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Mitigation of the negative impacts on biodiversity and fisheries values of the refurbishment of Waroona Dam, south-western Australia

Final report for the Water Corporation of Western Australia

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Executive summary

Brett Molony and Stephen Beatty

Prior to the commencement of the refurbishment of Waroona Dam by the Water Corporation of Western Australia, a management plan to mitigate the negative effects of draining on the biodiversity and recreational fishing values within Lake Navarino (the reservoir created by Waroona Dam) was instigated. The plan, the first of its kind in Australia, was devised and implemented by collaboration between the Water Corporation, the Department of Fisheries, Murdoch University, Alcoa and volunteers to meet the following objectives;

1. De-stock Lake Navarino of large numbers of target species of aquatic fauna prior to draining (marron - *Cherax tenuimanus*, gilgie - *Cherax quinquecarinatus*, western minnow - *Galaxias occidentalis*, western pygmy perch - *Edelia vittata*, rainbow trout - *Oncorhynchus mykiss* and brown trout - *Salmo trutta*);
2. Establish breeding populations of marron, gilgies and endemic fishes in secure, purpose built facilities at the Pemberton Freshwater Research Centre (PFRC – Department of Fisheries) and Alcoa's Willowdale marron farm (AWF) to produce animals for re-stocking into Lake Navarino following the completion of the refurbishment works;
3. Transport aquatic animals surplus to breeding requirements and trout to adjacent waters to boost recreational fishing opportunities;
4. Control feral species, principally redfin perch (*Perca fluviatilis*), within the residual coffer dams during refurbishment of Waroona Dam;
5. Install appropriate artificial habitats within the basin of Lake Navarino; and
6. Re-stock Lake Navarino with the ex-broodstock and progeny of marron, gilgies and native fishes, and eventually rainbow trout.

The de-stocking of Lake Navarino was successful in providing adequate numbers of three species to establish breeding populations. As considerable numbers of targeted aquatic animals were removed prior to drainage, the scale of post-drain faunal mortality was reduced. The success of the de-stocking program was the direct result of the valuable participation of volunteers that facilitated a large amount of de-stocking effort in a short period of time. The high level of volunteer involvement highlights the community's interest and support for such integrated natural resource projects.

Overall, the captive breeding programs performed better than expected. At the PFRC, high berry-up (i.e. spawning) rates of marron, high production of juveniles, and high survival rates of juveniles and adults were reported. This is the first demonstrated re-use of marron broodstock, likely a result of proven, intensive husbandry practices. Further, the project involved utilising very large nursery ponds for the mass production of juveniles to an advanced stage. The use of existing ponds at AWF was largely aimed at providing a secure, cost-effective back-up facility at which considerable numbers of all target species could be maintained throughout the project as part of risk minimisation. That is, should an unforeseen catastrophic loss of stock have occurred (e.g. outbreak of disease) at the purpose-built PFRC ponds, considerable numbers of Lake Navarino brood-stock and juveniles would still be available to re-stock the reservoir from an alternate facility.

The control of feral aquatic animals involved netting, draining and concussive (blasting) methods. The control techniques reduced the number of redfin perch by over 99%; however, 100% elimination was not achieved. This was likely due to small numbers of redfin perch avoiding the techniques employed (for example in the tributaries of Lake Navarino) or the larger than predicted coffer dams (residual pools maintained during the refurbishment of the Lake Navarino basin) reducing the effectiveness of those techniques. Nonetheless, the considerable reduction in the numbers of redfin perch, a major predator of juvenile marron and native fish, limited the predatory impact of this species on the captively-bred, newly stocked marron thus aiding their re-establishment in Lake Navarino.

The addition of artificial aquatic habitat will also increase the survival rate of stocked marron. Along with the large extension of rock habitat on the inside of the refurbished wall of Waroona Dam as part of the refurbishment, five lines of rocks of approximately 30-100 metres in length were established in Lake Navarino. The rocks formed a large number of irregularly sized holes and crevasses suitable for marron and other aquatic species. The artificial habitats were also placed away from major ski-areas and were well below the minimum water depth required for skiing. The design and placement of the habitats achieved the objective of increasing aquatic habitat while meeting Water Corporation's engineering requirements and not compromising other recreational values of Lake Navarino.

Over 63,000 aquatic animals were re-stocked into Lake Navarino (the majority being marron during 2004) and far exceeded the predicted numbers to be re-stocked at the commencement of the project. The captively bred marron and gilgies ranged in both size and age and the captive breeding programs were designed to maintain as wide a genetic variation as possible, a major difference to the breeding approaches adopted for commercial aquaculture. This breeding aim was necessary in order to produce stocks of aquatic species with similar levels of genetic variation that were present in those populations prior to the project. Further, the reintroduction of multiple age classes (i.e. the offspring from two captive breeding events in 2002, 2003 and the original broodstock) aimed to re-establish populations similar to those present before the refurbishment of the dam commenced. The program will allow legal sized marron to be present in Lake Navarino when the first post-project marron season opens (i.e. in January 2005). Although western minnows did not breed in captivity, close monitoring revealed its continued presence in the major tributary, Drakes Brook (highlighting its importance), and thus this species would have not have been completely eliminated by the draining event. High survival of the broodstock in captivity allowed restocking of a considerable proportion of those de-stocked, with the remainder with-held for further breeding attempts.

Overall, this unique project was extremely successful in mitigating the negative effects of draining for the refurbishment of a large sized irrigation dam on recreational fishing and biodiversity values. The success of the project was achieved via the participation of a diverse range of organisations their staff, and volunteers at all stages of the project. Although successful, a range of lessons were learned and a flow-chart of suggested management actions is included in this report to allow the Water Corporation, or other similar natural resource managers, to apply these techniques to other similar projects in the future. The long-term effectiveness of the current project will also be assessed via ongoing monitoring of the endemic species in Lake Navarino, in particular by using marron as the major indicator species.

1. General introduction and background

Brett Molony and Stephen Beatty

In addition to the supply of water for agriculture, irrigation dams of south-western Australia are important systems for recreational activities, including fishing (Molony & Bird 2002, Molony et al. 2002a). Lake Navarino (the reservoir created by Waroona Dam[1], figures 1 and 2, approx. 115° 55 E 32° 51 S) is the first major public access reservoir south of the Perth Metropolitan Area and is an important component of the Recreational Marron (*Cherax tenuimanus*[2]) Fishery (RMF) (Molony 2001a, 2002a, 2003a, Molony & Bird 2002, Beatty et al. 2003a). Further, it is the most northerly irrigation dam that is regularly stocked with rainbow trout (*Oncorhynchus mykiss*) produced at the Department of Fisheries' Pemberton Freshwater Research Centre (PFRC) to support its recreational freshwater fishery (Molony 2001b, 2002b, 2003b, Molony *in press*). As such, Lake Navarino is strategically important to these two licensed fisheries. Together, these two fisheries generate approximately $400,000 per annum in license revenue state-wide (Molony 2001a, b, 2002a, b, 2003a, b, Molony et al. 2002a) that is directed into the research and management of recreational fisheries. Further, the recreational fisheries in Lake Navarino generate income to the nearby regional centre of Waroona.

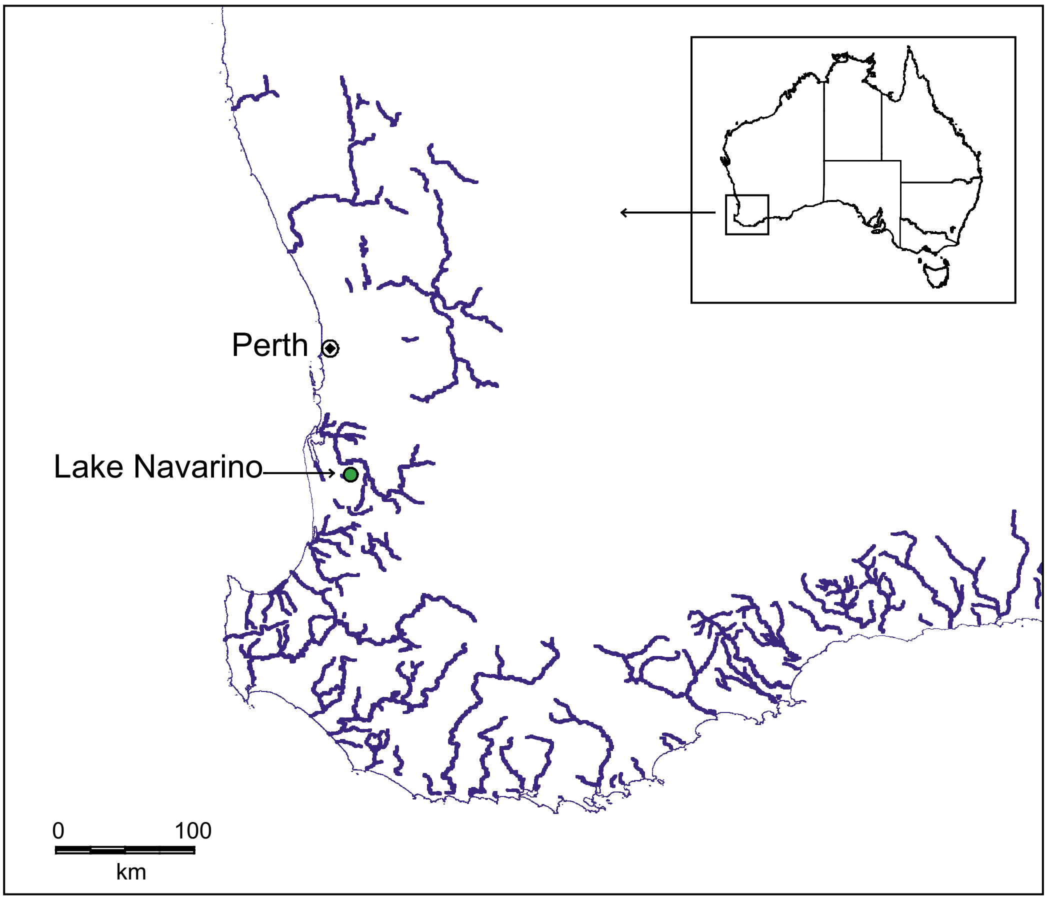


Figure 1. The location of Lake Navarino (Waroona Dam) in south-western Australia.

[1] *In this report 'Waroona Dam' has been used to refer to the physical dam wall or the wall plus Lake Navarino which was greatly expanded by the construction of the wall. 'Lake Navarino' is used to indicate the lake excluding the feeder streams.*
[2] *The nomenclature of marron is currently under review by the International Commission of Zoological Nomenclature (ICZN), case number 3267.*

Lake Navarino has not been completely filled since 1997 due to concerns with the upper sections of the dam wall (M. Rhodes, Water Corporation, pers. comm.). In 2002, the Water Corporation of Western Australia planned to repair and reinforce Waroona Dam and undertake other maintenance and refurbishment works within the basin of Lake Navarino. As a result, Lake Navarino was to be almost totally drained for at least nine months to allow the works to be undertaken. The draining of Lake Navarino would immediately remove a strategically significant component of both the RMF (Molony 2001a, 2002a, 2003a, Beatty et al. 2003a) and the south-west freshwater angling fishery (SWFAF) (Molony 2001b, 2002b, 2003b). Further, the extended period of draining of Lake Navarino was predicted to seriously impact populations of endemic crustaceans and fishes, including marron. Natural recovery of aquatic populations following such an event has rarely been studied but was likely to have been slow due to several reasons. Firstly, natural recruitment into Lake Navarino from downstream was highly unlikely due to the height of the refurbished wall (approximately 50 m). Secondly, two perennial tributaries that flow into Lake Navarino are also small, and were known to contain relatively small populations of marron and another endemic crayfish the gilgie (*Cherax quinquecarinatus*). Thirdly, the reproductive biology of marron (age at first maturity of approximately 2 years, brooders with low fecundity (Beatty 2000, Beatty et al. 2003b) and gilgies (Beatty et al. *in press*) was expected to result in a slow natural re-establishment of stocks. Given the size of Lake Navarino (~150 ha), the recovery of the recreational marron fishery would have taken many years. Finally, populations of the two endemic fishes in Lake Navarino and the two tributaries, the western minnow (*Galaxias occidentalis*) and western pygmy perch (*Edelia vittata*) were known to be relatively small (Beatty pers. obs.) and should the draining have greatly reduced their numbers, particularly in the tributaries (where greatest abundances were known to exist), the degree and rate of natural recovery of populations was unknown. Therefore, the refurbishment works posed an eminent risk to stocks of key species within Lake Navarino, particularly to the recreational marron fishery.

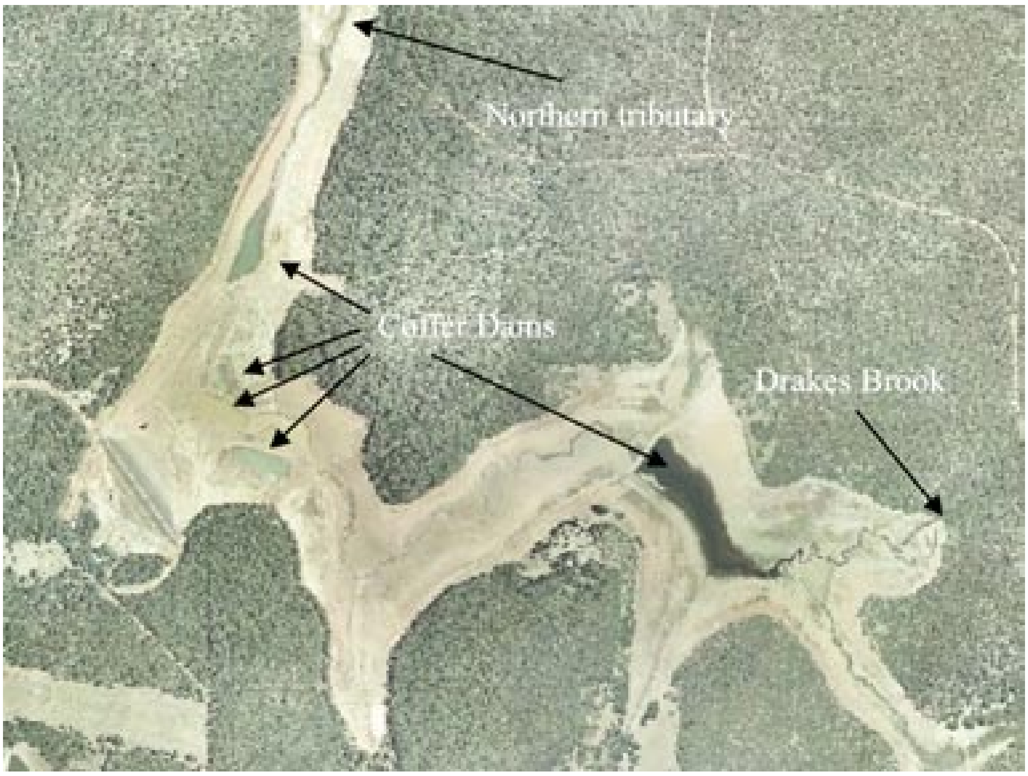


Figure 2. Aerial shot of the drained basin of Lake Navarino in Autumn 2003, showing location of the substantial coffer dams present and the two perennial tributaries.

Negotiations amongst the Department of Fisheries, Murdoch University and Water Corporation were undertaken in 2001 and an action plan to reduce the impacts of dam draining on the aquatic species within Lake Navarino was developed that would be compatible with the refurbishment works. The objectives of the plan were to;

- De-stock Lake Navarino of large numbers of target species of aquatic fauna prior to draining. The target species were the marron, gilgie, western minnow, western pygmy perch, rainbow trout and brown trout (*Salmo trutta*);
- Transport marron to purpose built ponds at the PFRC, gilgies and native fishes to culture facilities at Murdoch University and marron and native fishes to Alcoa's Willowdale marron farm, and establish and maintain breeding populations for re-stocking of Lake Navarino after the completion of the refurbishment works;
- Transport aquatic animals, surplus to breeding requirements, to adjacent waters open to recreational fishing;
- Control feral species within the residual coffer dams during refurbishment of Waroona Dam. The major species targeted for control was the redfin perch (*Perca fluviatilis*). However, if other feral species (e.g. yabby *Cherax destructor*) were identified in Lake Navarino, attempts would also be made to eliminate them;
- Install appropriate artificial habitats within the basin of Lake Navarino in an attempt to enhance marron and native fish stocks by providing refugia in the otherwise barren basin; and
- Re-stock the refurbished dam with marron, gilgies and native fishes, and eventually rainbow trout.

A management plan to mitigate the impacts of dam refurbishment for recreational fishing and biodiversity values of this scale has not been undertaken before on a reservoir of this size in Australia (Beatty et al. 2003a), although similar projects on smaller dams have been planned (Beatty et al. 2003c, Molony 2003c, Molony et al. 2003b) or undertaken (Beatty et al. 2003d). Therefore, an overall objective was to critically assess the effectiveness of the aquatic faunal strategies employed in Lake Navarino.

2. De-stocking Waroona Dam

Brett Molony, Stephen Beatty and Chris Bird

2.1 Introduction

The draining of a large reservoir created by a dam has major implications for aquatic fauna both within the reservoir and downstream of the dam wall. Aquatic fauna within the reservoir will either be flushed through the outlet to the downstream watercourse, be trapped within the drying basin or possibly move upstream into tributaries should they be present and accessible. While some aquatic species may be able to survive a transit from the reservoir through the outlet to the water course below the wall, it is possible that water quality below the dam will decline rapidly due to high sediment loads, turbidity and subsequent declines in dissolved oxygen levels. Besides the chronic effects, surviving animals would be concentred into downstream systems (in this instance the lower Drakes Brook and the much smaller Drakesbrook Dam) that already have large resident populations of marron, redfin perch and some trout. The introduction of large numbers of these species may result in the downstream environments exceeding their carrying capacity of these organisms and adversely affect the structure and function of these aquatic ecosystems.

Alternatively, aquatic animals within Lake Navarino may avoid the outlet and remain within the basin. However, residual water would also be expected to have lower dissolved oxygen levels, due to: high turbidity via resuspended sediments caused by water movement; increased temperatures due to the shallow nature of the residual water bodies (the final stage of draining of Lake Navarino was planned in April 2002, a period when the maximum air temperature was relatively high, i.e. >35°C); and high densities of animals. Therefore, water quality may deteriorate to the point that the survival thresholds of most residing aquatic species (table 1) are exceeded. Whether animals passed downstream through the outlet into lower Drakes Brook or remained in the draining basin of Lake Navarino, there was a high risk of large scale mortalities.

A major objective of the current project was to reduce the risks of mass mortalities of aquatic animals as a result of the draining of Lake Navarino and therefore collection of endemic crayfishes and finfishes was undertaken prior to draining. Endemic aquatic species residing in Lake Navarino and its feeder creeks have been isolated from downstream populations for at least 36 years by the Waroona Dam wall (completed 1966) and from those in other south-western catchments for much longer. Thus, the genetic makeup of animals within this catchment is likely to be different from other populations of endemic species, as suggested by the genetic studies on marron (Austin and Knott 1996, Imgrund 1997, Austin and Ryan 2002, Nguyen et al. 2002). It was therefore important to use animals sourced from Lake Navarino to breed and re-stock this waterbody (within which Lake Navarino is found). Furthermore, being able to catch adequate numbers of wild stock from within the Harvey catchment (Appendix 4) would have been extremely time consuming and would be undesirable in terms of impacting on the recreational fishery in other parts of the catchment. As such, the second objective of the overall project was to collect broodstock of endemic species, and maintain and breed these animals in specialised, secure facilities, to subsequently re-stock into Lake Navarino after refurbishment and re-filling was complete. Specifically, the objectives of this component of the study were to;

1. Collect marron, gilgies and native fishes from Lake Navarino; use these animals as broodstock at the PFRC, AWF and Murdoch University; and re-stock the broodstock and progeny into Lake Navarino once re-filled.
2. Collect animals additional to Objective 1, and release them in locations beyond the potential effects of the draining process within the Harvey catchment.
3. Euthanase feral animals, particularly redfin perch, incidentally collected during the de-stocking process.

Table 1. Summary of the known physiological requirements of endemic fishes and crayfishes expected to be present in Waroona Dam (modified from Molony 2001c, 2003c).

Species	Parameter	Tolerance Range (Preferred Level)	Notes	Source
western minnow (*Galaxiais occidentalis*)	pH	4.4 – 7.6	Field data	Christensen 1982
	Salinity	< 3620 $mg.l^{-1}$	Field data	Christensen 1982
western pygmy perch (*Edelia vittata*)	pH	4.2-8.4	Field data	Christensen 1982
	Salinity	< 5672 $mg.l^{-1}$	Field data	Christensen 1982
	Temperature	1.7 – 32.2 °C	Field data	Christensen 1982
nightfish (*Bostockia porosa*)	pH	3.9-7.6 (6.05)	Field data	Christensen 1982
	Salinity	< 4992 $mg.l^{-1}$	Field data	Christensen 1982
freshwater cobbler (*Tandanus bostocki*)	Temperature	(23-24 °C)	Field data	Hutchison 1991
marron *(Cherax tenuimanus*)	Temperature	12 – 25 °C 15 – 30 °C 10 – 30 °C (24 °C)	Field data Field data Laboratory trials	Beatty 2000 Morrissy 1974 Morrissy 1990 Lawrence and Jones 2002.
	Salinity	0-17000 $mg.l^{-1}$ (6,000 – 8,000 $mg.l^{-1}$)	Laboratory trial for upper lethal limit	Morrissy 1978 Morrissy 1990, Lawrence and Jones 2002
	Dissolved Oxygen	5.0 - 6.0 $mg.l^{-1}$ > 6.0 $mg.l^{-1}$	Laboratory trial Pond trial	Morrissy et al. 1984 Lawrence and Jones 2002
	pH	6.0-9.0	Pond trial	Lawrence and Jones 2002
gilgies (*Cherax quinquecarinatus*)	Slightly higher tolerance of extremes of temperature and hypoxic conditions than marron		Field observations	Beatty pers. comm.
rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*)	Temperature	>26.5 °C	Field data and laboratory trials	See Molony 2001c
	Salinity	0-30 $^o/_{oo}$	Field data and laboratory trials	See Molony 2001c
	pH	6.0-9.0	Field data and laboratory trials	See Molony 2001c
	Dissolved Oxygen	7.0 $mg.L^{-1}$	Field data and laboratory trials	See Molony 2001c

2.2 Methods

Three techniques were adopted to remove aquatic fauna from Lake Navarino; draining, netting and targeted de-stocking. The process of draining Lake Navarino was expected to be the major cause of mortality. All water from the lake was drained by controlled release by the Water Corporation via a single outlet (approximately 1.5 m diameter) that drained directly in the creek-line of Drakes Brook immediately below Waroona Dam. The water level of the dam fell rapidly, especially during the later stages of draining in March and April 2002 with the minimum drainable level reached on 12 of April 2002.

Extensive gill-netting (30 m x 2 m and ranged in mesh size between 12 – 75 mm) of Lake Navarino occurred between October 2001 and April 2002 (Molony et al. 2004a) to target large introduced fishes. As part of ongoing monitoring, additional gill-netting was undertaken in the coffer dams until May 2003. Up to six nets were set during de-stocking. Nets were set and checked twice daily; in the morning between 07:00 – 0:900 and in the afternoon between 16:00 – 18:00, providing two sets per day. All fish were removed from the nets after each set, identified and all redfin perch were euthanased in an ice slurry. All trout in good condition were released well downstream of Waroona Dam into Drakes Brook.

Targeted de-stocking involved the use of baited drop-nets, fish traps, opera-style crayfish traps and scoop nets used along a section of baited bank (see Molony et al. 2002 for details of nets). These gears mainly targeted marron and gilgies although fishes (rainbow trout) were also captured. A total of 40 drop nets, 20 fish traps, 71 crayfish traps (fished from a boat) and up to 8 scoop nets were used intensively during March and April 2002 (main period 13 – 18 March 2002).

The large amount of de-stocking effort greatly increased the success of the de-stocking program and would not have been possible without the involvement of large numbers of volunteers. These included members of the local Waroona community, marron log book holders, fishery liaison officers, fisheries officers, staff and students from Murdoch University and volunteers from the Water Corporation (table 2). The large number of volunteers enabled fishing efforts to be applied throughout Lake Navarino for six consecutive nights during the dark phase of the moon (the lunar phase associated with the highest capture rates of marron (Molony and Bird 2002).

During the most intensive de-stocking period, volunteers were requested to arrive at Waroona Dam by 17:00 h and were briefed by Research Staff. Drop nets and fish traps were baited and set by approximately 18:30 h. Volunteers were then divided into groups and transported around the perimeter of Waroona Dam where they baited a length of bank (typically 400-500 m) with layer pellets laced with aniseed to attract marron. Drop nets, fish traps and the baited banks were checked three to four times in an evening at approximately 45 minute intervals.

The large quantity of drop-nets and traps, deployed from boats, allowed fishing effort to be directed over the entire water body during the de-stocking period. The use of crayfish traps deployed from a boat occurred on nine occasions during March and April 2002. Traps were baited with poultry pellets and deployed at intervals of at least 10 m throughout the lake at approximately 17:00–18:00 h. They were retrieved approximately 14 hours later (07:00-08:00).

All references to mesh size indicate stretched mesh measurements unless otherwise indicated.

Table 2. List of staff and volunteers who assisted in the destocking of marron from Waroona Dam, April 2002.

