The effects of selected irrigation practices on fish of the Murray-Darling Basin

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NON-TECHNICAL SUMMARY

The effects of selected irrigation practices on fish of the Murray-Darling Basin

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OBJECTIVES:

- To quantify the occurrence of native fish in irrigation supply offtakes.
- To determine the size classes and composition of species that are affected by irrigation practices.
- To determine management strategies to help mitigate the effects of irrigation practices.
- To highlight knowledge gaps and determine areas for further research.

NON TECHNICAL SUMMARY:

The Murray-Darling Basin is Australia's largest catchment covering over one million square kilometres and draining water from five separate states and territories. Much of the catchment is located in semi-arid to arid climatic zones and receives low mean annual rainfall (430mm) with high evaporation. Ninety-eight percent of the catchment contributes little or no run-off, and subsequently, the system has a relatively small annual discharge (12,200GL) compared with other Australian rivers. Despite this reduced flow, the Murray-Darling Basin supports at least 40% of Australia's agricultural production, a population of over 2 million people and is one of Australia's most important natural resources. The overall health of the Murray-Darling system has declined over the last 100 years largely due to factors such as over-fishing, water extraction, land clearing, alteration of natural flow regimes, riparian degradation and reduced connectivity. Whilst the degradation of the Murray River has had detrimental effects on virtually all resident biota, impacts on the abundance and diversity of native fish have been particularly profound. In particular, recent estimates suggest native fish numbers within the Murray-Darling Basin may now be 10% of pre-European levels.

Several reviews have identified the factors associated with river regulation that could adversely affect aquatic fauna, including obstructions to migration, modification of flow regimes, alteration of habitat and the extraction of larvae and recruits. Furthermore, many scientists have identified that aquatic communities in unregulated rivers of the catchment are generally characterised by greater levels of species richness and diversity than regulated rivers. However, few researchers have specifically identified which ecological processes, interrupted by river regulation for irrigation, contribute to these observed discrepancies. Subsequently, there is little information to assist the development of management strategies aiming to reduce the potential impacts of these practices on aquatic ecosystems.

This study was subsequently undertaken as the first large-scale quantification of native fish in irrigation supply offtakes in the Murray-Darling Basin. The specific aims were to identify the species most susceptible to the effects of extraction and to identify possible mechanisms to mitigate these effects. To achieve this, sampling was undertaken in northern (at irrigation sites on the Namoi River) and Southern (in the Murrumbidgee and Mulwala canal systems) reaches of the catchment

to determine any spatial differences in expected ecological effects. The study was primarily undertaken to quantify the effects of three different irrigation practices on fish. These included diversions into irrigation canal systems, extraction into pumping systems and seasonal draw-down of irrigation canals.

Work to identify the impacts of diversions into canal systems was undertaken in the Murrumbidgee River and Bundidgerry Creek offtake (New South Wales). A wide range of species and size classes were entrained over the study period. Life history stages with poorer swimming abilities, such as larvae and juveniles, are most susceptible to entrainment, particularly when large proportions of water are extracted from the host river. Once entrained, some species are able to form self-sustaining populations; however, this is largely contingent on habitat availability. Areas with suitable habitat are generally associated with greater species richness and diversity. In channelised systems with fewer habitats, more resilient species such as carp and Australian smelt became dominant.

Sampling was also undertaken in the Namoi River to investigate the effects of pumping systems on fish. Irrigation pumps were found to extract large numbers of fish from many species and size classes. In some instances over 200 fish per day were extracted, with high-flow pumps having the greatest impact. Post extraction, two size classes of fish large (>200 mm) and small (<50mm) were susceptible to injuries and mortality. Although sampling was stratified over a diel period, there were no significant differences in entrainment rates between night and day. This observation suggests diel changes to operating protocols are not a suitable management option to mitigate the effects of pumping systems. High extraction rates of fish suggest that the cumulative effects of pumping systems, on a river or catchment scale could have substantial effects on fish and other aquatic fauna.

Finally, sampling was undertaken in the Mulwala canal system, at the end of the irrigation season, to quantify the effects of draw-down on fish and invertebrates. Rapid draw-down of irrigation systems was found to result in the stranding and entrapment of almost one million fish from 14 species. Impacts broadly fall into one of two broad categories, effects due to stranding or effects arising from changes in water quality. The impacts of both processes could be partly reduced by employing a gradual and staged draw-down process to provide sufficient time for fish to find refuge areas, and also to provide a buffer for water quality changes.

Ultimately, the study identified that the primary impact of irrigation development on fish of the Murray-Darling Basin is direct entrainment from main river systems. Preventing entrainment at the point of water extraction presents the most suitable method of mitigating the effects of irrigation systems on fish. The development of appropriate solutions is contingent on identifying the nature and scale of the impact and then developing cost effective solutions which ensure anticipated ecological benefits do not compromise the social advantages delivered by the irrigation scheme. Secondary impacts, which largely affect fish after entrainment has occurred, were also identified. These led to increased incidence of injury and mortality and could be ameliorated via a number of engineering and operational methods.

Results suggested that entrainment could be reduced or eliminated by developing engineering solutions to physically exclude fish or to develop operational protocols that minimise situations where diversion flows exceed river flows. Agencies should therefore initially investigate options for reducing fish extraction, possibly through the development of screening techniques, to minimise the potential for fish extraction. If screening is not cost effective or impractical, operational improvements should be progressed to try and transfer extracted fish back to the source river. If mitigation methods are addressed in a logical and systematic manner, the long-term effects of irrigation systems on fish could be effectively reduced or eliminated.

1. GENERAL INTRODUCTION

1.1. The Murray-Darling Basin and flow regulation

The Murray-Darling Basin is Australia's largest catchment covering over one million square kilometres and draining water from five separate states and territories. Its main constituent is the Murray River (2,560 km), which rises in the alpine regions of Southern NSW and meets the sea at the Coorong estuary in South Australia (Walker, 1985). The Darling River is the second largest drainage system in the Basin and rises as the Condamine River in Queensland and joins the Murray near Wentworth, approximately 700km from the sea. Although the Darling River is greater in length (2,740 km), it contributes much less total discharge than the Murray River (Walker, 1985).

Most of the Murray-Darling Basin represents a typical dryland river system. Much of the catchment is located in semi-arid to arid climatic zones and receives low mean annual rainfall (430mm) with high evaporation (King, 2002). Ninety-eight percent of the catchment contributes little or no run-off, and subsequently, the system has a relatively small annual discharge (12,200GL) (Crabb, 1997). Despite such relatively low discharge, the Murray-Darling Basin supports at least 40% of Australia's agricultural production (MDBC, 2003) and a population of over 2 million people (Jacobs, 1990). It is therefore an extremely important natural resource in Australia.

Since European settlement, increased river regulation has fundamentally changed the nature of flows within the Murray-Darling Basin. Flow peaks historically occurred in winter and spring (Walker, 1985) but now more frequently occur in summer, coinciding with increased irrigation demand. These flows are regulated by over 100 storages that have been constructed along the Murray and its tributaries (Walker, 1985), including a series of barrages at the tidal limit (Lay and Baumgartner, 2004). Seventeen of these weirs were constructed on the main channel of the Murray River to increase navigability for boats and other recreational users. Consequently, the main channel of the Murray River is now characterised by a series of large fragmented weir pools with suppressed flow peaks and disrupted longitudinal connectivity (Walker, 1985).

To meet the increasing demands of both a growing population and a developing agricultural industry, individual state agencies began (in the late 1800s) to divert and store water from major rivers and their associated tributaries (Jacobs, 1988). However, Australian river catchments have low annual rainfall and highly variable flow (Walker *et al.*, 1995; Puckridge *et al.*, 1998). To subsequently ensure that required volumes of water were constantly available, at least 144 large dams were constructed on various rivers between 1900 and 1995 (Kingsford, 1995). In addition, numerous smaller regulatory structures were also constructed for diversion and storage purposes (Kingsford, 1995). It is likely that such a degree of development has had a substantial impact on the abundance and distribution of aquatic fauna.

Several reviews have identified a number of factors associated with river regulation that could adversely affect aquatic fauna, including obstructions to migration, modification of flow regimes, alteration of habitat and the extraction of larvae and recruits (Walker, 1985; Kingsford, 2000). Furthermore, many scientists have identified that aquatic communities in unregulated rivers of the Basin are generally characterised by greater levels of species richness and diversity than regulated rivers (Gehrke *et al.*, 1995; Gehrke and Harris, 2001; Humphries *et al.*, 2002). However, few researchers have specifically identified which ecological processes, interrupted by river regulation, contribute to these observed discrepancies. There are subsequently few data to assist the development of management strategies aimed at reducing the potential impacts of these irrigation practices on aquatic ecosystems.

1.2. Current irrigation practices within the Murray-Darling Basin

Irrigation is the largest user of water in the Murray-Darling system (Mackay and Eastburn, 1990). Agricultural practices in the Basin are extensive, but diverse, and a variety of crops are cultivated annually including wheat, barley, corn, rice, cotton, grapes, citrus and vegetables. To adequately service these crops, an average (between 1988 and 1994) of approximately 10,232 Gl of water per year (MDBC, 1995) is diverted from rivers within the Basin to irrigate a total of 670,000 hectares of land. In contrast, extractions for town supply and domestic use are substantially lower at 452 Gl per year (MDBC, 1995).

In some cases, the amount of water extracted or diverted at weirs represents a large proportion of the total flow within individual rivers. For example, during times of peak irrigation demand, up to 50% of total river flow is extracted from the Murrumbidgee River at Berembed Weir to supply water to the Murrumbidgee Irrigation Area (Ebsary, 1992). Of all flows diverted within the Murray-Darling Basin, the greatest percentage (22% of total) is drawn from the Murrumbidgee River (MDBC, 1995).

Although irrigation is extensive in the Murray-Darling Basin, methods to extract water differ substantially between Southern and northern regions. Rivers within Southern reaches of the Basin generally exhibit higher annual rainfall (Nix and Kalma, 1988) and flow is largely regulated by controlled releases from upland storages. On the main channels of these rivers, regulatory weirs have been specifically constructed to gravity feed water into canals and effluent creek systems where irrigation water is required (Figure 1.1). End-users then either pump or siphon water out of these canals and creeks directly onto crops.

In contrast, rivers in northern regions of the Basin are relatively isolated, exhibit low topography, experience high evaporation rates and have variable and unpredictable flow patterns (Gehrke, 2001). In addition, northern rivers often begin and end in lowland regions, where there are seldom any suitable sites for large dams (Kingsford, 1999). Subsequently, most water used for irrigation is extracted directly from main river channels and deposited in privately owned off-river storages (Figure 1.2). Water is then extracted from these storages, and distributed onto irrigated crops. Although the relative volumes of water used to fill off-river storages do not differ from gravity-fed irrigation systems, they are more difficult to quantify, as pumping is largely regulated by private users than through the delivery of managed releases by government agencies (Kingsford, 1999).

This contrast in extractive water use between northern and Southern regions is likely to have different ecological impacts on aquatic fauna. Therefore, developing methods to mitigate any adverse ecological effects may require the implementation of management strategies that are quite specific to individual water extraction methods. Unfortunately, the development of such strategies is currently precluded by a lack of available information regarding the nature and extent of such impacts on aquatic fauna within the Murray-Darling Basin.

1.3. Potential impacts of irrigation practices on fish

Fish of the Murray-Darling Basin exhibit a diversity of behaviour at different life stages and it is therefore likely that irrigation practices will impact native fish in a variety of different ways. The expected differences in fish assemblage structure between northern and Southern regions (Table 1.1), combined with differences in extraction methods, may necessitate the development of mitigation measures that are specific to different species and regions of the Murray-Darling Basin.

Figure 1.1. A gravity-fed irrigation channel typical of those constructed in the Southern reaches of the Murray-Darling Basin.

Figure 1.2. An indication of extraction rates from a direct pumping system typical of those constructed in the Northern reaches of the Murray-Darling Basin.

Table 1.1. Fish of the Murray-Darling Basin (excluding estuarine species). Region refers to whether the fish were found in northern (N) or southern reaches (S). *(Supplied by the Murray-Darling Basin Commission).*

Scientific Name	Common Name	Region
Native species		
Mordacia mordax	Short-headed lamprey	S
Geotria australis	Pouched lamprey	S
Nematalosa erebi	Bony herring	S, N
Galaxias brevipinnis	Climbing galaxias	S, N
Galaxias fuscus	Barred galaxias	S
Galaxias olidus	Mountain galaxias	N, S
Galaxias sp 1.	Obscure galaxias	S
Galaxias sp 2.	Riffle galaxias	S
Galaxias rostratus	Flat-headed galaxias	S
Galaxias truttaceus	Spotted galaxias	S
Retropinna semoni	Australian smelt	N, S
Porochilus rendahli	Rendahl's tandan	N
Neosilurus hyrtlii	Hyrtl's tandan	N
Tandanus tandanus	Freshwater catfish	N, S
Craterocephalus amniculus	Darling River hardyhead	N
Craterocephalus fluviatilis	Murray hardyhead	S
Craterocephalus stercusmuscarum	Un-specked hardyhead	N, S
Melanotaenia fluviatilis	Murray-Darling rainbowfish	N, S
Melanotaenia splendida tatei	Desert rainbowfish	N
Ambassis agassizii	Olive perchlet	N, S
Macquaria ambigua ambigua	Golden perch	N, S
Macquaria australasica	Macquarie perch	S
Maccullochella macquariensis	Trout cod/Bluenose cod	S
Maccullochella peelii peelii	Murray cod	N, S
Bidyanus bidyanus	Silver perch	N, S
Leiopotherapon unicolor	Spangled perch	N
Nannoperca australis	Southern pygmy perch	S
Nannoperca obscura	Yarra pygmy perch	S
Gadopsis bispinosus	Two-spined blackfish	S
Gadopsis marmoratus	River blackfish	S
Philypnodon grandiceps	Flat-headed gudgeon	N, S
Philypnodon sp.1	Dwarf flat-headed gudgeon	S
Mogurnda adspersa	Southern purple-spotted gudgeon	N, S
Hypseleotris spp	Carp gudgeon	N, S
Introduced species		
Salmo trutta	Brown trout	N, S
Salmo salar	Atlantic salmon	S
Salvelinus fontinalis	Brook char	S
Oncorhynchus mykiss	Rainbow trout	N, S
Cyprinus carpio	Carp	N, S
Carassius auratus	Goldfish	N, S
Tinca tinca	Tench	S
Rutilus rutilus	Roach	S
Misgurnus anguillicaudatus	Oriental weatherloach	S
Gambusia holbrooki	Eastern gambusia	N, S
Perca fluviatilis	Redfin perch	S

Fish communities of the Murray-Darling Basin are highly migratory, exhibiting movements in both upstream (Reynolds, 1983; Mallen-Cooper, 1996) and downstream (Humphries *et al.*, 2002; Gilligan and Schiller, 2004; O'Connor *et al.*, 2004) directions. Until recently, fish migration studies within the Murray-Darling Basin focused primarily on species of recreational or commercial importance (Reynolds, 1983; Mallen-Cooper, 1996; Thorncraft and Harris, 1996). However, recent studies have also demonstrated that larval native fish also undertake substantial downstream movements (Humphries *et al.*, 1999; Humphries and Lake, 2000; Humphries *et al.*, 2002) and that many small-bodied species are also migratory (Baumgartner, 2004). Therefore, the development of suitable measures to reduce fish entrainment into irrigation systems should provide for upstream and downstream migrants of a large range of size classes and species.

The cues, nature and scale of migrations vary greatly between species but are usually in response to increases in water temperature or river flow (Mallen-Cooper, 1996). Fish movements are also highly seasonal, sometimes peaking during summer and autumn (Baumgartner, 2004) and, in some cases, individuals have traversed over 2,300km during flood conditions (Reynolds, 1983). Although migrations over such large scales are rare, many fish species are frequently observed to either negotiate fishways (Stuart *et al.*, 2004) or accumulate downstream of obstructions (Baumgartner, 2004). Therefore, if irrigation diversions involve a large proportion of river flow, and occur during times of increased migratory activity, many species may inadvertently move out of main river systems and into irrigation channels where there are limited possibilities for return.

Approximately 80% of natural flow in the Murray-Darling Basin is diverted and currently there are no mechanisms in place to prevent fish, or other organisms, from leaving main river systems (Blackley, 2003). Considering this situation, irrigation diversions are most likely to affect fish through direct extractions from main river channels, which will be manifest during larval and juvenile stages, because these generally have poorer swimming abilities (Koehn *et al.*, 2003). Furthermore, it is generally assumed that, once an individual has entered an irrigation system, it is effectively 'lost' from the main river population (Prince, 1923). Therefore, if many individuals are consistently 'lost' to irrigation diversions on an annual basis, the size and age structure of main-channel fish populations may be skewed towards larger, and older fish with stronger swimming abilities, because of the frequent extraction of larvae and juveniles.

1.4. The purpose of this study

The current study arose from a workshop examining the downstream movement of fish in the Murray-Darling Basin (Lintermans and Phillips, 2003) and was undertaken to fill several knowledge gaps regarding the occurrence and fate of fish in irrigation systems. Specifically, the project aimed to quantify the composition and abundance of fish entrained in irrigation systems, compare the effects of pumping and channel systems on fish species, identify life-history stages most at risk to entrainment, determine species likely to survive irrigation extraction and to provide comment on the fate of fish during periods of irrigation system draw-down. Given the expected regional differences in pumping regime and species composition, the study was conducted in two distinct components, which were independently undertaken in northern and Southern parts of the Murray-Darling Basin.

The general outcome of this work will be a greater understanding of irrigation practices and their effects on fish within the Murray-Darling Basin. Once these impacts have been determined, areas for further research will be identified, a management strategy will be discussed and a procedure outlined to communicate the results to relevant stakeholders within the wider community. A greater understanding and appreciation of irrigation impacts on fish will lead to the development of sustainable practices that can be applied throughout the entire Murray-Darling Basin. This report is structured to provide the results of the three major components in separate chapters (Chapter 3 – 5) followed by a synthesis (Chapter 6) and recommendations for further research (Chapter 7).

2. GENERAL METHODS

2.1. Larval sampling

Larval sampling was conducted for ten weeks to investigate the proportion of larval fish and eggs that are susceptible to extraction and entrainment into irrigation systems (Figure 2.1). Eggs and larvae were sampled using drift nets (double cone, 500 µm mesh, 1m entrance diameter). Each net was set below the surface and fitted with a flow meter to enable drift rates to be standardised per volume of water filtered. Nets were set continuously for five consecutive days, once a month between November 2004 and March 2005 and from November 2005 and March 2006. This gave a total of 10 samples (five days x once a month) over the study period. Nets were checked twice a day at 500h and 2100h to enable a comparison between daytime and night-time drifting rates.

Depending on time constraints, samples were either sorted live or preserved in 70% ethanol and later sorted in the laboratory. Preserved samples were first immersed in a 50mg/L benzocaine solution to anaesthetise any larvae within the sample. Samples were then transferred to white sorting trays and larvae were 'picked' and placed in small sample jars for later identification. Each 10^{th} sample was re-sorted by an independent staff member to validate the accuracy of the picking process. Similarly, a total of 50 larvae (randomly chosen) were initially identified, then re-assessed by an independent sorter to determine the accuracy of our larval identification methods.

2.2. Boat electrofishing

Boat electrofishing was done, using standardised protocols, at several control (irrigation affected) and reference (in the main river channel) sites to determine fish community composition (Figure 2.2). Fish were collected from each site on five occasions between November 2004 and April 2006 using a boat mounted 7.5 kW Smith-Root Model GPP 7.5 H/L electrofishing system. One senior operator controlled the boat and two operators controlled fishing operations from a platform at the bow. Sampling consisted of 12 replicate 90-second (elapsed time) electrofishing 'shots' during daylight hours. Where the channel width was greater than 15m, both banks were fished. Where smaller, both banks were fished in a zigzag pattern.

Fish were collected by dip net and placed into a live well for recovery prior to identification and measurement (fork length or total length depending on tail morphology). Each individual was inspected for diseases, parasites or injuries and any positively identified fish observed but not captured were also recorded. In instances of large individual species catches, random sub-samples of 50 individuals were measured per shot as this is the minimum sample required to effectively perform the non-parametric Kolmogorov-Smirnov (KS) test to compare length-frequency distributions (Sokal and Rohlf, 1996). Fish were then released to the river.

2.3. PIT tagging

All fish over 200mm (total length or fork length) were fitted with Texas Instruments-RFID (eco version) passive integrated transponder (PIT) tags to determine larger-scale movements within irrigation systems. PIT tags are small (23mm X 4mm) glass capsules that contain an individually-coded 9-digit number to enable identification if recaptured. Tags were inserted into the left-hand shoulder of each fish and the number recorded as part of normal data collection procedures. All PIT tagged fish were also implanted with an external dart tag for identification by anglers. Each fish collected via electrofishing was scanned for PIT tags using a hand-held Allflex transponder reader. This enabled the collection of re-capture data from subsequent electrofishing events in addition to angler re-capture data.

Figure 2.1. A typical deployment of larval sampling nets to collect drifting fish larvae in an irrigation canal. *(Photo: Leo Cameron, NSW DPI).*

Figure 2.2. Staff undertaking boat electrofishing surveys to document the structure of fish communities in irrigation systems. *(Photo: Charlotte Grove, NSW DPI).*

3. THE EFFECTS OF IRRIGATION DIVERSION CHANNELS AND CANALS ON FISH OF THE MURRAY-DARLING BASIN

3.1. Introduction

Gravity-based canal systems are commonly constructed throughout the world to provide water for town, agricultural and stock purposes. The use of gravity offers several financial and logistical benefits as there is no costly requirement to mechanically transport water to end users. Therefore, maintenance costs are reduced and water can be relatively accurately controlled via the manipulation of strategically-placed gates or regulators.

In Australia, the construction of gravity-fed systems commenced in 1880, with the development of the Goulburn-Murray Irrigation district in Victoria (McCoy, 1988). Since then, substantial systems have been constructed on the Murrumbidgee, Murray, Loddon and Campaspe Rivers. Gravity-fed systems are now a widely-adopted method of water delivery and control almost half of the irrigated agriculture requirements of the Murray-Darling Basin (MDBC, unpublished data).

Gravity-fed systems could potentially have serious effects on fish. For instance, at Berembed Weir on the Murrumbidgee River, up to 50% of total river flow can be extracted during peak irrigation periods (Ebsary, 1992). During times of such demand, it is possible that many fish, eggs and larvae are extracted from main channel systems. It is important to note that many of these systems are terminal, and contain few escapes back into the source river system. Under such situations, any extracted fish are effectively lost from the riverine population. If the number of extracted fish is significant, riverine populations could be compromised (King and O'Connor, 2007).

Little data presently exists on the spatial or temporal extent of fish extraction into irrigation systems. Furthermore, no study concerning the composition of fish communities in irrigation systems has been undertaken in the Murray-Darling Basin. The subsequent aim of this study was to investigate the effect of gravity-fed irrigation systems on fish, eggs and larvae in southern reaches of the Murray-Darling Basin. Fish were collected using a suite of sampling techniques to investigate the species, size and scale of fish extraction in the Basin.

3.2. Methods

3.2.1. Study sites

All work was conducted in the middle reaches of the Murrumbidgee River system, one of the 12 major sub-catchments within the Murray-Darling Basin. The Murrumbidgee rises in the Great Dividing Range near Canberra and meanders westward some 1,080 km (Cromarty, 1992). It drains 11,025km^2 (Harris and Gehrke, 1997) and joins the Murray River at Boundary Bend. Climatic conditions within the catchment are generally described as warm, dry with dominant winter rainfall (Nix and Kalma, 1982). Flow in the mid-Murrumbidgee River is regulated by nine headwater storages. Regulation is seasonal and, like most other rivers in the Murray-Darling Basin, is based largely on irrigation demand in summer and rainfall in winter (Ebsary, 1992). In addition to the headwater storages, another seven weirs have been constructed in the main river channel for diversionary, re-regulatory or supply purposes. Yanco, Berembed and Gogeldrie Weirs are diversionary and operated to gravitate water down canal and creek systems for irrigation purposes (Ebsary, 1992). Hay and Maude Weirs are operated in both a re-regulatory and diversionary manner to store surplus flow for later use or divert water onto wetlands in lowland reaches of the catchment (Ebsary, 1992). Balranald and Cooma Weirs are used primarily for storage and town supply.

