more widespread. The modification of water temperatures and flow variability by dams would have reduced the size of native fish populations and increased the abundance of carp. Carp populations breeding in water storages behind, and also in lowland habitats (less than 200 m ASL) probably maintain some inland carp populations at higher altitudes (200-500 m ASL) through the upstream migration of adult carp. Barriers to fish migration, dams and natural barriers, would have blocked these upstream migrations and thereby created a concentration of carp biomass densities in mid-altitude sites. These high-biomass density populations were also associated with conditions indicating high-energy flows such as coarse substrate, suggesting that carp populations can be maintained in sub-optimal habitat through adult migration. For the coastal rivers the relative importance of different human impacts on carp biomass density was difficult to discern. Carp populations, conditions indicating low-energy flows, river reaches with large upstream dams and land of greater agricultural value were all found along a narrow coastal strip. The implications of these results are that river management focused on carp spawning sites, carp migration, the effects of agriculture, and river regulation would be effective in reducing carp biomass densities, improving water quality and increasing native fish stocks.

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10 Performance of sampling-gear types in the New South Wales Rivers Survey

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Summary

Better knowledge of sampling-gear performance is needed to improve the design and benefit/cost of freshwater fish surveys. Aspects needing clarification include ability to sample representatively from the full range of fish species and sizes; capacity to collect an abundant sample quickly; cost, and ability to sample non-destructively. Five fish-sampling methods were used during the NSW Rivers Survey: boat electrofishing, back-pack electrofishing, fyke netting, panel netting and Gee trapping. The sampling regime was varied to suit river type (montane, slopes, and lowland) and a different suite of gear was used in each river type.

Of the gear used, boat electrofishing captured the greatest number of fish (11,255). Boat electrofishing also captured 50 of the 55 species sampled during the survey. The six missing species were all classified as ‘rare’ (<1% of total regional sample) and four were predominantly estuarine. The number of species (and number of fish) captured by the other methods were: back-pack electrofishing in pools, 13 spp. (724), back-pack electrofishing in riffles, 29 spp. (2,324), fyke netting, 27 spp. (760), Gee trapping, 30 spp. (8,936), and panel netting, 27 spp. (3,325). Electrofishing with both back-pack and boat units captured the majority of the fish by number in all river types and regions.

A comparison of panel-net catches with those from the boat electrofisher, *FRV Electricus*, at sites where turbidity was estimated showed that the catch by boat electrofisher at high turbidity was not significantly different from those at lower turbidities. The most effective method for collecting riverine fish to discern the effects of disturbance on a community are those which collect the most species, as the chance of capturing species which are sensitive to the change are increased. Electrofishing has benefit/cost advantages over passive gear types, it is rapid, relatively less selective of size and species, and can be applied among threatened species, so it is the method of choice for sampling most south-eastern Australian fish communities.

INTRODUCTION

Five different types of gear were chosen for fish sampling in the NSW Rivers Survey (Chapter 1). This broad range of equipment was needed to ensure that the catch represented the full range of fish species, sizes and habitat preferences at each site. The broad selection also reflects the lack of published knowledge on fishing-gear performance in the sampling of Australian freshwater species, with only the work of Growns *et al.* (1996) showing better species and size representation, as well as greater cost-effectiveness, of electrofishing compared to gill-netting.

This section of the report addresses the question of fishing-gear performance and efficiency in terms of the number and diversity (in terms of size and habitat preferences) of species captured by various gear types. Better knowledge on the performance of freshwater fish-sampling gear is needed for several reasons. Fish communities provide valuable indicators of river health (Chapter 6), but good data on the costs and efficiencies of sampling-gear types are needed for evaluating efficiency. Since most species are threatened or in decline, there is a need for knowledge on the risks to fish of the various gear types. Most immediately, it is likely that gear-performance data can guide the streamlining of fish-sampling procedures. In particular, electrofishing is generally a rapid and efficient technique (Reynolds 1983), and can be applied effectively in daylight, whereas the passive netting and trapping methods demand more time and are often less effective in daylight, necessitating fieldwork outside normal working hours. Thus, if the sampling performance of electrofishing compares well with the passive methods, substantial benefit/cost improvements are available.

METHODS

Fish sampling methods used in the survey were boat electrofishing, back-pack electrofishing, fyke nets, panel nets and Gee traps (Chapter 1). The sampling regime was modified to suit each of the main river types and is summarised in Table 1.1, Chapter 1.

Boat Electrofishing

Two 5 m electrofishing boats, *FRV Electricus* and *FRV AC/DC*, were used in the survey. In each boat an on-board petrol-powered 7.5KW Smith-Root generator produces an electric current which passes to a rectifier unit which produces a pulsed DC waveform, and an electric field is produced in the water through large electrodes (Cowx 1990; Cowx and Lamarque 1990). Output variable settings included; four voltage settings, 170, 340, 500, or 1000 volts; two pulse settings, 60 pulses per second or 120 pps; with a duty cycle range from 10%-100%. Amperage ranged from two amps up to 25 amps depending on water conductivity and output settings decided on site to maximise catch efficiency. Fish of all species and sizes are susceptible to the field, being attracted near the electrodes then immobilised, but there are variations in sensitivity (Growns *et al.* 1996; Reynolds 1983).

The sampling procedure involved electrofishing navigable habitats within the river channel, with one operator controlling the boat and two fish catchers. Electrofishing was carried out in standardised two-minute replicates or "shots" during which immobilised fish were netted from the river and placed in a live-well in the boat to recover before examination and release. Wherever possible 10 shots were made at each site. In a few cases where the habitat area was too small, fewer shots were made, and the catch data were subsequently adjusted to account for this. This technique is generally considered most efficient in areas of low turbidity (so fish catchers can see the fish more easily) and mid-range conductivity (100-500 μ S cm^{-1}) (Cowx and Lamarque 1990).

