Records of the Western Australian Museum **20**: 31–37 (2000).

Fish associations within the different inland habitats of lower south-western Australia

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Abstract – In order to determine whether certain fish species or groups of species are associated with the different habitat types occurring in the inland waterbodies of south-western Australia, 239 sites sampled between Margaret River and Broke Inlet were assigned to appropriate Ramsar wetland categories and their fish assemblages then subjected to classification. Each of the sample sites fell into one of the following categories, pools (ephemeral or permanent), riverine (fresh or salt affected), reservoirs, lacustrine (fresh or saline) or estuarine. One-way analysis using ANOSIM in the PRIMER package suggested that the fish communities of the ephemeral pools were significantly different to those of the rivers and lakes. Thus, the ephemeral pools were characterised by the presence of the endemic and restricted species, *Lepidogalaxias salamandroides* and/or *Galaxiella nigrostriata*, whereas the permanent rivers and lakes of the region were characterised by a fauna dominated by the other small endemic freshwater teleosts, i.e. *Galaxias occidentalis, Galaxiella munda, Bostockia porosa, Edelia vittata* and *Nannatherina balstoni* and in many cases the lamprey *Geotria australis*. ANOSIM also showed that there were significant differences between the fish faunas in each of the freshwater habitats in the study region when compared to the estuarine and salt affected waterbodies of the region. The species most commonly encountered in the estuarine and salt affected sites included the estuarine affiliated *Leptatherina wallacei* and *Pseudogobius olorum*, the endemic *G. occidentalis* and also the introduced *Gambusia holbrooki*.

INTRODUCTION

In 1971, several countries met in Ramsar, Iran to identify and discuss wetlands of international importance. Since that time, interest in wetlands has been increasing such that there are currently 106 countries which are signatories to what is now known as the Ramsar Convention (Phillips, 1993; iucn.org/themes/ramsar/about_infopack_4e.htm 4/9/1998). One of the outcomes of this convention was the development of numerous wetland habitat categories, which, in order to suit Australian conditions, have subsequently been modified by the Australian Nature Conservation Agency (Phillips, 1993). These broadscale types of habitat include, to name a few, freshwater and estuarine reaches of rivers, freshwater and saline lakes, permanent and ephemeral pools and also artificial waterbodies of various kinds. Although many of the waterbodies located in the south-western corner of Australia can be easily placed into one of the above modified Ramsar categories, others are either combinations of Ramsar's categories or fall outside any of their definitions. For example, the ephemeral pools of the peat flat region occur, by definition, on organic/humic soils and are thus a combination of the Ramsar categories B10 (seasonal/intermittent freshwater ponds and marshes on inorganic soils) and B15 (peatlands; forest, shrubs or open bogs), while salt affected waterbodies are not included in the classification (Phillips, 1993). The absence of a category for saline affected waterbodies is probably due to their relative paucity in the populated areas of the northern hemisphere (e.g. Europe and North America) (Williams, 1988; Phillips, 1993). The unnatural salinisation of waterbodies, however, is not confined to the south-west of Australia, but is becoming increasingly common in semi-arid regions of the world such as south-eastern Australia and southern and northern Africa (see for example Williams, 1988; Morelli and Drewien, 1993; Shaw and Newton, 1993).

While it is known that some of the freshwater fish species found in south-western Australia have very restricted distributions and occur in very specific habitat types, e.g. the salamanderfish *Lepidogalaxias salamandroides* is essentially restricted to some ephemeral pools of the peat flats (Christensen, 1982; Pusey and Edward, 1990; Morgan *et al.*, 1998), other species, such as the western minnow *Galaxias occidentalis*, nightfish *Bostockia porosa* and western pygmy perch *Edelia vittata*, are far more widespread and occur in a variety of habitat types (Christensen, 1982; Allen, 1989; Pusey and Edward, 1990; Morgan *et al.*, 1998).

The first aim of this paper was to define, for lower south-western Australia, the main waterbody types using Ramsar's definitions, and where necessary provide new/modified habitat definitions. The second aim, using the data presented in Table 2 of Morgan *et al.* (1998), was to determine if certain fish species or groups of species are associated with specific habitat types.