This study was conducted within the Murrumbidgee Main Canal, which is diverted from the Murrumbidgee River at Berembed Weir (Figure 3.1). The Murrumbidgee Main canal services the Murrumbidgee Irrigation area, which stretches from Narrandera to Griffith and encompasses 600,000 hectares and supports a population of 50,000. Water is gravitated into the system based on irrigation demand, which is greatest between September and April. The system is annually closed in May and large areas are known to dry out, or form a series of disconnected pools.

3.2.2. Egg and larval sampling

Larval sampling was undertaken at the Berembed Weir offtake to compare drifting rates above the extraction point (in the Murrumbidgee River) and in the canal (Figure 3.1). Two sites were sampled in the Murrumbidgee River, 500m upstream of Berembed Weir and one at the point of extraction. These sites served to provide an indication of drifting rates in the Murrumbidgee River. A third site was sampled immediately below the offtake to determine the number of eggs and larvae extracted along with irrigation water. No sites were sampled further into the irrigation system, as it would be difficult to determine whether fish were sourced from the river or were naturally spawned in the channel. At each site a total of five nets were set.

3.2.3. Boat electrofishing

Any fish which survive the extraction process could establish self-sustaining populations within channel systems. Boat electrofishing was subsequently undertaken to provide a comparison of adult and juvenile fish communities within the Murrumbidgee Main Canal and the river. Electrofishing was undertaken according to SRA protocol and six sites were sampled in total (Chapter 2; Figure 3.1). Two river sites were sampled 0.5km and 5km upstream of Berembed Weir. Two further sites were sampled 0km and 5km downstream of the offtake regulator in the Murrumbidgee Main Canal system. A final two sites were 0km and 5km downstream of the Narrandera regulator in a channelised section of the irrigation canal.

3.2.4. Data analysis

Data were analysed using S-PLUS (Insightful Corporation, 2000) and PRIMER (Warwick and Clarke, 1996). Significant differences in larval drifting rates among sites and between diel periods were investigated using a two-way ANOVA. Cochran's tests identified heterogeneous variances within the data and a subsequent log (x+1) transformation was undertaken.

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 species counts (standardised to electrofishing time or river flow in the case of larval samples) that were converted to Bray-Curtis similarity values as described in Clarke and Warwick (1994). Two-way analyses of similarities (ANOSIM) (Clarke and Warwick, 1994), using sites (river or offtake) and diel period (day or night) as factors, were performed on fourth-root transformed data to identify any differences in fish community composition. 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.

Two-tailed Kolmogorov-Smirnov tests (KS: Sokal and Rohlf, 1996) were performed on the most common species from each site to assess differences in length-frequency distributions among sites. For the purpose of the present study, length-frequency analysis revealed whether populations in the Murrumbidgee River, Bundidgerry Creek or the main canal were dominated by particular size classes. All data were standardised to either total time (fish per minute for electrofishing) or flow (fish per megalitre for larval nets) and all statistical tests were considered significant at $p < 0.05$.

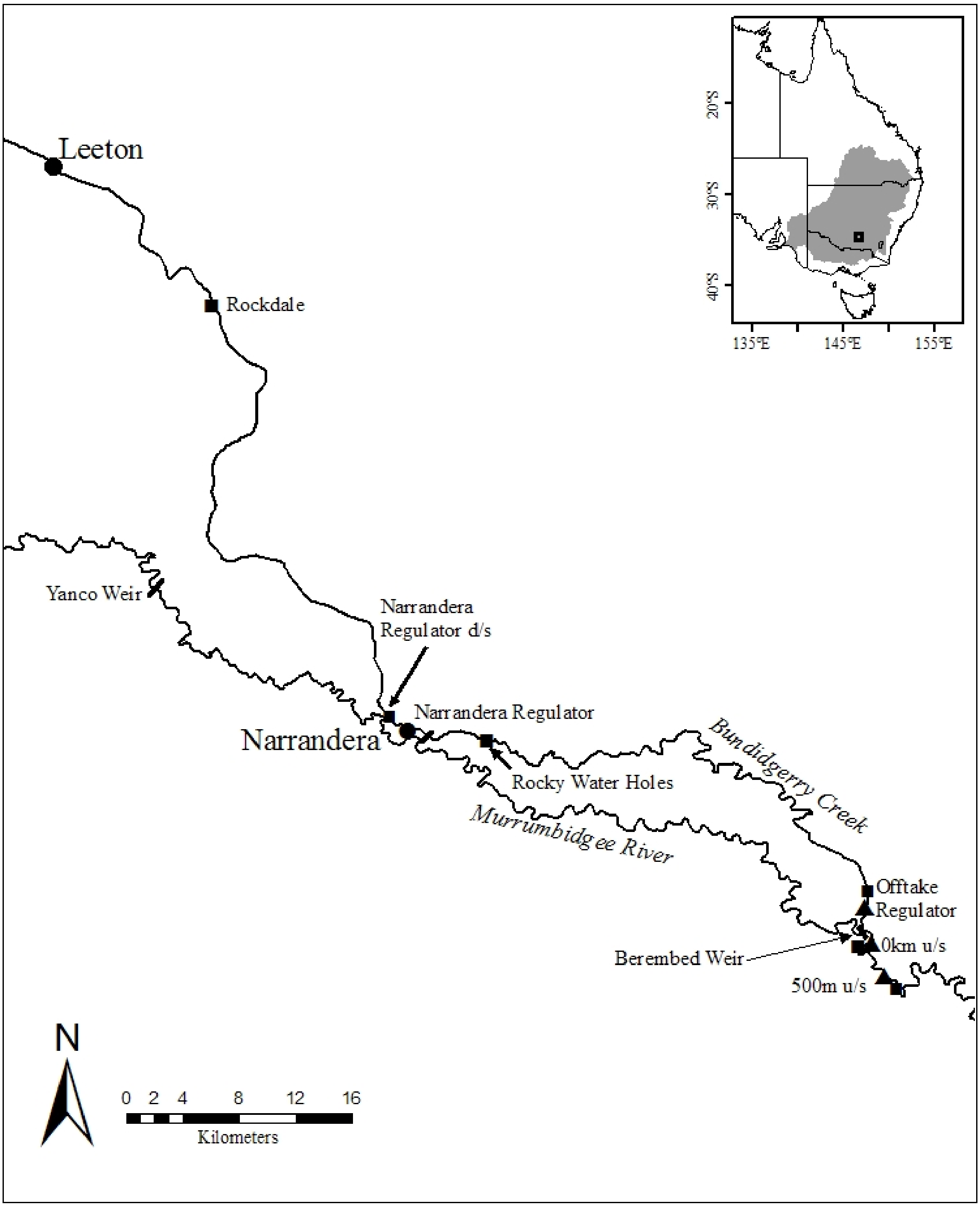


Figure 3.1. A map of the Murrumbidgee River and Bundidgerry Creek offtake system showing the location of electrofishing (square) and larval (triangle) sites surveyed.

3.3. Results

3.3.1. River and offtake flows

River flow averaged 4,321 ± 2,116 $Ml.day^{-1}$ over the study period (Figure 3.2). The greatest flow of 19,821Ml occurred during a rain rejection event in October 2005 whilst the minimum flow occurred shortly after the commencement of irrigation flows in September 2004. Average diversions into the Bundidgerry Creek offtake system were substantially lower (2,221 ± 1,469 $Ml.day^{-1}$) and peaked at 6,514 Ml in January 2006. No flow entered the irrigation system outside the irrigation season between May and August 2005.

In general, the amount of water released into the Murrumbidgee River downstream through Berembed Weir, was greater than flow diverted into the irrigation system at the offtake regulator. However, diversions into the irrigation system exceeded flow released downstream of Berembed Weir on 80 days over the study period.

On one occasion in December 2004, diversions into the offtake system were 283% greater than releases into the Murrumbidgee River downstream of Berembed Weir. The only situations where river flow was substantially greater than offtake diversions were during periods of unusually high flow in the river or when irrigation releases ceased between May and August.

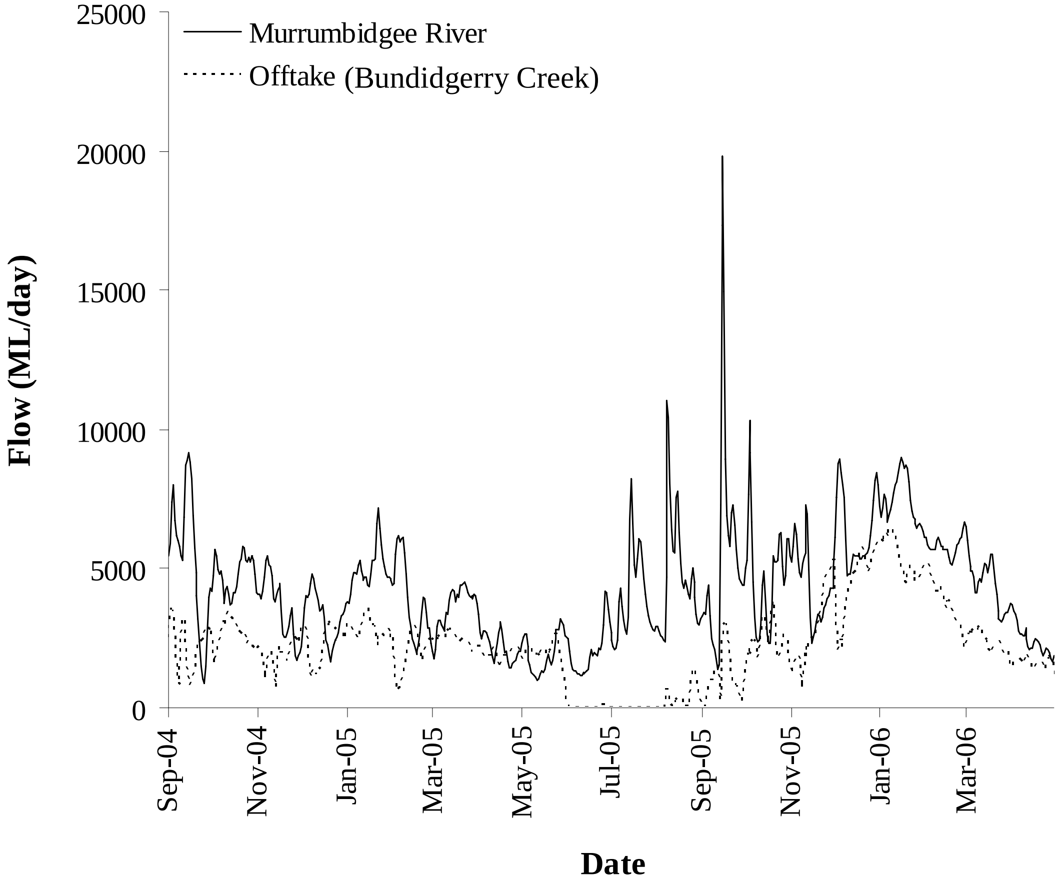


Figure 3.2. A comparison between river flow (Murrumbidgee River downstream of Berembed Weir) and total flow extracted into the Bundidgerry Creek irrigation system between September 2004 and April 2006.

3.3.2. Egg and larval sampling

In total, 850 eggs and larvae, from 8 species were sampled from the Murrumbidgee River and offtake sites sampled as part of this project (Table 3.1). Substantially more fish were sampled from the Murrumbidgee River sites than within the offtake although catches were largely dominated by carp (*Cyprinus carpio*) and cod (*Maccullochella*) species. Carp gudgeon (*Hypseleotris* spp) and Australian smelt (*Retropinna semoni*) were the only two species where more larvae were sampled from the offtake site.

The drifting rates of carp and carp gudgeon significantly differed among sites (ANOVA: Table 3.2). Substantially greater numbers of carp were sampled from river sites whilst carp gudgeon were more abundant in offtake systems. Interestingly, only one species, carp, exhibited diel differences in drifting rates where more larvae were sampled at night (ANOVA: Table 3.2).

In addition to spatial differences there was substantial temporal variation in the drifting rates of some species. Drifting rates were greatest in November, where significantly greater numbers of carp were caught drifting at night (Figure 3.3). Daytime drifting rates were greatest in December and January and were largely driven by increases in the number of drifting cod (*Maccullochella* spp). Carp were clearly dominant from night samples, particularly during November. In all other months, more fish drifted during the day. Interestingly, there was a substantial increase in the drifting rates of cod (*Maccullochella* spp) during February sampling which is indicative of a late spawning event.

Table 3.1. Total catches of fish eggs and larvae from sites sampled in the Murrumbidgee River highlighting differences between day (D) and night (N) sampling. Data represents total catches from all nets pooled across seasons at each site.

Species	**Bundidgerry Creek Offtake**		**Murrumbidgee R. 500m upstream**		**Murrumbidgee R. weir pool**	
	D	**N**	**D**	**N**	**D**	**N**
Fish						
Carp	1	2	21	220	44	186
River blackfish	0	0	0	3	0	1
Gambusia	0	2	0	1	0	0
Carp gudgeon	34	24	0	2	0	2
Golden perch	0	0	0	0	0	3
Cod spp	8	29	44	19	72	65
Australian smelt	16	8	6	0	2	2
Freshwater catfish	0	1	0	0	0	0
Unidentifiable						
Eggs	0	0	0	0	0	1
Fish	5	5	0	7	10	4
Total	64	71	71	252	128	264

Table 3.2. Results of a Two-Way ANOVA highlighting differences in species abundance between the most commonly sampled species in the Murrumbidgee River and Bundidgerry Offtake. Factors used in the test were sites (S) and diel sampling (D) period. Only F-values are presented and results are based on log (X+1) transformed data. Species are defined as CC: carp; CG: carp gudgeon; CS, cod (*Maccullochella*) species and AS; Australian smelt. An asterisk denotes a significant result at * ($p < 0.05$), ** ($p < 0.01$) and *** ($p < 0.001$).

Factor	CC	CG	CS	AS
S	4.32*	10.65***	0.07	2.90
D	5.34*	0.29	0.01	1.89
S*D	1.23	0.08	0.02	0.49

3.3.3. Electrofishing surveys

A total of 8,904 fish from 11 species were sampled by boat electrofishing in the Murrumbidgee River and Murrumbidgee main canal systems (Table 3.3). Goldfish, carp gudgeon, Murray rainbowfish and redfin perch were collected from sites in Bundidgerry Creek and Murrumbidgee main canal but not in the Murrumbidgee River. River blackfish were collected from all regions except within the Murrumbidgee main canal.

Multidimensional scaling identified a clear separation between river and offtake sites (Figure 3.4). This observation was confirmed statistically, with the Murrumbidgee River containing a significantly different fish community from both of the offtake regions (ANOSIM: Global R = 0.307; $p < 0.001$). The two offtake regions did not differ, an observation reflected in the relatively close groupings in ordinal space.

Australian smelt contributed most to the observed differences between Murrumbidgee River and offtake sites (SIMPER: Table 3.4). In both cases, abundance was greater because of high accumulations downstream of regulators in the irrigation systems. Greater abundances of carp in channel and offtake sites, and of Un-specked hardyhead in Murrumbidgee River sites, greatly contributed to differences (SIMPER: Table 3.4).

Table 3.3. Total numbers of fish caught during electrofishing sampling undertaken in the Murrumbidgee River and Murrumbidgee main canal system.

Species	Murrumbidgee River		Bundidgerry Creek		Murrumbidgee Canal	
	500m U/S Berembed	Berembed offtake	Offtake Regulator	Rocky Waterholes	Narrandera Regulator	Rockdale Channel
Goldfish	0	0	0	5	1	5
Un-specked hardyhead	46	63	7	4	0	2
Carp	9	10	35	49	24	23
River blackfish	17	7	15	0	0	0
Gambusia	1	0	3	0	2	0
Carp gudgeon	0	0	8	2	1	1
Golden perch	2	2	4	1	0	1
Murray cod	4	3	5	1	2	0
Murray rainbowfish	0	0	0	1	10	4
Redfin perch	0	0	0	10	2	0
Australian smelt	54	142	4,656	835	2,649	176

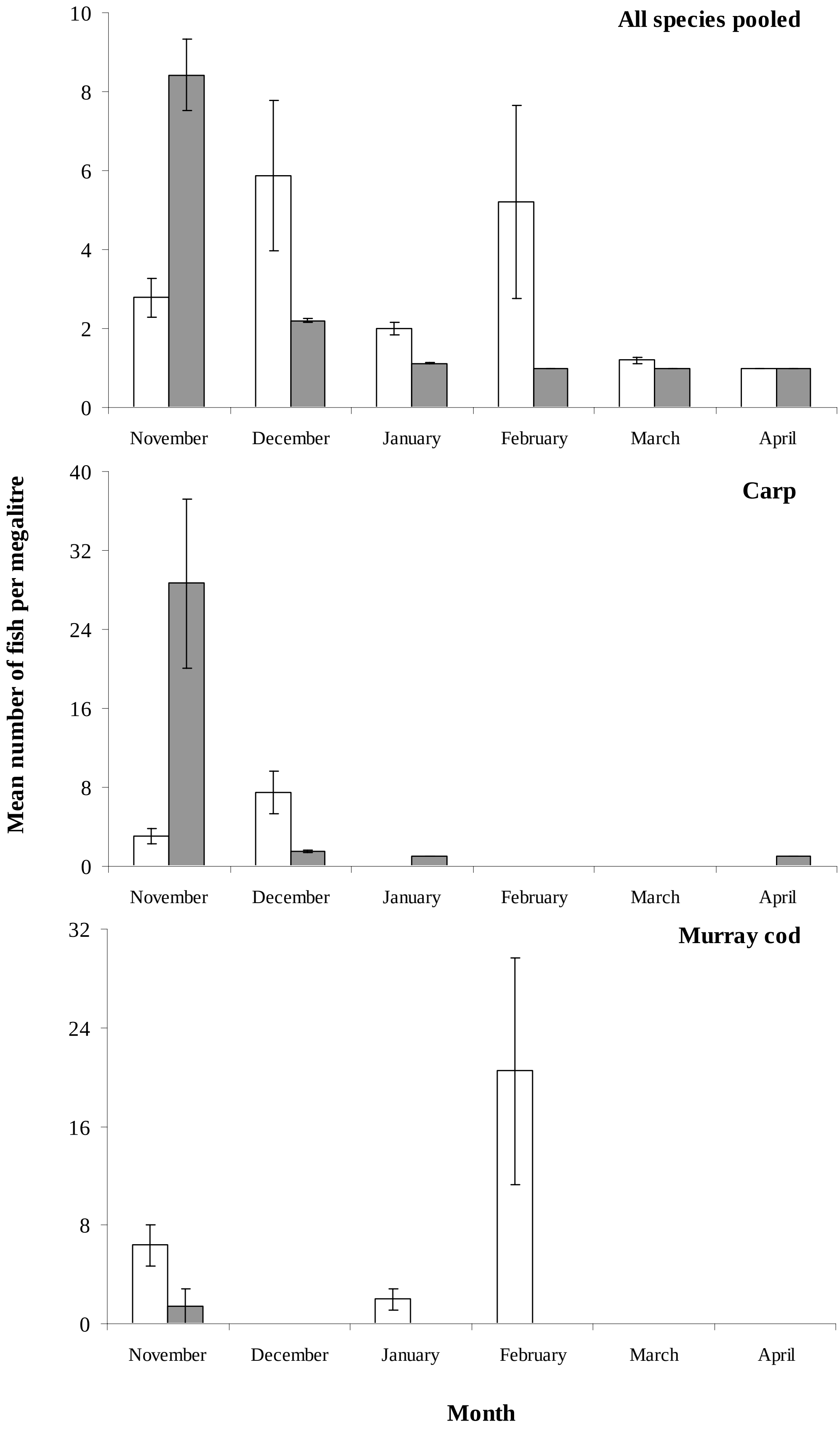


Figure 3.3. Mean monthly drifting rates of larvae pooled across sites sampled. Daytime drifting rates are hollow whilst night samples are shaded. Bars denote one standard error.

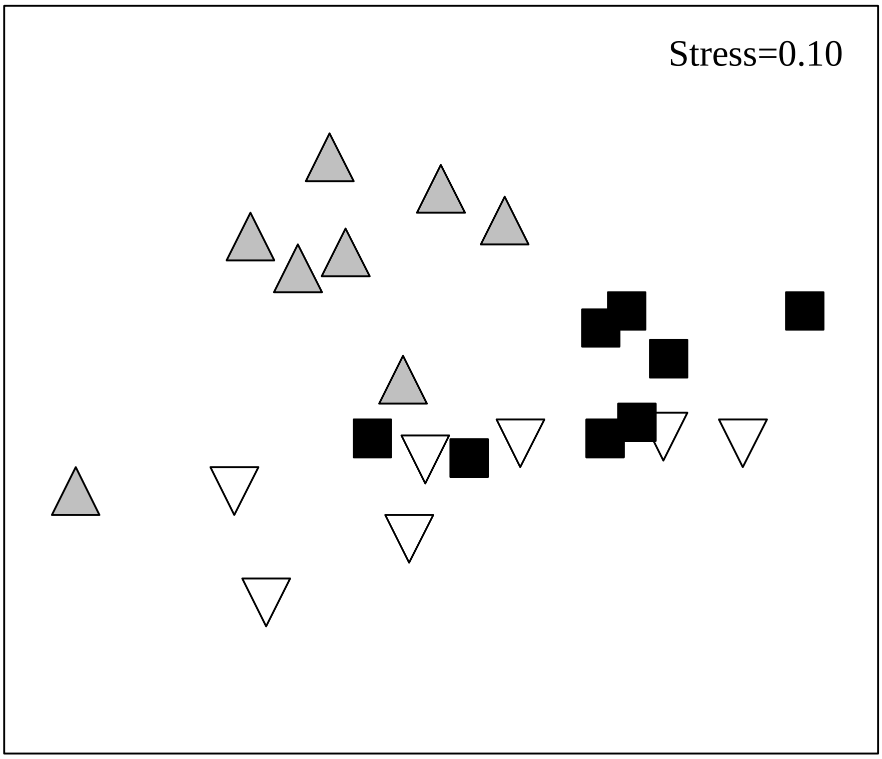


Figure 3.4. A two-dimensional multidimensional scaling ordination of fish communities sampled in the Murrumbidgee River (grey triangle), Bundidgerry creek (black square) and the MIA main irrigation channel (white triangle) as determined by boat electrofishing surveys.

3.4. Discussion

3.4.1. Impacts of irrigation diversions on fish and larvae

Several impacts of water diversion into irrigation canal systems were identified as potential issues for native fish. In particular, impacts on larval fish were most obvious from this study. During peak drifting periods, up to 283% of total flow within the Murrumbidgee River was extracted into irrigation canal systems. When larval drifting rates are high, many fish could be removed from main river channels during peak irrigation periods.

An assessment of flow diversions demonstrated that substantial amounts of water can be extracted from the Murrumbidgee River during the irrigation season. When extraction into irrigation offtakes is greater than river flow, high rates of fish entrainment could readily be expected at the Berembed offtake. Larval sampling identified seasonal trends in larval drifting rates. Carp drifted early in the season in October and November whilst Murray cod appeared initially in November then reappeared during samples in February. Such observations are consistent with larval behaviour previously identified in other areas of the Basin (Humphries *et al.*, 2000). Increasing extractions at times of expected periods of larval drift could therefore increase the risk of entrainment for many species.

Size of fish has a substantial effect on susceptibility to entrainment. Mountain whitefish (*Prosopium williamsoni*) are regularly entrained into irrigation canal systems of the Bow River, Alberta (Canada), especially during juvenile stages (Post *et al.*, 2006). Size selectivity during entrainment largely determines the most appropriate methods to prevent fish from being extracted; especially when dealing with eggs and larvae, which are inherently small and more susceptible to injury. To prevent these fish from entering irrigation canals would require the use of extremely small-meshed screens.

