Fish habitat in the Lower River Murray: an analysis of the nature, extent and the associated fish assemblages

Final Report

SARDI Publication No. F2007/000973-2
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Executive Summary

This report provides a description of the findings of the River Murray Fish Habitat project. This project aimed to identify priority areas of the South Australian River Murray main channel based on an assessment of fish habitat. An inventory of the different in-water and riparian (<50 cm above pool level) habitats and their distributions was undertaken in the River Murray main channel between Wellington and the New South Wales border. Mapping was undertaken from a boat and plant species (and other major habitat components such as large woody debris and man made structures) within a reach (greater than 50m in length) were recorded *in situ* onto a pocket computer with ArcPad software. The information was transferred onto an interactive GIS database using ArcGIS desktop software where the broad habitat types were determined based on the different habitat features and plant species present. The resultant database contains the mesohabitat data as well as snag locations, bathymetry, and aerial photographs.

At the conclusion of the mapping component 29 mesohabitat types were identified. The four most common habitat types along the main channel were classified as bare, Willows dense, 'Typha'/'Phragmites' and 'Phragmites'/ Red Gum sparse. The resultant database can be used to view the habitat types, depths and number of snags within a region or queries may be preformed on the data (e.g. location or total area of a habitat type). The database may be used for various projects based in the lower River Murray, particularly studies prioritising reaches for rehabilitation or protection.

In the final phase of the study fish assemblages were sampled in a representative sub-set of the identified mesohabitats and the information used to determine relationships between fish assemblages and mesohabitats. Due to differences in fish assemblages between regions, the lower River Murray was split into three regions: below Lock 1, Locks1-3 and above Lock 3 and priority habitats identified for each region. The were no high priority mesohabitats downstream of Lock 1 (based on fish diversity and presence of protected or EPBC listed species), probably due to low water levels stranding all of the structurally diverse mesohabitats. Between Locks 1 and 3 and upstream of Lock 3 the fish community was more diverse and protected and EPBC listed species were more abundant, which may be due to the greater diversity of structural habitats. Four high and two medium conservation value mesohabitats were present between Locks 1 and 3 and four high and four medium conservation value mesohabitats were present upstream of Lock 3.

The prioritisation of mesohabitats in this report was based on a single snapshot of the fish community and did not take into account temporal changes and deil changes. In addition, there are limitations to electrofishing especially in water deeper than 2.5 m that may have resulted in

some species not being captured in certain mesohabitats (especially cliffs and willow habitats downstream of Lock 1). Nevertheless, the results from this study provide a good starting point for selecting freshwater protected areas or areas for habitat rehabilitation or revegetation projects.

1. Background and Aims

The River Murray in South Australia is highly regulated with a series of low level (~3 m) weirs and upstream abstraction reducing the natural variability of the river's flow, inundation of the floodplain and obstructing the longitudinal movement of aquatic organisms (Gehrke *et al.* 1995; Maheshwari *et al.* 1995). Native fish populations have declined in range and abundance since river regulation (Cadawallader 1978; Humphries *et al.* 2002) and in order to manage fish stocks in the River Murray it is important that the preferred habitat for these species is identified and protected or improved (Gehrke *et al.* 1995). Currently, there is no quantitative data on the nature and extent of fish habitats in main channel of the River Murray (except for priority sites such as the main channel adjacent to the Chowilla Anabranch (Zampatti *et al.* 2006).

The South Australian Integrated Natural Resources Management (INRM) Strategy, River and Floodplain Management Program 5, outlined several resource condition targets for aquatic habitats in the South Australian River Murray (SAMDINRMG 2004). Specifically, task 5.1.5 (to undertake baseline aquatic fauna and in-stream habitat data collection and assessment) in the INRM Strategy requires baseline information on in-stream habitats to be collected to gain an assessment of the current condition of these habitats, their distributions and any associated fish communities, to determine whether resource condition targets are being achieved. In accordance with this task, the South Australian Murray-Darling Basin Natural Resources Management (SAMDBNRM) Board funded this study to investigate the relationship between different aquatic and riparian habitats and fish communities in the lower River Murray.

The first stage of the study (2006-2007) involved mapping the riparian, emergent and submerged vegetation of the River Murray and a range of additional physical habitat features, specifically bathymetry, large snags, man made structures and major wetland entrances. These habitat features were used to create a GIS database incorporating bathymetry, biological and structural features. In the autumn of 2008, representative habitats along the main channel were surveyed using Sustainable Rivers Audit (SRA) electrofishing techniques. In addition to electrofishing the major mesohabitats, quantitative assessments at the microhabitat (electrofishing shot) scale were also conducted at each site. Electrofishing was used to sample fish assemblages because it is an active, non-selective sampling method that enables fish to be collected in a standard manner in the habitat that they are occupying at that point in time (Baumgartner *et al.* 2008). This project also offered an opportunity to investigate associations between fish assemblage and specific habitat features.

This report outlines the findings of our three year study which aimed to:

- collect baseline information of the nature, extent and types of in-stream and riparian habitats in the lower River Murray,
- identify the fish communities associated with these habitat types and
- incorporate this information into a GIS database that can be used to identify priority areas in the River Murray Main Channel based on fish habitat at a reach scale that can be used to aid managers in conservation planning and management.

The results of this survey may be used to provide baseline information on the aquatic and riparian habitat of the South Australian River Murray. Using this information in conjunction with the fish survey data priority areas may be identified to aid managers in conservation planning to ensure a comprehensive and representative reserve system of freshwater protected areas. However, only one fish survey was conducted during a period of record low inflow into South Australia; therefore, it represents a snapshot of the fish community present at that point in time. Due to the river conditions at the time of the survey and the fact that it was a "one off" survey, the fish data and habitat associations need to be treated with some caution because it may not reflect long-term patterns or the fish community under entitlement flow (or greater) conditions.

2. Stage 1: Mesohabitat Mapping

2.1. Mesohabitat Mapping: Methods

A GIS database was constructed using ArcGIS Desktop 9.1 (ESRI, 2006). The database was populated with a combination of existing and constructed layers. The snag layer was obtained from Department for Environment and Heritage, Environmental Information and only contained the locations of large snags that are potentially hazardous to boating. The bathymetry and floodplain elevation layers were stitched together by DEH from the Department of Water, Land and Biodiversity Conservation LIDAR data (floodplain) and SA water sonar data (bathymetry) to form one layer. Topography layers, originally mapped by Department for Environment and Heritage, were obtained from the PIRSA SIS library. Features of this layer include place names and water body boundaries. The River Murray boundary was based on water body boundary mapping from the 1:50 000 Topographic GIS layer. Aerial photographs (from the 2008 fly over) provided by the SAMDBNRM Board were added to the database and used to verify the outline of the River Murray. In order for the polygons to be viewed on printed maps, the polygons had a thickness of between 50 and 70 metres. The River Murray outline was then transferred to a hand held Trimble Recon pocket personal computer (pocket PC) equipped with GPS and Arc Pad software.

Surveys of the aquatic and riparian (from the edge of the water to 50 cm above normal pool level) habitat were undertaken along the main channel of the River Murray between the Wellington ferry and the New South Wales border in the autumn and winter of 2007, when the water level in each weir pool was at normal pool level. Mapping was undertaken from a boat and recorded on the pocket PC *in situ*. Habitat types were attributed to reaches greater than 50 metres in length. Changes in habitat types were marked on the pocket PC as lines. Each different habitat was marked as a point and plant species within that reach were recorded on the pocket PC in order of abundance.

Dominant emergent and overstorey plant species were labelled either dense or sparse depending on their abundance within a reach. *Phragmites australis, Typha* spp., *Schoenoplectus validus* and *Bolboschoenus caldwellii* were considered dense if there was greater than 50% cover within a reach and sparse if one of these species was dominant, but occupied between 15 and 50% of the reach. *Eucalyptus camaldulensis* var. *camaldulensis, Salix* spp. and *Acacia stenophylla* were categorised as sparse in reaches with scattered trees present and dense in reaches where the canopy cover was greater than 50%. Other emergent and overstorey species observed during the study, which did not form dense stands or dominate a habitat, were recorded for the habitat groups in which they were found.

A reach that was categorised as bare in instances where the percentage cover of unvegetated bank was 85 % or greater (all species present have sparse abundances). Areas heavily impacted by human activity (e.g. shacks, locks, townships) along the banks of the River Murray were categorised as a modified mesohabitat. In each instance all species present in these areas were also recorded.

Habitat polygons were created in the GIS database from the lines and points recorded on the pocket PC. Each polygon was populated by a set of species in order of abundance; however, for illustrative purposes and future analyses polygons were categorised into mesohabitat types identified at the conclusion of the field component. Mesohabitat types were determined by the dominant plant species or physical features (e.g. cliffs, wetland entrances) present in the reach. Plants were identified using keys in Cunningham *et al.* (1981), Sainty and Jacobs (1981), Jessop and Toelken (1986), Romanowski (1998), Sainty and Jacobs (2003) and Jessop *et al.* (2006). In some cases due to immature individuals or lack of floral structures, plant were identified to genus only. Nomenclature follows Barker *et al.* (2005).

2.2. Mesohabitat Mapping: Results

Twenty nine mesohabitat types were identified at the conclusion of the field mapping component. Each mesohabitat category is associated with a specific set of attributes is described in Table 1:

Table 1: The 29 mesohabitat types determined for the Lower River Murray, their main habitat features and the corresponding number and percentage area of polygons. The percentage area of each habitat type was calculated by determining the total area of all polygons and the respective percent each habitat type contributed. These are to be interpreted as guides only as the width of the polygons are variable and were not drawn to scale.

Mesohabitat	Description of dominant habitat features	No. of Polygons	% Area
'Acacia'	*Acacia stenophylla* (dense) ± *Eucalyptus camaldulensis* var. *camaldulensis, Eucalyptus largiflorens, Salix* spp., *Phragmites australis, Typha* spp., *Schoenoplectus validus* or submerged vegetation.	23	1.09
Bare	Bare bank ± *Eucalyptus camaldulensis* var. *camaldulensis, Eucalyptus largiflorens, Acacia stenophylla, Salix* spp., *Phragmites australis, Typha* spp., *Schoenoplectus validus, Paspalum distichum, Bolboschoenus caldwellii* or submerged vegetation.	218	14.19
'Bolboschoenus'	*Bolboschoenus caldwellii* (dense) with *Eucalyptus camaldulensis* var. *camaldulensis* (sparse or dense) ± *Acacia stenophylla, Phragmites australis, Typha* spp., *Schoenoplectus validus* or submerged vegetation.	4	0.09
'Bolboschoenus' sparse	Sparsely distributed *Bolboschoenus caldwellii* with *Eucalyptus camaldulensis* var. *camaldulensis* (sparse) ± *Acacia stenophylla, Phragmites australis, Typha* spp. or submerged vegetation.	7	0.26
Cliffs	Cliffs ± *Eucalyptus camaldulensis* var. *camaldulensis, Eucalyptus largiflorens, Salix* spp., *Acacia stenophylla, Phragmites australis, Typha* spp. or *Paspalum distichum.*	120	9.20
Modified	Highly modified riparian zone including shacks, locks and weirs, marinas, townships and other infrastructure along the riparian zone.	181	9.16
'Phragmites'	*Phragmites australis* (dense) ± *Eucalyptus camaldulensis* var. *camaldulensis, Eucalyptus largiflorens, Salix* spp., *Acacia stenophylla* (all sparse), *Juncus usitatus, Schoenoplectus validus, Typha* spp., *Bolboschoenus caldwellii*, or submerged vegetation.	10	0.08
'Phragmites'/ 'Acacia'	*Phragmites australis* with *Acacia stenophylla* ± *Eucalyptus camaldulensis* var. *camaldulensis, Eucalyptus largiflorens, Salix* spp., (all sparse), *Schoenoplectus validus, Typha* spp., *Bolboschoenus caldwellii* or submerged vegetation.	22	1.01
'Phragmites'/ 'Bolboschoenus'	*Phragmites australis* with *Bolboschoenus caldwellii* (both dense) ± *Eucalyptus camaldulensis* var. *camaldulensis, Acacia stenophylla, Juncus usitatus, Schoenoplectus validus, Typha* spp. or submerged vegetation.	26	0.90
'Phragmites'/ Red Gum	*Phragmites australis* with *Eucalyptus camaldulensis* var. *camaldulensis* (both dense) ± *Salix* spp., *Acacia stenophylla* (all sparse), *Juncus usitatus, Schoenoplectus validus, Typha* spp., *Bolboschoenus caldwellii* or submerged vegetation.	117	5.38

