Impacts of Introduced Redfin Perch on Native Flathead Gudgeons in the South Para River.

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i. GENERAL FORWARD TO THE RESEARCH PAPER:

Following the provision of environmental water allocations (EWAs) to provide environmental flow releases to the Torrens, South Para and Onkaparinga Rivers (Pikusa and Bald 2005), The Department of Water, Land and Biodiversity Conservation (DWLBC) in collaboration with the Adelaide, Mount Lofty Ranges and SA Murray Darling Natural Resource Management Boards funded a project to investigate the relationship between stream flow patterns and the sustainability of native fish in those catchments. Specifically, study sites were chosen that possessed good natural habitat, and were located directly downstream of the flow release points (South Para, Gumeracha, Gorge and Clarendon weirs). Although the ongoing drought has resulted in the postponement of EWAs, the fish sustainability project has progressed into its second year, with a number of rainfall events resulting in natural stream flows. Just prior to the project initiation in November 2005, a large rainfall event caused significant flows in the South Para River, resulting in widespread flood damage lower in the Gawler River.

Initial sampling of the fish community in the area directly downstream of the South Para Weir indicated that the reach, although previously identified as being devoid of fish species (Darren Hicks-AWQC pers. com.), had a well established population of native flathead gudgeon (*Philypnodon grandiceps*) but had become home to large numbers of the introduced and piscivorous redfin (European) perch (*Perca fluviatilis*). This survey identified that both species were distributed downstream of the weir for many kilometres beyond the Parra Wirra National Park. The significance of this was that the large flow was apparently responsible for the downstream transport of huge numbers of redfin perch, which were known to be abundant within the South Para Weir (Darren Hicks AWQC- pers. comm.), although there is a chance that some upstream migration may be possible as floodwaters subsided.

Concern expressed by SA Water (Glyn Ashman) and subsequent discussion with the steering committee held on the potential for and impact of flow releases to facilitate the movement of introduced predatory perch into areas where they were previously absent. Subsequently, a project was developed between DWLBC, SARDI and Adelaide University to assess the impact of redfin predation on native fish, and more specifically, the impact of redfin perch in the South Para on the native flathead gudgeon. The resulting study was conducted by Phillipa Wilson as part of her Honours degree in Environmental Biology and the research outline; findings and discussion of the results are presented in their entirety.

A short summary of the significance of the study to fish sustainability and environmental flows in the Mount Lofty Ranges, and an outline of recommended research is also provided at the end of the thesis.

ii. ABSTRACT

Many ecosystems throughout the world are increasingly being disrupted by the introduction of non-native species that dramatically alter receiving communities and are a primary cause of loss of native species. The aim of this study is to establish the nature of a predator-prey relationship between the introduced redfin perch, *Perca fluviatilis*, and the native flathead gudgeon, *Philypnodon grandiceps*, through an intensive study within refuge waterholes in the South Para River, Mount Lofty Ranges. Combinations of field data, dietary analysis, controlled prey selections trials, and *in situ* predator removal experiments in the field were used to gain an understanding of the nature of the predator-prey relationship and to assess the potential impact of redfin perch introduction on the abundance, population dynamics and habitat use of the native prey species.

Redfin perch were found to readily consume all size classes of flathead gudgeons, however gudgeons only represented a small proportion of the predators diet. After determining broad scale patterns in the fish communities of this reach, redfin perch were then eradicated from a number of refuge pools to evaluate their impact on flathead gudgeons. The experimental removal of predators from a number of refuge pools revealed that redfin perch did not significantly influence the abundance of gudgeons, however, they were found to limit the microhabitat use of flathead gudgeons.

The two species were found to co-exist within all eight refuge pools indicating that predation pressure exerted by redfin perch was not sufficient to completely eradicate their sole prey fish species from these fairly isolated habitats. This could be partly due to extreme drought conditions that occurred during the study period. It is possible, however, that if environmental conditions were more stable and alternative food sources were scarce, redfin perch may negatively impact upon the abundance of gudgeons in this system. In highly variable systems, the implications of sustained removals of introduced predators for the management of threatened native species is discussed.

1. INTRODUCTION

Although species have always moved to inhabit or invade new habitats between continents and islands through various means, the last few centuries have seen a rapid increase in the human assisted dispersal of species across the planet moving towards global homogenisation (Lodge 1993). Biological invasions have resulted in the disruption of many ecosystems throughout the world (Jang *et al.* 2006) and have become the focus of a wide range of biological research (Grosholz and Ruiz 1996).

The introduction of a species into a new system poses a great threat to those ecosystems into which they are introduced as it brings with it changes and modifications to the recipient biota and the ecosystem itself (Vermeij 1996). These impacts include introduction of parasites and diseases, habitat and water quality alterations, genetic effects such as hybridisation or elimination of endemic species, competition for food and space, and predation (Ross 1991). Introduced species are the primary cause of the loss of native species (Everett 2000; Lepak *et al.* 2006). In fact, alien fish species have been implicated as a cause of 68% of species extinctions in North American fish (Lintermans 2004).

In Australia, 34 non-native fish species have become established through human-assisted introduction over the past 200 years due to the accidental or deliberate release of aquarium species, the intentional release of exotic species suitable for recreational fishing (Pusey *et al.* 2006), aquaculture and biological control of previously introduced pests (Lintermans 2004). Furthermore, the translocation or introduction of non-native fishes into Australia has largely occurred without prior assessment of the likely impacts of such actions, or indeed without subsequent assessment of any impacts that such introductions may cause (Lintermans 2004).

Piscivorous fish (fish that eat other fish) are among the most successful global invaders. Prey species in their new habitats are often vulnerable as they may have evolved without any similar high order predator and they have not usually encountered or adjusted to their predator's particular style of predation (Allen *et al.* 2002). The absence of behavioural or biological adaptations for predator evasion makes prey species particularly vulnerable to introduced species, possibly leading to broad-scale extinctions of prey species, or a whole range of species within the ecosystem (Kristensen and Closs 2004). The introduction of piscivorous fish species to new ecosystems is therefore worthy of research to investigate their impacts on the receiving ecosystem and on the species that exist therein.

Redfin perch, *Perca fluviatilis*, were first introduced into Tasmania in Australia from Europe in 1862 as an angling species and as an additional food source (Lintermans *et al.* 1989) and have since become a significant component of the River and Lakes fisheries throughout Australia (Pierce *et al.* 1991). They are a moderately large predatory fish (commonly 40-45 cm and 1-2 kg weight) that are now widespread in cooler waters of New South Wales, Victoria, Tasmania, South Australia, and south-western Western Australia, where they have replaced native perch such as golden perch (*Macquaria ambigua*) as the principal piscivore (Shirley 2002; Closs *et al.* 2005). Their overall distribution is limited in some areas due to high water temperatures (>31°C) and salinities (>10 ppt) (Morgan *et al.* 2002; 2004), and poor oxygen (McNeil and Closs 2007).

The spread of redfin perch in Australian inland waters has lead to competitive and predatory interactions with native species (Lintermans *et al.* 1989), which is enhanced by the complete absence of other large predators within many systems where redfin perch have become established (Morgan *et al.* 2002). In these habitats, they are likely to have a significant impact on small-bodied native fish, excluding them of prime habitats and food resources as well as direct predation which has the potential to cause local prey extinctions (Allen *et al.* 2002). They are known to be important in structuring the populations of native and introduced prey fish (McNeil 2004) and have been implicated in the local extinction of native fish species, although native prey species may co-exist with redfin perch if alternative food sources are plentiful (Pen and Potter 1992). There has been no published research on the effect of redfin perch on native species in South Australia, although several studies examined redfin perch distribution, biology and impacts in Western Australia where they are perceived to be the greatest local threat to native species of fish and decapods (Morgan and Gill 2000; Morgan *et al.* 2002; 2004).

This project investigates the impact of redfin perch on the native flathead gudgeon (*Philypnodon grandiceps*), within isolated refuge pools of the South Para River in the Northern Mount Lofty Ranges, South Australia. Prior to the introduction of redfin perch into the area, no large piscivorous fish were present in the system; however, the two species currently co-exist in the reach and are the only fish species present. This allows their relationship to be studied in isolation from highly complex multi species interactions present across most of their range. The mechanisms of redfin perch predation, the degree to which they rely on fish prey and the extent of how they shape the population and size structure of flathead gudgeons is unknown.

This project aims to establish the extent and nature of gudgeon predation by redfin utilising dietary and laboratory analysis to complement field surveys and *in-situ* predator removal experiments. The specific aims of this study were to:

(1) Determine whether redfin perch consume gudgeons in the South Para River, and
(2) If so, to establish broad scale patterns in the distribution and abundance of redfin perch and flathead gudgeons in the South Para River, and
(3) To identify the nature of this predator-prey relationship through dietary analysis and laboratory experiments principally to identify any size-selectivity or preference.

Experimental removal of redfin perch from a number of refuge pools will then be carried out:

(1) To investigate relationships between redfin perch presence and the abundance of gudgeons, and
(2) To determine if there is any relationship between the presence of redfin perch and the population structure of the gudgeon community.
(3) To investigate the impact of redfin perch on the abundance of gudgeons within microhabitats of refuge pools, and
(4) To determine if the presence of redfin perch affects the population structure of gudgeons across microhabitats within refuge pools.

2. METHODS

2.1 Dietary analysis of redfin perch

To determine what field-collected redfin perch preyed on in the South Para River, stomach contents of the fish from the removal experiments (see section 2.5 Perch removal) were examined. Stomach contents were transferred into a petrii dish and analysed under a magi-lamp. All prey items were recorded and measured if intact. The total length (TL, mm) of each redfin perch was also measured.

The size of gudgeons in the stomach contents of redfin perch was compared to the size distribution of gudgeons in each pool using a two-sample Kolmogorov-Smirnov test. Length data were pooled across all eight sites for the two sampling trips prior to redfin perch removal. Similarly, the size of prey eaten by medium (0-200mm TL) and large (>200mm TL) redfin perch was compared using a two-sample Kolmogorov-Smirnov test. Data used for this analysis only included redfin perch that had gudgeons in their stomach contents.

2.2 Study site

Studies on the impact of redfin perch on the population structure and habitat use of the native flathead gudgeon were conducted along one reach of the South Para River. The South Para River (SPR) is a medium sized stream (>2m average depth) on the western slope of the Mount Lofty Ranges that flows towards the Gulf of St Vincent, and drains the Mount Crawford region (see Appendix B for map of study area). The stream dries seasonally into a series of isolated pools with little or no connectivity throughout most of the year, although large floods often occur during winter and spring (e.g. November 2005 flood). Communities in these ponds are only connected to other waterbodies during such floods.

Within one reach of the SPR, eight isolated pools were selected on the basis of the presence of only two fish species, redfin perch and gudgeons, and physical characteristics such as habitat complexity, size, location and absence of any connection (flow). Community composition was determined by examining data collected during a previous fish survey of the area (McNeil and Hammer 2006) and data collected in a pilot study prior to the commencement of this study. Relatively small isolated pools were selected to allow intensive netting of each pool and to prevent the movement of fish from other areas obscuring experimental effects. The pools also had to be easily accessible for transportation of sampling gear into the gorge. At the start of this study these pools had been isolated since a large flood in November 2005.

2.3 Water quality parameters

Measurement of water quality characteristics of the eight study pools was conducted on six occasions during the course of this study. The analysis was undertaken prior to fish sampling in each pool to reduce the influence of sediment disturbance on water quality measurements. Variables were measured using a TPS MC81 handheld multimeter in the centre, upstream and downstream ends of the pools. Conductivity (micro-Siemens), pH, dissolved oxygen (milligrams per litre), and water temperature (degrees Celsius) were measured at the surface of the pools and within the bottom 20cm of each pool. Maximum depth (cm) of each pool was also recorded.

