The effects of Balranald Weir on spatial and temporal distributions of lower Murrumbidgee River fish assemblages

Lee J. Baumgartner

NSW Fisheries
Aquaculture and Sustainable Fisheries
Narrandera Fisheries Centre
P.O. Box 182, Narrandera NSW, 2700
Australia

June 2004

NSW Fisheries Final Report Series
No. 65
ISSN 1440-3544

The effects of Balranald Weir on spatial and temporal distributions of lower Murrumbidgee River fish assemblages

Lee J. Baumgartner

NSW Fisheries
Aquaculture and Sustainable Fisheries
Narrandera Fisheries Centre
P.O. Box 182, Narrandera NSW, 2700
Australia

June 2004

NSW Fisheries Final Report Series
No. 65
ISSN 1440-3544

The effects of Balranald Weir on spatial and temporal distributions of lower Murrumbidgee River fish assemblages

June 2004

Authors: Lee J. Baumgartner

Published By: NSW Fisheries

Postal Address: PO Box 21, Cronulla NSW 2230

Internet: www.fisheries.nsw.gov.au

DISCLAIMER

The publishers do not warrant that the information in this report is free from errors or omissions. The publishers do not accept any form of liability, be it contractual, tortuous or otherwise, for the contents of this report for any consequences arising from its use or any reliance placed on it. The information, opinions and advice contained in this report may not relate to, or be relevant to, a reader's particular circumstance.

ISSN 1440-3544

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This study was funded by Agriculture Fisheries and Forestry Australia under the National Heritage Trust MD2001 Fishrehab program.

I would like to thank John Botten, Keith Breheny, Leanne Faulks, Cameron Lay, Peter McLean, Matthew McIntosh, Damien Mill, Matthew Moore, Michael Rodgers, Ian Wooden and Nick Whiterod for their enthusiastic assistance with field sampling.

I would further like to thank Kim Nield and Tom Davy for allowing access to boat launching facilities.

A steering committee comprising Dr Peter Gehrke, Dr John Harris, Cameron Lay, Lindsay White, Kumar Sathasivam and Robert Shuttle provided direction and guidance.

Helpful comments on various drafts were provided by Drs Bob Creese, Dean Gilligan, Peter Gehrke, Robert Kearney and Mr Craig Boys.

Work was carried out in accordance with NSW Fisheries Animal care and ethics permit number 99/15.

NON-TECHNICAL SUMMARY

The effects of Balranald Weir on spatial and temporal distributions of lower Murrumbidgee River fish assemblages

PRINCIPAL INVESTIGATOR: Lee Baumgartner

ADDRESS: Narrandera Fisheries Centre
PO Box 182,
Narrandera, NSW, 2700
Telephone: 02 6959 9021 Fax: 02 6959 2935

OBJECTIVES:

(i) To document changes in the composition of fish assemblages upstream and downstream of Balranald Weir over different seasons.
(ii) To investigate whether small native fish are adversely affected by a low level weir.

NON-TECHNICAL SUMMARY:

Fish assemblages in rivers and streams of the highly regulated Murray-Darling River system are greatly affected by direct (physical) or indirect (behavioural) effects of dams and weirs. Direct effects arise from alteration of flow, changes to channel shape and barriers to migration. Indirect effects arise from factors such as cold water pollution, reduced nutrient loads and breakdowns of food webs because of changes in the composition of aquatic biota.

The proliferation of dams and weirs has significantly reduced migratory opportunities for Australian native fish species. At Euston Weir (Lock 15) on the Murray River, numbers of golden perch, silver perch and Murray cod recorded from a fish trap between 1940-45 and 1987-92 have been reduced by 51%, 94% and 96% respectively. However, most early studies of inland fish were confined to recreationally and commercially important species because these were considered highest priority by fisheries agencies. Consequently, little is known of the migratory requirements of small fish despite earlier studies suggesting that they may also be susceptible to the effects of weirs.

This present study focused on identifying the effects of Balranald Weir on fish of the Murrumbidgee River. Fish were sampled by boat electrofishing from upstream and downstream regions at three monthly intervals between April 2000 and September 2002. Sampling yielded 11,960 fish from 13 species. Bony bream (40.41% of total catch), Australian smelt (34.25%), crimson spotted rainbowfish (10.16%) and common carp (7.26%) were sampled in greatest relative abundance. Sampling immediately downstream of Balranald Weir yielded the most individuals and species such as western carp gudgeon, crimson spotted rainbowfish and flyspecked hardyhead were caught in large numbers despite previously being considered non-migratory.

The structure of upstream and downstream fish assemblages differed significantly between seasons. Alien species, in particular goldfish, carp and redfin perch accumulated downstream of Balranald Weir during summer. Some native species also accumulated during summer and increases in downstream abundance were observed for bony bream, crimson-spotted rainbowfish and western carp gudgeon. Few juveniles of golden perch, Murray cod or silver perch were sampled at all, indicating their recruitment may be compromised in this section of river.

Species diversity (Shannon's index) varied significantly among seasons but not between upstream and downstream regions. Seasonal changes in the relative abundance of bony bream, Australian

smelt, crimson-spotted rainbowfish and common carp lowered species diversity downstream of Balranald Weir. In contrast, species richness did not change significantly among seasons or between upstream and downstream regions, possibly because the occasional removal of Balranald Weir was permitting the upstream passage of some species.

In conclusion, the effect of Balranald Weir on fish assemblages of the lower Murrumbidgee River was greatest during summer and autumn, when fish were seeking upstream passage. The dominance of small species from downstream samples further suggest that fish passage facilities constructed in the Murray Darling Basin should provide passage for a much wider range of size classes.

1. INTRODUCTION

The construction of weirs is recognised as a serious issue for aquatic organisms not only in Australia (Gehrke *et al,* 1995; Kearney et al. 1999; Gehrke *et al*, 2002), but globally (Townsend, 1975; Fjellheim and Raddum, 1996; Holmquist, 1998; Rivinoja, 2001). The role of these structures in facilitating changes in macroinvertebrate and fish assemblages is well documented (Jansen *et al*, 1996; Lucas and Frear, 1997; Cortes *et al*, 1998; Lake, 1998; Gehrke and Harris, 2001; Agostinho *et al*, 2002) but one of the most common effects, the prevention or reduction in migration, is often underestimated (Lucas and Frear, 1997).

Sixty six species of fish native to south eastern Australia migrate to some extent and, for many species, migrations are an essential part of their life histories (Reynolds, 1983; Mallen-Cooper, 1989; Mallen-Cooper and Harris, 1990; Mallen-Cooper, 1996). Migrations are known to include both adult (Reynolds, 1983; Mallen-Cooper, 1996; Thorncraft and Harris, 2000) and juvenile (Mallen-Cooper and Brand, 1992; Harris *et al*, 1992; Mallen-Cooper, 1996) stages. Tagging studies in the extensive Murray-Darling River system have revealed some individuals can travel over 1,400km when dams and weirs are inundated by floods (Reynolds, 1983). Such observations have led researchers to implicate the obstruction of fish passage as a partial cause of population declines in some species (Cadwallader, 1978; Cadwallader and Lawrence, 1990; Allan and Flecker, 1993; Wager and Jackson, 1993).

Accumulations of migratory fish in the vicinity of dams and weirs are a well known phenomenon (Pavlov, 1989). Consequently, large abundances of upstream migrating fish are commonly sampled downstream of weirs (Bishop and Bell, 1978; Harris, 1983; Pavlov, 1989; Mallen-Cooper, 1996; Taylor *et al,* 2001; Gehrke *et al*, 2002). Early studies on fish migration within the Murray Darling basin were confined to large bodied species of recreational and commercial importance (Table 1), as these were considered highest priority by fisheries agencies (Reynolds 1983; Harris *et al*, 1992; Mallen-Cooper and Brand, 1992; Mallen-Cooper, 1996). Such studies were conducted over wide temporal and spatial scales to ensure any method of improving large fish passage, such as the construction of fishways, were applicable to many sites throughout the Murray-Darling Basin.

In contrast to large fish, the migratory requirements of small species remain largely unknown, despite some previous studies suggesting they may be equally susceptible to effects of weirs (Mallen-Cooper and Brand, 1992; Mallen-Cooper, 1996; Harris *et al*, 1998). For instance, Australian smelt (*Retropinna semoni*) were frequently observed attempting to ascend a vertical slot fishway at Torrumbarry Weir on the Murray River (Mallen-Cooper, 1996). Similarly, flyspecked hardyhead (*Craterocephalus stercusmuscarum*) and Australian smelt frequently attempted to negotiate a rock ramp fishway at Goondiwindi Weir on the Macintyre River (Harris *et al*, 1998). Although such observations may suggest these species were attempting to migrate, no studies have attempted to document the extent of such behaviour, over spatial or temporal scales. Therefore, management plans for dams and weirs in the Murray-Darling Basin frequently fail to provide for small fish species as they are generally regarded as non-migratory.

The present study used boat electrofishing to determine the composition of migratory fish assemblages upstream and downstream of Balranald Weir on the Murrumbidgee River over a period of two years. Data was collected in relation to the entire migratory fish community, including small species, to assess whether the weir obstructed fish attempting upstream migrations. Sampling was stratified over spatial and temporal scales to assess whether observed changes in relative abundance were consistent among species, among seasons or between upstream and downstream regions.

Table 1. Classifications of large and small potamodromous species referred to in this study and the current known age of migration (based on results of: Reynolds 1983; Battaglene, 1991; Harris *et al,* 1992; Mallen-Cooper, 1996; Stuart and Jones, 2002; the present study). Age of migration is defined as Y – young of the year, J – juvenile (1+ up to sexual maturity), A – adult (after sexual maturity).