Mesohabitat	Description of dominant habitat features	No. of Polygons	% Area
'Phragmites'/ Red Gum sparse	*Phragmites australis* (dense) with *Eucalyptus camaldulensis* var. *camaldulensis* (sparse) ± *Salix* spp., *Acacia stenophylla, Eucalyptus largiflorens,, Juncus usitatus, Schoenoplectus validus, Typha* spp., *Bolboschoenus caldwellii*, *Paspalum distichum* or submerged vegetation.	202	10.95
'Phragmites'/ 'Schoenoplectus'	*Phragmites australis* with *Schoenoplectus validus* (both dense) ± *Eucalyptus camaldulensis* var. *camaldulensis, Salix* spp., *Acacia stenophylla, Eucalyptus largiflorens, Juncus usitatus, Typha* spp., *Bolboschoenus caldwellii*, *Paspalum distichum* or submerged vegetation.	40	1.40
'Phragmites' sparse	Main habitat feature is *Phragmites australis* (sparse) with *Eucalyptus camaldulensis* var. *camaldulensis* (sparse) ± *Salix* spp., *Acacia stenophylla, Eucalyptus largiflorens, Juncus usitatus, Schoenoplectus validus, Typha* spp., *Bolboschoenus caldwellii*, *Paspalum distichum* or submerged vegetation.	121	5.39
'Phragmites'/ Willows	*Phragmites australis* (dense) with *Salix* spp. (sparse) ± *Eucalyptus camaldulensis* var. *camaldulensis, Acacia stenophylla, Typha* spp. or submerged vegetation.	51	1.59
Red Gum dense	*Eucalyptus camaldulensis* var. *camaldulensis* (dense) ± *Acacia stenophylla, Phragmites australis, Typha* spp., *Schoenoplectus validus, Juncus usitatus, Paspalum distichum,* herbs or grasses or submerged vegetation.	82	3.17
Red Gum sparse	*Eucalyptus camaldulensis* var. *camaldulensis* (sparse) with herbs and grasses ± *Acacia stenophylla, Phragmites australis, Typha* spp., *Schoenoplectus validus, Juncus usitatus* or submerged vegetation.	10	0.38
'Schoenoplectus'	*Schoenoplectus validus* (dense) ± *Eucalyptus camaldulensis* var. *camaldulensis, Salix* spp., *Phragmites australis, Juncus usitatus, Schoenoplectus validus, Typha* spp., *Bolboschoenus caldwellii*, *Paspalum distichum* or submerged vegetation.	19	0.44
Swamp	Inundated area of vegetation with a poorly defined bank ± *Eucalyptus camaldulensis* var. *camaldulensis, Salix* spp., *Acacia stenophylla, Phragmites australis, Juncus usitatus, Schoenoplectus validus, Typha* spp., *Bolboschoenus caldwellii* or submerged vegetation.	67	2.49
'Typha'/ 'Phragmites'	*Phragmites australis* and *Typha* spp. (both dense) ± *Eucalyptus camaldulensis* var. *camaldulensis, Salix* spp., *Acacia stenophylla, Eucalyptus largiflorens, Juncus usitatus, Schoenoplectus validus, Bolboschoenus caldwellii*, *Paspalum distichum* or submerged vegetation.	278	11.47
'Typha'	*Typha* spp. (dense) ± *Eucalyptus camaldulensis* var. *camaldulensis, Salix* spp., *Acacia stenophylla, Eucalyptus largiflorens, Phragmites australis, Schoenoplectus validus, Bolboschoenus caldwellii* or submerged vegetation.	59	1.32

Mesohabitat	Description of dominant habitat features	No. of Polygons	% Area
'Typha'/ 'Phragmites' sparse	*Phragmites australis*, *Typha* spp. (both sparse) and bare soil ± *Eucalyptus camaldulensis* var. *camaldulensis, Acacia stenophylla, Eucalyptus largiflorens, Juncus usitatus, Schoenoplectus validus, Bolboschoenus caldwellii* or submerged vegetation.	43	1.75
'Typha' /Willows	*Typha* spp. (dense) with *Salix* spp. (sparse) ± *Eucalyptus camaldulensis* var. *camaldulensis* or submerged vegetation.	9	0.22
'Typha' sparse	*Typha* spp. (sparse) and bare soil ± *Eucalyptus camaldulensis* var. *camaldulensis, Acacia stenophylla, Schoenoplectus validus* or submerged vegetation.	20	0.49
'Typha'/ 'Bolboschoenus'	*Typha* spp. with *Bolboschoenus caldwellii* (both dense) ± *Eucalyptus camaldulensis var. camaldulensis, Phragmites australis* or submerged vegetation.	7	0.18
'Typha'/ 'Schoenoplectus'	*Typha* spp. with *Schoenoplectus validus* (both dense) ± *Eucalyptus camaldulensis var. camaldulensis, Salix* spp., *Phragmites australis, Juncus usitatus* or submerged vegetation.	24	0.77
'Typha'/ Red Gum	*Typha* spp. with *Eucalyptus camaldulensis* var. *camaldulensis* (both dense) ± *Acacia stenophylla, Salix* spp., *Phragmites australis, Juncus usitatus, Schoenoplectus validus* or submerged vegetation.	38	0.98
Willows dense	Dense *Salix* spp. ± *Eucalyptus camaldulensis* var. *camaldulensis, Typha* spp., *Phragmites australis, Schoenoplectus validus* or submerged vegetation.	188	13.85
Willows/ Red Gum	*Salix* spp. and *Eucalyptus camaldulensis* var. *camaldulensis* (both sparse), ± *Typha* spp., *Phragmites australis, Schoenoplectus validus* or submerged vegetation.	8	0.23
Wetland entrance	An entrance to a floodplain wetland.	175	1.56

The most widespread habitat types in the South Australian River Murray were: Bare, Willows dense, 'Typha'/'Phragmites' and 'Phragmites'/Red Gum sparse, followed by cliffs and modified habitats (Table 1). The least prevalent habitat types were 'Phragmites' and 'Bolboschoenus'.

Reaches classed as bare were only found upstream of Swan Reach, and were most prominent between Morgan and the NSW border, with the greatest concentration around Loxton. 'Willows dense' habitats were predominant between Wellington and Purnong with scattered reaches upstream. 'Typha/Phragmites' habitats were distributed throughout the Lower River Murray, except where 'Willows dense' habitats were dominant (Wellington to Purnong) and around the Loxton area where the majority of the reaches were classified as bare. The 'Phragmites'/Red Gum sparse habitat type was also widely distributed from Purnong to the NSW border, although less common in the Loxton area and upstream of Renmark.

The database contains the habitat polygons, snag and depth layers, aerial photographs and topographical information. Users are able to view specific areas of the Lower River Murray and inspect the corresponding mesohabitats and specific species present in each polygon as well as perform queries on the habitat data. The information can also be converted into printable maps.

3. Stage 2: Fish and Microhabitat Survey

3.1. Fish and Microhabitat Survey: Methods

3.1.1. Site selection

From the 29 mesohabitats identified in the first stage of the project (Table 1), ten were selected for fish sampling (Table 2) based on the following criteria:

- Broad habitat polygons were only selected that were equal or greater than 100 metres in length to allow for sufficient area to complete six x 90 second electrofishing shots.

- Three or more polygons fitting the above criteria were required to be present in the study area.

- Polygons were ineligible to be surveyed if they were immediately downstream of a weir to avoid affecting similar sampling projects analysing fish movement in these regions and any confounding effects of the weirs themselves.

- Polygons fitting the above criteria were short listed and consideration was given to accessibility, the proximity to one or more potential sites and location to ensure an even spread of sites across the River.

- Broad habitats that were prominent and widespread across the main channel were sampled with a greater number of replicates than those that were less prevalent (Table 2).

Table 2: Number of sites in each broad habitat category sampled across the South Australian River Murray.

Broad Habitat type	Number of Sites
Cliffs	10
Modified	9
‘Acacia’	3
‘Phragmites’ Red gum sparse	3
‘Phragmites’ and Red gum	9
‘Typha’ and ‘Phragmites’	6
Willows	9
Bare	9
Red gum	3
‘Phragmites’ sparse	6
Total sites	**61**

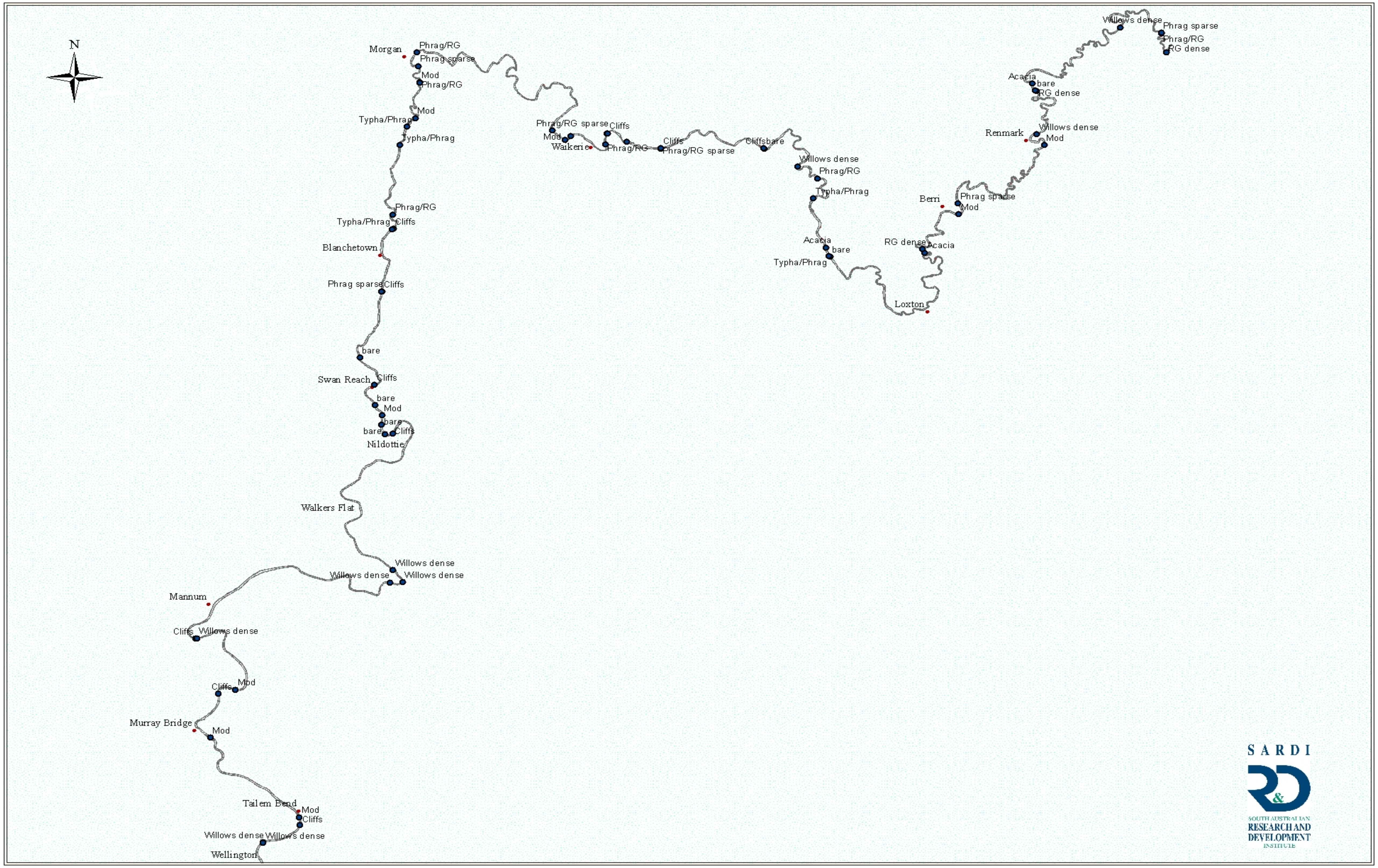

Figure 1: Distribution of fish sampling sites across the Lower River Murray.