In some cases, this may be economically or practically difficult to achieve because small mesh can restrict flow delivery or accumulate debris. Fisheries managers must therefore give careful consideration to the fish community and operation of infrastructure at individual sites when recommending mitigation measures.

Table 3.4. The contribution of individual species to observed differences in fish communities between sites sampled in the Murrumbidgee River and Bundidgerry Creek irrigation region as determined by SIMPER analysis. Mean dissimilarity describes the degree to which both groups differ ranging from 0% (Totally dissimilar) to 100% (Totally similar). Mean abundance refers to the mean abundance of fish from each site, CR is the consistency ratio, with higher value indicating lower variation in the abundance of each species among samples. The cumulative % denotes the cumulative contributions of individual species to observed differences.

Species	**Mean abundance**		**CR**	**Cumulative %**
Murrumbidgee River vs Murrumbidgee main canal *Mean Dissimilarity* = 62.34				
	Murrumbidgee	**Channel**		
Australian smelt	24.50	353.13	1.46	52.18
Un-specked hardyhead	13.63	0.25	0.68	61.97
River blackfish	3.00	0.00	1.12	70.93
Carp	2.38	5.88	1.07	78.47
Murray cod	0.88	0.25	1.00	83.86
Murray Rainbowfish	0.00	1.75	0.87	88.91
Goldfish	0.00	0.75	0.60	92.95
Golden perch	0.50	0.13	0.73	96.24
Carp Gudgeon	0.00	0.25	0.52	97.71
Gambusia	0.13	0.25	0.50	99.11
Redfin perch	0.00	0.25	0.56	100.00
Murrumbidgee River vs Bundidgerry offtake *Mean Dissimilarity* = 63.31				
	Murrumbidgee	**Offtake**		
Australian smelt	24.50	686.38	1.84	62.48
Carp	2.38	10.50	1.39	71.34
Un-specked hardyhead	13.63	1.38	0.81	79.87
River blackfish	3.00	1.88	1.06	85.70
Murray cod	0.88	0.75	0.93	88.89
Carp Gudgeon	0.00	1.25	0.89	92.06
Golden perch	0.50	0.63	0.93	94.42
Redfin perch	0.00	1.25	0.56	96.77
Gambusia	0.13	0.38	0.51	98.06
Goldfish	0.00	0.63	0.37	99.18
Murray rainbowfish	0.00	0.13	0.37	100.00

Restricting diversions practices to specific diel periods was previously identified as a possible mechanism to lower entrainment rates of some species (Gilligan and Schiller, 2004). No native species however, exhibited patterns in diel drifting behaviour in the current study. This observation indicates that restricting diversions to certain time periods would do little to reduce the probability of entrainment. In fact, the collection of significantly more carp at night was the only indication of diel drifting behaviour. Carp are an introduced species and minimising the extraction rates of this species would contribute little to the overall health of fish populations in Bundidgerry Creek or the Murrumbidgee River.

Most diversions predominantly affect juveniles, suggesting that source river recruitment can be affected by irrigation systems (Reiland, 1997). The long-term effects of irrigation systems would be reduced to some extent if recruitment in the source river system exceeds the entrainment rate. In the West Gallatin River, Montana (USA), screening of canal systems was deemed unnecessary as research determined that recruitment rates in the source river greatly exceeded entrainment rates (Earle and Post, 2001). Obtaining a detailed understanding of recruitment processes within the main river and canal is therefore an important step in determining an appropriate technique to mitigate the effects of irrigation systems.

3.4.2. Spatial distributions of fish in irrigation systems

Morphological characteristics of canal systems can greatly influence fish survival and the risk of entrainment. In North America, entrainment rates in many canals proportionally increase with canal size (Earle and Jones, 2001). Entrainment rates can also be highly variable depending on intake location and the amount of flow diverted. If the entrance to an irrigation channel contained a behavioural barrier such as poor entrance conditions or insufficient habitat, fish may not enter (Megargle, 1999). Adult golden perch and Murray cod in particular were previously observed to exhibit a behavioural inhibition to travelling through undershot gates (O’Connor *et al.*, 2004). The entrance to the Bundidgerry offtake, an undershot steel gate, may therefore present a behavioural barrier that deters some large-bodied fish from actively entering the system.

Undershot gates may also adversely affect the passive entrainment of fish, such as during larval stages when swimming abilities are reduced. Larval fish entrained via this water delivery method are subjected to high shear stress, turbulence and rapid changes in water pressure (Neitzel *et al.*, 2000). In some cases this can lead to increased incidences of injury or mortality, particularly of Murray cod and golden perch (Baumgartner *et al.*, 2006). Collection of drifting Murray cod and golden perch was greater in the main river than in the offtake. Mortality of these two species is known to be high during undershot passage, possibly explaining why few larvae or adults were caught within the offtake system.

Habitat within irrigation systems can also influence the probability of post entrainment survival (Megargle, 1999). Observed differences in the distribution of some species varied among different regions of canal systems. For example, in upper Bundidgerry Creek, habitat is comparable to pre-regulation conditions, with relatively natural channel morphology and an abundance of large wood. In this region, fish communities were relatively similar to those within the Murrumbidgee River. In the channelised section downstream of the Narrandera regulator there is little structural habitat, and the channel is man-made with few natural features. In this region, fish communities were largely dominated by two species, carp and Australian smelt. Improving habitat in channelised sections may therefore represent a suitable management intervention to improve the structure and diversity of entrained fish communities although these individuals are still effectively lost from the source river.

The dominance of Australian smelt and carp in channelised sections can be attributed to two major reasons. Firstly, post-entrainment survival may be greater in these two species, thus enabling them to colonise channelised areas. Secondly, habitat within channelised sections may be more suited to the survival of these species. The probability of fish establishing sustainable populations is likely to increase when usable habitat is abundant. In irrigation systems containing poor habitat, fish can quickly become stressed or starve (Megargle, 1999). Both carp and Australian smelt are highly resilient species, which can quickly adapt to a wide range of changes in river condition (Harris and Gehrke, 1997; Gehrke and Harris, 2001). Therefore, the establishment of large, sustainable populations in irrigation systems could be readily expected.

3.4.3. Management of flows into irrigation systems

Management of flows into irrigation systems requires careful planning to minimise potential impacts on fish. Previous studies have demonstrated substantial increases in entrainment rates of juvenile fish, particularly during periods of peak flow into irrigation systems (Reiland, 1997; Helwig and Fernet, 1993). For instance, the Murray Valley Irrigation system in Victoria (Australia) is dominated by fish of 0+ or 1+ age classes suggesting entrainment during early life history stages (King and O'Connor, 2007). During our study there were 80 days where discharge into the irrigation system exceeded total flow in the river. For larval fish and eggs that passively drift, increased discharge would greatly inflate the probability of entrainment. Reducing the frequency of these periods of increased diversion is an obvious management option to reduce the probability of entrainment without the need for costly capital expenditure.

Timing of these increased diversions can also affect the probability of entrainment. Restricting increased diversions to occur outside peak periods of larval drift may reduce the susceptibility of entrainment for some species. The only periods where irrigation releases were zero, occurred between May and August. Unfortunately, this period of minimal diversions occurs outside the larval drifting period for most native species (Humphries *et al.*, 1999). To reduce the potential impacts on fish, substantial reductions to irrigation diversions during spawning periods (October to February) would have greater ecological benefits for fish the Murrumbidgee system. This is unlikely to represent a practical option, as these correspond with periods of peak irrigation demand.

Fish may actively move into canals during periods of low river flow to escape density-dependent effects (Earle and Post, 2001). Megargle (1999) postulates that salmonids actively seek refugia in irrigation systems when river flow is low and suggests that fish would have otherwise died. The proportion of flow entering the Bundidgerry Creek system substantially increased during periods of low flow in the Murrumbidgee River. On one occasion, the proportion of flow entering the irrigation system was almost 300% greater than flow in the river. Under such situations, the natural cues for downstream migrating fish would be provided by the irrigation offtake and increase the chance of entrainment. Reducing instances of these unsuitable flows are therefore a necessary management action required to reduce entrainment risk to fish in source rivers.

3.4.4. Conclusions

This study identified that a wide range of species and size classes can be entrained into canal systems. Life history stages with poorer swimming abilities, such as larvae and juveniles, are most susceptible to entrainment, particularly when large proportions of water are extracted from the source river. Once entrained, some species are able to form self sustaining populations, however, this is largely contingent on habitat availability. Areas with suitable habitat are generally associated with greater species richness and diversity. In channelised systems with less habitat, more resilient species such as carp and Australian smelt became dominant. Entrainment could be reduced or eliminated by developing engineering solutions to physically exclude fish or to develop operational protocols that minimise situations where diversion flows exceed river flows.

4. THE EFFECTS OF IRRIGATION PUMPING SYSTEMS ON FISH OF THE MURRAY-DARLING BASIN

4.1. Introduction

In terms of flow, Australian rivers are among the most variable in the world (McMahon *et al.*, 1992). The Murray-Darling Basin is no exception, with highly unpredictable flood and drought regimes (Kingsford, 1999). Australian flora and fauna have adapted to this unpredictability and rely on a cycle of infrequent flooding and drought to maintain diversity and to regulate productivity (Smith, 1997). This cycling is extremely important for the structure and function of the complex arid river systems throughout the Murray-Darling Basin.

Such unpredictable climate conditions are often unsuitable for agricultural production. In the Murray-Darling Basin, there is a pressing need to guarantee enough water at critical times for crops and graziers, which is limited by low rainfall and high evaporation (Nix and Kalma, 1982). The development of water infrastructure in the Murray-Darling Basin is therefore largely based on reducing the impacts of extreme drought and flood conditions. In northern parts of the Murray-Darling Basin, extreme low topography is generally unsuitable for long distance irrigation channel systems. Subsequently, pumping systems are more commonly used and water is extracted directly from rivers into large private storage dams. Once removed from the river, irrigators have control over where and when this water is diverted.

Pumping systems have two potential impacts on fish. Firstly, fish could be directly removed from river systems. Depending on the size, capacity and location of the pumps, this activity could affect many different species at many different life history stages. Pumping systems are generally 'terminal', which means once water is extracted from the river, it (and any fish contained within) will not be returned. Secondly, pumps could physically injure or kill fish during the extraction process. Pumps containing a rotating impeller are most commonly used and could render some species or size classes susceptible to physical strike.

The timing of pumping activities could have a substantial influence on the degree of impacts on fish. Previous studies have identified diel changes in the behaviour of both larval (King, 2002; Gilligan and Schiller, 2004) and adult (Baumgartner, in press) fish of the Murray-Darling Basin. If these behavioural changes place certain species and size classes in the vicinity of pump intakes, fish may be more susceptible to extraction. The subsequent development of appropriate operating protocols, by restricting pumping activity to certain time periods, may reduce the potential impacts on fish. Whether these behavioural processes render certain species and size classes more or less susceptible to removal by pumping systems remain largely unknown for fish within the Murray-Darling Basin

The aim of this study was to therefore quantify the composition, and number, of fish removed from main river channels via pumping systems and to investigate any changes over the diel period. In addition, the degree of fish injury and mortality was also quantified to determine the relative physical impacts of the pumping process.

4.2. Methods

4.2.1. Study sites

This study was undertaken at two pumping sites on the Namoi River between Narrabri and Wee Waa. The Namoi River rises in the Great Dividing Range upstream of Armidale and tracks northwest some 845 km where it meets the Darling River. The river is heavily regulated between September and April by releases from two upland storages, Keepit and Split-Rock Dams. Lowland reaches of the Namoi catchment are heavily farmed for wheat, rice and cotton but are also heavily used by stock graziers. To determine the relative impacts of pumping practices throughout the catchment, fish were collected from a number of key sites, using a range of well-established methods.

4.2.2. Boat electrofishing

Four electrofishing sites were sampled in total (Figure 4.1). Two sites were established in the main river, upstream and downstream of the extraction site to act as reference sites to establish a baseline of adult fish abundance. Two sites were also selected in the storage dams of two major pumping systems between Narrabri and Wee Waa. These sites acted as 'terminal' sites to establish the number and species composition of fish surviving the extraction process. If large numbers of fish were being extracted, and surviving, the development of techniques to transport these fish back to the main river system may be a useful management option to reduce potential impacts.

A standard sampling protocol was deployed at each sampling site (See Chapter 2). Each site was sampled a total of five times during the study. However, due to the extreme drought conditions at the time, only three samples were possible from storage site two, which was completely drained twelve months prior to the completion of the study. During the course of boat electrofishing all fish were identified, counted and measured prior to release. All fish over 200mm total length were fitted with an external dart tag and a passive integrated transponder to monitor any potential movements from the river into irrigation systems. Movements of PIT tagged fish were assessed through returns from anglers and subsequent sampling surveys.

4.2.3. Egg and larval sampling

Larval and juvenile fish were collected from three additional sites to determine the relative impact of pumping systems on early life stages. Two sites were selected at the outlet of two main pumping systems on the Namoi River. These sites were used to determine the composition of larvae removed from the main river during the pumping process. The first site (Pump site 1) is characteristic of a low-flow pumping system. It contained two pumps with a maximum daily pump capacity of 36Ml. (Table 4.1). The second site (pump site 2) is typical of a high-flow system. This installation had 15 pumps with a combined pumping capacity of 150Ml per day (Table 4.1). A reference site was also selected in the main river upstream of the pumping systems to compare larval composition at pump sites and in the Namoi River.

All larval nets were fitted with a flow meter to allow standardisation of larval drifting rates to flow. At each site, five nets were set and retrieved during daylight hours, then again at night, to compare whether the relative impact of irrigation systems was likely to vary over the diel cycle. The contents from most larval nets were emptied into 20L buckets and incrementally transferred to sorting trays. Any live fish were picked from the tray, euthanased in a 100 mg/L Ethyl-p-aminobenzoate solution and then stored in 70% ethanol for identification in the laboratory. Samples unable to be immediately sorted were treated with a 100 mg/L Ethyl-p-aminobenzoate solution to euthanase any fish, then the entire contents were stored in 70% ethanol to be sorted in the laboratory at a later date. Non-larval fish were not included in any subsequent analysis.

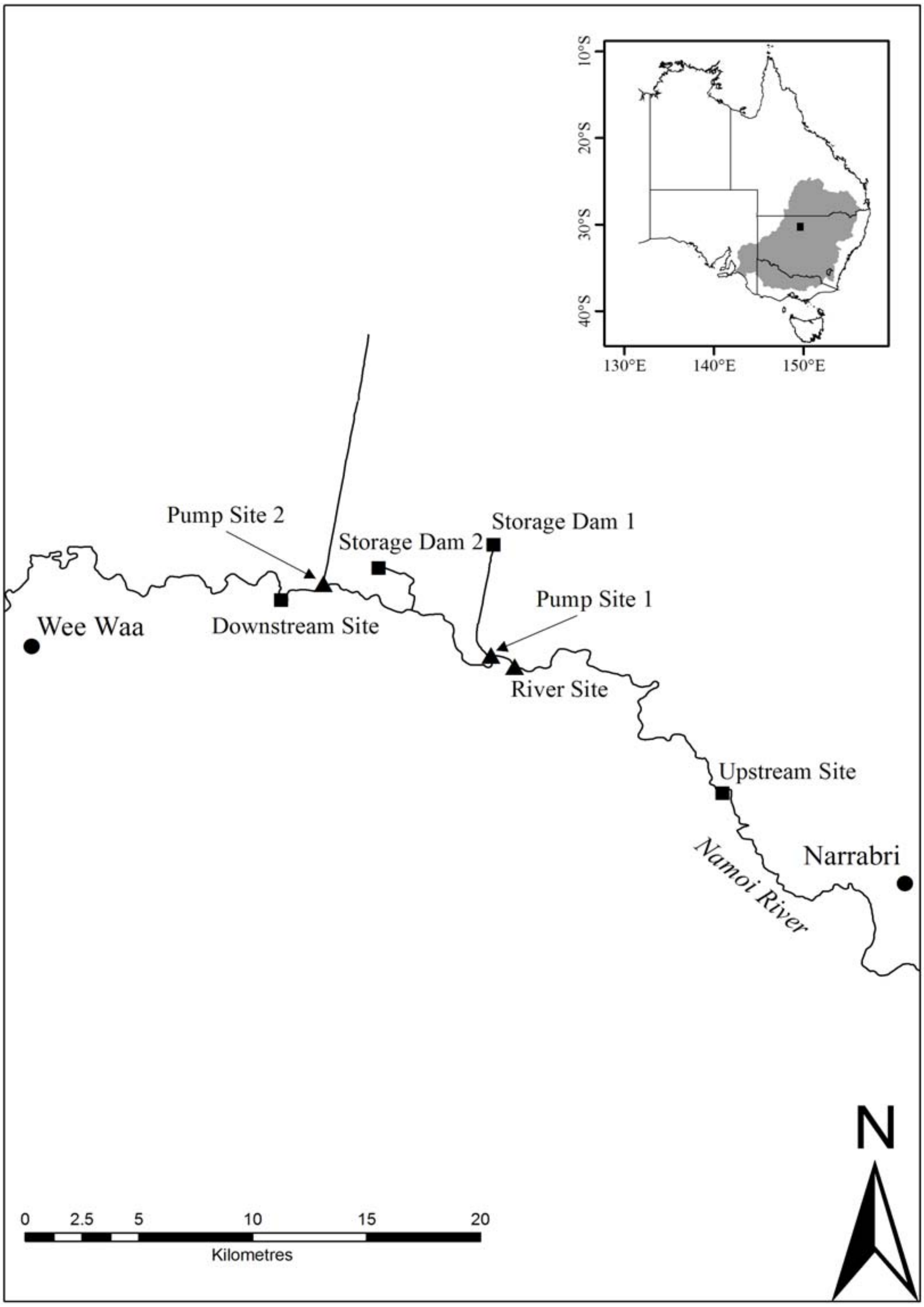


Figure 4.1. A map of the Namoi River reach between Wee Waa and Narrabri highlighting the location of pumps, storage dams, electrofishing sites (square) and larval (triangle) sites surveyed.

Table 4.1. Specifications of pump systems where fish extraction, injury and mortality were quantified on the Namoi River.

Pump site 1	
Number of Pumps	2
Pump type	Two-phase impeller
Intake diameter (mm)	300
Usual pumping time / day	12 hours (daylight)
Daily pumping capacity (max)	36 Ml
Pump Site 2	
Number of Pumps	15
Pump type	1 centrifugal, 14 two-phase impeller
Intake diameter (mm)	300 – 900
Usual pumping time / day	24 hours
Daily pumping capacity (max)	150 Ml

4.2.4. Injury and mortality

Large fyke nets (6mm mesh, 3m drop, 10m width) were placed over the pump outlets to collect any adult and juvenile fish transported via the pumping process. Fish collections were undertaken for a total of 10 weeks between September 2004 and April 2006. The net was set for five continuous and consecutive days during pumping periods but was cleared twice daily during periods of exclusive daylight (500h to 2100h) and darkness (2100h to 500h) to investigate any diel variation in entrainment rates. Upon clearing the net, all fish were identified, measured and inspected for injuries. Fish were recorded as alive, injured or dead and the nature of any injuries was recorded.

4.2.5. 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 sites as factors were performed on fourth-root transformed data to determine any differences between larval fish communities sampled among sample sites over the diel period (day and night). One way ANOSIM were used to identify any difference in fish community composition among electrofishing sampling sites. 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.

A two-way factorial Analysis of Variance (ANOVA) was performed to identify any significant differences in the relative abundance of individual species captured in fyke nets from the Namoi River and pumping sites over the diel period. 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 transformed 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 fish collected from all four sites sampled during electrofishing surveys. These analyses were performed to identify if storage dams contained a substantially different fish community than the river, which may have indicated species or size-selective mortality during the extraction process.

4.3. Results

4.3.1. Egg and larval sampling

A total of 224 larvae from 15 species were collected over the study period. Carp, carp gudgeon, spangled perch and Australian smelt were the most commonly-collected species (Table 4.2). All species sampled from pump sites were also present in river samples. In general, more fish were collected from the high-flow pump (Pump site 2) than the low-flow pump (Pump site 1).

A multidimensional scaling ordination identified a close grouping of pump sites with some separation of river sites (Figure 4.2). This difference however was not significant (Two-Way ANOSIM: Global $R = 0.026$; $p > 0.05$) suggesting that the larval composition of river and pump sites was relatively similar. Multidimensional scaling also revealed a tight grouping of the larval community between day and night samples. Although the diel abundance of some species varied (Table 4.2), no significant difference was detected (Global $R = -0.043$; $p > 0.05$).

The size range of fish sampled from larval drift nets was greater from river sites than in either pump system (Table 4.3). Only five species were collected from the river and two pump systems of which post-larval carp and spangled perch dominated catches. For all species, except Australian smelt and flatheaded gudgeon, the mean lengths of fish were lower in the river than from either pump site, suggesting a potential size-selective impact of pump systems.

Figure 4.2. A two-dimensional multidimensional scaling ordination of fish communities sampled at three larval sampling sites in the Namoi catchment. Night samples are black, white samples are daytime and sites are defined as river (square), pump site 1 (triangle) and pump site 2 (square).

Table 4.2. A summary of fish caught from larval nets at three sampling sites in the Namoi River catchment. Total number of fish caught during the day (D) and night (N) are given. Non-larval fish are excluded and the total number of fish standardised (fish per litre) is depicted by subscript (D_s and N_s).

Species	Pump 1				Pump 2				River			
	D	N	D_s	N_s	D	N	D_s	N_s	D	N	D_s	N_s
Silver perch	0	0	0.00	0.00	0	0	0.00	0.00	1	1	0.00	0.00
Goldfish	0	0	0.00	0.00	1	0	0.00	0.00	5	0	0.00	0.00
Un-specked hardyhead	0	0	0.00	0.00	0	0	0.00	0.00	4	3	0.05	0.00
Carp	3	1	0.02	0.00	10	14	0.05	0.04	22	27	0.44	0.22
Gambusia	1	0	0.00	0.00	0	0	0.00	0.00	5	3	0.07	0.00
Carp gudgeon	3	1	0.02	0.00	7	14	0.01	0.02	17	21	0.39	0.35
Spangled perch	4	2	0.63	0.09	13	4	0.34	0.04	1	1	0.00	0.00
Golden perch	0	0	0.00	0.00	0	0	0.00	0.00	1	0	0.00	0.00
Murray cod	0	0	0.00	0.00	0	0	0.00	0.00	0	1	0.00	0.00
Murray rainbowfish	0	0	0.00	0.00	0	1	0.00	0.00	0	1	0.00	0.00
Bony herring	0	0	0.00	0.00	0	2	0.00	0.00	0	0	0.00	0.00
Redfin perch	0	0	0.00	0.00	0	0	0.00	0.00	1	0	0.00	0.00
Flat-headed gudgeon	0	1	0.00	0.00	0	0	0.00	0.00	0	1	0.00	0.00
Australian smelt	1	0	0.00	0.00	1	1	0.00	0.00	8	13	0.01	0.35
Freshwater catfish	0	0	0.00	0.00	0	1	0.00	0.00	0	1	0.00	0.00

Table 4.3. Summary of length statistics for species sampled from larval drift nets at sites sampled on the Namoi River. N is the total number of fish measured, mean is the average length (in mm) with the standard deviation, range gives the minimum and maximum length recorded. Data includes non-larval fish to give an indication of the size range of fish caught in larval nets.