Surname	Christian Name	Affiliation
Molony	Brett	Department of Fisheries
Bird	Chris	Department of Fisheries
Brown	Warren	Department of Fisheries
Schofield	Dan	Department of Fisheries
Kirk	Bob	Department of Fisheries
Rhodes	Michelle	Water Corporation
Hawkes	Kerrie	Water Corporation
Harding	Peter	Water Corporation
Kilgour	Kathryn	Log book holder
Warren	Geoff Robyn Robert Megan	Log book holder and family
Chaffey	Gordon	Log book holder
O'Byrne	Joe	Log book holder
Leask	Karen John	Log book holders
Elrick	Dave	Via log book holder
Jacob	Belinda	Via log book holder
Bartle	Don	Log book holder
Chambers	Russell	Log book holder
Trafford	Ken	Log book holder
Andrews	Brian	Via Department of Fisheries
Cover	Andrea	Via Department of Fisheries
Tonkin	Ernie	Log book holder
?	Tom	Via log book holder
?	Peter	Via log book holder
Kinear	Shane Lynn Rebecca Ashleigh	Log book holder and family
?	Mark Rachael Justin	Via log book holder
Rocke	Dave Kylie	Log book holders
Bury	Geoff	VFLO
Deeming	Robert	VFLO
Grandal	Carl	VFLO
Wilson	Rob	VFLO
McAuliffe	Pat	VFLO
Lutey	Carrol	VFLO
O'Connor	Kath	VFLO
Beatty	Steve	Murdoch University
Morgan	David	Murdoch University
Gill	Howard	Murdoch University
Beatty	David	Via Murdoch University
Allen	Mark	Via Murdoch University
Visser	Simon	Via Murdoch University
Isles	Michael	Via Murdoch University
Johnston	Josh	Via Murdoch University
O'Shea Molony	Rachel Tom Jak	Via Department of Fisheries

2.3 Results

2.3.1 Pre-project marron population estimate

The 2001 pre-season surveys of Lake Navarino (20 November 2000) captured 305 marron over a one-kilometre length of bank, ranging in size between 37.7 – 90.0 mm OCL. Using a Leslie estimate of population size (Pauly 1984), the estimated number of catchable marron on the 1 km length of bank is approximately 404 (figure 3). As the perimeter of Lake Navarino is approximately 7 km, the minimum estimate of marron was 2,828 marron. However, the Leslie method typically under-estimates the number of marron by between 4.4 – 7.4 times, as the sampling gear rarely collects marron below 35 mm OCL (Molony and Bird 2002) and only a proportion of all marron present are catchable at any one time (Morrissy and Caputi 1981). Thus the total number of marron estimated in Lake Navarino was likely to be much greater (at least 12,443 – 20,927).

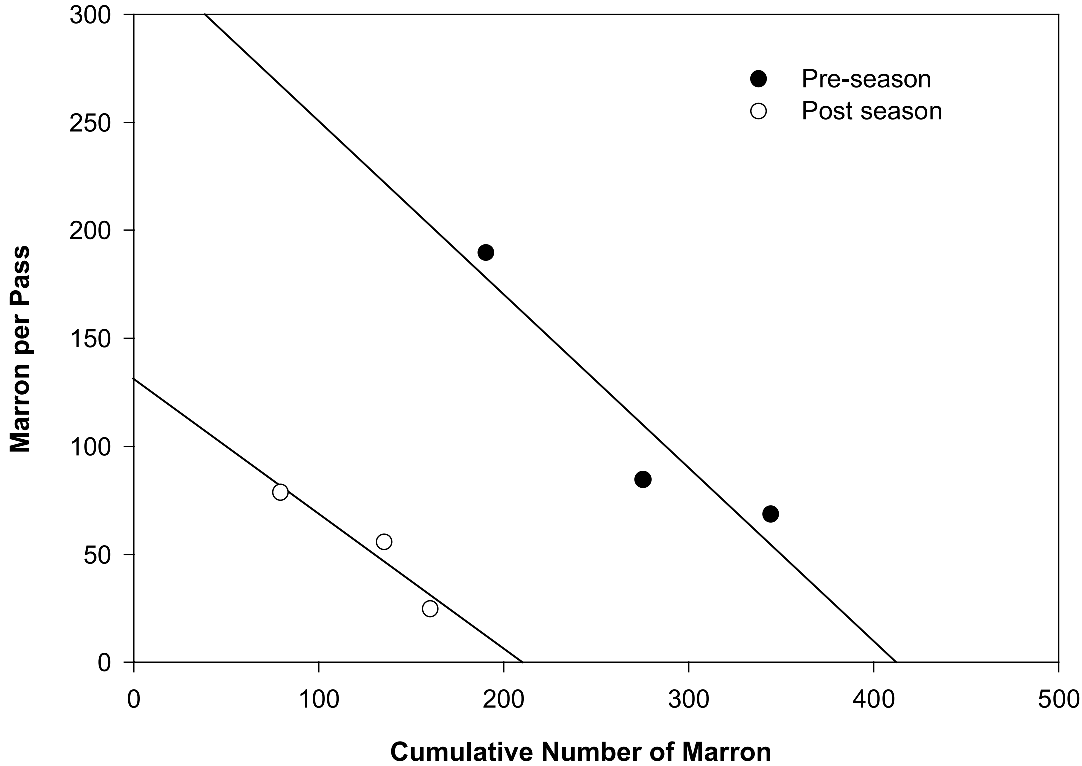
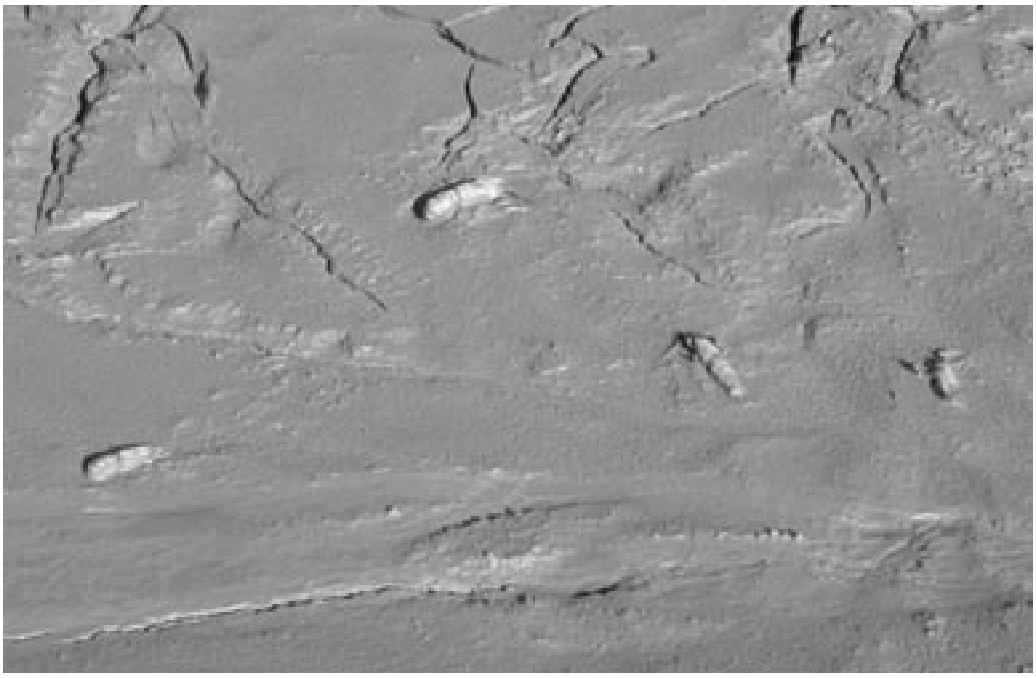


Figure 3. Leslie estimates of the number of marron per kilometre of bank from scientific surveys of Lake Navarino, pre (November 1999) and post (March 2000) 2000 recreational marron season. Note the sampling rarely collects marron less than 35 mm OCL.

2.3.2 De-stocking

A total of 2,104 marron were de-stocked from Lake Navarino representing approximately 10-17% of the total estimated number of marron pre-stocking. Mortality of marron was assessed by two methods. Firstly, several hundered dead marron were observed on the basin after draining (figure 4). Secondly, the tracks of several thousand marron were also observed in association with bird tracks (figure 11). It was assumed that these marron were consumed by birds. Live marron and gilgies captured by all methods were gill-flushed in clean water and separately packed into foam boxes fitted with ice-bricks and foam to maintain low temperature and high moisture, with a maximum of approximately 30 individuals in each box. Marron were promptly transported to the PFRC and stocked into two 150 m^2 ponds. Marron and native fishes transported to AWF were captured using the crayfish and fish traps and were similarly transported on the day of capture. The mortality rate during the transport process was less than 1%.

A.



B.

Figure 4. Examples of dead aquatic animals found in the basin of Lake Navarino immediately after draining in April 2002. A). Marron; B). Redfin.

A total of 891 marron (466 males and 425 females) were transported to purpose built ponds at the PFRC. A further 1,213 marron and 33 gilgies were transported to existing ponds at AWF and remaining gilgies (*n* = 368) were sent to facilities at Murdoch University (table 3). Approximately 95% of marron de-stocked were mature animals as shown by their length-frequency distributions as female and male marron have been found to mature in this system at ~32 and 38 mm OCL, respectively (Beatty et al. 2003b), and female and male gilgies have been found to mature elsewhere at ~19 and 25 mm OCL, respectively (Beatty et al. *in press*) (figures 5 and 6).

Figure 7 shows the catch per unit effort (CPUE) of the crayfish traps for marron and gilgies during the de-stocking period. This reveals that a reduction in the capture rate of marron during the de-stocking period was not achieved, suggesting that although large numbers were removed, it was likely that only a relatively small proportion of the total population was removed (see Chapter 3). Conversely, a significantly negative relationship existed for the CPUE of gilgies over the duration of the de-stocking period suggesting either a very low initial population of gilgies that the de-stocking reduced notably, or the gilgies were becoming less catchable due to burrowing into the substrate as the water levels declined. The latter scenario was certainly possible as this species has a propensity to burrow in both permanent (Beatty *in press*) and temporary systems (Austin and Knott 1996).

All western minnows (*n* = 108) were transported to ponds at AWF. Those de-stocked were likely to be mature (>68 mm TL, Pen and Potter 1991) as indicated by their length-frequency distribution (figure 8). Due to extremely low abundances of western pygmy perch in Lake Navarino, it was not possible to obtain sufficient numbers for a breeding program.

Approximately 50 rainbow trout were captured and most were released downstream of the wall of Waroona Dam (figure 9). Trout and redfin perch captured during the first 24 hours were euthanased and used to complete a trout fry versus trout yearling trial being conducted by Department of Fisheries (Molony et al. 2004a). All subsequent redfin perch captured were euthanased in an ice slurry.

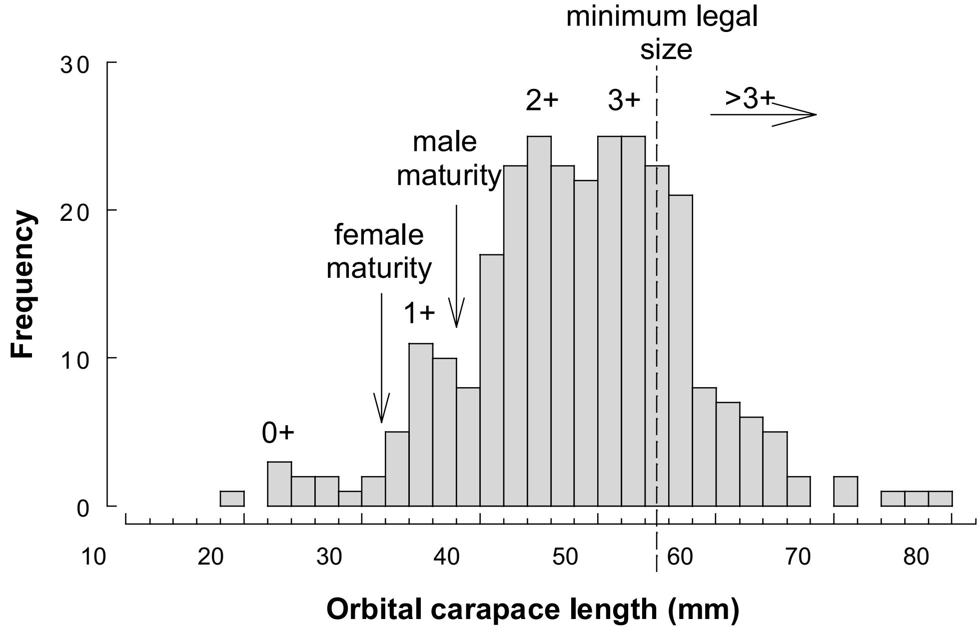


Figure 5. Length-frequency of a sub-sample (n = 282) of the 1,213 marron destocked from Lake Navarino into ALCOA's Wilowdale farm during March and April, 2002. N.B. The approximate modes of the age cohorts present are shown (0+ - 3+) as is the minimum legal recreational size limit and the lengths at which 50% of female and male marron mature in Lake Navarino (Beatty et al. 2003b).

Table 3. Summary of the fish and crayfish destocked from Lake Navarino and allocated to the captive breeding programs prior to the complete draining of Waroona Dam (12 April 2002) (DN= Drop Nets).

Date	Method	Species	Number	Fate
6 March	Traps	Marron	67	AWF
		Gilgies	5	Murdoch
13 March	Traps	Marron	14	PFRC
		Gilgies	32	AWF
		Marron	140	AWF
		Gilgies	10	Murdoch
		Trout	3	Sample
	Gillnet	Redfin	60	Sample
		Trout	10	Sample
14 March	Gillnet	Redfin	7	Sample
	Traps	Marron	18	PFRC
		Trout	3	Sample
	Scoop	Marron	64	PFRC
		Gilgies	2	Murdoch
	DN/traps	Marron	31	PFRC
		Gilgies	**3**	Murdoch
	Traps	Marron	177	AWF
		Gilgie	17	Murdoch
15 March	Scoop	Marron	94	PFRC
		Gilgies	6	Murdoch
	DN/traps	Marron	78	PFRC
16 March	Scoop	Marron	185	PFRC
		Gilgies	5	Murdoch
	DN/traps	Marron	36	PFRC
		Gilgies	7	Murdoch
17 March	Scoop	Marron	67	PFRC
		Gilgies	1	Murdoch
	DN/traps	Marron	60	PFRC
		Gilgies	1	AWF
18 March	Scoop	Marron	163	PFRC
		Gilgies	8	Murdoch
	DN/traps	Marron	77	PFRC
19 March	Traps	Marron	100	AWF
		Gilgies	1	Murdoch
20 March	Traps	Marron	110	AWF
		Gilgies	3	Murdoch
26 March	Traps	Marron	150	AWF
		Gilgies	7	Murdoch
27 March	Traps	Marron	134	AWF
		Gilgies	5	Murdoch
3 April	Traps	Marron	174	AWF
4 April	Traps	Marron	112	AWF
		Gilgies	2	Murdoch
19 July	Trap/electrofished	Gilgies	170	Murdoch
29 July	Trap/electrofished	Gilgies	23	Murdoch
23 August	Trap/electrofished	Gilgies	77	Murdoch
11 September	Trap/electrofished	Gilgies	27	Murdoch
15 October	Trap/electrofished	Gilgies	36	Murdoch

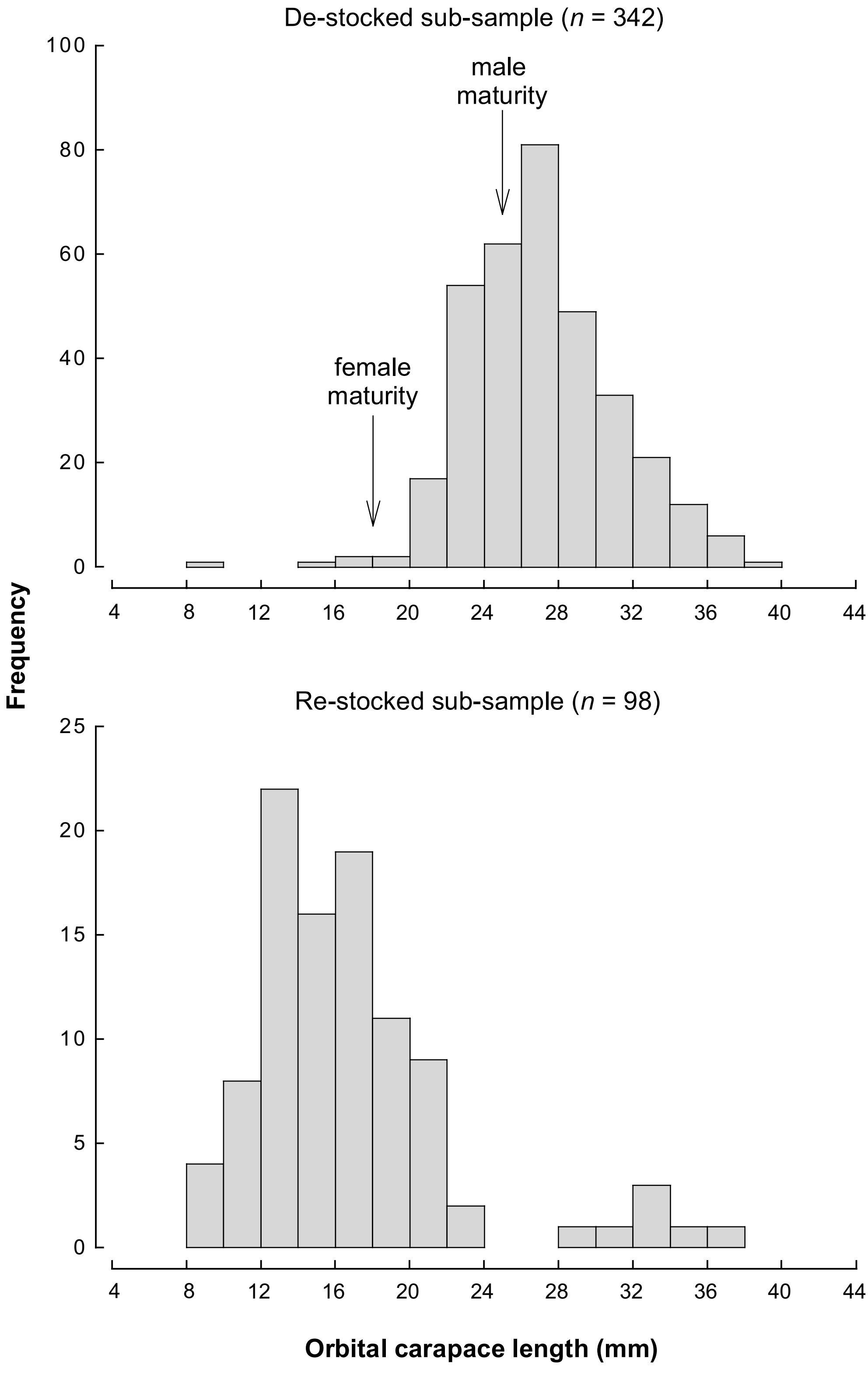


Figure 6. Length-frequency sub-samples of de-stocked (total 365) and re-stocked (total 642) gilgies from Lake Navarino. N.B. dominance of smaller size-cohort re-stocked into the reservoir and the previously recorded lengths at which 50% of females and males mature (Beatty et al. *in press*).

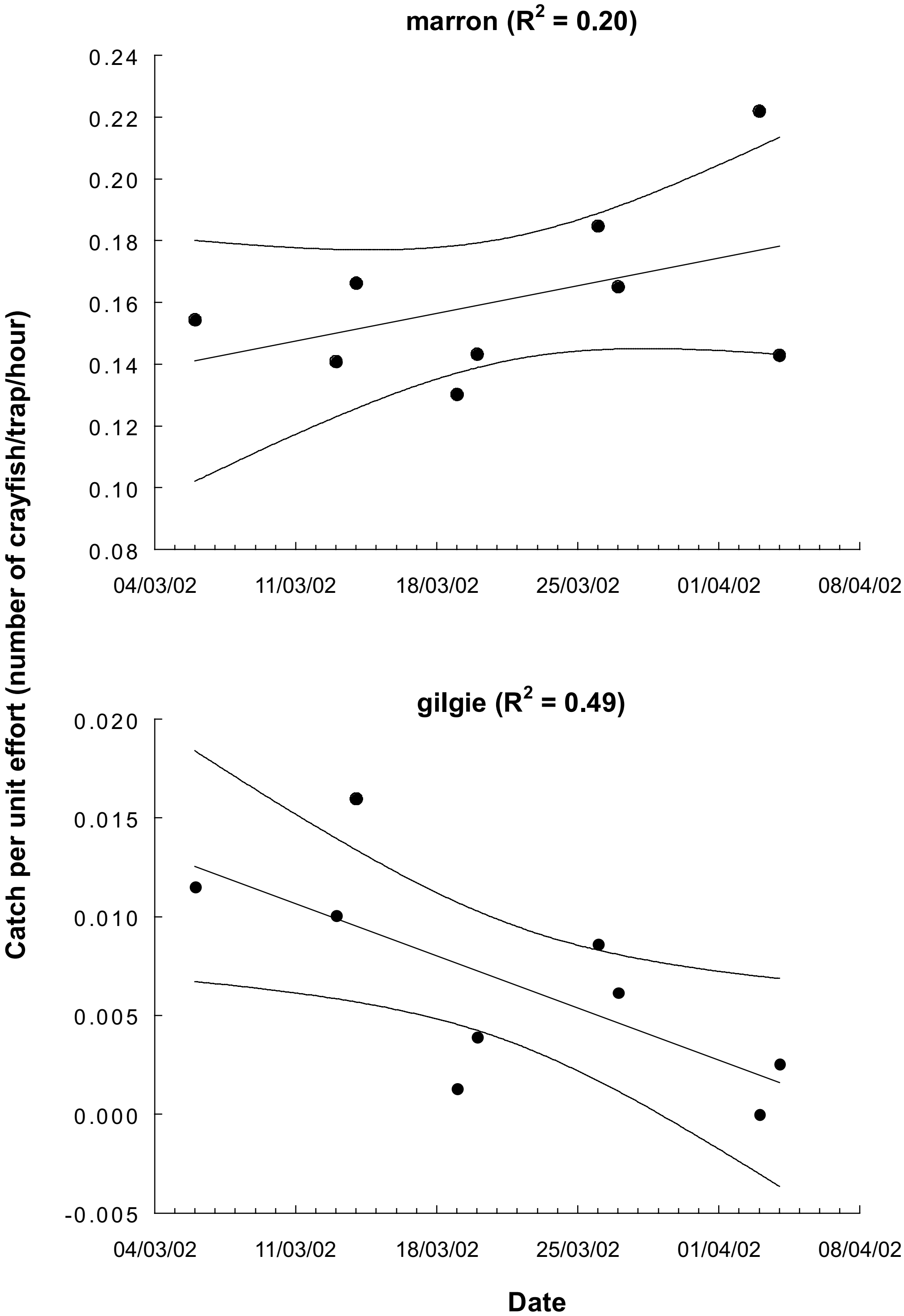


Figure 7. Catch per unit effort (number of crayfish/trap/hour) of the opera traps used as part of the de-stocking effort in Waroona Dam in March and April 2002. N.B. 95% confidence intervals are shown.

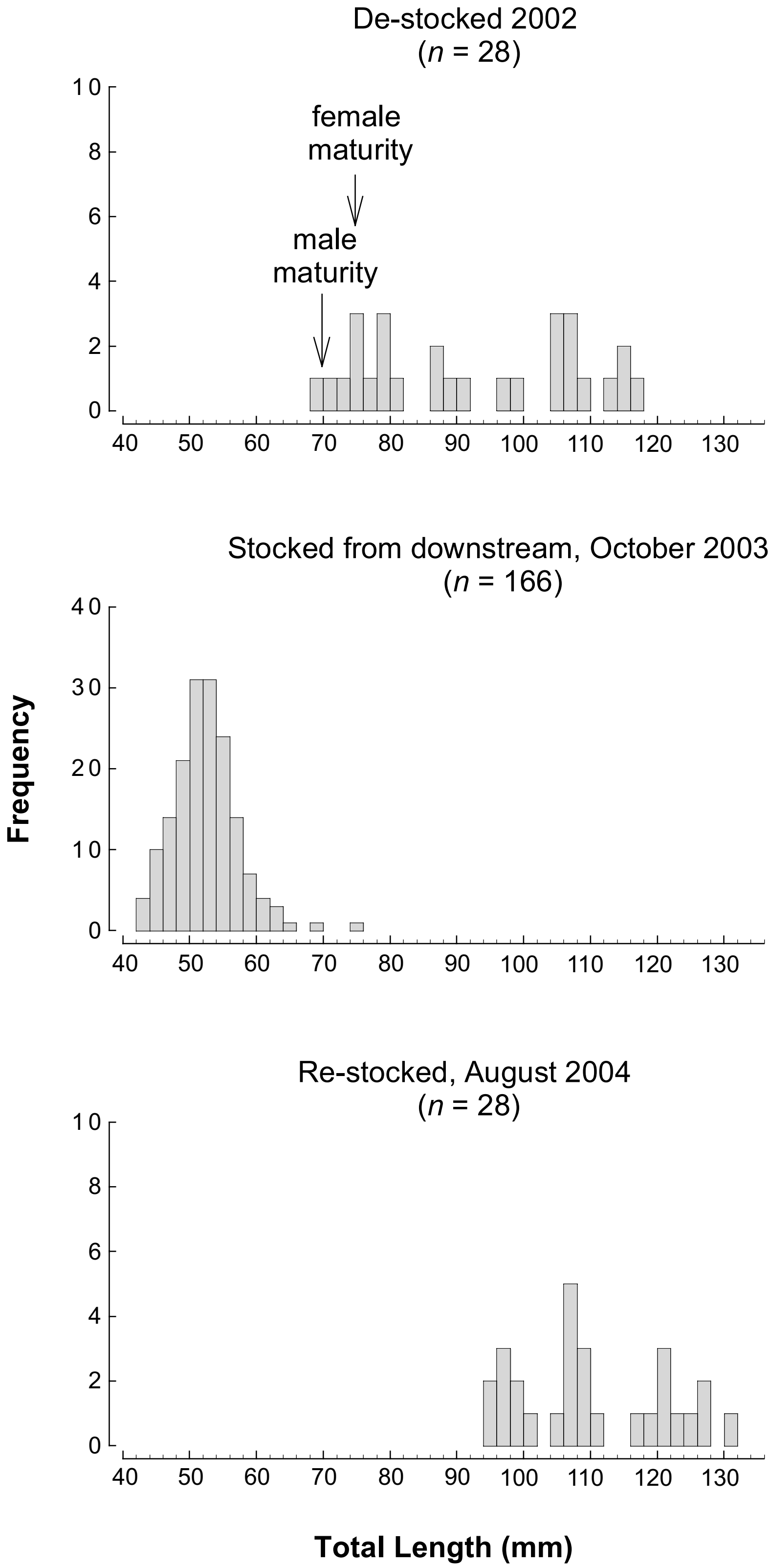


Figure 8. Length-frequency sub-samples of de-stocked (total 108) and re-stocked (including downstream captures) western minnows (total 1,110) from Lake Navarino. N.B. size differences of de-stocked and re-stocked highlighting growth in captivity. Previously determined lengths at which 50% of females and males mature are also shown (Pen and Potter 1991).