Back-pack electrofishing

Back-pack electrofishing uses the same principles as boat electrofishing, but on a smaller scale. This method is used in shallow pools and riffles (to a maximum depth of operator hip height) that are unsuitable for boating. Electricity is provided from batteries then transferred into the water, as a pulsed DC waveform, via a back-pack unit carried by the operator, with portable electrodes. The electrofishing units used were Smith-Root backpack models mark 12-A, operating from 24 volts and capable of producing 100-1000 volts output which was varied depending on the water conductivity. Immobilised fish are dip-netted from the water by an assistant, and placed in a bucket of water for recovery. The fish were identified and examined before being returned to the water. Fishing effort was standardised by fishing set bank lengths of riffle and pool stream habitats (Chapter 1).

Fyke nets

Fyke nets are a medium-sized trap which consist of a 6-metres-long wing or wall of net to direct fish into the body of the trap itself, which is fitted with three internal funnels which restrict the escape of fish. Mesh size was 30 mm (stretched mesh) and the width of the mouth was 300 mm. The fyke nets were set obliquely to the stream bank, and facing downstream to catch fish moving against the direction of flow. Trapped fish were retained in the 'cod-end' at the base of the trap until being examined and released. A float was placed in the cod-end to allow air-breathing, non-target animals such as platypus and turtles to survive if caught.

Gee traps

Gee traps are small (350 mm long, 200 mm diameter) oval funnel traps of galvanised wire mesh (3 mm square mesh) with a funnel entrance in each end tapering to a 15 mm opening. Traps were set unbaited on the stream bed and anchored to the bank or a snag. Nine traps were used to sample a variety of habitats at each site. Gee traps target the small-fish community (ie.<150 mm length) and, like fyke nets, are a non-destructive method of sampling.

Panel nets

Panel nets consist of a series of short gill-net panels made of monofilament line joined to form a wall of diamond-shaped meshes which entangle fish. Panel nets used in the survey consist of three sections of different mesh (38 mm, 67 mm, and 100 mm, stretched mesh size), with a 5m length of hung net for each mesh size. The panels were arranged in random sequence to avoid any location bias. Nets had a drop of 2 m and were rigged to sink. Panel nets are most efficient at sampling large and medium-sized fish in deep and/or turbid water, and in this way they may complement the catches from boat electrofishing (Growns *et al.* 1996).

Subsampling procedure

Where there were large catches of a species, subsampling was used to limit the numbers of fish to be measured in length and examined for abnormalities. For any single unit of gear (ie. a particular trap or net, electrofishing shot, etc.) only ten fish, of each species caught, selected at random, were measured. The nine Gee traps were treated as a single unit of gear, with their catches being combined. Ten fish of each species from the total Gee trap catch were measured and examined.

All fish caught in all gear units were counted and identified to species in the field, or occasionally preserved for later identification in the laboratory when field identification was difficult. Total numbers of fish referred to in this section are for actual captures by the gear concerned.

RESULTS

Fish abundance by gear type

Of the gear used, the boat electrofishers captured more fish (41.2%) than any other single gear tpe used during the survey without regard to river type or region (Figure 10.1).

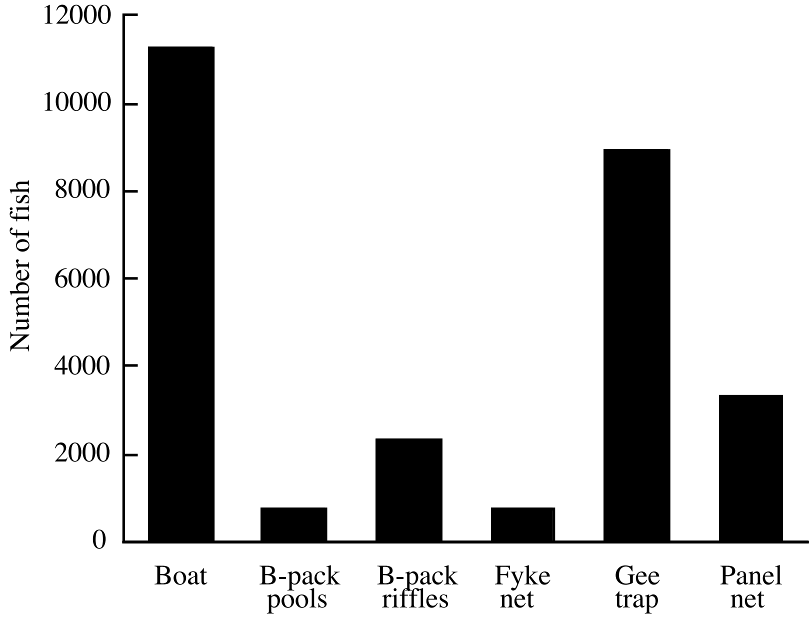

Figure 10.1 Numbers of fish captured by each method for the whole river survey

The number of fish from each species captured by each gear type during the whole survey (Table 10.1) indicate the important role of boat electrofishing in sampling about half the total catch of fish during the survey. Whilst Gee traps captured 32.7% of the total fish by number, these represented only the smaller fish species.

Table 10.1 Species and numbers of fish captured during all four surveys, listed by gear type.