Species Name	Common Name	Native or Alien	Age of migration
Large fish (>100mm at sexual maturity)			
Bidyanus bidyanus	Silver perch	Native	A, J
Carassius auratus	Goldfish	Alien	Y, A
Cyprinus carpio	Common carp	Alien	Y, J, A
Leiopotherapon unicolor	Spangled perch	Native	A
Nematalosa erebi	Bony bream	Native	Y, J, A
Maccullochella peelii	Murray cod	Native	J, A
Macquaria ambigua	Golden perch	Native	J, A
Perca fluviatilis	Redfin perch	Alien	Y, J, A
Tandanus tandanus	Freshwater catfish	Native	A
Small fish (<100mm at sexual maturity) *			
Craterocephalus stercusmuscarum	Flyspecked hardyhead	Native	Y, J, A
Gambusia holbrooki	Eastern gambusia	Alien	A
Hypseleotris spp	Carp gudgeon	Native	Y, J, A
Melanotaenia fluviatilis	Crimson-spotted rainbowfish	Native	Y, J, A
Retropinna semoni	Australian smelt	Native	Y, J, A

2. METHODS

2.1. Sampling sites

The Murrumbidgee River is a highly regulated stream incorporating eight weirs (Ebsary, 1992) and draining 86,467 km^2 (Harris and Gehrke, 1997) from its source to its confluence with the Murray River. The weirs were constructed for domestic water supply, stock water supply, irrigation, rediversion to irrigation areas and rediversion to effluent streams. Two storages, Burrinjuck and Blowering Dams, release water based on seasonal allocations with flows mostly released between September and March when all weir operations are based on irrigation demand.

Balranald Weir is the most downstream barrier on the Murrumbidgee River. It is located approximately 6km west of the Balranald township (Figure 1) and is a drop-board regulated structure measuring 40m long and 3.7m high. The weir is primarily used for stock and domestic water supply and presents a barrier to fish passage at flows up to 4,500ML.day^{-1}. Once flows exceed this level, all drop-boards are removed and free passage is restored. Two downstream sites (0 km and 25 km) and two upstream sites (25 km and 80 km) were sampled at three monthly intervals over two years (Figure 2). No site was sampled immediately upstream of Balranald Weir as the study focused primarily on obstructions of upstream migrating fish rather than downstream migrations.

2.2. Seasonal sampling and boat electrofishing

Sampling was conducted in spring (September-October), summer (December-January), autumn (March-April) and winter (June-July) between April 2000 and December 2001 (Figure 2). Fish were sampled using a boat mounted 7.5kW Smith-Root Model GPP 7.5 H/L electrofishing system. Sampling operations consisted of 20 replicate 2-minute (elapsed) electrofishing 'shots' during daylight hours. Fish were collected via dip net and placed into a live well for recovery prior to identification and measurement (fork length). Each individual was inspected for diseases, parasites or injuries. Any positively identified fish unable to be dip netted were recorded as "observed". In instances of large individual species catches, random sub-samples of 20 individuals were measured per shot.

2.3. Data analysis

Data were analysed using the PRIMER (Version 5.0) multivariate statistical package and S-PLUS 2000 (Insightful corporation, 2001). Multidimensional scaling ordinations of Bray-Curtis similarity measures were used to plot fish community data, in two dimensions, after pooling replicate shots at each site. For the purposes of this study, fish communities were defined by the relative abundance of species sampled during the course of routine electrofishing. Two-way analyses of similarities (ANOSIM), (as described in Clarke and Warwick, 1994), using regions (upstream and downstream) and seasons (summer, autumn, winter, spring), as factors were performed on fourth-root transformed data to determine spatial and temporal differences in fish communities. A one way ANOSIM was also performed to identify differences in fish communities between each site sampled. Where possible, each test was conducted using 20,000 Monte Carlo randomisations to calculate probabilities. A similarity percentages (SIMPER) test was subsequently performed to identify species contributing most to average dissimilarities within and between factors.

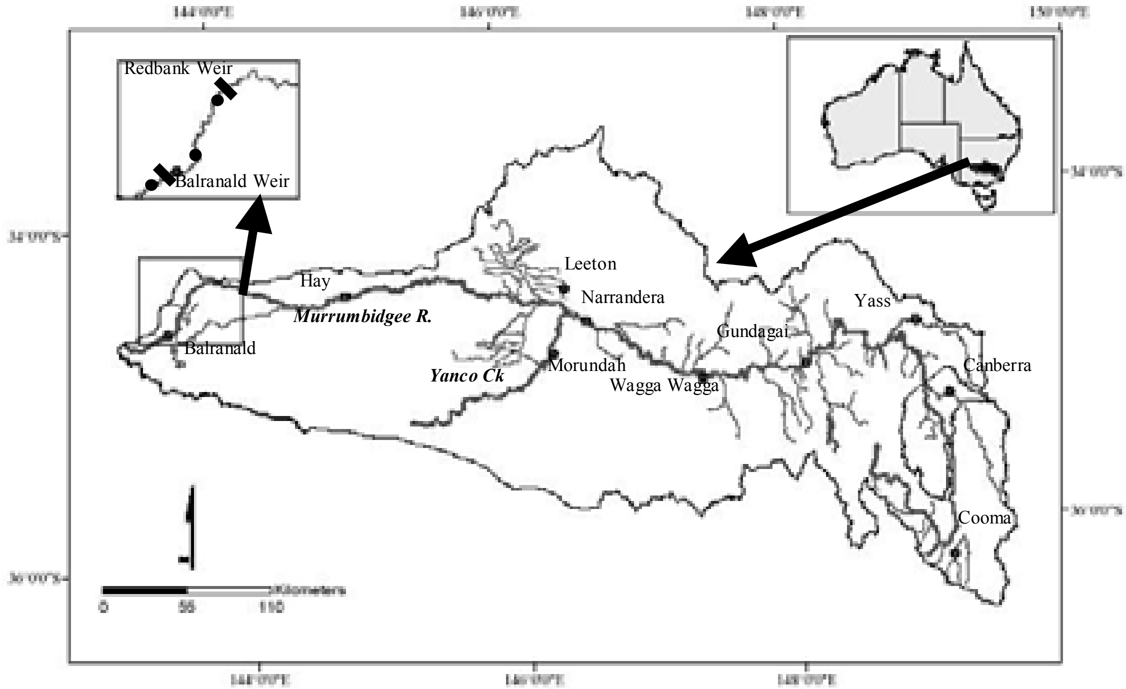

Figure 1. A map of the Murrumbidgee catchment along with sites sampled on the Murrumbidgee River (inset). The main channel of the Murrumbidgee River has been emboldened for clarification.

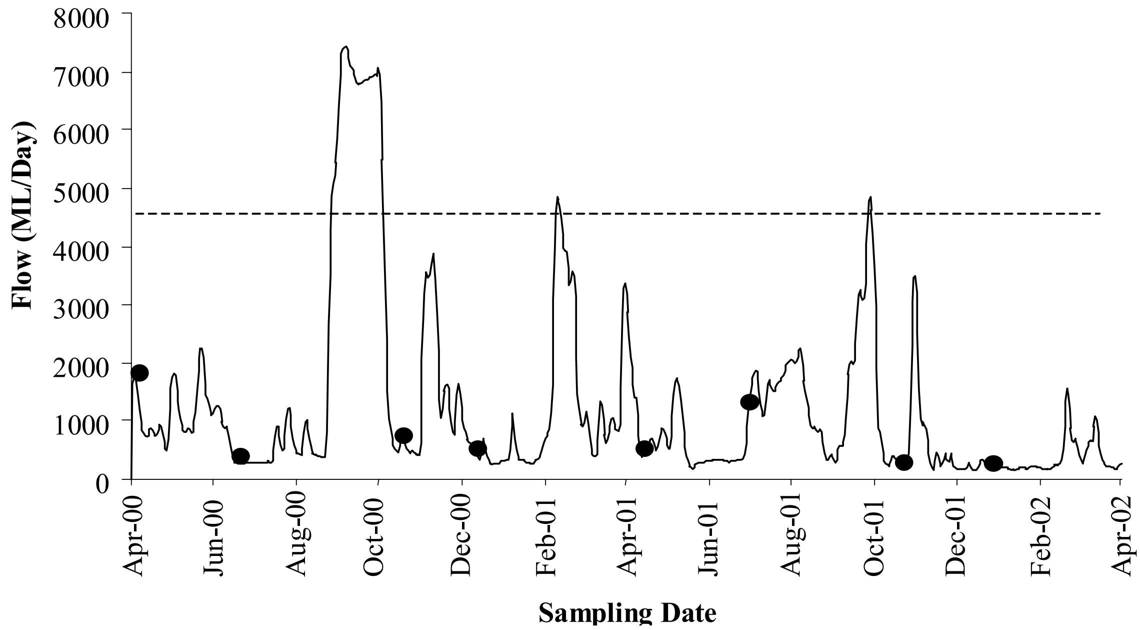

Figure 2. A hydrograph of the Murrumbidgee River between April 2000 and April 2002. Black dots represent sampling occasions and the dotted line represents flows where Balranald Weir is normally removed.

A two-way factorial Analysis of Variance (ANOVA) was performed to identify any significant differences in the relative abundance of individual species, species diversity (Shannon's H` as described in Clarke and Warwick, 1994) and species richness (total number of species) using regions and seasons as factors. Prior to performing ANOVA Cochran's tests determined non-homogeneity of variances within the data set and a variance stabilising transformation (log x+1) was subsequently performed. Quantile-quantile plots (as described in Insightful Corporation, 2001) confirmed the data were approximately normally distributed.

Two tailed Kolmogorov-Smirnov tests (KS: Sokal and Rohlf, 2001) were performed on the most common species from each site to assess differences in length frequency distributions among sites and seasons. For the purpose of the present study, length frequency analysis revealed whether populations upstream and downstream of weirs were dominated by particular size classes. All data were standardised to electrofishing time (fish per minute) and all statistical tests were considered significant at $p<0.05$.

3. RESULTS

3.1. Spatial and temporal variation in fish community composition

Sampling upstream and downstream of Balranald Weir over the two years of this survey yielded 11,960 fish from 13 species (Table 2). Bony bream (*Nematalosa erebi*) (40.41% of total catch), Australian smelt (34.25%), crimson spotted rainbowfish (*Melanotaenia fluviatilis*) (10.16%) and common carp (*Cyprinus carpio*) (7.26%) were sampled in greatest relative abundance. Significant differences in fish communities were detected among seasons (ANOSIM: Global R=0.220, p=0.004) and also between regions upstream and downstream of Balranald Weir (ANOSIM: Global R=0.151, p=0.048). Temporal differences arose because catches of most species were lower during spring and greater during summer and autumn (SIMPER). Spatial differences were characterised by higher relative abundances of common carp, goldfish (*Carassius auratus*), redfin perch (*Perca fluviatilis*), crimson-spotted rainbowfish and western carp gudgeons (*Hypseleotris* spp) from the downstream region. The only species consistently sampled in greater relative abundance from upstream samples was golden perch (*Macquaria ambigua*) (Table 2).