Figure 9. One of the trout de-stocked from Lake Navarino in April 2002 being released downstream of the wall into Drakes Brook by Mr Gordon Chaffey (volunteer).

2.4 Discussion

Although only representing a relatively small proportion of the overall pre-project estimated population, the de-stocking of marron from Lake Navarino was successful in obtaining large samples of broodstock. Although some dead marron were observed in the drained basin and there was also evidence of substantial predation of stranded marron by birds, mass mortalities of aquatic animals were not visually apparent within Lake Navarino or downstream following drainage. Unknown numbers of marron may have moved out of the lake through the outlet pipe. The de-stocking process, particularly of marron, was greatly assisted by volunteers.

The de-stocking process also promoted a positive public perception of the refurbishment of the dam. *The Harvey Reporter* (18 June 2002), *Western Fisheries* (the popular magazine published by the Department of Fisheries) (Anderson 2002), *The Miner's Write* (the newsletter of Alcoa) (Beatty and Morgan 2002) and *Company One* (the newsletter of the Water Corporation of Western Australia) (Walsh 2002) (appendix 2) all produced articles detailing the de-stocking efforts, highlighting the importance of the project and the efforts of volunteers. Posters were also in the town of Waroona, water corporation and site offices (Appendix 5).

Sufficient broodstock for two independent populations of marron were collected and transferred to secure breeding facilities at the PFRC and AWF. A relatively large number of gilgies were also de-stocked into both AWF and fibreglass tanks at Murdoch University in order to negate the risk associated with keeping stock in a single location. The use of brookstock from within the system ensured that progeny to be re-stocked into Lake Navarino would be of the same genetic type, an important biodiversity consideration for re-stocking projects (Molony et al. 2003a).

Of the two native fish species previously known from Lake Navarino, only western minnows were located during the de-stocking effort and both these species (particularly the western pygmy perch) were largely present in only two perennial tributaries. This was likely due to the large numbers of large piscivorous fish (particularly redfin perch) in the basin, coupled with a lack of habitat, which would have resulted in high levels of predation of these small native species. It has previously been proposed that redfin perch were responsible for the complete elimination of native fishes from Big Brook Dam (Pemberton) within four years of their introduction to that system (Morgan et al. 2002). It was therefore decided not to de-stock these two endemic fishes from the upstream tributaries as the habitat in those perennial systems appeared adequate for maintenance of these small populations, however, their abundances were monitored closely throughout the project to ensure their continued presence as there was the potential of larger predatory species moving into those tributaries (see Chapter 9).

A failure of the de-stocking component of the overall project was the loss of some marron in the drained basin of Lake Navarino (15 April 2002) (figure 4) (Molony and Bird, pers. obs.). It is likely that many of those marron became stuck in the sediments of the basin as the water level receded faster than marron could walk, with mortality likely a result of avian predation, suffocation or exposure. Many of the dead marron observed were juveniles of only a few months of age, released from females in approximately December 2001 (Beatty et al. 2003b). The small size of these marron (< 50 mm total length) meant that they had a reduced walking ability and would have easily become stuck in the thick mud and subsequently died as a result (likely due to suffocation, dehydration and/or exposure). The large number of marron mortalities also supports the large estimated population size of marron, and the lack of declining CPUE despite intensive de-stocking efforts.

Further, large marron and some redfin perch that were stranded by receding waters (figure 4) suffered high mortality from bird predators (e.g. cormorants, kookaburras, heron, etc) as observed by the large number of bird scats and regurgitated stomach contents containing marron gastroliths and carapace parts around the drained basin (figure 10). Further, many tracks left in the mud by marron terminated at bird prints (figure 11), suggesting that birds were easily able to capture exposed marron in the drained basin. The large number of such tracks observed in the basin and the large number of bird scats indicated that a large number of marron died this way, estimated at several thousand (Molony and Bird pers. obs.). However, few dead fish were observed in the basin. Specifically only 6 dead redfin perch were recorded (figure 4), suggesting a minor rate of mortality in the acutal basin as a result of the draining (see also Chapter 3). This was likely due to two factors: the ability of redfin to move rapidly into the residual waterbodies as the reservoir drained and the large downstream movement of redfin through the outlet pipe as the water receded. This latter factor was highlighted by the very large increase in abundances of this species observed immediately below the dam wall. Seine netting in the pool immediately below the dam wall revealed a redfin perch density of ~ 1 fish m^{-2} in April 2002.

In order to reduce the drainage mortality of marron observed in the current project, future refurbishment works should consider the following management options during the draining process;

1. A greater proportion of crayfishes should be removed by extending the period of drop-netting, trapping and scooping crayfishes. Gill-netting of feral fishes should also occur simultaneously. The benefits of additional use of these techniques would be an increase in the broodstock available and success of the breeding programs, the removal of additional unwanted fishes from the lake, reducing the likelihood of downstream escapes via the dam outlet impacting on downstream species and increasing marron available for stocking within the catchment.

2. The water level should be held at a low level for a longer period of time, allowing a greater period of de-stocking at higher crayfish densities.

3. The draining of a dam should occur more slowly, allowing crayfishes to follow the water level down, reducing the chances of becoming stuck or falling prey to avian predators.
4. An exclusion mesh screen should cover the entry to the outlet pipe to prevent the escape of large feral fishes, particularly redfin perch, into downstream waterways. A mesh size of 20-25 mm is recommended with the lower size being preferable to retain small redfin perch. However, if the mesh poses an unreasonable restriction to flow, 25 mm mesh should be used.

Figure 10. An example of the regurgitated stomach contents of a bird (probably a cormorant) found in the basin of Lake Navarino on April 13th 2002, showing the remains of at least five marron.

Figure 11. Examples of marron and bird tracks observed in the basin of Lake Navarino immediately after draining in April 2002. The marron tracks (characterised by the drag marks left by the claws) start in the bottom left-hand corner of the photograph and stop in the middle of the photograph, where a large number of bird prints are observed.

3. Controlling exotic species in Waroona Dam

Brett Molony, Stephen Beatty, Chris Bird and Vinh Nguyen

3.1 Introduction

The freshwater fish fauna of south-western Australia, although not high in species richness compared to freshwaters in eastern Australia and internationally (Pen 1999), is highly endemic with eight out of the ten species found only in this region (Morgan et al. 1998). This uniqueness also extends to the freshwater crayfishes of the south-west with all eleven species endemic (Horwitz 1995, Austin and Knott 1996; Horwitz and Adams 2000, Austin and Ryan 2002). The aquatic fauna of this region has been under threat from a number of sources, particularly habitat change such as salinisation (Morgan et al. 2003) and introduced species (Morgan et al. 1998, 2004). Redfin perch have been shown to have a high predatory impact on freshwater fish and crayfish of this region (Beatty et al. 2000, Morgan et al. 2002, Molony et al. 2004a, Appendix 3). The introduced yabby is also spreading throughout this region and also has the potential to impact on aquatic ecosystems (Molony et al. 2002, Beatty et al. *submitted* a).

Lake Navarino, like most waters of south-western Australia has a limited diversity of fishes and crayfish. The waters of Lake Navarino are dominated by marron and the introduced teleost species redfin perch, rainbow trout, brown trout and mosquitofish (*Gambusia holbrooki*). From a pre-draining study of Lake Navarino, Molony et al. (2004a) indicated that the relative abundance of redfin perch, rainbow trout and brown trout were 74%, 22% and 4% respectively. Further, redfin perch had a much greater predatory impact on endemic crayfish (marron and gilgies) than either species of trout (Molony et al. 2004a). The two main tributaries of Lake Navarino (figure 2) were known to contain marron, gilgies and the endemic teleosts western pygmy perch and the western minnow (Beatty pers. obs.). There is no evidence to suggest that rainbow trout can successfully spawn in Lake Navarino to any extent, and stocks are maintained by regular stocking. Brown trout are capable of breeding in the tributaries of Lake Navarino as evidenced by regular capture of small brown trout (< 80 mm total length, Beatty pers. obs.) despite no stocking of brown trout into Lake Navarino since 1997 (A. Church pers. comm.). However, the abundance of brown trout remains low (Molony et al. 2004a), suggesting a low breeding success. In contrast, redfin perch dominate the fish community in Lake Navarino, breeding successfully and uncontrollably. Their high breeding rate and abundance causes the small average size within the population (less than 100 mm TL) thereby reducing their angling value. Further, due to their impacts on fishes and crayfishes (Molony et al. 2004a), this species is considered a feral pest in Western Australia (Molony 2001a, b, 2002a, b, 2003a, b, Morgan et al. 2002).

Mosquitofish are present, however, unlike many systems in the south-west, their abundance is relatively low, likely a result of the presence of the piscivorous redfin perch and trout species (Molony and Beatty pers. obs.). There are also unconfirmed reports of yabbies (Molony et al. 2004b), however, this appears unlikely given their absence from the large numbers of crayfish captured in the system during this project.

Therefore, a major component of the project was to attempt to control or eradicate introduced aquatic species that pose a risk to the reestablishment of endemic crayfish and fish populations following the re-fill of Lake Navarino.

3.2 Methods

Four strategies were employed to control exotic species in Lake Navarino and the tributaries; netting, draining, concussive techniques and electrofishing. The first two methods are described in detail in Chapter 2, the remaining two are outlined below.

All references to mesh size indicate stretched mesh measurements unless otherwise indicated.

3.2.1 Concussive technique

The concussive technique was undertaken just prior to the commencement of re-filling between the 26 and 28 May 2003. This was to allow the lake to be drained to its lowest level, dividing the 150 ha basin of Lake Navarino into six smaller coffer dams (figure 2). Further, allowing about six weeks between the total draining of the lake and the application of concussive techniques exposed any remaining animals in the shallow coffer dams to poor water quality (e.g. high temperatures, low dissolved oxygen levels) during April and May 2003.

The concussive technique involved the use of emulsion explosives under the direction of Gary Kalem Consultancy (shot firing specialist) with assistant supervision provided by Craig Astbury from the Fish and Fish Habitat Protection Program (Department of Fisheries). Five of the six major coffer dams were targeted as the other was almost dry and it was obvious that no fish were present. Three explosive events were undertaken in the five coffer dams (figure 12) during the hours of 12:00-13:00 under a strict safety management plan devised by the consultant. The shock-wave results in internal injuries of resident fish, specifically the destruction of the swim bladder.

A.

B.

Figure 12. The concussive technique employed in May 2003 for the attempted elimination of redfin perch in Lake Navarino. (A) Setting the depth charges and (B) detonation of the largest of five coffer dams.

3.2.2 Electrofishing

In addition to the monitoring and eradication efforts of Lake Navarino for fish and freshwater crayfish, considerable sampling effort occurred in the two major tributaries throughout the project to ensure that native fishes were not impacted by the draining of Lake Navarino, and to remove large predatory fish should they move into these tributaries as a result of the draining. The sampling occurred using a back-pack electrofisher (*Smith-Root* Model 12-A), which temporarily stuns the fish over an area of approximately 2 m diameter. Drakes Brook was sampled on eleven occasions (figure 13) with up to 1,200 m^2 of the stream channel sampled on each occasion. The smaller northern tributary was sampled on three occasions in December 2002, August 2003 and April 2004 with up to 200 m^2 sampled on each occasion. Fish sighted were identified to species and densities determined.

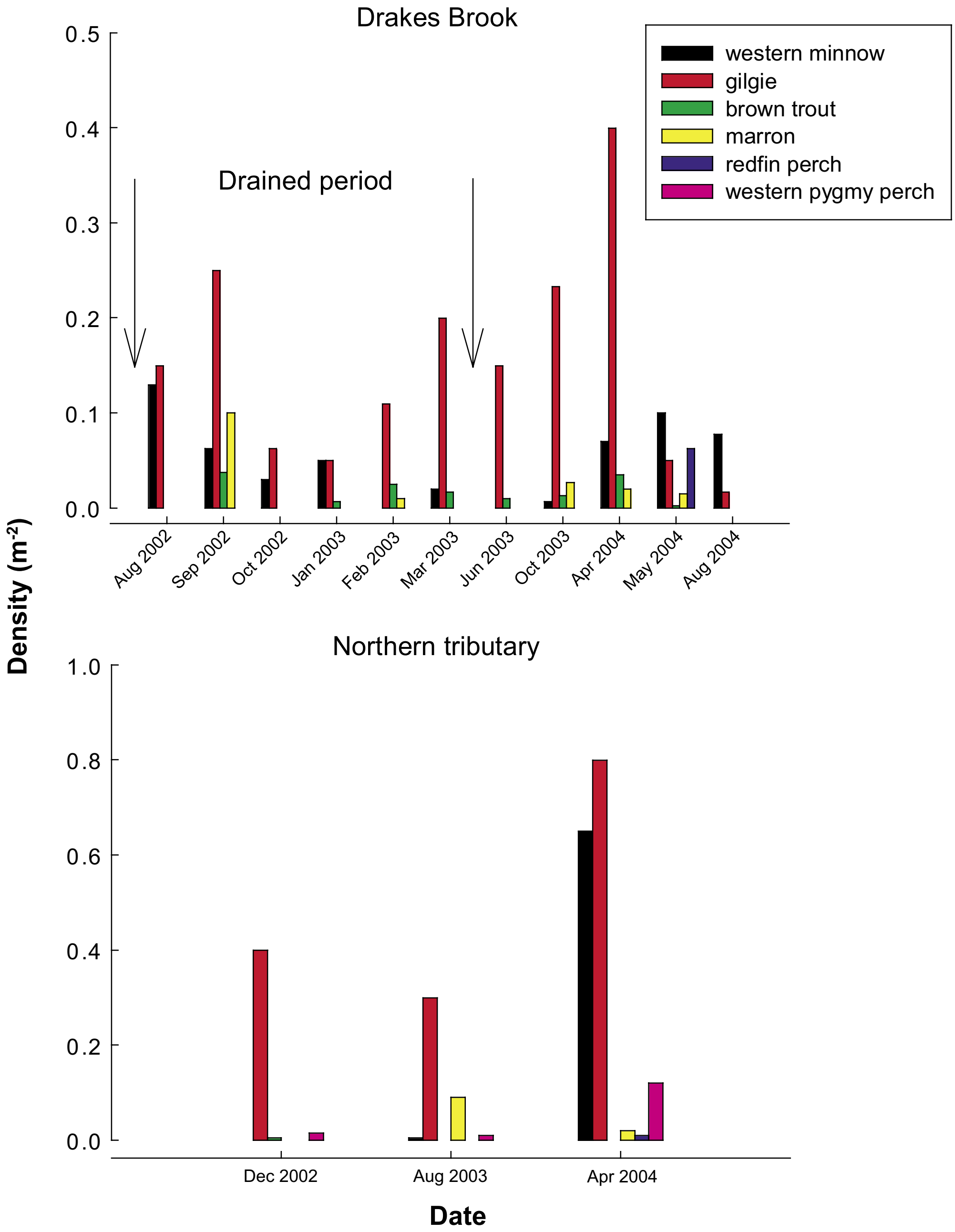


Figure 13. Density of fish and crayfish in Drakes Brook and the northern tributary throughout the project.

3.3 Results

3.3.1 Pre-draining population estimates of fishes

Petersen population estimates (Molony and Bird 2002) for each species of predatory fish in Waroona Dam were calculated in October 2001. The estimates were 22,400 ± 4,427.2 for redfin perch, 2,216 ± 274.6 for large (i.e. non-fry) rainbow trout and 1,225 ± 54.6 for brown trout. However, natural and fishing mortality would have reduced the numbers of all fishes prior to April 2002. Fishing and natural mortality rates estimated from telephone survey work (Molony et al. unpublished data) indicated that total mortality rate of rainbow trout in Lake Navarino was approximately 0.791, or 0.0659 month^{-1}. Assuming that all species have a similar mortality rate, the expected number of fishes at draindown would be 1 - 0.3955 or 0.605 of the October 2001 estimates. Thus, there was an estimated 12,070 redfin perch, 1,190 rainbow trout and 660 brown trout by April 2002.

3.3.2 Effectiveness of netting

A total of 922 redfin, 77 rainbow trout and 22 brown trout were removed from Lake Navarino by netting between October 2002 and April 2003 (Molony et al. 2004a), representing between 3.3-7.6% of the estimated pre-draining numbers of each species.

3.3.3 Effectiveness of draining

The full supply capacity (FSC) of Lake Navarino is approximately 14.8 million cubic metres. Even though Lake Navarino was not full at the commencement of draining, a considerable volume of water was still required to be drained before refurbishment works commenced. The controlled draining of Lake Navarino by Water Corporation resulted in unknown numbers of crayfishes and fishes moving through the outlet pipe downstream into Drakes Brook and Drakesbrook Dam. The majority of these fishes would have been redfin perch. As the de-stocking captured approximately 50 rainbow trout, and none were located in the coffer dams following draining, the draining accounted for the de-stocking of approximately 1,000 rainbow trout, or 89% of the estimated pre-drain number. Similar proportions of redfin and brown trout were also expected to have been destocked due to draining.

3.3.4 Effectiveness of concussive techniques

As mentioned, there remained sizable coffer dams within the basin of Lake Navarino at the lowest water levels at the time of deployment of the concussive technique (the largest was ~600 x 10 m, figure 2). The explosive event resulted in the mortality of 35 redfin perch with a size range of 109-172 mm TL. The technique was likely to have resulted in the death of many more redfin that were not killed instantly, due to the high turbidity of the water in the coffer dams after detonation.

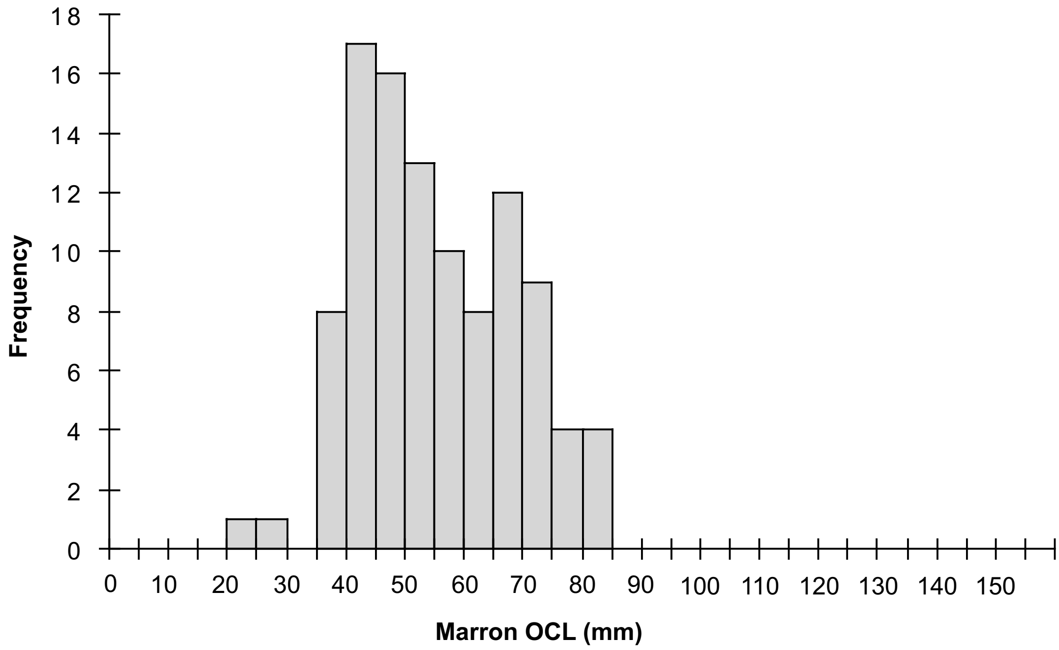


Figure 14. Marron OCL distribution from a trapping survey in areas around the artificial habitats and wall in May 2004. (n = 103 marron). [Note – 55.5 mm OCL is the approximate legal size of marron; 40 mm OCL is the approximate minimum size of berried females previously recorded at Waroona Dam].

3.3.5 Post control surveys

Gill netting

Surveys were undertaken following both the draining of Lake Navarino in April 2002 and re-filling of the Dam (May 2003). This allowed an evaluation of the effectiveness of the control techniques. An initial survey occurred in September 2002 involved the setting of two 30 m gill nets for approximately 8 hours during the day and 10 marron traps in two of the major coffer dams maintained during refurbishment of Lake Navarino. This sampling did not capture any fish or crustaceans, although a number of mosquitofish were observed in one coffer dam.

A similar gill netting effort occurred immediately prior to the concussive technique occurring in April 2003. This involved the use of three gill nets: a 50 m (50 mm mesh), 20 m (50 mm mesh) and a 20 m (75 mm mesh), set for three hours during the evening. This sampling targeted the largest coffer dam below Drakes Brook and resulted in the capture of one brown trout. It was therefore decided that this very large coffer dam was devoid of redfin and concussive techniques focussed on the other five downstream-most coffer dams (as described above) in which redfin had been sighted (W. Dart pers. comm.). These two surveys (along with the extremely high densities of redfin perch observed below the Waroona Dam wall, see Chapter 2) suggested that the draining resulted in substantial loss of fish and crayfish from the lake.

Thirdly, gill netting of the lake occurred in August 2003, following the concussive eradication attempt and prior to the re-stocking of any crayfish or fishes. An afternoon gill net set (approximately 6 hours) and an overnight gill net set (approximately 17 hours) were undertaken and a single redfin perch (~150 mm total length) was the only catch recorded from the gill nets. Additionally, 20 marron traps were set overnight, resulting in the capture of three marron (35 – 45 mm OCL) and one gilgie (20 mm OCL). No other aquatic species were observed.

This survey suggested that the draining event and feral control program, although not 100 % effective, was valuable in greatly reducing the abundances of redfin perch in the lake.

Further gill net sampling was conducted to coincide with the release of the second generation of Waroona Dam marron during May 2004. Considerable numbers of redfin perch (93) and a few brown trout (14) (but no rainbow trout) were captured over three nights of sampling (approximately 43 h soak time). A total of 20 traps were set for one night near to the habitats and resulted in the capture of 103 marron (OCL 20 – 80 mm) (figure 14) and one gilgie (OCL 37 mm).

A final gill netting and trapping survey was conducted in August 2004, which followed the release of 2,500 ex-broodstock and 4,000 yearling rainbow trout from the PFRC into Lake Navarino. This resulted in the capture of six rainbow trout and a single redfin perch. The relatively low fish captures during this survey was likely a result of the cool water temperatures reducing the activity of fish and thus the effectiveness of the gill nets, which rely on the fish actively swimming into the mesh. Six crayfish traps were also deployed which resulted in the capture of 20 marron at a CPUE of 0.238 marron per trap per hour which was greater than any of the de-stocking capture rates (Chapter 2, figure 7). These marron were consistent with the predicted sizes of captively bred marron, and the high CPUE suggested a high survivorship of re-stocked marron to that point in time. Further, as the feeding activity of marron declines with lower temperatures, this CPUE would be a minimum reflection of abundances at that time.

Tributary electrofishing

Figure 13 shows the density of aquatic organisms recorded from Drakes Brook on each of the eleven sampling occasions. Redfin were only captured in May 2004 with 25 0+ individuals (age based on growth curves of Morgan et al. 2002) being removed from Drakes Brook. Gilgies were the dominant aquatic species in both tributaries on most sampling occasions with marron only being caught less often and at lower densities in both systems (figure 13). The density of western minnows in Drakes Brook decreased during the drainage period, before increasing upon re-fill. Western pygmy perch were only captured in the northern tributary and at relatively low densities on each of the three sampling occasions. Redfin perch were only captured on one occasion in Drakes Brook and on two occasions in the northern tributary at relatively low densities. Brown trout were captured in Drakes Brook on most sampling occasions, including the drained period, however, they were always at relatively low densities (figure 13). This species is known to form self maintaining populations in parts of Western Australia.

3.4 Discussion

Although the control techniques were not 100% effective, the reduction in abundances of the feral redfin permitted the ecosystem of Waroona Dam to be effectively re-set and allowed the establishment of re-stocked animals (i.e. reduced predation by redfin on captively bred animals). Redfin perch dominated the aquatic fauna of Lake Navarino prior to this project (Molony et al. 2004a) due to their high densities and the known high predatory impact on fish and crustaceans in south-western Australia, including this system (Beatty 2000, Morgan et al. 2002, Beatty et al. 2003b, Molony et al. 2004a).