Species	**Boat electrofishin**	**Backpack pools**	**Backpack riffles**	**Fyke net**	**Gee trap**	**Panel net**
Acanthopagrus australis	6	0	0	0	0	2
Ambassis agassizi	61	0	0	0	1	0
Ambassis nigripinnis	17	0	2	0	473	0
Anguilla australis	3	15	11	19	0	0
Anguilla reinhardtii	245	33	211	89	0	0
Arius graeffei	0	0	0	0	0	59
Arrhamphus sclerolepis	4	0	0	0	0	0
Bidyanus bidyanus	1	0	0	0	2	6
Carassius auratus	361	33	26	26	5	58
Carcharhinus leucas	0	0	0	0	0	1
Craterocephalus fluviatilis	1	0	0	0	0	0
Craterocephalus marjoriae	10	0	0	0	0	0
Craterocephalus stercusmuscarum	208	0	9	0	5	0
Cyprinus carpio	1641	1	46	130	19	197
Gadopsis bispinosus	3	0	0	0	0	0
Gadopsis marmoratus		14	4	3	1	0
Galaxias brevipinnis	7	0	0	0	8	0
Galaxias maculatus	186	0	5	0	342	0
Galaxias olidus	1	98	476	0	141	0
Gambusia holbrooki	130	386	566	3	547	0
Gnathanodon speciosus	1	0	0	0	0	2
Gobiomorphus australis	454	0	9	14	492	0
Gobiomorphus coxii	352	0	332	12	142	0
Herklotsichthys castelnaui	2	0	0	1	0	4
Hypseleotris compressa	763	0	8	0	2109	1
Hypseleotris galii	146	0	7	0	584	0
Hypseleotris species	438	21	177	1	3305	0
Leiopotherapon unicolor	24	0	0	41	8	31
Liza argentea	22	0	0	0	0	0
Maccullochella peelii	44	0	3	1	0	2
Macquaria ambigua	121	0	0	47	2	52
Macquaria australasica	10	0	0	5	1	6
Macquaria colonorum	0	0	0	0	1	8
Macquaria novemaculeata	353	0	0	33	0	685
Melanotaenia duboulayi	216	0	3	0	93	0
Melanotaenia fluviatilis	94	0	2	0	1	0
Mordacia praecox	33	0	0	0	0	0
Mugil cephalus	547	0	0	17	0	178
Myxus elongatus	1	0	0	0	1	0
Myxus petardi	278	0	1	11	0	435
Nematalosa erebi	1193	3	0	108	0	697
Notesthes robusta	36	0	0	14	1	19
Oncorhynchus mykiss	26	10	31	6	0	23
Perca fluviatilis	233	22	33	56	4	74
Philypnodon grandiceps	229	4	24	4	427	0
Philypnodon sp1	69	0	9	0	69	0
Platycephalus fuscus	0	0	0	0	0	1
Potamalosa richmondia	249	0	0	6	0	347
Prototroctes maraena	9	0	1	8	0	44
Pseudaphritis urvillii	17	0	1	2	0	9
Pseudomugil signifer	73	0	26	0	94	0
Redigobius macrostoma	0	0	0	0	1	0
Retropinna semoni	2199	0	198	0	57	0
Salmo trutta	32	84	82	16	0	69
Tandanus tandanus	106	0	21	87	0	329
Total Number of fish	11255	724	2324	760	8936	3339
Total Number of species	50	13	29	27	30	27

Fish abundance by gear within river types

Electrofishing with both boat and backpack units captured the majority of the fish sampled in all river types (Figure 10.2) by number. In regulated lowland rivers, boat electrofishing accounted for 52.2% of the total catch. Electrofishing, both backpack and boat, similarly accounted for 57.6% of the total numbers captured in the slopes sites with the majority of the residual catch being from Gee traps (Figure 10.2). In the unregulated lowland sites, the boat electrofisher again accounted for the largest catch, with 46.2% being taken by this method and 38.6% taken by the Gee traps.