MATERIALS AND METHODS

Selection of data to be included in analyses

This study utilizes data collected in the area between Margaret River and Broke Inlet (see Table 2 in Morgan *et al.*, 1998). The association of species and/or suites of species within particular habitats was determined by estimating the similarity of the fish faunas based on the presence or absence of each species in each site. It should be noted that presence/absence data were preferred over abundance data for this study as all sites were not sampled in the same season and that the relative abundances change markedly between seasons in the south-west of Australia. For example, during winter, when the region receives the majority of its rainfall, water levels are extremely high and fish densities are consequently greatly reduced. In contrast, during summer, when there is little or no rain and evaporation is high, water levels fall dramatically and fish densities increase substantially. Thus, while the relative abundance of species at each site could not be confidently estimated, intense sampling at each site using several techniques (e.g. gill, seine, larval and scoop nets, electrofishing etc, see Morgan *et al.*, 1998 for precise details) provided a high degree of conviction that all of the species of fish present at each site were likely to have been captured.

Sites representing each of the following habitat types in lower south-western Australia as defined by Ramsar, i.e. permanent rivers and streams, permanent lakes, permanent freshwater pools, estuarine or intertidal waters and water storage areas, e.g. dams, and those habitats not defined by Ramsar, i.e. ephemeral pools and salt affected waterbodies, were included in the analyses.

It should be noted that those statistical packages which are currently available for generating similarity matrices and for the subsequent testing of these matrices, utilise agglomerative techniques to provide visual representations of any associations, i.e. classification dendograms and ordination plots. These packages can normally only 'handle' a set maximum small to moderate number of samples, e.g. TAXAN2 – 100 samples, SPSS-X – small to moderate number of samples (not defined), PRIMER – 124 samples. As the current study sampled more than 400 sites (= 400 samples) (see Table 2 in Morgan *et al.*, 1998), a rationalisation and reduction of sites for inclusion in these analyses was necessary. Thus, the 239 sites sampled in the waterbodies between Margaret River and Broke Inlet (see Table 2 in Morgan *et al.*, 1998) were selected for this part of the study as this region contains the majority of fish species that inhabit inland waters in south-western Australia, and this region also incorporates all of those different habitats defined above. Furthermore, this region also contains the largest river system in south-western Australia, as well as both cleared areas and some of the least disturbed areas of south-western Australia. Of the 239 different sites sampled during this study in the above watersheds, fish were not captured in 55 and these sites were thus omitted from further analyses. Furthermore, adjacent and seasonally connected sites were amalgamated if they were of the same habitat type and contained a similar suite of species. This reduced the total number of sites for analysis to 123, which is a suitable number for analyses to be performed using PRIMER.

Classification of sample sites, ANOSIM and SIMPER

On the basis of a species presence or absence, the distribution of the different fish species amongst the 123 sites was used to construct a similarity matrix employing the Bray-Curtis similarity coefficient in PRIMER (Clarke and Warwick, 1994). To illustrate the extent of similarity in the faunal composition of these sites, the matrix was then subjected to classification using PRIMER (Clarke and Warwick, 1994). In order to test the proposition that the different broad habitat types outlined above will contain different fish faunas, the 123 sites sampled were *a priori* allocated to one of these habitats and the significance of any faunal differences between these broad groups was tested by one-way analysis using ANOSIM in the PRIMER package (Clarke and Warwick, 1994).

Since more than half, i.e. 63, of the sample sites were within group V in the initial classification (see Figure 1), and as the other groups were likely to have strongly influenced the expression of variation within this group of the classification, the sites in group V were separately subjected to classification. The species that distinguish the two large resultant groupings from each other within this classification (see Figure 2), were then determined using SIMPER (similarity percentages) (Clarke and Warwick, 1994).