Species	River			Pump 1			Pump 2		
	n	mean ± SD	Range	n	mean ± SD	Range	n	mean ± SD	Range
Silver perch	3	16 ± 2	14 – 18	-	-	-	-	-	-
Goldfish	6	39 ± 5	31 – 48	-	-	-	1	40 ± 0	40-40
Un-specked hardyhead	18	23 ± 7	12 – 34	-	-	-	-	-	-
Carp	355	18 ± 9	8 – 64	8	50 ± 36	13 – 89	48	23 ± 12	11 – 52
Mosquitofish	11	17 ± 6	11 – 31	3	20 ± 6	14 – 27	1	19 ± 0	19 – 19
Carp gudgeon	474	15 ± 4	8 – 38	4	20 ± 7	14 – 32	35	17 ± 4	10 – 26
Spangled perch	5	30 ± 15	14 – 47	8	45 ± 9	34 – 62	49	58 ± 17	26 – 111
Golden perch	1	24 ± 0	24 – 24	-	-	-	-	-	-
Murray cod	2	34 ± 23	17 – 51	-	-	-	-	-	-
Murray rainbowfish	-	-	-	-	-	-	1	34 ± 0	34 – 34
Bony herring	-	-	-	-	-	-	2	21 ± 0	21 – 22
Redfin perch	1	19 ± 0	19 – 19	-	-	-	-	-	-
Flat-headed gudgeon	6	13 ± 1	10 – 15	2	13 ± 2	11 – 15	-	-	-
Australian smelt	47	21 ± 5	9 – 33	2	16 ± 5	12 – 20	2	28 ± 3	25 – 31
Freshwater catfish	1	32 ± 0	32 – 32	-	-	-	1	10 ± 0	10 – 10

4.3.2. Boat electrofishing

Boat electrofishing of four sampling sites yielded 2,286 fish from 10 species (Table 4.4). In general, more individuals (67%) and more species were sampled from river sites than storage sites (Figure 4.3). Bony herring, carp and Murray rainbowfish were most frequently sampled from river sites (Table 4.4). In contrast, storage sites were dominated by carp and bony herring with Australian smelt and goldfish sampled occasionally (Table 4.4). No other species were sampled within the storage sites.

Despite the apparent differences in species richness, no significant differences in fish community composition were detected among sites (ANOSIM: $R = 0.137$; $p > 0.05$). This analysis was confirmed by MDS, which demonstrated a tight grouping of sites in two dimensional space (Figure 4.4). A large degree of variability from storage sites accounted for this lack of differences. Most fish were sampled in the first two sampling occasions, when water allocations were still relatively high within the Namoi system. As the drought conditions worsened throughout the project, and water levels receded, fish catches from the storages declined but river catches remained relatively consistent.

Length-frequency analyses were only possible for carp and bony herring as no other species were collected in sufficient abundance (Figure 4.5). The size of carp significantly differed among all sites (KS: $p < 0.05$) except between the two river sites (KS: $D = 0.158$, $p > 0.05$). No fish smaller than 150mm were sampled from storage sites suggesting a combination of limited spawning success and poor survival during the extraction process. In contrast, river sites contained a much wider range of sizes.

The lengths of bony herring significantly differed among all sites (KS: $p < 0.05$). Storage dam 1 (35Ml capacity) was dominated by size classes less than 100mm. Storage dam 2 (1,000Ml capacity) contained a greater number of larger fish, possibly due to increased forage opportunities in the larger waterbody. River sites contained a range of sizes but more large fish (>300mm) were collected from the upstream site.

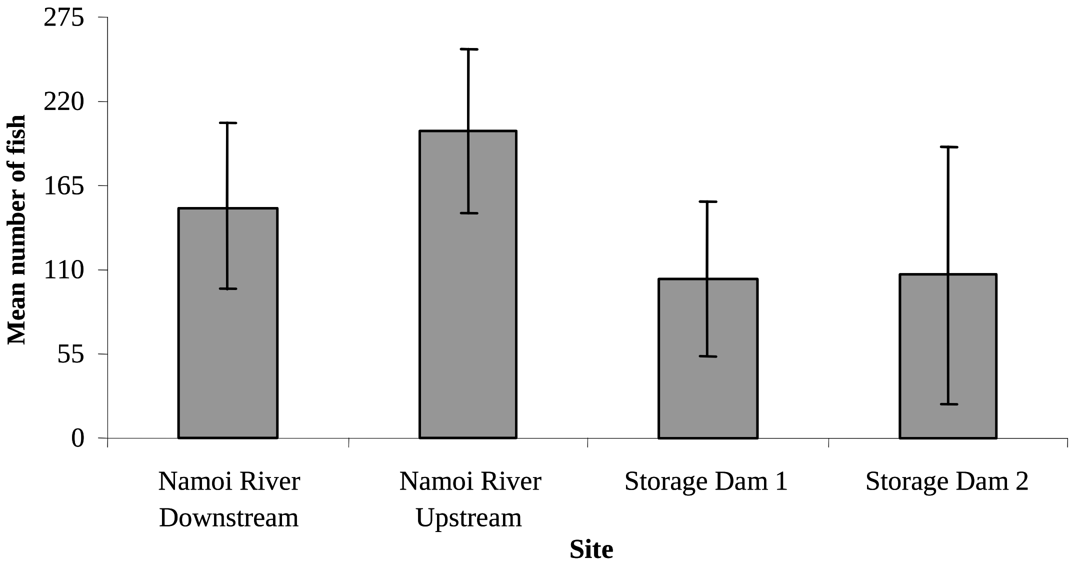


Figure 4.3. The mean abundance of fish (± one standard error) sampled from each site sampled in the Namoi River and its associated storages. Means are based on total catches per sampling occasion which have been weighted by sample size to account for the reduced number of samples from storage dam 1.

Table 4.4. A summary of fish caught by boat electrofishing undertaken at each site sampled on the Namoi River and its associated storage dams. All data is pooled for all five samples except for storage dam site 2, where only three samples were possible.

Species	**Namoi River**		**Storage Dams**	
	Downstream	**Upstream**	**Site 1**	**Site 2**
Native Fish				
Australian smelt	10	10	12	7
Freshwater catfish	0	1	0	0
Carp gudgeon	2	1	0	0
Spangled perch	1	5	0	0
Golden perch	0	7	0	0
Murray cod	16	9	0	0
Murray rainbowfish	47	46	0	0
Bony herring	536	647	438	195
Alien fish				
Goldfish	17	7	13	0
Carp	118	72	57	12
Grand Total	747	805	520	214

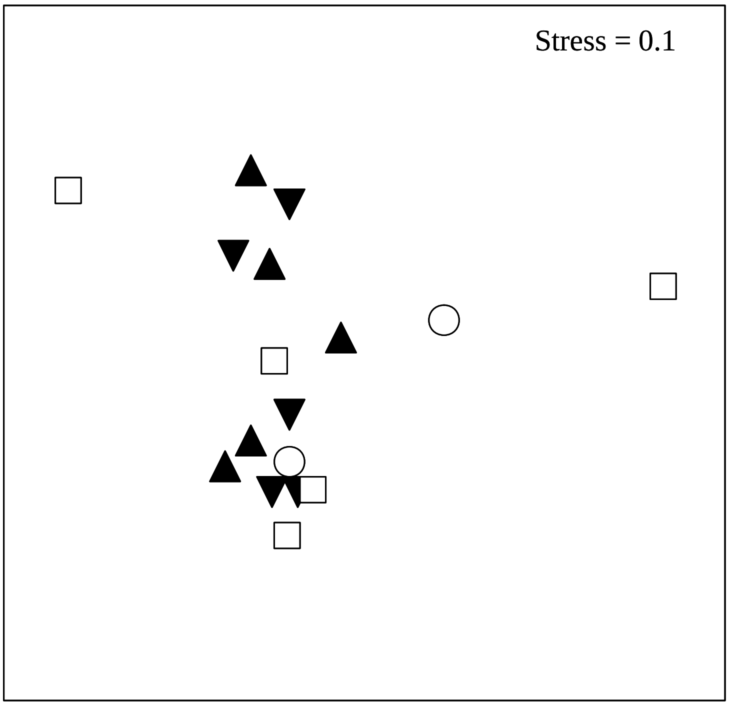


Figure 4.4. A two-dimensional multidimensional scaling ordination of fish communities sampled in the Namoi River and its associated storages. Sites are defined as Namoi River upstream (black upward triangle), Namoi River downstream (black downward triangle), storage dam 1 (white circle) and storage dam 2 (white square).

4.3.3. Entrainment rates, injury and mortality

A total of 2,326 fish from 11 species were sampled from fyke nets set at the outlets of irrigation pumps. The maximum extracted in a single day was 232 individuals, including larval, sub-adult and adult fish. Entrainment rates of certain species differed significantly among pumping sites (Two-Way ANOVA: Table 4.5). Significantly more carp, carp gudgeon, spangled perch and bony herring were extracted by the larger irrigation system at pump site 1 (Two-Way ANOVA: Figure 4.6). Significantly more goldfish were extracted at night but no other species were selectively extracted during a particular diel period.

A total of 85 (4.0%) fish were killed and 78 (3.6%) were injured during entrainment (Figure 4.7). No injuries or mortality were recorded for golden perch (n = 1), Murray rainbow fish (n = 3), freshwater catfish (n = 1) or Un-specked hardyhead (n = 1). The proportion of deaths and injuries varied substantially among species. Mortalities and injury were greatest for Australian smelt (10% killed, 10% injured), carp (11%, 7%) and goldfish (6%, 12%). Numerically, spangled perch (n = 1,056) was the most common species entrained into pump systems but surprisingly, only two individuals were killed and four injured.

The degree of mortality also substantially differed among size classes (Figure 4.8). The proportion of fish killed and injured was substantially greatest for fish between 0 – 50mm (10% killed, 6% injured) and greater than 200mm (7%, 7%). For the smaller size classes, carp contributed to 7% of the total mortality observed whilst goldfish, carp gudgeon, spangled perch, bony herring and Australian smelt accounted for the remainder. Carp were the only species >200mm entrained into the system and represented all mortalities. Interestingly, no mortalities were recorded for fish 100 – 200mm.

At both pumping sites, the total number of fish surviving the extraction process was substantially greater than those killed or injured (Table 4.6). Only one individual (a spangled perch) was killed during passage through pump one, which has the lowest pumping capacity of both sites. Pump site 2 had a much greater pumping capacity and was associated with substantially increased mortality and injury.

The nature of injuries sustained during pump entrainment varied greatly (Figure 4.9). The majority of fish injuries arose from loss of eyes (21% of total fish injured), loss of tail (17%), decapitation (16%) or from being halved (13%). Low incidences of opercular removal and disembowelment were also observed. It is difficult to ascertain species-specific injuries arising from pump passage due to small sample sizes for some fish. In general, greater incidences of injury were observed in the introduced species carp and goldfish (Table 4.6).

Table 4.5. Results of a Two-Way ANOVA highlighting differences in the total number of fish entrained between pumping sites (S) and diel period (D) for sites sampled in the Namoi River. Only F-values are presented and results are based on log (X+1) transformed data. Species are defined as GF, Goldfish (*Carassius auratus*); CC, carp (*Cyprinus carpio*); CG: carp gudgeon (*Hypseleotris* spp); SP, spangled perch (*Leiopotherapon unicolor*); BH, bony herring (*Nematalosa erebi*) and AS; Australian smelt (*Retropinna semoni*). An asterisk denotes a significant result at a bonferroni-corrected $p < 0.01$.

Factor	**GF**	**CC**	**CG**	**SP**	**BH**	**AS**
S	1.93	17.19*	22.73*	14.73*	19.92*	0.01
D	13.60*	2.16	0.33	0.10	4.37	0.29
S*D	1.93	0.13	5.32	0.09	0.98	0.53

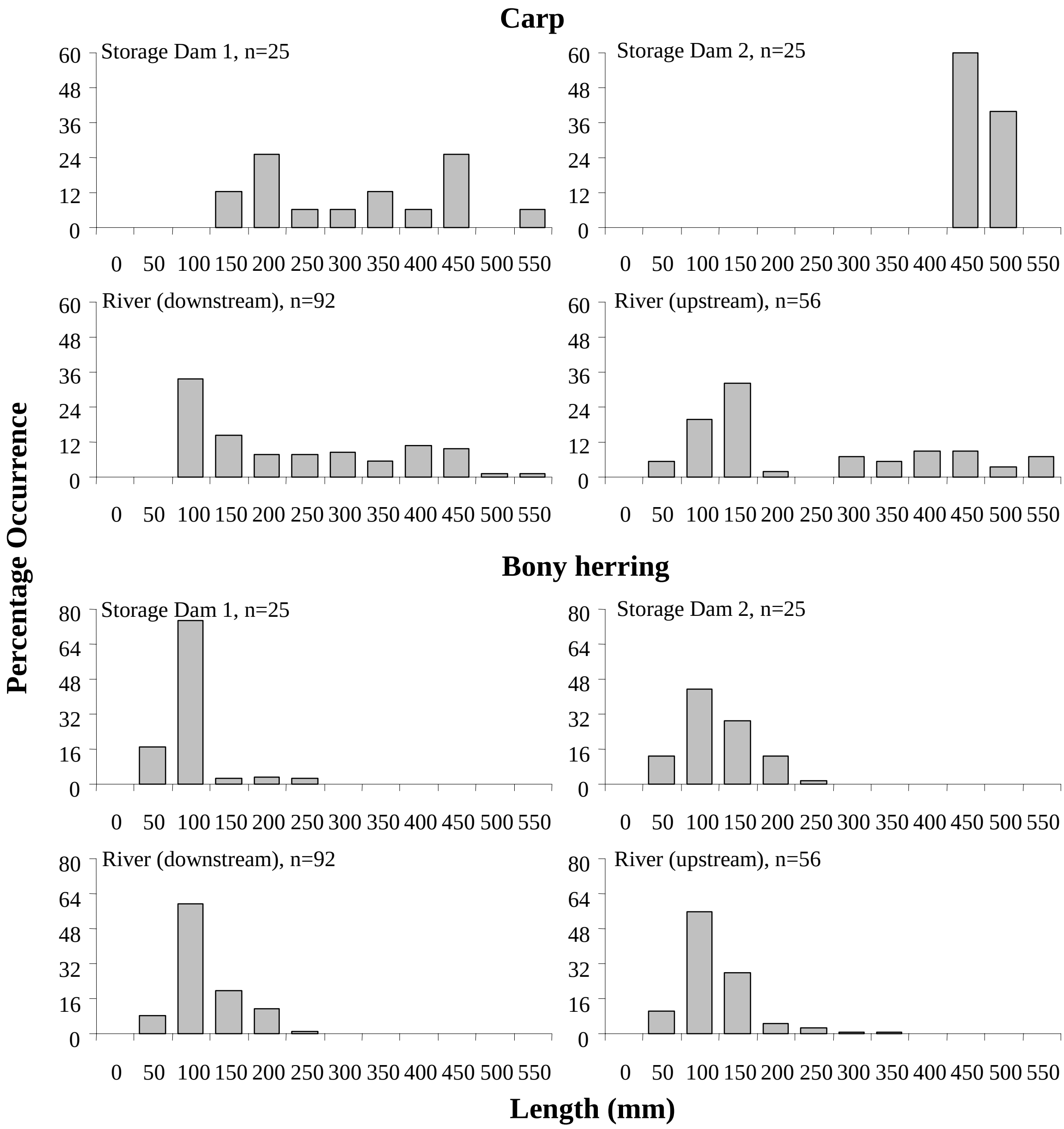


Figure 4.5. Length-frequency distributions of carp and bony herring from the four electrofishing sites on the Namoi River.

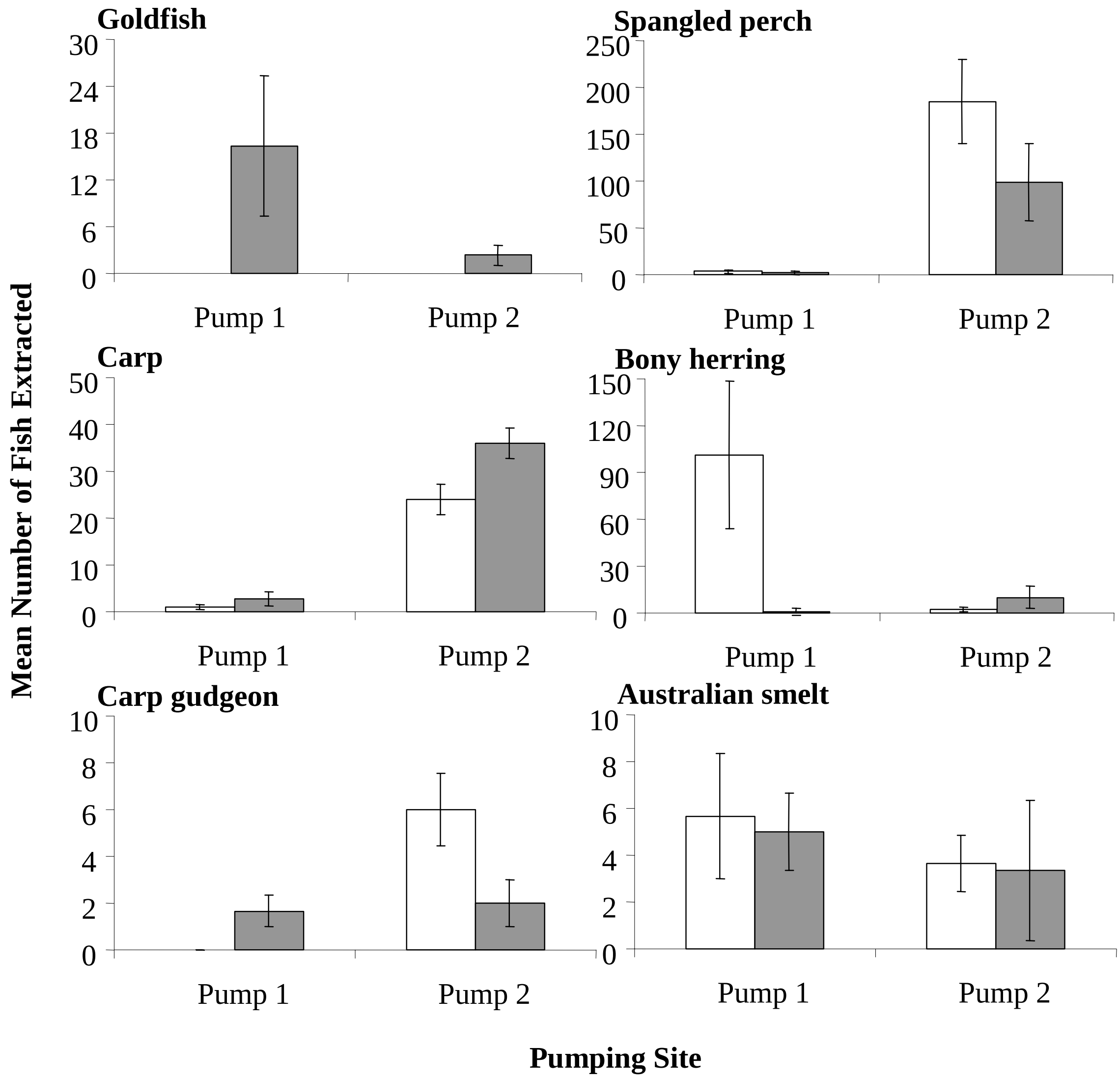


Figure 4.6. The mean extraction rates (per day) of the most common species collected from the outlet of two pumping systems on the Namoi River. Pump site 1 had three (24”, 600mm) pumps operating whilst pump site two could operate up to thirteen (24”, 600mm) pumps.

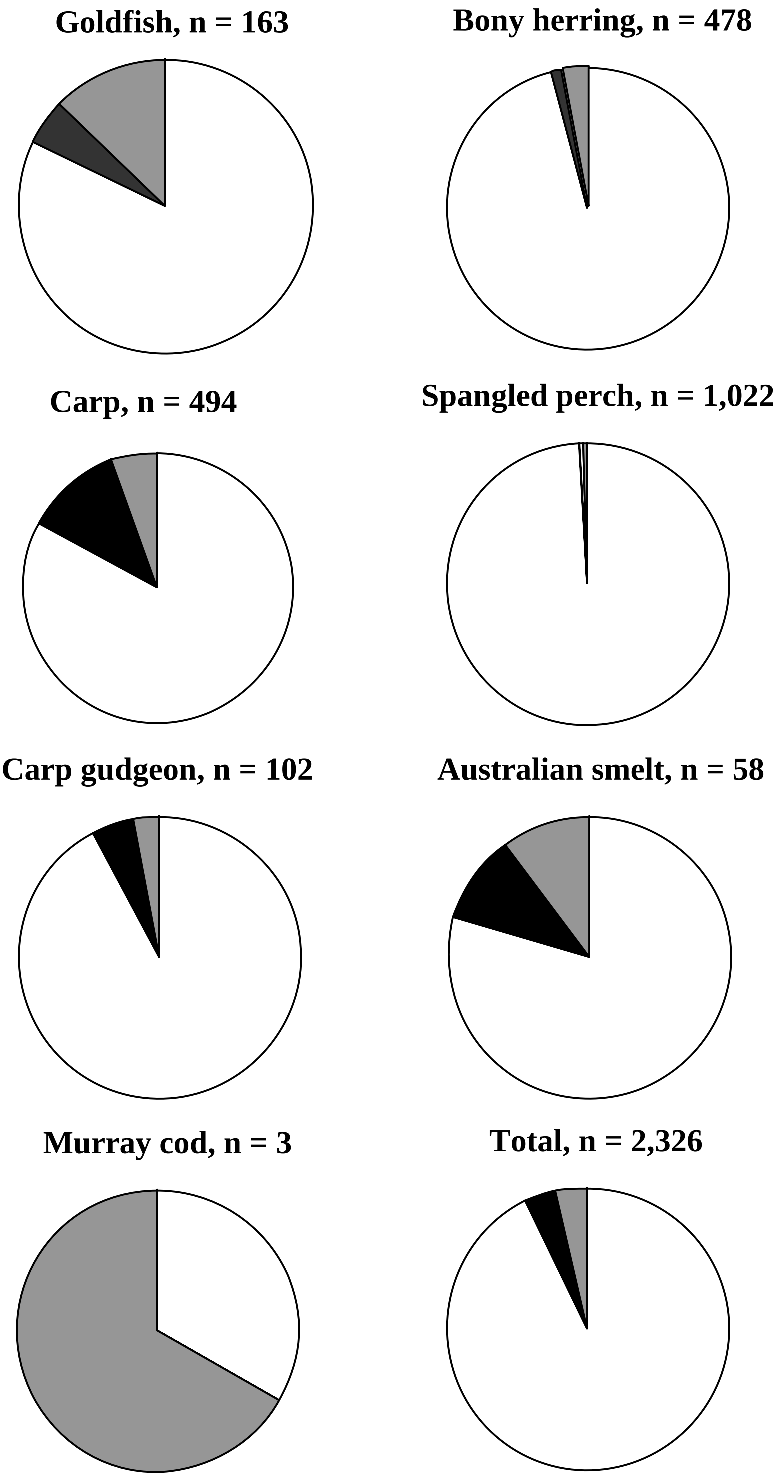


Figure 4.7. Percentage of all fish uninjured (white), injured (grey) and killed (black) following passage through irrigation pumps on the Namoi River. Only species injured during passage are shown. Consequently, Murray rainbowfish, golden perch, freshwater catfish and Un-specked hardyhead are not shown.