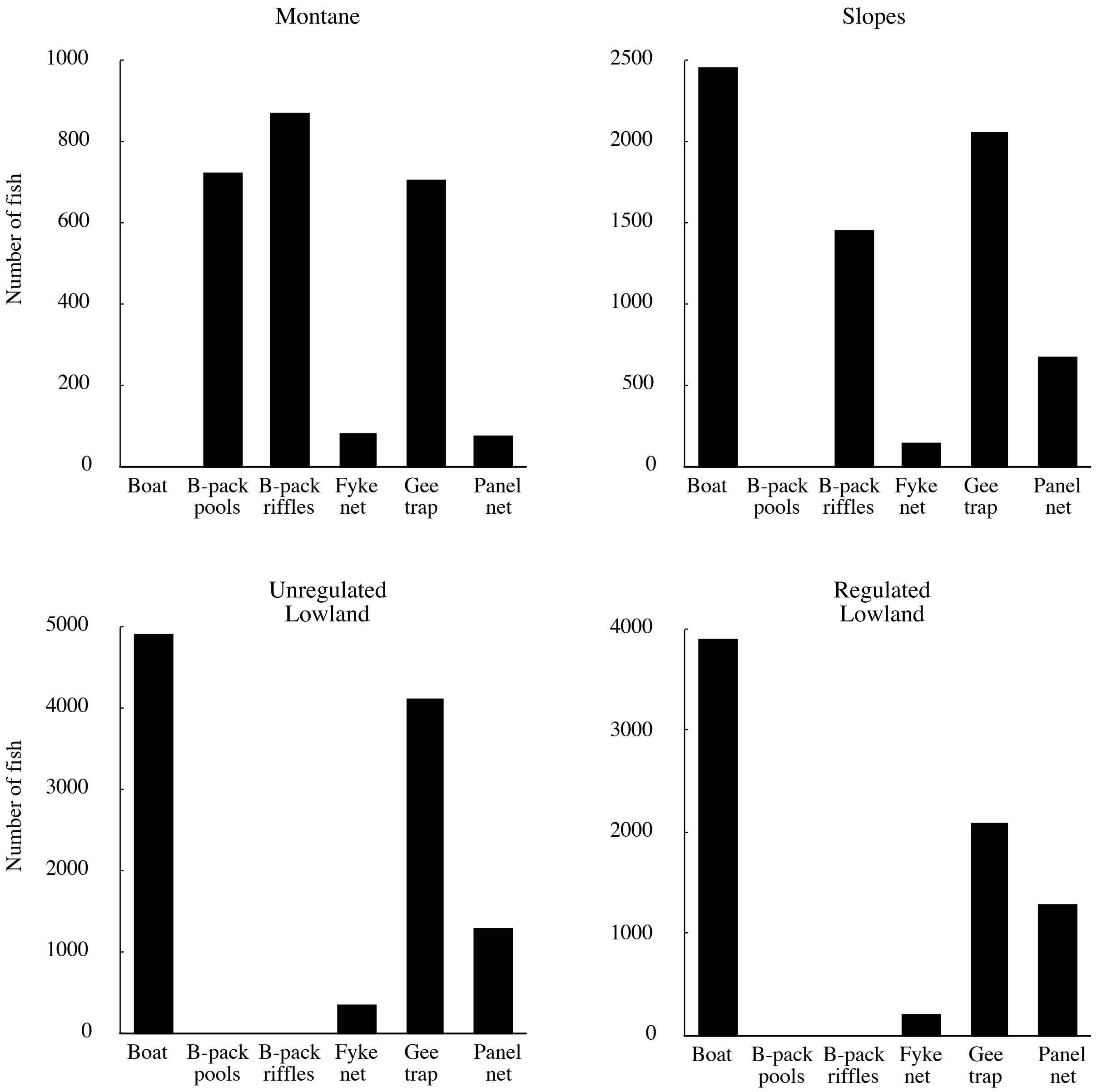

Figure 10.2 Number of fish captured by each gear type, by river types. Boat electrofishing was not used in montane reaches, and back-pack electrofishing was not used in the lowland reaches.

Fish abundance by gear within regions

Catches in each of the four regions, Darling, Murray, South Coast and North Coast, again showed that the electrofishing boat captured the greatest numbers of fish (Figure 10.3). Total fish abundance by all methods was highest in the North Coast region (9925 fish) followed by the Darling (9187 fish), the South Coast (5920 fish) and the Murray region (2292 fish). The electrofishing boats captured the most fish in all regions.

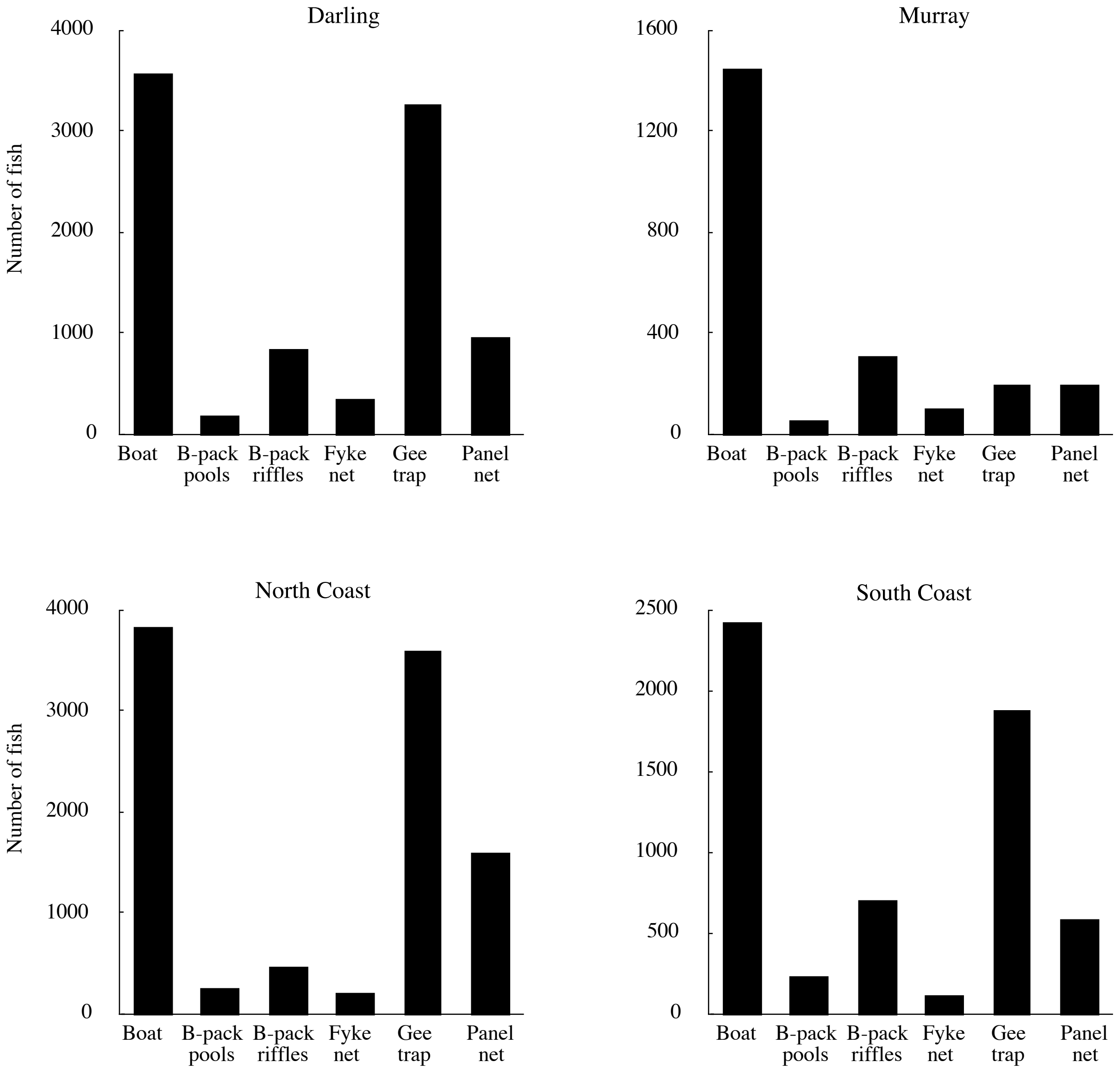

Figure 10.3 Numbers of fish captured by each gear type, by region, over all four surveys.

Nine fish species were captured by only one gear type. These species were *Arrhamphus sclerolepis*, *Craterocephalus fluviatilis, Craterocephalus marjoriae*, *Liza argentea, Mordacia praecox* (caught by the electrofishing boats) and *Carcharhinus leucas*, *Platycephalus fuscus*, and *Arius graeffei* (Panel nets) and *Redigobius macrostoma* (Gee traps).

