Describing levels of acceptable change (LACs) for indicators of various taxa (invertebrates, fishes, vegetation & birds) to develop a method of combining LACs in space & time

A report prepared for the Department of the Environment, Water and Natural Resources

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1 Introduction

Limits of acceptable change (LACs) are an integral part of the management process prescribed by the Ramsar Convention on Wetlands of International Importance (DEWHA 2008). They form the basis for our understanding when the ecological character of a region is changing so as to threaten the values for which the wetland was listed and thus intervention is required. However, LACs are typically developed for individual species or processes within a region, rather than the site as a whole (and all its features), and the species and processes so treated are often determined using expert opinion alone (rather than by any evidence-based analysis). Such species or processes are referred to as critical components, processes and services (CPS) and should be identified using defined criteria, including that: they are important determinants of the site's unique character; are important for supporting the Ramsar Convention criteria under which the site was listed; are components for which change is reasonably likely to occur over short or medium time scales (< 100 years); and/or that will cause significant negative consequences if change occurs (DEWHA 2008; Butcher 2011). This can mean, however, that different LACs may suggest that the ecological character of the overall site is in different conditions simultaneously (depending upon which CPS is focused upon), and thus make it difficult for managers to assess the overall condition of the site.

An LAC was defined by Phillips & Muller (2006, pg. 10) as

"…the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. This may include population measures, hectares covered by a particular wetland type, the range of certain water quality parameter, etc. The inference is that if the particular measure or parameter moves outside the 'limits of acceptable change' this may indicate a change in ecological character that could lead to a reduction or loss of the values for which the site was Ramsar listed. In most cases, change is considered in a negative context, leading to a reduction in the values for which a site was listed".

Another definition of LACs recognises them as being defined by the natural variation of a wetland component, process or service (Butcher 2011). Butcher (2011) also recognised that management triggers may differ from LACs and generally should represent smaller or earlier change points within the range bounded by LACs. Hence, LACs are not synonymous with management values or "trigger levels" and should be set to represent the point at which a possible change in the ecological character has occurred in absolute terms with no regard for detecting change prior to irrevocable changes in wetland ecology (Butcher & Hale 2011). Management plans should, in turn, identify management triggers relative to the LAC so that management actions can prevent the system approaching or exceeding LACs (Butcher 2011).

Therefore Butcher (2011) highlighted that the key points in regard to LACs are that: they be measurable; a confidence rating should be included; and they must represent the point at which ecological character would change. Butcher (2011) also highlighted that, more often than not, a temporal or spatial element should be included in the LAC. In addition, the pattern and degree of change should be considered, which could include accounting for changes in these temporal or seasonal patterns and changes in the spatial variability, as well as changes in the mean or median conditions (Butcher & Hale 2011).

In contrast to previous approaches, we sought to use patterns in available data sets to explore empirically what the values for LACs might be. Thus this project develops data-informed LACs for each of the Ramsar-significant biota and species analogous to the proverbial 'canary in the coalmine' (i.e. a species whose presence, absence, or relative well-being in a given environment is an early indicator of changing health of the ecosystem as a whole, as canaries in coal mines provided an early indicator of changing air quality) identified as critical to describing the overall condition of the region. Then a method was developed to enable the generation of spatially-explicit maps of ecological condition for the various management units and the region as a whole. Thus, the identification of the level of change that is considered meaningful, and also a refinement of indicator sets in relation to these LACs, will form an assessment of the success of environmental water requirements (EWR) in maintaining or enhancing the ecological character of the region (Lester et al. 2011a).

2 Methods

Setting limits of acceptable change based on natural variability is a difficult concept because wetlands are notoriously complex both spatially and temporally, with variability evident across all components and processes (Butcher 2011). Thus, the available data are required to provide estimates of the range in natural variability across different conditions (e.g. high- and low-flow years) and to identify those taxa and processes, where possible, that indicate wider changes in ecological character.

2.1 Data synthesis

The three data sets described below are those which were used for further LAC analyses. These data sets include some of the available data that cover a wide range of taxa that are relevant to the ecological character of the region. Data for other ecological components, processes and services were either not available, or were not considered appropriate for use in a first assessment of data-informed LACs (see Lester et al. 2011a).

2.1.1 Barrage Release Data Set

Different biological taxon assemblages (e.g. fish, birds and macroinvertebrates) of an ecosystem are likely to respond differently to increased River Murray flows and other environmental factors. Targeted monitoring occurred for phytoplankton (Aldridge & Brookes 2011), zooplankton (Shiel 2011), benthic macroinvertebrates (Dittmann et al. 2011), fish (Ye et al. 2011) and birds (Paton 2011) to measure the response to a given barrage release during 2010/11. Please refer to individual reports for details regarding the collection and processing methods for each taxonomic group.

Three syntheses of these data (Hamilton et al. 2011) were created to maximise the number of taxonomic groups and associated shared sites considered at once to explore for concordant patterns across data sets. Synthesis 1 used all taxonomic assemblages, including macroinvertebrates, fish phytoplankton and zooplankton across only four sites (downstream of Goolwa Barrage, Boundary Creek, Tauwitcherie and Mark Point). Synthesis 2 excluded fish but spanned eight sites, including Halfway (i.e. halfway between the Goolwa Barrage and the Murray Mouth), Sugars Beach, Hunters Creek and Ewe Island, in addition to the four sites used in Synthesis 1. Synthesis 3 included only phytoplankton and zooplankton assemblage data across all previously mentioned sites, with the addition of three more, namely Mundoo Channel, the Southern Ocean and the Murray Mouth. Each synthesis was across three time periods (November-December 2010, January-February 2011 and March-April 2011).

2.1.2 Goolwa Data Set

As part of the Goolwa Channel Water Level Management Project (GCWLMP), individual components of the ecosystem were monitored by specialists for each taxonomic group to measure the effect of the management actions in the Goolwa Channel to reduce the likelihood of acidification of adjacent waters. They included benthic macroinvertebrates (Dittmann et al. 2011), zooplankton (data collected and provided by R. Shiel, with assistance of the Fairweather lab, Flinders University); phytoplankton (collected by the EPA, provided through A. Rolston, DENR), fish (Bice & Zampatti 2011), and vegetation (Gehrig & Nicol 2011). Water quality data were sourced from the EPA (2011).

Synthetic analyses were undertaken, combining data sets of different taxonomic groups across both space and time. The design of the study sought to compare sites inside and outside the Goolwa Weir Pool (GWP), but subsequent changes to the exact sampling sites and times at which they were sampled meant that such syntheses were limited. To achieve the best possible synthesis, so-called aliasing of data was necessary, where data from slightly different times and/or sites were merged. The synthesis used in this report included macroinvertebrates, fish and vegetation. Sites included the Lakes side of Goolwa Barrage, both the Lakes and Goolwa sides of Clayton and Lower Currency Creek. Three time periods, including the first 6 months, 7-12 months and 19+ months were used (Lester et al. 2010; Hamilton et al. 2011; Lester et al. 2011b).