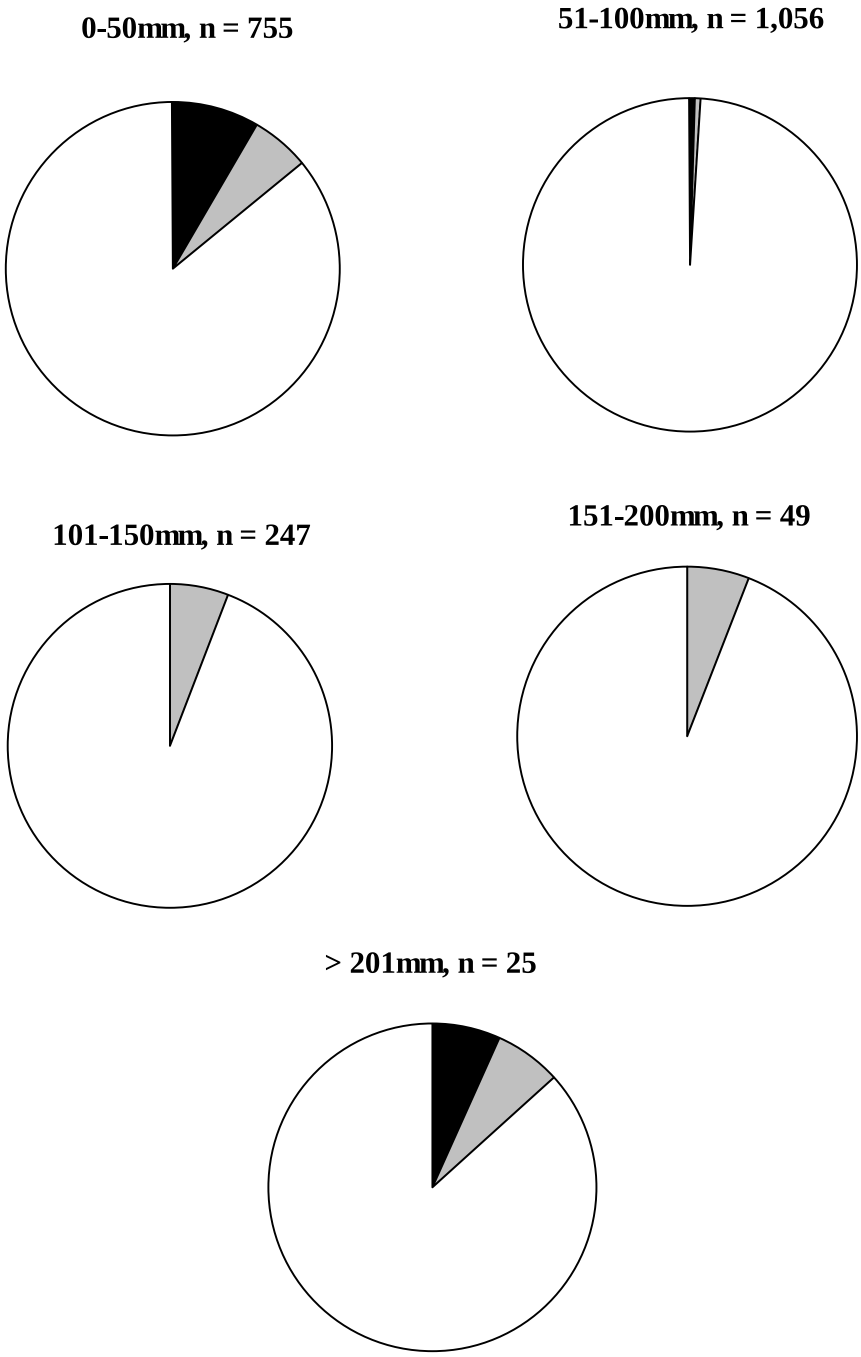


Figure 4.8. The percentage of fish uninjured (white), injured (grey) and killed (black) following passage through irrigation pumps on the Namoi River. The figure is based on size classes of fish entrained into the pump system and is pooled for all species.

Table 4.6. A summary of incidences of mortality and injury across all fish species collected from pump sites in the Namoi River.

Species	Pump 1			Pump 2		
	Survived	Killed	Injured	Survived	Killed	Injured
Spangled perch	117	1	2	905	1	4
Carp	121	0	6	373	58	20
Bony herring	432	0	0	46	6	14
Goldfish	113	0	14	50	8	7
Carp gudgeon	2	0	0	75	5	3
Australian smelt	20	0	0	38	6	6
Murray cod	0	0	0	3	0	2
Murray rainbowfish	1	0	0	2	0	0
Golden perch	0	0	0	1	0	0
Freshwater catfish	0	0	0	1	0	0
Un-specked hardyhead	1	0	0	0	0	0

Figure 4.9. An example of fish injuries sustained during passage through a pump system on the Namoi River.

4.4. Discussion

4.4.1. Impact of pumping systems on fish

Irrigation pumps have the potential to impact upon native fish species in a number of different ways. Firstly, water removed by pump systems contained a diverse range of species and size classes of fish. The passage of fish through the two pump systems resulted in permanent removal as no irrigation water was returned Namoi River from either site. Secondly, passage through pump systems resulted in the injury and mortality of several species. These impacts were species-specific but were common to pump systems at both sites.

This study only identified the effects of irrigation pump systems at two sites in an extensive river system. When operating at peak capacity, these two systems alone could collectively remove over 200Ml.day^{-1} from the Namoi River. The cumulative impact of pumping practices could therefore result in the abstraction of large volumes of water from river systems, especially during times of full allocation. In the Barwon-Darling River system, water extraction can remove volumes of water equivalent to 65% of daily flow during flood events (Thoms and Cullen, 1998). Extractions of this magnitude can reduce natural cues for spawning and decrease inundation of floodplain habitat (Kingsford, 2000).

Extracting high volumes of water also greatly increases the probability of fish extraction (Megargle, 1999). On the Namoi River, a maximum of 232 fish (including all life history stages) per day were extracted from the two pumping systems investigated. Although larger-bodied individuals could potentially avoid pump intakes, fish over 200mm were regularly collected from pump outlets, and is likely related to pump capacity. In some instances, a single pump can remove over 5ML in one hour. At installations containing multiple pumps, such as at site two, the probability of extraction could increase substantially when the cumulative impact of pumps exceeds the swimming ability of fish. Assuming similar processes are acting at other pumping sites on the Namoi River, the large-scale impacts on fish could be substantial.

Species composition varied greatly among the main river channel and storage dams suggesting that some species may not be able to survive all phases of the pumping process. Pumping into storage systems is a two stage process. In most cases water is initially extracted from the main river and delivered to end users via channel systems. Water is then pumped from the channel and delivered to large storage dams. From here, water is held for a variable amount of time and then re-diverted for crops or stock when required. Fish could be exposed to various sources of stress at different stages of this water transfer process. In particular, only four species were sampled from storage dams despite eleven being sampled at the pump outlet. These differences suggest that survival may be greater during the first stage of pumping.

Twelve species were sampled in fyke nets at the pump outlets but only four were collected from within the storage dams. This observation suggests that mortality is either greater during the second phase of pumping, when water is pumped from delivery channels into off-river storage dams. Alternatively, fish may survive subsequent pumping into storage dams but cannot survive due to insufficient habitat. Mortality beyond the first pumping stage was not assessed during this study, as once fish were removed from the first stage they were considered effectively lost from the river system. Electrofishing surveys were merely conducted to determine whether the composition of fish in storage dams was significantly different from those in the main river channel. Storage dams are usually man-made, devoid of suitable habitat and subject to large fluctuations in water level. The addition of snags and the implementation of suitable operational practices may improve survival of entrained fish, but these fish would have little opportunity to return to the source river.

Developing mechanisms to prevent entrainment would therefore represent a more suitable management solution than simply increasing opportunities for survival.

Few larval and juvenile fish were sampled from the pump sites, which suggests either a resilience to extraction or damage beyond identification during the pumping process. More were sampled from the high pump site, which is expected because greater amounts of water were removed. Larval Murray cod and golden perch are known to possess low tolerances to the type of shear and pressure changes likely to be experienced during entrainment (Baumgartner *et al.*, 2006). Therefore, severe damage during the pumping process is likely to occur, especially when large amounts of water are extracted.

Diel drifting behaviour by native fish larvae was previously considered a potential mechanism to control entrainment rates (Gilligan and Schiller, 2004). If drifting behaviour occurred within specific diel periods, water extractions could be timed to appropriately mitigate potential impacts. No significant diel differences in larval drifting rates were observed for any species, although overall drifting rates were low in comparisons to other studies (Humphries *et al.*, 1999). Modifying pumping regimes over the diel cycle would therefore contribute little to reducing entrainment rates of fish in the Namoi River. It should be noted, however, that larval work was carried out during one of the worst droughts on record. Reduced inflows arising from these conditions would have prevented spawning in many species by suppressing flow, one of the major cues for spawning in many species. Any reduction in larval production would have greatly reduced the ability to detect any impacts arising from pump systems, especially if larval drifting rates were substantially reduced in the Namoi River. Further study should be subsequently undertaken in years with high flow when larval abundance is expected to increase.

4.4.2. Pump-induced injuries and mortality

The collection of live individuals from river pump outlets suggested that overall survival rates were high for many species. Similar observations have been made in North America where eels (*Anguilla americana*) and rainbow trout (*Onchorhynchus mykiss*) successfully pass through screw-type hidrostal pump systems (Patrick and Sim, 1985; Rodgers and Patrick, 1985). Mortality and injury were also much lower at the low-flow pump site than the high flow site. The pumps were of identical designs, thus removing any bias that could have arisen from any differences between pumps. The high flow pump site was capable of delivering 500% more water than the low pump site and the outlet area was characterised by greater shear stress and pressure changes. Both of these factors are known to greatly increase fish mortality during periods of short term exposure (Morgan *et al.*, 1976; Hoss and Blaxter, 1979).

Mortality and injury was size specific, with size classes less than 50mm or greater than 200mm most susceptible. Small fish, given poor swimming abilities and reduced body size are likely to be more susceptible to the effects of sudden pressure changes and shear stress associated with passage through a pump system (Neitzel *et al.*, 2000). In contrast, large fish have a greater capacity to resist shear (Neitzel *et al.*, 2000) and are more likely to be impacted by physical strike with mechanical components (McNabb *et al.*, 2003). This assertion is supported by the observed increase in mortality among large fish (>200mm) and the proportion of fish which lost tails, were halved or decapitated during passage.

The size-specific nature of injuries may also be related to impeller design and operation. Passage through Hidrostal pumps is associated with low mortalities in American eels (*Anguilla Americana*) and rainbow trout (*Onchorhynchus mykiss*), but high mortality of yellow perch (*Perca flavescens*) and alewife (*Alosa psuedoharengus*) (Patrick and McKinley, 1987). These observations suggest that whilst different impeller designs can improve survival for some fish, reductions in injury and mortality are likely to be species-specific. Interestingly, when operated at increased extraction rates

(>600 rpm), mortality exponentially increased for North American species (Patrick and McKinley, 1987).

Pumps used on the Namoi River rotate at an average rate of 1400 rpm. Such operating conditions may greatly increase the risk of physical strike, subject fish to shear stresses and elevated turbulence. Evaluating the effects of impeller design and revolution rate were beyond the scope of this study. Casual observations indicate that higher incidences of injury and mortality were observed at site two. A subsequent biological assessment of different operating protocols and impeller designs would be useful to assess whether fish-friendly pump designs could represent an appropriate management tool to reduce these observed impacts on fish.

4.4.3. Conclusions

Irrigation pumps have the potential to extract large numbers of fish from many species and size classes. In some instances over 200 fish per day were extracted, with high-flow pumps having the greatest impact. Post extraction, two size classes of fish: large (>200 mm) and small (<50mm), were susceptible to injuries and mortality. Although sampling was stratified over diel period, there were no significant differences in entrainment rates between night and day, although relatively few eggs and larvae were sampled. This observation suggests diel changes to operating protocols are not a suitable management option to mitigate the effects of pumping systems. High extraction rates of fish suggest that the cumulative effects of pumping systems, on a river or catchment scale, could have substantial effects on fish and other aquatic fauna. Managers should therefore investigate the possibility of reducing fish extraction, possibly through the development of screening techniques, as a method of improving the operation of pumping systems for fish.

5. THE EFFECTS OF DRAWDOWN ON FISH ENTRAINED IN IRRIGATION CANALS

5.1. Introduction

In the Murray-Darling Basin, irrigation seasons are regulated over a strict timeframe depending on the amount of water available and annual climatic conditions. In Southern regions in particular, irrigation water is diverted from main river systems into channels for delivery to end users. This process is usually ongoing for the entire irrigation season. Once irrigation demand ceases, irrigation releases stop, and water levels within the irrigation channels drop dramatically. This sudden change in water level often reduces the channels to a series of disconnected pools where fish, and other aquatic fauna, could be stranded. It has been previously hypothesised that many species and size classes of fish could be susceptible to poaching, predation, poor water quality or desiccation during periods of irrigation system drawdown (King and O'Connor, 2007). There is little quantitative data to determine the extent of such impacts, and currently knowledge is based largely on anecdotal reports.

Removal techniques are widely used in fisheries research to obtain estimates of total fish population size and are extremely flexible with respect to gear type and simplicity of application (Johnson, 1965; Mahon, 1980; Pollock and Otto, 1983; Seber, 1986; Gatz and Loar, 1988; Pollock, 1991; Chao and Chang, 1999). Removal methods are based on the hypothesis that by progressively removing individuals from a population (termed depletion sampling) the total population size will get progressively smaller (Pollock, 1991). Population estimates are then predictively derived by examining the cumulative reduction in catch over three or more depletion samples. Estimators for this technique exist in various mathematical forms, each aimed at improving the accuracy of the population size estimate (see for example Seber, 1982).

Mathematical models are well tested but require robust experimental designs in order to avoid violating two major assumptions (Bryant, 2000). The first assumption requires that the population remains closed for the duration of sampling. Closure requires that immigration, emigration, mortality and recruitment should be zero to reduce any bias associated with natural changes in population size because of these mechanisms. Secondly, it is assumed that catchability does not vary; population estimates could be over or underestimated depending on the direction of bias. Violations of these assumptions can lead to large errors in population size estimates (Seber, 1982; Gatz and Loar, 1988). Although techniques for estimating such violations have been previously determined, they are often overlooked (Zippin, 1958; Gatz and Loar, 1988).

In this study, we used removal techniques to determine the population sizes of fish trapped in residual pools after draw-down. Fish were collected immediately after draw-down, and then again two weeks later to determine if any substantial population declines had occurred. The effects of draw-down on water quality are also largely unknown. Therefore, water quality was also recorded to determine if any changes could be detrimental to fish health in the system.

5.2. Methods

5.2.1. Study sites

Fish were collected from the Mulwala and Coleambally canals, which provide irrigation water to a large rural area extending southward northwest of Yarrawonga (Figure 5.1). Both irrigation systems service a combined area approximately of 995,000 Ha of land primarily to irrigate cereal crops such as rice and wheat.

Water is gravitated into both of these systems between September and April and volumes are largely driven by demand from irrigators. As with other systems in this region, canals are annually closed in May and large areas are known to dry out, or form a series of disconnected pools.

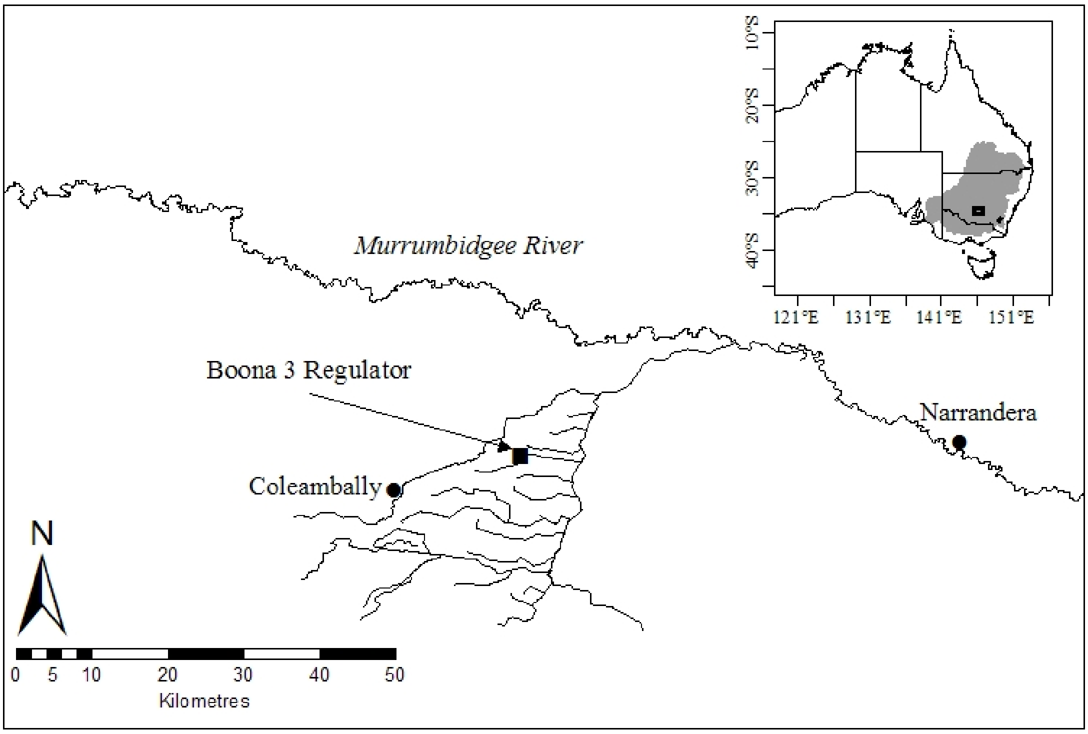
In the first year of sampling, a pilot study was undertaken to determine remnant pools where fish stranding occurs. In this pilot, sites were inspected, and the structure of fish communities investigated, to determine the ideal location for population estimation work. Following the pilot period, four sites were selected in each of the irrigation systems; three in the Mulwala Canal and one in the Coleambally Canal (Figure 5.1). In Mulwala canal, suitable sites were located at Dunn's regulator (extraction point at Lake Mulwala), Nolan's Road bridge and the Drop (a hydroelectric sump). On the Coleambally Canal, work was undertaken at Boona's regulator on one of the major waterways in the irrigation system.

5.2.2. Fish collection

Depletion sampling, in order to obtain removal estimates, was conducted in drawn-down pools to obtain population estimates. Fish were collected using a combination of backpack electrofishing and seine netting a total of five times over two days. All captured fish were removed and subsequently stored in a holding cage. Initially, backpack electrofishing was used for 500 seconds ('on' time) then five seine trawls were performed to remove as many fish as possible per depletion sample. At the completion of each depletion sample, all fish were identified, counted, measured and placed into holding cages. Once the final depletion sample was completed, all fish were returned to the pool.

The draw-down period is the only time where maintenance can be carried out on the hydroelectric facility at the Drop. To access the turbines, maintenance workers are required to pump the area dry, which could have adverse impacts on any fish remaining in the pool. Rather than return fish to an area that would be otherwise dry, removal sampling was undertaken as usual but, upon completion, all fish were translocated to the nearby Colombo Creek system.

Each site was re-sampled two weeks later (using the same techniques) to investigate any potential changes in population size that could be attributed to poaching, predation or mortality. Once irrigation channels had been drawn-down to isolated pools, the population could be considered closed as net migration and emigration from the study areas should be zero. Any subsequent changes in population size would be independent of migration-related mechanisms.



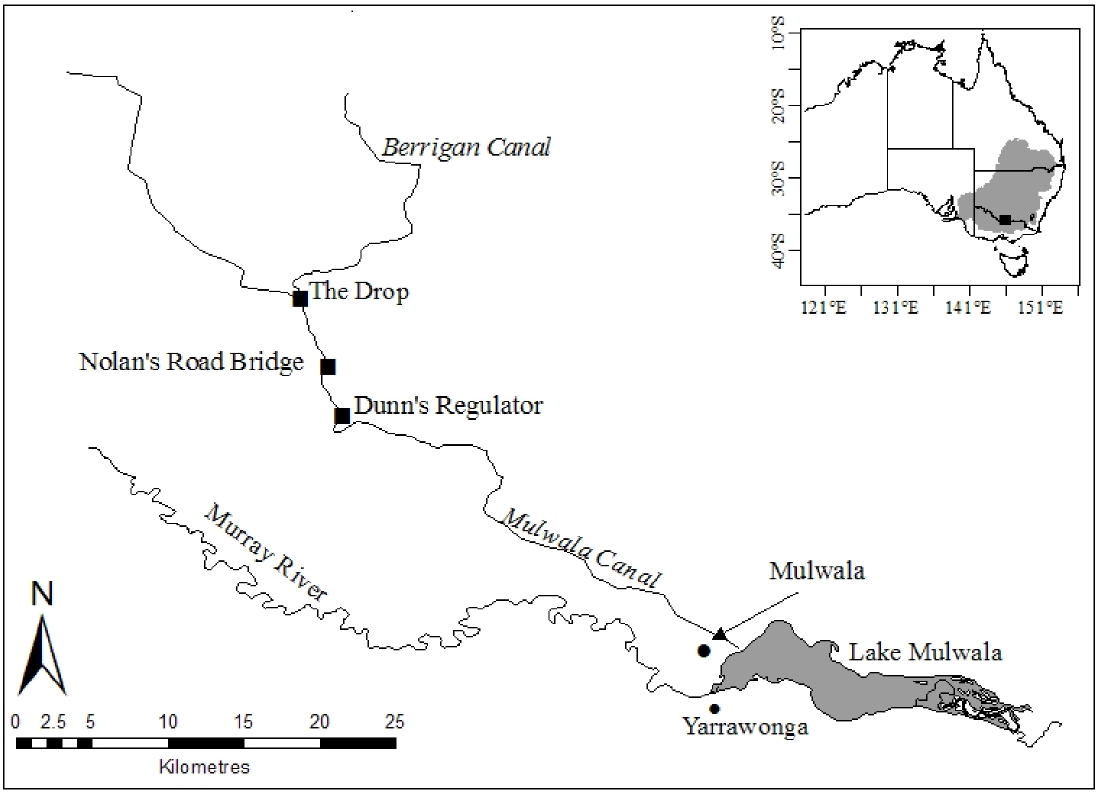


Figure 5.1. A map of the Coleambally (top) and Mulwala (bottom) canal systems showing the location of sites used in the irrigation canal draw-down study. Sampling sites are shown as squares.

5.2.3. *Population estimation methods*

Population size was estimated using the Jackknife estimator (Pollock and Otto, 1983) which is recommended as the most accurate estimator of population size for depletion experiments (Seber, 1982). Calculations of variance and 95% confidence intervals (CI) for the Jackknife removal method (after Pollock and Otto, 1983) were obtained from the May 1994 version of the program CAPTURE (Pollock, 1991; Reid *et al.*, 1997). When fish were only caught during one of the five depletion samples, no consistent decrease in numbers could be observed and, consequently, it was assumed that the entire population had been sampled. The total number of fish caught, marked, then relocated was recorded after each depletion sample.

5.2.4. *Water quality monitoring*

Water quality was monitored before and after drawdown to correlate any observed changes on fish health. A model U-10 Horiba water quality meter was used to measure temperature, turbidity, dissolved oxygen and pH. Three measurements were taken from each site before fish depletion sampling commenced.

5.2.5. *Data analysis*

Data were analysed using the S-PLUS 2000 statistical package (Insightful corporation, 2001) Two-way analysis of variance (without replication) using sites and sampling period (immediately after draw-down and two weeks after) as factors, were performed on population estimates to determine any significant differences in population size among sites or between sampling periods.

A two-way factorial analysis of variance (with replication) was also performed on water quality variables (temperature, conductivity, pH and dissolved oxygen) to determine if irrigation system draw-down influenced water quality within remnant pools. Prior to performing ANOVA, quantile-quantile plots (as described in Insightful Corporation, 2001) confirmed the transformed data were not normally distributed. A normality stabilising transformation (log x+1) was subsequently performed.

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 before and after draw-down. Differences in length-frequencies may provide a useful indicator of predation or poaching after drawdown has occurred.

5.3. Results

5.3.1. *Population estimates*

Population estimates were obtained for 12 fish species from the four irrigation draw-down sites. Murray cod, Carp gudgeon, river blackfish, Australian smelt and flat-headed gudgeon were sampled from all sites within the Mulwala Canal system (Figure 5.3). Golden perch and gambusia were collected from the Drop and Dunn’s regulator whilst silver perch and redfin were only collected at the drop. At all sites, population estimates were greater immediately following draw-down, compared with subsequent sampling taken two weeks after (Figure 5.2). The total population size (all species pooled) was far greater at the Drop, than any other site, where the total number of fish was estimated at 953,738 from 11 species. The lowest population size was calculated at Nolan’s Road bridge where 702 fish from 7 species were collected. The site sampled in the

Coleambally Canal contained the lowest species richness, with only three species collected including carp, goldfish and Australian smelt.