Fish abundance by gear between seasons

Over the four survey rounds each method, except for backpack electrofishing in pools, captured more fish by number in summer surveys (survey rounds two and four) than in winter ones (survey rounds one and three).

Table 10.2 Catch for each gear type for combined time periods, where Survey 1 & 3 represent the winter months and Survey 2 & 4 represent the summer months.

Method	**Fish Number**	
	Survey 1 & 3	**Survey 2 & 4**
Boat Electrofishing	4758	6497
Backpack Pools	423	301
Backpack Riffles	926	1398
Fyke Net	188	572
Gee Trap	2742	6194
Panel Net	1329	1996
Totals	10366	16958

Species captured by each gear type

Of the 55 fish species captured during the survey, 50 species were sampled by the electrofishing boats. The five species (and their numbers) not captured by the boat electrofisher were *Carcharhinus leucas* (1), *Platycephalus fuscus* (1), *Redigobius macrostoma* (1), *Arius graeffei* (59) and *Macquaria colonorum* (9). Except for *Arius graeffei*, these are all predominantly marine or estuarine species, and all were classed as rare species in the survey, constituting <1% of the total sample for the region (Chapter 2). Of the remaining gear types, backpack electrofishing collected 13 species in pools and 29 species in riffle zones while fyke nets, Gee traps and panel nets collected 27, 30 and 27 species, respectively.

Analysis of the numbers of species captured according to river type, with differing gear combinations used, indicates that electrofishing (both boat and backpack) was most efficient in capturing the majority of the species (Figure 10.4)

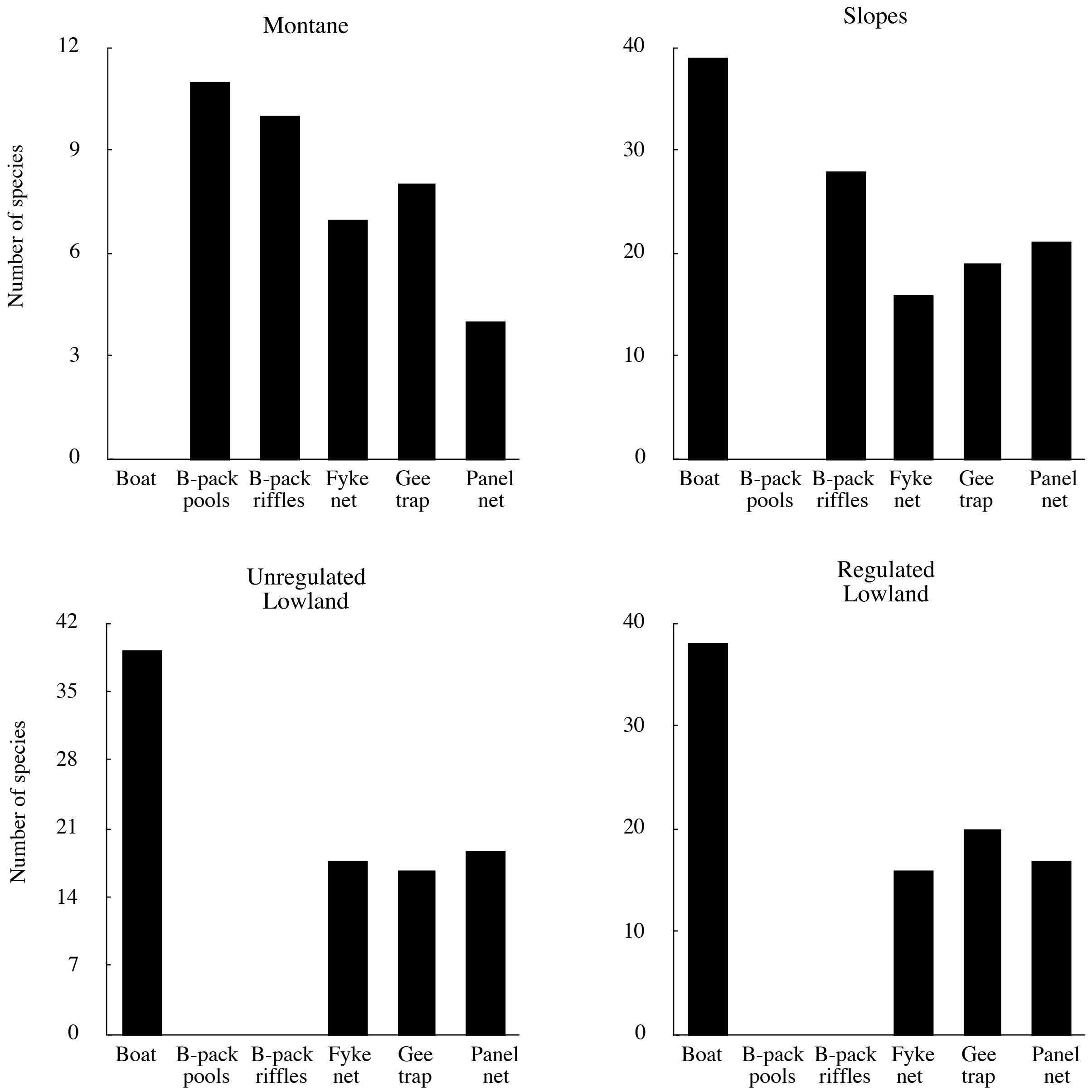

Figure 10.4 Number of species contributing to the catch by each gear type in each river type. Boat electrofishing was not used in montane reaches, and back-pack electrofishing was not used in the lowland reaches.

Table 10.3 shows that, as for fish abundance, species richness was greater for all sampling-gear types, except backpack electrofishing in pools, during the summer surveys.

In the montane sites, where backpack electrofishing was the only electrofishing method used, only one species, *Galaxias brevipinnis*, was not captured by this method (N = 12) and this species was rare. In the Slopes river type, two species were not captured by the boat electrofisher. These species, *Craterocephalus stercusmuscarum* and *Gnathodon speciosus,* are similarly regarded as rare in this river type with the former having a distribution in the lowland areas of the Murray-Darling and the latter being an estuarine fish.