The composition of fish communities varied significantly among sites within each region (upstream and downstream) with pairwise tests identifying a unique fish assemblage at the Balranald Weir site (ANOSIM: Global R=0.112, p=0.032). This site significantly differed from all other sites, because more species were present in greater relative abundance (Table 3). In contrast, pairwise comparisons of remaining sites were non-significant, confirming that observed differences between regions (upstream and downstream) were due to accumulations of fish downstream of Balranald Weir and that the relative abundance of fish downstream of Redbank Weir, and from the two non-weir sites, was of much smaller magnitude.

ANOSIM is unable to compute an interaction term, therefore a two-way ANOVA was performed to identify whether the relative abundance of individuals species was consistent among seasons and between regions. The relative abundance of two species, crimson spotted rainbowfish and common carp differed significantly between upstream and downstream regions and also among seasons (Table 4). Significant seasonal differences were also detected for goldfish. However, significant interactions demonstrated seasonal differences were not consistent between sampling regions in all three species (Table 4, Figure 3). During summer sampling the downstream relative abundance of crimson spotted rainbowfish was over 12 times that of upstream (Table 2, Figure 3). In addition, common carp and goldfish were sampled from both regions but were sampled in greatest relative abundance immediately downstream of Balranald Weir during summer (Table 2, Figure 3).

Most other species such as western carp gudgeon, redfin perch and bony bream were also sampled in the greatest relative abundance from downstream samples during summer, albeit not significantly (Table 2, Figure 3). Similar observations were made for Australian smelt but this species only accumulated downstream of Balranald Weir during autumn. These observations were contrasted during winter because the relative abundance of most species was greater from upstream samples, although this relationship was only significant for crimson spotted rainbowfish (Figure 3, Table 2).

Most species were sampled in lowest relative abundance during spring and highest during summer and autumn except for western carp gudgeon, which was relatively less abundant during winter than in spring, or summer (Figure 3).

Table 2. Summary of total fish catches from sites downstream (D) and upstream (U) of Balranald Weir showing sites and seasons sampled. Catches are pooled results from both years sampled.

Species name	Autumn		Winter		Spring		Summer	
	D	U	D	U	D	U	D	U
Native								
Silver perch	7	3	0	6	1	1	9	18
Flyspecked hardyhead	3	0	5	3	10	0	3	0
Western carp gudgeon	5	9	1	2	32	34	86	28
Murray cod	8	7	13	1	3	1	1	2
Golden perch	14	45	36	66	7	11	10	29
Crimson-spotted rainbowfish	82	41	47	306	22	4	660	54
Bony bream	988	807	525	1450	7	13	756	288
Flatheaded gudgeon	0	0	0	0	0	0	1	0
Australian smelt	999	129	626	1581	70	9	388	295
Alien								
Common carp	45	70	56	136	24	37	455	46
Goldfish	9	15	3	39	5	2	91	53
Mosquitofish	0	3	0	1	0	0	0	1
Redfin perch	14	23	1	9	9	2	134	9

Table 3. One-way ANOSIM results among sites sampled on the lower Murrumbidgee River. Probability values are based on 20,000 Monte-Carlo randomisations. Sites are defined as Willow Isles (25km downstream Balranald Weir), Balranald Weir (immediately downstream of Balranald Weir), boat ramp (25km upstream of Balranald Weir) and Redbank Weir (immediately downstream of Redbank Weir). Asterisks denote a significant result.

Comparison	R-value	P-value
Global test		
Among sites	0.112	0.032*
Pairwise tests – Sites		
Willow Isles v Balranald Weir	0.213	0.036*
Willow Isles v Boat Ramp	-0.018	0.517
Willow Isles v Redbank Weir	0.066	0.188
Balranald Weir v Boat Ramp	0.222	0.031*
Balranald Weir v Redbank Weir	0.080	0.013*
Boat Ramp v Redbank Weir	0.111	0.108

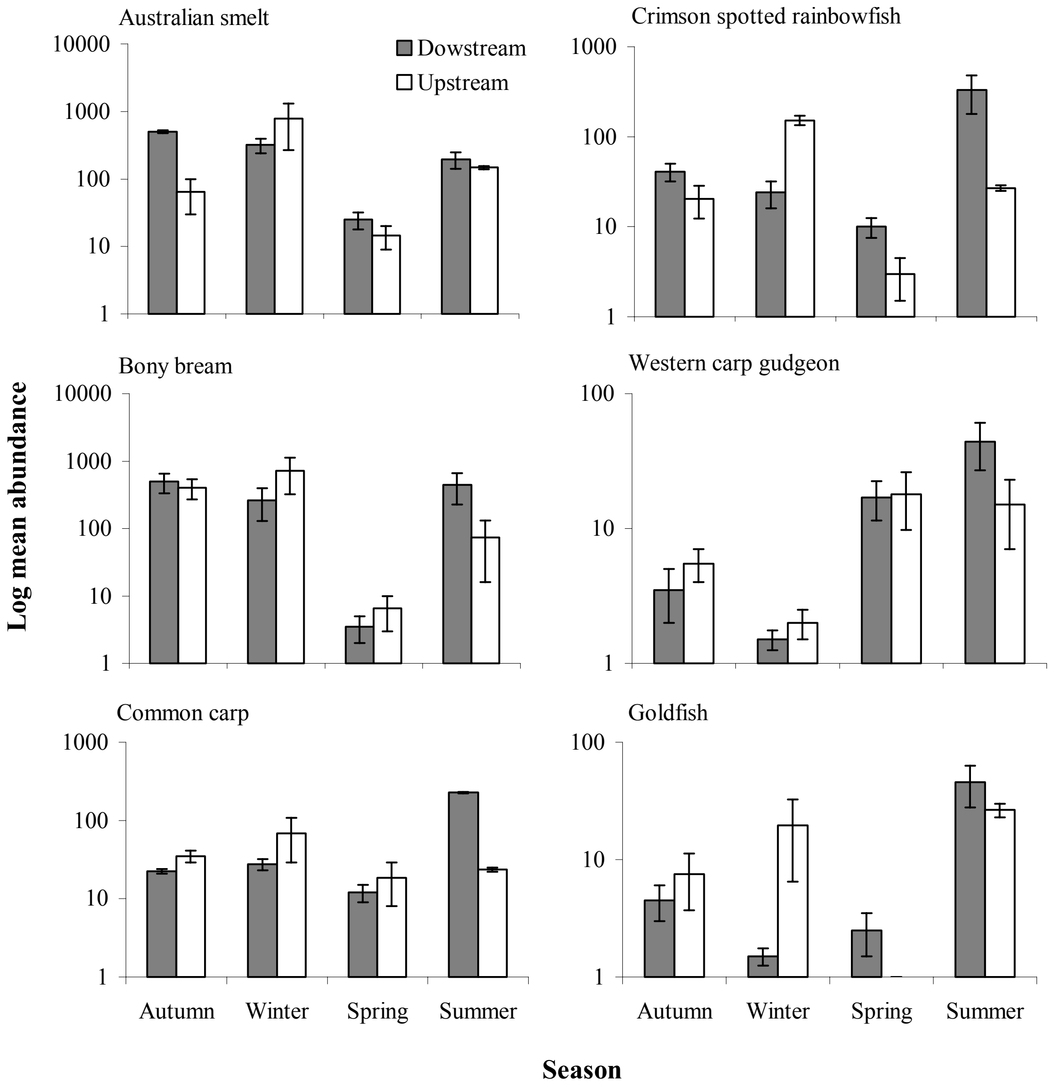

Figure 3. Interaction plot of seasonal changes in log mean relative abundance (±one standard error) for the most common fish species sampled upstream and downstream of Balranald Weir. Error bars represent one standard error.

Table 4. Results of Two-way ANOVA between upstream and downstream regions (R) and seasons (S) for the most common species sampled during the study. Only F-values are given and results are based on log transformed data. Species are: AS, Australian smelt; BB, bony bream; CR, crimson spotted rainbowfish; GP, golden perch; CC, common carp; GF, goldfish; RP, redfin perch. *p<0.05, **p<0.01, ***p<0.001.

Effect	df	Species						
		AS	BB	CR	GP	CC	GF	RP
R	1	0.13	0.03	17.00**	4.08	10.59*	1.10	0.72
S	3	1.86	1.75	25.15***	2.96	14.68**	14.97**	0.87
R*S	3	1.84	1.38	31.52***	0.36	17.57***	5.61*	0.91

3.2. Species richness and Shannon's H'

All species were sampled from both upstream and downstream regions except for eastern gambusia (*Gambusia holbrooki*), which was absent from downstream samples, and flatheaded gudgeon (*Phylipnodon grandiceps*), which was absent from upstream samples. Two way ANOVA determined no significant differences in species richness among seasons or between upstream and downstream regions (Figure 4, Table 5). There was no significant interaction. Despite seasonal changes in relative abundance, little variation in species richness led to significant differences in species diversity (Shannon's H`) among seasons but not between upstream and downstream regions (Table 5). This data suggests some species were dominating catches in some seasons. For example, when relative abundance of most species was low during spring, species diversity was greater (Figure 4). In contrast, greater relative abundances of Australian smelt, crimson-spotted rainbowfish, common carp and bony bream from downstream regions during summer lowered species diversity. The opposite occurred during winter as species diversity was greater from upstream regions where the relative abundance of all species had increased uniformly.

3.3. Differences in length frequencies between species

Only three species, common carp, goldfish, and golden perch were sampled in sufficient numbers from each season to permit length frequency analysis between regions and among seasons. Significant differences (KS: $p<0.05$) in length frequency distributions between upstream and downstream regions were detected in common carp and goldfish during summer months where large numbers of juvenile and young of the year fish were present from downstream samples (Figure 5). In addition, summer was the only season where the relative abundance of alien species was much greater from downstream samples, demonstrating aliens were recruiting well from downstream regions, and that accumulations of fish were predominantly juveniles and young of the year fish (Figure 5).