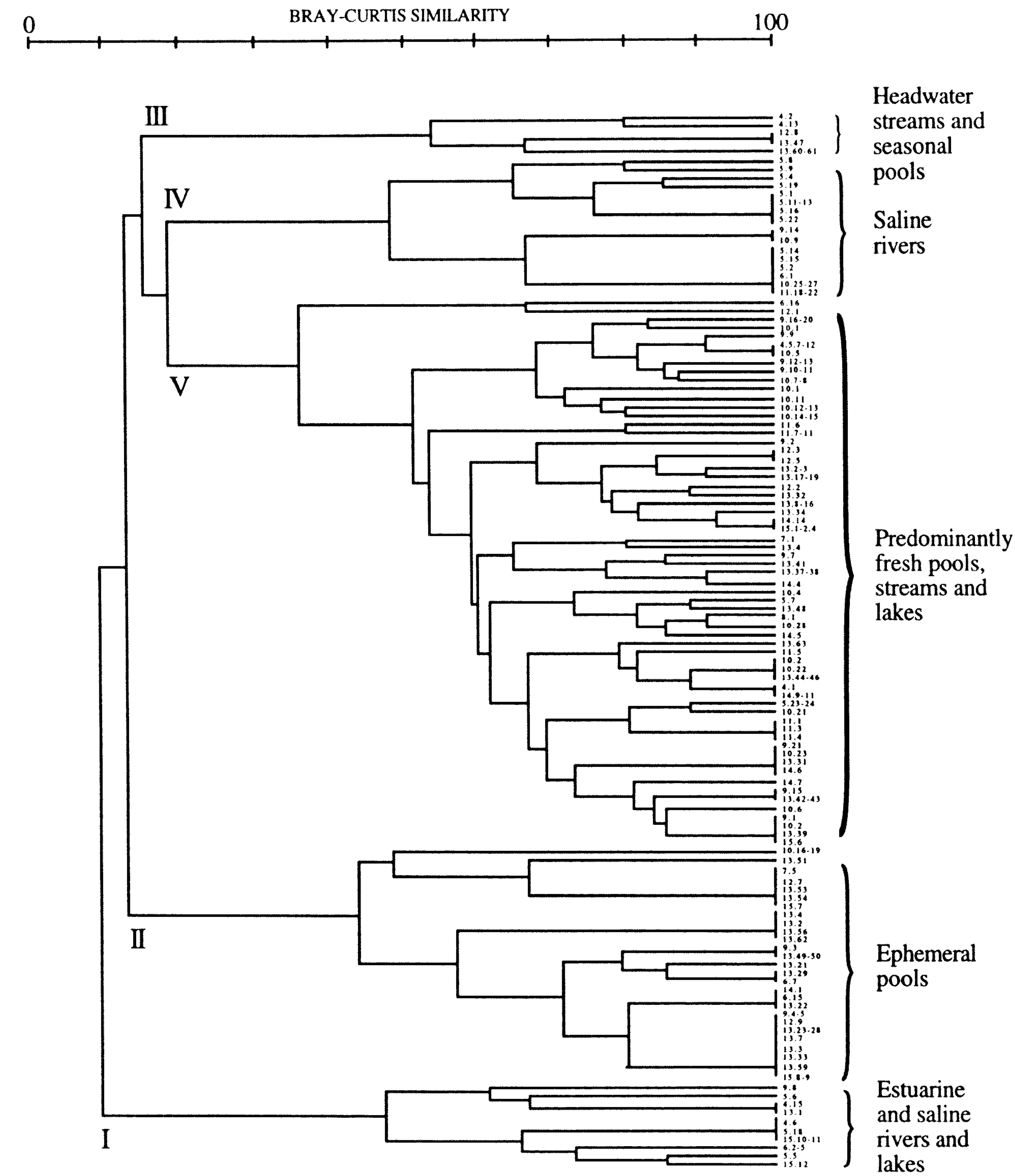