3.2. Electrofishing

Boat electrofishing was used to sample the fish communities associated with the different mesohabitat types in the lower River Murray. It was deemed the most appropriate method because it has been proven to effectively and rapidly sample both large and small bodied fish in the littoral zone of large, turbid lowland rivers (Faragher and Rodgers 1997; Baumgartner *et al.* 2008) and is used extensively in the main channel of the lower River Murray (e.g. Zampatti *et al.* 2006). The techniques used in this survey followed those outlined in the Sustainable Rivers Audit (SRA) (Murray Darling Basin Commission 2004) with the exception that one site (composed of six shots) was confined to a single side of the river allowing consistent sampling along a specific habitat type. In addition, the data will be comparable with the Chowilla fish condition monitoring (Zampatti *et al.* 2008), Katarapko (Leigh *et al.* 2008) and Pike River projects (in progress).

Fish surveys were conducted during daylight hours from March to May 2008 using a boat mounted 7.5kW Smith Root Model GPP electrofishing system. Six 90 second (power on time) shots were conducted at each site. All fish were dip netted and placed in a recirculating well. Fish from each shot were identified and measured for length (caudal fork or total length in mm). The littoral zone of each mesohabitat (between 0 and 5 m water depth) was fished in order to stay within the effective range of the electrofishing equipment.

3.3. Microhabitat Assessments

Quantitative visual habitat assessments were carried out at each electrofishing shot following the methods used by Zampatti *et al* (2006). One observer estimated the percentage cover of in-stream habitat including submerged and emergent vegetation, large woody debris, physical structures and open water. Large woody debris was categorised depending on the size of the wood, such that:

- CWD 1: twigs and branches with diameters <1 cm
- CWD 2: branches with diameters 1-5 cm
- CWD 3: branches and trunks with diameters >5 cm

3.4. Data Analysis

Fish assemblage and associations with meso and microhabitat types were analysed with various non-parametric multivariate techniques using PRIMER v. 6.1.12 (Clarke and Gorley 2006) and PC-Ord v. 5.12 (McCune and Mefford 2006) software packages. The number of fish caught in each shot was transformed into catch per unit effort (CPUE) which standardises the capture of fish based on the number of electrofishing seconds used per shot. The statistical package PRIMER was used to perform analysis of similarity (ANOSIM) and SIMPER (Clarke and Gorley 2006). ANOSIM provides information on the degree that samples are similar to each other and SIMPER compares the similarity of different groups, and indicates what factors are driving these differences. Therefore, we used this method to indicate what was driving the patterns of similarity (or dissimilarity) between regions and meso-habitats and Indicator Species Analysis (Dufrene and Legendre 1997) to determine fish habitat relationships at the micro-habitat scale (*sensu* Zampatti *et al.* 2006).

Simpson's Index (D) was used to quantify the cumulative fish diversity of each mesohabitat in each region. Simpson's index of diversity (1 – D) indicates the probability that two individuals randomly selected from a sample will belong to different species. The value of this index ranges between 0 and 1, with the greater the value, greater the sample diversity. There are two acceptable versions of Simpson's Index, in this report we used the following formula:

$$D = \Sigma (n/N)^2$$

where n = the total CPUE of a particular species caught in a mesohabitat type within a region and N = the total CPUE of all species caught in a mesohabitat type within a region.

The relative abundance of fish species within each mesohabitat of each region was determined by pooling the total of each species caught (in CPUE) and dividing the total catch within each mesohabitat.

4. Results

4.1. Catch summary

A total of 18,176 fish were caught during the survey (Table 3). Approximately 70% of the total catch was un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*: *n* = 6450) and bony herring (*Nematalosa erebi: n* = 6174) with Murray-Darling rainbowfish (*Melanotaenia fluviatilis: n* = 1973) and smelt (*Retropinna semoni*: *n* = 1529) also abundant (Table 3). Alien species made up 6.3% of the total catch and included common carp (*Cyprinus carpio: n* = 922), goldfish (*Caruassius auratus: n* = 112), gambusia (*Gambusia holbrookii: n* = 65) and redfin (*Perca fluviatilis: n* = 55) (Table 3). Low numbers of the protected species, freshwater catfish (*Tandanus tandanus: n* = 6) and silver perch (*Bidyanus bidyanus: n* = 15), and the iconic Murray cod (*Maccullochella peelii peelii: n* = 11) were caught during the survey (Table 3).

Table 3: Summary of fish caught during the 2008 survey and the conservation status of each species in South Australia (* denotes alien species).

Common Name	Scientific Name	Total caught	Conservation status
Bony herring	*Nematalosa erebi:*	6174	-
Carp gudgeon	*Hypseleotris* spp.	235	-
Common carp*	*Cyprinus carpio*	922	-
Common galaxias	*Galaxias maculatus*	39	-
Dwarf flathead gudgeon	*Philypnodon macrostomus*	5	-
Flathead gudgeon	*Philypnodon grandiceps*	271	-
Freshwater catfish	*Tandanus tandanus*	6	Protected under the SA Fisheries Act
Gambusia*	*Gambusia holbrookii*	65	-
Golden perch	*Macquaria ambigua ambigua*	314	-
Goldfish*	*Caruassius auratus*	112	-
Murray cod	*Maccullochella peelii peelii*	11	Listed as vulnerable under the Commonwealth EPBC Act
Murray-Darling rainbowfish	*Melanotaenia fluviatilis*	1973	-
Redfin*	*Perca fluviatilis*	55	-
Silver perch	*Bidyanus bidyanus*	15	Protected under the SA Fisheries Act
Australian smelt	*Retropinna semoni*	1529	-
Un-specked hardyhead	*Craterocephalus stercusmuscarum fulvus*	6450	-
Total		**18176**	

4.2. Regional comparisons of fish assemblage and habitat structure

Traditionally the South Australian section of the River Murray has been divided into four regions: the Lower Lakes, (The Barrages to Wellington, which was not part of the study area), Murraylands (Wellington to Mannum), the Gorge (Mannum to Overland Corner) and the Valley (Overland Corner to the NSW boarder) (Holt *et al.* 2005; Nicol *et al.* 2006). However, persistent drought across the basin has resulted in low river levels below lock one. Therefore, for analytical purposes in this report, we consider the river upstream of Wellington in three distinct regions: below Lock 1, Locks 1 to 3 and above Lock 3 (Fig. 2).

ANOSIM was used to compare the extent of similarity of fish assemblage between the three regions and showed that the respective regions had significantly different fish communities (R=0.124, p=0.001). SIMPER analysis, comparing the similarity of groups and each species contribution to the similarities, indicated that the abundance of un-specked hardyheads, bony herring and Murray-Darling rainbowfish contributed the most to the differences (Appendix 1).

Indicator species analysis, used to detect associations between fish species and region, revealed that each species was significantly associated with one region except golden perch and Murray cod (Table 4). Due to significant difference in the fish community, each of the aforementioned regions will be analysed separately.

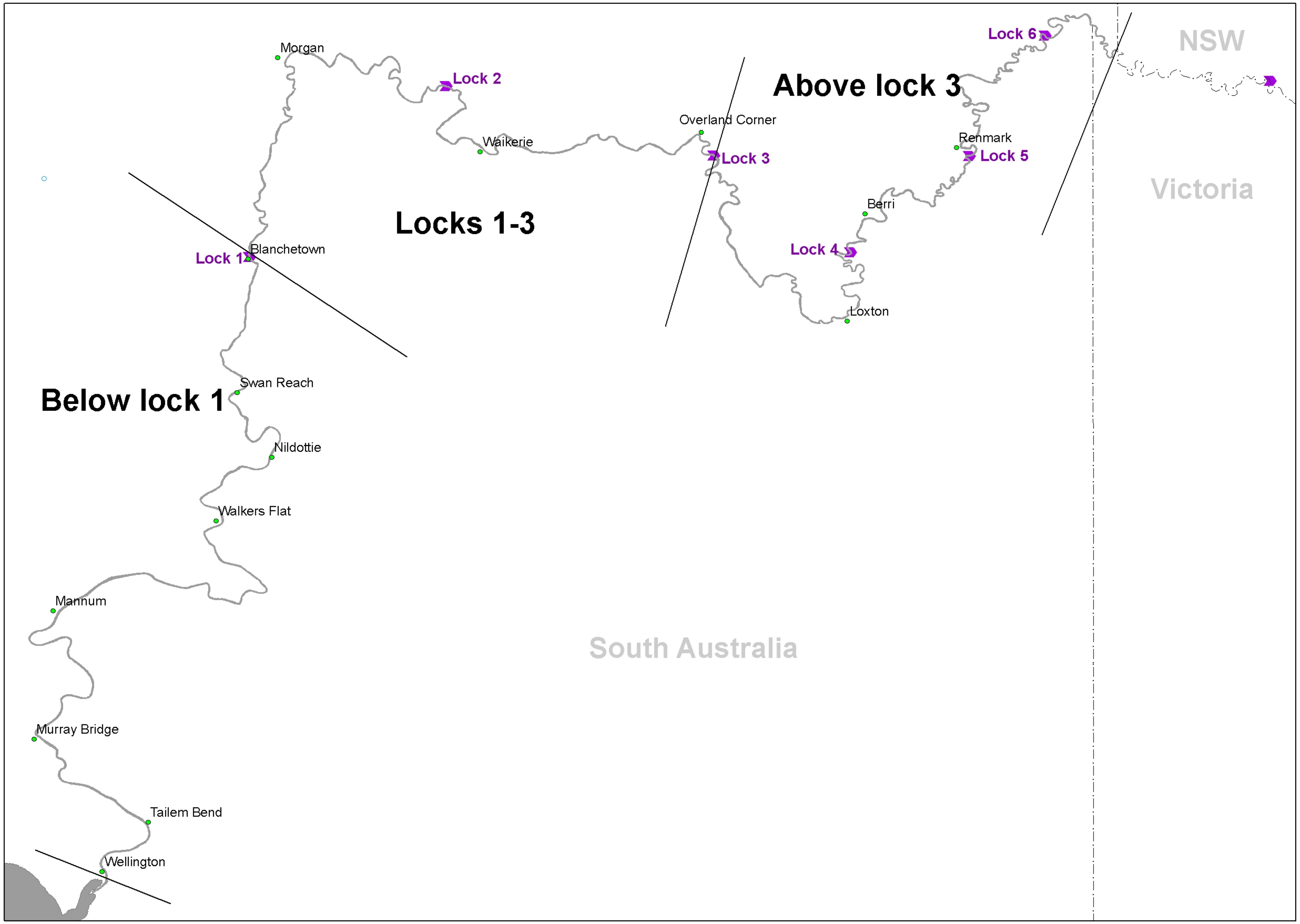

Figure 2: Map of the Lower River Murray indicating the three regions used for data analysis in this report; below Lock 1, locks 1-3 and above lock 3.

4.3. Fish assemblage and associations with mesohabitat types

ANOSIM was preformed to determine the level of similarity of fish assemblages between mesohabitats within each region. Within each region, a significantly different fish community was found between mesohabitats: below Lock 1 (R=0.085, p=0.001), locks 1-3 (R=0.187, p=0.001) and above lock 3 (R=0.091, p=0.002). Indicator species showed that un-specked hardyheads were significant indicators of modified habitats below Lock 1 and above lock 3, and Murray-Darling rainbowfish were significant indicators of willow habitats below Lock 1 and modified habitats between locks 1 and 3 (Table 4). The protected species, silver perch, was significantly associated with red gum habitats above lock 3 and the alien species common carp, goldfish and gambusia were indicators of bare (above lock 3), willows (above lock 3) and bare (locks 1-3) mesohabitats respectively (Table 4).