Most fishes were captured in gill nets, although some rainbow trout (n = 6) were trapped, 35 redfin perch were captured during the concussion effort and only a few fish were observed alive or dead in the coffer dams of the drained basin after April 2002. Therefore, these methods only accounted for a small proportion of the estimated populations of introduced fish present in Lake Navarino prior to draining, and it appeared that the majority therefore passed through the outlet pipe into Drakes Brook. A proportion of redfin that passed through the outlet pipe would have perished due to the high flow rate through the pipe causing damage to individual fish, however, very high densities of living fish were evident as indicated by 5 m seine netting (3 mm mesh) immediately below the dam outlet following draining.

In contrast, gill nets resulted in the mortality of most redfin perch captured in Lake Navarino, due to damage to gills and the long soak times used. Although rainbow and brown trout were also collected and also suffered mortality in gill nets, these species do not breed to any great extent in Lake Navarino and are supported by artificial stocking. As the breeding populations are maintained at the PFRC, the production and re-stocking of either or both trout species is relatively easy (and recommenced in May 2004). Thus, gill nets were a cost-effective control technique for fishes, allowing multiple nets to be deployed at a similar time and only requiring two people to set and monitor.

The blasting of the coffer dams immediately prior to re-filling aimed to eliminate remaining redfin perch. Although this did not eliminate all remaining redfin perch, this technique was deemed to be the most appropriate for a number of reasons:

- Although relatively expensive, the technique has a good record of controlling aquatic animals given adequate charges are set for the size of the waterbody and the species in question.
- Opportunity to access the coffer dams was limited due to the engineering works continuing in the basin right up until re-fill in May 2003. This technique was able to be implemented over two days without serious disruption to the expensive works program. Netting would have required ongoing access to each dam over an extended period of time and there would have been far less chance of eliminating all remaining redfin perch.
- It was inappropriate to employ toxic techniques (such as the use of chlorine or rotenone). This was due to the fact that the area of water in the coffer dams was relatively large which would have required an excessive amount of chemicals, and the potential movement of the chemicals through the outlet pipe downstream would have negatively impacted on the downstream ecosystem. However, toxins may be useful to treat coffer dams that are isolated from the rest of the watercourse.

Although significant numbers of redfin were removed by all techniques, 100% control was not achieved. As mentioned, it is likely that draining was the most effective control method used in the current study. However, there are downstream impacts by the movement of redfin into other waters, particularly on marron in Drakesbrook Dam.

Although the combination of feral elimination techniques was relatively effective and largely met the aims of the current project, refinements to their application for future projects involving feral fish in reservoirs are recommended:

1. As mentioned in Chapter 3, any drainage program should primarily consider the welfare of the endemic species in the reservoir, its tributaries and downstream ecosystem and therefore the rate of drainage should occur as slowly as possible to allow for endemic species to move into the coffer dams, which should be intensively de-stocked for as long as possible.
2. The use of a mesh screen (mesh size as small as possible) over the outlet pipe during drainage is recommended in future similar projects when a species of large feral fish are present to prevent the large-scale movement downstream (see Molony et al. 2003b, Beatty et al. 2003c).

3. Following the intensive de-stocking of endemic species from the coffer dams, the coffer dams should ideally be drained completely to ensure complete elimination of feral fishes, or, if this is not possible, drained to a very low level to increase the effectiveness of the final elimination technique selected.

4. The final elimination technique should be employed at the lowest possible water levels and the type of technique should be selected based on: the nature and abundance of the feral species in question, the degree of access to the final coffer dam, the volume of water to be treated, and the potential impact of the technique on downstream ecosystem. For example, should the concussion technique be employed, as it was in Lake Navarino, use of adequate explosives for the volume of water to be treated is an essential consideration.

All these refinements could be easily applied and should be considered for similar projects in the future. In order to be implemented they require:

- Good forward planning of the timing of the refurbishment process.
- Adequate communication between managers of the engineering and environmental aspects of the project (e.g. balancing the need of coffer dam water for construction purposes with consideration of the needs of the faunal management program).
- Adequate funds for both the endemic species de-stocking program and the complementary feral elimination program.

4. Breeding at the Pemberton Freshwater Research Centre

Brett Molony, Chris Bird and Vinh Nguyen

4.1 Introduction

Marron are endemic to Western Australia and the methods for their commercial culture are well known. A recent review by Lawrence and Jones (2002) presented up-to-date analyses on a range of marron aquaculture issues and techniques. However, the objectives for re-stocking an irrigation dam to meet recreational fishing and biodiversity objectives are quite different to objectives of commercial aquaculture (table 4).

Table 4. Comparison of issues for a commercial marron aquaculture venture and a re-stocking program with recreational fishing and conservation objectives (Modified from Molony 2002 c).

Issue	Aquaculture	Restocking
Genetic Stock	• Can be purchased • Faster growing lines preferred	• Unique for each irrigation dam • Can only be collected from the site of works • No other source available
Production	Profitable numbers	Very large numbers – as many as possible
Size range	Minimised	Wide as possible to reflect natural variability (figures 5, 6 and 15).
Size variation	Minimised	Wide as possible
Breeding	Selective	Haphazard
Age class of breeders	Known and controlled	Unknown
Age classes required	2 – 3 year olds	Mixed
Breeding rate	Relatively predictable	Only estimated from field surveys by proportion of berry rates
Proportion of breeders	Small	All
Fate	Human consumption	Restocking

One of the largest differences between breeding programs for commercial aquaculture and re-stocking wild populations is the production of a large number of juveniles from unselected broodstock for the latter program. In aquaculture farms, broodstock and nursery ponds are relatively small, typically around 150 m^2, due to the modest numbers of broodstock and juvenile marron needed to stock a farm of typical size (3,000 juvenile marron per grow-out pond of 1,000 m^2; typically 6 – 10 grow-out ponds with a two-year production cycle) (Lawrence and Jones 2002). As such, broodstock and juveniles to be on-grown can be selectively stocked to control the size variation and broodstock characteristics. In comparison, a breeding program for the re-stocking of large irrigation dam aims to produce as many juveniles as possible from as wide a range of breeding animals, increasing variability of size at age as found in natural situations, including Waroona Dam (figure 15).

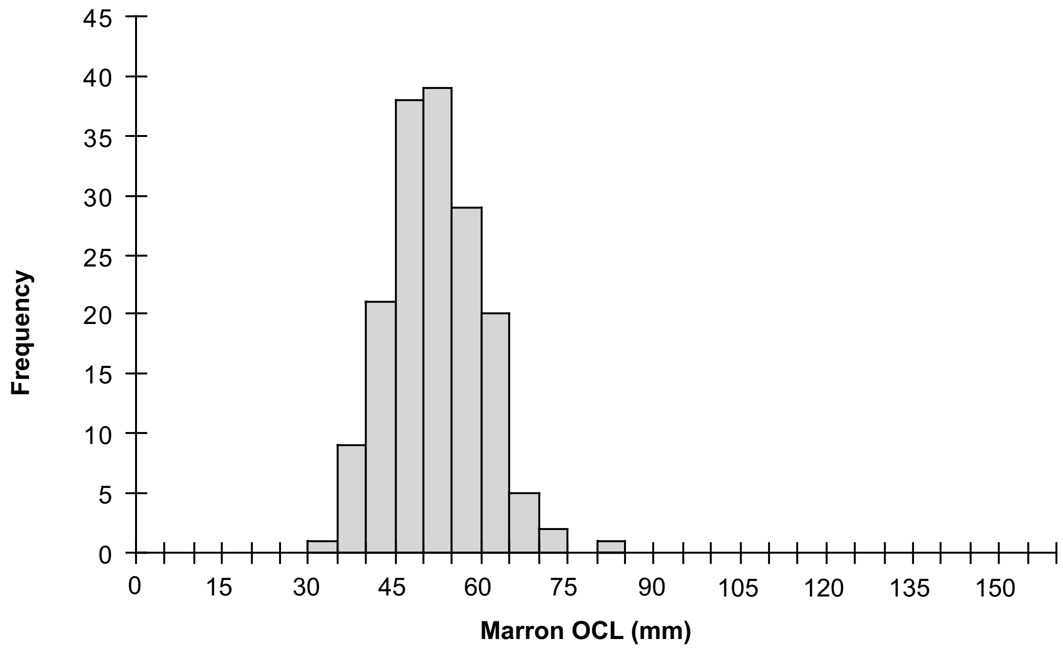


Figure 15. Marron OCL distribution from the March 2001 post-season survey of Waroona Dam. Marron were sampled from approximately one-kilometre of bank baited at 10 metre intervals. (n = 348 marron). [Note – 55.5 mm OCL is the approximate legal size of marron].

4.2 Specifics of the Waroona Dam Project

As marron in Lake Navarino release juveniles towards the end of a calendar year (Beatty et al., 2003b), the present project allowed for the production of two cohorts of juveniles (cohort 1 - December 2002; cohort 2 - December 2003). As most marron will not breed until two years of age (Lawrence and Jones 2002), the broodstock collected in April 2002 would have to be used for two consecutive breeding seasons, a practice rarely recorded from commercial aquaculture ventures (G. Cassells pers. comm.).

Three 1,000 m^2 purpose-built marron ponds were designed as large nursery ponds (Molony 2002c) and constructed at the Thomson's Flat annexe (PFRC) (figure 16). A modification of marron grow-out pond design was used (figure 17), equipped with a long concrete channel (figures 17 and 18) which was designed to aggregate large numbers of juvenile marron (<40 mm total length) during drain-down to assist in stock management and eventual de-stocking of the ponds when marron were moved back into Lake Navarino.

Marron collected from Lake Navarino during March 2002 were initially stocked into two 150 m^2 ponds at the PFRC pending the completion of the dedicated Water Corporation ponds. Marron were held in these ponds for approximately two months. Marron were transferred into commercial-sized grow-out ponds (1,000 m^2) that were built to act as large nursery ponds. Although the large nursery ponds were considerably larger than those normally used for juvenile production in commercial aquaculture of marron, the commonly used husbandry and production techniques for marron were adopted, albeit on a larger scale. All nursery ponds were provided with a paddlewheel aerator, set to run for approximately one hour four-times per day and sufficient weed bunch style artificial hides (~100 bunches per pond).

The first of the large ponds was stocked with Lake Navarino marron from one of the smaller ponds on 7 June 2002. Marron remained in the other small pond as they had commenced breeding considerably earlier than normal and a decision was made not to disturb them during this critical reproductive phase.

Figure 19 provides a flow diagram summary of stock management and numbers of marron within each pond at each census. In June 2002 and 2003 the large nursery ponds containing the broodstock Waroona Dam marron were drained and all marron carefully removed. The large ponds were cleaned and berried females placed into a separate, clean pond, with un-berried females and males moved into another pond.

Paddlewheel aerators were switched off during the period of June–October to maximise female berry-up rates. In November, ponds were again drained and berried female marron were counted and moved to freshly cleaned ponds. Paddlewheel aerators were switched-on at this stage to maintain high dissolved oxygen levels. Male and un-berried female marron were returned to a separate pond.

During January, after juvenile marron have been released, female marron were trapped and scooped to remove them from the juvenile pond, to reduce cannibalism by the females. Removal of females by these methods is not 100% effective. Typically, removal of post-release females would normally be achieved by draining a pond, removing the females and then rapidly re-filling the small (150 m^2) ponds. However, due to the larger size of the ponds (1,000 m^2) it was not possible to rapidly re-fill the ponds at the PFRC.

Figure 16. The very large purpose built marron ponds at the Pemberton Freshwater Research Centre used in the breeding of marron to be restocked into Lake Navarino after refurbishment.

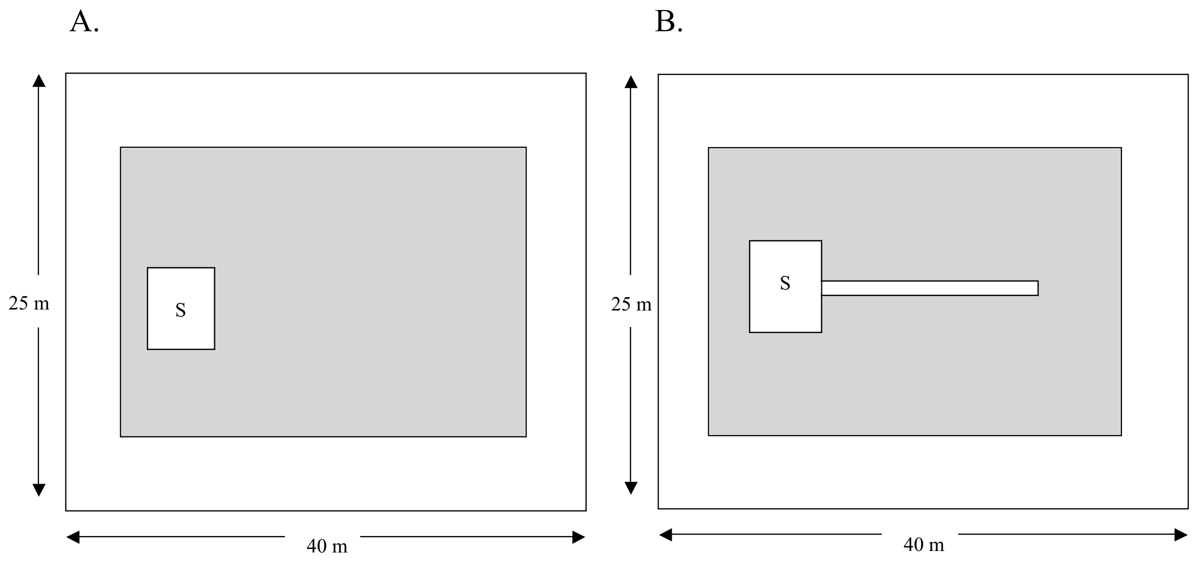


Figure 17. Schematic design of; A.) a typical 1,000 m^2 marron grow-out pond with 3 x 3 m concrete sump (S); B.) a 1,000 m^2 large nursery pond constructed at the Pemberton Freshwater Research Centre to support the current project, with a 3 x 3 m concrete sump (S) and a 9.6 m concrete channel to allow the aggregation of large numbers of juvenile marron. From Molony (2002c).

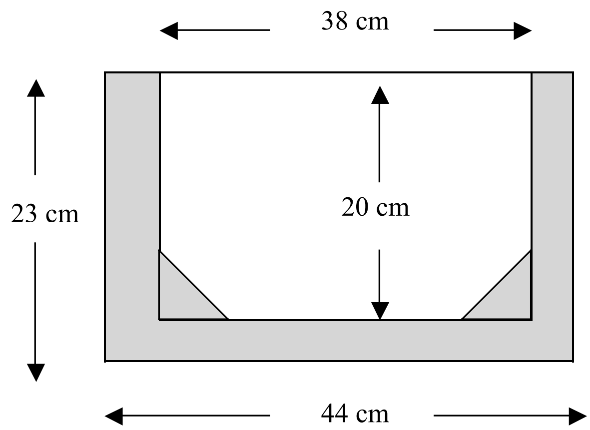


Figure 18. Details of the cross-section of the 9.6 m concrete drain available as 'small spoon drain section' from many concrete product manufacturers in 1.2 m lengths. From Molony (2002c).

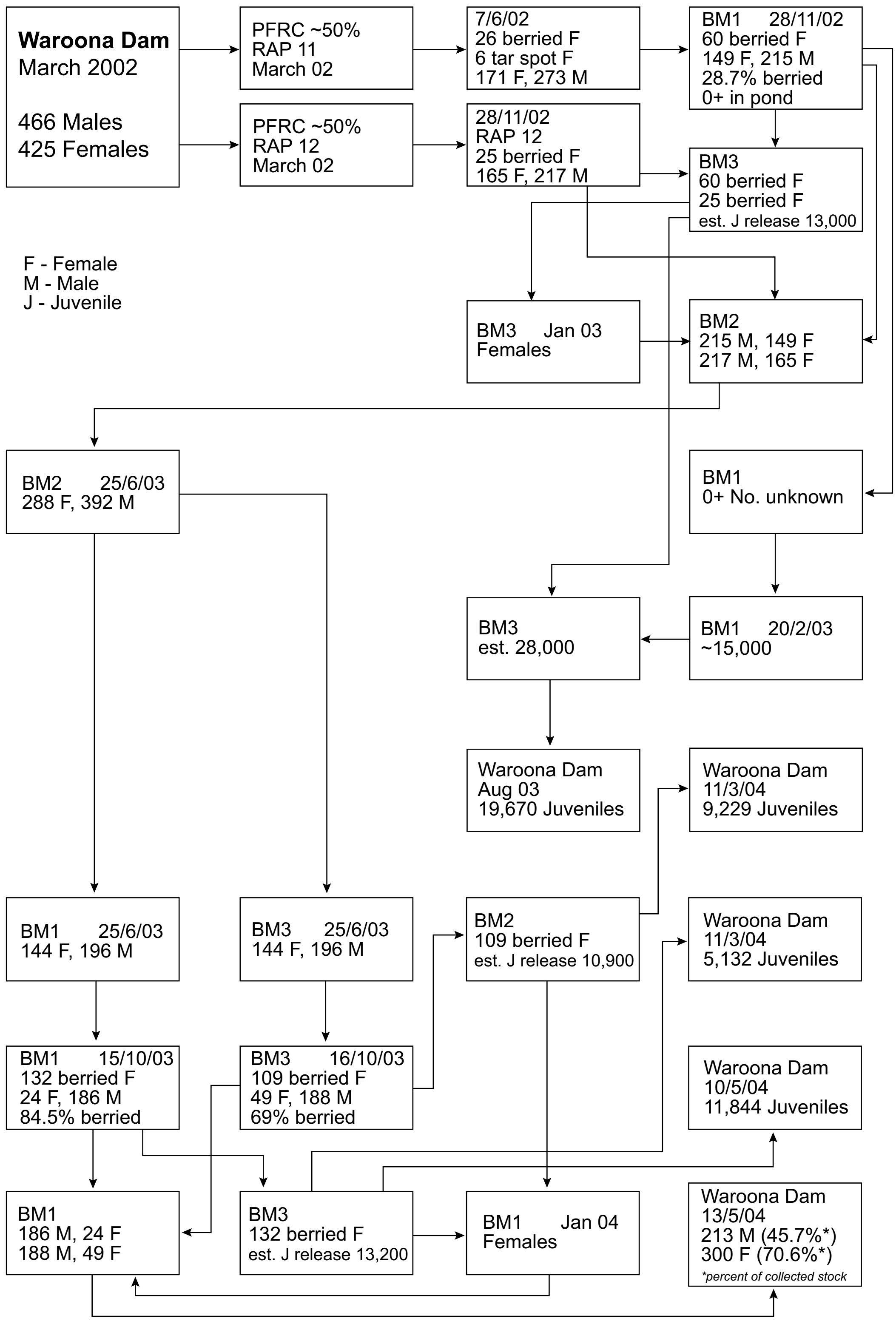


Figure 19. Flow-diagram of stock management for the marron breeding program at PFRC.

4.3 Results and discussion

It is generally assumed that an average of 100 juveniles survive to the juvenile harvesting stage per berried female (Lawrence and Jones 2002). In the first production year at PFRC (2002), it was estimated that from the 85 (21%) of females that had berried-up that approximately

8,500 juveniles would be released. However, during the transfer of females after the release of juveniles, the number of juveniles produced was estimated at 25,000. The higher then expected number of juveniles may be a result of under-estimating the berry-up rate, more eggs being produced per female or that individual females bred early and late while in the ponds at the PFRC. Regardless, by the time of stocking these juveniles into Waroona Dam in August 2003, approximately 19,670 advanced juveniles were released (the reduction in numbers was due to cannibalism by juveniles) (figure 20).

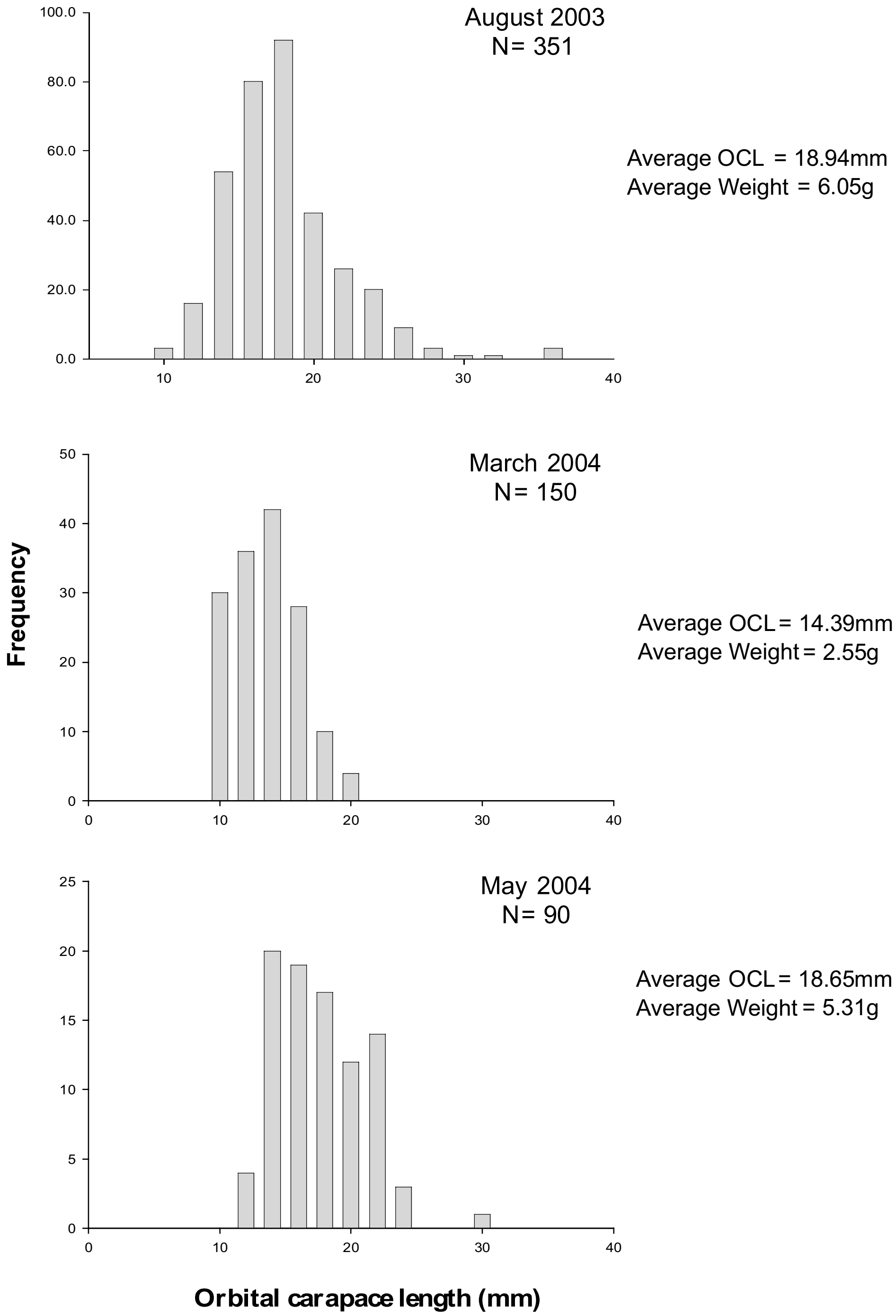


Figure 20. Size distribution of sub-samples of 0+ marron produced at PFRC at time of stocking into Waroona Dam (excludes broodstock).

In the second production year (2003), an estimated 241 (76.8%) of females had berried-up and therefore approximately 24,000 juveniles (i.e. 241 x 100 juveniles) could be expected. However, between March and May 2004, an estimated 26,205 juvenile marron were stocked into Waroona dam. Thus, approximately 45,875 juveniles were produced from the PFRC, far exceeding the target of 25,000 juveniles expected at the start of the project. The reason for the higher than expected production of juveniles is due to either the number of eggs produced per female or the high survival rate of juveniles (or both).

The re-stocking of juvenile marron commenced after the artificial habitats were submerged (>196 m AHD). Re-stocking of marron from the PFRC involved initially hide harvesting juveniles (figure 16) from the 1,000 m^2 ponds. When most juveniles had been removed from hides within an individual 1,000 m^2 pond, the pond was completely drained and all remaining juvenile marron collected by hand from the concrete channel of the drained pond. All marron harvested were moved into purging tanks with high dissolved oxygen levels until packing. Approximately 2 kg of juvenile marron (~250-500 individuals) were packed into a polystyrene foam boxes with ice bricks and damp sponge to keep cool. These were transported promptly to Lake Navarino and released on the shore-line adjacent to the artificial habitats (see Chapter 6) or along the rock armour of the inside of the dam wall (figures 21, 22, 23).

In May 2004, the pond housing the surviving original broodstock was drained with a total of 213 male (45.7% of the original number of males collected in March 2002) and 300 female marron (70.6% of the original number of females collected in March 2002) were similarly re-stocked into Lake Navarino, where they will have the opportunity to breed in situ and provide additional cohorts of juveniles. The survival of adults was extremely high, especially as the adults had been originally collected from a ‘wild’ source of unknown feeding history and condition, and were used as broodstock in two consecutive years.

