

**The ecological impacts of secondary salinisation on halo-tolerant
fishes in south-western Australia**



Mahmoud Rashnavadi

D.V.M

**This thesis is presented for the degree of Doctor of Philosophy of
Murdoch University, 2010.**



DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work that has not previously been submitted for a degree at any tertiary institution.

.....

Mahmoud Rashnavadi

Abstract

Secondary salinisation is an anthropogenic process that is increasingly disrupting the health of freshwater ecosystems in Australia. In a continent where supplying future water resources for a growing population is challenging, secondary salinisation not only makes freshwater ecosystems unsuitable for human use, but may also have substantial negative impacts on aquatic biota. A large body of research in Australia and overseas has found that increasing salinisation is associated with a loss of biodiversity in freshwater ecosystems. However, most of these studies are based on salinity tolerance tests conducted in the laboratory, which determine physiological effects of salinity without considering the synergistic impacts of other existing stressors in the system.

The south of Western Australia is a biodiversity hot spot, but has been severely impacted on by secondary salinisation. Only 44% of flow in the 30 largest rivers in the Southwest Coast Drainage Division is fresh and more than half of the rivers in the region can be classified as brackish or saline. Among these rivers, the Blackwood River is the second largest in the region, has the highest discharge and contains all eight native riverine fish species which are endemic to the south-west. More than 85% of the river catchment has been cleared and salinity has an annual upward trend throughout the upper catchment and in the main channel of the lower catchment, while lower catchment tributaries remain fresh. In this study, I have used a combination of field and laboratory studies to investigate the impacts of increasing salinity on the biological performance of native and exotic freshwater fishes in different parts of the Blackwood River.

Eleven species of fish were captured in the Blackwood River during the study; *Galaxias occidentalis*, *Gambusia holbrooki*, *Leptatherina wallacei*, *Pseudogobius olorum*, *Edelia vittata*, *Tandanus bostocki*, *Nannatherina balstoni*, *Bostockia porosa*, *Afurcagobius suppositus*, *Galaxiella munda* and *Oncorhynchus mykiss*. The greatest diversity of fish species (*G. occidentalis*, *G. holbrooki*, *L. wallacei*, *P. olorum*, *E. vittata*, *T. bostocki*, *N. balstoni*, *B. porosa* and *A. suppositus*) was found in the main channel of the lower catchment, where salinity typically varies between 2 and 5 ppt. Eight species (*B. porosa*, *E. vittata*, *G. occidentalis*, *N. balstoni*, *T. bostocki*, *A. suppositus*, *G. munda* and *O. mykiss*) were found in freshwater tributaries of the lower catchment, where salinity is always less than 0.5 ppt. In the upper catchment, where salinity varied from 7 ppt to over 31 ppt, only four species of fish were captured; the native riverine species *G. occidentalis*, the introduced *G. holbrooki* and the euryhaline species *L. wallacei* and *P. olorum*.

For the four species of fish that were distributed throughout the Blackwood River (*G. occidentalis*, *G. holbrooki*, *L. wallacei* and *P. olorum*), I investigated the size, morphology, life-cycle, diet and rate of parasitism between populations in the upper and lower catchment. All four fish species have relatively short life spans and this was more evident in the case of *G. holbrooki* and *P. olorum* in which 100% (n = 558) and 98% (n = 163), respectively, were classified as 0+. Forty-five percent of *L. wallacei* (n=788) and 41% of *G. occidentalis* (n=942) were classified as 0+. Significant numbers of *G. occidentalis* (46%) and *L. wallacei* (43%) were found in their second year of life, while this number was only 2% for *P. olorum*. No *L. wallacei* (n = 776) older than three years were captured in this study, while 1% (n = 937) of *G. occidentalis* were recorded as four years old.

Spawning of *L. wallacei* in the upper catchment peaked by mid spring, while fish in the lower catchment delayed spawning until early summer. There were no significant differences between spawning time of *G. occidentalis* and *P. olorum* populations in the upper and lower catchments of the Blackwood River, although biannual spawning of *P. olorum* was only recorded in upper catchment sites. The breeding season of *G. holbrooki* in both the upper and lower catchments of the Blackwood River lasted for a period of at least six months (from October to beyond March).