Table 4: Table showing significant (P<0.05) associations between each fish species and microhabitat components, mesohabitat types and region. For each microhabitat component + indicates a positive association and – shows a negative association. Growth forms of each plant species is shown in brackets where E = emergent aquatic plant, FL = floating leaved submerged macrophyte, S = submerged macrophyte and T = tree. If a category is classified as N/A the corresponding fish species was absent (or only one individual present) in the region.

Common Name	Associated Microhabitat Components			Associated Mesohabitats			Associated region
	Below Lock 1	**Locks 1-3**	**Above lock 3**	**Below Lock 1**	**Locks 1-3**	**Above lock 3**	
Silver perch	N/A	Not significant	+CWD 3	N/A	Not significant	Red gum	Above lock 3
Goldfish	+*Myriophyllum verrucosum* **(S)** +*Vallisneria americana* **(S)**	+*Elodea canadensis* **(S)** +*Potamogeton tricarinatus* **(FL)** +*Vallisneria americana* **(S)** +Tree roots +CWD 2 -Open water	+*Potamogeton crispus* **(S)**	Not significant	Bare	Not significant	Locks 1-3
Un-specked hardyhead	+*Typha domingensis* **(E)**	- Rock	+*Vallisneria americana* **(S)** -*Elodea canadensis* **(S)** -*Acacia stenophylla* **(T)**	Modified	Not significant	Modified	Locks 1-3
Common carp	+*Potamogeton crispus* **(S)** -*Salix* spp. **(T)**	- Open water	+*Typha domingensis* **(E)** +*Elodea Canadensis* **(S)** +*Potamogeton tricarinatus* **(FL)** -CWD 1 -CWD 2 -CWD 3	Not significant	Not significant	Bare	Below Lock 1
Common galaxias	+*Myriophyllum caput-medusae* **(S)** +*Typha domingensis* **(E)**	N/A	N/A	Not significant	N/A	N/A	Below Lock 1
Gambusia	Not significant	+*Typha domingensis* **(E)** +*Potamogeton crispus* **(S)** - Open water	+*Salix* spp. **(T)** +*Schoenoplectus validus* **(E)**	Not significant	Not significant	Willows	Above lock 3

Common Name	Associated Microhabitat Components			Associated Mesohabitats			Associated region
	Below Lock 1	Locks 1-3	Above lock 3	Below Lock 1	Locks 1-3	Above lock 3	
Carp gudgeon	+Open water +*Potamogeton tricarinatus* **(FL)** +*Vallisneria americana* **(S)** -*Salix* spp. **(T)** -CWD 2	+*Potamogeton tricarinatus* **(FL)** +*Myriophyllum verrucosum* **(S)** -Open water -Rock	+*Bolboschoenus caldwellii* **(E)** +*Typha domingensis* **(E)** +*Vallisneria americana* **(S)** +Open water + *Myriophyllum verrucosum* **(S)** -*Ludwigia peploides* **(FL)** -*Acacia stenophylla* **(T)**	Not significant	Not significant	'Typha'/ 'Phragmites'	Locks 1-3
Golden perch	+CWD 1 +CWD 3 +*Vallisneria americana* **(S)**	Not significant	+CWD 3	Bare	Not significant	Not significant	Not significan t
Murray cod	-CWD 3 +Rock	Not significant	+*Phragmites australis* **(E)**	Not significant	Not significant	Not significant	Not significan t
Murray-Darling rainbowfish	+Roots +*Salix* spp. **(T)** -CWD 3 -*Myriophyllum verrucosum* **(S)**	-*Elodea canadensis* **(S)** -*Typha domingensis* **(E)** -*Ludwigia peploides* **(FL)**	+Open water - *Elodea canadensis* **(S)** -*Typha domingensis* **(E)**	Willows	Modified	Not significant	Above lock 3
Bony herring	-*Typha domingensis* **(E)**	-*Myriophyllum verrucosum* **(S)**	- *Bolboschoenus caldwellii* **(E)** -*Myriophyllum verrucosum* **(S)**	Not significant	Bare	Not significant	Below Lock 1
Redfin	+CWD 2 +*Myriophyllum caput-medusae* **(S)** +Tree roots +*Typha domingensis* **(E)**	+*Salix* spp. **(T)** -*Phragmites australis* **(E)**	+*Elodea canadensis* **(S)**	Not significant	Not significant	Not significant	Below Lock 1
Flathead gudgeon	+CWD 2 +*Salix* spp. -*Potamogeton crispus* **(S)**	+*Schoenoplectus validus* **(E)** +*Vallisneria americana* **(S)** +Tree roots -Open water	+*Vallisneria americana* **(S)** +*Paspalum distichum* **(E)** +Open water +Tree roots -*Salix* spp. **(T)**	Modified	Not significant	Not significant	Locks 1-3

Common Name	Associated Microhabitat Components			Associated Mesohabitats			Associated region
	Below Lock 1	Locks 1-3	Above lock 3	Below Lock 1	Locks 1-3	Above lock 3	
Dwarf flathead gudgeon	N/A	+*Vallisneria americana* **(S)**	N/A	N/A	Not significant	N/A	Not significan t
Smelt	+CWD 3	+Tree roots - *Phragmites australis* **(E)** -*Potamogeton tricarinatus* **(FL)**	-*Elodea canadensis* **(S)** -*Ludwigia peploides* **(FL)** -*Potamogeton tricarinatus* **(FL)** -*Zannichellia palustris* **(S)** -*Typha domingensis* **(E)**	Not significant	Not significant	'Acacia'	Locks 1-3
Freshwater catfish	N/A	N/A	Not significant	N/A	N/A	Not significant	N/A

4.4. Fish preference for microhabitat features

Indicator Species Analysis (Dufrene and Legendre 1997) was conducted to determine the relationships between microhabitats and fish species in each region. Each species showed a preference to one or more particular microhabitat features; however, this was not always consistent across regions (Table 4).

4.5. Microhabitat features and associated mesohabitat types

As particular fish are associated with particular microhabitat components, we determined whether specific mesohabitats were associated with specific microhabitats. ANOSIM and SIMPER analysis of the microhabitat components within the three regions revealed that the abundance and type of components differed significantly (R= 0.147, p= 0.001). Indicator Species Analysis was preformed on the data to detect which microhabitat components were significantly associated with which mesohabitat in each region. Table 5 lists the microhabitat components that were significantly associated (p<0.05) with each mesohabitat in a specific region.

Table 5: Significant microhabitat associations for each mesohabitat type for the three regions. Growth forms of each plant species is shown in brackets where E = emergent aquatic plant, FL = floating submerged macrophyte, S = submerged macrophyte and T = tree. If a category is classified as N/A the corresponding mesohabitat was not sampled or not present in the region.

Mesohabitat	**Associated Microhabitat Components**		
	Below Lock 1	**Locks 1-3**	**Above lock 3**
Acacia	N/A	N/A	*Acacia stenophylla* **(T)** Tree roots CWD 2
Bare	CWD 3	*Bolboschoenus caldwellii* **(E)** *Cyperus gymnocaulos* **(E)** *Potamogeton tricarinatus* **(FL)** *Vallisneria americana* **(S)** CWD 2 CWD 3 Tree roots	*Potamogeton tricarinatus* **(FL)** Open water
Cliffs	Rock	Rock Open water	N/A
Modified	*Potamogeton tricarinatus* **(FL)**	Not significant	*Potamogeton crispus* **(S)**
'Phragmites'/ Red gum	N/A	*Phragmites australis* **(E)**	*Elodea canadensis* **(S)**
'Phragmites'/ Red gum sparse	N/A	Not significant	N/A
'Phragmites' sparse	N/A	*Elodea canadensis* **(S)** *Myriophyllum verrucosum* **(S)**	*Ludwigia peploides* **(FL)** Rock
Red gum	N/A	N/A	*Vallisneria americana* **(S)** *Zannichellia palustris* **(S)** *Juncus usitatus* **(E)** CWD 3
'Typha'/ 'Phragmites'	N/A	*Typha domingensis* **(E)** *Schoenoplectus validus* **(E)** *Potamogeton crispus* **(S)**	*Typha domingensis* **(E)** *Phragmites australis* **(E)** *Bolboschoenus caldwellii* **(E)** *Myriophyllum verrucosum* **(S)**
Willows	*Salix* spp. **(T)** CWD 2 Tree roots	N/A	*Salix* spp. **(T)**

4.6. Fish diversity comparisons across different mesohabitat types in each region

Simpson's Index of diversity calculates diversity by considering both evenness and number of species. Therefore those mesohabitats with the lowest cumulative diversity, such as bare below Lock 1 and willows below Lock 1 (Figure 3), have both a lower number of species and a disproportionately larger number of one or two species. Mesohabitats with a Simpson's Index of diversity greater than 0.75 were only found upstream lock 1 (Figure 3). Those mesohabitat types with the greatest diversity were Red gum and 'Acacia' above lock 3 and 'Phragmites' sparse between locks 1-3 (Figure 3).

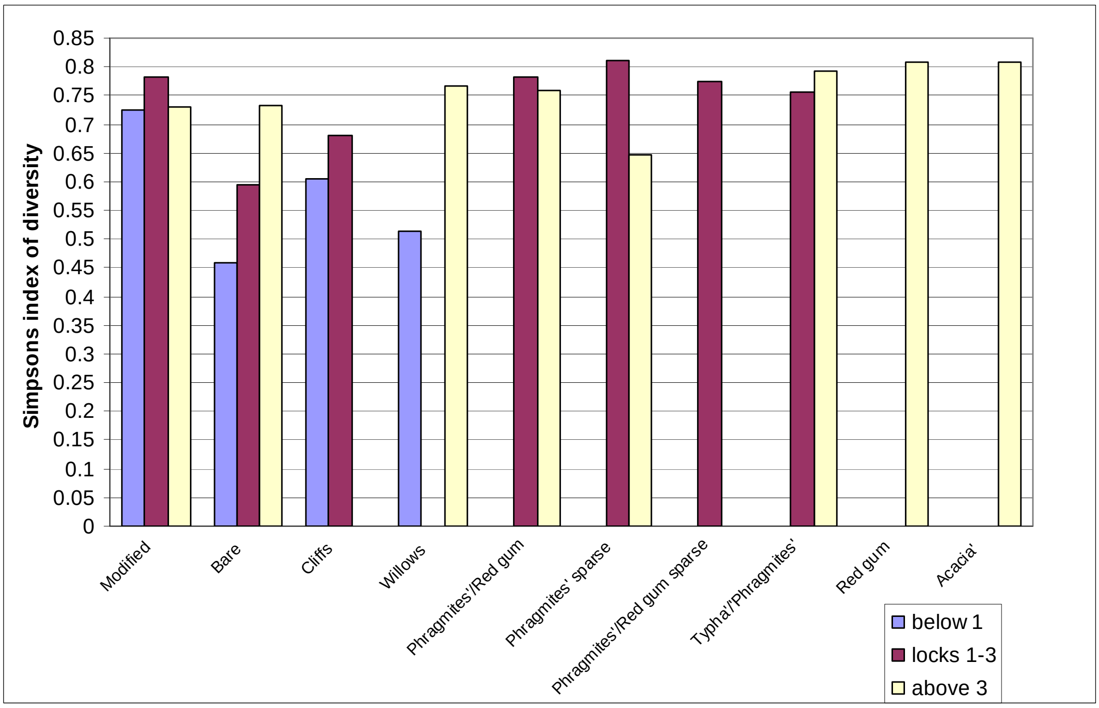

Figure 3: Graph displaying total fish diversity for each mesohabitat sampled from the three regions of the Lower River Murray (below Lock 1, locks 1-3 and above lock 3). Simpson's Index of diversity (1 – D, where Simpson's Index, D =Σ $(n/N)^2$ was used to calculate fish diversity. Values range from 0 – 1, higher values indicate greater diversity.