In contrast to alien species, there were relatively few juvenile golden perch sampled at all. Significant differences in length frequencies were only detected in autumn (KS: ks=0.483, p=0.002) where larger fish were sampled from the upstream region (Figure 6). However, only one individual less than 100mm was sampled over the entire study period, suggesting this species may be recruiting poorly both upstream and downstream of Balranald Weir.

Significant differences in length frequency distribution were also detected for bony bream in all seasons except spring (KS: $p<0.05$). In summer, autumn and winter, significantly greater proportions of smaller individuals were sampled downstream of Balranald Weir with young of the year fish present in greatest proportions during summer and winter (Figure 6). In addition, downstream samples contained the greatest proportions of large individuals during autumn.

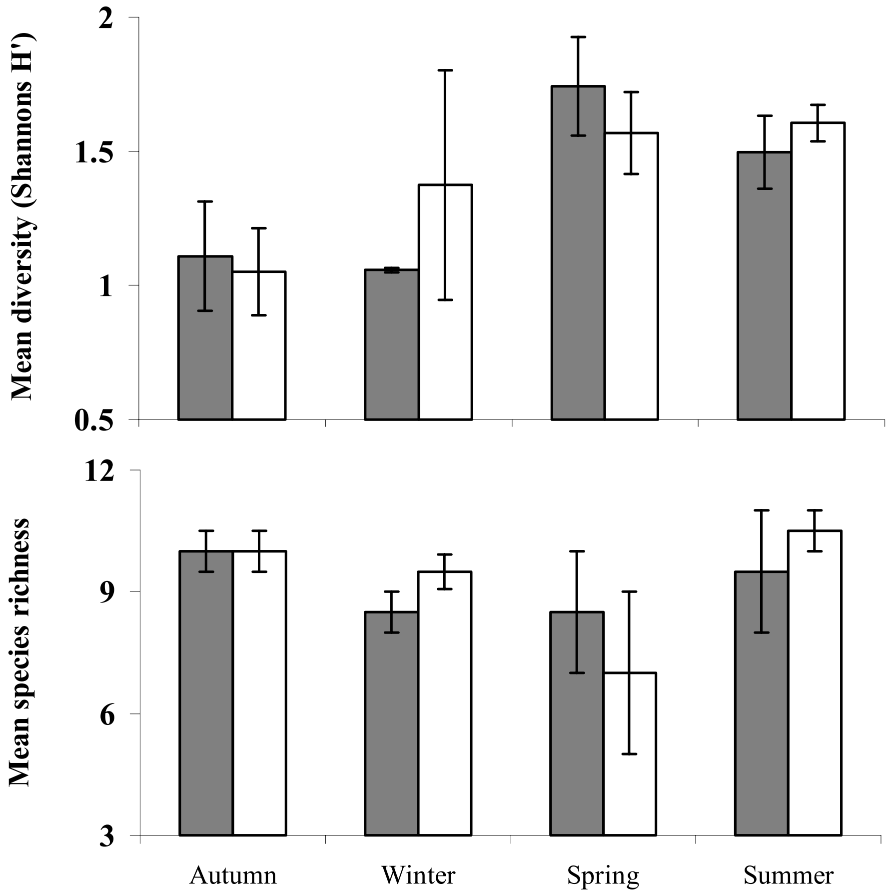

Figure 4. Interaction plots of (a) mean species diversity (Shannon's H' as described by Clarke and Warwick, 1994) and (b) mean species richness and downstream of Balranald Weir on the lower Murrumbidgee River. Error bars represent one standard error.

Table 5. Summary of two-way analysis of variance of species richness, total relative abundance and Shannon's H` between sampling region (upstream and downstream) and seasons on the lower Murrumbidgee River. df is the degrees of freedom for the test. All tabulated values represent the F-statistic of the test. * p<0.05, **p<0.01, ***p<0.001.

Effect	df	Species Richness	Shannon's H`
Region	1	0.03	0.78
Season	3	1.36	9.36**
Region * Season	3	0.57	0.87

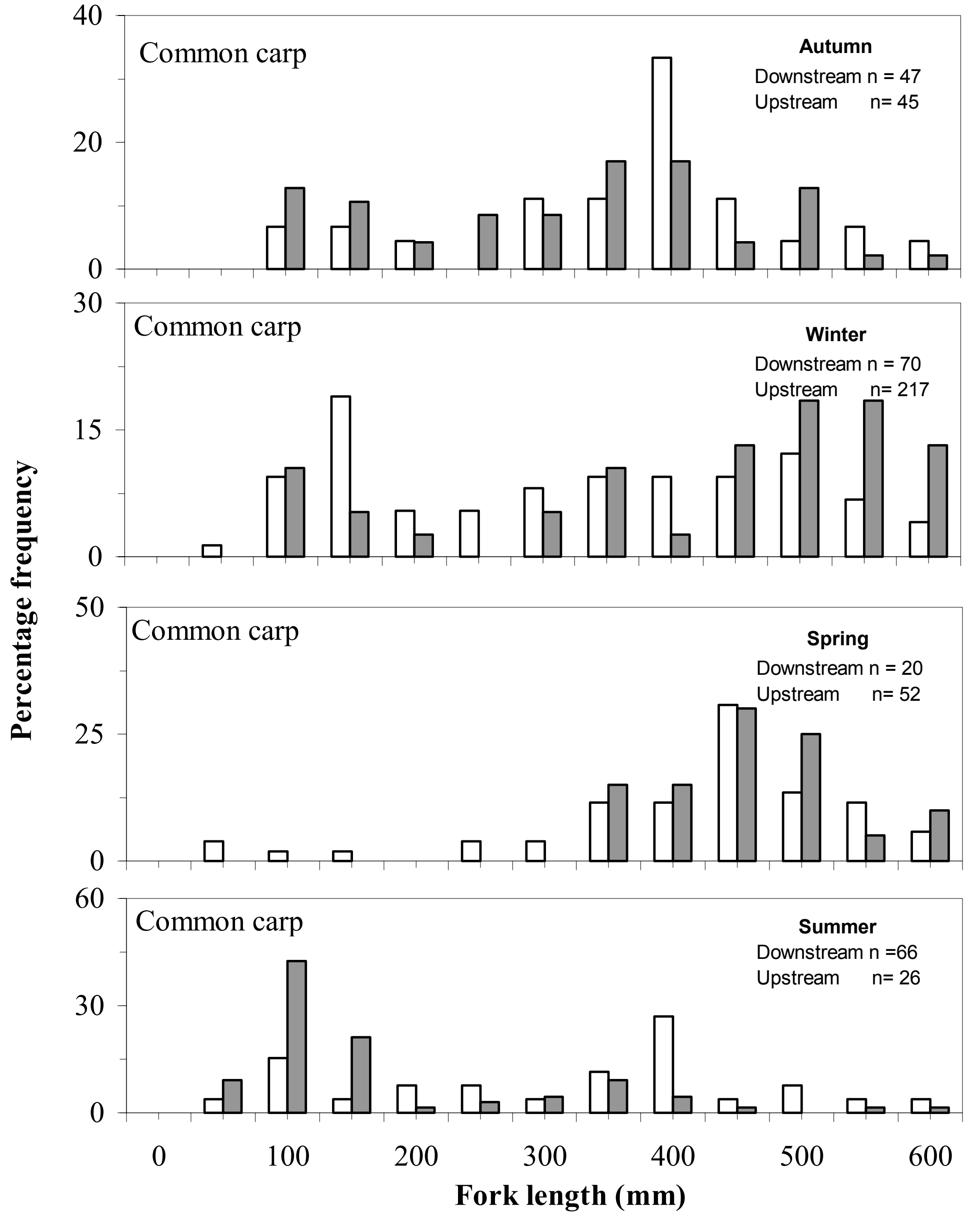

Figure 5. Spatial and temporal changes in length frequency distributions of common carp sampled downstream (grey) and upstream (white) of Balranald Weir. Only comparisons deemed significantly different by Kolmogrorov-Smirnov tests are shown.