No significant differences in population size were detected among sites (Two Way ANOVA: F = 1.04; $p > 0.05$) or between sampling times (Two Way ANOVA: F = 1.00, $p > 0.05$). However, total population size was substantially lower two weeks after draw-down. There were significant reductions in the population size of Australian smelt, Murray cod and river blackfish from Dunn's regulator and no carp or goldfish were captured at Boona regulator. Although fish populations were lower at the Drop, this could not be determined statistically because fish were removed for relocation. The abundance of carp gudgeon and Un-specked hardyhead increased at Nolan's Road bridge and Dunn's regulator suggesting potential immigration into the study area.

Data were only based on a single season of data, coupled with the extremely large population estimate obtained from the Drop, increased variability which masked any potential differences among sites. Similar variability was evident for the temporal analysis (immediately after draw-down versus two weeks after) and anticipated sampling of these sites over coming seasons will enable a more accurate determination of changes in population size among seasons.

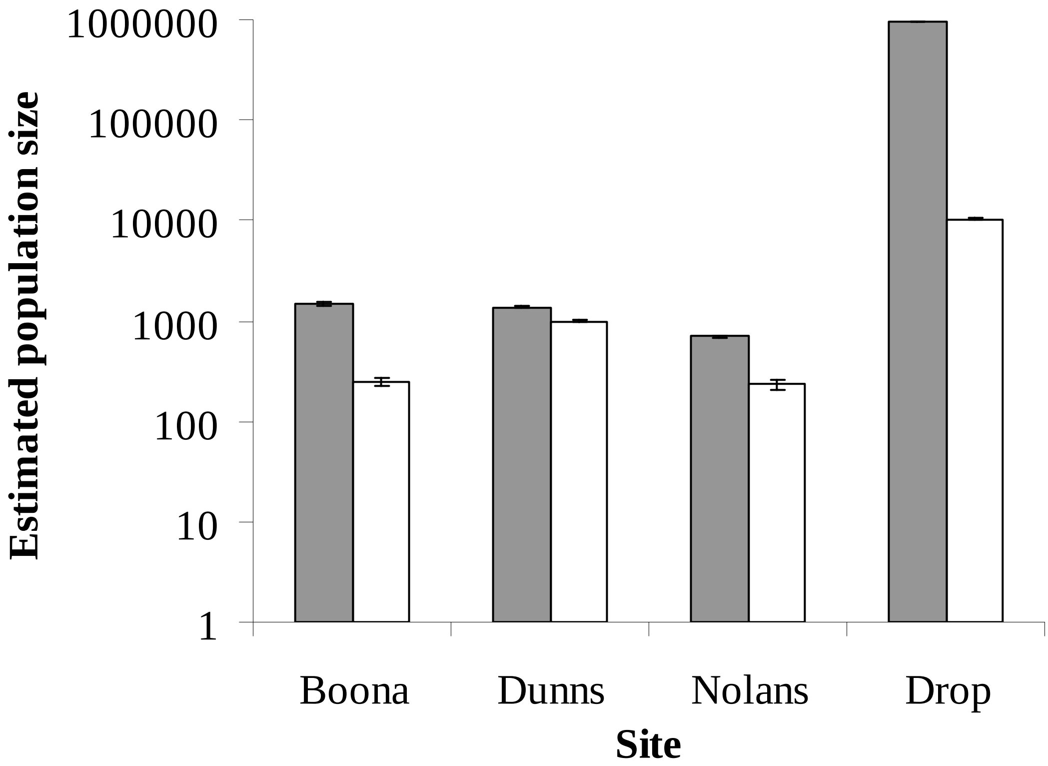


Figure 5.2. Estimates of population size (all species pooled ± 95% confidence intervals) at all sites sampled in the Mulwala and Coleambally irrigation systems. Bars indicate population size immediately after drawdown (shaded) and two weeks later (hollow).

5.3.2. Length frequency

Length frequency analysis determined that populations of fish in irrigation systems were largely dominated by adult small-bodied species, such as Australian smelt, Un-specked hardyhead and carp gudgeon. In addition, juvenile large-bodied species such as Murray cod, golden perch and river blackfish were also caught. The length-frequencies of four species were substantially smaller in Mulwala Canal two weeks after draw-down (KS: $p < 0.05$; Table 5.1). The length of Australian smelt and carp gudgeon significantly reduced at Dunn's regulator and Nolan's Road Bridge respectively. The only large-bodied species sampled in sufficient numbers for length frequency analysis was Murray cod at Dunn's regulator where the mean length reduced by over 100mm in two weeks.

Three species, Un-specked hardyhead, carp gudgeon and Australian smelt, were substantially smaller at the Drop two weeks after draw-down. However, after initial sampling the site was pumped down to 50mm depth to enable maintenance work to be undertaken on the hydroelectric turbine. In anticipation of this event, all fish captured on the initial draw-down sampling were removed from the site and translocated to a more permanent nearby water source. This effectively removed all large-bodied fish from the site to prevent a likely fish kill event or poaching.

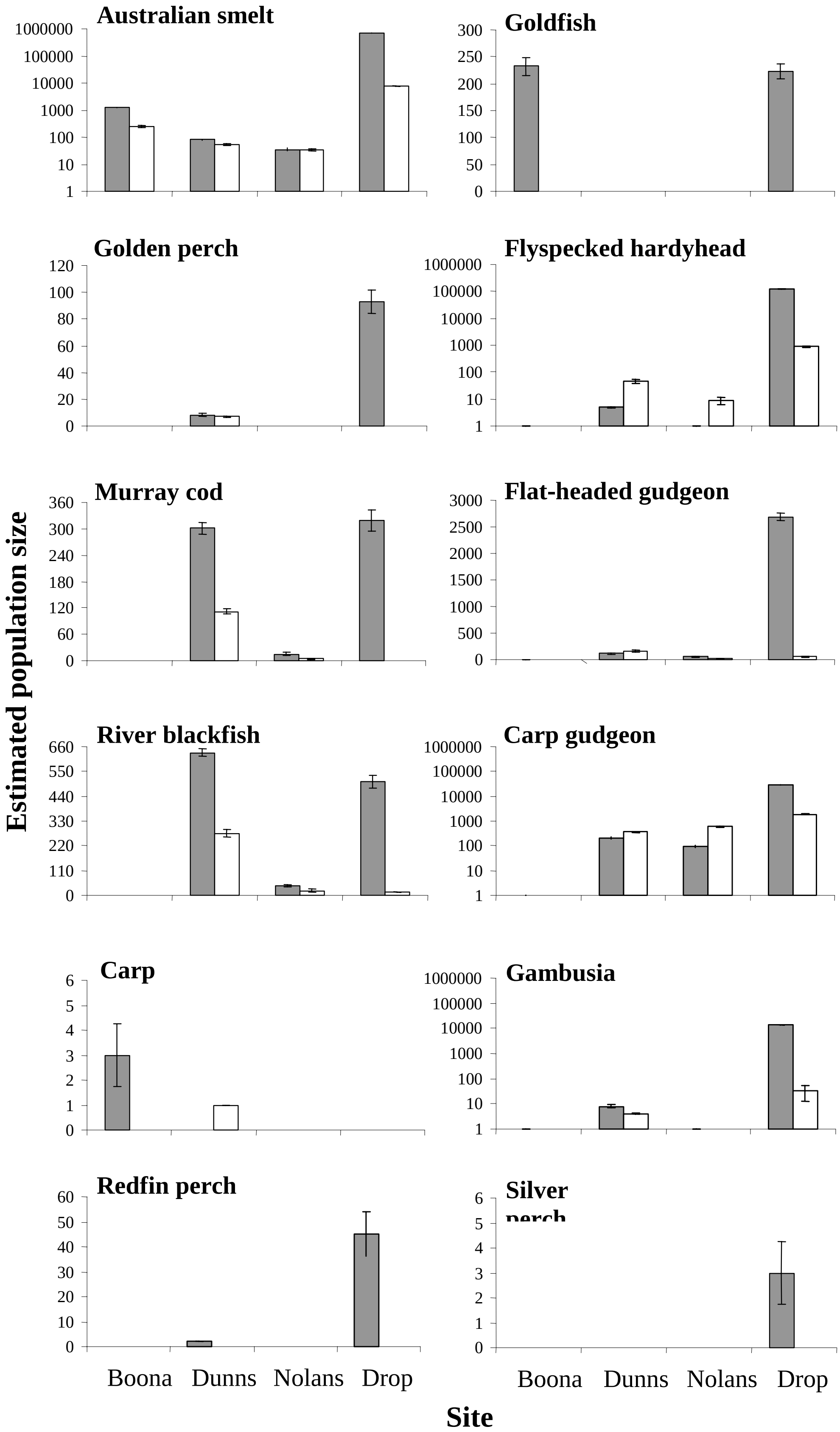


Figure 5.3. Population estimates for all species sampled in the Mulwala and Coleambally canal systems immediately after (grey) and two weeks after (white) draw-down.

Table 5.1. Kolmogorov-Smirnov test results comparing the size classes of fish sampled immediately, and two weeks after, draw-down. n represents the total number of fish measured for length, mean ± SD given the average length (Fork length [FL] for fork tailed species and standard length [SL] for non-forked species in millimetres) and one standard deviation. Only species collected during both surveys are included here. Tests could only be performed where more than 30 individuals were collected in each sample.

Species	At Drawdown		Two weeks after		KS stat	Sig. smaller fish
	n	mean ± SD	n	mean ± SD		
Boona's Regulator						
Goldfish	117	104 ± 14	1	101 ± 0	-	-
Australian smelt	203	47 ± 6	150	48 ± 8	0.081	ns
Dunn's regulator						
Un-specked hardyhead	9	29 ± 11	31	31 ± 11	-	-
River blackfish	250	139 ± 32	180	139 ± 29	0.052	ns
Gambusia	7	34 ± 8	4	37 ± 7	-	-
Carp gudgeon	157	36 ± 5	195	35 ± 6	0.089	ns
Golden perch	7	84 ± 42	4	63 ± 4	0	-
Murray cod	208	243 ± 65	73	130 ± 60	0.171	After
Flat-headed gudgeon	83	60 ± 14	76	55 ± 16	0.176	ns
Australian smelt	75	43 ± 7	37	30 ± 5	0.784	After
Nolan's Road Bridge						
Un-specked hardyhead	1	24 ± 0	7	30 ± 7	-	-
River blackfish	33	120 ± 40	11	112 ± 34	-	-
Carp gudgeon	62	33 ± 7	352	28 ± 7	0.306	After
Murray cod	9	124 ± 34	3	97 ± 32	-	-
Flat-headed gudgeon	47	47 ± 14	25	48 ± 13	0.158	ns
Australian smelt	33	41 ± 8	30	39 ± 10	0.282	ns
The Drop						
Un-specked hardyhead	157	30 ± 9	150	24 ± 5	0.390	After
River blackfish	165	144 ± 35	1	86 ± 0	-	-
Gambusia	44	29 ± 13	2	26 ± 3	-	-
Carp gudgeon	170	27 ± 8	150	25 ± 8	0.185	After
Flat-headed gudgeon	45	63 ± 17	3	39 ± 6	-	-
Australian smelt	170	41 ± 12	150	32 ± 6	0.41	After

Table 5.2. Results of a Two-Way ANOVA highlighting differences in water quality parameters immediately following and two weeks after draw-down Factors used in the test were sites (S) and time (immediately after and two weeks later). Only *F*-values are presented and results are based on log (x+1) transformed data. *** indicates a significant difference at $p < 0.001$.

Factor	Temp	pH	Cond	DO
Site	0.89	6,404.56***	1,751***	13.04***
Time	222.14***	51,437.87***	7,390***	18.72***
Site * Time	27.50***	7,339.01***	6,315***	6.54***

5.3.3. Water quality

Apart from temperature, which did not differ among sites, significant differences were detected among sites and between times for all water quality variables measured (Table 5.2; Figure 5.4). Conductivity varied little among Boona's regulator, Nolan's bridge and Dunn's regulator sites but was substantially greater at the Drop on both sampling occasions (Figure 5.4). Immediately after drawdown, lower pH values were detected at all sites in the Mulwala Canal system. These values had stabilised after two weeks and were relatively similar among sites. Dissolved oxygen was relatively uniform among sites but was significantly lower at the drop immediately following draw-down (Figure 5.4). Two weeks after draw-down, dissolved oxygen had significantly increased at all sites within the Mulwala system. Although not significant, temperature was greater at all sites immediately following draw-down than when re-measured two weeks later.

5.4. Discussion

5.4.1. Effects of irrigation system draw-down on fish communities

The application of population estimation techniques demonstrated that many species and size classes of fish could be annually stranded in irrigation canal systems. In general, species richness was high in the draw-down sites, particularly in the Mulwala Canal system. Annual entrainment of small-bodied species could therefore contribute to continual recruitment in the Mulwala system. The structure of fish assemblages within draw-down pools, and the size of some species reduced significantly over two weeks. These changes in fish communities and water quality parameters suggest management intervention may be required to reduce any potentially adverse impacts on fish communities.

Samples were dominated by small-bodied species or sub-adult large-bodied species. This absence of adult large-bodied fish suggests that sub-adults of these species were likely entrained into the irrigation canal system as juveniles or larvae. Such extractions are not uncommon, for instance 0+ Arctic Grayling (*Thymallus thymallus*) are entrained into irrigation canals in Montana (USA) (Barndt and Kaya, 2000). Adult large-bodied species are generally more mobile, possess a greater swimming ability and could therefore physically avoid entrainment.

Several sources of evidence suggested draw-down substantially affected fish population structure in the canal systems. Firstly, excepting Un-specked hardyhead and carp gudgeon, population size was substantially lower from all sites two weeks following draw-down, than immediately after. In addition, reductions in mean length was also observed in small-bodied species such as carp gudgeon, Un-specked hardyhead and Australian smelt at some sites. Anecdotal accounts suggest that the abundance of piscivorous birds can substantially increase after draw-down in irrigation systems of Victoria (King and O'Connor, 2007). Avian predation upon small-bodied species may therefore represent a substantial factor influencing reductions in population size after draw-down has occurred.

Large-bodied species such as Murray cod and golden perch are susceptible to exploitation immediately after draw-down (King and O'Connor, 2007). At Dunn's regulator, population estimates of these species substantially reduced two weeks after draw-down, suggesting these species may have been removed from the pool. If human exploitation is the source of reduced population estimates, it could be readily expected that large-bodied individuals would be most susceptible to removal, as these are most suitable for consumption or are more highly valued as recreational species that could be removed and translocated. Therefore, the second factor suggesting impacts of draw-down on fish is the significant reduction in size of Murray cod two weeks after draw-down, especially at Dunn's regulator.

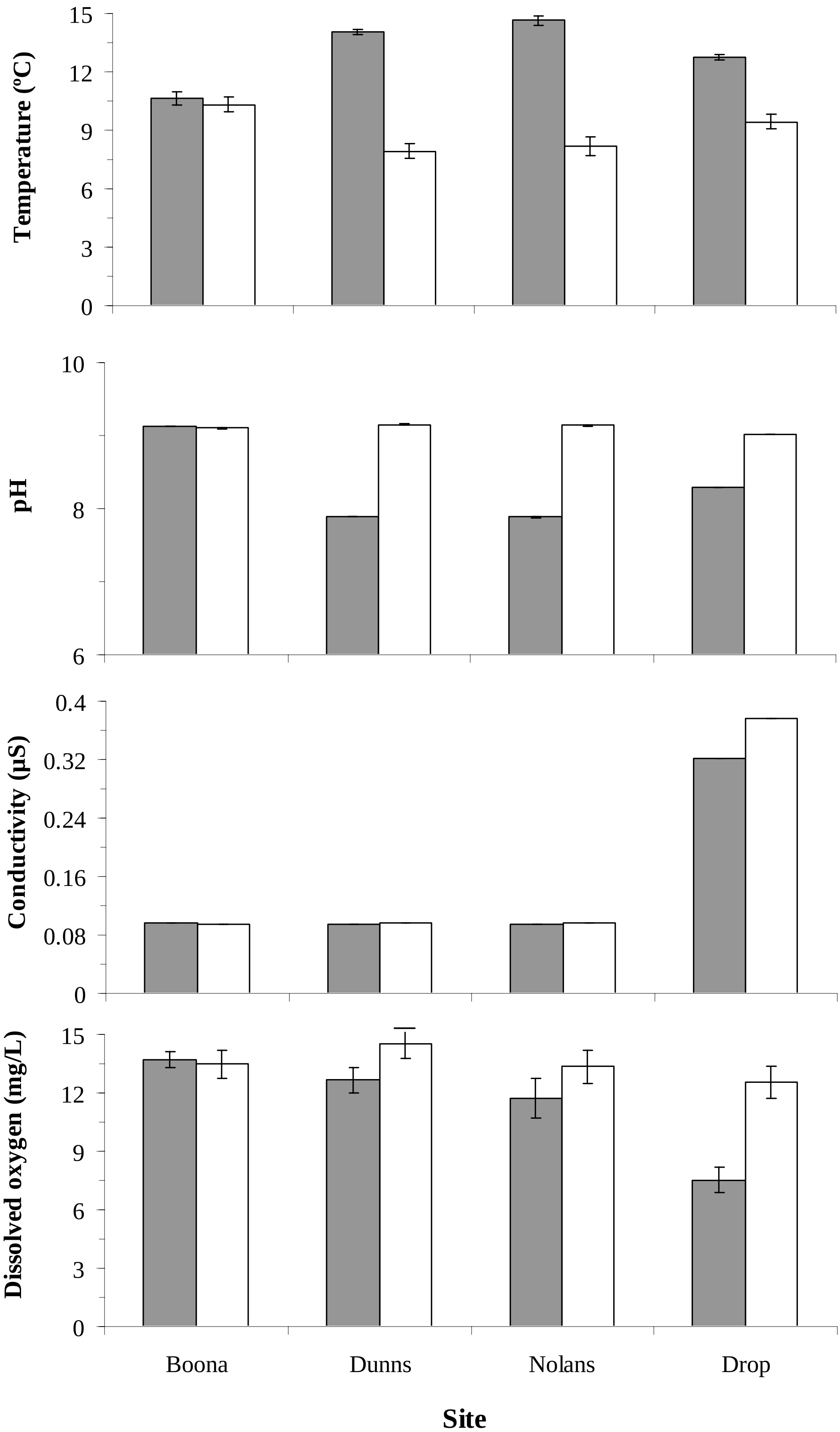


Figure 5.4. Mean water quality variables (± one standard error) of sites sampled immediately after (grey) and two weeks after (white) draw-down.

The presence of adult fish in draw-down pools suggests some fish survive the low-flow period in winter or that many large-bodied fish are also entrained. King and O'Connor (2007) suggest adult fish may be attracted into irrigation systems by inflows and can potentially form self-sustaining populations. Prior to undertaking the present study, a pilot was conducted in 2004 to determine optimal sampling methods for fish in remnant pools (NSWDPI unpublished data). Part of this study involved tagging fish, and a number of species were pit tagged and released into the irrigation canal. Sampling as part of this study yielded three individuals which were PIT-tagged the previous year. Although the sample size was small, it provides evidence that at least some individuals can survive the draw-down period and remain within the irrigation system for subsequent years.

Casual observations of invertebrate species were also recorded as part of this study. Yabbies (*Cherax destructor*) and Murray crayfish (*Euastacus armatus*) were both identified in pools affected by draw-down activities. Staging draw-down can be important for macroinvertebrates as it provides a natural cue for certain species to dig burrows (Masser *et al.*, 1997). The burrows provide important refugia to prevent desiccation during periods of low water. If draw-down is undertaken too rapidly for some species to dig burrows, population declines would be observed.

5.4.2. Effects of irrigation system draw-down on water quality

Another potential factor contributing to reduced population sizes is changes in water quality following draw-down. Water quality varied after draw-down and also two weeks later, although some evidence for potential sources of stress for fish were identified. The most obvious factor was the reduction in dissolved oxygen levels immediately after the water level was reduced at the Drop site. The site was relatively small in area (Figure 5.5) and is drawn-down over a short period of time despite containing an extremely high density of fish. Dissolved oxygen is known to reduce rapidly when high densities of fish are present (Radull *et al.*, 2002). If reductions in dissolved oxygen are common following draw-down, and reach critical values, fish could be affected at many sites within the Murray-Darling Basin.

Mean temperature in pools also substantially reduced following draw-down. When irrigation canals are full, the effects of ambient temperature changes are buffered by increased depth and flow. After draw-down, canals are characterised by long shallow pools with little or no flow that are subject to sudden temperature variations (Koehn *et al.*, 2003). In some cases, post draw-down pools contained temperatures lower than 9ºC. Most fish of the Murray-Darling Basin have low tolerances to sudden changes in temperature and this could contribute to mortality arising from thermal shock.

5.4.3. Management of draw-down practices

Dropping water levels over a relatively short amount of time can prevent fish from finding suitable refuge habitat (Megargle, 1999) and is known to result in substantial losses of fish in some areas of the USA (Barndt and Kaya, 2000). In the Murray-Darling Basin, water releases are usually immediately ceased when the irrigation season concludes by closing gates at inlet regulators on canal systems.

Staged draw-downs are a useful management option to reduce the probability of fish being stranded. The principle involves gradually reducing water levels within irrigation canals, rather than undertaking an immediate and sudden reduction in water levels. Managing draw-downs in this manner could be actioned relatively easily in consultation with local irrigation authorities and has substantial scope to improve opportunities for fish survival. For example, staging draw-downs can maintain the thermal buffer which will temporarily protect fish from sudden changes in temperature. In addition, for closed canal systems it will provide fish with sufficient time to find suitable refuge habitat to minimise stranding (Figure 5.6). In open canal systems, fish may have sufficient time to migrate upstream and leave the canal system before it dries (Megargle, 1999), especially if fish passage facilities are present.

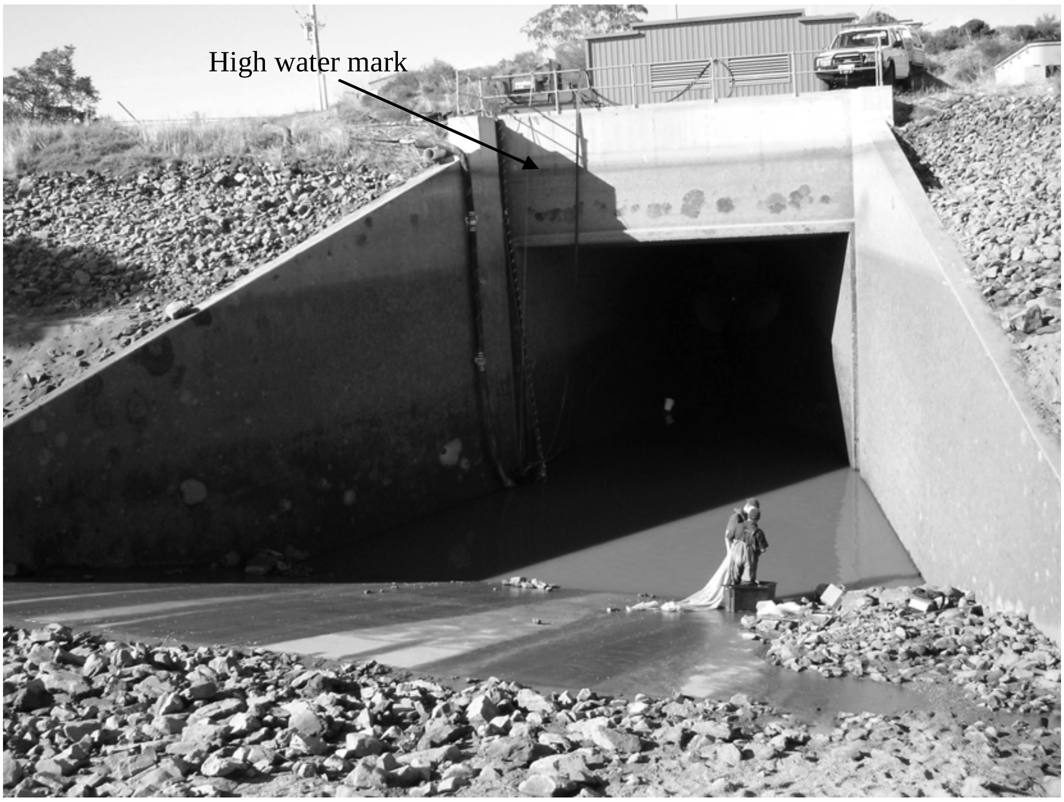


Figure 5.5. The site known as "The Drop" on the Mulwala irrigation canal system demonstrating the extremely small volume and size of the pool. Note the high water level marks at the top of the outlet area.