2.1.3 Coorong Data Set

Two data sets were collated using a mixture of qualitative, quantitative and semi-quantitative data available for the Coorong between 1999 and 2007. Data were thus collected using a variety of methods at different temporal and spatial scales, supplied through available literature, CLLAMMecology Research Cluster researchers (Brookes et al. 2009), and monitoring and modelling data for the Coorong (see Lester and Fairweather 2009 for details of data provenance). Variables were over either long-term (annual time-step between 1999 and 2007) or short-term (quarterly time-step between 2005 and 2007) periods.

A biological data set consisted of abundance data for macroinvertebrates (short term only), fisheries-independent fish (short term only) and birds (long and short term), as well as coverage and abundance of propagules of the plant *Ruppia tuberosa* (long term only). Catch per unit effort (CPUE) from commercial fisheries was also used in both long- and short-term data sets. An environmental data set was used that modelled water flow, water level, depths and salinities, as well as meteorological and water quality data from 1999 to 2007 (Lester & Fairweather 2011).

2.2 Trophodynamic descriptions

Based on extensive literature and internet searches each of the taxa across the data sets were allocated into a trophodynamic group (adapted from the feeding guilds for fish in Elliott et al. 2007 but applied across all taxonomic groups here). Taxa were thus grouped into one of 11 trophodynamic groups, based on their main food items (see Table 1 for further description of each group). Those taxa which are labelled 'unallocated' represent taxa for which a specific allocation to a functional group was not able to be made.

Table 1: Feeding mode functional group categories and their main characteristics adapted from Elliott et al. (2007) for fish. Some taxa were not able to be allocated to any of these categories.

Functional Group	Feeding characteristics
Autotrophic	Photosynthesise organic materials required from inorganic sources (e.g. CO_2 and nitrates)
Heterotrophic	Take in and digest organic substances, normally plant or animal tissues
Detritivore	Eat small organisms in or on the surface layer of the substratum (e.g. benthic algae such as diatoms, microfauna and to a lesser extent meiofauna) and associated organic matter (i.e. usually of plant origin). Ingest relatively large volumes of sand or mud, digest the food material and pass out the inorganic particles
Herbivore	Graze or browse, predominantly on living macroalgal and macrophyte material
Omnivore/Opportunist	Ingest both plant and animal material by feeding mainly on macrophytes, periphyton, filamentous algae and associated epifauna. Opportunistically feeding species are often also grouped with the omnivore species.
Planktivore	Predominantly feed on zooplankton and occasionally on phytoplankton in the water column, mainly by filter feeding
Planktivore/Hyperbenthivore	Predominantly feed on zooplankton but also on smaller mobile invertebrates living over the bottom
Macrobenthivore	Mainly feed on benthic, epibenthic and hyperbenthic fauna, with prey size <1 cm. Other prey items include small invertebrates and wind-blown terrestrial insects.
Hyperbenthivore/Piscivore	Predominantly feed on larger mobile invertebrates living on the bottom and fish living near the bottom
Piscivore	Carnivorous, primarily target fish
Predator	Carnivorous, main prey items not specified

2.3 Selection of indicator taxa

For each synthesis from the three data sets, a series of BVSTEP structural redundancy analyses (Clarke & Warwick 1998; Clarke & Gorley 2006) were undertaken. These data-reduction analyses identify which taxon (or combination of taxa) is most highly correlated with the entire biological data set, using a stepwise search (Clarke & Gorley 2006). Following the initial BVSTEP analysis, the combination of taxa which were found to be the most highly correlated (or similarly high in correlation, but using fewer taxa) were removed and the BVSTEP analysis was repeated. These analyses were repeated until five subsets (called 'peels') were completed for each of the syntheses within each data set. Five subsets were chosen on the basis of the strength of the correlations obtained, where the degree of structural redundancy is reflected in the number of peels that can be removed without damaging the integrity of the total community signal (i.e. maintaining a high correlation with the total data set, Clarke & Warwick 1998; Figure 1). Spearman correlation coefficients (rho values) were used to measure the strength of correlation of each of the peels with the whole data set. Strongly correlated peels were considered to be those which had an associated rho value of ≥ 0.95 (Clarke & Warwick 1998), meaning that their patterns were the most closely associated (i.e. virtually identical) to the whole data set. For the majority of the analyses undertaken, by the time five peels were identified, rho values had fallen to 0.6 or lower (Figure 1), indicating only a moderate (or at least weaker) correlation to the overall data set.

From the results of the BVSTEP analyses, a summary for each taxon was produced to highlight which peel (whether significant or not) they had appeared in. This was done across all of the taxonomic groups, comparing the results across data sets. Tables A1.1-A1.9 (Appendix 1) show the results of each individual BVSTEP analysis, with taxa grouped under the trophodynamic classification described above (Table 1). Indicator taxa were selected based on the frequency with which each taxon appeared in the more strongly-correlated peels across multiple syntheses and multiple data sets (Tables 2-7). These taxa were then explored further for the setting of LACs. In addition to those taxa selected based on the BVStep analyses, expert opinion regarding other potential indicator species (e.g. those which were considered characteristic of a range of conditions within the site) were also included, and additional taxa were excluded where it was not considered to be a good indicator or where insufficient data were available for that taxon to make a realistic assessment.