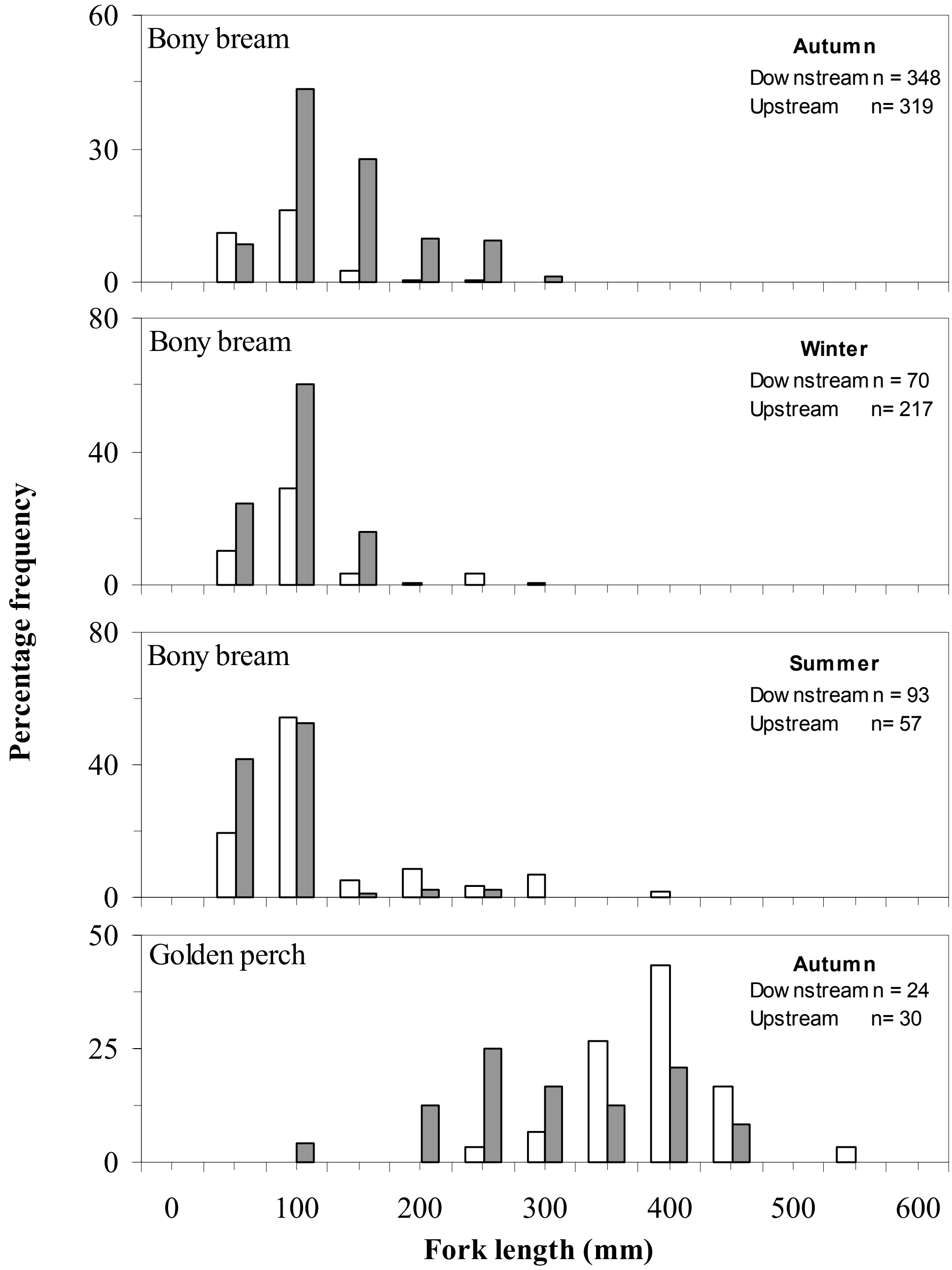

Figure 6. Spatial and temporal changes in length frequency distributions of bony bream (*Nematalosa erebi*) and golden perch (*Macquaria ambigua*) sampled downstream (grey) and upstream (white) of Balranald Weir. Only comparisons deemed significantly different by Kolmogrorov-Smirnov tests are shown.

4. DISCUSSION

4.1. Fish communities upstream and downstream of Balranald Weir

This study has identified that a low-level weir was significantly affecting migratory fish assemblages of the lower Murrumbidgee River on a seasonal basis. The weir was acting as an obstruction to upstream fish passage during summer and autumn when the relative abundance of Australian smelt, fly-specked hardyhead, crimson-spotted rainbowfish, western carp gudgeon, common carp and goldfish was greater downstream of Balranald Weir than at any other site.

Australian smelt, one of the most common species, was observed to accumulate downstream of Balranald Weir during summer and autumn. Within the Murray-Darling Basin, this species was previously recorded migrating through a vertical slot fishway at Torrumbarry Weir on the Murray River (Mallen-Cooper, 1996), rock ramp fishways on the Namoi River (Baumgartner and Lay, 2001), MacIntyre River and Bell River (Thorncraft and Harris, 1996) and a lock fishway on the Murrumbidgee River (Baumgartner, 2003; Chapter 6). Although accumulations downstream of Balranald Weir observed in this study were not surprising, the requirement for upstream passage varied with time of year. The greatest difference in relative abundance between upstream and downstream regions was during summer and autumn, demonstrating this species can have an extended migratory period.

Bony bream have been sampled actively migrating upstream in a number of studies (Mallen-Cooper and Brand, 1992; Mallen-Cooper, 1996; Thorncraft and Harris, 1996; Baumgartner and Lay 2001) but few of these studies have documented temporal variation in such behaviour. Most migration in other clupeid species is typically anadromous (Messiah, 1977; Loesch, 1987; Jessop, 1994) and exclusively freshwater representatives of this family are generally non-migratory (Lucas and Baras, 2003). In contrast, bony bream commonly migrate through fishways in the Murray-Darling Basin with activity greatest in late summer and smallest in late spring (Mallen–Cooper, 1996). Accumulations of this species downstream of Balranald Weir, including both adults and juveniles, were greatest during summer and are consistent with previous studies (Mallen-Cooper, 1996; Harris *et al*, 1998).

Prior to this study, there were few accounts of migrations in crimson-spotted rainbowfish, flyspecked hardyhead or western carp gudgeon within the Murray-Darling Basin and it was suggested these species only undertake localised movements (Harris and Gehrke, 1997). A species of coastal melanotaenid, *M. splendida*, is known to undertake long upstream migrations during autumn in the tropical Alligator River (Bishop *et al*, 1995). Similarly, species of hardyhead (atherinidae) are also known to migrate through a vertical slot fishway on the Fitzroy River barrage (Stuart and Mallen-Cooper, 1999). Data collected at Balranald Weir suggest fish within these families also migrate within the Murray Darling Basin, especially during summer, when they were observed to accumulate downstream. This interpretation was further supported when flyspecked hardyhead and crimson spotted rainbowfish passed through a recently constructed fishlock at Balranald Weir (Baumgartner, 2003) and suggests these species may benefit from improved passage at other weirs within the Murray Darling Basin.

Excluding flatheaded gudgeon and eastern gambusia, all small fish species were present downstream of Balranald Weir in all seasons but their relative abundance was generally greatest following periods of high flow in spring. Displacements of fish by high flow are not uncommon, and large numbers of coastal fish were previously reported to be transported downstream of a large dam on the Fitzroy River during a flood event (Stuart and Berghuis, 1997). Similarly, accumulations of 1+ fish immediately downstream of a large dam on the Warta River in Poland were also thought to have been attempting to counter displacement during floods (Penczak *et al,* 1998). Small species have relatively poor swimming abilities (Mitchell, 1989; Mallen-Cooper and Brand, 1992) and would be expected to be susceptible to downstream displacement during high flow events. If downstream displacements after high flows are frequent, the provision of passage after periods of high flow may be critical for recolonisation of upstream habitat.

Reductions of downstream accumulations during winter, and also the low relative abundances of fish during spring, were likely impacted by reduced water temperature, and subsequently reduced activity by individual fish. Araujo *et al* (1999) demonstrated that temperature had a significant influence on temporal changes in fish assemblages of the Thames River, with some species decreasing in relative abundance as temperatures fell. In addition, Northern Hemisphere clupeids (Slotte, 1999; Vaboe *et al*, 2002) and salmonids (Seki *et al*, 2000) are known to cease upstream migrations and seek wintering habitat until water temperatures subsequently rise in spring. In the Murray River common carp, golden perch, silver perch, bony bream or redfin perch do not migrate during the months of May to September (i.e. winter and early spring), when water temperatures are significantly lower (Mallen-Cooper, 1996). The results of the present study are consistent with these findings, as accumulations of Australian smelt, crimson-spotted rainbowfish, western carp gudgeon and alien species such as common carp and goldfish, were sampled downstream of Balranald Weir in greatest relative abundance during summer and autumn when water temperatures were warmest. All of these species have a widespread distribution throughout the entire Murray-Darling Basin (McDowall, 1996; Allen, 2002) and seasonal accumulations could be readily expected at many other barriers to migration. Therefore, improving opportunities for passage, at least during summer and autumn, would enable large proportions of the migratory community to continue upstream migrations.

For at least one species, bony bream, seasonal accumulations can be related to previously observed spawning behaviour, as was suggested by Mallen-Cooper (1996). Adult bony bream are known to perform upstream migrations in spring and summer (Mallen-Cooper and Brand, 1992) and spawn until the end of autumn (Puckridge and Walker; 1991). Downstream of Balranald Weir, adults formed a high proportion of catches in spring samples whilst young-of-the-year fish dominated catches in summer and winter. The appearance of young-of-the-year fish in summer suggests that this species spawned in spring or earlier. Further, the reappearance of similar sized young-of-the-year fish in winter is also suggestive of a repeat spawning sometime in autumn. Therefore, any obstruction to passage during these seasons could limit spawning success in bony bream.

Accepted migratory species such as golden perch, silver perch and Murray cod were not common in either upstream or downstream reaches during this study. The rarity of these fish might be an issue of catchability, but this is unlikely. The present study sampled fish accumulations from riverine habitats using boat electrofishing, whereas previous studies have used panel nets, fyke nets (Harris *et al*, 1992; Mallen-Cooper, 1996) and drum nets (Harris *et al*, 1992) which are particularly effective for sampling large migratory fish from deep habitats under high flows. Although electrofishing is limited in the depth over which it is effective (Koehn and McKenzie, 1985; Bohlin *et al*, 1989; Harvey and Cowx, 1996), the depth immediately downstream of weirs sampled in this study was less than 1.5m in all instances, and is within the effective range of boat electrofishing. Furthermore, few juvenile individuals of these species were sampled indicating that either spawning or recruitment may be limited in this section of river.

4.2. Effects of Balranald Weir on species diversity (Shannon's H`) and richness

Dam and weir construction can seriously affect species richness and diversity. Gehrke *et al* (1995) and later Gehrke and Harris (2001) identified significant decreases in species richness and diversity in reaches downstream of dams in regulated Australian streams. In the Northern Hemisphere, species richness and evenness decreased significantly only 3 years after the construction of the Pitit-Saut Dam on the Sinnamary River (De Merona and Albert, 1999). Similarly, localised extinctions of fish species were observed only four years after the construction of a dam on the

Warta River (Penczac *et al*, 1998). These observations suggest that the effects of dams and weirs on species richness may be quite sudden and the impact of Balranald Weir was probably most dramatic in the years immediately following its construction. On the Murrumbidgee River, seasonal changes in the relative abundance of bony bream, Australian smelt, crimson-spotted rainbowfish and common carp influenced species diversity (Shannon's H`), especially during spring, summer and autumn. By improving passage during times when these species are likely to accumulate, possibly by increasing the frequency and duration of temporary weir removal, weir inundation events or constructing a fishway, the adverse seasonal effects of Balranald Weir on species diversity (Shannon's H`) may be reduced. Original ecosystem structure may be restored to at least some degree, if such methods benefit all species and size classes.

4.3. Proliferation of alien species

Adult alien fish were frequently sampled in all seasons but large numbers of young of the year common carp, goldfish and redfin perch were most common in summer. Young-of-the-year fish were less commonly sampled from upstream samples, suggesting these species are recruiting well downstream of Balranald Weir. Although few juvenile fish were present in spring samples, this is consistent with other studies documenting alien fish recruitment in Australian systems (Gehrke et al, 1995; Harris and Gehrke, 1997; Stuart and Jones, 2002; Gilligan and Schiller, 2003). However, during spring juveniles are most likely to be caught as larvae (Humphries and Lake, 2000; Humphries et al, 2002; Stuart and Jones, 2002; Gilligan *et al*, 2003) which are inefficiently sampled by electrofishing.