Dietary analyses of all four fish species from the upper and lower catchments of the Blackwood River revealed their opportunistic feeding behaviour. Overall, the highest diversity of invertebrate fauna was recorded in the diet of *L. wallacei*, while the lowest diversity was recorded in *P. olorum*. Crustaceans including Amphipoda, Copepoda, Cladocera and Ostracoda, made up a greater proportion of the diet of all four fish species in the salt affected upper catchment than in the lower catchment. There were significant differences between the dietary compositions of all fish species in both upper and lower catchments. The eggs or larvae of native fishes were not commonly found in the diet of *G. holbrooki*, although dietary analysis showed that this species is clearly in competition with native fish fauna.

Over all, five species of macroparasites, including nematodes, trematodes and cestodes, were found in association with the four fish species studied. The highest prevalence of parasite infections were recorded in the native species *G. occidentalis* (5.9%), *P. olorum* (5.7%) and *L. wallacei* (2.8%) with the lowest prevalence in the introduced *G. holbrooki* (0.2%), despite *G. holbrooki* making up approximately 77% of the fish population in the

river. This reduced parasite diversity in introduced species, compared with native hosts, has also been reported in a wide range of other taxa, and may contribute to the competitive advantage of introduced pest species. There was a correlation between the distribution of one species of parasite, *Diplostomum* sp., and position of its fish intermediate host in the catchment. This trematode, which has a complex life-cycle involving a number of different hosts, was mainly restricted to the freshwater tributaries, occurred rarely in the main channel of the lower catchment where the salinity was relatively low and was never found in the salinised upper catchment.

Despite the circumstantial evidence from field studies that the current pattern of fish distributions in the Blackwood River has been influenced by secondary salinisation, salinity tolerances of native freshwater fishes have not previously been measured under controlled laboratory conditions. The acute salinity tolerance of populations of *G. occidentalis* from the upper and lower catchments of the Blackwood River was studied experimentally, and compared with the tolerance of two other native fish species; *E. vittata* which is found in the main channel of the lower catchment, but not in the upper catchment; and *N. balstoni* which is restricted to a single small, freshwater tributary of the lower catchment. *Nannatherina balstoni* was found to have the lowest salinity tolerance with $EC_{50} = 8.2$ ppt and $EC_{95} = 9.3$ ppt. This confirms that the upper catchment of the Blackwood River, where the salinity was significantly higher than this range throughout most of the year, is unsuitable for this species and this may explain its absence from most of the catchment. The salinity tolerance of both *E. vittata* ($EC_{50} = 14.5$ and $EC_{95} = 15.6$) and *G. occidentalis* ($EC_{50} = 14.6$ ppt and $EC_{95} = 15.8$ ppt) was considerably higher than that of *N. balstoni* ($LC_{50} = 8.2$ ppt and $LC_{95} = 9.2$ ppt). It is possible that the eggs, larvae or juvenile stages of *E. vittata* are more sensitive

to salinity than adults and this prevents this species from establishing its life-cycle in the upper catchment of the Blackwood River. Additionally, the greater dispersal capabilities of *G. occidentalis* may enable it to maintain its life-cycle in the upper catchment by moving into refuge areas as salinity increases.

This study has provided valuable insight into the impact of secondary salinisation on the biological performance of freshwater fishes in south-western Australia. These impacts are likely to be further exacerbated by continued increases in salinisation and reduced rainfall due to climate change.

Acknowledgements

I used to be a vet clinician and this study gave me the opportunity to look at the world from a different angle. This shift in my career had its own hardships but at the same time it offered much to learn. This time I was facing the Blackwood River and as with the veterinary environment, when something goes wrong there are environmental symptoms which communicate the problem. This study was all about finding these symptoms and interpreting them. In this endeavour, I had the privilege to be supervised by Professor Alan Lymbery. I would like to extend my sincere thanks to you and my co supervisors Dr David Morgan and Dr Stephen Beatty, who were also beside me throughout this journey.

I wish to thank the Iranian Ministry of Research, Science and Technology and Murdoch University for their Scholarships and support. A special thank to South West Catchments Council and the Western Australian Department of Water, and the Australian Federal Government for their financial support.