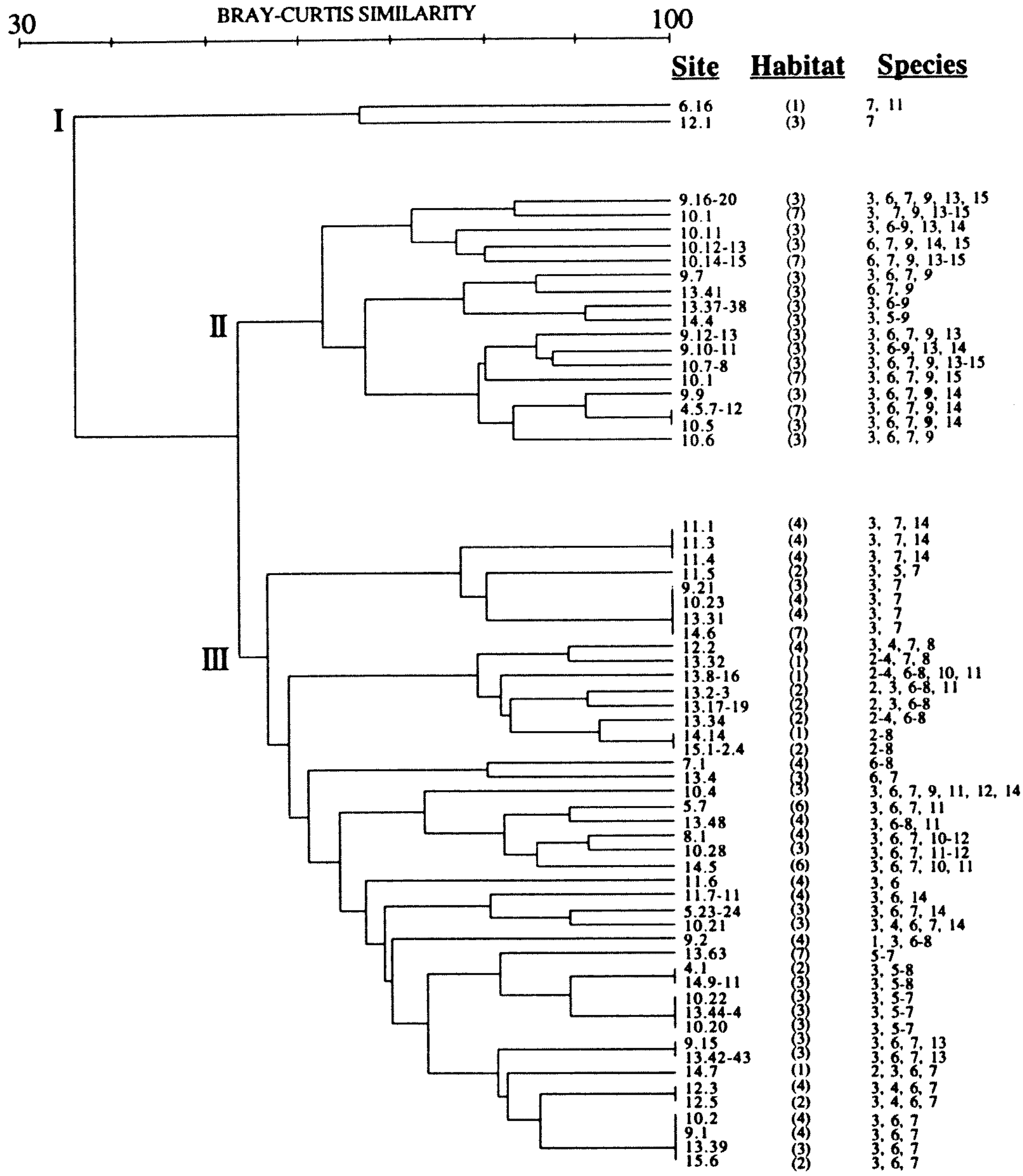