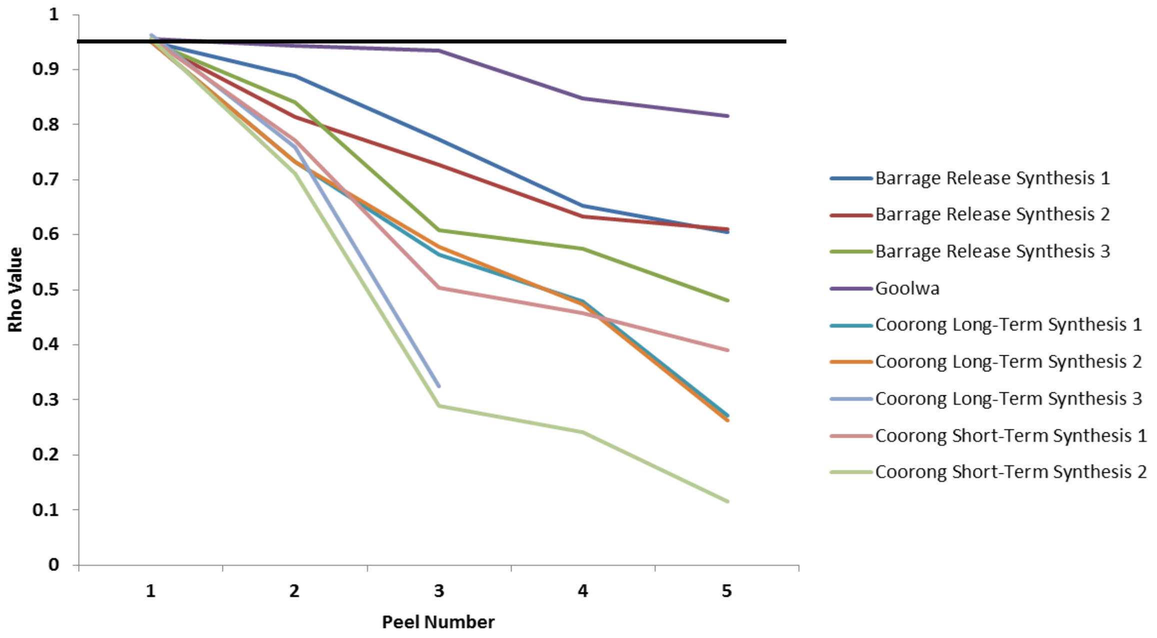

Figure 1: Summary of Rho values across the successive peels within each of the data sets. Rho values are Spearman correlation coefficients which measure the strength of correlation of each of the peels (subset of taxa) with the whole data set. The black solid line shows Rho = 0.95.

Note: Coorong Long-Term Synthesis 3 has only three peels because all of the available taxa were selected within these three peels, thus no further peel analyses were possible.

2.4 Exploring environmental thresholds: approach used with macroinvertebrates

Regression tree analyses (in CART v.6) split response variable data (i.e. indicator taxa abundance data) into increasingly homogenous groups based on a variety of exploratory variables (i.e. environmental variables), to minimise the variation within groups of a specified response variable (De'Ath & Fabricius 2000; Lester et al. 2011a). A regression tree was produced using each of the macroinvertebrate indicator species (Table 8) abundances. Potential predictor variables included water depth, temperature, EC, pH, dissolved oxygen, turbidity, ammonia, oxidised nitrogen, Total Kjeldahl Nitrogen (TKN), total nitrogen, phosphorus, and water level. Least-squares regression was used to obtain the best tree (using the 1 standard error rule for selecting the best tree; Breiman et al. 1984), where the minimum parent node was set at a sample size of 10 and the minimum terminal node cases was set at a sample size of one. For each regression tree, we then determined the most influential variables using the importance score produced (i.e. based on the reported variable importance, with a range of 0 as least important to 100 as most important), the threshold values for the key variables and steps in the trajectory (i.e. the identification of terminal nodes). Where variables were significantly correlated (at α = 0.05; e.g. TKN and total nitrogen for Collembola, and oxidised nitrogen and ammonia for Amphipoda), the variable with the higher importance in the CART analysis was retained and the other removed until we obtained a regression tree with no significantly-correlated predictor variables.

Least-squares regression analyses (in SYSTAT v.13) were also performed to identify the strength of the relationship between the individual variables which were identified by the regression tree analyses and the corresponding abundance of the indicator species. This analysis was to determine whether any linear relationships existed beyond what might be expected by chance (as measured by the proportion of total variation explained; r^2). Scatterplots were also produced (in SYSTAT v.13) for each relationship, as a visual representation of the relationship (especially non-linear relationships) between the variables, and the key threshold values for each variable at each step of the regression tree.

Refer to Appendix C for a description of the identification of environmental thresholds for plant indicators and Appendix D for a similar discussion for fish indicators.

Regression tree analyses produced key data-derived environmental thresholds for each of the macroinvertebrate indicator species. These thresholds thus are a preliminary step in producing LACs for the indicator species because they provide environmental thresholds above and below which the abundance of each taxon changes dramatically. These can then be developed into LACs by validating each threshold with known tolerance levels for that taxon based on the literature and expert judgements about whether the thresholds that appear in the analyses accord with our understanding of the site.

2.5 Combining indicators to assess ecological condition in the CLLMM region

In a separate analysis showing how LACs might be combined, a prototype spreadsheet model was developed in Microsoft Excel to assess ecological conditions in the CLLMM region based on the environmental thresholds identified. A workshop was held between DEWNR and the project team to identify an initial list of indicators for which sufficient information existed to justify their inclusion in a prototype. Between two and seven species or assemblages were selected for each taxon group of vegetation, macroinvertebrates, fish and birds. These prototype taxa were also selected as there were known ecological links among the taxonomic levels (e.g. some fish species relied upon access to submergent vegetation). Thresholds for the presence/absence of each taxon were developed, and measures of assemblage health (e.g. presence of adults) were also identified.

Typical environmental monitoring data were added to the spreadsheet model for 1995 to 2008 for the Coorong (taken from the hydrodynamic model for the Coorong developed by Webster 2010) and between 2010 and 2012 for the Lakes (including the EPA water quality data and water level data available at waterconnect.sa.gov.au). These were intended to represent the environmental information likely to be available to managers upon which to base an assessment of the CLLMM region relative to LACs. The number and location of sites that were able to be assessed varied among data sets. Formulae were developed to identify in each location, for each year, whether conditions were considered suitable or unsuitable for each taxon (relative to their stated tolerances). These were summarised across taxa.

In addition, example biological monitoring data for each group were also included. These were used as an alternative assessment of the suitability of each location for the taxon in question (i.e. if the health measure were met, then the location was considered suitable – this may be indicated by the presence of adult birds that were feeding or resting in a particular location, for example). Each location in each year was independently assessed as either suitable or unsuitable based on the biological health measure specified for each species.

The assessment of suitability based on the environmental conditions was then compared with the assessment of suitability based on the biological health measures. Where these disagreed, a location was identified as requiring further investigation. If a location was considered suitable, but was not identified, this may indicate that biological monitoring had not identified a species that was indeed present, or that there was the opportunity for colonisation of the species to a new area, or that there was a lack of understanding as to why the species was not present (i.e. it was not represented adequately in the thresholds used). Conversely, if a species was present in a location that was considered unsuitable, then this may indicate that the species was at risk of local extinction in that location or that again there was a lack of understanding as to the requirements of the species (i.e. that the species was in fact more tolerant than suggested by the thresholds included here).

The suitability of habitat in each location based on the LACs in each year was used to assess the overall ecological health of the CLLMM region. The proportion of sites within each management unit (i.e. the Coorong, Lake Alexandrina or Lake Albert) was used to determine the likelihood that each unit was in good, moderate or poor condition for each identified indicator taxon, via a fuzzy logic classifier (Negnevitsky 2005). This likelihood was then aggregated across the various taxa. As all taxa are not equally likely to be found in each site, a weighting was given by the project team (i.e. based on previous experience in the CLLMM region) to each in each management unit (e.g. freshwater submerged plant communities were given a weighting of 0.1 in the Coorong, as they are unlikely to be found there, so the lack of suitable habitat is of less overall importance than the lack of suitable habitat for a fairy tern, for example, which was given a weighting of 1 in the Coorong). The product of the likelihood and the weighting was averaged across all indicator taxa for each of the poor, moderate and good condition categories.