Typically, broodstock marron are either purchased from a commercial marron producer or are on-grown from juveniles produced at a site. In both cases the breeding history, feeding history and condition of broodstock are known. Nonetheless, it is rare that broodstock are re-used in commercial farming situations and broodstock are usually sold for human consumption after juvenile release. This is due to the concept that reproduction is energetically expensive for marron and that the reuse of broodstock would result in the low production of juveniles in future years. This is supported by the observation of high mortality rates of females during the first post-spawning moult (G. Cassells pers. comm.). However, in the production system at the PFRC this was not observed with juvenile production and overall survival being extremely high. The reasons are likely to be due to the supply of good quality food (marron and trout pellets), experienced husbandry of the staff at the PFRC and the high level of monitoring throughout the entire project. The results demonstrate the importance of good husbandry practices in marron production for a re-stocking program.

The aquaculture benefits of high survival of broodstock marron following breeding is that there is the ability to sell more stock for consumption (at approximately \$20 – 25 per kg) or to reuse broodstock in future years, allowing for selective breeding based on preferred traits (e.g. high juvenile production, good juvenile survival).

Figure 21. Juvenile marron collected from the Pemberton Freshwater Research Centre, May 2004, by hide harvesting showing the variation in sizes from a single cohort (see also Fig 16).

A.

B.

Figure 22. Restocking of marron from the Pemberton Freshwater Research Centre in May 2004. A). A load of marron packed in foam boxes arriving at Waroona Dam. B). Restocking marron into Lake Navarino adjacent to one of the artificial habitats.

A.

B.

Figure 23. Inside view of the new wall of Lake Navarino showing the extension to the rock armour (to reduce the damage to the wall due to wave action). A). Extent of the new wall with the side extensions visible (as light coloured rock). B). Close up of the wall showing a large number of crevasses and holes.

5. Breeding at Alcoa's Willowdale Farm and Murdoch University

Stephen Beatty

5.1 Introduction

Alcoa's Willowdale Farm (AWF) (figure 24) aimed to provide a close-by, secure backup facility to the PFRC to house endemic Lake Navarino fauna, addressing the risk of stock loss from the main facility. As described in Chapter 4, the intensive management techniques employed at PFRC proved very successful. An alternative management technique of the wild stocks placed in AWF aimed to provide a assessment of the relative benefits of relatively high cost, labour intensive management of captively held aquatic fauna (as occurred at PFRC) to less intensive management of the wild stock in AWF, as would be more typical of conditions naturally encountered by marron in Lake Navarino. Although beyond the scope of this report, some cost-benefit comparisons would also be able to be drawn in terms of production of marron between the two sites, which may be useful in selecting appropriate breeding programs in future projects.

The use of Murdoch University as an additional site for holding aquatic fauna from Lake Navarino was designed as a further precautionary measure against stock losses of native fish and gilgies from AWF. As mentioned in Chapter 2, the abundances of native fishes in Lake Navarino were extremely low. As no western pygmy perch were located in Lake Navarino, the western minnow was the only endemic fish species to be de-stocked from the lake and transferred to the two holding sites.

A.

B.

Figure 24. The capture of ex-broodstock in August 2004, from Alcoa's Willowdale farm for restocking into Lake Navarino. A) Using a 10 m seine net. N.B. the artificial marron hides (black floats) and the perimeter marron fence (foreground). B) An ex-broodstock western minnow (August 2004).

5.2 Methods

5.2.1 Alcoa's Willowdale Farm

The AWF is a purpose built aquaculture facility located next to major areas of bauxite mining and is managed under the Alcoa *Farmlands* program. For the current project, two ponds with areas of 810 and 900 m^2, not directly part of the aquaculture program at AWF, were made available. These ponds did not have bird netting which is a crucial part of predator (i.e. cormorants) control in marron farming, including at PFRC, and therefore bird netting was constructed in April 2002 (during the latter part of de-stocking). The lateness of construction, i.e. towards the end of the de-stocking program, was due to the timing of the drainage of Lake Navarino being unexpectedly brought forward. One hundred weed-bunch style hides were constructed and placed into the ponds to increase the available habitat which increases survival of juveniles upon release from females. A diesel-powered blower provided aeration during the early morning, when oxygen levels are generally lowest due to autotrophic respiration.

As described in Chapter 2, 1,213 marron (sex ratio 1 female : 1.248 male) de-stocked from Lake Navarino were placed in the AWF ponds during April and March, 2002. There were early stock losses due to the avian predation prior to the bird netting being constructed and from marron walking out of the ponds. An estimated 300 marron were lost during the first two months. However mesh fencing was constructed to prevent further walking and the bird netting was completed and subsequently very few deaths were observed. The average density of these animals in the ponds was ~0.7 m^{-2}. A majority of these animals were mature when stocked (figure 5) (Beatty et al. 2003b). As with the PFRC program, the de-stocked broodstock marron from Lake Navarino were used for two consecutive breeding periods with juvenile release occurring in late 2002 and 2003. Marron were fed commercial marron pellets.

In contrast to the management techniques of PFRC, no pond draining occurred at AWF with the use of the less obtrusive techniques of trapping, seine netting and hide harvesting occurring to remove adult and juvenile individuals during the project. Juvenile marron periodically harvested from hides by manual scooping the hide using an *Environet* ™, which prevents damage to the crayfish by tangling upon capture. The final capture of ex-broodstock for transfer back into Lake Navarino occurred via the use of opera-style crayfish traps and a 10 m seine net (3 mm mesh width) (figure 24).

Western minnows that were de-stocked from Lake Navarino during February 2002 (figure 8) were also stocked into the larger of the two ponds (n = 80). These were not specifically fed as there was adequate invertebrate life in this large, established pond. These were removed from the ponds by a 10 m seine net (figure 24) and transported to Lake Navarino in an aerated fish carrier.

All references to mesh size indicate stretched mesh measurements unless otherwise indicated.

5.2.2 Murdoch University

As part a further risk management action, a secure site at Murdoch University also housed a sample of the western minnows as well as the majority of gilgies that were de-stocked from Lake Navarino. For this purpose, eight outdoor 1,500 l fibreglass tanks and an indoor 3,000 l concrete tank were stocked with 28 western minnows and 368 gilgies during 2002 (figures 6, 8). This site was chosen as the principal site for housing gilgies as this species has the propensity for burrowing and therefore harvesting from the AWF ponds would have been problematic and there would be the potential for damage to pond walls and competition with larger marron stocked into AWF. Outdoor fibreglass tanks were covered with shade cloth to reduce summer temperatures and prevent predation. Artificial marron hide material was placed in each tank and aeration was provided by electric blowers. Gilgies were fed commercial marron pellets and western minnows were fed live invertebrates sourced from North Lake (32° 04' 36.2" S, 115° 49' 16.7" E).

5.3 Results and discussion

5.3.1 AWF

Spawning rates of the 406 females in the AWF (total of 913 remained following initial losses) in 2002 were estimated at 30%, resulting in approximately 122 females spawning (c.f. 85 in PFRC in the first year (~21%)) (Chapter 4). However, juvenile harvesting during August 2003 resulted in the transfer of only 1,144 juveniles (of the expected 12,200) into Lake Navarino, reflecting an extremely high rate of cannibalism (figure 25). The estimated berry-up rate of the second breeding period during the latter part of 2003 was approximately 40% (~162 females). The progeny of the second breeding period were harvested earlier (first in April 2004 and again in August 2004) than the 2002 offspring and resulted in the transfer of 4,510 juveniles into Lake Navarino, approximately three times the survival rate of juveniles compared to the first breeding period (figure 25).

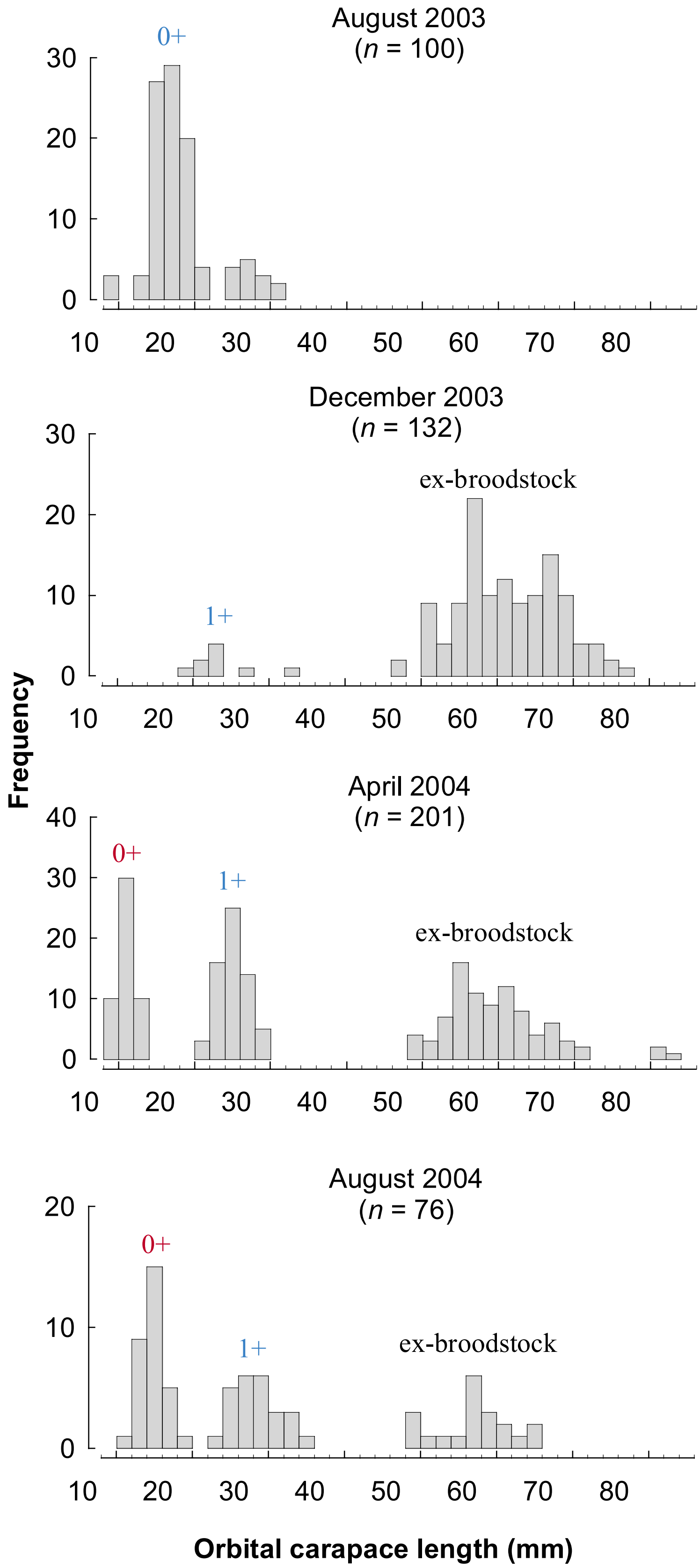


Figure 25. Length frequencies (sub-samples of overall total of 6,342 of re-stocked marron from Alcoa's Willowdale farm into Lake Navarino. N.B. blue labels the mode of the cohort produced from the 2002 breeding event and the red labels the cohort from the 2003 breeding event.

The extremely high rate of cannibalism in the AWF ponds was likely due to the high initial stocking densities, the lack of removal of females early in the year following juvenile release following the first breeding period, and the relatively late harvesting of juveniles. The greater survival rate of juveniles following the second breeding period suggests that the partial removal of ex-broodstock (from December, 2003) and early harvesting of juveniles (April 2004 c.f. August 2003 for the first breeding period) at a small size was more effective than leaving the juvenile harvesting to mid-year, when juveniles are larger and more robust.

However, as reflected by the far superior stocking figures produced from the PFRC (Chapter 4), intensive management techniques, particularly the intensive removal of females following the release of brood early in the year, appear to be a far more effective management technique for increasing juvenile survival than managing the captive population as would be more typical of a wild situation (at AWF). It was thought that the juveniles produced from AWF would be fitter (i.e. larger) than those produced from PFRC due to selection for those juveniles able to out-compete other siblings and avoid predation early in life, a situation that would be more typical of what naturally occurs in Lake Navarino. However, comparison of 0+ sizes for both production sites (PFRC and AWF) for August 2003 and March-April 2004 (figures 20 and 25) indicated that there was little effect of management site.

Re-stocking of 688 ex-broodstock marron into Lake Navarino occurred during late 2003 and 2004 (figure 25). Overall broodstock survival in AWF was approximately 57% with most losses occurring from walk-outs and avian predation within the first two months of de-stocking in 2002.

As shown by figure 13, western minnows continued to exist in Drakes Brook throughout the project and thus complete loss from the system was unlikely. However, given the previously very low abundances of western minnow in Lake Navarino (Molony et al. 2004a), with the control of the predatory redfin perch and the addition of extra (artificial) habitat (see Chapter 6), it was hoped that stocking large numbers in the lake would result in long term increases in the abundance of this endemic species. However, reproduction of western minnows from the 80 western minnows stocked into the AWF pond was not achieved. It was therefore decided to source western minnows from a downstream site in Drakes Brook, where there were known high abundances. As this is part of the same river, genetic differences between the stocks would have been negligible as downstream movement of this species (particularly larvae), is likely to have occurred via the outlet pipe. During October 2003, 1,110 western minnows (estimated to be 0+ fish which would spawn the following spring at age one, Pen and Potter 1991, figure 8) were stocked near the refurbished wall. Although the breeding of western minnow in AWF was not successful, high broodstock survival was recorded and approximately 35% of the original broodstock were re-stocked into Lake Navarino in August 2004 (figure 8) with remaining broodstock to be held at AWF in order to continue to attempt to induce spawning by increasing habitat in the pond.

It was obvious that the intensive management techniques used at PFRC proved to be far more effective in the production of juvenile marron for re-stocking into Lake Navarino with approximately eight times the number of juveniles produced at this facility compared with AWR. Despite greater expenses involved (such as the creation of large purpose-built ponds) and greater labour costs, future similar projects that require production of large numbers of juvenile marron to allow relatively rapid re-establishment of a recreational marron fishery should also invest adequate resources to enable such intensive husbandry techniques to be employed. Conversely, should the water-body not be subject to recreational fishing and therefore the aim of the project was to ensure that the population was not lost and recovered over a period of time following re-fill, then less intensive management such as was employed at AWF, may be adequate. However, at least two facilities should be used to mitigate the risk of the loss of the population should the stock at a facility be lost (e.g. through disease).

5.3.2 Murdoch University

Figure 6 shows the length frequency distribution of the gilgies de-stocked from Lake Navarino (the vast majority of which were mature, see Chapter 2). Only 72 (21%) of these were females. This species has a relatively low fecundity compared to marron and also has a relatively short life-span (Beatty et al. *in press*). Of the 642 gilgies re-stocked into Lake Navarino throughout the project, 420 were bred in captivity at Murdoch University. These juveniles were moved into nursery tanks (to reduce cannibalism in the relatively small tanks) soon after release in late 2002 and again in late 2003. The first breeding event resulted in the production and re-stocking of 242 juveniles that were removed from the nursery tanks using an *Environet*™ and re-stocked into Lake Navarino in late 2003 at an approximate age of 1 year. This species is relatively slow growing (Beatty et al. *submitted* a) and it was deemed necessary to allow the juveniles to reach an adequately robust size before transporting back to Lake Navarino.

The second breeding event occurred using fewer females, with natural mortality (due to age) apparently accounting for many of the brood deaths. As with the first breeding event, re-stocking of the 180 juveniles in 2004 occurred after a considerable period of time (approximate age of 10 months). Re-stocking of ex-broodstock into Lake Navarino occurred during the latter part of 2003, following the second major spawning event that occurred during spring 2003, the balance being re-stocked in April and August 2004.

Given the relatively small abundances of gilgies in the lake prior to this project, and this species reproductive biology, the breeding program resulted in relatively large numbers being re-stocked into Lake Navarino. Further, the location of the stocking site (near the refurbished wall) will help ensure their establishment as excellent structural habitat was available. The two tributaries continued to house relatively high abundances of gilgies (figure 13) and, there exists the possibility of this species being able to re-establish itself in the lake following re-fill. However, re-establishment of gilgies into Lake Navarino has occurred at a much faster rate as a result of the breeding program being undertaken.

6. Design and installation of artificial habitats

Brett Molony

6.1 Introduction

Correct habitat-type and availability are essential for maintaining healthy populations of all organisms, including crayfish (Rallo and Garcia-Arberas 2002) by supplying feeding opportunities, sites for breeding and refugia from predators (Molony and Bird *submitted*). However, with human development the modification and removal of habitats is common. Although the most obvious anthropogenic habitat changes occur in terrestrial systems, aquatic systems have also been heavily modified. For example, during the construction of water supply dams it is common practice to remove all structure (e.g. trees, rocky outcrops) (Molony and Bird *submitted*). The removal of structures from the basins of dams has benefits for the managers of the water supply. For example, the removal of trees can maintain high water quality by reducing the levels of organic material that will slowly decompose over time in the newly formed lake. Further, the removal of trees and timber from the basin reduces the chances of blockage of the outlet by mobile timber, potentially reducing maintenance costs. The removal of rocky outcrops often occurs to provide fill and armour for lining the inside of wall of the new dam. Finally, contouring of the new basin standardises the slope of the basin, reducing slippage and thereby reducing future maintenance costs.

Although the removal of structures from the basin of a new irrigation dam has positive engineering and maintenance outcomes, the resulting basin becomes habitat limited for aquatic species when re-filled (Molony and Bird *submitted*). A majority of the total area of new basins is composed of structurally-simple habitats, generally extensive areas of muddy or sandy substrata, typically avoided by many crayfish species (Rallo & Garcia-Arberas 2002). The subsequent lack of aquatic habitats is common in the large irrigation dams of south-western Australia (Figure 26).

One management option for mitigating the negative impacts of habitat loss is the installation of appropriate artificial habitats. Although the use of artificial habitats has a long history of application in marine ecosystems (e.g. Seamand and Sprague 1991), the application in freshwater ecosystems is relatively new, with most emphasis placed upon restoration of fish passage and access to upstream areas (Pen 1999). However, Molony and Bird (*submitted*) showed that simple artificial habitats, representing common freshwater structures of south-western Australian freshwater systems (rocky outcrops, fallen trees and aquatic macrophytes, Pen 1999) not only concentrated existing marron biomass within a habitat-limited water supply dam, but also increased the productivity of marron and local biodiversity. Further, Molony and Bird (*submitted*) found that marked marron were faithful to a habitat-type and that catch-rates and abundance of marron were much higher on rocky-type and fallen-timber type habitats than control sites or macrophyte-type habitat.

Figure 26. Views of the basin of Lake Navarino prior to refurbishment works, April 2002. Note the lack of structure and the generally homogenous nature of the basin with the exception of the original creek-line and the dam wall.

6.2 Habitat design

It was proposed and accepted that artificial structures would be installed into the basin of Lake Navarino during refurbishment operations. The artificial habitats were designed to be suitable for marron and other endemic aquatic species based on the results of Molony and Bird (*submitted*). Further, the habitats were designed to meet the requirements of Water Corporation; specifically, the habitats had to be constructed so as not to increase the risks of blocking the outflow of the dam and to not reduce water quality. Finally, habitats had to be simple to construct and cost-effective. As a result, a rock-line habitat was designed (figures 27 and 28), using rocks sourced from surrounding areas.

A.

B.

Figure 27. Views of two complete rock-pile habitats in Lake Navarino. Note the extensive rock armour of the dam wall that will also provide habitat. Also note the lack of other structure in the basin. (Photographs by Kerrie Hawkes, Water Corporation of Western Australia).

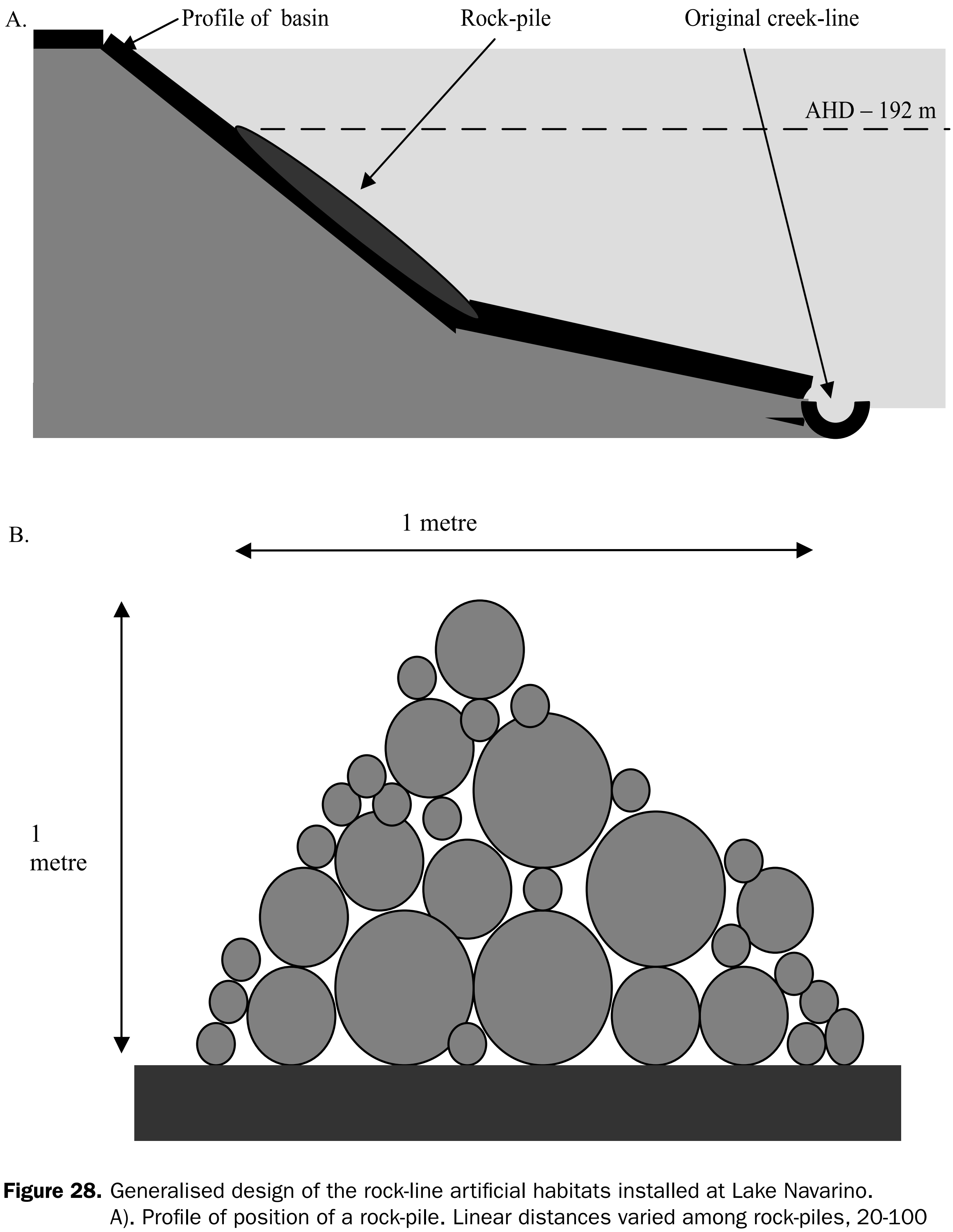


Figure 28. Generalised design of the rock-line artificial habitats installed at Lake Navarino. A). Profile of position of a rock-pile. Linear distances varied among rock-piles, 20-100 m long; B). Stylised cross-section of a rock-pile demonstrating the large number and random position of holes and crevices of the structures.

6.3 Habitat location and construction

The position of the habitats within the basin also had to meet certain requirements. From a biological perspective, the habitats had to be distributed around the dam to generate as large an area as possible to be positively affected by the provision of the habitats. The habitats also had to be positioned such that at least part of each structure would be covered by water, regardless of the water level in the dam, allowing constant access by aquatic organisms. Secondly, the placement had to allow access by earth-moving equipment within the basin during the refurbishment process. Thirdly, the top of each habitat had to remain below 196 metres AHD, two metres below the water level when Waroona Dam is closed to water skiing (198 metres AHD). Finally, habitats could not be placed adjacent to the two major ski take-off and landing areas. The last two requirements were to reduce the risks of injury to members of the public.

Originally, sites for twelve rock-pile habitats were selected. However, the reinforcing of the inside of the Waroona Dam wall with rock rubble to minimise erosion (figure 23) provided a large area of similar habitat and it was agreed that the wall plus five rock-piles would provide more habitat than twelve rock-piles alone. Construction of the rock-piles commenced at the end of the basin refurbishment process and was completed in May 2003.

6.4 Discussion

The installation of artificial habitats into Waroona Dam is only the second large-scale installation of habitats into the basin of a large reservoir in Australia. The first was during the refurbishment and extension of Harvey Dam, also in conjunction with the Water Corporation and the Department of Fisheries.

The benefits of installing habitats into the basins of dams in which most structures were removed have been demonstrated by Molony and Bird (*submitted*). In Big Brook Dam (116° 05' E, 34° 33' S), small habitats not only concentrated marron and increased the abundance of juvenile marron (less than 10 mm orbital carapace length) but also increased local biodiversity. For example, gilgies, aquatic snails, dragonfly nymphs (Order: Odonata) and epiphytic algae were commonly found on or under the artificial habitats. Further, catch rates of marron were higher around rock-type and pipe-type habitat than in control sites and weed-type habitat, increasing recreational fishing value. There was also evidence of increased abundances of berried female marron around the artificial habitats (Molony and Bird *submitted*).