4.7. Relative abundance and species richness of fish in different mesohabitat types in each region

The relative abundance of fish species varied between mesohabitats (Figures 4-6). Bony herring was consistently the most abundant species below Lock 1 (Figure 4). Between locks 1-3 and above lock 3 the most abundant species varied between mesohabitats. Murray-Darling rainbow fish was the most abundant species in modified habitats, bony herring was the most abundant species in 'Phragmites' sparse, 'Phragmites' red gum sparse, bare and cliff habitats and unspecked hardyhead was the most abundant species in 'Typha'/'Phragmites' and 'Phragmites' red gum habitats between Locks 1 and 3 (Figures 4-5). Above Lock 3 unspecked hardyhead was the most abundant species in 'Acacia', modified, 'Typha'/'Phragmites' and willow habitats and bony herring was the most abundant species in 'Phragmites'/red gum, 'Phragmites' sparse, red gum, willow and bare habitats (Figures 5-6).

The most species rich mesohabitat was 'Red gum' (above Lock 3), with 14 species recorded (Figure 5h). Of these species, four were alien, one was listed as vulnerable nationally (Murray cod) and 2 were protected in SA (catfish and silver perch). The only other mesohabitat where both protected species, silver perch and freshwater catfish, were present was 'Typha'/'Phragmites' between Locks 1-3 (Figure 5d).

The number of native fish species found in any mesohabitat ranged from seven to ten. Those mesohabitats with the least number of native fish species were bare, cliffs and willow mesohabitats below Lock 1, modified and bare between Locks 1-3 and 'Phragmites'/Red gum and willows above lock 3 (Figures 4-6). The greatest number of native fish species were present in 'Typha'/'Phragmites' between Locks 1-3 and Acacia and Red gum mesohabitats above Lock 3 (Figures 4-5).

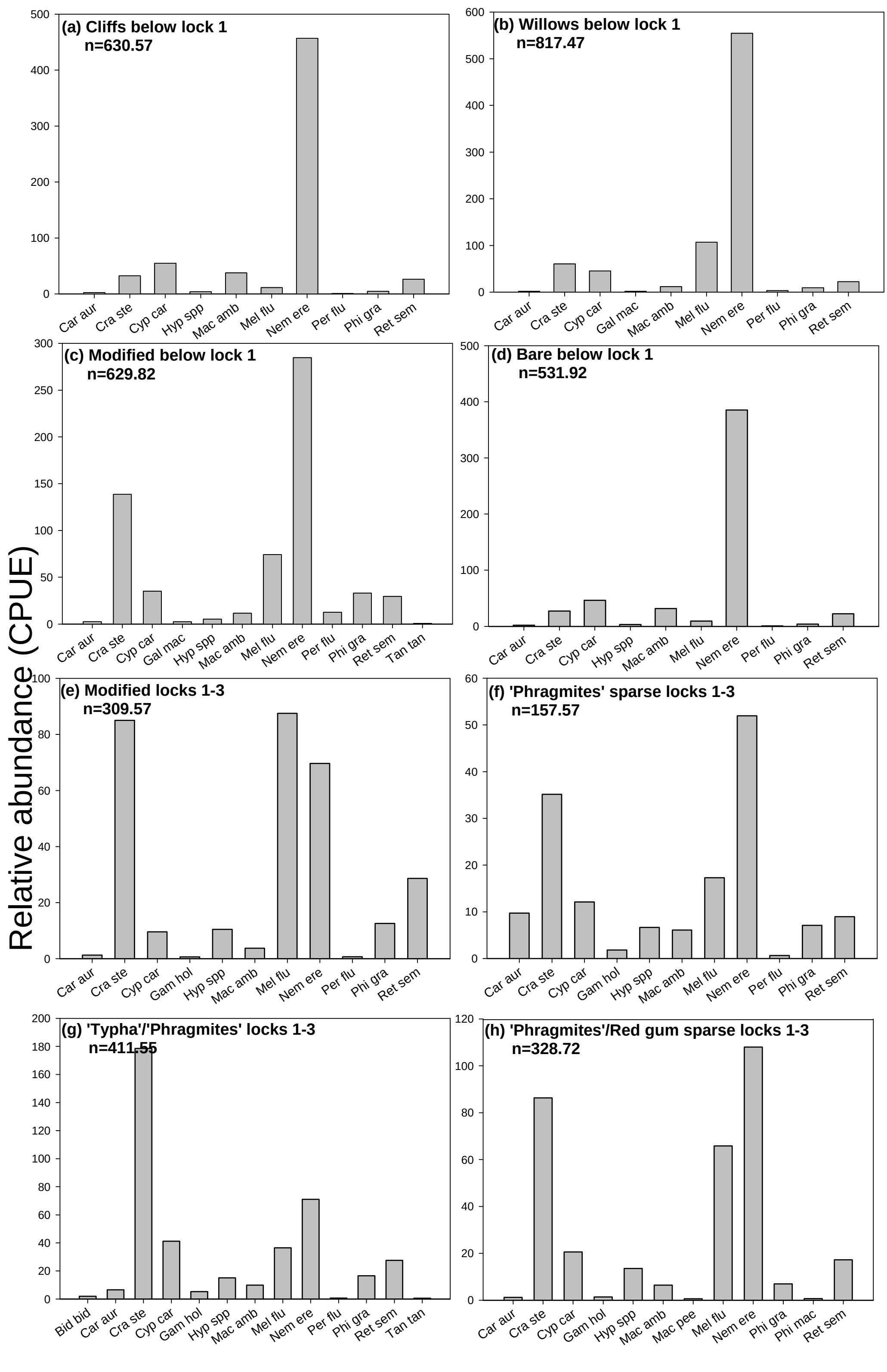

Figure 4: Relative abundance of fish species for each mesohabitat per region. Number of fish (CPUE) is indicated by n. Fish species are recorded in taxa code where Bid bid=silver perch, Car aur=goldfish, Cra ste=un-specked hardyhead, Cyp car=common carp, Gal mac=common galaxias, Gam hol=gambusia, Hyp spp=carp gudgeon, Mac amb=golden perch, Mac pee=Murray cod, Mel flu=Murray-Darling rainbowfish, Nem ere=bony herring, Per flu=redfin, Phi gra=flathead gudgeon, Phi mac=dwarf flathead gudgeon, Ret sem=smelt, Tan tan=freshwater catfish.

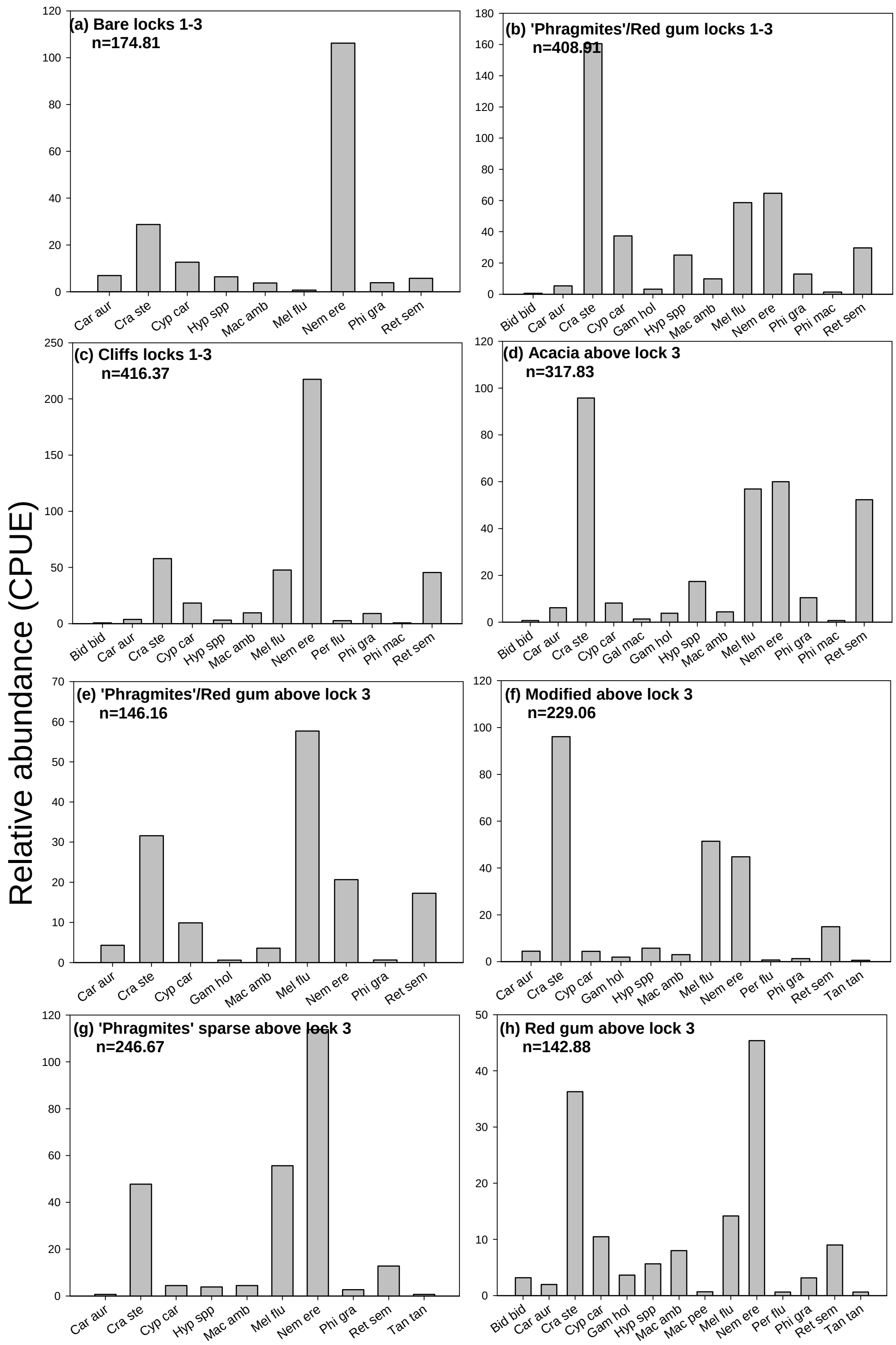

Figure 5: Relative abundance of fish species for each mesohabitat per region. Number of fish (in CPUE) is indicated by n. Fish species are recorded in taxa code where Bid bid=silver perch, Car aur=goldfish, Cra ste=un-specked hardyhead, Cyp car=common carp, Gal mac=common galaxias, Gam hol=gambusia, Hyp spp=carp gudgeon, Mac amb=golden perch, Mac pee=Murray cod, Mel flu=Murray-Darling rainbowfish, Nem ere=bony herring, Per flu=redfin, Phi gra=flathead gudgeon, Phi mac=dwarf flathead gudgeon, Ret sem=smelt, Tan tan=freshwater catfish.