3 Results

3.1 Selection of indicator taxa

Tables 2-6 represent the outcomes from the preliminary structural redundancy analyses (i.e. the ‘peels’) (see Appendix A for more comprehensive result outputs). Those species which appeared in significant peels or appeared in most (if not all) of the possible analyses across the data sets were identified as potential indicator species. A summary of the numbers of taxa occurring in very highly correlated and not so correlated peels for each taxonomic group is shown in Table 7.

From the structural redundancy analyses, a total of 14 birds, 15 fish, 9 macroinvertebrates, 6 vegetation species and 22 plankton species were chosen as potential indicator species (Tables 2-6). In addition to these results, additional species were included or some were excluded based on expert opinion (see Appendix B for further justification). The final list of indicator taxa based both on the structural redundancy analyses and expert opinion are shown in Table 8.

Table 2: Bird species – Summary of the total number of analyses in which each taxon appeared in very highly correlated peels (i.e. rho ≥ 0.95) and in the not so highly correlated of the first five peels (grouped within functional feeding categories) across all possible data sets. A '-' indicates that the species did not get chosen within the first five peels produced (from a total of four analyses for birds, and four significant peels). Species in bold were those selected based on the analyses as potential indicator species. Some species were selected based on moderately significant peels, or to ensure that each group was represented.

	Total number of peels	
Species	**Very highly correlated**	**Not so**
Herbivore		
Australian shelduck (*Tadorna tadornoides*)	**4**	**-**
Black swan (*Cygnus atratus*)	**3**	**-**
Cape barren goose (*Cereopsis novaehollandiae*)	-	4
Chestnut teal (*Anas castanea*)	**3**	**1**
Eurasian coot (*Fulica atra*)	-	1
Pacific black duck (*Anas superciliosa*)	-	3
Omnivore/Opportunist		
Australasian shoveler (*Anas rhynchotis*)	-	3
Banded stilt (*Cladorhynchus leucocephalus*)	**4**	**-**
Black-winged stilt (*Himantopus himatopus*)	-	3
Curlew sandpiper (*Calidris ferruginea*)	**2**	**-**
Grey teal (*Anas gracilis*)	**4**	**-**
Hoary-headed grebe (*Poliocephalus poliocephalus*)	1	3
Masked lapwing (*Vanellus miles*)	**2**	**2**
Musk duck (*Biziura lobata*)	-	3
Pink-eared duck (*Malacorhynchus membranaceus*)	-	2
Red-necked stint (*Calidris ruficollis*)	**2**	**1**
Royal spoonbill (*Platalea regia*)	-	1
Sharp-tailed sandpiper (*Calidris acuminata*)	**2**	**-**
Silver gull (*Chroicocephalus novaehollandiae*)	**4**	**-**
White-faced heron (*Ardea novaehollandiae)*	-	3
Macrobenthivore		
Australian white ibis (*Threskiornis molucca*)	-	4
Black-tailed godwit (*Limosa limosa*)	-	2
Common greenshank (*Tringa nebularia*)	-	2
Eastern curlew (*Numenius madagascariensis*)	-	2
Hyperbenthivore/Piscivore		
Greater sand plover (*Charadrius leschenaultia*)	-	1
Red-capped plover (*Charadrius ruficapillus*)	-	4
Piscivore		
Australian pelican (*Pelecanus conspicillatus*)	**3**	**1**
Black-faced cormorant (*Phalacrocorax fuscescens*)	-	3
Caspian tern (*Sterna caspia*)	-	4
Crested tern (*Sterna bergii*)	**3**	**1**
Fairy tern (*Sterna nereis*)	-	4
Great cormorant (*Phalacrocorax carbo*)	-	4
Great crested grebe (*Podiceps cristatus*)	1	3
Great egret (*Ardea alba*)	-	2
Little egret (*Egretta garzetta*)	-	2
Little pied cormorant (*Phalacrocorax melanoleucos*)	**2**	**2**
Whiskered tern (*Chlidonias hybridus*)	**2**	**2**
Macrobenthivore/Piscivore		
Little black cormorant (*Phalacrocorax sulcirostris*)	-	3
Pied cormorant (*Phalacrocorax varius*)	-	4
Pied oystercatcher (*Haematopus longirostris*)	-	3

Table 3: Fish species– Summary of the total number of analyses in which each taxon appeared in very highly correlated peels (i.e. rho ≥ 0.95) and in the not so highly correlated of the first five peels (grouped within functional feeding categories) across all possible data sets. A '-' indicates that the species did not get chosen within the first five peels produced (from a total of seven analyses for fish, and three significant peels). Species in bold were those selected based on the analyses as potential indicator species. Some species were selected based on moderately significant peels, or to ensure that each group was represented.

	Total number of peels	
Species	**Very highly correlated**	**Not so**
Detritivore		
Bony bream (*Nematalosa erebi*)	**-**	**5**
Omnivore		
Blue-spot goby (*Pseudogobius olorum)*	**1**	**6**
Bridled goby (*Arenigobius bifrenatus*)	**1**	**1**
European carp (*Cyprinus carpio*)	**1**	**3**
Goldfish (*Carassius auratus*)	-	2
Murray hardyhead (*Craterocephalus fluviatilis*)	-	1
River garfish (*Hyporhamphus regularis*)	**1**	-
Omnivore/Opportunist		
Australian salmon (*Arripis truttacea*)	-	3
Black bream (*Acanthopagrus butcheri*)	-	5
Yellow eye mullet (*Aldrichetta forsteri*)	**1**	**3**
Planktivore		
Jumping mullet (*Liza argentea*)	-	2
Sandy sprat (*Hyperlophus vittatus*)	-	1
Planktivore/Macrobenthivore		
Greenback flounder (*Rhombosolea tapirina*)	-	4
Redfin perch (*Perca fluviatilis*)	-	2
Macrobenthivores		
Australian smelt (*Retropinna semoni*)	-	1
Carp gudgeon complex (*Hypseleotris spp.)*	**1**	-
Common galaxias (*Galaxias maculatus*)	**1**	-
Congolli (*Pseudaphritis urvillii*)	**-**	**2**
Callop (*Macquaria ambigua*)	-	5
Flathead gudgeon (*Philypnodon grandiceps*)	-	2
Lagoon goby (*Tasmanogobius lasti*)	**1**	**1**
Small-mouthed hardyhead (*Artherinosoma microstoma)*	**1**	-
Tamar River goby (*Afurcagobius tamarensis*)	-	1
Hyper-/Macrobenthivore/Piscivore		
Gummy shark (*Mustelus antarcticus*)	**-**	5
Mulloway (*Argyrosomus hololepidotus*)	**1**	**3**
Hyper-/Macrobenthivore/Piscivore		
Rays (Ray spp./skate spp.)	-	3
Piscivore		
Bronze whaler shark (*Carcharhinus brachyurus*)	-	4

Table 4: Macroinvertebrate species – Summary of the total number of analyses in which each taxon appeared in very highly correlated peels (i.e. rho ≥ 0.95) and in the not so highly correlated of the first five peels (grouped within functional feeding categories) across all possible data sets. A '-' indicates that the species did not get chosen within the first five peels produced (from a total of three analyses for macroinvertebrates, and three significant peels). Species in bold were those selected based on the analyses as potential indicator species. Some species were selected based on moderately significant peels, or to ensure that each group was represented.