There are risks to aquatic animals with the installation of effective artificial habitats. As marron and other aquatic species are likely to become concentrated around effective artificial habitats, they may become more vulnerable to recreational fishing. If the recreational fishers can locate artificial habitats, fishing effort may locally deplete marron abundance and increase the local exploitation rates around artificial structures, a similar situation recorded in marine studies (Polovina 1991, Pickering and Whitmarsh 1996). As a result, details of the location of the artificial habitats in Lake Navarino have not been released.

Although the artificial habitats installed in Lake Navarino and the refurbished wall of Waroona Dam are likely to have positive effects to populations of aquatic organisms in Lake Navarino, including marron, the formal evaluation of these structures should be undertaken. In a single pilot evaluation in Lake Navarino (10 and 11 May, 2004), the catch rates of re-stocked marron increased with proximity to the artificial habitats (Bird and Nguyen pers. obs.). Formal evaluation of the effectiveness of the installation of artificial habitats in Lake Navarino in-terms of biodiversity and recreational fishing objectives is likely to occur after the present project, managed by the Department of Fisheries. This will provide insight into the overall effects of a known area of artificial habitat, allowing fishery and dam managers to consider the installation of an appropriate number or extent of artificial habitats for a given water body. Further, as the structures are separated by at least 100 m, evaluation of the distance that effects can be detected (e.g. catch-rates of marron) can provide information on the appropriate distance apart that structures should be placed during the refurbishment of other dams. The evaluation of the artificial habitats in Lake Navarino and Harvey Dam provide the ideal locations for testing the effectiveness of artificial habitats in irrigation dams of south-western Australia and should be undertaken.

7. Re-stocking of Rainbow Trout from the PFRC

Brett Molony, Anthony Church, Chris Bird and Vinh Nguyen

Since 1990, catches of rainbow trout from Lake Navarino have been relatively low, while catch rates of redfin have been increasing (Molony unpublished data). The re-stocking of rainbow trout into Lake Navarino was planned to commence in late 2004 or 2005, depending on the recovery of marron populations to at least pre-dam refurbishment levels, to reduce predation on small, newly released stocked marron. However, reported illegal public stocking of rainbow trout allegedly occurred in early 2004 (Department of Fisheries Trout Stocking Committee meeting, April 2004) although gill netting surveys conducted in May 2004 were unable to capture any rainbow trout. This may be a result of poor stocking practices or that the stock used was inappropriate for the location. For example, Lake Navarino is the most northerly public impoundment regularly stocked with trout from the PFRC. Recently, Molony et al. (2004c) showed that the growth performance and heat tolerance of the PFRC line of rainbow trout exceeded that of a naturalised line from Serpentine Dam. Thus, the illegal stocking of trout may have been unsuccessful. However, the decision was made to re-stock rainbow trout as soon as possible in time for the 2004 freshwater angling season (commencing in early September).

Due to the production cycle of trout at the PFRC, trout for recreational stocking are only available at certain time of the years. Typically, yearling rainbow trout (ca. 100 mm total length (TL) and 8 – 10 months of age) are available for stocking in April and May each year, fry (ca. 45 mm TL and 3 – 5 months of age) are available for stocking between August and October and ex-broodstock (ca. 350 mm TL and two years old) become available for stocking in late July (Anthony Church, PFRC Manager, pers. comm.).

A total of 6,000 yearlings were stocked in into Waroona Dam in May 2004. Additionally, 2,755 ex-broodstock were stocked into Waroona Dam in August 2004. It was decided that rainbow trout fry would not be stocked into Waroona Dam due to the presence of juvenile redfin perch observed in the dam in January 2004 (G. Chaffey, pers. comm.) and their high predatory impact on rainbow trout fry (Molony et al. 2004a).

8. Post-stocking monitoring of Lake Navarino

Chris Bird, Vinh Nguyen, Stephen Beatty and Brett Molony

8.1 Introduction

Without post-implementation assessment, the effectiveness of the control and re-stocking programmes of the current project would be unknown (Molony et al. 2003c). Therefore, a range of monitoring surveys occurred after all control measures and after different stages of the re-stocking programme. This section briefly highlights the monitoring activity and results (much of which was completed in conjunction with the control of exotic species (Chapter 3).

8.2 Methods and results

On the 13 and 14 August 2003 (two weeks prior to the commencement of re-stocking), a fish and crayfish survey using gill nets and 20 marron traps was undertaken (see Chapter 3). After approximately 18 hours soak time of all gear, a total of three marron, one gilgie and a single redfin were captured. All crayfish were retuned while the redfin was euthanased.

At dusk on the 7 October 2003, approximately 800 m of bank was baited with layer pellets laced with blood and bone at 10 metre intervals. The baits were left for one hour and then a visual inspection of all baits for the presence of marron and fishes was performed, with a second visual inspection approximately two hours post baiting. No marron were observed at this time, likely due to the small expected size of marron present at this time (that were stocked in August 2003).

Sampling of fishes and crayfishes occurred prior, during and after restocking between 10-12 May, 2004 to coincide with the release of the second cohort of juvenile marron from the PFRC. Sampling for crayfish was conducted by scoop netting around the artificial habitat sites on the night of the 10 May 2004 with a total of 103 marron (figure 14) and 1 gilgie captured (Chapter 3). Gill nets were set in order to cover all areas of the basin of Lake Navarino. Sampling resulted in the capture of 93 redfin perch and 14 brown trout, with no native fishes or rainbow trout captured. The gut contents of 39 redfin perch captured after the release of 11,844 juvenile marron were examined for the presence of final stocking of juvenile marron. Eight redfin (20.5%) contained juvenile marron at an average of 2.4 marron per fish. This level of predatory impact by marron is high but not as high as the pre-draining estimated (Molony et al. 2004a). No brown trout were captured after the stocking of juvenile marron and therefore the guts were not examined.

The final survey was conducted in August 2004 using gill nets and opera traps, which resulted in the capture of a six rainbow trout and a single redfin perch, probably reflecting cool temperatures at that time rather than a decline in the redfin population.

8.3 Discussion

The pre-stocking fish survey revealed the presence of a single redfin, indicating that the control of feral fishes in Waroona Dam was not 100% effective. Although less than 100% control of redfin was recorded, the number of redfin was reduced by over 99.9% compared to pre-control estimates (Chapter 3) and the reduction in redfin would at least allow marron and other aquatic species to establish while feral redfin numbers were low. The high proportion of redfin with juvenile marron in their guts highlights the need for ensuring 100% control of this species in future projects of this type, potentially with more extensive and/or additional techniques employed.

The size distribution of marron collected in the May and August 2004 suggested that they were likely composed of ex-broodstock marron from Alcoa Willowdale stocked in April 2004 and juvenile marron stocked from the PFRC in August 2003 (table 5). The distribution and abundances of marron indicates that stocked marron have survived well in the refurbished Waroona Dam. Further, the establishment of a large marron population, was probably assisted by the additional habitat established within the basin as part of the refurbishment process.

However, to accurately compare pre- and post- refurbishment populations of marron, a full assessment is required. An assessment of this type is planned for Lake Navarino in late 2004, as part of a pre-season survey for marron before the commencement of the first marron season in Lake Navarino for three years (January 2005). At this time, a full fish assessment will also be undertaken.

Table 5. Summary of restocking of aquatic animals into Lake Navarino in 2003 and 2004. [Value provide an estimated dollar value of stock without a premium for a specific genetic line]. Juvenile marron - $0.50 ea.; Adult marron - $25-00 kg^{-1}; Native fishes - $3-00 ea.; Gilgies - $3-00 ea.; Rainbow trout yearlings - $1-00 ea; Rainbow trout ex-broodstock - $4-00 ea.

Species	Breeding Site	Life Stage	Stocking Date	Numbers Stocked	Value* ($)
Marron	PFRC	Juvenile	August 2003	19,670	9,835.00
	PFRC	Juvenile	May 2004	26,205	12,602.50
	PFRC	Ex-broodstock	May 2004	513	2,137.50
	AWF	Juvenile		5,654	2,827.00
	AWF	Ex-broodstock		688	2,866.50
Total marron				**52,730**	**30,268.50**
Gilgies	Murdoch	Juvenile	October 2003	202	606.00
		Adult	October 2003	123	369.00
		Juvenile	December 2003	40	120.00
		Adult	December 2003	80	240.00
		Adult	April 2004	3	9.00
		Juvenile	August 2004	180	540.00
		Adult	August 2004	14	42.00
Total gilgies				**642**	**1,926.00**
Western minnows	Drakes Brook	Adult	October 2003	1,110	3,330.00
	AWF	Adult	August 2004	28	84.00
Total western minnow				**1,138**	**3,414.00**
Rainbow trout	PFRC	Yearlings	May 2004	6,000	6,000.00
	PFRC	Ex-broodstock	July 2004	2,755	11,020.00
Total rainbow trout				**8,755**	**17,020.00**
Grand Total				**63,265**	**52,628.50**

9. General discussion

Brett Molony, Stephen Beatty, Chris Bird and Vinh Nguyen

9.1 Project summary

Each objective of the project is measured against the outcomes, below.

- *De-stocking program.*

  1. Many animals were removed from the lake. Apart from the mortality of a large number of marron that occurred during the last stages of draining of the dam, no major mortalities of other species observed. This is a critical outcome as even relatively small fish kills invoke public concern.
  2. In excess of 50 volunteers were involved in the night-time de-stocking work. The involvement of a large number of volunteers from a range of groups greatly assisted the destocking program by providing a higher level of effort than would be possible by project staff alone. Further, the assistance by volunteers encouraged community ownership for the project and a great deal of publicity.
  3. Popular articles in local press and corporate publications publicised the importance of the project for two government organisations, a leading University and a multi-national company. In addition, two scientific documents also discussed the objectives and importance of the project during the initial phases.
  4. Similar projects in the future should consider maximising the amount of time and resources allocated to de-stocking programs. This would have further increased the success of this aspect of the project and the breeding programs.

The results of the de-stocking component of the project met and exceeded the expectation of the first objective.

- *Breeding programs.*

  1. Intensive and semi-extensive breeding programs were used for a range of endemic species in this project. The comparison of breeding programs with different management strategies highlighted the appropriateness of intensively managing stocks for the production of large numbers of aquatic animals, especially for recreationally important species.
  2. All programs addressed the issue of maintaining the genetic diversity of the stocks of aquatic animals from Lake Navarino by not applying selection for broodstock, using multiple, independent stocks, and returning all progeny and ex-broodstock back into Lake Navarino.
  3. Less than expected numbers of broodstock of all species were de-stocked for the breeding programs. This could be improved in the future by allowing more time and resources for destocking work.
  4. The breeding programs were particularly successful given that all stocks were undomesticated and there was no specific information about the performance of any of these stocks under culture conditions.

5. More than twice as many marron were returned to Lake Navarino than estimated prior to draining (pre-draining estimate: 12,443 – 20,927 marron; total re-stocked was >50,000 captively bred marron plus 1,201 ex-broodstock). Further, three cohorts of marron were returned, providing a stable population structure, including marron of greater than minimum legal size; that is, an instant fishery.

6. The use of multiple production sites reduced the risk of complete breeding-stock loss due to unforeseen events at any single site.

7. The consequences of the breeding failure of the captively-held western minnow was negligible as this species uses perennial tributaries that feed into Lake Navarino as a refuge. The stocking of individuals sourced from downstream into Lake Navarino following re-fill was deemed appropriate as there would have been historical movement of this species from Lake Navarino downstream through the outlet pipe.

Therefore, the results of this component of the project generally exceeded initial expectations.

- *Excess stock relocation to adjacent water-bodies.*

  1. Very few animals above that required for the breeding programs were removed from Waroona Dam.

  2. Only a small number of rainbow trout were relocated below the wall Waroona Dam into lower Drakes Brook.

  3. Nevertheless, all additional stock were moved to adjacent waters where they were released and available for recreational angling or for biodiversity reasons.

Greater time allocated for de-stocking would have increased the success of this aspect of the project.

- *Control of feral species*

  1. This was the most ambitious objective of the project as the control of feral aquatic species in large impoundments has rarely been attempted.

  2. Due to the scale of the dam, the control of feral species commenced in October 2001 and continued until August 2003. During this time in excess of 1,500 redfin perch were removed and euthanased prior to the commencement of re-stocking. Although not 100% effective, the number of redfin were reduced by greater than 99.9% by the combined effect of movement downstream, netting, draining and concussive techniques. It is also possible that illegal stock of redfin occurred during 2004, similar to the original illegal introduction of redfin in the early 1980s (Molony et al. 2004a), compromising the eradication attempts.

  3. It is likely that most redfin were removed by movement through the outlet pipe downstream. Although effective in reducing numbers within the lake, this was not a desirable result due to likely impacts on downstream ecosystems.

  4. Future similar projects involving feral species should screen the pipe during drain-down and control of the species should occur exclusively within the lake. The screen should be as small as possible to reduce the risk of feral species moving among waterbodies.

5. Successful establishment of re-stocked marron was aided by multiple age classes being present at the time and the increase in habitat providing refugia from predation, reducing the impacts of predatory fishes.

6. The concussive technique was only partially successful due to the relatively large volumes of residual waterbodies and the complex topography of the coffer dams. Designing and building coffer dams to allow more efficient control of feral species should be considered in the future (e.g. smooth regular basins with no depressions).

7. The extensive netting and sampling of the lake confirmed that yabbies, another feral species that can potentially negatively impact endemic species including marron, were not present.

8. To ensure complete eradication of feral species in future similar projects, either complete drainage of the lake would be required or very small residual coffer dams be constructed to increase effectiveness of eradication techniques. This is a critical consideration for future projects.

Overall, redfin numbers were greatly reduced although not totally eliminated. However, the reduction in redfin abundance would have allowed a 'head-start' for highly vulnerable stages of endemic species re-stocked into the dam, especially marron.

- *Habitat creation*

1. Prior to the project, the basin of Waroona Dam contained very little structure.

2. The establishment of rock-piles plus the massive extension of the rock armour of the inside of the wall of Waroona Dam, dramatically increased the diversity of aquatic habitats.

3. The positioning of the habitats and extension of the wall mean that at least some proportion of all habitats will be submerged at all expected operating levels of Waroona Dam.

4. The type of material was appropriate for both aquatic species and water managers as it is locally available and has been previously shown to be used by marron, gilgies and other aquatic species in south-western Australia.

5. The position of the rock-piles means that other users of Lake Navarino (particularly water skiers) will not have their amenities impacted by the habitats.

This objective of the project was successfully met.

- *Trout stocking*

1. Ideally, this was to occur later than May 2004 due to the presence of relatively small, captively bred marron in the lake upon which trout are known to predate.

2. The alleged, illegal stocking of rainbow trout and the continued presence of redfin perch was thought to reduce the value of delaying the stocking of trout. It was considered more appropriate to stock trout in May 2004 to enable recreational trout fishing to recommence in late 2004.

Despite the change in timing of the re-stocking of rainbow trout, this was planned to occur regardless and therefore this objective was met.

9.2 Likely results of a 'do-nothing' approach

Lake Navarino has been drained before (early 1980s) and populations of aquatic organisms recovered without intervention. Therefore, it is likely that aquatic populations would have again recovered without intervention following the draining and refurbishment of 2002. However, the rate of recovery without intervention would have been considerably slower than is predicted following the current project.

There are some major differences between the most recent draining and the draining of the early 1980s. Firstly, the period of draining in the 1980s was much shorter than the most recent event. However, in the current, Lake Navarino has not been allowed to totally fill since 1997; thus the volume of in the reservoir has been reduced and there is likely to be reduced abundances of aquatic organisms than if the dam was at full capacity. Secondly, the draining of the dam in the most recent refurbishment works resulted in the level of the dam being reduced, partially filled and then again drained over about an 18 month period. This was likely to have reduced the abundance and reproductive success of aquatic organisms, especially fishes where reproduction is often cued by changes in water levels at the correct time of the year (Morgan et al. 1998, Pen 1999). Thus populations of aquatic organisms are likely to have been reduced in Waroona Dam prior to the final drain-down in April 2002, reducing capture rates during de-stocking. Further, a large number of marron mortalities were observed immediately after the lake was drained to minimum levels in April 2002. Without de-stocking, more deaths would have resulted.

Finally, the breeding programs resulted in the re-stocking of multiple size and age classes of crayfish species that are similar to natural populations. This means that there are animals of a range of life-stages that increase the likelihood of establishment of species in the refurbished dam and therefore positive biodiversity values. Further, a proportion of both marron and rainbow trout populations will be above legal size at the commencement of the next fishing season, resulting in an 'instant' fishery.

9.3 Lessons learned

Despite the overall project being successful, there are some refinements that could improve the outcomes of similar projects in the future.

- *Increase in efforts of de-stocking*

The de-stocking programme was limited by the time available to collect animals before drain down. An increase in time would allow further de-stocking efforts. This would both increase the number of broodstock animals collected, increasing the genetic diversity and numbers of animals produced, and further reduce marron mortality. In addition, earlier collection of broodstock (i.e. December – January) would allow more time to improve the breeding condition of marron (and other aquatic species) that may have increased the berry-up rates in the first year of breeding, to the 78% estimated in the second breeding year at the PFRC. This would have resulted in even more marron being re-stocked into the refurbished Lake Navarino.

- *More effective control*

A longer de-stocking time period before draining would have better ensured the complete eradication of redfin perch in the lake. Two major coffer dams were of a regular, relatively deep profile, ideal for blasting. However, the walls of the coffer dams were removed 24 hours prior to blasting, resulting in, larger irregularly-shaped water-bodies. Further, the profile of the dam was not even and contained many shallow areas which were effectively protected from the blasting effects. This reduced the effectiveness of destocking through concussive techniques. Better communication is required between contractors to create appropriate coffer dams during the refurbishment process and to retain dams until concussive control methods have been applied. Further, it is likely that many aquatic organisms escaped through the outlet and moved into lower Drakes Brook and eventually Drakes Brook Dam. Although the numbers and survival of animals is unknown, it is likely that at least some redfin survived and impacted on populations of aquatic organisms downstream in Drakes Brook. During future similar projects, a mesh screen should be used to prevent downstream release of feral species and allow the eradication of these species within the lake.

- *The installation of additional habitats*

The installation of habitats is one of the most effective and low cost techniques for increasing the abundance of aquatic organisms, especially given the lack of habitat in the basin prior to refurbishment. It is likely that the installation of even more habitats would result in a greater increase in aquatic populations due to the provision of shelter, refugia and hard surfaces for the establishment of epiphytic communities.

9.4 Conclusion

Overall, this unique project has been successful in mitigating the negative impacts of dam draining and refurbishment on biodiversity and fishery values of the lake. This has not been attempted before on a dam of this scale in Australia. The planned, long-term monitoring of the aquatic fauna of Lake Navarino will allow full evaluation of the entire project.

Further, this project has created strong linkages among the Department of Fisheries, Murdoch University, the Water Corporation of Western Australia, Alcoa, the local Waroona community and other volunteers. The results of this study can be used as a model basis for future dam works planned by Water Corporation and water management agencies in other States. The flowchart provided (figure 29) summarises the steps involved, allowing easy application to refurbishment projects in other dams planned for Western Australia.

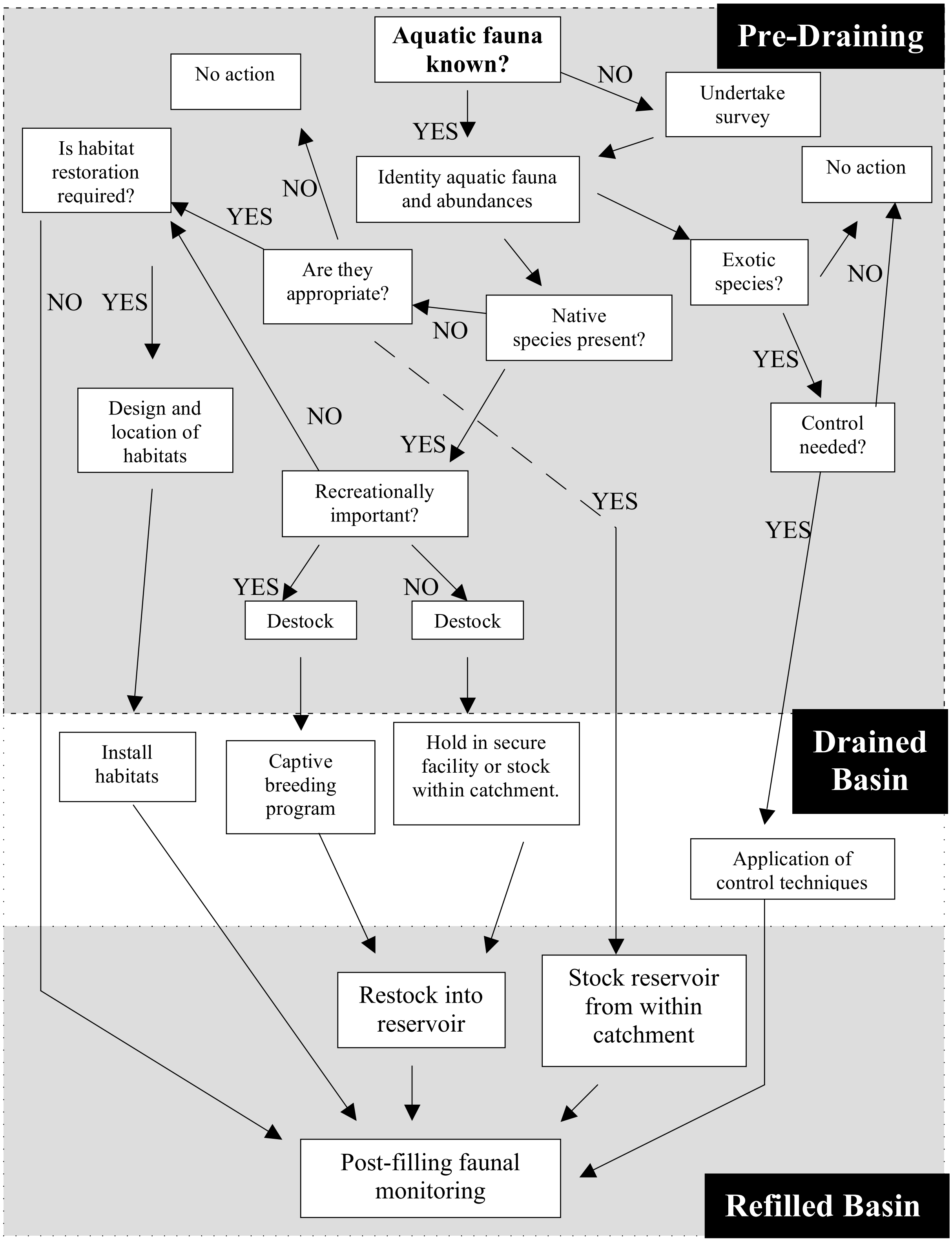


Figure 29. Flow-chart for the management of the effects of dam refurbishment on aquatic biodiversity and recreational fishing values.

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12. Appendices

Appendix 1. Future monitoring of aquatic species in Lake Navarino

Chris Bird, Vinh Nguyen, Stephen Beatty and Brett Molony

1. Comprehensive sampling of marron planned for November 2004, involving;
   - capture – mark – recapture estimates for marron;
   - Gill netting to estimate populations of predatory fish and;
   - Telephone surveys of both the recreational marron fishery and south-west freshwater angling fishery to estimates participation rates and catch rates of recreationally important species from Waroona Dam.
2. Census of artificial habitats and the inner wall of Waroona Dam to determine species use and densities. This is planned to involve;
   - Underwater visual census of the habitats to examine species use, densities and the establishment of other species (e.g. aquatic insects and other components of the aquatic biodiversity of Waroona Dam (where visibility allows));
   - The setting of fish and crayfish traps and fish traps radiating away for artificial habitats to estimate the densities of aquatic species around the habitats.
3. Regular sampling of the sediments and water column to describe the pattern of establishment of other components of the aquatic community (e.g. insects, plankton, benthos) in the refurbished dam. This will be undertaken via;
   - Estimating the densities of a range of aquatic fauna;
   - Stable isotope analysis of the community to describe the establishment of stable trophic pathways.

Appendix 2. Publications arising from this project

A.2.1. Scientific Publications

Molony, B. 2002. Evaluating large nursery ponds. In: Proceedings of Marron farming Open Day 2002 (Maguire, G. compiler). *Fisheries Management Report*. No. **6**: 33-36.

Beatty, S.J., Molony, B.W., Rhodes, M. and Morgan, D.L. 2003a. A methodology to mitigate the negative impacts of dam refurbishment on fish and crayfish values in a south-western Australian reservoir. *Ecological Management and Restoration.* **4:** 147-149.

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Molony B.W., Bird, C. and Nguyen, V. 2004. The relative efficacy of stocking fry or yearling rainbow trout (*Oncorhynchus mykiss*) into a large impoundment dominated by redfin perch (*Perca fluviatilis*) in south-western Australia. *Marine & Freshwater Research.* **55**: 1-5. (An expanded version of this paper is provided as Appendix 3 of this report.)

A.2.2 Presentations

Molony, B. 2002. Evaluating large nursery ponds. *Oral presentation at the Marron Open Day, Pemberton, October 2002*.

Molony B., and Bird, C. 2002. Evaluation of artificial habitats for marron (*Cherax tenuimanus*) enhancement in habitat-limited impoundments. *Oral presentation at the 2002 Australian Society for Fish Biology Meeting, Cairns, August 2002.*

Beatty, S. and Molony, B. 2002. Mitigation of the negative impacts on fish and fisheries values during remedial works at Waroona Dam (Poster presentation). This poster won the Murray Wetlands Working Group sponsored Best Student Conference, Margaret River. Management Poster at the 2002 Australian Society of Limnology.