2.4 Size-selective predation of redfin perch

To determine the size of gudgeons preyed upon by redfin perch a predation experiment was conducted in laboratory aquaria in early 2007. Redfin perch and gudgeons were collected from pools in reaches of the South Para River using similar fyke net methodology (see below). The pools used to collect the fish were not those used in the field study. Fish required for the predation experiment were placed in a portable aquarium and supplemented with running oxygen. The fish were returned to SARDI Aquatic Sciences alive and placed in flow-through tanks (1000 x 800 x 500cm). Redfin perch were fed on live mosquitofish (*Gambusia holbrooki*) and gudgeons were fed live brine shrimp and frozen bloodworms.

To examine whether habitat structural complexity influenced predation of redfin perch on gudgeons, two treatments of differing structural complexity were examined: bare sand (no structural complexity) and rocks (increased structural complexity). Fifteen gudgeons [5 gudgeons from each of three size classes (20-30 mm TL, 40-50mm TL, 60+mm TL)] were placed into the experimental tank with one redfin perch (200+mm TL). Five replicate experiments were run for each treatment. The order of prey items eaten was obtained from visual counts made every 15 minutes. Experiments were run for three hours or until all prey fish were consumed.

To determine if redfin perch ate different sized gudgeons and if this changed with differing structural complexity after both 15 minutes and 3 hours, one-way ANOVA's were conducted. Four individual ANOVA's were done (bare sand 15 mins and 3 hours, rocks 15 mins and 3 hours) as the same redfin perch were used for both treatments (n=5). The factor used for the ANOVA was prey size.

2.5 Perch removal

The eight pools selected for this study were randomly allocated one of two treatments: perch removal (impact) and non-perch removal (control). The impact treatment consisted of four pools where progressive removal of redfin perch was undertaken. The control treatment consisted of the four pools in which no perch removal was undertaken. The sampling undertaken in this study involved redfin perch removals in October/November 2006, monitoring of the fish community monthly from October 2006 to January 2007, and monitoring the habitat use of gudgeons in October (before perch removal) and November (after perch had been removed).

To remove redfin perch fyke nets were set overnight (n=6/pool) over a period of three to five nights for each removal pool (or until two consecutive nights where no catches were made). When no redfin perch were caught for two consecutive night periods, gear was then increased in pools where redfin perch were still being captured. Fyke nets were set by attaching the floating top line of the wing to the bank (e.g. by tying to nearby vegetation) then extending the net at an angle of 45° to the bank and anchoring the end using a heavy metal chain. All equipment was set for approximately twenty-four hours.

All redfin perch captured were killed immediately by delivering a sharp blow to the head. They were then measured to the nearest millimetre and placed in a portable freezer for further dietary analysis. All fish other than redfin perch (gudgeons) were immediately released back into the pool they were collected from.

To validate the successful removal of redfin perch from the four removal pools, SARDI Aquatic Sciences personnel conducted sweep-net electro fishing on one occasion in each pool.

2.6 Abundance of redfin perch and flathead gudgeons

To determine if the presence of redfin perch affects the abundance and size structure of gudgeon populations, the fish populations in each pool were monitored monthly from October 2006 through to December 2006. All pools were sampled using large fyke nets (wing length 6 m, stretched mesh 8 mm, n=2) and small fyke nets (wing length 3 m, mesh size 3 mm, n=4). For the final two monitoring times fewer nets were set in each pool due to low water levels and decreased pool size (due to the current drought) (n=3). Monitoring of all eight pools took between 4 and 15 days each month.

Fyke nets were set overnight for one night per pool on each sampling occasion. Fyke nets were set randomly with no selection for areas with or without macrophytes. Equipment was retrieved within approximately 24 hours of the nets being set. All fish captured (or a subsample per net, n=100) were measured to the nearest millimetre and then immediately released.

Data on gudgeon abundance were analysed using a four-way ANOVA (Factors: impact vs control, before vs after removal of perch, location nested within impact vs control, and trip number nested within before vs after) to determine if there was an effect of removing perch on flathead gudgeon abundance. The factors impact versus control and before versus after were treated as fixed factors since these were the only treatments possible. The other factors (location and trip number) were random factors since these were chosen from a range of possible pools or sampling times. For monitoring the gudgeon abundance, equal replication of nets was not possible in all pools due to drought. For pools that could not be sampled on the final sampling trip due to no water, zeros were added for gudgeon abundance allowing statistical analysis to be completed.

The size distribution of the gudgeon population in the control and impact pools was compared using two-sample Kolmogorov-Smirnov tests run on data prior to redfin perch removal (October and November 2006) and following redfin perch removal (December 2006 and January 2007). Length data from small and large fyke nets were pooled across the four pools in each treatment for the two sampling times before and after perch removal. All gudgeons in each pool could not be measured on every sampling trip due to bushfires in surrounding areas; therefore graphs are displayed as a percentage of the total number of gudgeons for each frequency.

2.7 Flathead gudgeon microhabitat use

To determine if there were differences in the habitat use between gudgeons in impact pools and gudgeons in control pools, the distribution of gudgeons in littoral versus benthic and pelagic pool habitats was measured. Sampling of the habitat use of the fish population in each pool was conducted on two occasions, once before and once after redfin perch removal. All pools were sampled using collapsible, rectangular unbaited box traps (stretched nylon mesh 1mm, 40 x 24 x 24 cm in size with 7cm opening), which were set in three primary microhabitats [littoral (close to the bank, resting on the substrate); benthic (deepest areas of the pool, resting on the substrate); pelagic (floating in the top 20cm of the water column, directly above the deep bottom)]. Box traps were used to target gudgeons.

Box traps were set overnight in each pool on each sampling occasion. On each trip, 10 box traps were set in all three primary microhabitats within each pool. Traps were set randomly with no selection for areas with or without macrophytes. Equipment was retrieved within 24 hours of the traps being set. All fish captured were measured to the nearest millimetre and then immediately released. The depth of each deep bottom trap was also recorded.

For analysis of gudgeon abundance across the three primary microhabitats a four-way ANOVA (Factors: impact vs control, time, microhabitat and location) was conducted to determine if there was an effect of removing redfin perch on gudgeon abundance. The factors impact versus control and microhabitat were treated as fixed factors since these were the only treatments/microhabitats possible. The other factors (location and time) were random factors since these were chosen from a range of possible pools or sampling times. Equal replication of box traps was not possible in all pools due to drought. If significant differences were found among treatments, Student-Newman, keuls, (SNK) tests were used to determine where the differences lay.

The size distribution of the gudgeon population in the three microhabitats, in the control and impact pools, were compared using a two-sample Kolmogorov-Smirnov test. Length data were pooled for each microhabitat across the four pools in each treatment for the after sampling trip to determine if there was a difference between control and removal pools. Each microhabitat was then compared to determine if any changes in size distribution occurred before and after redfin perch removal.

3. RESULTS

3.1 Dietary analysis of redfin perch

The length distribution of gudgeons found in the dietary analysis of redfin perch (removed as part of the experimental treatments) did not differ from the length distribution of gudgeon populations present in all eight pools prior to perch removal (Fig. 1). Stomach contents of redfin perch did not contain gudgeons less than 30 mm TL.

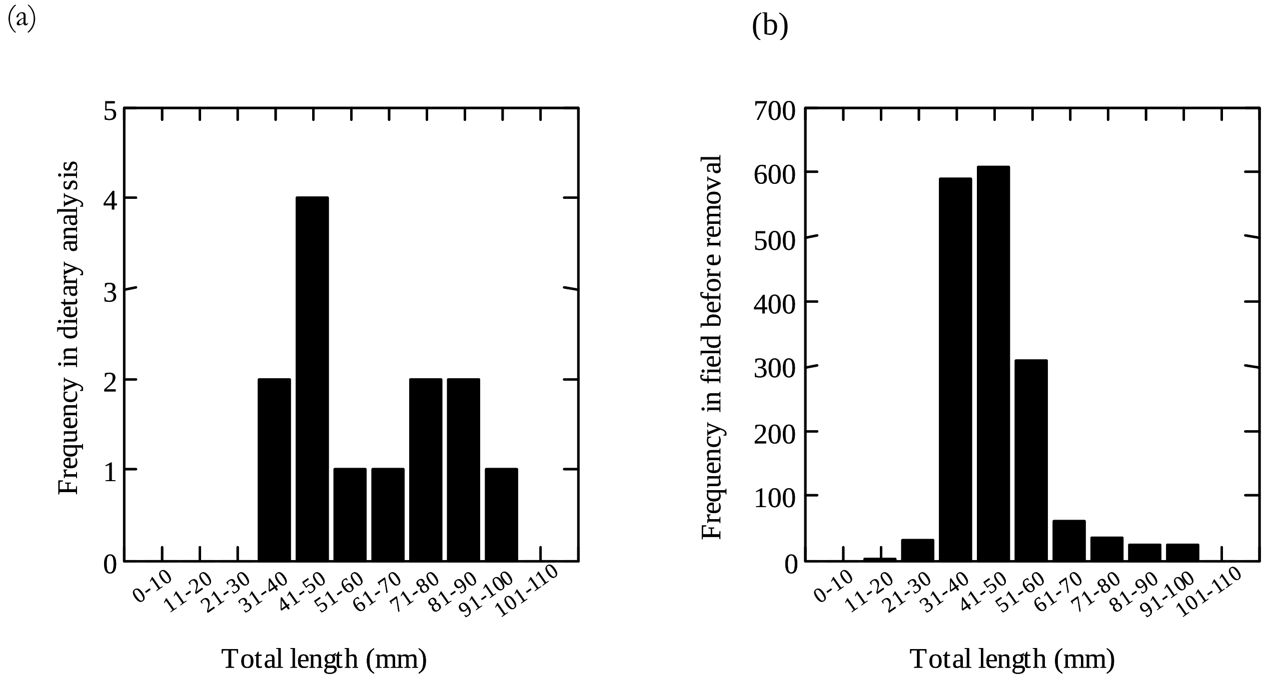

Fig. 1. Size frequency distribution of gudgeons in (a) stomach contents of wild caught redfin perch and (b) in the field prior to redfin perch removal. Note that data used for the field data was pooled from all eight pools in the October and November 2006 sampling times. Note different scales on the Y-axis.

Other prey items found in the stomach contents of redfin perch consisted of invertebrates such as yabbies and dragonfly nymphs (Fig. 2). A large proportion of redfin perch were found to contain nothing in their stomach. Cannibalism was also found as redfin perch were eating their smaller counterparts (Fig. 2). Stomach contents of small redfin perch (0-80mm TL) were mainly empty, although they did contain a small proportion of invertebrates and gudgeons (16.7% and 3.3%, respectively) (Fig. 3a). The diet of medium redfin perch (81-160 mm TL) mainly consisted of invertebrates (37.5%) and gudgeons (12.5%), however 50% of the proportion of fish sampled were empty (Fig. 3b). Larger ranges of prey items were found in the stomach contents of large redfin perch (161+mm TL). These included invertebrates (47.1%), redfin perch (5.9%), gudgeons (19.6%), unidentified (7.8%) and empty (19.6%) (Fig. 3c).

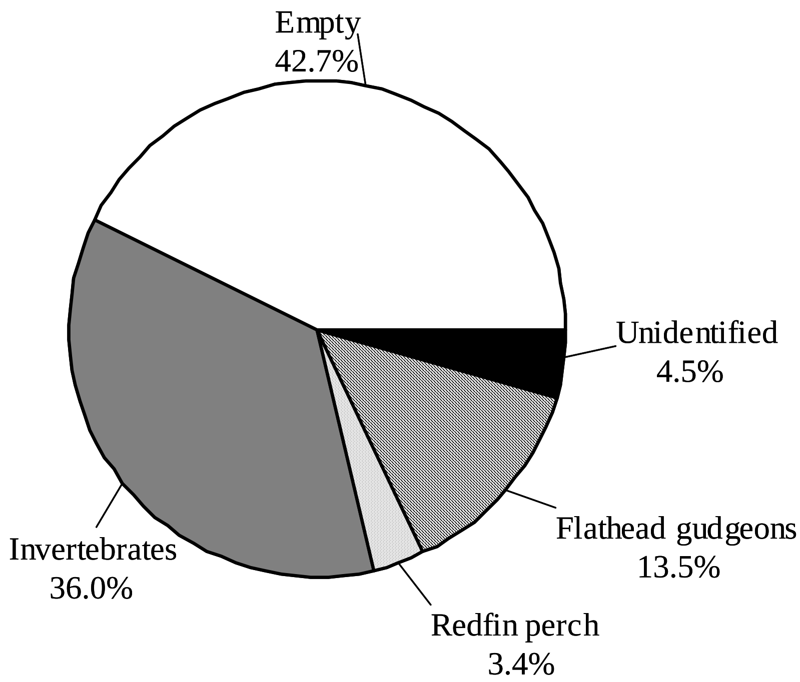

Fig. 2. Pie chart of the proportion of prey items found in stomach contents of wild-caught redfin perch.