	Total number of peels	
Species	**Very highly correlated**	**Not so**
Herbivore/Detritivore		
Chironomidae (Larvae & Pupae)	**-**	**2**
Chrysomelidae sp. 2 (Leaf Beetle)	-	1
Collembola	**1**	**-**
Dolichopodidae (March flies)	-	1
Ephydridae (Pupae) (Diptera)	**1**	**1**
Ostracoda.	-	1
Spionidae (Polychaete)	-	1
Detritivore		
Boccardiella novaehollandiae (Spionidae)	-	1
***Capitella* sp. (Polychaete)**	**1**	**1**
Oligochaete	-	1
Omnivore/Opportunist		
Amphipoda. (Crustacea)	**1**	**1**
***Simplisetia aequisetis* (Polychaete)**	**1**	**2**
Planktivore		
Anostraca (Brine shrimp)	-	1
***Arthritica helmsi* (Bivalve)**	**1**	**1**
Macrobenthivore		
***Nepthys australiensis* (Polychaete)**	**1**	**2**
Predatory		
Mysidacea (Larvae)	**1**	**1**
Pisauridae (Fishing spider)	-	1
Staphylinidae (Beetle)	-	1
Parasite		
Ceratopogonidae (Biting Midge)	-	1
Unallocated		
Coleoptera. (Beetle)	-	1
Juvenile Insect	-	-

Table 5: Vegetation species – Summary of the total number of analyses in which each taxon appeared in very highly correlated peels (i.e. rho ≥ 0.95) and in the not so highly correlated of the first five peels (grouped within functional feeding categories) across all possible data sets. A '-' indicates that the species did not get chosen within the first five peels produced (from a total of two analyses for vegetation, and one significant peel). Species in bold were those selected based on the analyses as potential indicator species. Some species were selected based on moderately significant peels, or to ensure that each group was represented.

	Total number of peels	
Species	**Very highly correlated**	**Not so**
Autotrophic		
African Daisy (*Senecio pterophorus*)	-	1
Australian Gypsywort (*Lycopus australis*)	**-**	**1**
Common Reed (*Phragmites australis*)	-	1
Great Bindweed (*Calystegia sepium*)	-	1
Kikuyu grass (*Pennisetum clandestinum*)	-	1
Duckweed *(Lemna* sp.)	**-**	**1**
Lignum (*Muehlenbeckia florulenta*)	-	1
Mint/Peppermint (*Mentha* sp.)	-	1
Tuberous Sea Tassel (*Ruppia tuberosa*)	**-**	**1**
Pale Knotweed (*Persicaria lapathifolia*)	-	1
Pondweed (*Potamogeton pectinatus*)	**1**	**-**
Ribbon weed (*Triglochin procerum*)	-	1
Saltbush (*Chenopodium galucum*)	**-**	**1**
Spiny flat hedge (*Cyperus gymnocaulos*)	-	1
Water Couch (*Paspalum distichum*)	**1**	**-**

Table 6: Plankton species – Summary of the total number of analyses in which each taxon appeared in very highly correlated peels (i.e. rho ≥ 0.95) and in the not so highly correlated of the first five peels (grouped within functional feeding categories) across all possible data sets. A '-' indicates that the species did not get chosen within the first five peels produced (from a total of three analyses for plankton, and three significant peels). Species in bold were those selected based on the analyses as potential indicator species.

	Total number of peels	
Species	**Very highly correlated**	**Not so**
Autotrophic Phytoplankton		
Actinastrum (Algae)	-	2
Anabaena (Straight) (Cyanobacteria)	-	1
Ankistrodesmus (Algae)	-	2
Ankistrodesmus sp. 2 (Algae)	**2**	-
Aphanizomeno (Cyanobacteria)	**2**	-
Aphanocapsa (Cyanobacteria)	**1**	-
Aulacoseira (Diatom)	-	3
Chaetoceros (Diatom)	**1**	**2**
Chlamydomonas (Algae)	-	2
Chlorophyceae (Algae)	-	2
Chodatella (Algae)	-	2
Chodatella (*Lagerheimia*) (Algae)	-	-
Closterium (Algae)	**1**	**2**
Coelosphaerium (Cyanobacteria)	**1**	**1**
Coscinodiscus (Diatom)	-	3
Cosmarium (Algae)	-	1
Crucigenia (Algae)	-	2
Cryptomonas (Algae)	-	2
Cyanogranis (Cyanobacteria)	-	1
Cyclotella (Diatom)	-	2
Cyclotella (Large) (Diatom)	-	1
Cyclotella (Small) (Diatom)	**1**	-
Cyphoderia ampulla (Protist)	**1**	-
Dictyosphaerium (Algae)	-	2
Elakatothrix (Algae)	-	3
Geitlerinema (Cyanobacteria)	-	3
Merismopedia (Cyanobacteria)	-	2
Microcystis aeruginosa (Cyanobacteria)	-	2
Oedogonium (Algae)	-	1
Oocycstis-(Algae)	**2**	-
Oocycstis (Large) (Algae)	-	3
Oocystis (Small) (Algae)	-	1
Pediastrum (Cladoceran)	**1**	-
Planctonema (Algae)	**2**	-
Planktolyngbya (Cyanobacteria)	**2**	-
Planktothrix (Cyanobacteria)	-	2
Pseudanabaena (Cyanobacteria)	**1**	**2**
Pseudo-nitzschia (Diatom)	-	1
Romeria (Cyanobacteria)	-	1
Scenedesmus (Algae)	-	2
Schroedaria (Algae)	-	2
Skeletonema (Diatom)	-	1
Sphaerocystis (Algae)	-	3
Staurosira (Diatom)	**2**	-
Synedra (Diatom)	-	1
Tetraspora (Algae)	-	3
Tetrastrum (Algae)	**2**	-
Planktivore/Herbivore/Detritivore Zooplankton		
Alona (Cladoceran)	-	1
Anthalona sp. (Cladoceran)	-	1