Figure 1 Classification of the sites sampled for fish in the water catchments between Margaret River and Broke Inlet, inclusive, in lower south-western Australia. N.B. The site numbers are given. For the locality of each site and its associated fish fauna see Table 2 in Morgan *et al.* (1998).

RESULTS

Classification of the different fish faunas at the different sampling sites produced five major groups (Figure 1). The first group of sites (I) was dominated by species with marine affinities, i.e. the western hardyhead *Leptatherina wallacei*, Swan River goby *Pseudogobius olorum* and big headed goby *Afurcagobius suppositus*. All of these sites were either estuarine or salt affected waterbodies. Group II comprised those sites that were of an ephemeral nature and contained predominantly *L. salamandroides* and/or the black-stripe minnow *Galaxiella nigrostriata*. However, other endemic freshwater teleosts, such as *G. occidentalis*, *B. porosa*



Habitat type

(1) Ephemeral pools
(2) Permanent pools
(3) Freshwater rivers and streams
(4) Freshwater lakes
(5) Estuarine
(6) Saline rivers
(7) Dams

Species

1. *Tandanus bostocki*
2. *Lepidogalaxias salamandroides*
3. *Galaxias occidentalis*
4. *Galaxiella nigrostriata*
5. *Galaxiella munda*
6. *Bostockia porosa*
7. *Edelia vittata*
8. *Nannatherina balstoni*
9. *Geotria australis*
10. *Leptatherina wallacei*
11. *Pseudogobius olorum*
12. *Afurcagobius suppositus*
13. *Oncorhynchus mykiss* or *Salmo trutta*
14. *Gambusia holbrooki*
15. *Perca fluviatilis*

Figure 2 Further classification of the sites in Group V of Figure 1. The site number (see Table 2 in Morgan *et al.* (1998)) and the prevailing habitat type, as well as those species present at each site, are given. N.B. For *Geotria australis* – ammocoetes (larval) are represented by an italicised *9*, adults by a bolded **9** and when both are present a standard (i.e. not bolded or italicised) 9 is given.

and *E. vittata*, were also commonly found in these environments, which they utilise as both spawning and nursery grounds. The small number of sites that comprised group III were either headwater streams or seasonal water bodies and were characterised by the presence of the mud minnow *Galaxiella munda* and either one or two other endemic species (Figure 1). The sites in group (IV) in Figure 1 were from saline rivers, and were characterised by the presence of the introduced *Gambusia holbrooki*, but also included *G. occidentalis*, *L. wallacei*, *P. olorum* and to a lesser extent *B. porosa* and *Oncorhynchus mykiss*/*Salmo trutta*. Group V, which contained the majority of sites sampled, i.e. 63, comprised those sites with a relatively 'natural' assemblage of fishes, with the dominant species being those that are endemic to the south-west of Australia and also the lamprey *Geotria australis*. Furthermore, those species which have been introduced into the region, such as the mosquitofish *G. holbrooki*, redfin or Eurasian perch *Perca fluviatilis* and the trout species *O. mykiss*/*S. trutta* were also recorded in some of these sites. The habitats within this group included both ephemeral and permanent pools, streams, lakes and dams (Figure 1).

When the samples for Group V were classified separately, three distinct groups were apparent (Figure 2). The first group (I) in this dendogram contained two outliers, with the first site containing only *E. vittata*, while the other contained *E. vittata* and *P. olorum*. The classification then, with respect to the remaining sites, produced two main groups (Figure 2). The smaller group (II), which contained exclusively freshwater riverine or dammed sites, was shown by SIMPER to be characterised by the presence of *G. australis*. Within this group, the other species that were found in most sites included *E. vittata*, *B. porosa* and *G. occidentalis*. The larger group (III) contained these three latter species at most sites, and were of a wide range of habitat types, e.g. ephemeral and permanent pools, freshwater rivers and streams, freshwater lakes, saline rivers and dams.

The distinct differences between the species composition in the saline waters (e.g. estuarine and Blackwood River) and the fresh waters in south-western Australia are further highlighted when the fish faunas of the different habitat types (i.e. ephemeral pools, permanent pools, fresh rivers, lakes, estuarine, salt affected rivers and dams) are subjected to one-way analysis using ANOSIM. Thus, ANOSIM showed that there were indeed significant faunal differences ($p<0.05$) between each of the freshwater habitats in the study region when compared to each of the saline habitat types. ANOSIM also showed that there were significant differences ($p<0.05$) between the fish fauna of ephemeral pools of the region and those of the rivers and lakes, this being a reflection of the absence of *L. salamandroides* and *G. nigrostriata* from the vast majority of the latter habitats (Table 1).