Table 10.3 Catch for each gear type for combined time periods, where Surveys 1 & 3 represent the winter months and Surveys 2 & 4 represent the summer months.

Method	**Species Richness**	
	Survey 1 & 3	**Survey 2 & 4**
Boat electrofishing	41	46
Backpack pools	11	13
Backpack riffles	22	28
Fyke net	21	25
Gee trap	21	25
Panel net	21	27

In the regulated lowlands rivers the electrofishing boat captured all but six of the 44 species taken. Of these all except *Ambassis nigripinnis* are also defined as 'rare'. Electrofishing in the unregulated lowlands failed to capture four of the 46 species taken in this river type. These species were *Arius graeffei* (rare), *Bidyanus bidyanus* (rare), *Carcharhinus leucas* (rare and estuarine) and *Platycephalus fuscus* (rare and estuarine).

Species acquisition over the four surveys

The total number of species captured during the survey was 55. This cumulative total was attained during the last survey round. However, 50 of the species (91%), were captured after only two rounds. The five species collected in the final two rounds were *Arius graeffei*, *Craterocephalus fluviatilis*, *Gnathodon speciosus, Herklotsichthys castelnaui*, and *Liza argentea,* all of which were classed as 'rare' species.

Figure 10.5 (a) shows that in the South Coast region, all but one were caught by the second survey and the last species, *Macquaria colonorum,* was captured during Survey 4. In the Darling, the last three species were caught during survey 2 and no other new species were caught after this survey. In the Murray and the North Coast however, Figure 10.5(a) indicates that, although most species were recorded in the first survey, additional species were caught in each subsequent survey. In the North Coast, *Ambassis agassizi* and *Liza argentea* were caught during Survey 3 and *Herklotsichthys castelnaui* and *Gnathanodon speciosus* were caught during Survey 4. In the Murray, two new species, *Craterocephalus fluviatilis* and *Melanotaenia fluviatilis*, were caught in Survey 3, and four species, *Bidyanus bidyanus*, *Craterocephalus stercusmuscarum*, *Galaxias brevipinnis*, and *Leiopotherapon unicolor*, were caught in Survey 4. All of these were 'rare' species in the Murray region catches.

Figure 10.5(b) shows that, in the Montane sites, all but one species were caught in Survey 1. The other river types had an increase in species numbers with each survey.

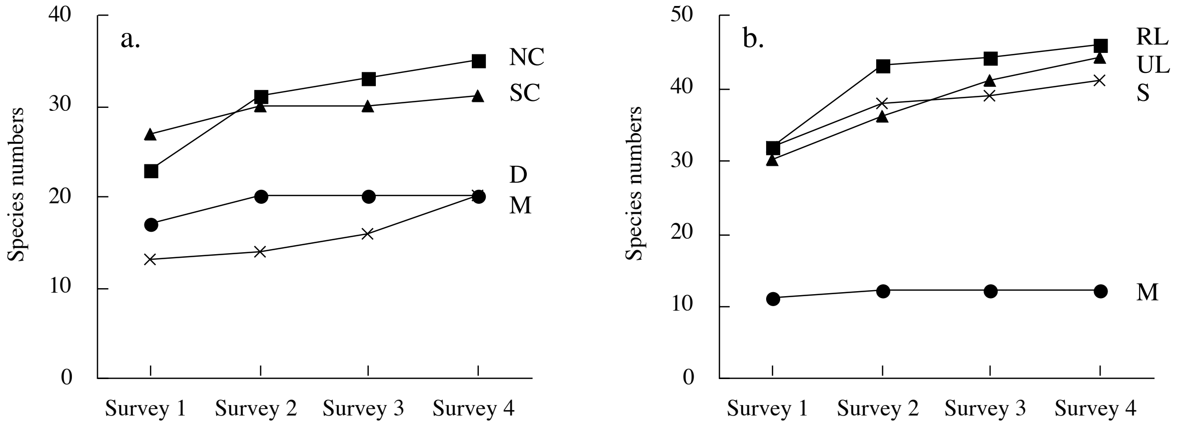

Figure 10.5 Cumulative number of species captured over the four survey rounds (a) by Region, where D - Darling, M - Murray, NC - North Coast, SC - South Coast, and (b) by River type where M - Montane, S - Slopes, UL - Unregulated Lowland, and RL - Regulated Lowland.

Overall, 75% of species were caught in the first survey, and only 'rare' species, many of them estuarine, were added to lists in the subsequent surveys.

Species acquisition at selected sites

Three sites, Leycester Creek (NCUL60), Clarence River (NCR52), and the Macleay River (NCR53) which were sites where ten or more species were taken by the boat electrofisher, were chosen to analyse species acquisition over electrofishing shots in the ten-shot sample during the second survey round. This was done to estimate the number of shots which most efficiently sampled the full complement of fish species. Figure 10.6 shows that in site NCUL60, 13 of the 14 species were captured by shot five, with one species not captured until shot ten. At site NCR53 only half of the species had been sampled by shot five, and new species were captured in shot nine. The ten species captured in site NCR52 were all captured by shot five.

Gear type and fish size

Each of the gear types used in the survey was included to maximise the likelihood of fish capture in all habitats, and to ensure that all sizes of the available fish were caught. Mean length of fish varied with gear type, with panel nets contributing the highest mean length (Table 10.4). The greatest fish-length range was recorded by the electrofishing boat (12-1300 mm). Mean fish length may have been underestimated for this gear type, as many of the eels observed were not measured. This could also be the case with backpack electrofishing and to a lesser extent the fyke nets. The high mean length of fish and large length range recorded from the fyke nets was contributed to by the comparatively large number of eels captured by this method.