Beatty, S. and Molony, B. 2004. Mitigation of the negative impacts on fish and fisheries values during remedial works at Waroona Dam *Oral presentation at the Australian Society of Fish Biology meeting, Adelaide September 2004.*

A.2.3 Popular articles

Company One: 10 June 2002. "Great Escape from Waroona Dam". Article by Penny Walsh, with text and Photographs supplied by Brett Molony.

Western Fisheries: Winter 2002. "A home of one's own…". Article by Cathy Anderson, with text and photographs supplied by Brett Molony.

Western Fisheries: Winter 2002. "Rounding up at Waroona Dam". Article by Cathy Anderson, with text and photographs supplied by Brett Molony.

Beatty, S. and Morgan D. 2002. Rescue operation for marron in Waroona Dam. *Miner's Write (Alcoa)*. October/November 2002: 4 – 5.

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Anonymous. 2003. A new start for Waroona Dam. *Western Fisheries*, Spring 2003: 40-41.

A.2.4 Media Reports

Harvey Reporter: 18 June 2002. Rescue made p13

The West Australian; *Peel Supplement*, January 2004.

Appendix 3.

The relative efficacy of stocking fry or yearling rainbow trout (Oncorhynchus mykiss) into a large impoundment dominated by redfin perch (Perca fluviatilis) in south-western Australia and associated predator risk and impact analyses

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Abstract

To compare the efficacy of stocking fry and yearling rainbow trout, *Oncorhynchus mykiss*, into impounded waters of south-western Australia to support the put-and-take recreational fishery, 20,000 fry and 1,400 yearlings were stocked into Lake Navarino (LN) and sampled over a five month period. *O. mykiss* fry were collected via seine-nets within 24 hours of stocking, however, within 60 hours of stocking, no *O. mykiss* fry could be collected by netting suggesting the total mortality of fry. However, within 24 hours of stocking, *O. mykiss* fry were present in the guts of *P. fluviatilis* and *S. trutta*. No *O. mykiss* fry were recorded in from the guts of larger *O. mykiss*. Yearling-stocked *O. mykiss* initially consumed a broader range of prey items than resident *O. mykiss* before consuming similar food within three months. A simple risk analysis of stocking *O. mykiss* fry, based on the predation rates and relative abundances of predatory fishes, indicated that *P. fluviatilis* have a relative predatory impact on *O. mykiss* fry more than 100 times greater than other fishes. *P. fluviatilis* also have greater relative predatory impact on the freshwater crayfishes *Cherax tenuimanus* and *C. quinquecarinatus* than either species of trout. Further, estimates of fishing mortality on yearling *O. mykiss* in LN were higher than natural mortality, indicating that most yearling *O. mykiss* contribute to the quality of the freshwater fishery in south-western Australia, especially given the frequency with which fishers catch and release *O. mykiss*. The results demonstrate the advantages of stocking yearling *O. mykiss* in impounded waters dominated by *P. fluviatilis*. The use of existing data of relative abundances of predatory fishes to estimate risks and relative predatory impacts can provide managers with a powerful and simple tool to assess strategies for stocking fish and the application other management options.

Key words: stock enhancement, diet-shift, marron, mortality.

A condensed version of this Appendix has been published as Molony B.W., Bird, C. and Nguyen, V. 2004. The relative efficacy of stocking fry or yearling rainbow trout (*Oncorhynchus mykiss*) into a large impoundment dominated by redfin perch (*Perca fluviatilis*) in south-western Australia. *Marine & Freshwater Research.* **55**: 1-5.

Introduction

The production and stocking of rainbow trout (*Oncorhynchus mykiss*) to provide recreational fishing opportunities are common practice throughout the world, including within Australia. In Western Australia, rainbow trout were originally translocated into the State in the early 1900's (Molony 2001, Anonymous 2002) and a purpose built hatchery was established in Pemberton (116^{o} 05' E, 34^{o} 33' S) in the 1930's (Morrissy 1972). Rearing of *O. mykiss* continues today at the Pemberton Freshwater Research Centre (PFRC) and three developmental stages are currently produced and stocked into the local south-west freshwater angling (SWFA) fishery; fry (up to 4 months old and 50 - 80 mm standard length (SL)), yearlings (between 9 – 15 months and 120 - 150 mm SL) and ex-broodstock fish (24 months old and 350+ mm SL) (Molony and Morrissy 2000). Most stocking currently involves the use of fry or yearling fish with approximately 420,000 fry and 20,600 yearlings stocked into 22 sites in the south-west coastal drainage division during the 2002 calendar year (T. Church, pers. comm.). Despite approximately 100 years of stocking, little information is available on the success of stocking *O. mykiss* in Western Australia (Molony in press). Recent catch information collected from surveys of licence holders in the SWFA fishery has indicated that between 14,000 and 26,000 *O. mykiss* have been captured annually between 1999 and 2002 (Molony 2003). It is unknown, however, whether captured fish were stocked as fry or yearlings.

O. mykiss fry are likely to suffer high mortality, especially in locations where the fish community is dominated by the introduced red-fin perch (*P. fluviatilis*), a known predator of small fishes (Thorpe 1977, Morgan *et al.* 1998, 2002). In Victoria, Baxter *et al.* (1985) showed that there was a high mortality of *O. mykiss* fry in Lake Burrumbeet, which supported a large *P. fluviatilis* population. Anecdotal evidence from experienced recreational trout anglers (Western Australian Trout & Freshwater Angling Association WATFAA pers. comm.) and staff involved in stocking operations (T. Church pers. comm.), suggest that the mortality of *O. mykiss* fry by *P. fluviatilis* immediately post-stocking may also be high in Western Australia. Despite these concerns, a relatively high proportion of *O. mykiss* produced for the SWFA fishery are still stocked as fry (ca. 95% of fish in 2002), because they are relatively cheap to produce and easy to transport. Further, the production and stocking of large numbers of *O. mykiss* fry is perceived by many recreational fishers to result in a better recreational fishery than from stocking smaller numbers of yearling fish.

One of the factors complicating the estimation of relative survival of stocked fishes is the difficulty in completely assessing survival due to the ability of fish to move beyond sampling areas. Recently, however, an opportunity arose in Western Australia to completely sample a site where movement of fish was restricted. During refurbishment of the dam wall of Lake Navarino (LN), a large (150 ha) irrigation dam in south-western Australia, the managers (Water Corporation of Western Australia) indicated that LN would be completely drained for an extended period. This allowed the assessment of the relative survival of *O. mykiss* fry and yearlings in an impoundment reservoir, typical of many dams stocked with *O. mykiss* for recreational fishing in Western Australia.

The overall objective of the project was to compare the survival of fry-stocked and yearling-stocked *O. mykiss* in LN, in order to determine their relative contribution into a significant component of the SWFA fishery. As intensive sampling was undertaken both before and after stocking, the time to the commencement of feeding in LN for each stage of newly stocked *O. mykiss* was also assessed. Finally, as large fishes resident in LN were sampled pre- and post-stocking, the project also assessed relative predation by resident fish species on newly stocked *O. mykiss*.

Materials and methods

Lake Navarino (115° 55' E, 32° 51' S), is the first large irrigation dam open to freshwater angling south of the Perth metropolitan area (approximately 120 km south). LN has been stocked with *O. mykiss* for over 30 years (T. Church pers. comm.) but catch records from WATFAA indicate that *P. fluviatilis* were illegally stocked into LN in the early 1980's and trout catches rapidly declined (WATFAA pers. comm.). Although LN has continued to be stocked with *O. mykiss* fry and yearlings, recent catch records have shown catches are dominated by *P. fluviatilis* (Molony 2003). Further, LN also supports a large recreational crayfish fishery for the marron, *Cherax tenuimanus* (Molony *et al.* 2002) and *P. fluviatilis* has been identified as a major predator of *C. tenuimanus* and other endemic crayfishes in Western Australia (Morgan *et al.* 2002).

Pre-Stocking

Prior to stocking, LN was sampled using seine (40 x 3 m, mesh size 12 mm, with a 6 mm cod end) and gill (30 x 2 m, mesh sizes 15 mm, 20 mm, 25 mm, 50 mm and 75 mm) nets in order to determine the relative proportion and sizes of fishes resident in LN and their diets prior to the introduction of *O. mykiss* fry. Samples were obtained from four seine shots between 16:00 and 18:30 hours, which were separated by at least 500 m and gill nets, with one day-time soak (set approximately 10:30 h and retrieved approximately 17:00 h) and one overnight soak (set approximately 17:00 h and retrieved approximately 07:30 h the following day). The pre-stocking sampling did not capture any *O. mykiss* fry despite collecting small *P. fluviatilis* (ca. 50 - 80 mm SL) in both seine and gill nets.

Stocking

All *O. mykiss* stocked in the present study were produced at the Pemberton Freshwater Research Centre (PFRC). At approximately 17:00 h on 30 October 2001, 20,000 *O. mykiss* fry (35 – 55 mm SL) were spread throughout LN in 1,000 fry lots. On 31st October 2001 at approximately 10:30 h, 1,400 *O. mykiss* yearlings (ca. 130 mm TL) were stocked into LN at a single location. All yearlings had their adipose fin removed the day before stocking to allow identification of *O. mykiss* stocked for the current trial from resident *O. mykiss*. (Fin-clipping of trout is commonly used at the PFRC and mortality rate and behavioural changes are negligible; T. Church pers. comm.).

Post-stocking

Sampling by seine and gill nets occurred daily from the 30 October until 2 November 2001. Subsequently, sampling using seine and gill nets occurred in January, March and April 2002, when LN was completely drained for refurbishment works. All fishes captured by seine or gill nets were retained, fishes were identified to species, counted and measured (SL ± 1 mm). On return to the laboratory, at least 10 fish per species from each seine net sample and all fish from each gill net sample were weighed and their gut and intestinal contents examined. Food items were identified to the lowest possible taxa. If *O. mykiss* fry were identified in the gut contents of any large fish, the gut contents of ingested fry were also examined to determine if fry had been feeding prior to their ingestion. Prey types were expressed as the percentage of guts (with contents) of each predatory species that contained a particular prey-item within each sampling occasion.

Risk and impact analyses

The relative risk (RR) of predation of *O. mykiss* fry by each species of predatory fish was calculated by multiplying the relative abundance of each species of predatory fish sampled during the week of fry stocking (29/10 – 2/11/2001) by the percentage of each species of predatory fish captured with one or more *O. mykiss* fry in their guts. RR was standardised by dividing the resulting number by the lowest RR calculated for any predatory species (greater than zero). Similarly, the relative predatory impact (RPI) that each species of predatory fish imposed on *O. mykiss* fry was calculated by multiplying the standardised RR by the mean number of *O. mykiss* fry in the guts of each species of predatory fish that contained *O. mykiss* fry. RPI was standardised by dividing the resulting number by the lowest RPI calculated for any species (greater than zero). Similar estimations of RR and RPI were calculated for *C. tenuimanus*, *C. quinquecarinatus* and total crayfish (i.e. pooled *C. tenuimanus, C. quinquecarinatus* and unidentified crayfish).

Population estimates for each of the three predatory species of fishes during the week of fry stocking were generated by Petersen estimates (Pauly 1984). As a known number of fin-clipped *O. mykiss* yearlings (n = 1,400) were released in LN and assuming that the catchability of all three species (*O. mykiss*, *P. fluviatilis* and *S. trutta*) by gill nets is similar (Molony pers. obs.), a population estimate can be calculated based on the proportion of tagged animals (i.e. fin-clipped) that make up a sample and the total number of animals tagged in a population (Pauly 1984). An estimate of population size for each species is calculated via;

$$N = \frac{T \times n}{m} \qquad (1)$$

where N is the estimated population of size of that species, T is the number of clipped *O. mykiss* released into LN, n is the total number of a species of fish captured at a given time and m is the total number of clipped *O. mykiss* captured at a given time. A standard error of the estimate of N is calculated via;

$$\text{s.e.}(N) = (T^2 \times n\,(n - m)/\,m^3)^{0.5} \qquad (2)$$

Estimates of mortality for yearling-stocked *O. mykiss* were able to be calculated as numbers of *O. mykiss* stocked into LN are known and estimates of angler capture rates in the SWFA fishery and angler effort to LN exist from annual surveys (Molony 2002). The estimated average fishing mortality (F) of *O. mykiss* in LN was estimated via;

$$F = \frac{(\text{total catch in LN x proportion of catch of } O.\ mykiss)}{\text{number of } O.\ mykiss \text{ stocked into LN of catchable size}} \qquad (3)$$

As a known number of yearling *O. mykiss* were stocked into LN both prior to and during the study, natural mortality (M) can also be estimated via;

$$M = \frac{(\text{Number of yearlings stocked - Current } O.\ mykiss \text{ population estimate})}{\text{Number of yearlings stocked}} \qquad (4)$$

Thus, total mortality rate (Z) of *O. mykiss* yearlings in LN during the present study is estimated via;

$$Z = F + M \qquad (5)$$

Results

No *O. mykiss* fry were captured from LN prior to stocking on 30/10/2001. Catches were dominated by *P. fluviatilis* (n= 55, 82.1%) of a range of sizes (91 – 305 mm SL), while *O. mykiss* (290 – 340 mm SL; n= 8, 11.9%) and *S. trutta* (270 – 469 mm SL; n= 4, 6.0%) were relatively rare. Only three endemic fish were recorded, all larval *Galaxias* spp. (< 10 mm SL) (Figure 1).

O. mykiss fry were captured throughout LN within 24 hours of stocking. The abundance of *O. mykiss* fry declined rapidly from 47.0 ± 20.55 per seine shot at 24 h post-stocking to 20.3 ± 17.37 per shot after approximately 48 h post-stocking. No *O. mykiss* fry were captured at approximately 60 h post-stocking (Figure 1). Petersen population estimates for each species of predatory fish during the week of *O. mykiss* fry stocking were 22,400 ± 4,427.2 for *P. fluviatilis*, 2,216 ± 274.6 for large (i.e. non-fry) *O. mykiss* and 1,225 ± 54.6 for *S. trutta*.

A total of 922 *P. fluviatilis*, covering a wide range of sizes, were captured throughout the study representing 74.9% of all fish captured (Figure 1). *P. fluviatilis* dominated all samples, except in seine net samples immediately post stocking when *O. mykiss* fry dominated the catches. Large *O. mykiss* (6.3% of total fish captured, n = 77) and *S. trutta* (1.7% of total fish captured, n = 22) were also captured throughout the study, as were fin-clipped *O. mykiss* yearlings post-stocking.

Prey items were recorded from the guts of *O. mykiss* fry within 24 hours post-stocking (Table 1) indicating that they readily fed on available prey. Gut contents of fry were dominated by Coleoptera and Hymenoptera (mainly flying stages of ants that had fallen onto the surface of the water). There was little difference in gut contents of samples collected from different days. The *O. mykiss* fry obtained from the guts of predatory fishes also contained prey items similar to those captured in seine nets (Table 1), indicating that they had been feeding, and therefore were alive, prior to being consumed.

Table 1. Gut content of *O. mykiss* fry from seines and from the guts of predatory fishes. Data are expressed as percentage of guts containing a particular prey item. Most prey items were present on the surface of the dam. (A = adult; L = larvae).

Prey Item	Seines 31/10/2001 n = 23	1/11/2001 n = 10	Predatory 31/10/2001 n = 15	Fishes 1/11/2001 n = 10
Order: Arachnida (A)	8.7			
Order: Coleoptera				
Aquatic (A)	34.8	100.0	33.3	50.0
Terrestrial (A)	4.3	100.0		
Order: Dipteran (L)	47.8	80.0		
Order: Ephemoptera (A)	13.0			
Order: Hemiptera				
Aquatic (A)	13.0	60.0		
Order: Odonata (L)		20.0		
Order: Hymenoptera				
Fam: Vesipdae (A)	82.6	100.0	60.0	80.0
Fam: Formicidae (A)	8.7	40.0		10.0
Misc: Organic matter	4.3			
Inorganic matter	8.7		46.7	60.0

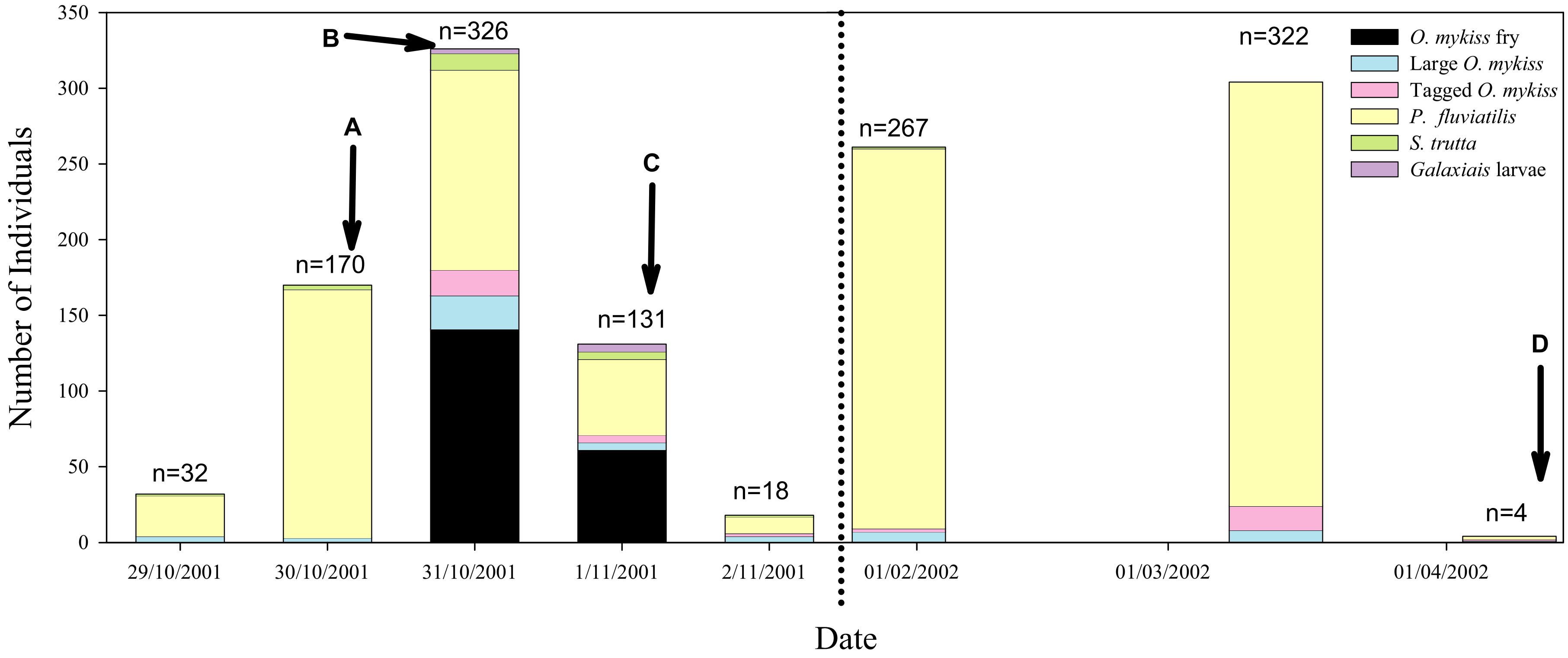

Figure 1. Catches of fishes in seine and gill nets from Lake Navarino throughout the study. [A - indicates the approximate time of stocking *O. mykiss* fry; B - indicates the approximate time of stocking *O. mykiss* yearlings; C - indicates the approximate time when *O. mykiss* fry could not be sampled via nets; D – time of complete draining of LN].

Prior to the stocking of *O. mykiss* fry, the gut contents of resident *O. mykiss* were dominated by Coleoptera (terrestrial and aquatic species), Hymenoptera (vespid wasps, flying ants), dipteran larvae, Lepidoptera and *Cherax quinquecarinatus* (gilgies) (Table 2). Although Coleoptera were also consumed, the guts of most *P. fluviatilis* contained adults Ephemoptera, smaller *P. fluviatilis* and *C. quinquecarinatus*. Guts of *S. trutta* pre and post stocking contained a narrower range of prey items, but included *P. fluviatilis* or flying ants. No *C. tenuimanus* were recorded from the guts of any fishes prior to the stocking of *O. mykiss* fry.

After stocking, resident *O. mykiss* had similar prey types as pre-stocking; no *O. mykiss* fry or yearlings were recorded from the guts of large *O. mykiss*. In contrast, over 41.5 % of *P. fluviatilis* guts contained between one and 13 *O. mykiss* fry (mean = 6.2 ± 0.85) within 12 hours of stocking. The size range of *P. fluviatilis* which contained *O. mykiss* fry within their guts was 106 – 255 mm SL (Figure 2). The gut of a single *S. trutta* contained four *O. mykiss* fry. The diet of newly stocked *O. mykiss* yearlings (fin-clipped) was much broader than that of resident large *O. mykiss* (Table 2).

Throughout the remainder of the study, the gut contents of *O. mykiss* were dominated by insects, often with high abundances of Hymenoptera and Coleoptera. *P. fluviatilis* consumed a wider range of prey items, particularly aquatic prey species such as crustaceans and fishes. For example, small *C. tenuimanus* were consumed by a wide size range of *P. fluviatilis* in January and March 2002, with the largest *C. tenuimanus* (total length 122 mm) consumed by a *P. fluviatilis* of 237 mm SL (Figure 2). *P. fluviatilis* also preyed upon smaller *P. fluviatilis* of a range of sizes, with the largest *P. fluviatilis* prey item (138 mm SL) consumed by a *P. fluviatilis* of 270 mm SL.

Perca fluviatilis displayed the highest RR and RPI of any predatory fish in LN throughout the study (Figure 3). *P. fluviatilis* imposed more than 70 times more risk of consuming *O. mykiss* fry and imposed a RPI more than 100 times greater on *O. mykiss* fry than *S. trutta*. *P. fluviatilis* also displayed a greater RR and RPI on all species of crayfish than *O. mykiss* or *S. trutta*. In contrast, *O. mykiss* did not prey upon *O. mykiss* fry during the study (RR and RPI = 0) and had much lower RR and RPI on all species of crayfish than *P. fluviatilis*.

Table 2. Gut contents of large fishes collected by seine nets immediately pre- and post-stocking of *O. mykiss* fry. Data are expressed as percentage of guts containing a particular prey item. [*O.m.* = *O. mykiss*; *P.f.* = *P. fluviatilis*; *S.t.* = *S. trutta*; A = adult form; L = larval form; uc = unclipped *O. mykiss*; c = fin-clipped *O. mykiss*]. Note that clipped *O. mykiss* were only stocked after *O. mykiss* fry were stocked.

Prey Item	**O.m (uc) Pre**	**Post**	**P.f. Pre**	**Post**	**S.t. Pre**	**Post**	**O.m. (c) Post**
Sample size (n)	7	8	43	84	4	6	23
Gut Fullness: Empty (%)	0	0	46.5	36.9	50	33.3	17.4
Contents (%)	100	100	53.5	63.1	50	66.7	82.6
Order: Arachnida (A)							5.3
Order: Copepoda (A)			4.3	17.0			
Order: Ostracoda (A)			4.3	9.4			
Order: Anostraca (A)				5.7			
Order: Decapoda							
Family: Atyidae (A)				1.9			5.3
Family: Parastacidae (unidentified)		12.5		1.9			
C. tenuimanus				9.4		50.0	
C. quinquecarinatus	14.3		13.0	1.9			5.3
Order: Lepidoptera (A)	14.3						
Order: Coleoptera							
Aquatic (A)	71.4	50.0	8.7	1.9			31.6
Terrestrial (A)	71.4	62.5					26.3
Order: Dipteran (L)	28.6	12.5		9.4			10.5
Order: Ephemoptera (A)			56.5				
Order: Hemiptera							
Aquatic (A)		25.0		1.9			5.3
Terrestrial (A)							
Family: Cicadidae (A)							10.5
Order: Hymenoptera							
Family: Apidae (A)							10.5
Family: Vesipdae (A)	28.6	25.0					21.1
Family: Formicidae (A)	14.3	37.5		3.8	50.0	25.0	63.2
Order: Orthoptera (A)		12.5					5.3
Teleosts: *O. mykiss* (fry)				41.5		25.0	
Perca fluviatilis			52.2	9.4	50.0		
Edelia vittata				1.9			
Other native fishes			4.3	1.9			
Misc: Feathers							5.3
Cigarette butts	14.3	25.0					10.5
Organic matter				1.9			10.5
Inorganic matter							

Table 3. Gut contents of large fishes collected by seine nets during the later part of the study. Data are expressed as percentage of guts containing a particular prey item. [*O.m.* = *O. mykiss*; *P.f.* = *P. fluviatilis*; *S.t.* = *S. trutta*; A = adult form; L = larval form; uc = unclipped *O. mykiss*; c = fin-clipped *O. mykiss*].