I would like to thank Stephen Beatty and Travis Faseldean, who travelled miles to help me on field trips sampling fishes in different parts of the Blackwood River. You both made the time out in the bush much more enjoyable.

I would like to thank Mr. Russell Hobbs from Murdoch University Parasitology Laboratory for his help in identifying parasites in this study. Also thanks to Fiona McAleer, Gordon Thomson and Rowan Lymbery for your data sharing and assistance in laboratory.

A special thanks to Michael Klunzinger for your unlimited support which made our work place much friendlier.

A special thanks to my wife, Kolsoum Nematizad and my sons Parsa and Daniel for your continuing support, without which I would not be in this position today.

TABLE OF CONTENTS

Abstract	iii
Acknowledgements	viii
List of Figures	xvii
List of Tables	xxv

Chapter 1: Effects of secondary salinisation on the freshwater fish fauna of the south-west of Western Australia.....1

1.1 Freshwater ecosystems in the south-west of Western Australia	1
1.2 Freshwater fishes in the south-west of Western Australia	4
<i>1.2.1 Native riverine species</i>	4
<i>1.2.2 Native species with marine affinities</i>	5
<i>1.2.3 Introduced freshwater species</i>	5
1.3 Health of freshwater ecosystems	6
<i>1.3.1 Secondary salinisation</i>	8
<i>1.3.2 Salinisation of the Blackwood River</i>	12
1.4 Indicators of river health	14
<i>1.4.1 Fishes as bioindicators</i>	15
1.5 Effects of salinisation on freshwater fishes	17
<i>1.5.1 Effects on mortality rate</i>	19
<i>1.5.2 Effects on growth rate</i>	19

1.5.3 Effects on reproduction.....	21
1.5.4 Effects on fluctuating asymmetry of morphological traits	22
1.5.5 Effects on diet.....	23
1.5.6 Effects on parasite load.....	24
1.6 Aims.....	25

Chapter 2: Ecological response of an endemic galaxiid, *Galaxias*

<i>occidentalis</i> Ogilby, 1900, to secondary salinisation	27
2.1 Introduction.....	27
2.2 Materials and Methods.....	30
2.2.1 Sampling protocol.....	30
2.2.2 Environmental parameters.....	32
2.2.3 Fish sampling.....	34
2.2.4 Size, morphology, age and reproductive status.....	34
2.2.5 Dietary analysis.....	35
2.2.6 Fluctuating asymmetry.....	36
2.2.7 Parasite sampling	37
2.3 Results	38
2.3.1 Environmental variables and fish distribution.....	38
2.3.2 Sex ratio, size, age and growth rates	41

2.3.3 Gonadal development.....	45
2.3.4 Fish diets	48
2.3.5 Fluctuating asymmetry.....	49
2.3.6 Parasite fauna	51
2.4 Discussion	54
2.4.1 Distribution of <i>Galaxias occidentalis</i>	54
2.4.2 Growth and life-cycle of <i>Galaxias occidentalis</i>	56
2.4.3 Diet of <i>Galaxias occidentalis</i>	57
2.4.4 Parasitic infection of <i>Galaxias occidentalis</i>	58
2.5 Conclusions	60
Chapter 3: Ecological response of an estuarine atherinid, <i>Leptatherina wallacei</i> (Prince, Ivantsoff and Potter, 1981), to secondary salinisation ..	61
3.1 Introduction	61
3.2 Materials and Methods	64
3.3 Results	64
3.3.1 Environmental variables and fish distribution.....	64
3.3.2 Size, age and growth rates	65
3.3.3 Gonadal development.....	70
3.3.4 Fish diets	71

3.3.5 <i>Fluctuating asymmetry</i>	72
3.3.6 <i>Parasite fauna</i>	75
3.4 Discussion	76
3.4.1 <i>Distribution of Leptatherina wallacei</i>	76
3.4.2 <i>Life-cycle of Leptatherina wallacei</i>	77
3.4.3 <i>Diet and parasitism of Leptatherina wallacei</i>	79
3.5 Conclusions	82