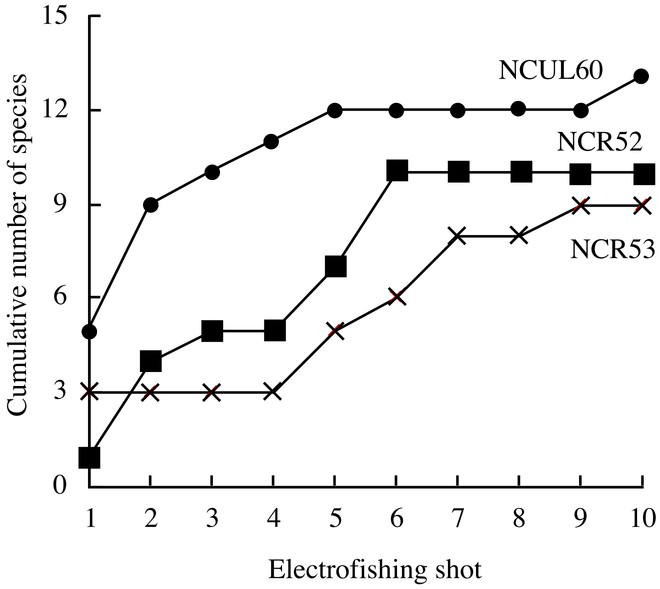

Figure 10.6 Cumulative catch over the 10 boat electrofisher shots at three sites for second survey. (Site NCUL60: Leycester Creek at Lismore; NCR53, Macleay River at Bellbrook; NCR52, Clarence River at Tabulam).

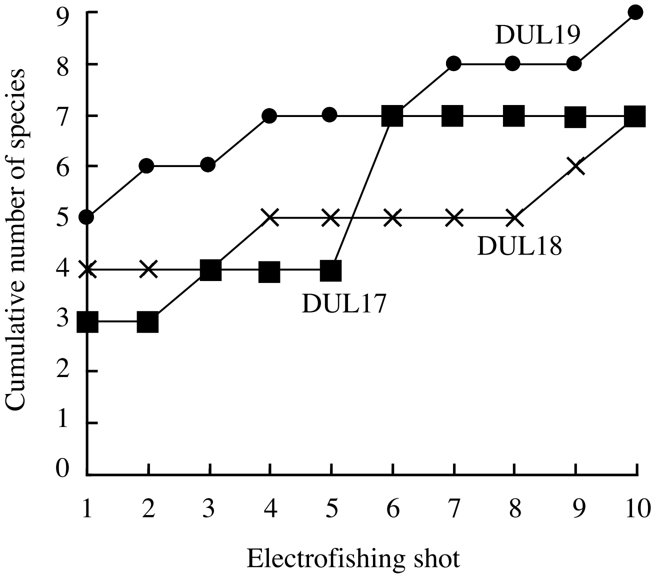

Figure 10.7 Cumulative catch over the 10 boat electrofisher shots at three inland sites for second survey (Site DUL17, Bogan River at Bourke; DUL18, Macquarie River at Carinda; DUL19, Bogan River at Nyngan).

Gee traps, with the small (15 mm) opening are designed to capture the smaller fish species as is reflected in the small mean size of fish captured.

Table 10.4 Fish-size statistics from each gear type. All fish which were measured for length were included.

Method	**Boat electrofishing**	**Backpack pools**	**Backpack riffles**	**Fyke net**	**Gee trap**	**Panel net**
Mean Length (mm)	165.4	108.1	89.7	240.7	46.9	252.7
SD	162.8	144.9	102.3	182.9	19.1	100.7
SE	1.7	6.5	2.4	6.9	0.4	1.9
n	8830.0	490.0	1804.0	703.0	2373.0	2847.0
Min Length (mm)	12.0	12.0	16.0	21.0	16.0	53.0
Max Length (mm)	1300.0	1000.0	950.0	1200.0	186.0	700.0

Comparison of boat electrofishing with panel nets

Mean catches obtained using panel nets and boat electrofishing (by *FRV Electricus*) were compared for those sampling occasions (N = 235) at which both gear-types were used and at which the turbidity was estimated. For the same sites, mean catch from all gear types combined was also calculated. Turbidity was classed as either clear, low, moderate or high. Effects of turbidity on fish catches were assessed by *t*-tests between turbidity levels.

Catches from *Electricus* showed no significant difference among turbidity levels ($p>0.05$), indicating that catches did not decline in turbid waters because of the operators' impaired ability to observe and capture fish (Figure 10.8). Mean catch per visit by all methods combined was not significantly different among waters rated as having clear, low or moderate turbidity. However, catches were significantly lower ($p<0.05$) in sites with high turbidity. Catches obtained using panel nets showed no significant differences between clear, low and moderate turbidity sites, but the mean catch at high turbidity sites was significantly lower than at lower turbidity levels ($p<0.05$).