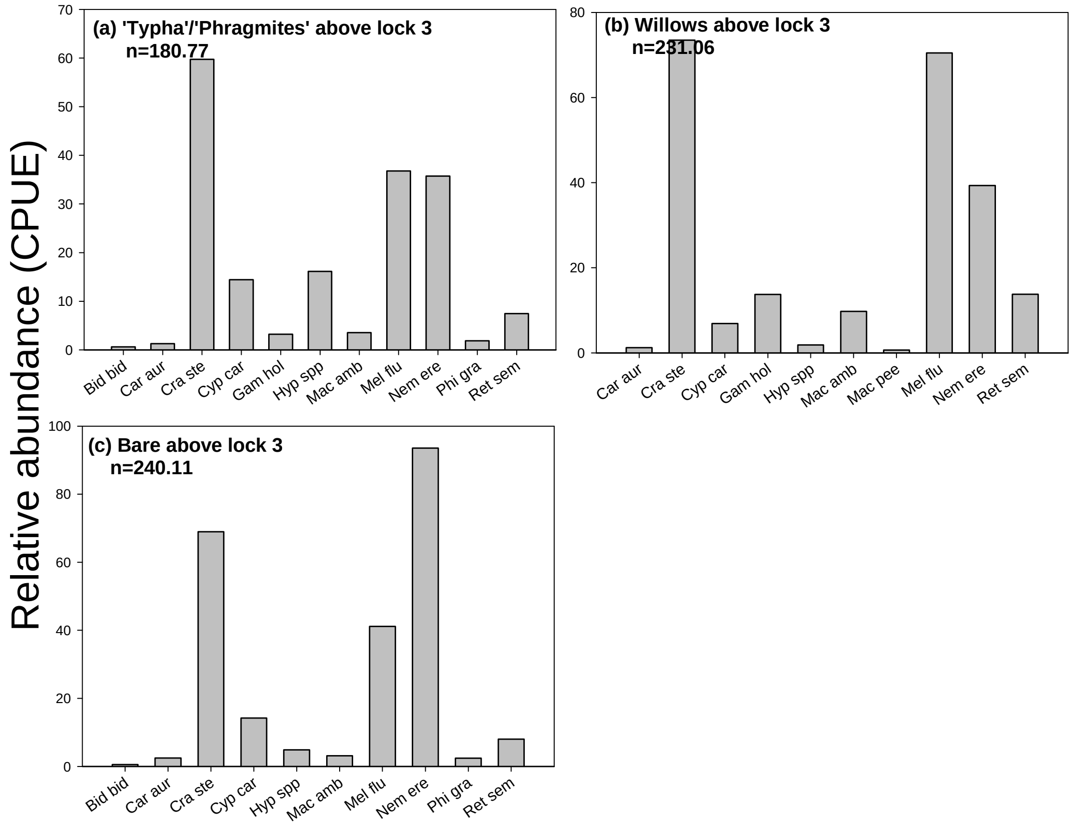

Figure 6: Relative abundance of fish species for each mesohabitat per region. Number of fish (in CPUE) is indicated by n. Fish species are recorded in taxa code where Bid bid=silver perch, Car aur=goldfish, Cra ste=un-specked hardyhead, Cyp car=common carp, Gal mac=common galaxias, Gam hol=gambusia, Hyp spp=carp gudgeon, Mac amb=golden perch, Mac pee=Murray cod, Mel flu=Murray-Darling rainbowfish, Nem ere=bony herring, Per flu=redfin, Phi gra=flathead gudgeon, Phi mac=dwarf flathead gudgeon, Ret sem=smelt, Tan tan=freshwater catfish.

5. Discussion

5.1. The extent and distribution of habitats in the lower River Murray

The extent and distribution of habitats throughout the lower River Murray between Wellington and South Australia-New South Wales border is the result of a combination processes and factors at catchment and local scales.

The River Murray between Wellington and the South Australia-New South Wales border has been extensively modified due to abstraction and the construction of Locks 1 to 6 and the barrages (e.g. Walker 1985; Walker 1986; Walker *et al.* 1992; Walker and Thoms 1993; Maheshwari *et al.* 1995). The impact of abstraction and operation of the barrages and the weirs associated with Locks 1 to 6 has resulted in greatly reduced flow and water level variability in the study reach (Maheshwari *et al.* 1995), which has had consequences for the riparian and instream vegetation and habitat (e.g. Walker *et al.* 1994; Blanch *et al.* 2000). The generally static water levels immediately upstream of the weirs and between Wellington and Mannum have led to large areas of river bank being dominated by willows (*Salix* spp.) and native emergent species such as *Typha* spp. and *Phragmites australis* (e.g. Walker *et al.* 1994; Roberts and Marston 2000). Immediately downstream of the weirs there are larger water level fluctuations (Walker *et al.* 1994); however, this has often led to bank erosion and unvegetated banks (Thoms and Walker 1993).

Local land management and recreation also have a large influence on habitat (especially in the riparian zone). The River Murray and associated wetlands provide a water source in an otherwise dry landscape, which makes them important watering points for domestic stock and poor riparian condition is often associated with livestock grazing in lowland rivers (e.g. Robertson and Rowling 2000; Jansen and Robertson 2001). In addition, the River Murray is often thought as South Australia's playground and is important recreational asset. There are a large number of holiday homes on the banks of the River Murray (between Wellington and Blanchetown alone there are over 3000 holiday homes (D. Brown pers. comm.), which often have landscaped gardens, artificial beaches, jetties and desnagged areas for boat access. Finally, there are five (Murray Bridge, Waikerie, Loxton, Berri and Renmark) large (by south Australian standards) regional centres and numerous small townships located on the banks of the River Murray and the structure of the riparian and in stream habitat has been significantly modified in these urban or built up areas.

The impact of the combination of the aforementioned factors is evident in the distribution and extent of mesohabitats in the lower River Murray between Wellington and the South Australia-New South Wales border. The most abundant mesohabitat type, "Bare" (14.19%) (Table 1) was generally the result of local land management practices, principally grazing by domestic stock. "Willows dense" was the second most abundant mesohabitat (13.85%) (Table 1), which was dominated by an exotic species that is adapted to static water levels (Cremer 2000). Furthermore, 43.89% of river bank was occupied by mesohabitats dominated by native species that are adapted to static water levels (e.g. *Typha* spp. *Phragmites australis, Bolboschoenus caldwellii, Schoenoplectus validus*). The mesohabitats that were dominated by species that are adapted static water levels were generally located between Wellington and Mannum (mainly willows) and immediately upstream of the locks. Finally, the "Modified" mesohabitat (9.16% of habitat (Table 1) was distributed throughout the study reach but more common in areas with large numbers of holiday homes (Wellington to Morgan) and adjacent to towns and large regional centres.

5.2. Regional-scale fish distribution and mesohabitat associations

Differences in fish assemblages were evident between regions, with the most distinct difference between the regions upstream and downstream of Lock 1. The diversity was lower downstream of Lock 1 compared with the two regions upstream, with three out of the four sampled mesohabitats only recording the presence of 10 native species. Additionally, no Murray cod or silver perch were caught and only a single freshwater catfish was recorded. The lower diversity downstream of Lock 1 may be the result of the small number of different mesohabitats and the dominance of structurally simple mesohabitats (particularly the dominance of willows from Swan Reach to Wellington and bare habitats between Lock 1 and Swan Reach) (*sensu* Boys and Thoms 2006). However, the reduction in mesohabitat diversity downstream of Lock 1 may also be attributed to the low water levels during the survey as a result of the on going drought in the Murray-Darling Basin. Large areas of riparian vegetation, including extensive stands of emergent plants, were disconnected from the main channel during the fish surveys, which consequently reduced the area of in-stream structural habitat available to fish. Re-surveying this region after water levels rise to normal pool level may yield different results and should be conducted to provide a more accurate picture of the fish community over a range of flow scenarios. In addition, there are sections of the main channel of the River Murray that are very deep downstream of Lock 1 (especially between Murray Bridge and Wellington where depths can exceed 20 m) and electrofishing is generally not as effective in depths greater than 2.5 m, which may have resulted in species not being captured in this reach.

Species diversity, species richness, the dominance of native species and the presence of EPBC listed species and species protected under the South Australian Fisheries Act were similar between Locks 1-3 and above Lock 3 and silver perch was significantly associated with the region upstream of Lock 3 (Table 4). Both regions supported a larger number of different mesohabitats that were dominated by native plant species than below Lock 1, which may have resulted in the observed higher species richness and diversity (*sensu* Boys and Thoms 2006).

The boat electrofishing used in this survey was considered to be the most appropriate method for sampling fish communities in freshwater rivers (Faragher and Rodgers 1997) and specifically the lower River Murray (Baumgartner *et al.* 2008). Electrofishing has been proven to capture more fish species, over a range of sizes in an unbiased and efficient manner compared with other methods of sampling (Faragher and Rodgers 1997; Baumgartner *et al.* 2008). Nevertheless, there are limitations in the data that were used to prioritise habitats (Section 5.3), which need to be taken into consideration. The limitations include:

- Lack of temporal replication. The fish and habitat data collected represents a snapshot at a single point in time, which happened to be during a period of extreme low flows. Changes in the fish community or habitat structure through time or due to management actions (e.g. watering, weir pool manipulations or environmental flows) were not taken into consideration.

- Fish were only sampled during daylight hours. Ideally, fish sampling should be undertaken both in daylight and night hours to gain a more representative picture of the fish community at each site. Baumgartner *et al.* (2008) used similar electrofishing techniques in the lower River Murray and found an increase in species richness during night time hours. Nevertheless, due to time and budget restrictions and the large number of sites necessary to sample in this project, diel sampling was not undertaken. Therefore it is important to note that the fish communities at each site may be more diverse than presented in this report although each site was sampled in the same way therefore comparisons of relative differences in the fish communities may be made.

- Electrofishing is generally not effective in water deeper than 2.5 m (especially in the highly turbid lower Murray River); therefore, species may have been missed in the deeper mesohabitats. This is of particular importance for the "cliffs" mesohabitat because they were generally deep and are important Murray cod habitat, particularly downstream of Lock 1 (Ye and Zampatti 2007).

5.3. Prioritisation of mesohabitats based on fish assemblage and diversity

Prioritisation matrix

A prioritisation matrix was developed for the mesohabitats sampled in this study (Table 6) based on the associated fish community. The factors used to rank the mesohabitats for conservation value of fish were species diversity (using Simpson's Index of diversity, Section 5.6) and the presence of listed or protected species (EPBC or South Australian Fisheries Act). A numerical value out of ten was assigned to each mesohabitat based on the criteria listed in Table 6.

Table 6: Prioritisation matrix based on the diversity of the fish community and number of species listed under the EPBC Act or protected under the South Australian Fisheries Act present in a mesohabitat.

Score	Simpson's diversity Index	Score	Presence of Listed species
5	>80%	5	3 Listed species
4	75-80%	4	2 Listed species
3	70-75%	3	1 Listed species
2	65-70%	2	-
1	55-65%	1	-
0	<55%	0	-

A nominal conservation value was then attributed to each score such that a score of >6 = high, 4-6 = Medium and <4 = Low.

Based on this framework, Red gum and 'Typha'/'Phragmites' mesohabitats (between Locks 1-3) may be the most important for fish when considering these habitats were found to have the greatest species richness, high species diversity and each supported a larger number of listed and protected species. In addition to supporting the largest number of listed and protected species (i.e. 3), Red gum mesohabitats also were significantly associated with silver perch (Table 4). Phragmites/red gum, Phragmites/red gum sparse and cliffs between locks 1-3 and Acacia, Typha/Phragmites and Willows dense above Lock 3 also had high fish species richness with listed and protected species present. It is likely that these mesohabitats are important for fish as all had a diverse assemblage of submerged and emergent vegetation and large and small woody debris.

Based on the criteria of diversity and the presence of EPBC listed and protected native fish species those mesohabitats that were considered the lowest priority for fish were bare, willows and cliffs below Lock 1 and bare (locks 1-3), Phragmites red gum (above Lock 3) and Phragmites sparse (Locks 1-3 and above Lock 3). However, Ye and Zampatti (2007) reported that professional fishermen target Murray cod adjacent to cliffs especially downstream of Lock 1 and these areas are import habitat for the aforementioned species.