Chapter 4: Ecological response of an estuarine gobiid, *Pseudogobius*

<i>olorum</i> (Sauvage 1880), to secondary salinisation	83
4.1 Introduction	83
4.2 Materials and Methods	86
4.3 Results	87
4.3.1 <i>Environmental variables and fish distribution</i>	87
4.3.2 <i>Sex ratio, size, age and growth rate</i>	87
4.3.3 <i>Reproduction</i>	93
4.3.4 <i>Fish diets</i>	94
4.3.5 <i>Fluctuating asymmetry</i>	94
4.3.6 <i>Parasite fauna</i>	96
4.4 Discussion	96

4.4.1 <i>Distribution of Pseudogobius olorum</i>	96
4.4.2 <i>Differences in the biology of Pseudogobius olorum in the upper and lower catchments</i>	97
4.5 Conclusions	99
Chapter 5: Ecological response of an introduced freshwater fish, <i>Gambusia holbrooki</i> (Girard 1859), to secondary salinisation	101
5.1 Introduction	101
5.2 Materials and Methods	105
5.3 Results	106
5.3.1 <i>Environmental variables and fish distribution</i>	106
5.3.2 <i>Sex ratio, size, age and growth rate</i>	107
5.3.3 <i>Gonadal development and reproduction</i>	113
5.3.4 <i>Fish diets</i>	114
5.3.5 <i>Fluctuating asymmetry</i>	116
5.3.6 <i>Parasite fauna</i>	117
5.4 Discussion	117
5.4.1 <i>Distribution of <i>Gambusia holbrooki</i></i>	117
5.4.2 <i>Life-cycle of <i>Gambusia holbrooki</i></i>	119
5.4.3 <i>Diet of <i>Gambusia holbrooki</i> in the upper and lower catchments</i>	120

5.4.4 <i>Impacts of Gambusia holbrooki on native fish species</i>	121
5.5 Conclusions	123
Chapter 6: Salinity tolerances of three endemic freshwater fishes, <i>Galaxias occidentalis</i> Ogilby 1900, <i>Edelia vittata</i> Castelnau 1873 and <i>Nannatherina balstoni</i> Regan 1906, from the Blackwood River	125
6.1 Introduction	125
6.2 Materials and Methods	129
6.2.1 <i>Sampling of fishes</i>	129
6.2.2 <i>Laboratory procedures</i>	130
6.2.3 <i>Statistical analysis</i>	132
6.3 Results	133
6.3.1 <i>Galaxias occidentalis</i>	133
6.3.2 <i>Nannatherina balstoni and Edelia vittata</i>	136
6.3.3 <i>Comparison of EC₅₀ and EC₉₅ among populations and species</i>	139
6.4 Discussion	140
6.4.1 <i>The effect of secondary salinisation on freshwater fishes</i>	140
6.4.2 <i>Distributions in the upper catchment</i>	141
6.4.3 <i>Distributions in the lower catchment</i>	142
6.4.4 <i>Seasonal habitat utilisation in the lower catchment</i>	143

6.5 Conclusions	144
Chapter 7: General conclusions	146
7.1 Secondary salinisation in the south-west of Western Australia	146
7.2 Blackwood River as a case study	147
7.3 Impacts of rising salinity on freshwater fish species	148
<i>7.3.1 Lethal effects of increasing salinity</i>	150
<i>7.3.2 Sub-lethal effects of increasing salinity</i>	151
7.4 Potential bioindicators of salinisation	158
7.5 Implications for conservation	159
References	162
List of publication from this thesis	189

List of Figures

Figure 1.1	The major river systems of the Southwest Coast Drainage Division.	3
Figure 1.2	Blackwood River in the south-west of Western Australia, showing differences in water salinity between upper and lower catchments.	14
Figure 1.3	Frequency (f) distributions of the signed difference in a trait between right (R) and left (L) sides, illustrating three commonly observed patterns of deviation from bilateral symmetry: (a) fluctuating asymmetry; (b) directional asymmetry; (c) antisymmetry (platykurtic or bimodal). From Somarakis <i>et al.</i> (1997).	22
Figure 2.1	Distribution of <i>Galaxias occidentalis</i> in the Southwest Coast Drainage Division, showing Blackwood River and rivers at extremities of range. Filled circles represent capture sites, unfilled circles represent non-capture sites. Based on data from Morgan <i>et al.</i> (1998, 2003 & 2006).	29
Figure 2.2	Sampling sites in the Blackwood River showing differences in salinity between the upper and lower catchments and areas sampled in this study. Also shown (in italics) are sites from which flow readings were obtained (see Figure 2.3).	31