	Total number of peels	
Species	**Very highly correlated**	**Not so**
***Boeckella triarticulata* (Copepoda)**	**1**	**-**
Bosmina meridionalis (Cladoceran)	-	1
Brachinonus calyciflorus amphiceros (Rotifer)	-	2
Brachionus calyciflorus s.l. (Rotifer)	-	1
Brachionus rubens (Rotifer)	-	2
Brachionus sp. (Rotifer)	-	1
Calamoecia ampulla (Copepoda)	-	1
Centropagidae copepodites (Copepoda)	-	-
Centropagidae nauplii (Copepoda)	-	1
Ceriodaphnia cornuta (Cladoceran)	-	1
Conochilus (Colonial Rotifer)	-	1
Cypretta (Ostracoda)	-	2
Daphnia carinata (Cladoceran)	-	*1*
Daphnia lumholtzi (Cladoceran)	-	*1*
Filina opoliensis (Rotifer)	-	1
***Filinia australiensis* (Rotifer)**	**1**	**-**
***Filinia pejleri* (Rotifer)**	**1**	**-**
Harpacticoida adult (Copepoda)	-	2
Harpacticoida copepodites (Copepoda)	-	1
Hexarthra intermedia (Rotifer)	-	1
Keratella australis (Rotifer)	-	2
***Keratella tropica* (Rotifer)**	**1**	**1**
***Moina micrura* (Cladoceran)**	**1**	**1**
Mysidacea (indet.) (Crustacea)	-	-
Polyarthra dolichoptera (Rotifer)	-	1
Proales daphnicola (Rotifer)	-	1
Proalides tentaculatus (Rotifer)	-	1
Stenosemella lacustris (Ciliate)	-	3
Stentor sp. (Ciliate)	-	1
Heterotroph		
***Arcella hemisphaerica* (Amoebozoa)**	**1**	**1**
***Difflugia* sp. C (Amoebozoa)**	**1**	**2**
Carnivore/Predator		
Prorocentrum (Dinoflagellate)	-	1
Protoperidinium (Dinoflagellate)	-	1

Table 7: Summary of the total number of taxa appearing in very highly correlated peels (i.e. Rho ≥ 0.95) and peels that were less well correlated for each taxonomic group across all analyses, and the number of taxa chosen as indicative for each taxonomic group.

Taxonomic Group	**Total # Taxa**	**Total # of analyses**	**# of very highly correlated peels**	**Total # taxa chosen**	**# of not so correlated peels**	**Total # taxa chosen**
Birds	40	4	42	16	83	33
Fish	28	7	10	10	66	24
Macroinvertebrates	22	4	8	8	22	19
Vegetation	15	2	2	2	13	13
Plankton	82	3	39	22	100	65

Table 8: List of indicator species selected within each taxonomic group. Those in bold here indicate the species which were added based on expert opinion. Note: No bird or plankton species have been included as indicators, as further analyses were not done on these taxonomic groups.

Species	Functional feeding category	Life-cycle categories
Fish – 23 chosen		
Australian Salmon (*Arripis truttacea*)	Omnivore/Opportunist	Marine migrant
Australian Smelt (*Retropinna semoni*)	**Macrobenthivore**	**Freshwater migrant**
Blue-spot Goby (*Pseudogobius olorum)*	Omnivore	Estuarine
Bony Bream (*Nematalosa erebi*)	Detritivore	Freshwater migrant
Bridled Goby (*Arenigobius bifrenatus*)	Omnivore/Opportunist	Estuarine
Carp Gudgeon complex (*Hypseleotris spp.)*	Macrobenthivore	Freshwater straggler
Common Galaxias (*Galaxias maculatus*)	Macrobenthivore	Catadromous
Congolli (*Pseudaphritis urvillii*)	Macrobenthivore	Catadromous
European Carp (*Cyprinus carpio*)	Omnivore	Freshwater straggler
Golden Perch (*Macquaria ambigua*)	**Macrobenthivore**	**Freshwater migrant**
Gummy Shark (*Mustelus antarcticus*)	Hyperbenthivore/Piscivore	Marine straggler
Lagoon Goby (*Tasmanogobius lasti*)	Macrobenthivore	Estuarine
Mulloway (*Argyrosomus hololepidotus*)	Hyperbenthivore/Piscivore	Marine migrant
Murray Cod (*Maccullochella peelii peelii*)	**Opportunist**	**Freshwater straggler**
Murray Hardyhead (*Craterocephalus fluviatilis*)	**Omnivore**	**Freshwater straggler**
Pouched lamprey (*Geotria australis*)	**Detritivore**	**Anadromous**
River Garfish (*Hyporhamphus regularis*)	Herbivore	Estuarine
Sandy Sprat (*Hyperlophus vittatus*)	**Planktivore**	**Marine migrant**
Short-headed Lamprey (*Mordacia mordax*)	**Detritivore**	**Anadromous**
Small-mouthed Hardyhead (*Artherinosoma microstoma)*	Macrobenthivore	Estuarine
Southern Pygmy Perch (*Nannoperca australis*)	**Macrobenthivore**	**Freshwater straggler**
Yarra Pygmy Perch (*Nannoperca obscura*)	**Macrobenthivore**	**Freshwater straggler**
Yellow eye Mullet (*Aldrichetta forsteri*)	Omnivore/Opportunist	Marine migrant
Macroinvertebrates – 8 chosen		
Amphipoda spp. (Crustacea)	Omnivore/Opportunist	
Arthritica helmsi (Bivalve)	Planktivore	
Capitella sp. *(Polychaete)*	Detritivore	
Chironomidae (Larvae & Pupae)	Detritivore	
Collembola	Herbivore/Detritivore	
Ephydridae (Pupae) (Diptera)	Herbivore/Detritivore	
Nepthys australiensis (Polychaete)	Macrobenthivore	
Simplisetia aequisetis (Polychaete)	Omnivore/Opportunist	
Vegetation – 13 chosen		
Brittlewort (*Nitella* spp.)	Autotroph	
Charophyte (*Chara* spp.)	Autotroph	
Hornwort (*Ceratophyllum demersum*)	Autotroph	
Large fruit-tassel (*Ruppia megacarpa*)	Autotroph	
Pondweed (*Potamogeton* spp.)	Autotroph	
Ribbon weed (*Triglochin procerum*)	Autotroph	
River club-sedge (*Schoenoplectus validus*)	Autotroph	
River ribbon (*Vallisneria australis*)	Autotroph	
Salt paperbark (*Melaleuca halamaturorum*)	Autotroph	
Sonewort (*Lamprothamnium macropogan*)	Autotroph	
Tuberous tassel (*Ruppia tuberosa*)	Autotroph	
Water mat (*Lepilaena* spp.)	Autotroph	
Water milfoil (*Myriopyhllum* spp.)	Autotroph	

3.2 Data-derived macroinvertebrate thresholds

The most influential variable on the crustaceans Amphipoda abundance was ammonia (thus given an importance score of 100) (Figure 2). Other variables that were also important from the regression tree analysis included oxidised N (importance = 42.62), temperature (importance = 24.58), total phosphorus (importance = 20.98) and water depth (importance = 13.31). Both oxidised N and temperature, although higher in importance than water depth, for example, are not represented in the tree (Figure 2), as they are treated as surrogate variables to those that are included in the tree, but may be useful to be considered when defining LACs nonetheless.