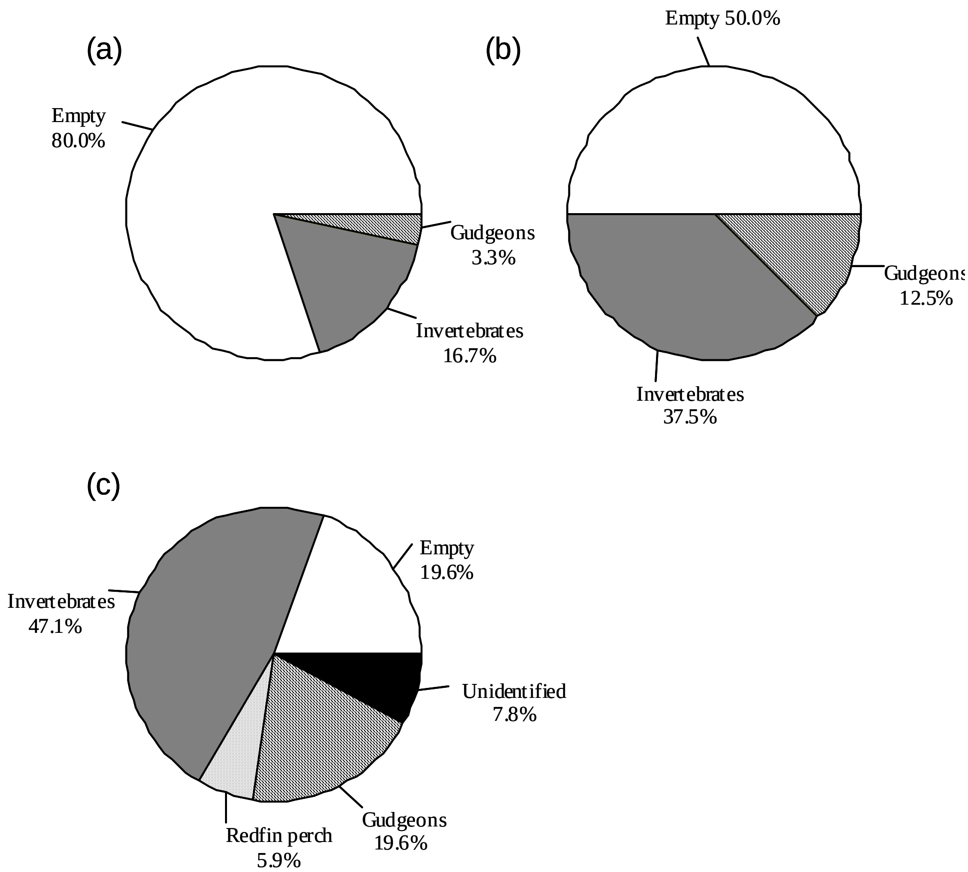

Fig. 3. Pie chart showing the proportion of prey items found in stomach contents of wild caught redfin perch (a) 0-80mm TL, (b) 81-160mm TL, and (c) 161+mm TL.

Medium and large redfin perch (80-160 mm TL and 161+ mm TL, respectively) consumed similar sized flathead gudgeons (P>0.05) (Fig. 4). No relationship was found between redfin perch size and prey size (Fig. 4). Redfin perch consumed all size classes of gudgeons, indicating that there is no maximal prey size beyond which redfin perch predation pressure was removed.

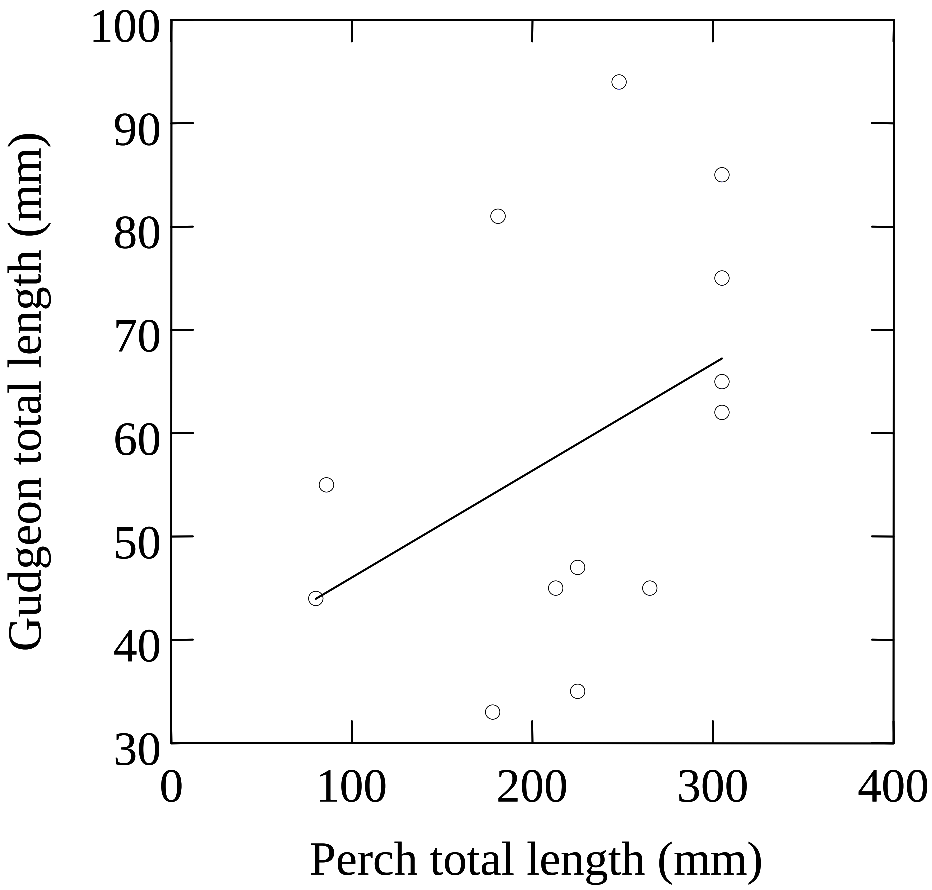

Fig. 4. Scatterplot of redfin perch size (mm TL) against gudgeon size (mm TL) from dietary analysis of wild caught redfin perch. Line of best fit plotted ($r^2 = 0.164$). Slope of line not significant (P=0.055).

3.2 Broad scale patterns in fish community

A comparison of the eight pools in the initial sampling trip (October 2006) indicated that with increasing total numbers of redfin perch there was a general decrease in the total number of gudgeons (Fig. 5). Gudgeon abundance was low in most pools at the start of the study and increased over the field sampling.

The removal of redfin perch from the four pools in late October/early November indicated that reasonable perch populations had been present in all four removal pools. Four perch ranging in size from 180 to 265 mm TL were removed from Para Wirra 1. Similarly, in Para Wirra 4 three perch (210-280 mm TL) were removed. Sixteen (167-305 mm TL) and thirty-eight perch (37 perch 74-86 mm TL plus a 275 mm TL individual) were removed from Quarry Track 2 and South Para Weir 3, respectively. No redfin perch were subsequently caught following the removals in the four treatment pools indicating that the perch removal had been successful.

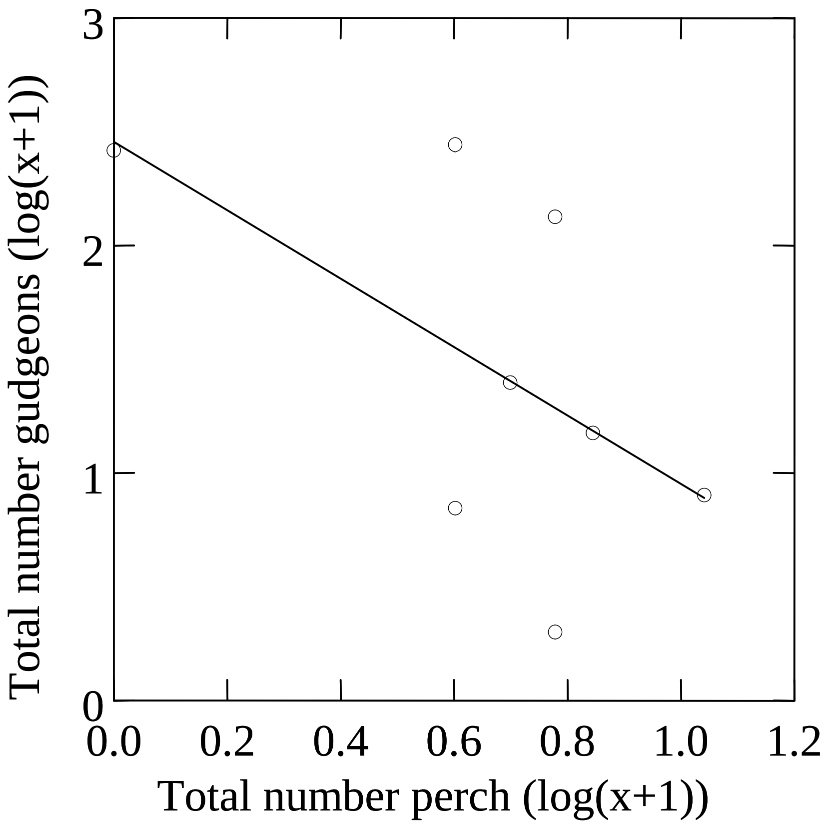

Fig. 5. Total number of redfin perch and total number of gudgeons caught at each site in the October sampling trip. Note that data for each site has been log (x+1) transformed. Line of best fit plotted (r^2 = 0.331). Slope of line significant (P<0.05).

3.3 Size-selective predation of redfin perch

No significant differences were found in the size of prey consumed by redfin perch in the two treatments (bare sand and rocks) for both 15 minutes and 3 hours (Table 1). Although no significant differences were found, large gudgeons (60+ mm) appeared to be the most common size range eaten by redfin perch for both times (15 mins and 3 hrs) of the bare sand laboratory trials (Fig. 6a, Fig. 6b). With increased structural complexity, medium and large gudgeons were the most common sizes eaten by redfin perch in the first 15 minutes (Fig. 6c), whereas after 3 hours all size classes were eaten by perch, presumably because larger fish had already been eaten (Fig. 6d).