In contrast to native fish species, aliens are frequently reported to benefit, at least relatively, from the construction of a dam or weir (Martinez *et al,* 1994*;* Taylor *et al*, 2001; Koel and Sparks, 2002). In less than a decade, the fish assemblage of the lower White River (Colorado) significantly decreased in relative abundance and changed from a composition of 90% native to 80% alien species after the construction of Taylor Draw Dam (Martinez *et al*, 1994). Similarly, common carp became established in the Shoalhaven River system following the construction of Tallowa Dam (Gehrke *et al*, 2002). Dams and weirs have also been responsible for observed inverse relationships between the relative abundance of alien and native species in Caribbean streams (Holmquist, *et al*, 1997). Although no pre-construction sampling was possible, the present study supported these observations because alien species were well represented, relative to large native species, in the lower Murrumbidgee River 23 years after Balranald Weir was completed.

Seasonal accumulations of juvenile alien fish downstream of weirs are a phenomenon rarely reported in Australia (Stuart and Jones, 2002). Such behaviour may render these species susceptible to control measures such as capture in selective separation cages, which are presently in trial on the Murray River (see Stuart and Jones, 2002). A limitation of this technology is that it is currently only suitable for large individuals that have the ability to jump. However, developing this technology to selectively trap alien species of all sizes could help control the proliferation of these species throughout the Murray Darling Basin through species selective harvesting during periods of accumulations downstream of weirs.

4.4. Mitigating the effects of Balranald Weir

Balranald Weir is usually partially removed when flows exceed 4,500ML.day^{-1} (Ebsary, 1992). Since some species of native fish are known to migrate during high flows (Reynolds, 1983; Battaglene, 1991; Mallen-Cooper, 1996), weir removal may provide increased opportunities for upstream passage. Adult silver perch, golden perch and spangled perch (*Leiopotherapon unicolor*), were observed to successfully pass Bourke Weir (Darling River) as it became inundated during a flood event (Harris *et al*, 1992). Unfortunately, these previous studies only confirmed passage for large native fish during times of weir inundation and the issue of small fish passage was not addressed. The occasional removal of Balranald Weir is likely to provide passage for many more species as the dropboards that create the weir crest are totally removed, thus restoring relatively natural flow conditions during floods.

The lack of significant differences in species richness upstream and downstream of Balranald Weir may be explained by increased opportunities for fish passage during the temporary removal of dropboards when flooded. Similarly, regular cycles of flooding helped maintain species diversity upstream of a small dam on the Niger River (Victor and Tetteh, 1988). To be efficient at providing passage, periods of weir inundation must occur relatively frequently, during peak periods of migration and last for an appropriate period of time, to allow a sufficient proportion of fish to migrate upstream (Gilligan *et al,* 2003). However, fish continued to accumulate downstream of Balranald Weir even after the dropboards were replaced suggesting current weir removal events are of insufficient duration to provide passage for all species.

In Australian coastal systems, accumulations of small catadromous fish species downstream of dams and weirs are common. Downstream of Tallowa Dam on the Shoalhaven River, large relative abundances of Australian smelt and some gudgeon species (Eleotridae) have been reported on a number of occasions (Bishop and Bell, 1978; Gehrke *et al,* 2002). Similarly, a number of gudgeon species were netted whilst accumulating downstream of a tidal barrage on the sub-tropical Fitzroy River (Stuart and Mallen-Cooper, 1999). These coastal fishways must be constructed on conservative slopes, which lower water velocity and turbulence, to enable small fish with relatively poor swimming abilities to ascend (Mallen-Cooper, 2000). Once these fishways are constructed, the effects of weirs on small fish of coastal streams are effectively mitigated.

Constructing fishways is a common method to mitigate effects of weirs in the Murray-Darling Basin (Mallen-Cooper, 2000). At Torrumbarry Weir on the Murray River, downstream accumulations of golden perch, silver perch and common carp significantly decreased as passage was restored upon fishway construction (Mallen-Cooper, 1996). However, the fishway was inefficient at passing small fish species as large numbers of Australian smelt were observed to accumulate at the fishway entrance. Consequently these fish, which are hypothesised to only negotiate flows less than 1.4 ms^{-1} (Mallen-Cooper and Brand, 1992), did not successfully ascend the fishway in large numbers despite the fishway being constructed on a conservative 1:18 slope (Mallen-Cooper, 1996). Applying the principles of fishway construction used for small fish on coastal streams would facilitate the design of more effective fishways within the Murray Darling Basin (Mallen-Cooper, 2000). Migratory pathways would then be restored to a wider range of species and size classes of native fish. In light of the small fish accumulations observed at Balranald Weir, this should be seen as a research priority.

5. SUMMARY AND RECOMMENDATIONS

(i) This study determined that small fish species, previously not considered migratory, such as Australian smelt, western carp gudgeon, crimson-spotted rainbowfish and fly-specked hardyhead were seeking upstream movement. Given the magnitude of these attempted migrations, it is recommended that these species be considered when designing fish passage facilities in the Murray-Darling Basin.

(ii) Fish were present from downstream samples in highest relative abundance during summer and autumn when migratory behaviour was greatest. As there was wide seasonal variation between species it is recommended that functional fishways, to cater for small species, are constructed in the Murray Darling Basin and operate continually.

(iii) High catches of juvenile alien species downstream of Balranald Weir further indicated that these actively seek upstream migration in lowland river reaches. These observations have been seen elsewhere in the Murray Darling Basin and it is recommended that research be conducted into possible control mechanisms that exploit this behaviour.

(iv) Although Balranald Weir was removed periodically during this study, there was little evidence to suggest that this adequately provided passage for all species because fish continued to accumulate after the event. Further, there was no detectable increase in relative fish abundance upstream of the weir. Whilst the removal of Balranald Weir most likely restored passage to some species in the short term, it does not represent a permanent option for fish passage at this site.

6. REFERENCES

Agostinho, A.A., Gomes, L.C., Fernandez, D.R. and Suzuki, H.I. (2002). Efficiency of fish ladders for neotropical ichthyofauna. *River Research and Applications*, **18:** 299-306.

Allan, J.D. and Flecker, A.S. (1993). Biodiversity conservation in running waters. *Bioscience* **43:** 32-43.

Araujo, P.G., Bailey, R.G. and Williams, W.P. (1999). Spatial and temporal variations in fish populations in the upper Thames estuary. *Journal of Fish Biology*, **55:** 836 – 853.

Battaglene, S.C. (1991). The Golden Perch, *Macquaria ambigua*, (PISCES: PERCICHTHYIDAE) of Lake Keepit, NSW. Masters Thesis, University of New South Wales.

Baumgartner, L. and Lay, C. (2001). The effectiveness of partial width rock ramp fishways. In: R.J. Keller and C. Peterken (eds) *Proceedings of the Third Annual Technical Workshop on Fishways,* Monash University, Melbourne.

Bishop, K.A. and Bell, J.D. (1978). Observations on the fish fauna below Tallowa Dam (Shoalhaven River, New South Wales) during flow stoppages. *Australian Journal of Marine and Freshwater Research,* **29:** 543-549.

Bishop, K.A., Pidgeon, R.W.J and Walden, D.J. (1995). Studies of fish movement dynamics in a tropical floodplain river: prerequisites for a procedure to monitor the impacts of mining. *Australian Journal of Ecology*, **20:** 81-107.

Bohlin, T., Hamrin, S., Heggberget, T.G., Rasmussen, G. and Saltveit, S.J. (1989). Electrofishing – Theory and practice with special emphasis on salmonids. *Hydrobiologia.* **173:** 9-43.

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

Cadwallader, P. and Lawrence, B. (1990). Fish. In: D. Mackay (ed.). *The Murray*. Murray-Darling Basin Commission, Canberra, pp. 316-335.

Clarke, K.R. and Warwick, R.M. (1994). *Change in Marine Communities: An approach to statistical analysis and interpretation.* Bourne Press Limited, Plymouth.

Cortes, R.M.V., Ferreira, M.T., Oliveria, S.V. and Gondinho, F. (1998). Contrasting impact of small dams on the macroinvertebrates of two Iberian mountain rivers. *Hydrobiologia,* **389:** 51-61.

Ebsary, R. (1992). Regulation of the Murrumbidgee River. In J Roberts and R Oliver (eds), *The Murrumbidgee Past and present*. CSIRO Division of Water Resources. pp. 125.

Fjellheim, A. and Raddum, G.G. (1996). Weir building in a regulated west Norwegian River: Long term dynamics of invertebrates and fish. *Regulated Rivers: Research and Management*, **12:** 501-508.

Gehrke, P.C. and Harris, J.H. (2001). Region-scale effects of flow regulation on lowland riverine fish communities in New South Wales, Australia. *Regulated Rivers: Research and Management*, **17:** 369-391.

Gehrke, P.C., Brown, P., Schiller, C.B., Moffatt, D.B., and Bruce, A.M. (1995). River regulation and fish communities in the Murray-Darling River System, Australia. *Regulated Rivers Research and Management*, **2:** 363-375.

Gehrke, P.C., Gilligan, D.M. and Barwick, M. (2002). Changes in fish communities of the Shoalhaven River 20 years after construction of Tallowa Dam, Australia. *River Research and Applications* **18:** 265-286.

Gilligan, D.M., Harris, J.H. and Mallen-Cooper, M. (2003). Monitoring changes in Crawford River fish community following replacement of an ineffective fishway with a vertical-slot fishway design: Results of an eight year monitoring program. NSW Fisheries Final Report Series No. 45, NSW Fisheries Office of Conservation, Narrandera.

Harris, J.H. and Gehrke, P.C. (eds). (1997). *Fish and Rivers in Stress: The NSW Rivers Survey.* NSW Fisheries Office of Conservation and the Cooperative Research Center for Freshwater Ecology, Canberra.

Harris, J.H., Edwards, E.D. and Curran, S.J. (1992). Bourke Weir Fish Passage Study. NSW Fisheries report to the NSW Department of Water Resources. 18pp.

Harris, J.H., Thorncraft, G.A. and Wem, P. (1998). Evaluation of rock ramp fishways in Australia. In M. Jungwirth, S. Schmutz and S. Weiss (eds), *Fish Migration and Fish Bypasses*. Fishing News Books, Oxford. pp. 331-347.