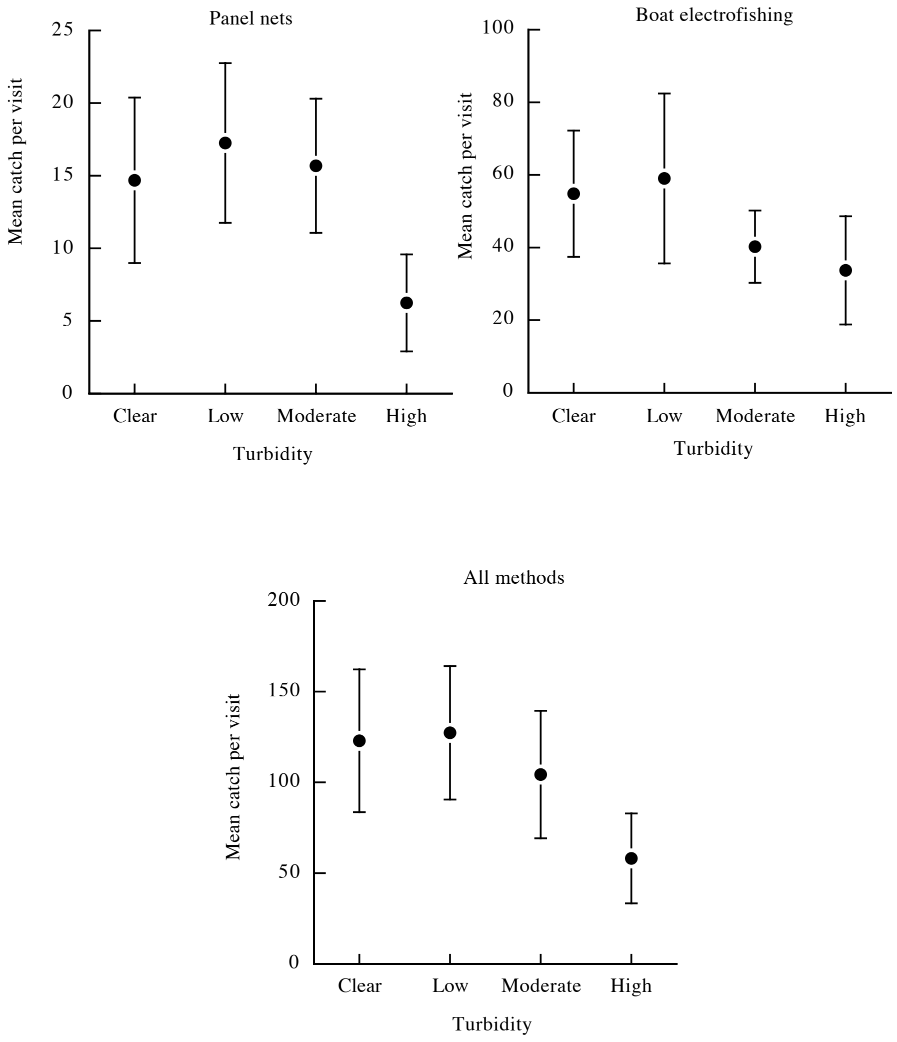

Figure 10.8 Mean catch rates for panel nets, boat electrofishing, and all methods combined (with 95% confidence intervals), over a range of estimated turbidities (N=235).

Thus, although electrofishing relies on operators observing and capturing immobilised fish, increased turbidity did not significantly decrease the catch. Although mean catch per visit from all gear types was significantly less at the highest turbidity rank, catch from boat electrofishing was not the contributing factor.

DISCUSSION

In the lowland and slopes river types in which the electrofishing boat was used, it captured not only the most fish by number but also the most species. In the montane rivers, backpack electrofishing collected most fish by number and sampled 11 of the 12 species from this river type.

Passive fish-sampling gear is selective for certain species, sizes or sexes of fish (Cadwallader 1984; Hubert 1983; Growns *et al*. 1996). While all methods depend on fish availability, passive gear can only capture fish as the result of their own activity, and fish activity varies among species and with such variables as flow, time of day, water temperature and spawning times. While it is often possible to assess impacts on fisheries with passive gear there are difficulties in establishing the species composition of a community because of size and species selectivity. It is often assumed that the probability of a fish encountering passive gear is dependent on fish density. Borgstrom (1992), however, found that in gillnetting brown trout (*Salmo trutta*) in four lakes with different stock levels, catchability decreased with increasing population size. This finding was considered to be a result of a decrease in fish activity because of reduced food - and thus feeding activity - in lakes with large populations. It is therefore important to have knowledge from an independent source of the target species' behaviour and probable abundance.

Electrofishing methods were less species-selective than the passive methods, with only five 'rare' species not captured by the boat electrofisher, and only one species by the backpack electrofisher, in those areas where each was used. Unlike passive gear, electrofishing does not depend on fish activity for success. The optimum number of shots is site-and-species-dependent, and for any specific sampling may require pilot sampling of the fish community to determine the best sample size.

Size of fish has been proposed as a primary factor in determining the probability of capture by electrofishing (Zalewski and Cowx 1990). This is explained according to Rushtons Law relating to nerve length such that the total body potential increases with length, producing greater stimulation of larger fish (Zalewski and Cowx 1990). Nevertheless, the electrofishing boats captured all the smaller fish species captured during the survey and in fact captured more of some of the smaller species than any other single method (e.g. *Ambassis agassizii*, *Gobiomorphus coxii*, *Melanotaenia duboulayi*, *M. fluviatilis*, *Retropinna semoni* and *Pseudaphritis urvillii*). Thus, the electrofishing methods were less selective for both size and species of fish in the NSW Rivers Survey than the passive gear types.

Preliminary analyses of gear efficiency in the First Annual Report of the NSW Rivers Survey (Harris *et al*. 1995) were considered at the project's Mid-term Review. Questions addressed by the review included how each particular gear type was contributing to the objectives of sampling, and whether there were gear types that were redundant and could be dropped from the sampling design. It had been concluded that, although at that stage electrofishing boats were producing the bulk of the data, and collecting between 70-80% of all species recorded in each ecological region, the continuation of the whole suite of sampling methods was justified by the need to ensure the most comprehensive representation of the whole fish community.

Growns *et al.* (1996), in a Hawkesbury River sampling experiment comparing boat electrofishing and gill nets of mesh sizes ranging from 22 mm to 132 mm, found that the electrofishing boat captured more species (16) than the mesh nets (7). The electrofishing boat also captured more fish by number than the nets. They considered that the most effective methods of collecting fish to discern the effects of a disturbance on community would be those which collect most species, as the chances of capturing the species which are sensitive to the disturbance is greater. Faith and Norris (1989) found that for pattern analysis the inclusion of the greatest number of taxa improves the definition of the environmental gradients. Growns *et al.* (1996) state that the use of change in number of indicator species or species richness requires a collecting method that is unbiased between disturbed and undisturbed sites. Boat electrofishing satisfies these criteria. Electrofishing also has considerable benefit/cost advantages (Chapter 2): it is rapid, and can be safely applied by skilled operators in populations of many threatened species or communities (Cowx and Lamarque 1990, NSW Fisheries, unpublished data). Thus, final results of the Rivers Survey strongly support the conclusion that electrofishing is the method of choice for sampling south-east Australian freshwater fish communities.

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