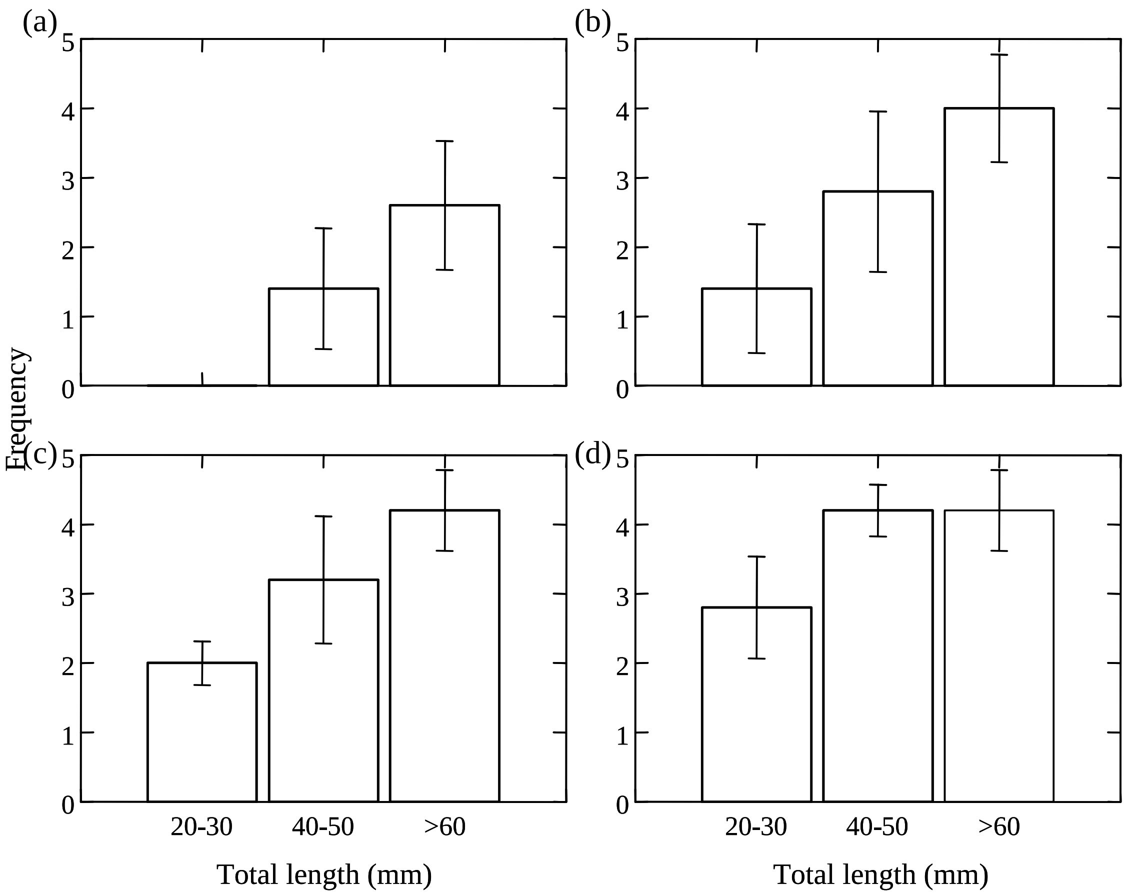

Fig. 6. Mean number of gudgeons (± SE) from each size class that were eaten by redfin perch in (a) the first 15 minutes and (b) 3 hours in the bare sand trials, and (c) 15 minutes and (d) 3 hours in the structurally complex rock habitats.

Table 1. Results of ANOVA model testing for differences in size of prey consumed by redfin perch over 15 minutes and 3 hours in bare sand and structurally complex trials. The error df were 12.

Source of variation	df	MS	*F*	*P*
Size of gudgeons 15 mins bare sand	2	1.5062	3.68	0.0567
Size of gudgeons 3 hours bare sand	2	1.0161	1.83	0.2032
Size of gudgeons 15 minutes rocks	2	0.3760	1.62	0.2388
Size of gudgeons 3 hours rocks	2	0.2274	2.18	0.1556

Note that the data used in the ANOVA's were log(x+1) transformed.

3.4 Redfin perch and flathead gudgeon abundance

No significant interaction was detected for the impact x trip number (before) term in the ANOVA model indicating that the removals did not have a consistent affect on abundance of gudgeons (Fig. 7, Table 2). The abundance of gudgeons did, however, differ between sampling trips and pools, but consistent differences for each sampling occasion were not found [significant trip number (before) x location (impact) term in ANOVA model] (Fig. 7, Table 2). Most control locations differed between both of the two trips before redfin perch removal, but few differences were found for both of the trips after the removal of perch. The impact locations differed between trips both before and after redfin perch removal.

A comparison of the sampling trips found that there were few differences for each location during the before redfin removal sampling (exception impact location South Para Weir 3), but several locations showed significant differences between the two after perch removal sampling trips (e.g. control locations, Para Wirra 2 and Quarry Track 1; impact locations, Para Wirra 1 and 4, and South Para Weir 3). These differences were largely due to drying of the pools through the summer, which led to zero catches in some pools during that season. Gudgeon abundance was low in most pools prior to the redfin perch removals. Following redfin perch removal the mean abundance of gudgeons in all pools increased (Fig. 7). In summary, although there was a strong seasonal increase in gudgeon abundance, there was no impact of redfin perch removal on gudgeon abundance.

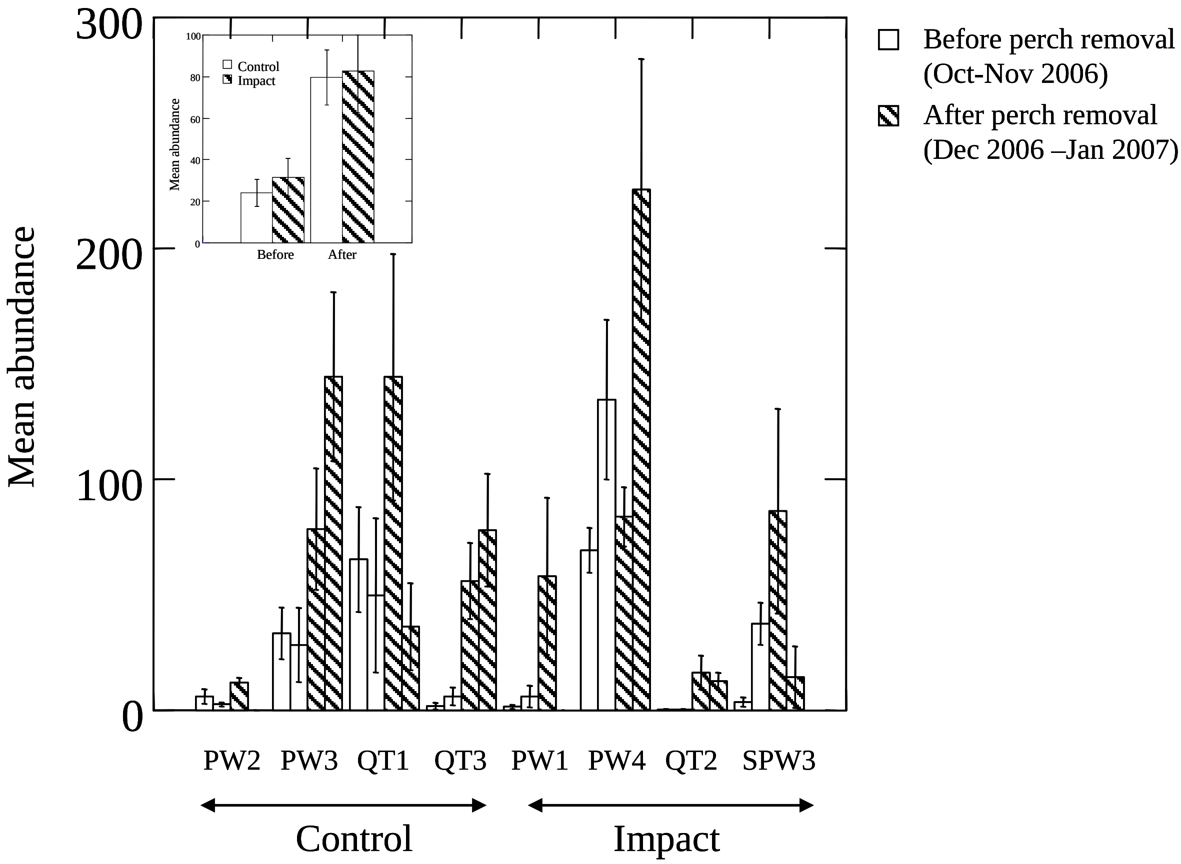

Fig. 7. Mean abundance (± SE) of gudgeons in each pool on each sampling occasion both before and after redfin perch removal. Control sites: Para Wirra 2 (PW2), Para Wirra 3 (PW3), Quarry Track 1 (QT1), and Quarry Track 3 (QT3), respectively. Impact sites: Para Wirra 1 (PW1), Para Wirra 4 (PW4), Quarry Track 2 (QT2), and South Para Weir 3 (SPW3), respectively. Inserted figure summarizes sampling trips before perch removal (n=2) and after perch removal (n=2). Note that the data used for this insert was pooled across control and impact treatments within each of the before and after treatments.

Table 2. Results of ANOVA model testing for differences in control vs impact treatments (impact term in table) both before and after redfin perch removal (before term in table). Multiple locations (pools) within each of the impact and control treatments were sampled, and there were two before and two after removal sampling times (trip number in table).

Source of variation	**df**	**MS**	***F***	***P***
Impact	1	3.793	No test	No test
Before	1	37.915	No test	No test
Impact*Before	1	0.482	0.602	0.440
Location (Impact)	6	30.445	7.818	**0.001**
Trip number (Before)	2	7.468	1.918	0.189
Impact*Trip number (Before)	2	3.097	0.795	0.474
Before*Location (Impact)	6	4.076	1.047	0.443
Trip number (Before)*Location (Impact)	12	3.894	4.857	**0.000**
Error	89	0.802		

Significant results are in bold (P<0.05). Note that the data used in the ANOVA was taken from the small fyke data only on all four sampling occasions (October 2006 to January 2007). Data were log(x+1) transformed.

3.5 Flathead gudgeon size distribution

No difference was found between the size distribution of gudgeons in control and impact pools in the two sampling trips before redfin perch were removed (P>0.05) (Fig. 8). However, the size distribution of gudgeons differed significantly between control and impact treatments after redfin perch removal (Kolmogorov-Smirnov pairwise testing, D = 0.083, P<0.001) (Fig. 9). Gudgeons ranging from 30-60 mm TL made up the majority of the gudgeon populations in both treatments prior to redfin perch removals, whereas the majority of gudgeons were slightly larger (40-70 mm TL) in both treatments after perch removals. Control locations had greater numbers of fish for each size than impact locations after redfin perch removals, however this was mainly due to only a subsample of gudgeons being measured in some impact pools due to bushfires in the area. Despite this, the size distribution of gudgeons throughout all pools was very similar following the removal of redfin perch (Fig. 9).

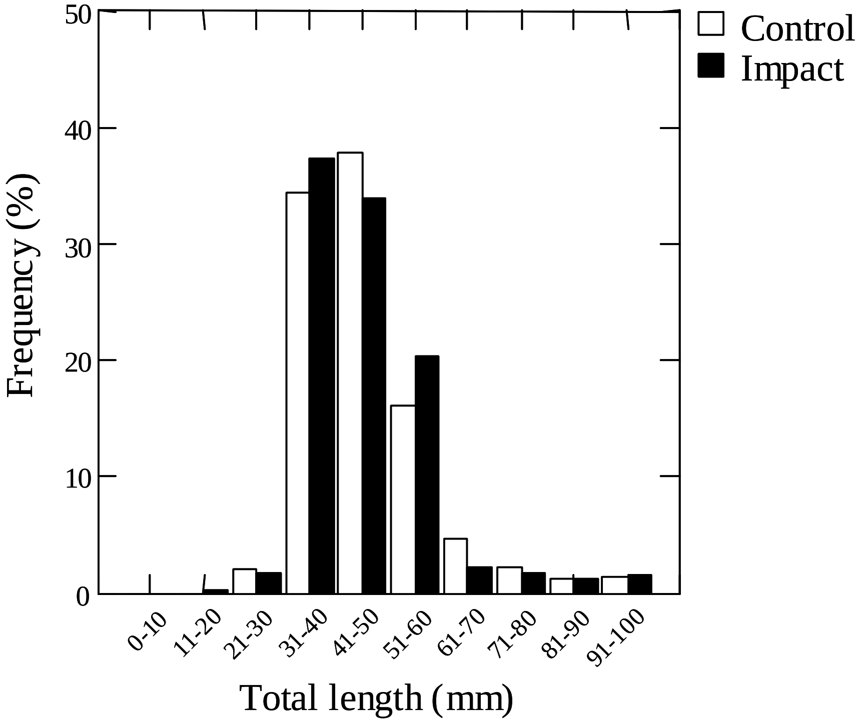

Fig. 8. Size frequency distribution of gudgeons in control and impact pools before redfin perch removal. Note that the data used for this graph were taken from the October and November 2006 sampling times and includes both small and large fyke net data. Note data are displayed as a percentage.