Harvey, J. and Cowx, I.G. (1996). Electric fishing for the assessment of fish stocks in large rivers. In: I.G. Cowx (ed), *Stock assessment in inland fisheries*. Fishing News Books, Oxford. 513pp.

Holmquist, J.G., Schmidt-Gengenbach, J.M. and Yoshioka, B.B. (1998). High dams and Marine-Freshwater linkages: Effects on native and introduced fauna in the Caribbean. *Conservation Biology*, **12 (3):** 621-630.

Humphries, P. and Lake, P.S. (2000). Fish larvae and management of regulated rivers. *Regulated Rivers: Research and Management* **16:** 421-432.

Humphries, P., King, A. and Koehn, J.D. (1999). Fish flows and floodplains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes.* **56:** 129-151.

Humphries, P., Serafini, L.G. and King, A. (2002). River regulation and fish larvae: variation through space and time. *Freshwater Biology*, **47:** 1307-1331.

Insightful Corporation. (2001). S-PLUS 6 for Windows users guide. Insightful Corporation, Seattle.

Jansen W., Berthold, K. and Böhmer, J. (1998). Fish diets and densities of benthos upstream and downstream of a man-made barrier on the Glems River, Baden-Württemberg, Germany. *Polish Archives of Hydrobiology*, **43 (2):** 225-244.

Jessop, B.M. (1994). Homing of alewives (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*) to and within the Saint John River, New Brunswick, as indicated by tagging data. *Canadian Technical Report of Fisheries and Aquatic Sciences*, **2005:** 1-25.

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

Koehn, J., Doeg, T., Harrington, D., Milledge, G. (1996). Dartmouth Dam: Effects on the downstream aquatic fauna. In: R.J. Banens and R. Lehane (Eds) P*roceedings 1995 Riverine Environment Research Forum* Murray Darling Basin Commission, Attwood. pp. 44-56.

Koehn, J.D. and McKenzie, J.A. (1985). Comparison of electrofisher efficiencies. Arthur Rylah Institute for Environmental Research, Technical Report Series No. 27. 24pp.

Koel, T.M. and Sparks, R.E. (2002). Historical patterns of river stage and fish communities as criteria for operations of dams on the Illinois River. *River Research and Applications* **18:** 3-19.

Lake, J.S. (1971). *Freshwater fishes and rivers of Australia*. Nelson publishing, Melbourne.

Loesch, J.G. (1987). Overview of the life history of anadromous alewife and blueback herring in freshwater habitats. *American Fisheries Society Symposium,* **1:** 89-103.

Lucas, M.C. and Baras, E. (2003). *Migration in freshwater fishes*. Blackwell Science, Oxford.

Lucas, M.C. and Frear, P.A. (1997). Effects of a flow-gauging weir on the migratory behaviour of adult barbel, a riverine cyprinid*. Journal of Fish Biology,* **50:** 382-396.

Mallen-Cooper, M. and Brand, D. (1991). Assessment of two fishways on the River Murray and historical changes in fish movement. Report to the Murray Darling Basin Commission, NSW Fisheries.

Mallen-Cooper M. and Harris J. (1990). Fishways in mainland south-eastern Australia. In: S. Komura (ed) *Proceedings of the International Symposium on Fishways '90*. Japan. 221-229.

Mallen-Cooper, M. (1989). Fish passage in the Murray-Darling Basin. In: B Lawrence (ed) *Proceedings of the Native Fish Management Workshop*. Murray-Darling Basin Commission, Canberra, 123-136.

Mallen-Cooper, M. (1996). Fishways and freshwater fish migration in South-Eastern Australia. PhD Thesis, University of technology, Sydney.

Martinez, P.J., Chart, T.E., Trammell, M.A., Wullschleger, J.G. and Bergersen, E.P. (1994). Fish species composition before and after construction of a mainstream reservoir on the White River, Colorado*. Environmental Biology of Fishes*, **40:** 227-239.

Messieh S.N. (1977). Population structures and biology of alewives (*Alosa pseudoharengus*) and blue-back herring (*Alosa aestivalis*) in the St John River, New Brunswick*. Environmental Biology of Fishes*, **2:** 195-210.

Mitchell, C.P. (1989). Swimming performances of some native freshwater fishes. *New Zealand Journal of Marine and Freshwater Research.* **23:** 181 – 187.

Moring, J.R. (1993). Anadromous stocks. In CC Kohler and WA Hubert (eds) *Inland fisheries management in North America*. American Fisheries Society, Bethedsa. pp. 553-580.

Pavlov, D.S. (1979). Structures assisting the migrations of non-salmonid fish: USSR. FAO Fisheries Technical Paper No. 308, Rome.

Penczak, T., Glowacki, L., Galicka, W. and Kozalinski, H. (1998). A long-term study (1985-1995) of fish populations in the impounded Warta River, Poland. *Hydrobiologia*, **368:** 157-173.

Pethebridge, R., Lugg, A. and Harris, J.H. (1998). *Obstructions to fish passage in New South Wales South Coast streams*. Cooperative Research Centre for Freshwater Ecology and NSW Fisheries, Cronulla.

Puckridge, J.T. and Walker, K.F. (1990). Reproductive biology and larval development of a Gizzard shad, *Nematalosa erebi* (Günther) (Forosomatinae: Teleostei), in the River

Murray, South Australia. *Australian Journal of Marine and Freshwater Research*, **41:** 695-712.

Reynolds, L.F. (1983). Migration patterns of five fish species in the Murray- Darling River system. *Australian Journal of Marine & Freshwater Research* **34:** 857-872.

Rivinoja, P., McKinnell, S. and Lundqvist, H. (2001). Hindrances to upstream migration of Atlantic Salmon (*Salmo salar*) in a Northern Swedish River caused by a hydroelectric power station. *Regulated Rivers: Research and Management*, **17:** 101-115.

Seki, Y., Uchida, Y., Sato, G. and Hosino, M. (2000). Over wintering downstream migration to the Okutadami Dam Lake in the juvenile masu salmon released in the Kitanomata River, Niigata Prefecture. Niigita Prefect Report - Inland Water Fish Experiment Station. No. 24**:** 19-26.

Slotte, A. (1999). Differential utilisation of energy during wintering and spawning migration in Norwegian spring-spawning herring. *Journal of Fish Biology*, **52 (2):** 338-355.

Sokal, R.R. and Rohlf, F.J. (1996). *Biometry*. WH Freeman and Company, New York.

Stuart, I.G. and Berghuis, A.P. (1997). Assessment of Eden Bann Weir Fishlock Fitzroy River. Queensland. Department of Primary Industries, Rockhampton. 50pp.

Stuart, I. and Jones, M. (2002). Ecology and management of common carp in the Barmah-Millewa forest. Arthur Rylah Institute, Heidelberg.

Stuart, I.G. and Mallen-Cooper, M. (1999). An assessment of the effectiveness of a vertical-slot fishway for non-salmonid fish at a tidal barrier on a large tropical/subtropical river. *Regulated Rivers: Research and management*. **15:** 575-590.

Thorncraft, G.T. and Harris, J.H. (1996). Assessment of rock ramp fishways. NSW Fisheries Research Institute and the Cooperative Research Centre for Freshwater Ecology. 39pp.

Thorncraft, G.T. and Harris, J.H. (2000). Fish passage and fishways in New South Wales: A status report. Cooperative research Centre for freshwater ecology, Canberra. 32pp.

Townsend, G.H. (1975). Impact of the Bennett Dam on the Peace-Athabasca Delta. *Journal of the Fisheries Research Board of Canada*. **32:** 171-176.

Vaboe, R., Olsen, K. and Huse, I. (2002). The effect of vessel avoidance of wintering Norwegian spring spawning herring. *Fisheries Research,* **58 (1):** 59-77.

Victor, R. and Tetteh, J.O. (1988). Fish communities of a perturbed stream in southern Nigeria. *Journal of Tropical Ecology*, **4:** 49 – 59.

Wager, R. and Jackson, P.D. (1993). The Action Plan for Australian Freshwater Fishes. Australian Nature Conservation Agency.

Walker, K.F. (1985). A review of the ecological effects of river regulation in Australia. *Hydrobiologia*. **125:** 111-129.

Walker, K.F. (1992). The River Murray, Australia: A semiarid lowland river. In: P. Calow and G.E. Petts (eds). *The Rivers Handbook Volume 1*. Blackwell Science. pp 472-492.

Other titles in this series:

ISSN 1440-3544

No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. Final Report to Fisheries Research and Development Corporation. Project No. 96/139.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters. Final Report to Fisheries Research and Development Corporation. Project No. 94/024.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales. Final Report to Fisheries Research and Development Corporation. Project No. 95/151.

No. 4 Pethebridge, R., Lugg, A. and Harris, J., 1998. Obstructions to fish passage in New South Wales South Coast streams. Final report to Cooperative Research Centre for Freshwater Ecology. 70pp.

No. 5 Kennelly, S.J. and Broadhurst, M.K., 1998. Development of by-catch reducing prawn-trawls and fishing practices in NSW's prawn-trawl fisheries (and incorporating an assessment of the effect of increasing mesh size in fish trawl gear). Final Report to Fisheries Research and Development Corporation. Project No. 93/180. 18pp + appendices.

No. 6 Allan, G.L. and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. Final Report to Fisheries Research and Development Corporation. Project No. 93/120-03. 237pp + appendices.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. Final Report to Fisheries Research and Development Corporation. Project No. 93/120. 54pp + appendices.

No. 8 Heasman, M.P., O'Connor, W.A. and O'Connor, S.J., 1998. Enhancement and farming of scallops in NSW using hatchery produced seedstock. Final Report to Fisheries Research and Development Corporation. Project No. 94/083. 146pp.

No. 9 Nell, J.A., McMahon, G.A. and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. Final Report to Cooperative Research Centre for Aquaculture. Project No. D.4.2. 25pp.

No. 10 Nell, J.A. and Maguire, G.B., 1998. Commercialisation of triploid Sydney rock and Pacific oysters. Part 1: Sydney rock oysters. Final Report to Fisheries Research and Development Corporation. Project No. 93/151. 122pp.