The results of this study suggest that structurally diverse riparian and littoral zones, especially those dominated by river red gums, Acacia and both *Typha* and *Phragmites* are important habitats that support a diversity of fish (including EPBC listed and protected species) in the lower River Murray and as such should be protected. In contrast, degraded riparian and littoral zones, especially those dominated by exotic species (willows) or devoid of vegetation, only provide simple structural habitat and consequently have low fish diversity. These results support studies undertaken in other parts of the Murray-Darling Basin (Growns *et al.* 1998; Humphries *et al.* 1999; Erskine and Webb 2003; Balcombe and Closs 2004; Bond and Lake 2005; Boys and Thoms 2006), throughout Australian river systems (Hortle and Lake 1983; Davies and Nelson 1994; Koehn *et al.* 1994; Pusey *et al.* 1998; Morgan and Gill 2000; Houston and Duivenvoorden 2002; Brooks *et al.* 2004) and in other parts of the world (Clarke and Wharton 2000; Newbrey *et al.* 2005; Roni *et al.* 2006; Katz *et al.* 2007)

<u>Below Lock 1</u>

Due to low water levels there was a low diversity of fishable mesohabitats downstream of Lock 1 (i.e. the majority of mesohabitats surveyed were stranded) with the mesohabitats that were able to be fished generally degraded (willows, bare and modified). The low species richness of freshwater species may be in part due to the prevalence of modified, bare, degraded and exotic species dominated mesohabitats downstream of Lock 1 (*sensu* Growns *et al.* 1998; Boys and Thoms 2006). However, without further investigation into the age structure and spawning of fish in this region, it is impossible to predict whether or not the diversity and abundance of fish will decline further if the riparian zone in this region remains degraded. Nonetheless, it is our recommendation that bare habitats in this region be rehabilitated with a combination of revegetation and stock exclusions. Increasing river levels below Lock 1 may also be instrumental in revegetating the sparsely vegetated banks. Beneficial effects of revegetating the banks would also include reducing erosion and consequent impacts on water quality (Caffrey and Beglin 1996; Frankenberg 1997; Abernethy and Rutherfurd 1998; Carline and Walsh 2007).

The dominance of willows in the riparian zone from Purnong to Wellington should also be addressed to improve habitat for fish. Although these habitats do support some fish species, the results of this study show that species richness and diversity can be low in willow habitats (Table 7). This may be a result of the dense, spreading growth habit of willow trees and their consequent ability to exclude light and the growth of other plant species (Cremer 2000). Willows are difficult to eradicate completely and if removed suddenly bank erosion can occur (Cremer 1995; Cremer 2000). Therefore, a combination of removal and revegetation needs to be considered (Cremer 1995; Cremer 2000; Stokes and Cunningham 2006; Stokes 2008).

Highly modified riparian zones including shacks, marinas and townships are also common below Lock 1, particularly because of the proximity of this region to Adelaide. This mesohabitat was the most species rich and diverse of those below Lock 1 (Table 7), and the likely reason is the greater complexity of habitat features found in modified habitats compared with bare, cliffs or those dominated by willows. Shack owners and local government should be encouraged to maintain and enhance the diversity of submerged, emergent and riparian vegetation along these zones and prevent the removal of large snags.

Locks 1-3

The region between Locks 1-3 and above Lock 3 contained a greater diversity of mesohabitats than the region below Lock 1 (Table 7).

The most important mesohabitat in this region for fish diversity and species richness was Typha/Phragmites (Table 7). Phragmites/Red gum, Phragmites/Red gum sparse and 'Phragmites sparse were also identified as high priority habitats and should be protected. In addition, Cliffs and Modified mesohabitats were identified as having a moderate conservation status and should either be protected or for the modified mesohabitats encourage shack owners and local government to maintain and enhance the diversity of submerged, emergent and riparian vegetation and prevent the removal of large snags. Bare habitats in this region were given a low conservation status and attempts should be made to revegetate and remove grazing from these areas.

Above Lock 3

Upstream of Lock 3 Red Gum dense mesohabitats were identified as having the highest conservation value based on the fish community present and need to be protected (Table 7). Typha/Phragmites, Willows dense and Acacia mesohabitats also had high conservation value and Bare, Modified and 'Phragmites'/Red Gum were identified as being of moderate conservation status (Table 7). The region upstream of Lock 3 had the largest number of fishable mesohabitats (eight) (Table 7) and inturn a greater diversity of structural habitats compared with the downstream regions (Table 7). This region 3 also had the most diverse fish community and largest number of listed species, which may be due to the greater diversity of structural habitats (sensu Davies and nelson 1994; Pusey and Arthington 2003; Brooks *et al.* 2004; Boys and Thoms 2006; Shields *et al.* 2006).

Table 7: Prioritisation of mesohabitats based on conservation value for fish and suggested actions required (* cliffs were classified as having a low conservation value downstream of Lock 1 and medium value between Locks 1and 3 using this framework; however, they have been identified as important Murray cod habitat (Ye and Zampatti 2007) that may warrant a higher conservation value).

Mesohabitat	Below Lock 1		Locks 1-3		Above Lock 3	
	Conservation value	Suggested action	Conservation value	Suggested action	Conservation value	Suggested action
'Acacia'	-	-	-	-	High	Conserve
Bare	Low	Revegetate &/or remove grazing	Low	Revegetate &/or remove grazing	Medium	Revegetate &/or remove grazing
Cliffs	Low*	Remove willows (where present)	Medium*	-	-	-
Modified	Medium	Maintain or increase diversity of riparian & in-stream habitat	Medium	Maintain or increase diversity of riparian & in-stream habitat	Medium	Maintain or increase diversity of riparian & in-stream habitat
'Phragmites'/ Red Gum	-	-	High	Conserve	Medium	Conserve
'Phragmites'/ Red Gum sparse	-	-	High	Conserve	-	-
'Phragmites' sparse	-	-	High	Remove grazing	Medium	Remove grazing
Red Gum dense	-	-	-	-	High	Conserve
'Typha'/ 'Phragmites'	-	-	High	Conserve	High	Conserve
Willows dense	Low	Identify areas for removal and revegetation	-	-	High	Identify areas for removal and revegetation

6. Summary, Further Studies and Management Recommendations

In order to describer the nature and extent of aquatic and riparian habitats in the River Murray main channel from Wellington to the NSW border (Task 5.15 in the NRM investment strategy) we mapped and classified mesohabitats greater than 50 m length along both banks. A sub-set of mesohabitats were then sampled using standard SRA electrofishing methods from February to April 2008. Along with this report, the end-product of this component of the study is a GIS database containing vegetation group, snag, bathymetry and topographical layers along with the locations and results of the fish survey.

The prioritisation of mesohabitat types based on a snapshot of the fish community has limitations due to the lack of temporal replication and deil sampling and limitations of electrofishing in sampling water deeper than 2.5 m. Nevertheless, the methods were consistent (direct comparisons between mesohabitats are valid) and repeatable (can be compared with fish data collected using the same methods in the future), provided good spatial coverage of the main channel and provide a good starting point for the identification of potential freshwater protected areas or to identify reaches that may be targeted for rehabilitation. However, before work of this nature commences a robust and scientifically defensible investigations and a monitoring program (preferably a BACI design *sensu* Underwood 1992) need to be established. Additionally, the GIS layer has the potential to be valuable to a range of projects associated with the Lower River Murray.

It is the recommendation of the authors that habitat data for significant anabranches associated with the Lower River Murray also be collected using the methods outlined in this report. This would provide greater information about the nature and extent of fish habitat in the Lower Murray system from which management decisions concerning the enhancement and protection of important habitat for native fish could be identified. In addition, the habitat database could be used to identify important bird or mammal habitat in the riverine corridor.

7. References

Abernethy, B. and Rutherfurd, I.D. (1998). Where along a river's length will vegetation most effectively stabilise stream banks? *Geomorphology* **23**: 55-75.

Barker, W.R., Barker, R.M., Jessop, J.P. and Vonow, H.P. (2005). 'Census of South Australian Vascular Plants (5.00 edn).' (Botanic Gardens of Adelaide & State Herbarium: Adelaide).

Baumgartner, L.J., Stuart, I.G. and Zampatti, B.P. (2008). Determining diel variation in fish assemblages downstream of three weirs in a regulated lowland river. *Journal of Fish Biology* **72:** 218-232.

Blanch, S.J., Walker, K.F. and Ganf, G.G. (2000). Water regimes and littoral plants in four weir pools of the River Murray, Australia. *Regulated Rivers-Research & Management* **16**: 445-456.

Bond, N.R. and Lake, P.S. (2005). Ecological restoration and large-scale ecological disturbance: the effects of drought on the response by fish to a habitat restoration experiment. *Restoration Ecology* **13**: 39-48.

Boys, C.A. and Thoms, M.C. (2006). A large-scale, hierarchical approach for assessing habitat associations of fish assemblages in large dryland rivers. Hydrobiologia **572:** 11-31.

Bren, L.J. (1988). Effects of river regulation on flooding of a riparian red gum forest on the River Murray, Australia. *Regulated Rivers: Research and Management* **2:** 65-77.

Brooks, A.P., Gehrke, P.C., Jansen, J.D. and Abbe, P.B. (2004). Experimental reintroduction of woody debris on the Williams River, NSW: geomorphic and ecological responses. *River Research and Applications* **20**: 513 - 536.

Burns, A. and Walker, K.F. (2000). Effects of water level regulation on algal biofilms in the River Murray, South Australia. *Regulated Rivers-Research & Management* **16:** 433-444.

Cadwallader, P.L. (1978). Some causes of the decline in range and abundance of native fish in the Murray-Darling River system. *Proceedings of the Royal Society of Victoria* **90:** 211-224.

Caffrey, J.M. and Beglin, T. (1996). Bankside stabilisation through reed transplantation in a newly constructed Irish canal habitat. *Hydrobiologia* **340**: 349-354.

Carline, R.F. and Walsh, M.C. (2007). Responses to riparian restoration in the spring creek watershed, central Pennsylvania. *Restoration Ecology* **15**: 731-742.

Clarke, K.R. and Gorley, R.N. (2006). PRIMER version 6.1.12. PRIMER-E Ltd (Plymouth).

Clarke, S.J. and Wharton, G. (2000). An investigation of marginal habitat and macrophyte community enhancement on the River Torne, UK. *Regulated Rivers-Research & Management* **16**: 225-244.

Cremer, K. (2000). Willow management for Australian rivers. *Natural Resource Management, The Journal of the Australian Association of Natural Resource Management* **Special Issue**: 1-22.

Cremer, K.W. (1995). 'Willow Identification for River Management in Australia.' CSIRO Division of Forestry, 3, Canberra.

Cunningham, G.M., Mulham, W.E., Milthorpe, P.L. and Leigh, J.H. (1981). 'Plants of Western New South Wales.' (New South Wales Government Printing Office: Sydney).

Davies, P.E. and Nelson, M. (1994). Relationships between riparian buffer widths and the effects of logging on stream habitat, invertebrate community composition and fish abundance. *Australian Journal of Marine and Freshwater Research* **45**: 1289-1305.

Dufrene, M. and Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* **67**: 345-366.

Erskine, W.D. and Webb, A.A. (2003). Desnagging to resnagging: new directions in river rehabilitation in southeastern Australia. *River Research and Applications* **19**: 233-249.

Faragher, R.M. and Rodgers, M. (1997). Performance of sampling-gear types in the New South Wales Rivers Survey. In 'Fish and rivers in stress; the NSW rivers survey' (Eds Harris, A.H. and Gehrke, D.C.). (NSW Fisheries Office of Conservation/CRC for Freshwater Ecology. Sydney/Canberra)

Frankenberg, J. (1997). 'Guidelines for growing *Phragmites* for erosion control.' Cooperative Research Centre for Freshwater Ecology and Muuray nDarling Freshwater Research Centre, Albury.

Gehrke, P.C., Brown, P., Schiller, C.B., Moffatt, D.B. and Bruce, A.M. (1995). River regulation and fish communities in the Murray-Darling River System, Australia. *Regulated Rivers-Research and Management* **11**: 363-375.

Growns, I.O., Pollard, D.A. and Gehrke, P.C. (1998). Changes in river fish assemblages associated with vegetated and degraded banks, upstream of and within nutrient-enriched zones. *Fisheries Management and Ecology* **5**: 55-69.

Holt, M., Swingler, K., O'Donnell, E., Shirley, M., Lake, M., Conallin, A., Meredith, S., Ho, S., Prider, J., Poulsen, D., Richardson, S. and Cooling M (2005). 'River Murray Wetlands Baseline Survey.' River Murray Catchment Water Management Board, Berri.