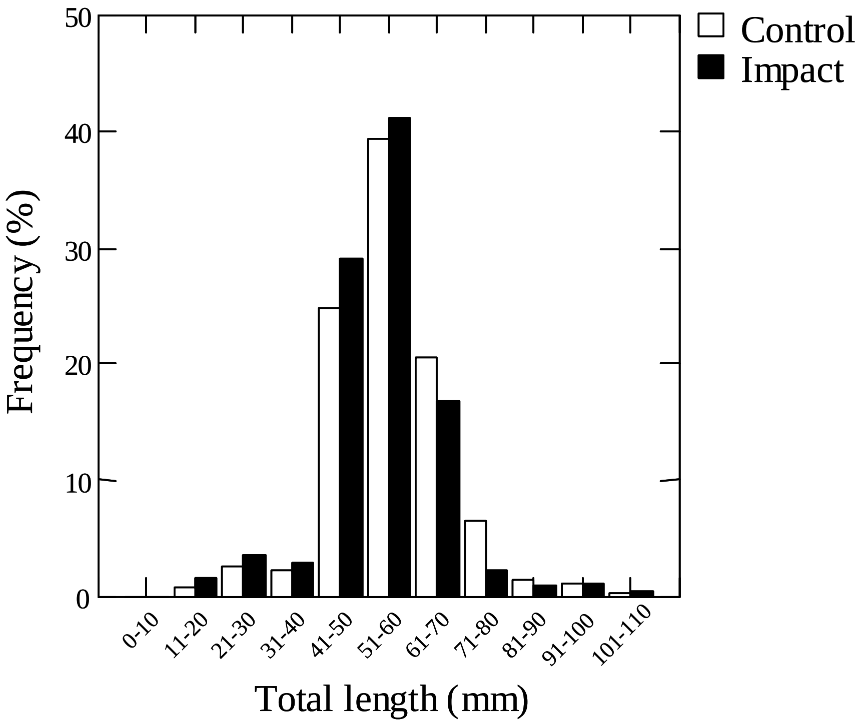

Fig. 9. Size frequency distribution of gudgeons in control and impact pools after redfin perch removal. Note that the data used for this graph were taken from the December 2006 and January 2007 sampling times and includes both small and large fyke net data. Note data are displayed as a percentage.

3.6 Flathead gudgeon microhabitat use

No significant interaction was detected for the impact x time x microhabitat term in the ANOVA model indicating that the removals did not have a consistent affect on abundance of gudgeons in each microhabitat (Fig. 10a and 10b, Fig. 11, Table 3). The abundance of gudgeons did, however, differ in different microhabitats at different times, but consistent differences were not found in each treatment for each microhabitat [significant microhabitat x time x location (impact) term in ANOVA model] (Fig. 10a and 10b, Table 3). The abundance of gudgeons in control pools differed among the three microhabitats in the before time (with the exception of Para Wirra 2) and similarly in the after time (with the exception of Quarry Track 3). Few differences in the abundance of gudgeons were found between impact sites in the before trip, whereas many differences were found between microhabitats in the after trip.

A comparison of the sampling times found that there were significant differences between microhabitats for each pool between the before and after sampling, especially in the benthic areas. Prior to redfin perch removal, all gudgeons were primarily found in the benthic and littoral areas across all pools (Fig. 11a), with no difference in abundance of gudgeons between control and impact treatments (Fig. 10a). Few differences in abundance were found between the before and after sampling in the littoral and pelagic areas (with the exception of Para Wirra 4), however, following redfin perch removal, gudgeons did begin using the pelagic area, but this affect was seen in both the control and impact pools (Fig. 10b, Fig 11b). When redfin perch were removed increased abundances of gudgeons were found in benthic areas in all impact pools (Fig. 10b, Fig 11b).

Gudgeon abundance in benthic areas of control pools during the before sampling trip differed between locations, however, the abundance of gudgeons in the remaining two microhabitats did not differ (with the exception of Quarry Track 3 and Para Wirra 2). Similarly, after removing perch, differences in the abundance of gudgeons in all areas (except the pelagic area) of control pools were found. The abundance of gudgeons in each area of impact pools also differed in both the before and after redfin perch removal sampling times (with the exception of pelagic areas in the before removal sampling).

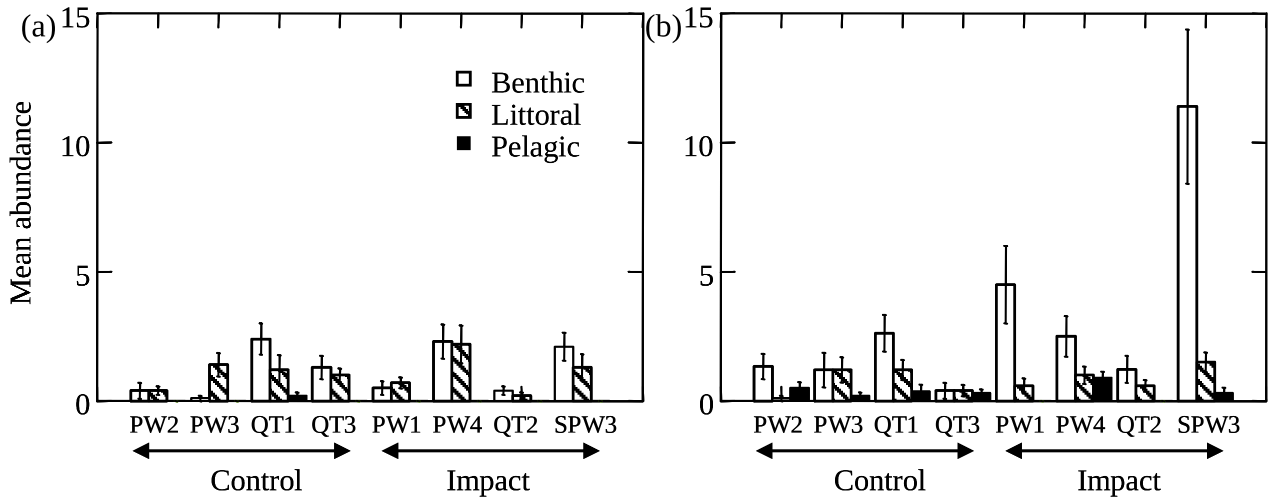

Fig. 10. Mean abundance (± SE) of gudgeons in each microhabitat of each pool (a) prior to redfin perch removal and (b) after redfin perch removal. Control sites: Para Wirra 2 (PW2), Para Wirra 3 (PW3), Quarry Track 1 (QT1) and Quarry Track 3 (QT3), respectively. Impact sites: Para Wirra 1 (PW1), Para Wirra 4 (PW4), Quarry Track 2 (QT2) and South Para Weir 3 (SPW3), respectively.

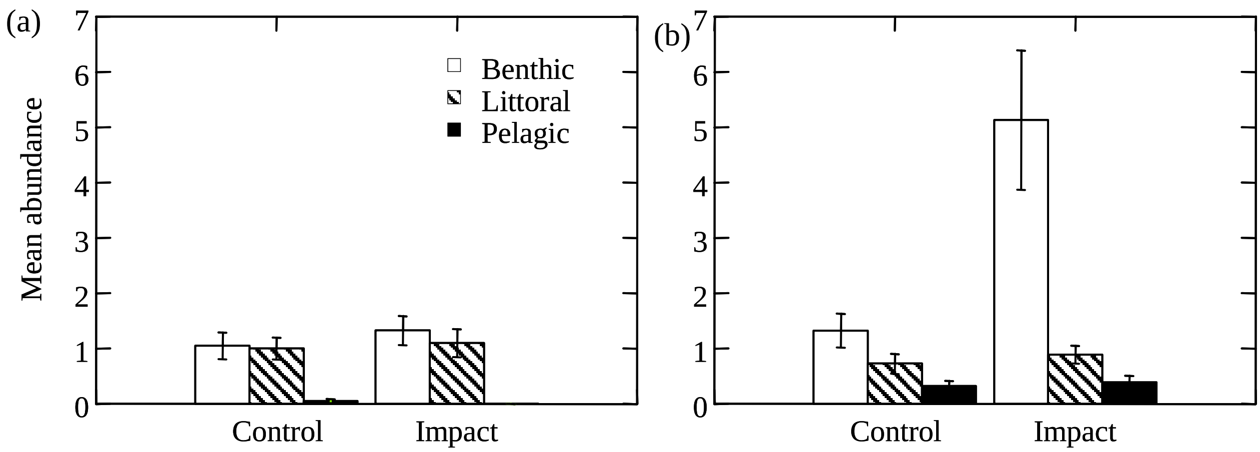

Fig. 11. Mean abundance (± SE) of gudgeons in each microhabitat of each treatment (a) prior to redfin perch removal and (b) after redfin perch removal. Note that data used was pooled for all control and impact sites on each trip and for each microhabitat.

Table 3. Results of ANOVA model testing for differences between impact and control treatements (impact term in table) before and after redfin perch removal (time) in different microhabitats.

Source of variation	df	MS	*F*	*P*
Impact	1	0.494	No test	No test
Time	1	0.651	5.715	0.054
Microhabitat	2	2.708	No test	No test
Impact*Time	1	0.290	2.541	0.162
Impact*Microhabitat	2	0.395	No test	No test
Time*Microhabitat	2	0.493	4.033	**0.046**
Impact*Time*Microhabitat	2	0.181	1.479	0.267
Pool (Impact)	6	0.489	4.292	0.050
Time*Pool (Impact)	6	0.114	2.747	**0.013**
Microhabitat*Pool (Impact)	12	0.193	1.582	0.219
Microhabitat*Time*Pool (Impact)	12	0.122	2.947	**0.001**
Error	406	0.041		

Significant results are in bold (P<0.05). Note that the data were log (x+1) transformed.

3.7 Flathead gudgeon size distribution in relation to microhabitat use

The length distribution of gudgeons in each microhabitat did not differ significantly between pools where redfin perch were present or where redfin perch were removed. Prior to redfin perch removal only two individual gudgeons were found in the pelagic area of control pools (Fig. 12a). Following the removal of redfin perch there was no difference between treatments in gudgeon distribution within the pelagic area, however a greater number of gudgeons (n = 21) were using this microhabitat across both treatments (Fig. 12b).

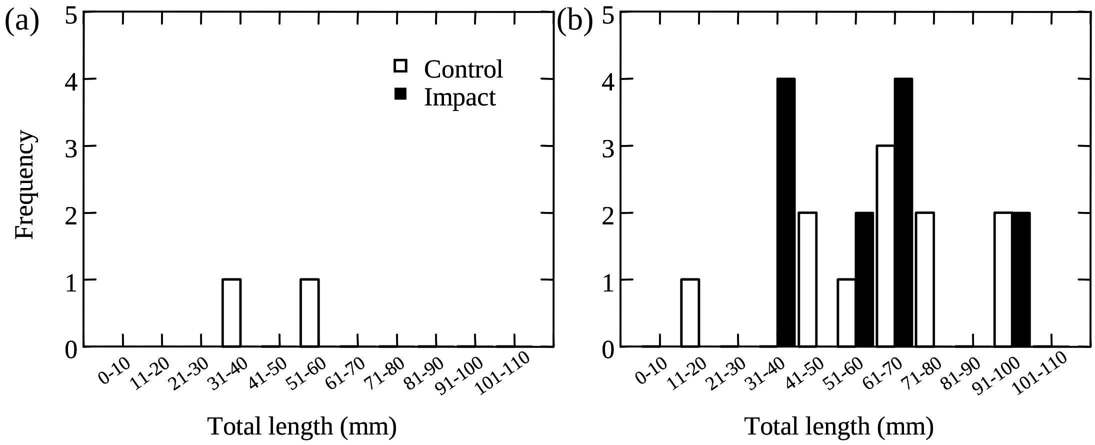

Fig. 12. Size frequency distribution of gudgeons using the pelagic area in control and impact pools (a) before redfin perch removal and (b) after redfin perch removal.