No. 11 Watford, F.A. and Williams, R.J., 1998. Inventory of estuarine vegetation in Botany Bay, with special reference to changes in the distribution of seagrass. Final Report to Fishcare Australia. Project No. 97/003741. 51pp.

No. 12 Andrew, N.L., Worthington D.G., Brett, P.A. and Bentley N., 1998. Interactions between the abalone fishery and sea urchins in New South Wales. Final Report to Fisheries Research and Development Corporation. Project No. 93/102.

No. 13 Jackson, K.L. and Ogburn, D.M., 1999. Review of depuration and its role in shellfish quality assurance. Final Report to Fisheries Research and Development Corporation. Project No. 96/355. 77pp.

No. 14 Fielder, D.S., Bardsley, W.J. and Allan, G.L., 1999. Enhancement of Mulloway (*Argyrosomus japonicus*) in intermittently opening lagoons. Final Report to Fisheries Research and Development Corporation. Project No. 95/148. 50pp + appendices.

No. 15 Otway, N.M. and Macbeth, W.G., 1999. The physical effects of hauling on seagrass beds. Final Report to Fisheries Research and Development Corporation. Project No. 95/149 and 96/286. 86pp.

No. 16 Gibbs, P., McVea, T. and Louden, B., 1999. Utilisation of restored wetlands by fish and invertebrates. Final Report to Fisheries Research and Development Corporation. Project No. 95/150. 142pp.

No. 17 Ogburn, D. and Ruello, N., 1999. Waterproof labelling and identification systems suitable for shellfish and other seafood and aquaculture products. Whose oyster is that? Final Report to Fisheries Research and Development Corporation. Project No. 95/360. 50pp.

No. 18 Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P. and Walford, T.R., 2000. Sampling estuarine fish species for stock assessment. Includes appendices by D.J. Ferrell, B.C. Pease, T.R. Walford, G.N.G. Gordon, C.A. Gray and G.W. Liggins. Final Report to Fisheries Research and Development Corporation. Project No. 94/042. 194pp.

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

No. 20 Allan, G.L. and Rowland, S.J., 2000. Consumer sensory evaluation of silver perch cultured in ponds on meat meal based diets. Final Report to Meat & Livestock Australia. Project No. PRCOP.009. 21pp + appendices.

No. 21 Kennelly, S.J. and Scandol, J. P., 2000. Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery. Final Report to Fisheries Research and Development Corporation. Project No. 96/135. 43pp + appendices.

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

No. 23 Survey Development Working Group, 2000. Development of the National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. Project No. 98/169. (Volume 1 – 36pp + Volume 2 – attachments).

No.24 Rowling, K.R and Raines, L.P., 2000. Description of the biology and an assessment of the fishery of Silver Trevally *Pseudocaranx dentex* off New South Wales. Final Report to Fisheries Research and Development Corporation. Project No. 97/125. 69pp.

No. 25 Allan, G.L., Jantrarotai, W., Rowland, S., Kosuturak, P. and Booth, M., 2000. Replacing fishmeal in aquaculture diets. Final Report to the Australian Centre for International Agricultural Research. Project No. 9207. 13pp.

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

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

No. 28 Otway, N.M., 1999. Identification of candidate sites for declaration of aquatic reserves for the conservation of rocky intertidal communities in the Hawkesbury Shelf and Batemans Shelf Bioregions. Final Report to Environment Australia for the Marine Protected Areas Program. Project No. OR22. 88pp.

No. 29 Heasman, M.P., Goard, L., Diemar, J. and Callinan, R., 2000. Improved Early Survival of Molluscs: Sydney Rock Oyster (*Saccostrea glomerata*). Final report to the Aquaculture Cooperative Research Centre. Project No. A.2.1. 63pp.

No. 30 Allan, G.L., Dignam, A and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 1. R&D Plan. Final Report to Fisheries Research and Development Corporation. Project No. 1998/335.

No. 31 Allan, G.L., Banens, B. and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 2. Resource Inventory and Assessment. Final report to Fisheries Research and Development Corporation. Project No. 1998/335. 33pp.

No. 32 Bruce, A., Growns, I. and Gehrke, P., 2001. Woronora River Macquarie Perch Survey. Final report to Sydney Catchment Authority, April 2001. 116pp.

No. 33 Morris, S.A., Pollard, D.A., Gehrke, P.C. and Pogonoski, J.J., 2001. Threatened and Potentially Threatened Freshwater Fishes of Coastal New South Wales and the Murray-Darling Basin. Report to Fisheries Action Program and World Wide Fund for Nature. Project No. AA 0959.98. 177pp.

No. 34 Heasman, M.P., Sushames, T.M., Diemar, J.A., O'Connor, W.A. and Foulkes, L.A., 2001. Production of Micro-algal Concentrates for Aquaculture Part 2: Development and Evaluation of Harvesting, Preservation, Storage and Feeding Technology. Final Report to Fisheries Research and Development Corporation. Project No. 1993/123 and 1996/342. 150pp + appendices.

No. 35 Stewart, J. and Ferrell, D.J., 2001. Mesh selectivity in the NSW demersal trap fishery. Final Report to Fisheries Research and Development Corporation. Project No. 1998/138. 86pp.

No. 36 Stewart, J., Ferrell, D.J., van der Walt, B., Johnson, D. and Lowry, M., 2001. Assessment of length and age composition of commercial kingfish landings. Final Report to Fisheries Research and Development Corporation. Project No. 1997/126. 49pp.

No. 37 Gray, C.A. and Kennelly, S.J., 2001. Development of discard-reducing gears and practices in the estuarine prawn and fish haul fisheries of NSW. Final Report to Fisheries Research and Development Corporation. Project No. 1997/207. 151pp.

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

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

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

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

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

No. 43 Fielder, D.S. and Allan, G.L., 2003. Improving fingerling production and evaluating inland saline water culture of snapper, *Pagrus auratus*. Final Report to the Aquaculture Cooperative Research Centre. Project No. C4.2. 62pp.

No. 44 Astles, K.L., Winstanley, R.K., Harris, J.H. and Gehrke, P.C., 2003. Experimental study of the effects of cold water pollution on native fish. A Final Report for the Regulated Rivers and Fisheries Restoration Project. 55pp.

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

No. 46 Pollard, D.A. and Rankin, B.K., 2003. Port of Eden Introduced Marine Pest Species Survey. Final Report to Coasts & Clean Seas Program. 67pp.

No. 47 Otway, N.M., Burke, A.L., Morrison, NS. and Parker, P.C., 2003. Monitoring and identification of NSW Critical Habitat Sites for conservation of Grey Nurse Sharks. Final Report to Environment Australia. Project No. 22499. 62pp.

No. 48 Henry, G.W. and Lyle, J.M. (Ed), 2003. The National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. Project No. 1999/158. 188 pp.

No. 49 Nell, J.A., 2003. Selective breeding for disease resistance and fast growth in Sydney rock oysters. Final Report to Fisheries Research and Development Corporation. Project No. 1996/357. 44pp. (Also available - a CD-Rom published in March 2004 containing a collection of selected manuscripts published over the last decade in peer-reviewed journals).

No. 50 Gilligan, D. and Schiller, S., 2003. Downstream transport of larval and juvenile fish. A final report for the Natural Resources Management Strategy. Project No. NRMS R7019. 66pp.

No. 51 Liggins, G.W., Scandol, J.P. and Kennelly, S.J., 2003. Recruitment of Population Dynamacist. Final Report to Fisheries Research and Development Corporation. Project No. 1993/214.05. 44pp.

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

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

No. 54 Growns, I., Astles, A. and Gehrke, P., 2003. Spatial and temporal variation in composition of riverine fish communities. Final Report to Water Management Fund. Project No. SW1 part 2. 24pp.

No. 55 Gray, C. A., Johnson, D.D., Young, D.J. and Broadhurst, M. K., 2003. Bycatch assessment of the Estuarine Commercial Gill Net Fishery in NSW. Final Report to Fisheries Research and Development Corporation. Project No. 2000/172. 58pp.

No. 56 Worthington, D.G. and Blount, C., 2003. Research to develop and manage the sea urchin fisheries of NSW and eastern Victoria. Final Report to Fisheries Research and Development Corporation. Project No. 1999/128. 182pp.

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

No. 58 Allan, G.L., Booth, M.A., David A.J. Stone, D.A.J. and Anderson, A..J., 2004. Aquaculture Diet Development Subprogram: Ingredient Evaluation. Final Report to Fisheries Research and Development Corporation. Project No. 1996/391. 171pp.

No. 59 Smith, D.M., Allan, G.L. and Booth, M.A., 2004. Aquaculture Diet Development Subprogram: Nutrient Requirements of Aquaculture Species. Final Report to Fisheries Research and Development Corporation. Project No. 1996/392. 220pp.

No. 60 Barlow, C.G., Allan, G.L., Williams, K.C., Rowland, S.J. and Smith, D.M., 2004. Aquaculture Diet Development Subprogram: Diet Validation and Feeding Strategies. Final Report to Fisheries Research and Development Corporation. Project No. 1996/393. 197pp.

No. 61 Heasman, M.H., 2004. Sydney Rock Oyster Hatchery Workshop 8-9 August 2002, Port Stephens, NSW. Final Report to Fisheries Research and Development Corporation. Project No. 2002/206. 115pp.

No. 62 Heasman, M., Chick, R., Savva, N., Worthington, D., Brand, C., Gibson, P. and Diemar, J., 2004. Enhancement of populations of abalone in NSW using hatchery-produced seed. Final Report to Fisheries Research and Development Corporation. Project No. 1998/219. 269pp.

No. 63 Otway, N.M. and Burke, A.L., 2004. Mark-recapture population estimate and movements of Grey Nurse Sharks. Final Report to Environment Australia. Project No. 30786/87. 53pp.

No. 64 Creese, R.G., Davis, A.R. and Glasby, T.M., 2004. Eradicating and preventing the spread of the invasive alga *Caulerpa taxifolia* in NSW. Final Report to the Natural Heritage Trust's Coasts and Clean Seas Introduced Marine Pests Program. Project No. 35593. 110pp.

No. 65 Baumgartner, L.J., 2004. The effects of Balranald Weir on spatial and temporal distributions of lower Murrumbidgee River fish assemblages. Final Report to the Department of Agriculture, Fisheries & Forestry - Australia (National Heritage Trust MD2001 Fishrehab Program). 30pp.