The tabulation of the number of sites at which each species occurred for each of the habitat types further illustrates the associations described above (Table 1). Thus, *L. salamandroides* and *G. nigrostriata* were essentially restricted to the pools of the region, being found in 25 and 24 of the 32 ephemeral pools sampled, and in two and five of the 10 permanent pools sampled, respectively. In contrast, *G. occidentalis*, *B. porosa* and *E. vittata* were most frequently found in permanent freshwater habitats, i.e. lakes, rivers and pools. Thus, these three species

Table 1 The number of sites within each broad habitat type, between Margaret River and Broke Inlet, that each of the inland fish species of south-western Australia were captured. The total number of sites sampled in each habitat type is also given.

	Habitat type								
Species	**Ephemeral pools (32)**	**Permanent pools (10)**	**Riverine (32)**	**Lakes (16)**	**Estuarine (7)**	**Salt affected (17)**	**Dams (8)**	**Salt lakes (1)**	**TOTAL (123)**
Tandanus bostocki				1	1				2
Lepidogalaxias salamandroides	25	2							27
Galaxias occidentalis	8	8	24	15	1	8	2		66
Galaxiella nigrostriata	24	5		2					31
Galaxiella munda	3	4	5				1		13
Bostockia porosa	6	7	26	10		3	2		59
Edelia vittata	9	7	29	15		3	5		68
Nannatherina balstoni	3	5	4	4					16
Geotria australis			15				4		17
Leptatherina wallacei	1			1	4	9		1	16
Pseudogobius olorum	2	1	2	2	7	6		1	20
Afurcagobius suppositus			2	1	2	1			6
Oncorhynchus mykiss/Salmo trutta			7				5		12
Gambusia holbrooki			10	5		12	5		32
Perca fluviatilis			5				3		8

were captured in 49, 45 and 56 of the 66 permanent freshwater habitats sampled, respectively (Table 1). The remaining two small endemic species, *G. munda* and *N. balstoni*, were much rarer, being found only in ephemeral pools (three each), permanent pools (four and five, respectively) and in riverine sites (five and four, respectively). *Nannatherina balstoni* was also captured in four lakes. The freshwater catfish or cobbler *Tandanus bostocki* was very rarely captured during this study.

Leptatherina wallacei was not captured in the freshwater rivers of the region. It was, however, found in one fresh and one salt lake, four estuarine sites and nine salt affected river sites. Similarly, *P. olorum* was most often found in estuarine (seven) and salt affected sites (six), but also in freshwater rivers (two) and lakes (two) and in one salt lake. Both of the latter species were very occasionally captured in ephemeral pools (Table 1). The other species that is commonly associated with estuaries, i.e. *A. suppositus* (see Morgan *et al.*, 1998), was found in two estuarine sites, one freshwater lake, one salt affected river and two freshwater riverine sites. The lamprey *G. australis* was only captured in riverine sites (15) and in dams (two), as were the introduced trout (seven and five sites, respectively) and *P. fluviatilis* (five and three sites, respectively). The remaining introduced species, *G. holbrooki*, was captured on more occasions, being found in 32 sites in both fresh (10) and salt affected (12) rivers, lakes (five) and dams (five) (Table 1).

DISCUSSION

While two of the endemic freshwater species of south-western Australia, i.e. *L. salamandroides* and *G. nigrostriata*, are essentially restricted to ephemeral pools, the five remaining small endemic freshwater teleosts are found in a wider variety of habitat types such as streams, lakes and ephemeral and permanent pools. Of these latter species, *N. balstoni* and *G. munda* were found in fewer sites than the other small endemics, namely *G. occidentalis*, *B. porosa* and *E. vittata* (see Table 1; Morgan *et al.*, 1998). It should be noted that, like *L. salamandroides* and *G. nigrostriata*, *N. balstoni* and *G. munda* are restricted in their distribution and are most common in the waterbodies of the peat flats.