Hortle, K.G. and Lake, P.S. (1983). Fish of channelized and unchannelized sections of the Bunyip River Victoria Australia. *Australian Journal of Marine and Freshwater Research* **34**: 441-450.

Houston, W.A. and Duivenvoorden, L.J. (2002). Replacement of littoral native vegetation with the ponded pasture grass *Hymenachne amplexicaulis*: effects on plant, macroinvertebrate and fish biodiversity of backwaters in the Fitzroy River, Central Queensland, Australia. *Marine and Freshwater Research* **53**: 1235 - 1244

Humphries, P., King, A.J. and Koehn, J.D. (1999). Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes* **56**: 129-151.

Humphries, P., Serafini, L.G. and King, A.J. (2002). River regulation and fish larvae: variation through space and time. *Freshwater Biology* **47:** 1307 – 1331.

Jansen, A. and Robertson, A.I. (2001). Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river. *Journal of Applied Ecology* **38**: 63-75.

Jessop, J., Dashorst, G.R.M. and James, F.R. (2006). 'Grasses of South Australia. An illustrated guide to the native and naturalised species.' (Wakefield Press: Adelaide).

Jessop, J.P. and Tolken, H.R. (1986). 'The Flora of South Australia.' (Government of South Australia Printer: Adelaide).

Katz, S.L., Barnas, K., Hicks, R., Cowen, J. and Jenkinson, R. (2007). Freshwater habitat restoration actions in the Pacific Northwest: a decades investment in habitat improvement. *Restoration Ecology* **15**: 494-505.

Koehn, J.D., O'Connor, N.A. and Jackson, P.D. (1994). Seasonal and size-related variation in microhabitat use by a southern Victorian stream fish assemblage. *Australian Journal of Marine and Freshwater Research* **45**: 1353-1366.

Leigh, S., Zampatti, B., Marsland, K. and Nicol, .J (2008). 'An assessment of the fish assemblage in the Katarapko Anabranch system.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Maheshwari, B.L., Walker, K.F. and McMahon, T.A. (1995). Effects of regulation on the flow regime of the River Murray, Australia. *Regulated Rivers Research and Management* **10**: 15-38.

McCune, B. and Mefford, M.J. (2006). PC-ORD. Multivariate Analysis of Ecological Data, Version 5.12. In. (MjM Software Design: Glenden Beach, Oregon, USA).

Morgan, D.L. and Gill, H.S. (2000). Fish associations within the different inland habitats of lower south-western Australia. *Records of the Western Australian Museum* **20**: 31-37.

Murray Darling Basin Commission (2004). 'Sustainable rivers audit program. A six year program for the design and implementation of the sustainable rivers audit program November 2004.' Murray Darling Basin Commission, Canberra.

Newbrey, M.G., Bozek, M.A., Jennings, M.J. and Cook, J.E. (2005). Branching complexity and morphological characteristics of coarse woody structure as lacustrine fish habitat *Canadian Journal of Fisheries and Aquatic Sciences* **62**: 2110-2123.

Nicol, J.M., Weedon, J.T. and Doonan, A. (2006). Vegetation Surveys. In 'River Murray Wetlands Baseline Survey – 2005'. (Eds D Simpson, M Holt, T Champion, A Horan and M Shirley). (South Australian Murray Darling Basin Natural Resources Management Board: Berri).

Pusey, B.J., Arthington, A.H. and Read, M.G. (1998). Freshwater fishes of the Burdekin River, Australia: biogeography, history and spatial variation in community structure. *Environmental Biology of Fishes* **53**: 303-318.

Pusey, B.J. and Arthington, A.H. (2003). Importance of the riparian zone to the conservation and management of freshwater fish: a review. *Marine and Freshwater Research* **54**: 1-16.

Roberts, J. and Marston, F. (2000). 'Water Regime of Wetland and Floodplain Plants in the Murray-Darling Basin.' CSIRO Land and Water, 30-00, Canberra.

Robertson, A.I. and Rowling, R.W. (2000). Effects of livestock on riparian zone vegetation in an Australian dryland river. *Regulated Rivers Research and Management* **16**: 527-541.

Romanowski, N. (1998). 'Aquatic and Wetland Plants. A Field Guide for Non-tropical Australia.' (University of New South Wales Press: Sydney).

Roni, P., Bennett, T., Morley, S., Pess, G.R., Hanson, K., van Slyke, D. and Olmstead, P. (2006). Rehabilitation of bedrock stream channels: the effects of boulder weir placement on aquatic habitat and biota. *River Research and Applications* **22**: 967-980.

Sainty, G.R. and Jacobs, S.W.L. (1981). 'Water Plants of New South Wales.' (Water Resources Commission New South Wales: Sydney).

Sainty, G.R. and Jacobs, S.W.L. (2003). 'Waterplants in Australia.' (Sainty and Associates: Darlinghurst, N.S.W., Australia).

Shields, F.D., Knight, S.S. and Stofleth, J.M. (2006). Large wood addition for aquatic habitat rehabilitation in an incised, sand-bed stream, Little Topashaw Creek, Mississippi. *River Research and Applications* **22**: 803-817.

Sheldon, F. and Walker, K.F. (1998). Spatial distribution of littoral invertebrates in the lower Murray-Darling River system, Australia. *Marine and Freshwater Research* **49**: 171-182.

Stokes, K.E. (2008). Exotic invasive black willow (*Salix nigra*) in Australia: influence of hydrological regimes on population dynamics. *Plant Ecology* **197**: 91-105.

Stokes, K.E. and Cunningham, S.A. (2006). Predictors of recruitment for willows invading riparian environments in south-east Australia: implications for weed management. *Journal of Applied Ecology* **43**: 909-921.

Thoms, M.C. and Walker, K.F. (1993). Chanel changes associated with two adjacent weirs on a regulated lowland alluvial river. *Regulated Rivers: Research and Management* **8**: 271-284.

Underwood, A.J. (1992). Beyond BACI: the detection of environmental impacts on populations in the real, but variable world. *Journal of Experimental Marine Biology and Ecology* **161**: 145-178.

Walker, K.F. (1985). A review of the ecological effects of river regulation in Australia. *Hydrobiologia* **125**: 111-129.

Walker, K.F. (1986). The Murray-Darling River system. In 'The Ecology of River Systems'. (Eds Davies, B.R. and Walker, K.F.). (Dr W. Junk Publishers: Dordrecht, The Netherlands).

Walker, K.F., Boulton, A.J., Thoms, M.C. and Sheldon, F. (1994). Effects of water-level changes induced by weirs on the distribution of littoral plants along the River Murray, South Australia. *Australian Journal of Marine and Freshwater Research* **45**: 1421-1438.

Walker, K.F. and Thoms, M.C. (1993). Environmental effects of flow regulation on the lower River Murray, Australia. *Regulated Rivers: Research and Management* **8**: 103-119.

Walker, K.F., Thoms, M.C. and Sheldon, F. (1992). Effects of weirs on the littoral environment on the River Murray, South Australia. In 'River Conservation and Management'. (Eds Boon, P.J., Calow, P.A. and Petts, G.E.) pp. 270-293. (Wiley: Chichester).

Ye, Q. and Zampatti, B. (2007). 'Murray cod stock status – the Lower River Murray, South Australia. Stock Status Report to PIRSA Fisheries.' South Australian Research and Development Institute (Aquatic Sciences), F2007-000211-1, Adelaide.

Zampatti, B.P., Leigh, S.J. and Nicol, J.M. (2008). 'Chowilla Icon Site-fish assemblage condition monitoring 2005-2008.' South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication Number F2008/000907-1, Adelaide.

Zampatti, B., Leigh, S., Nicol, J. and Weedon, J. (2006). '2006 progress report for the Chowilla fish and aquatic macrophyte project.' SARDI Aquatic Sciences, Adelaide.

Balcombe, S.R. and Closs, G.P. (2004). Spatial relationships and temporal variability in a littoral macrophyte fish assemblage. *Marine and Freshwater Research* **55**: 609-617.

8. Appendices

Appendix 1: Simper results comparing fish assemblage between regions.

Parameters

Standardise data: Yes
Transform: Fourth root
Cut off for low contributions: 90.00%
Factor name: Lock

Factor groups
Above lock 3
locks 1-3
Below lock 1

Group Above lock 3

Average similarity: 56.98

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cra ste	4.48	14.11	1.50	24.77	24.77
Nem ere	3.98	13.50	1.31	23.70	48.47
Mel flu	3.37	13.28	1.41	23.31	71.78
Ret sem	1.19	5.92	0.80	10.39	82.17
Cyp car	0.64	4.38	0.62	7.69	89.86
Mac amb	0.35	2.57	0.44	4.51	94.37

Group locks 1-3

Average similarity: 65.15

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cra ste	5.27	16.73	3.11	25.68	25.68
Nem ere	5.74	14.71	1.89	22.58	48.27
Mel flu	2.62	10.22	1.36	15.68	63.95
Cyp car	1.26	8.13	1.16	12.48	76.43
Ret sem	1.36	6.78	0.97	10.40	86.83
Hyp spp	0.67	2.99	0.56	4.59	91.42

Group Below lock 1

Average similarity: 58.05

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Nem ere	12.27	24.98	2.08	43.03	43.03
Cyp car	1.52	10.39	1.13	17.91	60.94
Cra ste	2.10	8.82	1.00	15.19	76.13
Ret sem	0.85	4.27	0.63	7.35	83.47
Mel flu	1.74	4.23	0.55	7.28	90.76

Groups Above lock 3 & locks 1-3

Average dissimilarity = 39.86

	Group Above lock 3	Group locks 1-3				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Cyp car	0.64	1.26	4.87	1.22	12.23	12.23
Ret sem	1.19	1.36	4.47	1.14	11.22	23.44
Nem ere	3.98	5.74	4.41	1.07	11.07	34.51
Mel flu	3.37	2.62	4.37	1.06	10.98	45.49
Mac amb	0.35	0.41	4.18	1.04	10.48	55.97
Hyp spp	0.49	0.67	4.11	1.07	10.32	66.29
Cra ste	4.48	5.27	3.76	0.92	9.44	75.73
Phi gra	0.20	0.57	3.36	0.95	8.44	84.17
Car aur	0.21	0.29	2.64	0.73	6.63	90.81

Groups Above lock 3 & Below lock 1

Average dissimilarity = 47.34

Group Above lock 3 Group Below lock 1

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Mel flu	3.37	1.74	6.95	1.27	14.69	14.69
Cra ste	4.48	2.10	6.02	1.14	12.73	27.42
Cyp car	0.64	1.52	5.74	1.20	12.13	39.54
Nem ere	3.98	12.27	5.49	1.05	11.60	51.14
Ret sem	1.19	0.85	5.15	1.15	10.88	62.02
Mac amb	0.35	0.56	5.01	1.05	10.57	72.59
Hyp spp	0.49	0.07	3.31	0.78	7.00	79.59
Phi gra	0.20	0.41	3.08	0.75	6.50	86.10
Car aur	0.21	0.06	2.17	0.57	4.58	90.67

Groups locks 1-3 & Below lock 1

Average dissimilarity = 42.79

Group locks 1-3 Group Below lock 1

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Mel flu	2.62	1.74	5.95	1.30	13.91	13.91
Cra ste	5.27	2.10	5.41	1.10	12.65	26.57
Ret sem	1.36	0.85	4.81	1.17	11.24	37.80
Cyp car	1.26	1.52	4.55	1.10	10.63	48.44
Mac amb	0.41	0.56	4.42	1.10	10.34	58.77
Nem ere	5.74	12.27	4.29	1.07	10.03	68.81
Phi gra	0.57	0.41	3.95	1.00	9.24	78.05
Hyp spp	0.67	0.07	3.93	0.98	9.18	87.23
Car aur	0.29	0.06	2.03	0.60	4.74	91.97