Figure 2.3	Total monthly flows at four sites in the main channel of the Blackwood River (see Figure 2.2) from January 2006 to March 2008: Nannup (red); Darradup (blue); Gingilup (black) and Hot Pool (yellow). Figure courtesy of Department of Water, Bunbury.	32
Figure 2.4	Total monthly rainfall (white) during the study period and long term average (black) (from Bridgetown). Data from Australian Bureau of Meteorology.	33
Figure 2.5	Mean monthly maximum air temperature during the study period (solid line) and long term average (broken line) (from Bridgetown). Data from Australian Bureau of Meteorology.	33
Figure 2.6	Total length, width, perimeter and area of both left and right otolith were measured for each fish using Motic Images Plus 2 (Motic instrument Inc. Richmond, B.C., Canada).	37
Figure 2.7	Mean and standard error (a) water temperature, (b) salinity, (c) pH and (d) dissolved oxygen of sampling sites in the upper catchment (black), main channel of the lower catchment, (red) and freshwater tributaries of the lower catchment (green) of the Blackwood River.	40
Figure 2.8	Seasonal changes in water salinity (ppt) at one of the central sites (Jalbaragup Road) in the main channel of the lower catchment of the Blackwood River.	41

Figure 2.9	Fish composition in the Blackwood River sites (a) upper catchment (b) main channel of the lower catchment and (c) freshwater tributaries.	42
Figure 2.10	Length-frequency distribution for all <i>Galaxias occidentalis</i> examined in this study (n = 937).	43
Figure 2.11	Relationship between total length (TL) and weight (W) for (a) female and (b) male <i>Galaxias occidentalis</i> captured in this study. Curves were fitted using JMP v4 (SAS Institute, Cary, NC).	44
Figure 2.12a	Length-frequency histograms for <i>Galaxias occidentalis</i> populations in the upper catchment of the Blackwood River.	46
Figure 2.12b	Length-frequency histograms for <i>Galaxias occidentalis</i> populations in the lower catchment of the Blackwood River.	47
Figure 2.13	Mean seasonal changes in gonadosomatic index (95% CI) in female (black) and male (white) <i>Galaxias occidentalis</i> from (a) upper catchment and (b) lower catchment sites of the Blackwood River.	48
Figure 2.14	Examples of the species of parasites found in <i>Galaxias occidentalis</i> in the Blackwood River: (a) <i>Eustrongylides</i> sp.; (b) <i>Diplostomum</i> sp. (arrowed); (c) <i>Contracaecum</i> sp.	52

Figure 3.1	Distribution of <i>Leptatherina wallacei</i> in the Southwest Coast Drainage Division. Based on data from Morgan <i>et al.</i> (1998, 2006). Filled circles are captured sites.	63
Figure 3.2	Length-frequency distributions for all <i>Leptatherina wallacei</i> examined in this study (n=776).	66
Figure 3.3	Relationship between total length (TL) and standard length (SL) for all (a) female and (b) male <i>Leptatherina wallacei</i> collected in this study. Curves were fitted using JMP v4 (SAS Institute, Cary, NC).	67
Figure 3.4a	Length-frequency histograms of <i>Leptatherina wallacei</i> populations in the upper catchment of the Blackwood River.	68
Figure 3.4b	Length-frequency histograms of <i>Leptatherina wallacei</i> populations in the lower catchments of the Blackwood River.	69
Figure 3.5	Seasonal changes in gonadosomatic index (95% CI) in female <i>Leptatherina wallacei</i> from upper catchment (grey) and lower catchment (black) sites of the Blackwood River.	70
Figure 3.6	Percentage contributions of different gonad stages for female <i>Leptatherina wallacei</i> from the upper (grey bars) and lower (black bars) Blackwood River catchment in mid-spring.	71