A comparison of the size distribution of gudgeons in the benthic area prior to redfin perch removal showed a significant difference between the control and impact treatments (K-S pairwise testing, D= 0.302, $P<0.05$) (Fig. 13a). A greater number of gudgeons in the 51-60 mm TL size class were using the benthic areas in the impact pools. No difference was found in the size distribution of gudgeons in the benthic areas following redfin perch removal, however the frequency of gudgeons using this microhabitat in the impact sites was much higher than control sites (Fig. 13b). No small gudgeons (<30mm TL) used the benthic areas both before and after perch removal in either control or impact treatment (Fig. 13a and 13b).

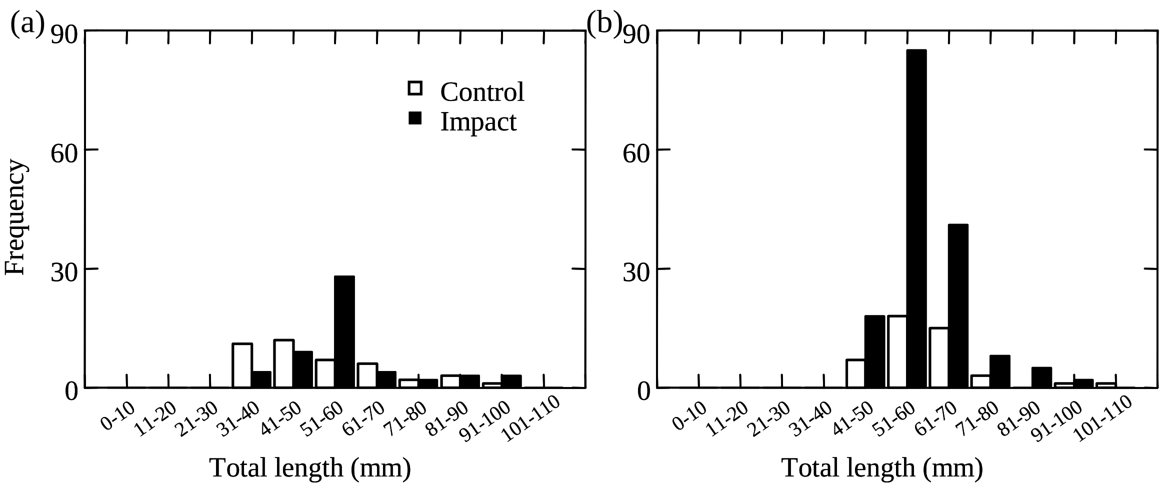

Fig. 13. Size frequency distribution of gudgeons using the benthic area in control and impact pools (a) before redfin perch removal and (b) after redfin perch removal.

The size distribution of gudgeons in the littoral area did not differ between control and impact pools prior to or after redfin perch removal (Fig. 14a). No small gudgeons (<30 mm TL) used the littoral zone in either control or impact treatment during the before trip, or in the control treatment after perch removal. New recruits (<21 mm TL) used the littoral area once redfin perch had been removed (Fig. 14b). Large gudgeons (>70 mm TL) used the littoral areas in the impact treatment before and after perch were removed (Fig. 14a). Even though redfin perch were not removed from the control pools, large gudgeons used littoral areas in these pools in the after trip (Fig. 14b).

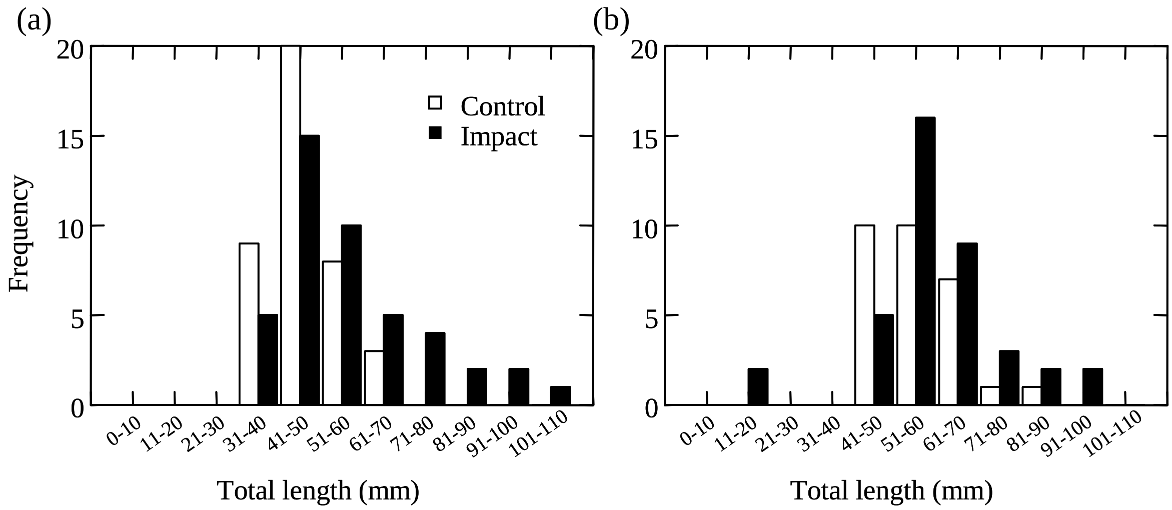

Fig. 14. Size frequency distribution of gudgeons using the littoral area in control and impact pools (a) before redfin perch removal and (b) after redfin perch removal.

A comparison of the size distribution of gudgeons in areas in each pool, before and after redfin perch removal, found no significant differences for six of the eight pools. Even though no significant differences were found for most pools, two pools, in which redfin perch were not removed, were significantly different between areas in the before and after sampling (Fig. 15). In one control pool (Para Wirra 3) smaller gudgeons (<61 mm TL) were using the littoral areas in the before sampling, however, by the second trip, all gudgeons using the littoral areas were above 50 mm TL (Fig. 15a). Similarly, the size distribution of gudgeons in the benthic zone in a control pool (Quarry Track 1) also differed between sampling times (Fig. 15b). Initially smaller gudgeons were using these areas, however, by the second trip benthic areas were mainly occupied by larger fish. No fish below 30 mm TL used the benthic area in either sampling time at this site. By the second sampling time, larger gudgeons were making greater use of the benthic areas (Fig. 13b).

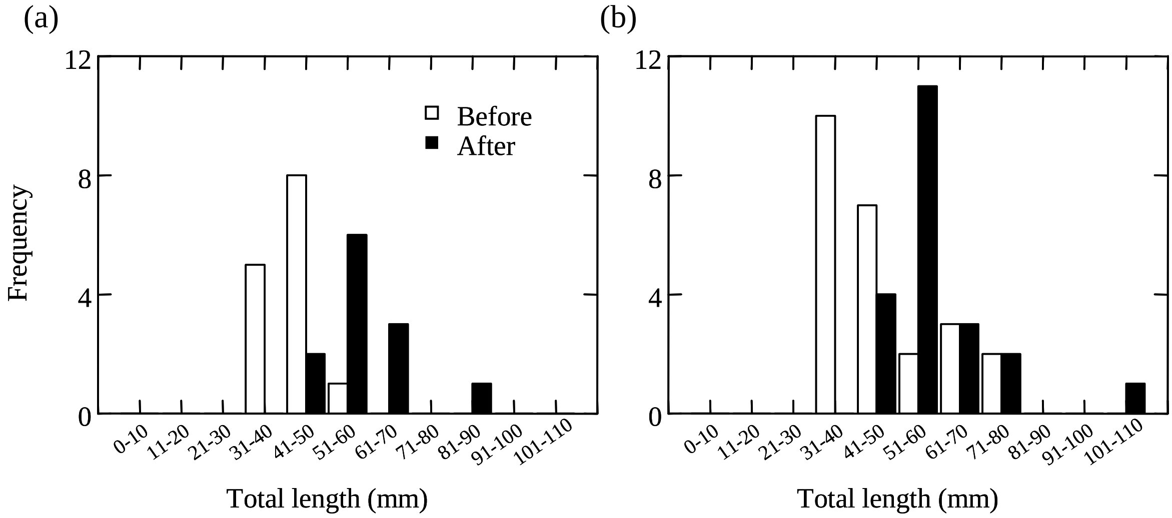

Fig. 15. Size frequency distribution of gudgeons using the littoral and benthic areas in control pools (a) Para Wirra 3 (P<0.005) and (b) Quarry Track 1 (P<0.005), both before and after redfin perch removal.

4. DISCUSSION

Dietary analysis of fish caught from the field sites revealed that redfin perch do consume flathead gudgeons and that there is a definite predator-prey relationship between the introduced predator and native prey fish. This was backed up by observations in the laboratory that redfin perch will chase and consume large numbers of gudgeons within test aquaria. Predation of juveniles and adults by introduced fish species has been identified as a potential threat to the flathead gudgeon in the southern part of its range (Pusey *et al.* 2004).

4.1 Broad scale patterns in the distribution and abundance of redfin perch and flathead gudgeons in the South Para River

The two species, however, were found to co-exist within all of the eight refuge pools sampled indicating that the predation pressure exerted by redfin perch is not sufficient to completely eradicate their sole prey fish species from these fairly small isolated habitats. Assessment of species abundances, however, revealed a strong negative relationship between redfin perch and gudgeon abundance (i.e. higher predator abundance was associated with lower prey abundances) suggesting a broad scale impact of redfin perch predation on gudgeon abundance.

In other systems, the introduction of a large piscivorous fish has been shown to completely remove prey species from the area leading to local, predator mediated extinctions (Hutchison 1991; McIntosh 2000; McDowall 2006). Prey species are however known to co-exist with redfin perch providing there is a sufficient diversity of prey items for the perch to eat (Pen and Potter 1992).

Indeed, dietary analysis revealed that gudgeons made up only a small percentage of the total food items found in the stomach contents of redfin perch suggesting that other desirable prey items are present in enough abundance to alleviate some of the predation pressure from the gudgeon population.

The gudgeon size frequency distribution showed the recruitment of smaller bodied individuals into the population as well as the survival of very large individuals that are important for sustained successful recruitment into the future. This indicates that gudgeon population in the South Para River is likely to be sustainable, despite the observed consumption of individuals by redfin perch. It is possible, however, that changes to the ecosystem balance, particularly those that might impact on alternative prey sources such as yabbies or other aquatic invertebrates, may increase the pressure for redfin perch to consume higher numbers of gudgeon prey.

4.2 Nature of predator-prey relationship

Prey size

The effects of predators on the population structure and abundance of prey species is often regulated and limited by the size of the prey (Paine 1976; Lappalainen *et al.* 2000; Dorner and Wagner 2003). Although laboratory based prey choice trials found no statistically significant differences between prey sizes consumed, there was a pattern for redfin perch to consume medium to larger prey items in the short term. It is likely that this pattern ($P<0.1$) could be statistically significant if more statistical power were incorporated into the experimental design. Alternative experimental approaches may also have strengthened such a pattern by increasing the regularity of observations (i.e. from 15 minute intervals to 5 minute intervals). Alternatively, if each prey item could have been replaced with an identically sized fish once eaten, preventing the predator from consuming sub-optimal prey items simply because it has depleted the preferred size class (Underwood *et al.* 2004), a scenario that is likely under the present experimental design, given the slightly increased consumption of smaller size classes after three hours compared to after 15 minutes.

This weak pattern gains some support from the dietary analysis that indicated a slightly higher proportion of larger sized individuals were represented in redfin perch stomachs than would be expected from the overall size-frequency distribution for the broader gudgeon population. Such a pattern, if found to be real, could be biologically significant, especially as it relates to ecological theories such as the 'optimal foraging model', which postulates that larger prey items should be taken to maximise net energy intake (Mittelbach 1981). Also, previous laboratory studies have found redfin perch to attack larger prey at a higher rate (Magnhagen 2006). Clearly, further experimentation needs to be done to establish the true nature of prey size selectivity for these species.

The primary prey of interest in many studies of large piscivorous fish are new recruits and previous studies have found larger predators to consume recruits despite being able to consume larger prey (Baxter *et al.* 1985; Connell 1998). There is, however, no evidence from the results to suggest that redfin perch target or impact smaller bodied gudgeon recruits. No gudgeon recruits (<30 mm TL) were found in the stomach contents of wild caught redfin perch, although they were consumed in the laboratory trials. At a local spatial scale, patterns of prey mortality within the field study pools indicate that gudgeon recruitment was not limited by redfin perch predation.