The key thresholds identified for ammonia and total phosphorus were 0.04 mg L^{-1} and 0.24 mg L^{-1}, respectively. In both, higher average abundances of Amphipoda were found with increased levels of ammonia and phosphorus (i.e. > 0.04 mg L^{-1} and 0.24 mg L^{-1}, respectively). Despite these higher average abundances, they only occurred within nine and two of the 59 cases respectively, and had high variability (SD = 1742.34 and 1284.21, respectively). The key threshold identified for water depth was 4.32 m, with average abundances of Amphipoda at 358 individuals per m^2 (SD = 414.01) for water levels below 4.32 m. Of the three key variables represented in the tree, linear regression analyses indicated that none of the relationships between the variables and Amphipoda abundance were significant alone.

The trajectory for Amphipoda abundance identified four outcomes (i.e. the number of identified terminal nodes). The majority of cases (i.e. the number of samples) fell within the outcome associated with the combination of lower ammonia (i.e. < 0.04 mg L^{-1}), lower total phosphorus (< 0.24 mg L^{-1}) and shallower water depths (< 4.32 m) (Figure2), where the average abundance of Amphipoda was 238 individuals per m^2 and there was moderate amount of variability between the cases (SD = 414.01). A total of nine cases fell within the outcome associated with higher levels of ammonia (i.e. > 0.04 mg L^{-1}), with a reasonably high average abundance of Amphipoda (1572 individuals per m^2) and high variability (SD = 1742.34). Under low ammonia (< 0.04 mg L^{-1}) and higher total phosphorus (> 0.24 mg L^{-1}) conditions, average abundance of Amphipoda was high at 1404 individuals per m^2, but the variability between the cases was also high (SD = 1284.21) and the number of cases which represented this outcome was low (*n* = 2). Only a single case was found under low ammonia (< 0.04 mg L^{-1}), low total phosphorus (< 0.24 mg L^{-1}) and deeper water depth (> 4.32 m), where the abundance was high at 1806 individuals per m^2; thus this outcome was considered the least common.

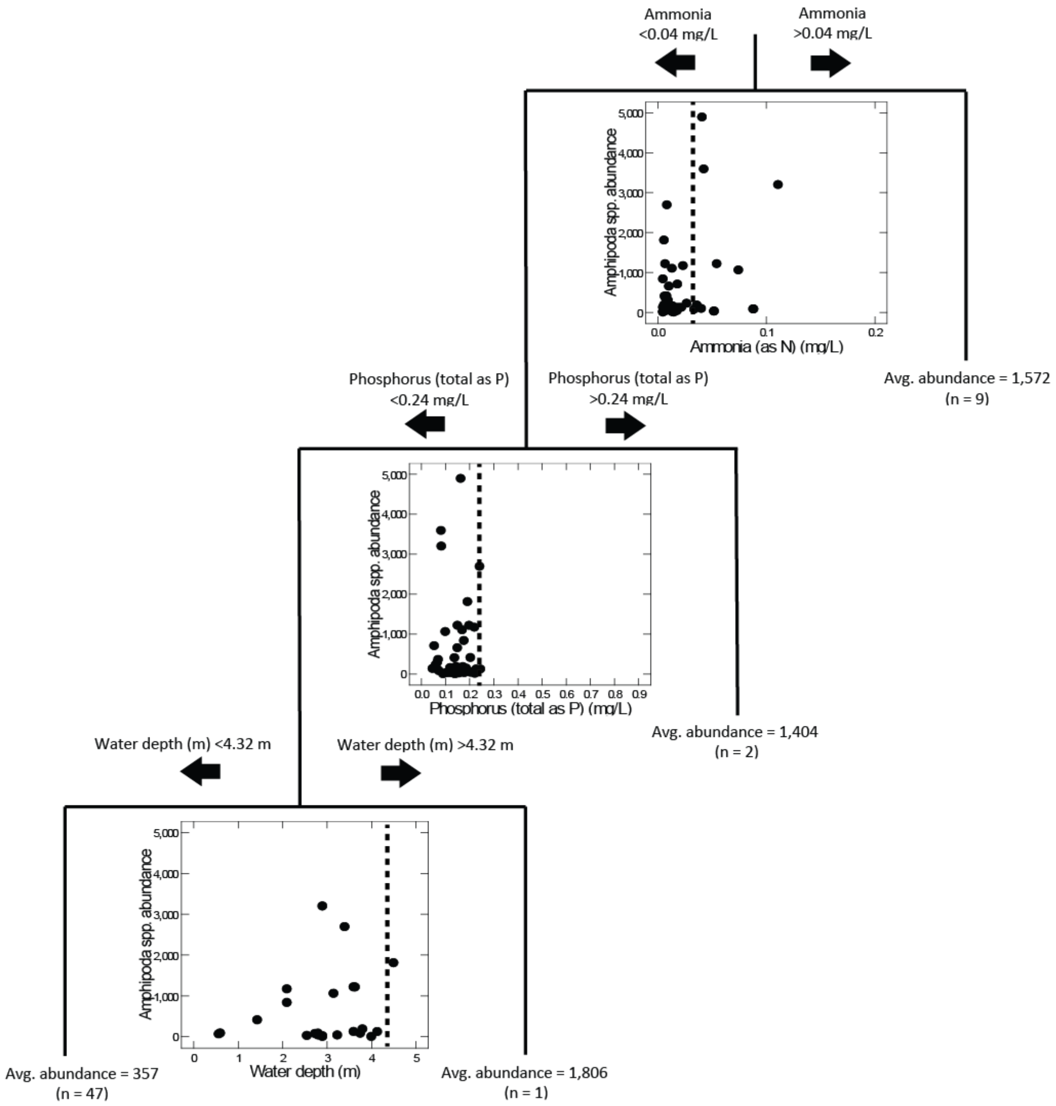

Figure 2: Regression tree output generated from Amphipoda abundance data (individuals per m^2 as the response variable) and the selected available environmental variables (driving variables). The driving variables are labelled above each split in the tree and the trajectory is the number of distinct breaks identified in the response variable (e.g. here there are three breaks) resulting in the relative abundance described by each of the four terminal nodes. Thresholds for each driving variable are displayed (and are shown as dotted lines on the scatterplots), in addition to the average abundance of Amphipod and the number of cases (i.e. the number of samples that were classified in that terminal node) for each terminal node.