Figure 4.1	The distribution of <i>Pseudogobius olorum</i> in the south-western corner of Australia (data from Morgan <i>et al.</i> 1998, 2006; Morgan & Beatty unpublished). Filled circles are capture sites.	85
Figure 4.2	Length-frequency distributions for all <i>Pseudogobius olorum</i> examined in this study (n = 163).	88
Figure 4.3	Relationship between total length and weight for (a) female and (b) male <i>Pseudogobius olorum</i> examined in this study. Curves were fitted using JMP v4 (SAS Institute, Cary, NC).	89
Figure 4.4a	Length frequency histograms of male and female <i>Pseudogobius olorum</i> from the upper catchment and of the Blackwood River.	91
Figure 4.4b	Length frequency histograms of male and female <i>Pseudogobius olorum</i> from the lower catchment of the Blackwood River.	92
Figure 4.5	<i>Pseudogobius olorum</i> gonadal development (males and females combined) in (a) the upper catchment in autumn and (b) the lower catchment in summer.	93
Figure 5.1	The distribution of <i>Gambusia holbrooki</i> in the south-western corner of Australia (data from Morgan <i>et al.</i> 1998, 2006). Filled circles are capture sites, clear circles are sampling sites where fish were not captured.	103

Figure 5.2	Length-frequency distributions for all <i>Gambusia holbrooki</i> examined in this study (n = 558).	108
Figure 5.3	Relationship between total length and weight of (a) female and (b) male <i>Gambusia holbrooki</i> captured in this study. Curves were fitted using JMP v4 (SAS Institute, Cary, NC).	109
Figure 5.4a	Length-frequency histograms of <i>G. holbrooki</i> in the upper catchment of the Blackwood River.	111
Figure 5.4b	Length-frequency histograms of <i>G. holbrooki</i> in the lower catchment of the Blackwood River.	112
Figure 5.5	Seasonal changes in gonadosomatic index (95% CI) in female (black) and male (white) <i>Gambusia holbrooki</i> in upper catchment sites of the Blackwood River.	113
Figure 5.6	Monthly trends of pregnancy rate among <i>Gambusia holbrooki</i> populations in the Blackwood River upper catchment sites.	114
Figure 6.1	<i>Galaxias occidentalis</i> , <i>Edelia vittata</i> and <i>Nannatherina balstoni</i> as a percentage of total fish captures in (a) the upper catchment, (b) the main channel of the lower catchment and (c) tributaries of the lower catchment of the Blackwood River. Data taken from Figure 2.9, Chapter 2.	127

Figure 6.2	Sites sampled for sourcing the fish for the salinity trials and the maximum salinities recorded at all sites sampled in the Blackwood River.	130
Figure 6.3	Percentage mortalities over the different salinity treatments of <i>G. occidentalis</i> sourced from: (a) the Hillman River in the upper Blackwood River catchment, and (b) Poison Gully in the lower Blackwood River catchment. Logistic curves (including 95% confidence limits) from the logistic regression analysis are provided.	134
Figure 6.4	Percentage of <i>Galaxias occidentalis</i> affected in the different treatments throughout the trials using fish from (a) the Hillman River in the upper Blackwood catchment and (b) Poison Gully in the lower Blackwood River catchment. Note 100% survival rate for fish in 0, 5 and 10 ppt for both populations.	135
Figure 6.5	Percentage mortalities over the different salinity treatments of (a) <i>Nannatherina balstoni</i> and (b) <i>Edelia vittata</i> from the lower Blackwood River catchment. Logistic curves (including 95% confidence limits) from the logistic regression analysis are provided.	137
Figure 6.6	Percentage of <i>Nannatherina balstoni</i> (above) and <i>Edelia vittata</i> (below) surviving in the different salinity treatments throughout the trials.	138

Figure 7.1

MDS plots of similarities in diet between four fish species in the (a) upper catchment and (b) lower catchment of the Blackwood River during the dry season. Plots are shown in three dimensions to increase the separation among data points; stress values for three dimensional plots = 0.01.