Figure 5.6. Goldfish (*Carrasius auratus*) stranded in a riffle immediately following draw-down in the Mulwala Canal system.

The site at the Drop is annually pumped out for maintenance on turbines at a nearby hydro facility. To provide access to the turbine, a pool on the downstream side of the regulator must be totally pumped dry. This study identified almost one million fish were trapped in the pool when it became disconnected from the main canal after draw-down. Should draw-down occur without subsequent human intervention, these fish would surely die. This situation was avoided during the present study by translocating all fish before drying occurred. Although such an action reduces the potential mass-mortality of these fish, it does not prevent any subsequent stranding during future draw-down events.

5.4.4. Conclusions

Rapid draw-down of irrigation systems can result in the stranding and entrapment of large numbers and species of fish. Impacts broadly fall into one of two broad categories, (i) effects due to stranding and (ii) arising from changes in water quality. The effects of both processes could be partly reduced by employing a gradual and staged draw-down process to provide sufficient time for fish to find refuge areas, and also to provide a buffer for water quality changes. If this staged draw-down is possible, the effects could be partly mitigated for fish entrained in canal systems.

6. SYNTHESIS: IMPROVING IRRIGATION SYSTEMS TO ENHANCE RIVER FISH COMMUNITIES

6.1. Developing solutions to mitigate impacts of irrigation systems

Essentially, this study has identified the effects of irrigation systems can be categorised as either primary or secondary impacts. Primary impacts are mainly concerned with direct entrainment from main river systems. Preventing entrainment at the point of water extraction presents the most suitable method of mitigating the effects of irrigation systems on fish. Secondary impacts occur after fish have been extracted from the main river system. These fish are already considered lost from the main population and are of secondary concern from a management perspective. The development of appropriate solutions to mitigate these effects is contingent on identifying the nature and scale of the impact and then developing cost effective solutions which ensure anticipated ecological benefits do not compromise the social advantages delivered by the irrigation scheme.

6.2. Developing solutions to primary impacts of irrigation systems

Primary impacts of irrigation systems can be defined as those that affect fish on the river side of the irrigation pump. These effects are largely due to alteration of flow regimes or increasing the potential for extraction or entrainment into irrigation systems. The extent of primary impacts on fish communities is therefore largely dependent on the amount of water extracted per irrigation development, which can cumulatively affect a large proportion of fish populations in given river reach. In Lao, the development of relatively small-scale irrigation schemes can have significant negative impacts on aquatic resources (Lorenzen *et al.*, 2000). In terms of the Murray-Darling Basin, rivers and streams with higher degrees of irrigation development would experience a proportional increase in the risk of primary impacts on fish.

The simplest (from an ecological perspective) method to eliminate primary impacts on fish is to reduce or cease irrigation activities. However, Australia has made a substantial public investment in water ‘development’ for a variety of social and economic objectives (Thoms and Cullen, 1998), therefore limiting extraction practices is not always practical or possible. In areas where water is removed to fill off-river storages, restricting or eliminating pumping activities to periods of low expected fish migration, may present a suitable management option to reduce potential risks, particularly for poorer swimming larvae or small-bodied fish. Opportunities for such operational flexibility are limited, and are likely to only apply to areas where pumping is undertaken in winter. In the Murray-Darling Basin, most irrigation takes place over summer (Thoms and Cullen, 1998). Such solutions therefore represent a solution unlikely to reduce the impacts of irrigation systems on fish on a catchment-wide scale.

Engineering solutions, that modify or physically exclude fish from extraction points represent a more practical option, provided most size classes and species can benefit from any proposed works. In Northern hemisphere systems, screening mechanisms have been widely used to reduce entrainment rates without reducing water delivery capacity. Screening mechanisms offer great potential for wider application throughout the Murray-Darling Basin to mitigate primary effects, but are largely untested, and would require robust scientific assessments of the various designs and operating protocols to ascertain the scale of expected ecological benefits.

6.2.1. Solutions for irrigation canal systems

Fish screening facilities can be designed to direct fish away from irrigation diversions and back to the river (Neitzel, 1990). The appropriateness of a particular screen design to an installation depends largely on the target species, the expected volume of flow, the shape (and nature) of the diversion system and maintenance requirements. In North America, screening facilities are commonly constructed to prevent the extraction of anadromous salmonids from main river systems, and incorporate mesh sizes sufficient to exclude particularly small individuals (NMFS, 1997; Neitzel *et al.*, 1990). Given the vulnerability of smaller-bodied fish to be extracted, the swimming ability of target species is the primary factor determining the ultimate design of a screen (NMFS, 1997). Subsequently, fish screens are often individually designed for specific installations and are based on prior knowledge of the fish community.

Fish of the Murray-Darling Basin are likely to be entrained into canal systems during larval or sub-adult stages, when swimming abilities are less developed. The development of screens for target species of this size would require extremely small mesh sizes and strict operating protocols. High sediment and debris loads in streams within Murray-Darling Basin would also necessitate the development of self-cleaning screens to reduce on-going maintenance costs. Travelling or rotating drum screens, which mechanically rotate to remove debris collection, are probably the most suitable for wider application (Blackley, 2003).

Vertical travelling screens consist of rotating mesh, in a belt-type configuration, powered by electric motors (Figure 6.1). The screen presents a physical barrier to fish smaller than the chosen mesh size, but also continually rotates to minimise debris accumulation. Any mesh size can be used but it is essential that the water delivery capacity is not compromised. The screen can be applied to irrigation canals of any width or depth provided it can be structurally achieved. In the Murray-Darling Basin, this type of screen could easily be applied to most small-medium scale irrigation developments.

Rotary drum screens are similar in concept to vertical travelling screens but comprise screen mesh that covers a rotating cylinder. As the screen rotates, debris is picked up and deposited on the downstream side to prevent fouling (Figure 6.2). A major advantage of the rotary drum system is that it can cope with large discharges ($60ms^{-3}$) provided the ratio of submergence to drum diameter is between 65% and 85% (Neitzel *et al.*, 2000). Higher submergence values increase the risk of fish impingement whilst lower submergences decrease the ability of the screen to remove debris. This type of screen could therefore be applied to most irrigation systems within the Murray-Darling Basin provided large fluctuations in water level would not compromise efficiency.

6.2.2. Solutions for pump systems

Screening mechanisms also have substantial potential to reduce the primary impacts of pumping systems on fish. A diversity of screening systems is also available for pumping systems but mitigation works will be specific to particular pump designs, and river sites, as fish communities (Harris and Gehrke, 2000) and irrigation methods (Kingsford, 2000) widely differ across the Murray-Darling Basin. Pumping systems adversely affected adult, sub-adult and larval fish on the Namoi River. Therefore, the development of screens for wider application in the Murray-Darling Basin should contain a range of mesh sizes which exclude a wide variety of species and size classes but have limited impact on water extraction capacity.

In North America, infiltration galleries are successfully used to prevent fish entering pump systems (WDFW, 2000; Figure 6.3). Infiltration galleries involve burying the pump intake beneath the streambed or bank. Removing the pump intake from the water column in this manner would eliminate the risk of entrainment for most species. The system is advantageous as it can be implemented without the need to develop fine mesh screens, because the intake is effectively drawing water through the substrate.

Figure 6.1. A vertical travelling screen commonly used in the USA to prevent fish entrainment into irrigation canal systems. *(Photo Courtesy of Oregon Department of Fish and Wildlife).*

Figure 6.2. An example of a rotating drum screen installed on Cowiche Creek, Washington State USA. *(Photo courtesy of the Washington Department of Fish and Wildlife).*

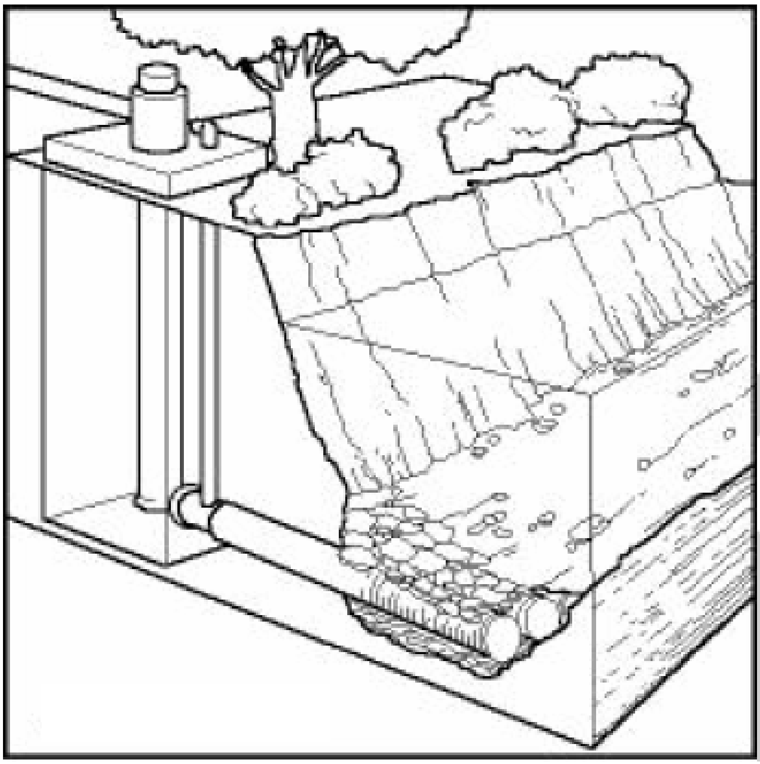


Figure 6.3. A conceptual diagram of an infiltration gallery to minimise fish entrainment at pump sites *(From WDFW, 2000).*

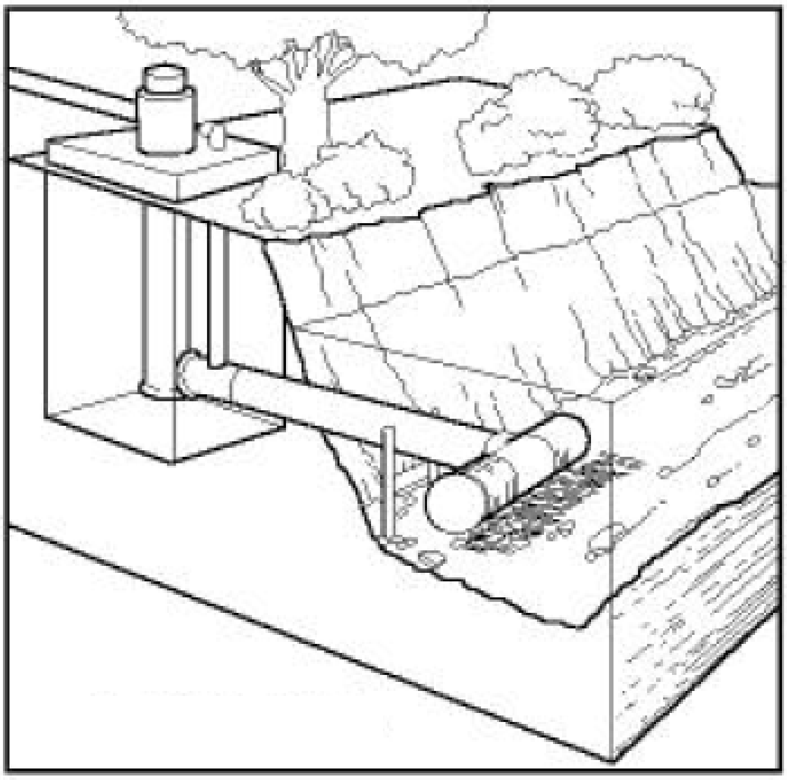


Figure 6.4. Cylindrical pump intake to minimise fish entrainment into pump systems *(From WDFW, 2000).*

These screens however, can be particularly susceptible to debris accumulation and fouling (WDFW, 2000). Therefore, infiltration galleries must include some type of cleaning mechanism to ensure water delivery requirements are not compromised.

Cylindrical pump intakes (WDFW, 2000; Figure 6.4) are another useful method to reduce fish entrainment into pump systems. This solution involves the placement of a fine-mesh cylindrical screen over the pump intake. The screen is placed into the water column above the substrate but has a large surface area to reduce the velocity of water entering the pump. If required, jet cleaning systems can be incorporated to prevent fouling (WDFW, 2000). The systems are simpler to construct and install than infiltration galleries and are commercially available in some areas of the USA.

6.3. Developing solutions to mitigate secondary impacts of irrigation systems

Secondary impacts of irrigation systems arise after fish have been removed from the source river system. Processes contributing to secondary impacts include effects of draw-down, poor water quality or injuries/mortality occurring during the extraction process. If primary impacts are addressed at a site, there would be little or no requirement to deal with issues arising from secondary impacts. However, the construction and operation of irrigation infrastructure is often complex. The prevention of fish extraction through screens or operational modifications is not always practically feasible without compromising irrigator requirements. Mitigating secondary effects could require more complex methods because solutions may need to be developed for a number of different processes. The ultimate goal of these interventions would be the safe transfer of live fish back to the source river system. These transfers however are largely contingent on increasing the survival of extracted fish by reducing injury and mortality; particularly within pumping systems.

The design and operation of pump systems can substantially affect survival. In particular, pumps operating with high revolution rates are associated with increased risks of physical strike and injury (McKinley, 1987; McNabb *et al.*, 2003). Low-revolution pumps, or jet-type pumps without impellers offer suitable mechanical options that would not reduce water extraction capacity. There are few instances however, where these types of pumps have been installed in Australian systems to specifically reduce the potential impacts on fish. The establishment of a demonstration site with ‘fish-friendly’ pumping technology may be a useful mechanism to progress the development of this technology for wider application in the Murray-Darling Basin.

Once sources of injury and mortality have been identified and controlled, techniques to return fish to the source river should be investigated. If water is gravitated from a higher head, such as from a weirpool, the construction of a suitable fishway may facilitate the movement of fish back into the river. The criteria for fishways within the Murray-Darling Basin are now well-developed and can cater for many species and size classes that may be removed from source rivers (Barrett and Mallen-Cooper, 2006). For a fishway to work effectively, it must complement the hydrology, fish community and layout of a particular site. The design and construction of fishways should therefore involve the cooperation of engineers and biologists to ensure a suitable solution is developed.

Conventional fishways are unlikely to represent suitable mitigation measures at pumping sites because water is usually drawn from a lower region and would have no driving head to operate. Under such circumstances it might be practical to construct a fish lift or develop a mechanical trap and transport arrangement to return fish to the source river. A fish lift would involve herding fish into a trap or cage and then performing a mechanical transportation back to the source river for release (Clay, 1995). Such installations can be fully automated and operated with little human interaction. Fish lifts generally have a high capital cost and an ongoing maintenance requirement to ensure the system operates continuously.

Trap and transport arrangements operate on a similar principle but involve physically trapping any fish that have been extracted via the pumping process, and performing a subsequent manual transportation back to the river system. These systems have a much lower requirement for capital expenditure but have ongoing operating costs associated with transport and release of fish. Trap and transports can also only be operated when staff are present on site. If the site is un-manned for a significant amount of time, the movement of fish would be delayed.

In channel and pump systems, opportunities may exist to provide access back to source rivers via ‘escapes’. Escapes are drains or siphons where water within irrigation systems could be directed to reduce water levels over a relatively short amount of time. Escapes are common to many irrigation diversions in the Murray-Darling Basin. For example, in the Murray Irrigation system of southern New South Wales, five escapes, with a combined capacity of 3,250 $Ml.day^{-1}$, are used to regulate water levels within the canal system (Murray Irrigation, 2005). If fish can be directed to offtake points for these escapes, potential exists to re-establish links to source rivers provided there are no operational restrictions or limitations.

6.4. Developing a research-based approach to determining the success of mitigation measures

The current study is one of the first attempts at quantifying the effects of irrigation systems on native fish of the Murray-Darling Basin. Whilst a number of potential impacts were identified and outlined, detailed research should be undertaken to determine whether potential mitigation measures are suitable for wider application throughout the Murray-Darling Basin. The composition of fish assemblages, and the design of irrigation infrastructure, differs substantially among different areas of the Basin. It therefore appears that methods to mitigate the effects of irrigation systems may necessitate the development of unique solutions for different sites based on local conditions.

For instance, water use is governed by the type of crop being grown (each has different watering requirements), location within the Basin (crops have different requirements depending on climatic zone), current and historical climatic state (i.e., drought or wet, this determines the amount of water available for crops) and upland storage situation (irrigators may be able to extract more water when major dams are full). These factors greatly influence the design of irrigation infrastructure required to successfully deliver water. Different flow and climatic regimes also influence the fish species composition, spawning behaviour, migration, growth and development (Mallen-Cooper, 1996). This combination of variation in irrigation requirements, coupled with expected changes in fish community structure, presents a complex matrix of factors which could influence the development of management interventions to mitigate impacts on fish.

The diversity of potential irrigation schemes and fish communities makes it costly, and logistically difficult to conduct enough fieldwork to determine the complete impact of irrigation systems throughout the entire Murray-Darling Basin. However, existing biological information should be sufficient to effectively predict potential impacts for a number of different species. A useful exercise to determine the theoretical impact of irrigation development would be through the development of a spatial model to predict potential impacts on fish on a Basin-wide scale. The model should incorporate factors such as crop types, climate, historical water use, storage capacity, time of year and location in the Basin to try and identify common zones of extractive water use throughout the Basin which would have relatively similar impacts on fish. Once determined, this data could be combined with detailed information of expected fish distribution to define large-scale management zones where common methods of mitigation could be developed to minimise any predicted impacts.

Whilst this approach would provide useful data to progress the management of irrigation impact on fish, this study has identified a number of impacts that require attention at a localised scale. To develop solutions at specific installations, future research should focus on manipulative experiments to provide recommendations for on-ground works that could improve conditions for fish at individual sites. Given the inherent differences in extraction processes, research priorities would substantially differ between canal and pump systems.

6.4.1. Research priorities for canal systems

In North America particularly, the construction and operation of screening systems are extremely effective at preventing the entrainment of fish into canal systems (Nestler *et al.*, 1992; Post *et al.*, 2006). No effective screening device has ever been installed on an irrigation system in the Murray-Darling Basin despite substantial advances in this technology over the past 20 years. Current drought conditions, and expected investment in irrigation infrastructure in the near future suggest that developing effective methods to mitigate adverse effects on fish should be a key priority area for further research. The two sites investigated as part of this study, Bundidgerry Creek offtake and Mulwala Canal offer excellent opportunities for further research. This study has provided baseline data on the structure of fish communities in both the Bundidgerry Creek and Mulwala Canal systems. Survey data was collected using a standardised protocol and would form a useful basis for a before and after study seeking to determine any reduction in fish entrainment arising from mitigation works.

Bundidgerry Creek is a complex site for the construction of fish exclusion devices as the offtake regulator is located within the Berembed Weirpool. As the weirpool is rarely drawn-down, construction would be difficult to initiate without costly de-watering facilities. Downstream of the offtake, the channel system supported a diverse and abundant native fish community which would benefit from restored connectivity to the weirpool. This site may therefore be more appropriate for assessing secondary effects of irrigation systems, either through the construction of a fishway (at the offtake regulator) or be directing water through natural escapes to provide migration routes back to the Murrumbidgee River. If either solution is progressed at this site, a detailed assessment of relative effectiveness should be undertaken to ensure the works are meeting the anticipated ecological objectives.

Post draw-down assessments within the Mulwala Canal system suggested that the risk of fish entrainment is substantial and affects many different species and size classes. Population sizes of fish, particularly juveniles, were substantial in this system and the development of screening systems should be progressed to reduce entrainment rates. The inlet regulator for this system is located in Mulwala (New South Wales) and has sufficient depth, flow rates and channel morphology to suit construction of a rotary drum system. If progressed, the system would be the first of its kind on an irrigation channel system of the Murray-Darling Basin and should be accompanied by a detailed biological assessment to ensure the facilities are adequately preventing the entrainment of native fish.

6.4.2. Research priorities for pumping systems

Research into mitigating the effect of pumping systems should firstly investigate solutions to eliminate or reduce primary impacts on fish communities. Screening devices are generally available commercially or could be relatively easily engineered for specific applications at pump intakes (Figure 6.5). The present study identified small (<50mm) and large (>200mm) fish were susceptible to injury are pump sites. Initial work should therefore seek to install and assess the effectiveness of screening systems to prevent the extraction of fish within these size classes. Work could take place at the existing sites established in this study where baseline datasets have already been established. Given the diversity of pumping systems, especially in Northern reaches of the Murray-Darling Basin, work could be easily undertaken at any site where fish extractions are suspected. A series of simple, controlled, experiments are required to assess the current degree of fish extraction, which can then be compared against a number of different screen configurations to determine the most appropriate solution to minimise any adverse effects.

Figure 6.5. An example of a cylindrical cone screen adapted to fit over the intake of a pump system on Mill Creek, Oregon (USA). *(Photo courtesy of Oregon Department of Fish and Wildlife).*

These experiments should be well replicated, and undertaken in the field, during periods of peak fish migration, spawning and water extraction to obtain results that can be widely-applied to other sites in the Murray-Darling Basin.

Methods to reduce the incidence of injury and mortality should be investigated at sites where screening is not appropriate. In most pump systems, injuries arise from physical strike (Patrick and McKinley, 1987; McNabb *et al.*, 2003). Where physical strike is suspected, experiments should focus on assessing of different impeller designs and rotation rates to reduce impacts on fish. Trials comparing single and two-stage pumps would help to provide recommendations for future pump installations in the Murray-Darling Basin. In addition, comparisons between screw-type impellers (which are widely considered to be fish friendly) and conventional open impeller designs are essential to identify specific factors contributing to increased injury or mortality. Such experimentation should again be appropriately replicated and carried out in the field during periods of peak water extraction and fish migration.

If sources of pump-induced mortality can be controlled, methods to return extracted fish to the river should then be assessed. Fish passage assessment methods are well-established (Mallen-Cooper, 1996; Stuart *et al.*, 2004; Barrett and Mallen-Cooper, 2006), and an application to assessments of fish transfers out of pumping systems would be relatively straightforward. A paired sampling design should be adopted which compares the composition of fish at the pump outlet with those successfully returning to the river via the transportation mechanism. Success can then be expressed as a proportion of extracted fish being returned to the river. The occurrence of larvae, sub-adults and juveniles in pump systems requires many life history stages to be incorporated into subsequent sampling designs.

7. RECOMMENDATIONS

This study has identified at least three processes associated with irrigation systems that can have adverse impacts on native fish. Firstly, extracting or diverting large volumes of water was demonstrated to remove adults, juveniles and larvae from the source river. Secondly, pump systems were shown to injure or result in increased mortality of fish during the water extraction process. Thirdly, the draw-down of irrigation systems resulted in large numbers of fish being stranded in remnant pools. Each of these processes could have substantial impacts on fish in certain areas of the Murray-Darling Basin.

Based on the outcomes and discussions arising from this study, the following recommendations are provided to improve existing and future irrigation infrastructure projects.

7.1. Irrigation canal systems

- Undertake a desktop modelling study to try classify broad-scale management zones for irrigation systems and fish communities of the Murray-Darling Basin.
- Reduce the frequency of time where discharges into irrigation systems greatly exceed flow in the source river to reduce the risk of entrainment.
- Reduce diversions of water into irrigation systems during periods of expected larval drift (November to February) to reduce the risk of entrainment for early life history stages.
- Advance the construction of a screening system at one or more major canal systems and perform an ecological assessment of its success to reduce the entrainment of fish.
- Advance the construction of a fish passage facility to return entrained fish to source river systems at sites where screening is not practical or appropriate.
- Investigate the use of natural escape systems to return entrained fish back to source river systems.