	O.m. (uc)			**O.m. (c)**			**P.f.**			**S.t.**
Date	**30.1**	**13.3**	**8.4**	**30.1**	**13.3**	**8.4**	**30.1**	**13.3**	**8.4**	**30.1**
Sample size (n)	8	5	1	2	10	1	47	65	1	1
Gut Fullness: Empty (%)	25.0	0	0	0	30.0	100	23.4	35.4	100	100
Contents (%)	75.0	100	100	100	70.0	0	76.6	64.6	0	0
Order: Arachnida (A)	16.7									
Order: Copepoda (A)							33.3			
Order: Ostracoda (A)	16.7	20.0					2.8			
Order: Anostraca (A)							19.4	2.4		
Order: Decapoda										
Fam: Atyidae (A)		40.0			57.1		2.8	11.9		
Fam: Parastacidae (unidentified)		20.0			71.4			4.8		
C. tenuimanus		20.0					16.7	14.3		
C. quinquecarinatus								2.4		
Order: Coleoptera										
Aquatic (A)	50.0	60.0			71.4			9.5		
Terrestrial (A)	33.3			50.0						
Order: Dipteran (L)	33.3		100	100	14.3		44.4	95.2		100
Order: Ephemoptera (A)				50.0						
Order: Hemiptera										
Aquatic (A)	16.7				14.3					
Terrestrial (A)										
Fam: Cicadidae (A)								2.4		
Order: Odonata							30.6			
Order: Hymenoptera										
Fam: Apidae (A)		20.0			14.3			4.8		
Fam: Vesipdae (A)		40.0			42.9			2.4		
Fam: Formicidae (A)	33.3	20.0								
Order: Orthoptera (A)	16.7									
Teleosts: *O. mykiss* (fry)										
Perca fluviatilis							8.3	2.4		
Edelia vittata								4.8		
Other native fishes										
Misc: Feathers		40.0	100					2.4		100
Cigarette butts					14.7					
Organic matter	33.3	20.0					2.8	2.4		
Inorganic matter	33.3							16.7		

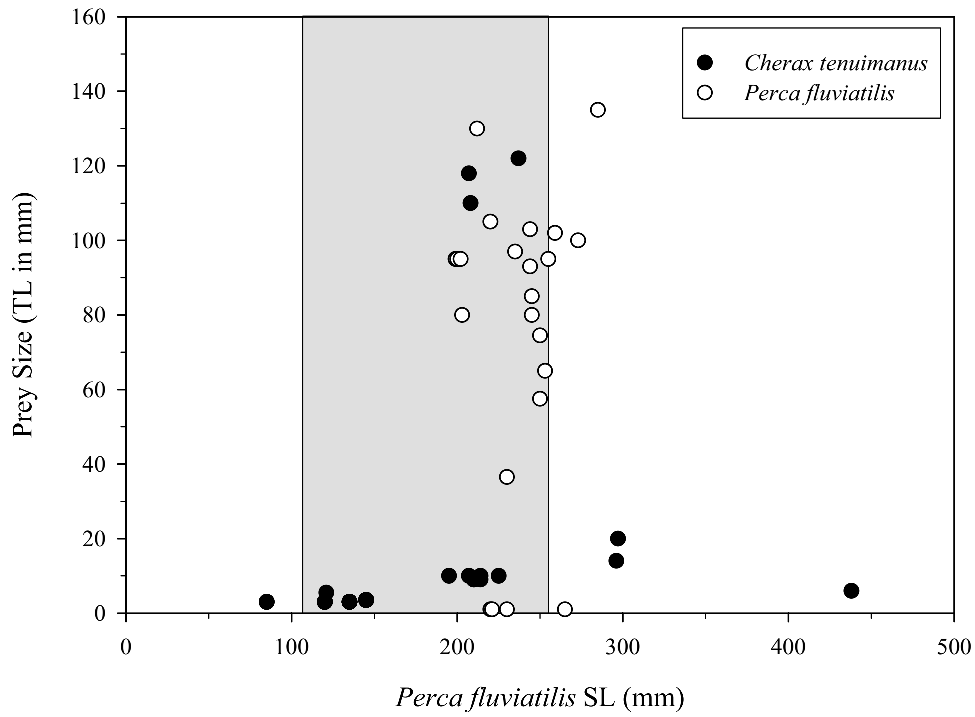

Figure 2. Size of *C. tenuimanus*, *P. fluviatilis* and *O. mykiss* fry in the guts of *P. fluviatilis* predators. Shaded area indicates the size range of *P. fluviatilis* predators that contained *O. mykiss* fry.

Mortality Estimates

Approximately 3,900 non-fin-clipped yearling *O. mykiss* were stocked into LN between April 2000 and April 2001 that would have contributed to the fishable *O. mykiss* population during the present study. The capture rates of fishes in the SWFA fishery prior to the start of the current study were 3.22 fish per angler per day across the entire fishery, consisting of 2.49 fish retained per day and 0.72 captured and released per day (Molony 2002). The estimated fishing effort applied to LN of approximately 2,089 angler days in the 12 months prior to the commencement of the current study(Molony 2002). From the distribution of catch by species in the SWFA (estimated to be 57.88% *P. fluviatilis*, 36.37% *O. mykiss* and 5.75% *S. trutta*) (Molony 2002), and assuming that *O. mykiss* fry survival is zero, the number of *O. mykiss* retained by anglers was estimated via;

= total SWFA catch in LN x proportion of catch of *O. mykiss*

= (2,089 x 2.49) x 0.3637 = 1,892 *O. mykiss* retained from LN,

with a further 547 *O. mykiss* captured and released. Thus, fishing mortality of yearling stocked *O. mykiss* is estimated as;

= number *O. mykiss* captured from LN / number of *O. mykiss* stocked into LN

= 1,892 / 3,900 = 0.485.

From the population size of *O. mykiss* estimated within LN during the present study (2,216) and the number of fin-clipped *O. mykiss* added during the study (1,400), an estimate of natural mortality can also be calculated via;

= [Total fish stocked - ((*O. mykiss* population size – number of fin-clipped fish) + estimated number of fish removed by anglers)]/ Total fish stocked

= [3,900 – ((2,216 – 1,400) + 1,892)]/ 3,900

= [3,900-1,604] / 3,900 = 0.306.

Thus, total mortality rate of *O. mykiss* yearlings in LN during the present study was = 0.306 + 0.485 = 0.791.

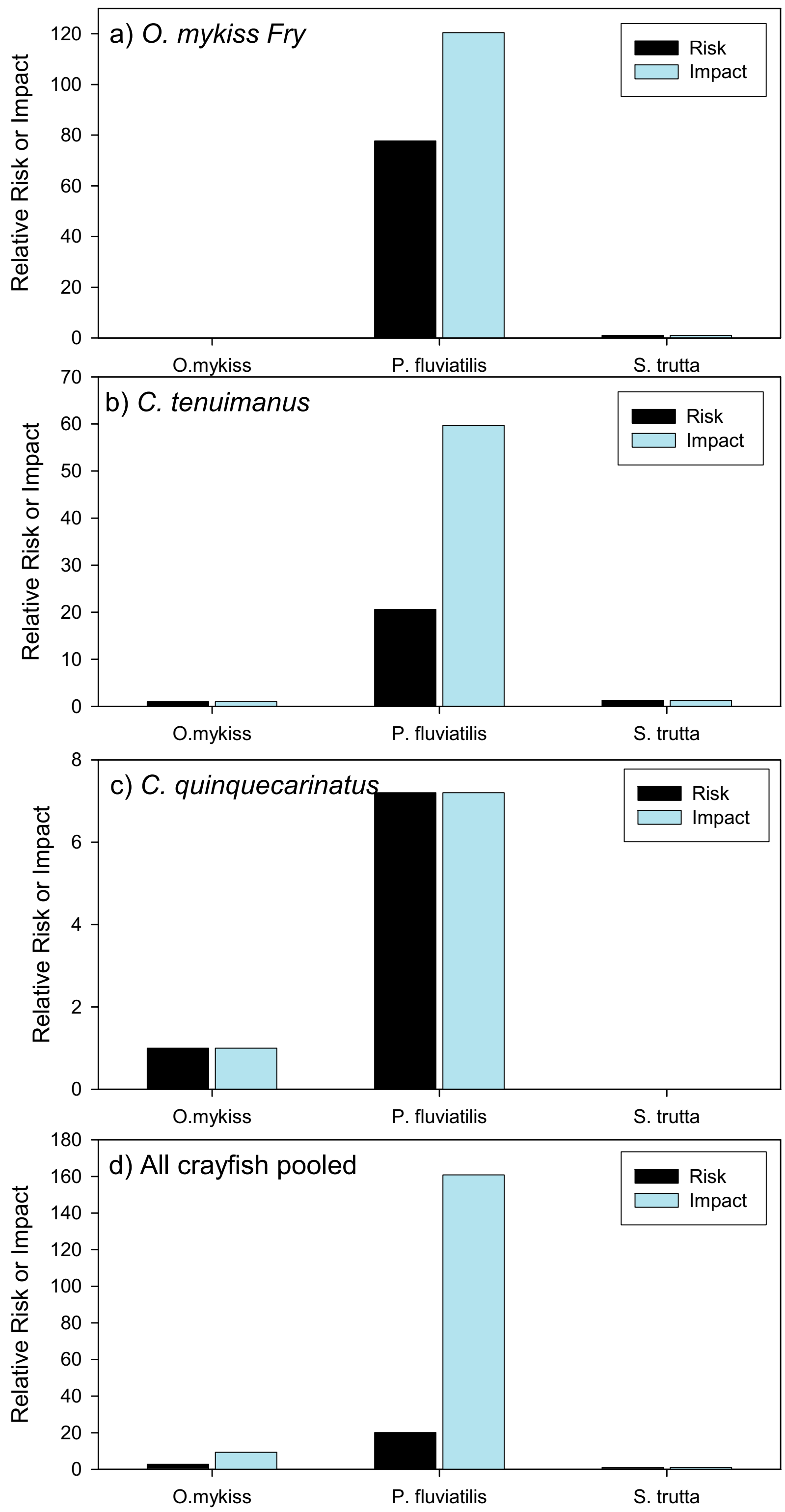

Figure 3. Relative risk and relative predatory impact of each of the three species of predatory fishes in Lake Navarino on a) *O. mykiss* fry, b) *C. tenuimanus*, c) *C. quinquecarinatus* and d) pooled crayfish. [Note that Pooled crayfish includes *C. tenuimanus*, *C. quinquecarinatus* and unidentified crayfish].

Discussion

Although all three species of introduced predatory fishes present in LN are known piscivores (McCarter 1986, Arthington and McKenzie, 1997), *P. fluviatilis* were the major and most abundant fish predator of *O. mykiss* fry and crayfishes. In the 60 hours after the stocking of *O. mykiss* fry, 41.5 % of *P. fluviatilis* guts contained *O. mykiss* fry (n = 53 guts), while the guts of a single *S. trutta* contained four *O. mykiss* fry. *P. fluviatilis* displayed a higher incidence of predation of *O. mykiss* fry and had more fry in their guts than any other species (mean: 6.2 ± 0.85 *O. mykiss* fry per *P. fluviatilis* gut). As such, the RR of *O. mykiss* fry being consumed by *P. fluviatilis* was more than 70 times greater, and the RPI of *P. fluviatilis* on *O. mykiss* fry more than 100 times greater than for *S. trutta*, and was zero for *O. mykiss* (Figure 3), as no *O. mykiss* fry were recorded from the guts of larger *O. mykiss* (Table 2).

Even relatively small *P. fluviatilis* were able to consume *O. mykiss* fry (Figure 2) supporting previous studies that recorded juvenile fishes in the guts of all size classes of *P. fluviatilis* (Pen and Potter 1992, Pen *et al.* 1993, Arthington and McKenzie 1997, Morgan *et al.* 2002). *P. fluviatilis* of a wide range of sizes also predated upon *C. tenuimanus* (Figure 2), similar to the findings by Morgan *et al.* (2002). In particular, *P. fluviatilis* in LN had a RPI on *C. tenuimanus* almost 60 times greater than the impact imposed by *O. mykiss*. *P. fluviatilis* also had a much greater RPI on *C. quinquecarinatus* and crayfishes in general than either *O. mykiss* or *S. trutta* (Figure 3).

Oncorhynchus mykiss of all sizes consumed a wide range of food sources in LN. Insects, both aquatic and terrestrial, were consumed by all life-stages of *O. mykiss*. Adult insects on the surface of the water (e.g. vespids, formicids, etc) made up a large proportion of the diets of all stages of *O. mykiss*. It is likely that the presence of flying stage-formicids in the diets of all species of predatory fishes reflected the peak breeding period for ants (Summer) (Tables 1, 2 and 3). Upon stocking, yearling *O. mykiss* consumed a wider range of food sources compared to large *O. mykiss* already present in LN. However, by the end of January 2002 (91 days post-stocking), stocked yearling *O. mykiss* had a similar range of food items as other *O. mykiss* in LN. *S. trutta* appeared to have the most specialised diets of any species of predatory fish in LN, consuming only five prey types throughout the study (*P. fluviatilis* – 22 prey types; *O. mykiss* – 18 prey types). *P. fluviatilis* diets contained the highest incidences of fishes and crayfishes of any predatory fish in LN and are known to be able to consume almost all animals that are available in an aquatic system (Thorpe 1977).

The stocking of *O. mykiss* fry also demonstrated prey-switching by *P. fluviatilis*. Prior to stocking *O. mykiss* fry, the guts of most *P. fluviatilis* contained smaller *P. fluviatilis* and/or ephemopetrans. Within 12 hours following-stocking, a large proportion of guts of *P. fluviatilis* contained *O. mykiss* fry. Although much smaller samples sizes were collected, gut content data from *S. trutta* are also suggestive of a prey-switch from smaller *P. fluviatilis* to *O. mykiss* fry. Thus both species of predatory fishes, while still consuming small fishes, were capable of switching from *P. fluviatilis* to *O. mykiss* fry. The ability to prey-switch is important for predatory fishes, especially in the relatively unproductive aquatic systems of south-western Australia (Pen 1999) where food is likely to be limiting. The ability to prey-switch is more important for a feral species like *P. fluviatilis* which dominate many lentic waters in south-western Western Australia due to the ability to reproduce and reach relatively large populations sizes in these waters.

Although not assessed in the present study, other sources of mortality are likely to also exist for *O. mykiss* fry. Avian predators have been shown to contribute to high levels of mortality in small trout in Europe and North America (e.g. Myers and Peterka 1976, Tabor and Wurtsbaugh 1991), including species of birds similar to those present in LN (e.g. cormorants *Phalacrocorax* spp, Dieperink 1995, Modde *et al.* 1996, Derby and Lovvorn 1997). However, birds tend to target larger *O. mykiss* (e.g. up to 1000 g, Dieperink 1995; 100 – 160 mm SL, Derby and Lovvorn 1997) than the *O. mykiss* fry in the present study (ca. 50-80 mm SL) and smaller *O. mykiss* may be less visible to avian predators, particularly in the turbid waters commonly observed in LN. Transport and stocking may also induce mortality, however, *O. mykiss* fry were visually examined prior to stocking and showed normal, healthy behaviours. Further, as the guts of *O. mykiss* fry retrieved from the guts of predatory fishes contained prey items, *O. mykiss* fry were feeding prior to predation, also suggestive of capable behaviours. Thus, mortality from predatory fishes within LN is the most likely cause the apparent total mortality of *O. mykiss* fry in the present study.

Although the mortality rate of young fishes is usually high, the naivety of *O. mykiss* fry stocked into LN may explain the apparent total mortality in the present study. At the PFRC, *O. mykiss* fry are raised in raceways (5 x 0.4 x 0.2 m) at high densities, are not exposed to predators and subsequently formed loose schools on the surface of LN. Naive *Oncorhynchus* spp. fry, without previous experience of predatory stimuli, have been shown to be more vulnerable to predation than experienced fry (Ginetz and Larkin 1976) and appropriate behavioural training prior to stocking may reduce naivety and increase survival (Brown and Day 2002) of *O. mykiss* fry in Western Australia. Further, most of the large irrigation dams of south-western Australia are cleared of all structure prior to filling (Molony and Bird, in press). In other studies, juvenile *O. mykiss* (60 – 120 mm SL) avoided simple habitats (sand, mud), preferring complex habitats (e.g. fallen timbers, Culp *et al.* 1996) to avoid predation by birds and predatory fishes (Tabor and Wurtsbaugh 1991). Thus a combination of *O. mykiss* fry naivety and lack of refugia in LN may explain the apparent total mortality of stocked *O. mykiss* fry within 60 hours in the current study.

Mortality estimates from the current study indicated that more than half the *O. mykiss* stocked as yearlings into LN are captured by anglers, with some of the natural mortality estimate likely to be attributable to *O. mykiss* leaving LN via the drain of the dam. It thus appears that natural mortality of yearling stocked *O. mykiss* is relatively low. However, the mortality rates in the current study were estimated accepting certain assumptions. Firstly, the natural recruitment of *O. mykiss* (i.e. reproduction of *O. mykiss* in LN) was assumed to be zero. It is unlikely, given the muddy substrate of LN and low water levels, that reproduction would have occurred for this stock; in fact natural reproduction of *O. mykiss* in south-western waters is assumed to be negligible in most locations (Molony, 2001). Secondly, given the results of the current study, the contribution of *O. mykiss* fry to the fishable stock in LN is likely to be zero. Thirdly, it was assumed that *O. mykiss* captured by anglers and released suffered no post-release mortality, a reasonable assumption given the high levels of catch-and-release rates and the lack of reports of dead *O. mykiss* observed in heavily fished waters of the SWFA fishery. Further, immigration of *O. mykiss* into LN is not likely as no *O. mykiss* stocks exist in waters above LN and the dam wall is relatively high (36 m) and lacks a fish ladder. However, net emigration from LN is likely as the water from LN is drained to irrigate fields below the dam through a large diameter (ca. 1.5 m) pipe, drawn from the base of the dam, although the emigration rate was not estimated in the current study.

The estimated total mortality of yearling-stocked *O. mykiss* (0.791) calculated in the current study is relatively high compared to mortality rates of *Oncorhynchus* spp. estimated in other studies (e.g. McGurk 1999). Although natural mortality of *O. mykiss* in LN was estimated to be lower than fishing mortality, is likely to that predation of *O. mykiss* via birds, unreported and unlicensed fishing effort and loss of *O. mykiss* from the population due to the draining of

LN will contributed to the estimate of natural mortality. Thus, is therefore likely that natural mortality rates of yearling stocked *O. mykiss* in LN are actually lower than reported here.

RR and RPI provided useful comparisons of the impact of predatory fishes on stocked *O. mykiss* in LN. Further, the RPI of predatory fishes on other recreationally important species (*C. tenuimanus*, Molony *et al.* 2002) and other important components of the ecosystem (i.e. other crayfishes) will allow managers to determine which management strategies are likely to benefit freshwater angling in the future. For example, using relative abundance data and gut content data that already exists, the RPI of all species of predatory fishes on key fishery species (e.g. O. *mykiss* and *C. tenuimanus*) in a range of key waters can be calculated. This advice will allow management decisions about the stocking of *O. mykiss* and *S. trutta* based on simple risk analyses that can be readily interpreted by stakeholder groups (e.g. anglers, conservationalists). In this way, management can focus on the major limitations to each stock in a rapid way and rapidly assess adaptive management applications. It should be noted that the relative risks and impacts for *O. mykiss* fry calculated in the present study are likely to be sound estimates due to the apparent total mortality of fry within 60 hours of stocking.

It should be noted that the RR and RPI is likely to vary among waters and at different times of the year. For example, the relative abundance of predatory fishes varies greatly among waters, with *P. fluviatilis* being absent in some impounded waters (WATFAA website). Further, *P. fluviatilis* do not appear to be able to reach such high abundances in riverine systems and thus may have less impact on fishes and crayfishes in rivers than in dams. The prey species available will also vary spatially and temporally due to differences in productivity among waters (Pen 1999) and breeding seasons of individual species (e.g. juvenile *C. tenuimanus* are released late in the calendar year (Beatty *et al.* 2003) and will only be available as a prey item for a short period of each year).

Although large numbers of *O. mykiss* fry are produced and stocked into south-western Australian waters annually, the results from the present study suggests that stocking *O. mykiss* fry in impounded waters dominated by *P. fluviatilis* has little benefit to the SWFA fishery. During the refurbishment of Waroona Dam (Beatty *et al.* 2003), control of *P. fluviatilis* by netting, draining and concussive methods has been undertaken and stocking LN with *O. mykiss* fry and other stages may be beneficial to increasing the recreational fishing values in this dam. However, with the relative abundance of *O. mykiss* greatly increased and *P. fluviatilis* greatly decreased, the RR and RPI of both species will vary and should be monitored in the future.

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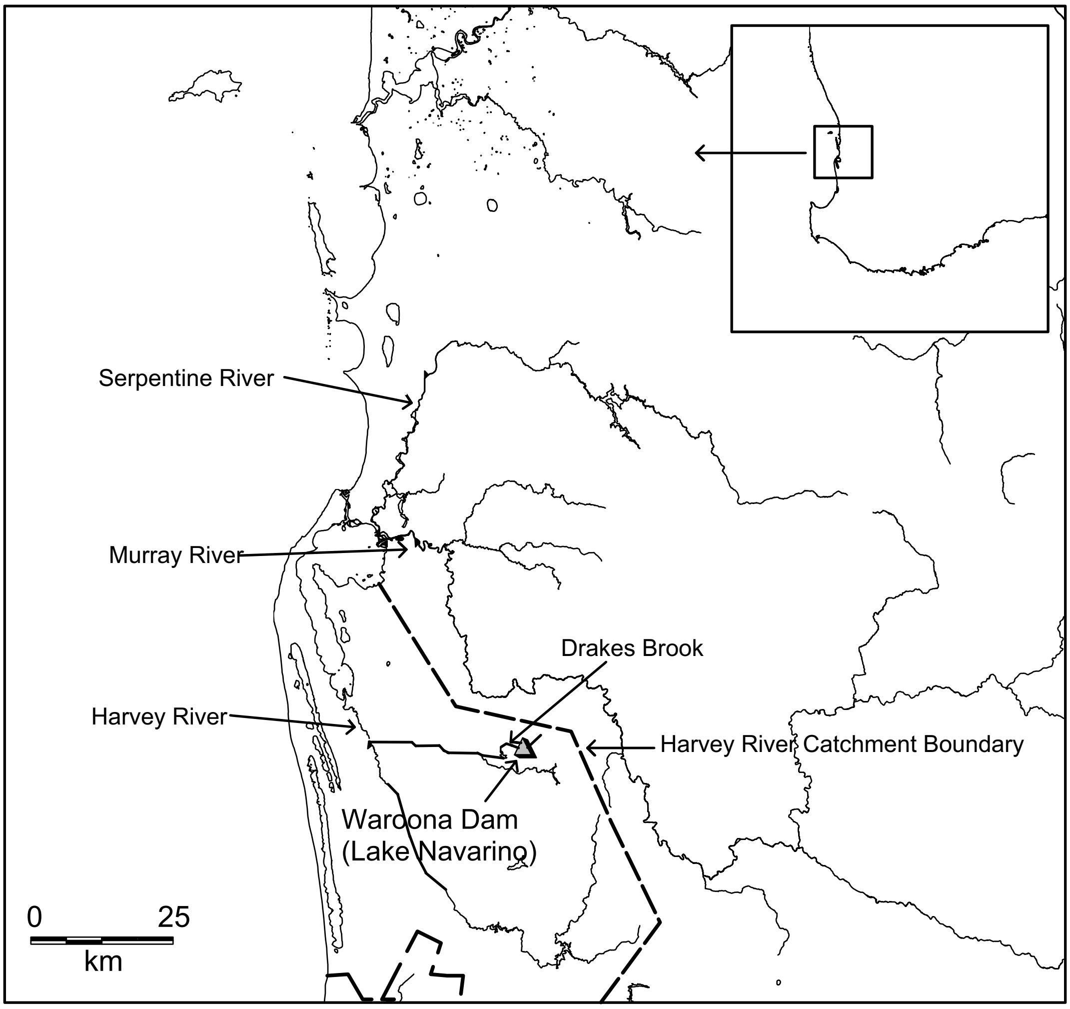
Appendix 4. The boundary of the Harvey River Catchment, adjacent major Rivers and the location of Waroona Dam (Lake Navarino)



Appendix 5. Poster – Mitigation of negative impacts on fish and fisheries values during remedial works at Waroona Dam

List of Fisheries Research Contract Reports

Most available online at http://www.fish.wa.gov.au/res

1 Feeding and management practices to enhance yabby *Cherax albidus* (Clark 1936) production from farm dams, Final Report for FRDC Project number 1997/319. Lawrence, C.S., Cheng, Y.W., Bellanger, J.E., Maguire, G.B. (Updated 2004).

2 Towards an assessment of natural and human use impacts on the marine environment of the Abrolhos Islands Phase 1: Data consolidation and scoping, Final Report for FRDC Project 2000/166. Chubb, C.F. and Nardi, K. (2003).

3 Early life history of abalone (*Haliotis rubra, H. laevigata*): settlement, survival and early growth, Final Report for FRDC Project 1998/306. Daume, S. (2003).

4 Determining waste excretion parameters from barramundi aquaculture, Final Report for Aquaculture Development Fund of WA. Glencross, B., Rutherford, N. and Hawkins, W. (2003).

5 Pilot assessment of the potential for canola meal and oil use in aquaculture feeds, Final Report for the Grains Research and Development Corporation. Glencross, B. (2003).

6 Assessment of the nutritional variability of lupins as an aquaculture feed ingredient, Final Report for the Grains Research Committee of WA Project. Glencross, B., Curnow, J. and Hawkins, W. (2003).

7 Defining the impact of hydrological changes associated with lake-turnover events on barramundi cage aquaculture in Lake Argyle, Final Report for Aquaculture Development Fund of WA Project. Felsing, M. and Glencross, B. (2004).

8 The nutritional management of barramundi. Glencross, B. (2004).

9 Enhancing the emergency disease response capability of the Western Australian Department of Fisheries and industry bodies associated with freshwater crayfish, Aquatic Animal Health Subprogram: FRDC Project No. 2003/671. Stephens, F., Jones, B., East, I., Scott, K., Bennison, S. (2004).

10 Mother-of-pearl shell (*Pinctada maxima*): Stock evaluation for management and future harvesting in Western Australia, FRDC Project 1998/153. Hart, A.M., Friedman, K.J. (2004).