Since *G. occidentalis*, *G. holbrooki*, *L. wallacei*, *P. olorum* and *A. suppositus* were all found in a wide range of salinities, they must be at least moderately euryhaline. The other teleosts caught during this study were almost always captured in fresh waters and it can therefore be assumed that these species are either stenohaline or show strong preferences for fresh water. The results presented in this paper demonstrate that the salinisation of water bodies in south-western Australia is likely to cause a decline in the number of endemic freshwater species in such systems. In contrast, the introduced *G. holbrooki* and also those species commonly associated with estuaries, i.e. *L. wallacei* and *P. olorum*, are likely to either become more prevalent in waters which have higher than 'normal' salinities or are not going to be affected by such conditions. The salinisation of many freshwater habitats, through land clearing within the immediate catchment, is increasing in south-western Australia and is causing the extinction or decline in populations of other aquatic fauna and also flora, and consequently, is having major effects on stream ecology (Hart *et al.*, 1991; Pen, 1997). Thus, while certain macrophytes, microalgae, fringing vegetation, invertebrate species and waterbirds may increase in abundance in such saline systems, others may decline (Hart *et al.*, 1991; Williams, 1995). Within the Blackwood River (the largest salt affected river in Western Australia with an average annual increase in dissolved salts of *ca* 15 mg/L (Schofield and Ruprecht, 1989; Pen, 1997)), for example, Williams *et al.*, (1991) found little or no longitudinality with regard to faunal composition of this system, despite the salinity gradient along its length. Although this is likely to be a consequence of an increase in halotolerant species, it presumably also indicates that there has been an elimination of less tolerant species that once characterised a more diverse system (Trayler *et al.*, 1996). It could therefore be argued that the increasing salinity in the Blackwood River is resulting in a loss of populations of endemic freshwater teleosts and a concomitant increase in halotolerant species such as *L. wallacei*, *P. olorum* and *G. holbrooki*.

It is worth noting that when the introduced species *G. holbrooki* and *P. fluviatilis* were present in artificial environments, e.g. dams, the native species were rarely captured. In contrast, in riverine sites, native and introduced fish species were often found together, however, during the periods when water levels were greatly reduced and sections of rivers became a series of small pools, native fish were usually absent in those pools that harboured *P. fluviatilis* and/or the two trout species. When the results of this study are considered in conjunction with the studies of Hambleton *et al.* (1996), Morgan and Gill (1996) and Gill *et al.* (1998), it becomes evident that the small endemic freshwater teleosts of south-western Australia are vulnerable to the continuing loss or alteration of habitat and to the introduction of agonistic or piscivorous species such as *G. holbrooki* and *P. fluviatilis*.

The fact that adult and larval (ammocoetes) lampreys were only captured above four of the eight dams sampled may reflect the fact that large dam walls can act as a major barrier to the upstream migration of lampreys and that dams may also modify flow regimes and thereby cause adverse changes to the sediment composition of ammocoete beds.

While this paper has provided data on the broad scale habitat associations of the fishes of lower south-western Australia, it does not provide information on their specific habitat requirements, preferences and tolerances, e.g. suitable spawning substrate, flow regimes, preference for complex habitats, and pH and salinity tolerances. Future studies should therefore be aimed at the provision of such information, which will aid in both the formulation of management plans for the conservation of this unique fauna and also the identification of prospective habitats for their re-introduction.

ACKNOWLEDGEMENTS

Financial support for this project was provided by the Natural Heritage Trust, Water and Rivers Commission of Western Australia, Fisheries WA, National Fishcare and Murdoch University. Thankyou to Steven Head, Murray Stevenson, Simon Visser, Dean Campbell-Smith, Paul Wright and Simon Hambleton for their invaluable help with the extensive sampling and to Margaret Platell for her comments on the manuscript.

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Manuscript received 5 July 1999; accepted 11 October 1999.