7.2. Pump systems

- Reduce pumping activity during periods of expected larval drift (November to February) to reduce the risk of entrainment for early life history stages.
- Develop and assess the efficiency of a screening system for irrigation pumps to minimise or prevent fish entrainment.
- Proceed with assessments to investigate the applicability of ‘fish-friendly’ turbines and/or low revolution pump systems to reduce incidences of injury and mortality during passage.
- Investigate the potential to develop an ‘escape’ or trap and transport system to actively guide surviving fish back to the source river.

7.3. Irrigation draw-down management

- Implement and assess staged draw-down protocols to improve the likelihood of fish surviving during periods of low flow.
- Investigate the use of escape systems during draw-down as a mechanism to transport entrained fish back to source rivers.
- Identify areas where major fish strandings are known to occur and implement temporary management interventions (i.e., fish rescue operations) to prevent potential mortality of fish.
- Establish appropriate intervention measures to monitor and control water quality within irrigation channels before, during and after draw-down.

8. APPENDIX 1: FUTURE RESEARCH SUGGESTIONS

8.1. Key management issue(s) (as identified in the Native Fish Strategy)

The following projects relate specifically to improving the collective knowledge and understanding of irrigation infrastructure and specific effects on fish. Initially, a number of factors related to irrigation infrastructure should be investigated to determine the impacts on fish, which was partly addressed in the current report. Now that preliminary investigations have identified potential sources of impacts, new research should be initiated to determine the scale of impacts on a Basin-wide scale and identify any species-specific effects that may require detailed management consideration. Once a more detailed understanding of the effects of irrigation infrastructure has been achieved, resources should then be directed to determine potential solutions that provide long-term protection for native fish.

In respect to the Native Fish Strategy, this research is important and directly related to the following objectives:

- To protect the natural functioning of wetlands and floodplain habitats by preventing fish entrainment into irrigation systems.
- To modify flow regulation practices by improving the operation of irrigation infrastructure.
- To create and implement management plans that protect fish by reducing the threat of entrainment or injury.
- Manage fisheries in a sustainable manner by protecting source populations in main rivers and streams where irrigation water is drawn.

The specific development of research and management responses to these objectives will provide useful progress to successful implementation of the six driving actions of the Native Fish Strategy. Given the high profile of irrigated agriculture throughout the Murray-Darling Basin, community engagement is essential to ensure the objectives are successfully achieved.

8.2. Context, and how this addresses key management issue(s), strategies or policies

The Murray-Darling Basin supports at least 40% of Australia's agricultural production, a population of over 2 million people and is one of Australia's most important natural resources. The overall health of the Murray-Darling system has declined over the last 100 years largely due to factors such as over-fishing, water extraction, land clearing, alteration of natural flow regimes, riparian degradation and reduced connectivity. Whilst the degradation of the Murray River has had detrimental effects on virtually all resident biota, impacts on the abundance and diversity of native fish have been particularly profound. In particular, recent estimates suggest native fish numbers within the Murray-Darling Basin may now be 10% of pre-European levels.

Irrigation is the largest user of water in the Murray-Darling system. Agricultural practices in the Basin are extensive, but diverse, and a variety of crops are cultivated annually including wheat, barley, corn, rice, cotton, grapes, citrus and vegetables. To adequately service these crops, an average (between 1988 and 1994) of approximately 10,232 Gl of water per year is diverted from rivers within the Basin to irrigate a total of 670,000 hectares of land. In contrast, extractions for town supply and domestic use are substantially lower at 452 Gl per year. Although irrigation is extensive in the Murray-Darling Basin, methods to extract water differ substantially between Southern and northern regions. Rivers within Southern reaches of the Basin generally exhibit higher annual rainfall and flow is largely regulated by controlled releases from upland storages. On the main channels of these rivers, regulatory weirs have been specifically constructed to gravity feed water into canals and effluent creek systems where irrigation water is required. End-users then either pump or siphon water out of these canals and creeks directly onto crops.

Approximately 80% of natural flow in the Murray-Darling Basin is diverted and currently there are no mechanisms in place to prevent fish, or other organisms, from leaving main river systems. Considering this situation, irrigation diversions are most likely to affect fish through direct extractions from main river channels, which will be manifest during larval and juvenile stages, because these generally have poorer swimming abilities. Furthermore, it is generally assumed that, once an individual has entered an irrigation system, it is effectively ‘lost’ from the main river population. Therefore, if many individuals are consistently ‘lost’ to irrigation diversions on an annual basis, the size and age structure of main-channel fish populations may be skewed towards larger, and older fish with stronger swimming abilities, because of the frequent extraction of larvae and juveniles.

The projects listed here aim to increase the understanding of irrigation infrastructure on fish and to develop suitable methods to mitigate any subsequent effects. If this research is commissioned and conducted in a logistical and systematic manner, results should feedback into suitable management outcomes that delivery practical outcomes as demanded by the six driving actions outlined in the Native Fish Strategy.

8.3. The Commission’s need to fund this work

Preventing and protecting fish from entrainment into irrigation systems in a Basin-wide issue. The demand for water to provide irrigation opportunities is increasing, and users are coming under increased pressure to become more efficient water-users and to minimize impacts on the environment. The Native Fish Strategy provides a useful mechanism to benchmark the impacts of current practices by initiating targeted research throughout different regions of the Murray-Darling Basin. It also provides a framework to influence natural resource management on a whole-of-Basin scale by using the results of targeted research to develop practical outcomes that protect aquatic resources. No other organization has the sufficient resources or ability to influence management on a scale that could facilitate large-scale improvements to existing practices. Incorporating the effects of irrigation infrastructure into the strategic objectives and key driving actions of the Native Fish Strategy will play a pivotal role in protecting native fish, particularly during early life history stages that are susceptible to entrainment.

8.4. Opportunities for linkage or collaboration

Projects identified on subsequent pages should be undertaken in a collaborative manner that includes both state-managed and private research institutions to undertake on-ground research. Depending on the nature of the work, some aspects could be undertaken by sole providers or collaboratively, especially where impacts act in multiple jurisdictions. Importantly, addressing irrigation infrastructure offers enormous opportunities for community engagement and involvement in research and on-ground works. Specifically, irrigators should be engaged when determining potential solutions to mitigate the impacts of irrigation infrastructure on fish. This could be facilitated through the development of effective demonstration reaches that attempt to showcase ecological improvements to the wider-community, especially where large-scale uptake could enhance fish communities on a large-scale.

Funding bodies should also give consideration to co-investment. Irrigation agencies may be interested in co-investing in infrastructure that improves the environmental delivery of water. The development of ecologically-friendly infrastructure may also meet the strategic objectives of the national water initiative, especially where improvements in water delivery are a key outcome arising from the work. In these instances, the development of strategic co-investment strategies may provide a cost-effective method to achieve the multiple objectives, spanning a number of initiatives which are relevant on a multi-jurisdictional scale.

<u>PROJECT SUGGESTION 1</u>: Identification of broad-scale irrigation management zones in the Murray-Darling Basin

Overview

There are a large variety of irrigation practices, some of which are specific to certain areas within the Basin. Different irrigation methods are likely to have different impacts on native fish because each has unique techniques used to extract, deliver and use water. It is therefore unlikely that a single management response would ameliorate all impacts on fish over a Basin-wide scale; it will likely require a number of smaller approaches specific to certain areas, irrigation methods and climatic conditions. The development of effective management practices is currently precluded by a lack on information regarding the spatial and temporal extent of specific irrigation practices throughout the Basin. This project seeks to develop a conceptual model to document the expected impacts of various irrigation methods on fish communities in different reaches of the Basin. The model should be performed over a number of temporal scales and climatic conditions to determine conditions conducive to increased fish entrainment. The results could then be used to identify potential management areas where potential impacts on fish can be eliminated or adequately controlled.

Project objectives

- To establish a Basin-wide inventory of irrigation practices.
- To identify "zones" of common irrigation areas that may require specific management interventions.
- To develop a model that relates potential zones of irrigation infrastructure to likely impacts on fish.

Key tasks

- To perform a desktop review of existing irrigation practices on a Basin-wide scale.
- To use historical data to model extraction patterns over a range of climatic scales.
- To use GIS technology to map areas of the Basin with common irrigation practices and hence, similar impacts on native fish.
- To identify and list irrigation zones throughout the Basin and quantify the degree of entrainment risk within each.
- To provide feedback on future research and management implications.

Anticipated products

This project should be desktop in nature but may require a consultation component to meet with key irrigation groups during the initial review period. The ultimate product of this project will be a detailed report outlining the spatial and temporal factors influencing the risk of entrainment to native fish. This will include the development of detailed spatial information that can be incorporated into Murray-Darling Basin Commission databases.

Anticipated outcomes

The major outcome of this work will be an improved understanding of the mechanisms influencing irrigation supply, demand and the subsequent impacts on fish. If common zones of irrigation practices are identified and documented, it will enable the development of informed management decisions that can reduce the cumulative impacts on native fish.

Opportunities for end-user involvement

Irrigators and community groups should be involved in the review phase of this project, especially when seeking to document the extent of existing irrigation practices. In fact, initial discussions should at least involve key organizations (i.e., Cotton CRC, Auscott, Murray Irrigation, Murrumbidgee Irrigation, NSW Irrigators Council) within the irrigation industry to determine the extent or different irrigation methods. The Community Reference Panel could be a useful conduit to facilitate community-based discussions with end-users and irrigators.

Mechanisms for transfer and adoption

The products and outcomes of this specific project could be transferred to end-users via:

- The production of a final report and summary brochure upon completion.
- Presentations to interested community groups and also to a scientific audience via the annual Native Fish Strategy forum.
- The dissemination of the project products via the Native Fish Strategy Coordinators and members of the Native Fish Strategy Implementation Working Group.
- Engaging relevant media where possible (radio, TV and written press).
- Via the Murray-Darling Basin Commission website and through online mechanisms offered by other agencies.

Estimated cost and duration

The project could be carried out by a single agency provided it can demonstrate sufficient experience in irrigation development, ecological modelling and fish ecology. The entire project should be delivered within 6 – 12 months for a maximum amount of $100,000 (this would include a community consultation period during the review process).

<u>PROJECT SUGGESTION 2</u>: Assessment of a screening system to prevent fish entrainment into irrigation systems

Overview

One of the greatest impacts of water diversions on fish is the removal of fish from source rivers into terminal canals where there is little opportunity for return. Fish can be affected by these systems at any life history stage, especially during periods where large volumes of water are extracted. Screening systems are constructed throughout the Northern Hemisphere to reduce or eliminate entrainment risk but no such facilities have been previously constructed in the Murray-Darling Basin. Should a screening facility be constructed at either a pumping system or irrigation canal system, a detailed study should be undertaken to ascertain effectiveness to determine the potential for wider application.

Project objectives

- To undertake a detailed ecological assessment of the effectiveness of a irrigation canal screening facility
- To quantify the species and size classes effectively excluded by the screen
- To document incidences of fish injury and mortality associated with the screen
- To document subsequent improvements in source river fish recruitment

Key tasks

- To facilitate the construction and installation of the screening system (if as part of a wider program on irrigation infrastructure)
- To workshop and appropriate experimental design that is sufficiently robust to detect changes associated with the screening facility
- To ensure appropriate trapping and fish collection facilities are in place
- Undertake fish sampling as required by the experimental design
- To report on results
- To provide suggestions for design improvements and report on feasibility for wider application

Anticipated products

The project will be largely field-based and involved with collecting ecological data. Products that should be produces from this report would include a project report and brochure outlining the major results and findings. The report should incorporate ideas for future research and also recommendations for the design and construction of future screening facilities (i.e., Lesson's learnt). The project will generate substantial ecological and spatial information on fish that should be incorporated into relevant databases. If the project is developed and packages as a large-scale program, there is substantial scope to develop an irrigation canal demonstration reach to showcase the works and research program.

Anticipated outcomes

The ultimate outcome of this project would be a detailed understanding of a management technique that could effectively reduce or eliminate the entrainment of fish into irrigation canals. Ideally, the project should be conducted under a range of climatic conditions (e.g., different seasons, time of year, under various flow conditions) to increase the impact of the results. The ultimate aim of the work should be to collect ecological information that will influence the future management of irrigation extractions and diversions.

Opportunities for end-user involvement

The end-users for this work would be water delivery organizations, constructing authorities and co-operatives, rather than individual irrigators as the construction of screening mechanisms will likely attract a high capital outlay. This type of project would contain a number of phases and involve a multidisciplinary approach to ensure all objectives are achieved. Therefore, key irrigation groups should be included in design and assessment phases, either as direct members of the project team or in an advisory capacity through steering committee representation.

Mechanisms for transfer and adoption
The products and outcomes of this specific project could be transferred to end-users via:

- The production of a final report and summary brochure upon completion
- Presentations to interested community groups and also to a scientific audience via the annual Native Fish Strategy forum
- The dissemination of the project products via the Native Fish Strategy Coordinators and members of the Native Fish Strategy Implementation Working Group
- Engaging relevant media where possible (radio, TV and written press).
- Via the Murray-Darling Basin Commission website and through online mechanisms offered by other agencies
- Through federal agencies that have influence across a broad range of jurisdictions
- Through industry representatives appointed to a project steering committee

Estimated cost and duration
Actual project costs will be determined by the adopted approach and workplan. This work may be let as an entire package, where construction, assessment and management costs are provided in a lump sum. Alternatively, it could be funded in stages with a competitively selected initial consultation and construction stage. This would be followed by an independently commissioned research project to determine effectiveness of the screening facility.

Depending on the selected location, and the nature of site specific issues (i.e., whether a pump or canal system is selected), the cost of a screening facility could cost anywhere between $AUD 0.5 – 4 Million. There may be scope to incorporate a project of this nature this into the Living Murray Environmental Works and Measures program or to seek funds through industry or via federal initiatives. Alternatively, a co-investment approach could be developed. Once funding is secured, a possible workplan could include:

- An initial workshop to determine appropriate screening mechanisms.
- Engaging a suitable engineering firm to draft concept diagrams and provide indicative costing.
- Assigning a project manager to ensure works will be undertaken as planned.
- Engaging a contractor to undertake the works.

The biological assessment should include a ‘before’ and ‘after’ component. This would aim to establish an initial benchmark of fish communities in the canal and river system which is incorporated into an experimental design that can adequately detect ecologically-significant changes ‘after’ construction has occurred. The work would be largely field-based and therefore necessitate a high operating budget. It would also require the employment of at least 1.5 FTE to undertake fieldwork, reporting and extension activities. This would necessitate an annual budget of $AUD 175 – 225K over a minimum four year period (to provide two years of ‘before’ and ‘after’ data).

PROJECT SUGGESTION 3: Reducing pump-induced mortality of fish

Overview

A secondary impact of pumping systems on native fish is increased incidences of injury and mortality during passage through pump systems. At sites on the Namoi River, up to 200 fish per day were extracted by pump systems with many fish being either injured or killed during passage. Work conducted in North America has suggested that the use of fish-friendly pumps and impellers can substantially reduce or eliminate these risks and provide substantial increases in fish survival. Mechanisms to improve the passage of fish through pumping systems remain poorly understood within the Murray-Darling Basin and an assessment of fish-friendly pumping systems would provide a suitable mechanism to improve conditions for fish at some sites.

Project objectives

- To initiate research to assess the effectiveness of these pumps for Murray-Darling Basin fish.
- To determine benefits for a range of species and life history stages.
- To assess the relative impacts of different impeller designs and rotation rate on fish.
- To provide management recommendations for the wider application of fish-friendly pump systems throughout the Murray-Darling Basin.

Key tasks

- To undertake a review of fish-friendly pump designs.
- To purchase (or arrange construction) of fish-friendly pumps for use in experimental assessments.
- To undertake a field or laboratory based research program.
- To report on results.

Anticipated products

The project will be largely experimental in nature so the major products will be a project report and summary brochure. The report should contain detailed management recommendations for the construction of fish-friendly pumps, and provide a framework for widespread adoption and application throughout the Murray-Darling Basin.

Anticipated outcomes

The major outcome from this project will be the identification of fish-friendly pump designs and operating protocols for irrigators in the Murray-Darling Basin. This information will be expected to influence management strategies, especially for the widespread application of pumping systems if substantial increases in fish survival are expected.

Opportunities for end-user involvement

Irrigation groups should be considered early in the project to provide feedback on irrigator requirements for pumping systems. Members of irrigation councils should therefore be included in the site selection process and also through a project steering committee. After experimentation the results should be disseminated to irrigators through the Community Reference Panel.

Mechanisms for transfer and adoption

A key aspect of this report however will be the provision of post-experimental extension activities to transfer the knowledge to industry. A useful mechanism to ensure adoption of fish-friendly pump systems is via the establishment of one or more demonstration sites where existing pump systems are suspected of adversely affecting fish communities.

Specific methods to enhance the transfer information arising from this project are via:

- Distributions of a final report and summary brochure upon completion.

- Presentations to interested community groups and also to a scientific audience via the annual Native Fish Strategy forum.
- The dissemination of the project products via the Native Fish Strategy coordinators and members of the Native Fish Strategy Implementation Working Group.
- Engaging relevant media where possible (radio, TV and written press).

Estimated cost and duration

The project should be completed within two years for a nominal annual budget of $AUD150K. Staffing requirements would be 1 FTE to oversee the project and organize experiments. An additional 0.5 FTE may be required to assist with fieldwork. Project proponents should demonstrate an appreciated for native fish ecology and scope to establish links with relevant industry groups if the results are to have widespread applications.

PROJECT SUGGESTION 4: Improving connectivity between terminal irrigation systems and source rivers

Overview

The entrainment of fish into irrigation systems often involves removal from source rivers into terminal systems that offer little opportunity for return. Whilst screening mechanisms are the most useful mechanism to exclude fish from entering these systems, they may not be practically feasible at all irrigation offtakes due to factors such as high depths or insufficient flow conditions. Under these circumstances if may be necessary for managers to accept some degree of fish entrainment and provide fish passage facilities to provide connectivity to the source river. Most fish passage development in the Murray-Darling Basin has previously occurred on main river sites of high conservation significance. Although work has demonstrated that high numbers of fish can be extracted at irrigation diversions, no fish passage facilities exist to enable passage back to source rivers.

Project objectives

- To undertake a detailed ecological assessment of the effectiveness of a fish passage facility within an irrigation diversion system.
- To quantify improvements in fish community in the source river and irrigation canal following construction.
- To identify priority irrigation diversion for fish passage facilities throughout the Murray-Darling Basin.

Key tasks

- To identify a suitable site for the construction of fish passage facilities at an irrigation diversion with large fish entrainment rates.
- To workshop suitable fish passage designs and arrange construction.
- To facilitate the construction and installation of the fish passage facilities (if as part of a wider program on irrigation infrastructure).
- To workshop an appropriate experimental design that is sufficiently robust to detect fish community changes associated with fish passage construction.
- To ensure appropriate trapping and fish collection facilities are in place.
- Undertake fish sampling as required by the experimental design.
- To report on results.

Anticipated products

If packaged as a total project, the project should deliver:

- A functional fish passage facility at a key irrigation diversion.
- An ecological study to determine the effectiveness of the works.
- A project report and brochure outlining key results.
- Extension activities to widely disseminate the results to key groups.

Anticipated outcomes

The major outcome of this project would be improved fish passage at a key irrigation diversion in the Murray-Darling Basin. A subsequent ecological study would be required to outline the success of the fish passage facility and to recommend priority sites in the Murray-Darling Basin for further works.

Opportunities for end-user involvement

A project of this nature offers opportunities for co-investment among industry groups and federal agencies. End-users must be involved during project planning stages to ensure irrigator requirements are maintained throughout the development of the project. Irrigators can be informed of project through the Native Fish Strategy Community Reference Panel.

Mechanisms for transfer and adoption
Specific methods to enhance the transfer information arising from this project are via:

- Distributions of a final report and summary brochure upon completion.
- Presentations to interested community groups, international forums and via the Native Fish Strategy forum.
- The dissemination of the project products via the Native Fish Strategy Coordinators and members of the Native Fish Strategy Implementation Working Group.
- Engaging relevant media where possible (radio, TV and written press).

Estimated cost and duration
Actual project costs will be determined by the adopted approach and workplan. This work may be let as an entire package, where construction, assessment and management costs are provided in a lump sum. Alternatively, it could be funded in stages with a competitively selected initial consultation and construction stage. This would be followed by an independently commissioned research project to determine effectiveness of the fish passage facility.

Depending on the selected location, and the nature of site specific issues, the cost of a fish passage facility could cost anywhere between $AUD 0.5 – 4 Million. There may be scope to incorporate a project of this nature this into the Living Murray Environmental Works and Measures program or to seek funds through industry or via federal initiatives. Alternatively, a co-investment approach could be developed. Once funding is secured, a possible workplan could include:

- An initial workshop to determine appropriate designs.
- Engaging a suitable engineering firm to draft concept diagrams and provide indicative costing.
- Assigning a project manager to ensure works will be undertaken as planned.
- Engaging a contractor to undertake the works.

The biological assessment should include a ‘before’ and ‘after’ component. This would aim to establish an initial benchmark of fish communities in the canal and river system which is incorporated into an experimental design that can adequately detect ecologically-significant changes ‘after’ construction has occurred. The work would be largely field-based and therefore necessitate a high operating budget. It would also require the employment of at least 1.5 FTE to undertake fieldwork, reporting and extension activities. Work would only be undertaken at a single site however, and an annual budget of $AUD 150K over a minimum four year period (to provide two years of ‘before’ and ‘after’ data) should be sufficient.

PROJECT SUGGESTION 5: Quantifying the effects of irrigation canals on fish during high flow events

Overview

One of the major limitations of the present study was that work was conducted during the worst drought on record. If is therefore difficult to generalize the applicability of results to all climatic conditions because relative impacts on fish could increase under higher irrigator entitlements. It would therefore be useful to undertake a short-term replication of the current methodology when inflows return to non-drought conditions.

Project objectives

- To quantify the effects of irrigation systems during increased periods of flow and entitlements.
- To investigate adults, sub-adults, eggs and larvae.
- To investigate the impacts on canal systems and pumping systems.

Key tasks

- Replicate the current methodology at the existing sites.
- Undertake work in the Namoi River and Bundidgerry Creek systems.
- Use fyke netting, electrofishing and larval sampling.

Anticipated products

The results would be presented in a report and a project brochure would be produced to disseminate information to a wider audience. If performed in conjunction with management interventions, the project could also provide recommendations for potential management practices to reduce large-scale impacts on fish.

Anticipated outcomes

If funded, this work would provide fill a useful knowledge gap that could not be addressed by the current project. The project would replicate the existing work, but provide additional data on the relationship between flow regime and irrigation impacts. It would be expected that fish spawning and recruitment would increase under high flow conditions, which would add value to egg and larval components.

Opportunities for end-user involvement

The project must involve relevant industry partners including the Australian Cotton CRC, Namoi Irrigators, Australian Cotton Research Institute and Murrumbidgee Irrigation. These groups must be involved during project planning stages to ensure irrigator requirements are maintained throughout the development of the project. Irrigators can be informed of project through the Native Fish Strategy Community Reference Panel.

Mechanisms for transfer and adoption

Specific methods to enhance the transfer information arising from this project are via:

- Distributions of a final report and summary brochure upon completion.
- Presentations to interested community groups, international forums and via the Native Fish Strategy forum.
- The dissemination of the project products via the Native Fish Strategy Coordinators and members of the Native Fish Strategy Implementation Working Group.
- Engaging relevant media where possible (radio, TV and written press).

Estimated cost and duration

To give statistically comparable results, the project should be replicated in its entirety. This would involve a nominal budget of $150 – 200K with the employment of 1.5 FTE to undertaken fieldwork and reporting.

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