Previous studies have found redfin perch to be size-limited, with prey over 80 mm having a refuge from their predation largely due to the gape size of the predator (Wainwright 1988; Norton 1991; Tonn and Paszkowski 1992; Magnhagen 2006). Unfortunately, the size classes used during laboratory prey preference trials were unable to establish such an upper limit, although dietary analysis established that redfin perch in the wild consumed gudgeons over 90mm in length and even small perch (~80 mm TL) were able to consume medium sized gudgeons. These results suggest that redfin perch of the size found in the South Para are not restricted by gape size in relation to eating gudgeons, and that there is no upper 'size refuge' for gudgeons, as exists for a number of predator-prey relationships (Paine 1976).

Predator size

Age-specific differences in feeding are known to be ecologically significant and many species show observed differences in the size of prey eaten between young and intermediate year-classes (Polis 1984; Heibo and Magnhagen 2005). A number of studies have focussed on the relationship between redfin perch size and their predatory behaviours and prey selection. The timing of the onset of piscivory is very important in fish communities as it allows rapid growth so these fish can obtain a size advantage over their prey (Mittelbach and Persson 1998). Previous studies have found redfin perch to start feeding on fish at length of 140 mm (Griffiths 1976), with fish over 160 mm in length being predominantly piscivorous (Rezsu and Specziar 2006).

Dietary analysis revealed that redfin perch from the South Para River were incorporating gudgeon prey into their diet at much smaller sizes (below 80mm TL), supplementing a diet dominated by invertebrates. The gudgeon component of redfin perch diets increased with greater predator length as fish began to be more efficient predators (proportion of 'empty' fish being greatly reduced) over 80 mm TL. Above 160mm in length, redfin perch were far from exclusively piscivorous (as expected) with less than a quarter of their diet consisting of fish prey. At this size, cannibalism (Persson *et al.* 2000) also became evident with redfin perch over 160mm consuming a significant number of smaller redfin perch. Overall, redfin perch in the South Para River consumed fish at smaller sizes than recorded previously and became more effective piscivores as they grew, even consuming their own species at larger sizes.

An apparent positive relationship between redfin perch size and gudgeon prey size was not statistically significant (P=0.055), but indicated that such a pattern may be real with higher sample sizes. Although over a hundred fish were sampled for dietary analysis, only thirteen of these consumed gudgeon prey and were therefore used to analyse this pattern. Although redfin perch size was found to be important in determining the proportion of gudgeons consumed in relation to other prey items, this study provides little evidence that there is differential prey size selectivity across different sized redfin perch. Conversely, only large redfin perch (over 160mm) were found to consume smaller redfin perch.

4.3 Impacts of redfin perch on flathead gudgeon abundance

The experimental removal of redfin perch from refuge pools was not found to significantly influence the abundance of gudgeons within the South Para River over the sampling period, in a consistent manner. Assessment of gudgeon abundance after redfin perch were removed revealed a dramatic increase in abundance in both pools containing redfin perch and in those where redfin perch had been removed. This indicates that the abundance of populations of gudgeons in the South Para River is not regulated by the presence of redfin perch, despite direct evidence of consumption of this prey species.

The eradication of introduced species is seen as a key management tool in the recovery of native biological diversity as it has been known to result in an increase in prey fish abundance (Closs and Lake 1996; Lintermans 2000; Ludgate and Closs 2003; Genovesi 2005; Lepak *et al.* 2006). Previous studies have found redfin perch to be a major factor contributing to the loss or reductions of some populations of native fish (Morgan and Gill 2000; Morgan *et al.* 2002; Ludgate and Closs 2003; Molony *et al.* 2004). For example, native western pygmy perch, *Edelia vittate*, in south-Western Australia was believed to have been eliminated by redfin perch (Hutchison 1991). There is, however, no evidence from the results to suggest that redfin perch directly influence the abundance of gudgeons in the South Para River. Similarly, in other systems, introduced predators have been found to have no apparent effect on native prey species assemblages (Ross 1991; Simon and Townsend 2003).

The sampling season for the redfin perch removal experiment (summer 2006/07) unfortunately coincided with one of the worst droughts in Australia's history. As a result, refuge pools in the study reach were subject to extremely harsh climatic conditions (See Appendix A), resulting in the accelerated desiccation of study pools. A summary of water quality data collected during each sampling trip shows that water temperatures, salinity and dissolved oxygen levels all reach levels that can pose a threat to the survival of freshwater fish species (Koehn and O'Connor 1990; McNeil and Closs 2007). Although the impact of these factors was not assessed, it is likely that these harsh climatic conditions may have interfered with the predator prey interaction between these species that may occur under more benign environmental conditions, where biotic factors are more important in structuring fish communities (Matthews 1998).

Outcomes of the interactions between species have been found to substantially differ under different environmental circumstances (Hutchison 1991). The natural elimination of redfin perch from control pools was observed during the progressive drying of the pools and dead redfin perch were observed floating on several pools in the region as summer progressed. Redfin perch are known to be limited to cooler, non-saline streams (Morgan *et al.* 2002) and are known to be relatively intolerant of harsh summer conditions allowing relatively tolerant prey species, such as the native flathead gudgeon, to benefit from the exclusion of the predator from harsher habitats (Baxter *et al.* 1985; McNeil 2004; Closs *et al.* 2005, McNeil and Closs 2007). Conversely, native fish such as flathead gudgeons, tend to be adapted to or are known to recover faster from local disturbance regimes such as drought than introduced species (Gehrke *et al.* 1995; McIntosh 2000; Kennard *et al.* 2005).

These findings support the results of this study in that environmental instability aids in the co-existence of these two species by regulating redfin perch predation. It is possible, therefore, that if environmental conditions were less severe, redfin perch may negatively impact upon the abundance of gudgeons in this system. In rivers not subjected to periodic drying, redfin perch predation may be of greater importance in structuring fish communities and should be a focus for future research.

The observed increase in abundance of gudgeons in all pools following redfin perch removal (from treatment pools) was also likely to be due to extreme seasonal variation throughout the field sampling season (See Appendix A). As refuge pools shrank in size, subsequent catch rates are likely to increase due to the concentration of individuals in a decreasing volume of water.

This pattern also reflects a general trend for fish catch rates to become higher in summer (Ye *et al.* 2006) and may also reflect an increased efficiency in the effectiveness of passive sampling gear such as fyke nets (as used here) as ectothermic fish become more active under warmer water temperatures (McNeil 2004).

4.4 Impact of redfin perch on flathead gudgeon population structure

The size frequency distribution showed that the population structure (length frequency) of gudgeons was not influenced by the removal of redfin perch. For both redfin perch removal pools and for control pools, the data provided evidence of successful recruitment of smaller-bodied gudgeons into the population as well as the survival of larger individuals that are important for future recruitment success. This result is consistent with the failure to detect an impact of redfin perch presence on gudgeon abundance and results from the dietary analysis and prey preference trials that there was no prey size selectivity for redfin predation.

4.5 Impact of redfin perch on the abundance of flathead gudgeons within microhabitats of refuge pools

Native fish can be restricted to less preferred microhabitats in the presence of introduced piscivorous predators (Tonn and Paszkowski 1992; Persson and Eklov 1995; Brabrand 2001; Simon and Townsend 2003; Kahl and Radke 2006). Analysis of the abundance of gudgeons in refuge pools showed that the presence of redfin perch limited the microhabitat use of flathead gudgeons in this system. Later in the sampling season, significantly more gudgeons were found to be using benthic areas in pools where redfin had been removed. This effect was not found in control pools where redfin perch were still present, suggesting a specific impact of redfin perch on the microhabitat use of gudgeons.

Predation risk and habitat complexity have been found to be responsible for different fish responses to predators (Okun and Mehner 2005; Magnhagen 2006). Previous studies have found that redfin perch are mobile and visually orientated predators (Granqvist and Mattila 2004; Snickars *et al.* 2004), that are known to use benthic and pelagic zones, foraging in areas with low structural complexity (Persson and Eklov 1995; Mittelbach and Persson 1998; Borcherding *et al.* 2000; Persson *et al.* 2000; Schleuter and Eckmann 2006). Supporting these finding, flathead gudgeons shifted to using mainly benthic microhabitats following the eradication of redfin perch.

The greater proportion of gudgeons using benthic habitats following redfin perch removal may also be explained by changing foraging demands. Animals are known to spend the majority of their time foraging in richer habitat patches in the absence of direct predation (Werner *et al.*

1981), therefore the removal of predation pressure may explain the greater use of benthic areas by gudgeons, as these areas may have provided greater foraging returns. For large gudgeons, the foraging returns associated with feeding on prey in the benthos may be greater than that feeding on planktonic taxa in the water column. It is well known that fish prefer patches where they obtain the highest per capita food intake (Krause *et al.* 1998).

Progressive analysis of the abundance of gudgeons over the sampling season in different microhabitats revealed an increase in the number of gudgeons using the pelagic areas throughout all pools. As environmental conditions became harsher in the South Para, many differences were found in the abundance of gudgeons in most microhabitats of all pools. It is likely that these differences were largely due to shrinking pool volumes caused by the drying effect of the drought.

Prior to redfin perch removal, gudgeons primarily used littoral and benthic areas in all pools and avoided open habitats. Although redfin perch are known to occupy benthic areas (Schleuter and Eckmann 2006), these two microhabitats would have provided gudgeons with greater structural complexity, which is known to help prey to avoid encountering predators (Hambright 1994; Connell 2002; Willis and Anderson 2003; Snickars *et al.* 2004; Closs *et al.* 2005; Vainikka *et al.* 2005; Sass *et al.* 2006). A fundamental response of importance to prey is the ability of prey to recognize predatory threats and to seek refuge (Kristensen and Closs 2004). Laboratory prey preference trial tested to levels of substrate complexity to identify whether increased benthic refuges did in fact alter prey selection.

Although no significant results were found, the tendency for larger gudgeons to be eaten first over sandy substrates was greatly reduced with redfin perch consuming a more even spread of prey sizes. It is possible that the increase in complexity lead to better refuge use in larger fish, increasing the susceptibility of smaller, less experienced gudgeons, that may not use refuges as effectively. A large number of refuges were provided, which suggests that the pattern was not due to saturation of refuges by more dominant, larger gudgeons. The ability for native fish to utilise habitat complexity as refuges against predation, and the scales of complexity that influence predator prey interactions is worthy of further research as there is little knowledge as to how predators affect their prey when they are confined to sub-optimal habitats or are unable to forage in their structural refuge.

4.6 Impact of redfin perch on the population structure of flathead gudgeons across microhabitats within refuge pools.

Predator avoidance by means of structural complexity and a broad variety of food is often characteristic of littoral zones (Kahl and Radke 2006). New gudgeon recruits, however, were found to use the littoral zone in predator free environments following the removal of redfin perch, whilst they were found to use the pelagic zone in control pools where redfin perch remained. This result was unexpected as the foraging efficiency of highly visual redfin perch has been suggested to be stronger in lighter pelagic habitats (Stoffels and Humphries 2003). The low numbers of recruits observed in the present study disallow a powerful analysis of this pattern, which could be assessed through more dedicated research on the behaviour and habitat use associated with gudgeon recruitment.

Although there initially appeared to be differences between the size distributions of gudgeons using the benthic microhabitats within all eight pools, this disappeared after redfin perch were removed. However, size frequency distributions of gudgeons using benthic areas revealed that no small gudgeons were found to occupy this microhabitat over the entire sampling period. The size at which gudgeons appeared to switch to using the benthic habitat was between 41–50 mm TL.