156

List of Tables

Table 1.1	Types and causes of environmental impacts in Australian rivers.	8
Table 1.2	Classification of bioindicators, according to process (structural or functional) and level of organisation. Examples of bioindicators are shown in the body of the table.	15
Table 1.3	Species of fish caught in the Blackwood River, abundance (% of total captures) and presence/absence in different salinity zones (see Figure 1.2); - represents species absence; + represents species presence; ++ represents the species is abundant. Data from Morgan <i>et al.</i> (2003), Beatty <i>et al.</i> (2008).	18
Table 1.4	Estimated salinity LC ₅₀ scores for adult native and introduced freshwater fishes in Australia. Single scores are from one study; where a range of scores are given they are from several studies, with the number of studies indicated in parentheses. Acute LC ₅₀ refers to a sudden increase and chronic LC ₅₀ to a gradual increase in salinity. Table adapted from James <i>et al.</i> (2003).	20
Table 2.1	Proportional contribution (by volume) of different prey taxa in the diet of <i>Galaxias occidentalis</i> from upper and lower catchment sites in wet and dry seasons.	50

Table 2.2	Mean abundance of different prey taxa in the diet of <i>Galaxias occidentalis</i> from upper and lower catchment sites (averaged over seasons), and cumulative percentage of dissimilarity between these site explained by these taxa (calculated from two-way SIMPER analysis). Taxa are arranged in order of decreasing contribution to dissimilarity, and taxa which contributed less than 1% to the cumulative percentage of dissimilarity have been omitted.	51
Table 2.3	Prevalence and mean intensities of infection (with 95% confidence intervals in parentheses) of parasite species found in <i>Galaxias occidentalis</i> sampled from sites in the upper catchment and lower catchment of the Blackwood River.	53
Table 3.1	Proportional contribution (by volume) of different prey taxa in the diet of <i>Leptatherina wallacei</i> from the upper and lower Blackwood River in wet and dry seasons.	73

Table 3.2	Mean abundance of different prey taxa in the diet of <i>Leptatherina wallacei</i> from upper and lower catchment sites in each season, and cumulative percentage of dissimilarity between these site explained by these taxa (calculated from one-way SIMPER analyses, because of significant interaction between catchment and season). Taxa are arranged in order of decreasing contribution to dissimilarity, and taxa which contributed less than 1% to the cumulative percentage of dissimilarity have been omitted.	74
Table 3.3	Prevalence and mean intensities of infection (with 95% confidence intervals in parentheses) of parasite species found in <i>Leptatherina wallacei</i> sampled from sites in the upper catchment and lower catchment of the Blackwood River.	76
Table 4.1	Proportional contribution (by volume) of different prey taxa in the diet of <i>Pseudogobius olorum</i> from upper and lower catchment sites in the Blackwood River during the dry season.	95

Table 4.2	Mean abundance of different prey taxa in the diet of <i>Pseudogobius olorum</i> from upper and lower catchment sites in the dry season, and cumulative percentage of dissimilarity between these site explained by these taxa (from one-way SIMPER analysis). Taxa are arranged in order of decreasing contribution to dissimilarity, and taxa which contributed less than % to the cumulative percentage of dissimilarity have been omitted.	95
Table 5.1	Proportional contribution (by volume) of different prey taxa in the diet of <i>Gambusia holbrooki</i> from upper and lower catchment sites in the Blackwood River during the dry season.	115
Table 5.2	Mean abundance of different prey taxa in the diet of <i>Gambusia holbrooki</i> from upper and lower catchment sites in the dry season, and cumulative percentage of dissimilarity between these site explained by these taxa (from one-way SIMPER analysis). Taxa are arranged in order of decreasing contribution to dissimilarity, and taxa which contributed less than % to the cumulative percentage of dissimilarity have been omitted.	116
Table 6.1	Salinities (including 95% confidence intervals) at which 50% (EC ₅₀) and 95% (EC ₉₅) of fish were removed from the treatments due to continuous loss of equilibrium (see text for experimental methods).	139

Table 7.1	Matrix of differences (R values from ANOSIM analysis) between diets of four fish species in the Blackwood River upper catchment during the dry season. All R values < 0.05, with a Bonferroni correction.	155
Table 7.2	Matrix of differences (R values from ANOSIM analysis) between diets of four fish species in the Blackwood River lower catchment during the dry season. All R values < 0.05, with a Bonferroni correction.	155
Table 7.3	The parasite fauna of the four salt tolerant fish species in the Blackwood River (+ infected, - not infected).	157
Table 7.4	Distribution of the parasite species found in ranges of different salinity throughout the Blackwood River (+ infection occurrence; - no occurrence).	158