Size dependant shifts in microhabitat use were identified for flathead gudgeon in the present study. Large gudgeons appeared to have quite a broad distribution, but were found mainly in the benthic areas, whereas smaller gudgeons (<40mm TL) were only found in the pelagic and littoral areas. Australian carp gudgeons (*Hypseleotris spp*.) have also been found to become increasingly benthic with age, suggesting that ontogenetic habitat shifts in isolated refuge pools may be similar between these species and across habitat types (montane versus floodplain pools) (Stoffels and Humphries 2003; Closs *et al.* 2005). The restriction of medium-small sized gudgeons to pelagic and littoral areas is likely to lead to overlap in diet and habitat use with the introduced mosquitofish (*Gambusia holbrooki*) (Stoffels and Humphries 2003). This is likely to have implications for young flathead gudgeon recruits if mosquitofish, which are present just downstream of the study site in the South Para, are able to invade the reach. These patterns of population structure of gudgeons across the three microhabitats were not, however, influenced by redfin perch within refuge pools of the South Para River.

5. CONCLUSION

This study suggest that the introduced redfin perch had little noticeable impact on native gudgeon abundance, population structure and microhabitat use within isolated pools of the South Para River, even though it provided direct evidence of a strong predator prey relationship between these species. This predatory impact was alleviated by a diverse redfin perch diet that depended predominantly on invertebrate prey items, suggesting that redfin perch predation is unlikely to severely threaten the long-term sustainability of the gudgeon population in the river unless alternative food sources become scarce. This emphasises the need to protect the ecosystem integrity of the reach to maintain invertebrate populations and protect the sole native fish species present.

It also revealed that the predator prey relationship between redfin perch and flathead gudgeons is complex and is likely to be heavily influenced by the harsh climatic variability present within ephemeral systems such as the South Para River. This variability is likely to contribute to the successful co-existence of the two species. However, in systems with low environmental variability, such as permanent regulated rivers, redfin perch might be expected to more severely impact on the populations of flathead gudgeons and other native prey species. Structurally and environmentally complex habitats such as the isolated pools of the SPR are likely to aid in the co-existence of these two species.

From a management perspective, efforts to physically control the abundance of introduced redfin perch may not have a significant benefit for the sustainability of the local gudgeon population. It does suggest, however, that control efforts will be more effective during dry summers where environmental conditions greatly reduce the abundance and distribution of redfin perch along the reach.

5.1. General summary and implications for environmental water allocations in the Mount Lofty Ranges:

This project has concluded that, despite the widespread distribution of redfin perch attributed to the November 2005 flood, there was no observed extinction of native gudgeons attributable to the predator during the summer of 2006/07. Even in shrinking and isolated pools, where space and opportunities for hiding from predators was greatly reduced, flathead gudgeon populations remained viable with at least some level of recruitment and the survival of large fecund individuals. This was attributed predominantly to the large contribution that invertebrate prey items made to the redfin perch diet, relative to prey fish. This suggests that areas with sound habitat such as the South Para Gorge, that are able to support a healthy and diverse aquatic fauna, are likely to provide enough dietary opportunities to relieve pressure on native prey fish. This re-establishes the strong need to provide adequate and appropriate flow regimes to these areas of high habitat value so as to maintain this biotic diversity. The destabilisation of the stream processes that support healthy invertebrate populations could lead to increased predation pressure on native fish.

The study also gave a clear insight into the highly variable nature of the South Para River and the manner in which flow variability interacts strongly with biological processes to influence trophic processes such as predator prey interactions. Specifically, the extreme drying conditions experienced in the South Para Gorge during 2006/07 were severe enough to eliminate large bodied redfin perch from many of the remnant waterholes. Furthermore, flathead gudgeons were able to survive these harsh conditions up until pools became totally desiccated. The superiority for flathead gudgeons to tolerate harsh summer conditions to a much greater degree than their introduced predator redfin perch has been observed under laboratory conditions and across floodplain pools in the Murray-Darling basin (McNeil 2004, McNeil and Closs 2007).

This finding shows the importance of the extreme low flow component of the hydrograph in protecting native prey species from less tolerant predators providing 'predatory refuges' within remnant stream pools. Just as the large flood caused disturbance through the distribution of the predator, the drought period provided a release from that same disturbance through physico-chemical preclusion of the predator.

In the 2006/07 season, this harsh drying period was characteristic of the natural flow patterns that would have occurred regardless of the large upstream storage as little rain fell anywhere in the catchment. During wetter years, however, this natural desiccation would not occur and therefore reasonable summer flows may be required in some (wetter) years to benefit native fish populations, especially in periods following the removal of redfin perch.

The research highlights a key issue related to the proposed provision of summer baseline flows designed to maintain water quality during hot summer periods in refuge pools (Pikusa and Bald 2005). The provision of refreshing flows may serve to maintain redfin perch populations that would normally be controlled through the natural seasonal drought process. As a result, summer baseline flows would need to be timed in line with up to date knowledge of the state of the refuge pool populations and should follow observed natural fish kills of redfin perch (as were observed in 2006/07).

Reinstatement of some baseline flows, however, following the natural removal of redfin, may enable native fish to 'blossom' following the removal of the predator. Manipulating summer flows for the specific control of redfin perch or other predatory fish has not been tried, however, the current research suggests that there may be an opportunity for experimentation on this subject in the South Para River.

5.2. Related research: suggested areas for further study

- The impacts of redfin perch on other native fish species and prey preference trials to determine on which species predation pressure is likely to be heaviest. This is likely to be important if management actions return more vulnerable native species to high predation areas.

- The impacts of other introduced predators such as brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) on native fish in the Mount Lofty Ranges. This should be investigated for a range of native fish, especially the Galaxiids.

- The impacts of introduced mosquitofish (*Gambusia holbrooki*) on native fish, trophic processes and predator prey interactions. Mosquitofish populations boom and bust in the South Para River and at their peak they dominate the fish assemblage. Summer base flow may provide low flow access for mosquitofish upstream into areas that they are currently absent, probably due to the high flow velocities that occur in the South Para gorge.

- The impacts of managed summer base flow on introduced predator survival. This may also be informed from the long-term sampling under the MLR fish sustainability project.

- Invertebrate assemblage and temporal/successional changes in invertebrate population structure in the South Para River. Knowledge of the invertebrate community will assist in the correct management of flows to maintain prey variety for introduced predators.

- Fish assemblage in adjacent and tributary streams: potential for new species in the South Para Gorge. Flow management and the removal of barriers such as the Gawler and Para woodlands weirs, will introduce new species to the reach. This is especially relevant for the three Galaxiids that would most likely move into the reach from tributary or downstream populations under improved flow conditions (Or if the friends of the Gawler keep moving them). A short study to asses the distribution of fish in tributary streams, as well as the North Para and Gawler rivers will provide information on which native and pest fish are likely to invade or re-establish under different management scenarios.

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8. APPENDIX A

8.1 Water quality parameters in all pools over the sampling period

The pH of the water became more acidic in all pools as they began to dry in the summer months. Similarly, salinity increased in all pools due to the drying effect. Temperature varied within and between all pools and was highly dependant on the time of the day and air temperature. Dissolved oxygen also varied between pools and times, however, it became noticeably low in control and impact sites, Para Wirra 2 and Para Wirra 1, respectively, due to the complete drying of these locations (Table 4).

Table 4. Mean and SE of water quality parameter for each location over November, December and January.

Sampling time	pH	Temperature (°C)	Conductivity (micro-Siemens)	DO (mg/L)
Control 1 (Para Wirra 2)				
November	**8.52 ± 0.04** (n = 3)	**22.23 ± 0.77** (n = 3)	**2.43 ± 0.12** (n = 3)	**6.73 ± 1.67** (n = 3)
December	**7.75 ± 0.11** (n = 4)	**23.25 ± 0.83** (n = 4)	**3.11 ± 0.06** (n = 4)	**4.05 ± 0.91** (n = 4)
January	**7.57 ± 0.28** (n = 2)	**17.25 ± 0.05** (n = 2)	**5.65 ± 0.82** (n = 2)	**0.68 ± 0.27** (n = 2)
Control 2 (Para Wirra 3)				
November	**8.67 ± 0.13** (n = 7)	**21.77 ± 0.15** (n = 7)	**2.34 ± 0.05** (n = 7)	**7.28 ± 0.37** (n = 7)
December	**8.17 ± 0.09** (n = 3)	**25.07 ± 0.50** (n = 3)	**2.45 ± 0.05** (n = 3)	**6.63 ± 0.13** (n = 3)
January	**8.09 ± 0.03** (n = 2)	**19.20 ± 0.1** (n = 2)	**3.24 ± 0.005** (n = 2)	**5.30 ± 0.20** (n = 2)
Control 3 (Quarry Track 1)				
November	**8.40 ± 0.14** (n= 4)	**21.18 ± 0.37** (n = 4)	**4.25 ± 0.28** (n = 4)	**5.77 ± 0.66** (n = 4)
December	**8.16 ± 0.02** (n = 2)	**22.6 ± 0.20** (n = 2)	**4.75 ± 0.32** (n = 2)	**5.65 ± 0.50** (n = 2)
January	**8.07 ± 0.04** (n = 2)	**20.9 ± 0.70** (n = 2)	**5.20 ± 0.31** (n = 2)	**7.55 ± 2.53** (n = 2)
Control 4 (Quarry Track 3)				
November	**8.46 ± 0.08** (n = 4)	**23.28 ± 0.98** (n = 4)	**4.01 ± 0.16** (n = 4)	**6.79 ± 0.51** (n = 4)
December	**8.09 ± 0.03** (n = 3)	**22.87 ± 0.50** (n = 3)	**4.63 ± 0.07** (n = 3)	**5.57 ± 0.09** (n = 3)
January	**8.02 ± 0.12** (n = 3)	**22.53 ± 0.44** (n = 3)	**6.59 ± 0.17** (n = 3)	**4.08 ± 0.14** (n = 3)
Impact 1 (Para Wirra 1)				
November	**8.24 ± 0.04** (n = 7)	**21.79 ± 1.06** (n = 7)	**2.53 ± 0.23** (n = 7)	**7.24 ± 0.63** (n = 7)
December	**7.32 ± 0.08** (n = 2)	**23.75 ± 1.75** (n = 2)	**3.86 ± 0.37** (n = 2)	**3.18 ± 1.22** (n = 2)
January	**7.00 ± 0** (n = 1)	**19.80 ± 0** (n = 1)	**6.92 ± 0** (n = 1)	**0.57 ± 0** (n = 1)
Impact 2 (Para Wirra 4)				
November	**8.18 ± 0.08** (n = 11)	**19.50 ± 0.67** (n = 11)	**2.18 ± 0.07** (n = 11)	**6.47 ± 0.58** (n = 11)
December	**8.05 ± 0.003** (n = 3)	**25.57 ± 0.18** (n = 3)	**2.44 ± 0.02** (n = 3)	**7.09 ± 0.23** (n = 3)
January	**8.14 ± 0.07** (n = 2)	**19.40 ± 0.3** (n = 2)	**3.04 ± 0.01** (n = 2)	**5.76 ± 0.31** (n = 2)
Impact 3 (Quarry Track 2)				
November	**8.34 ± 0.04** (n = 7)	**16.81 ± 0.89** (n = 7)	**3.60 ± 0.27** (n = 7)	**6.30 ± 0.68** (n = 7)
December	**8.07 ± 0.02** (n = 8)	**22.04 ± 0.56** (n = 8)	**4.79 ± 0.03** (n = 8)	**5.46 ± 0.23** (n = 8)
January	**7.96 ± 0.32** (n = 2)	**21.40 ± 0.6** (n = 2)	**4.96 ± 0.005** (n = 2)	**5.18 ± 0.015** (n = 2)
Impact 4 (South Para Weir 3)				
November	**8.47 ± 0.33** (n = 5)	**23.48 ± 1.91** (n = 5)	**0.85 ± 0.06** (n = 5)	**8.75 ± 1.03** (n = 5)
December	**6.57 ± 0.27** (n = 2)	**18.25 ± 0.05** (n = 2)	**1.28 ± 0.006** (n = 2)	**4.55 ± 0.15** (n = 2)
January	**7.97 ± 0.14** (n = 2)	**18.90 ± 0.20** (n = 2)	**1.85 ± 0.13** (n = 2)	**2.17 ± 0.16** (n = 2)

9. APPENDIX B

Map of the South Para River study sites showing experimental pools used for the field study.