Water depth was the most influential variable on the bivalve *Arthritica helmsi* abundance (i.e. with an importance score of 100) (Figure 3). Regression tree analysis also identified that other variables including Total Kjeldahl Nitrogen (TKN) (importance = 71.63), total phosphorus (importance = 70.63) and water level (importance = 25.25) were important. Of these variables, only water depth and total phosphorus were represented in the tree (Figure 3). The key thresholds identified for water depth were 1.15 m and 1.13 m, with increased *A. helmsi* abundances likely with water depths between 1.13 and 1.15 m, suggesting that depths between these two thresholds may be optimal for the taxon, although the very small range (i.e. only 0.02 m) suggests that further investigation is warranted (Figure 3). The key threshold identified for total phosphorus was 0.14 mg L^{-1}, with higher average abundances of *A. helmsi* with lower levels of total phosphorus. Of the two variables, only water depth had a significant linear relationship with abundance of *A. helmsi* ($r^2 = 0.056$, $p = 0.030$; Figure 3).

The trajectory for *A. helmsi* abundance identified four outcomes. The majority of the cases ($n = 102$) were found with deeper water depths (i.e. > 1.15 m), where abundance, on average, was the lowest of the four outcomes identified at 308 individuals per m^2, and the variability between the cases was also the lowest (SD = 1039.13) (Figure 3). A total of 11 cases fell within the outcome associated with shallower water depths (< 1.15 m and < 1.13 m) and lower concentrations of total phosphorus (< 0.14 mg L^{-1}), with reasonably high average abundances of *A.helmsi* (4974 individuals per m^2), but also the highest variability between these cases (SD = 4719.64). Under shallow water depth (< 1.15 m) and high total phosphorus (> 0.14 mg L^{-1}) conditions *A. helmsi* were absent across the six cases within this outcome. The highest average abundance (11865 individuals per m^2) of *A. helmsi* was found under a combination of shallow initial water depth (< 1.15 m), lower levels of total phosphorus (< 0.14 mg L^{-1}) and deeper water depth (> 0.13 m), but the highest variability was also found under these conditions (SD = 1457.21).

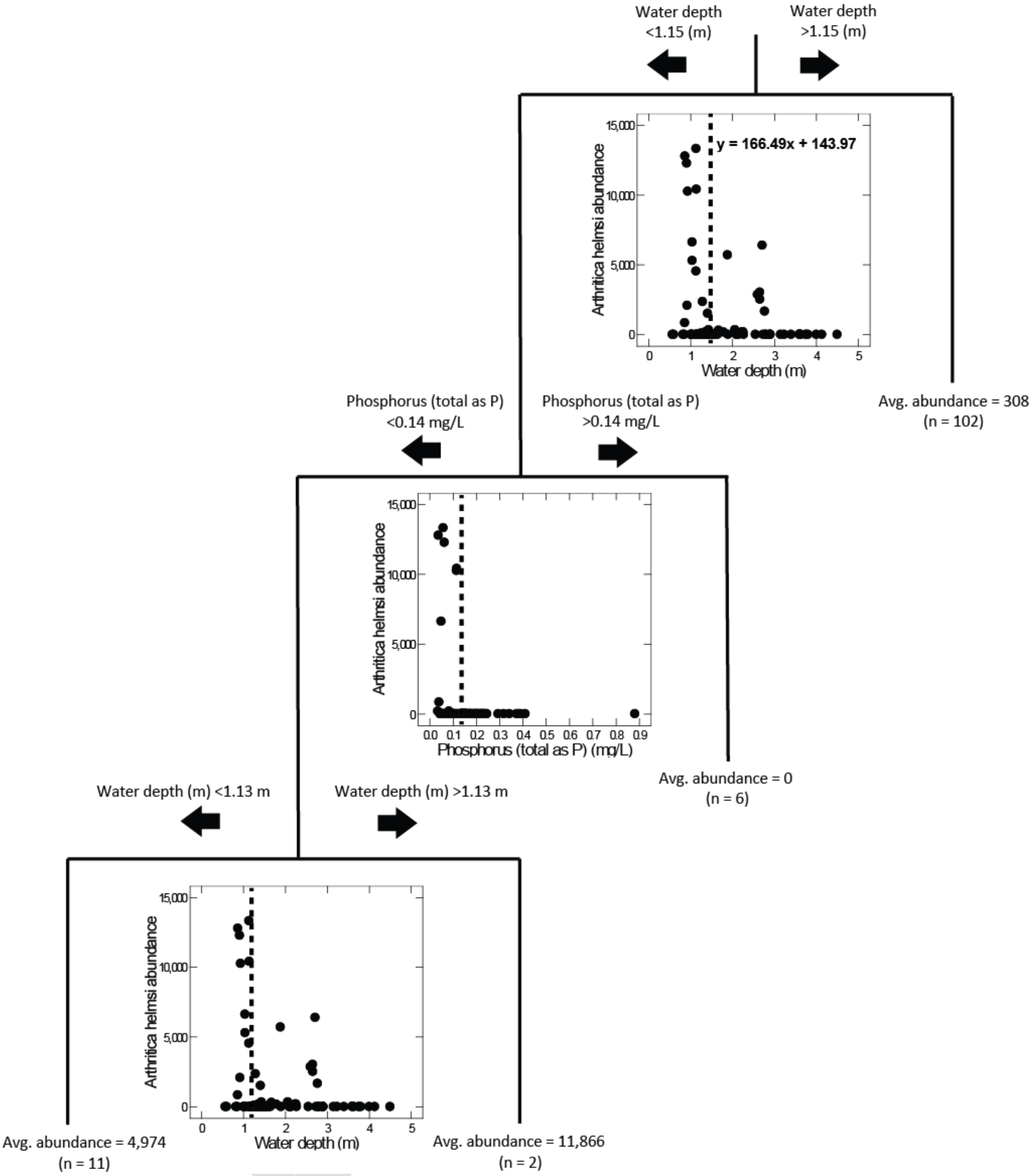

Figure 3: Regression tree output generated from *Arthritica helmsi* abundance data (response variable) and environmental variables (driving variables). See Figure 2 for further explanation of the conventions adopted here. The regression equation for the significant relationship between *A. helmsi* abundance and water depth is shown in the top right of the scatterplot.

The most influential variable on the polychaetes *Capitella* spp. abundance was water depth, with an importance score of 100 (Figure 4). Other variables that were also important from the regression tree analysis included TKN (importance = 94.8), total phosphorus (importance = 89.54), EC (importance = 72.82) and water level (importance = 57.98). Of these variables only water depth and total phosphorus are represented in the tree (Figure 4), with the others considered surrogate variables. The key threshold identified for water depth was 1.15 m, with on average, higher abundances of *Capitella* spp. found with water levels shallower than 1.15 m (Figure 4). The key threshold identified for total phosphorus was 0.20 mg L^{-1}, with average abundances of *Capitella* spp. also found with lower concentrations of total phosphorus (i.e. < 0.20 mg L^{-1}). Of the two key variables represented in the tree, linear regression analyses indicated that none of the relationships between the variables and *Capitella* spp. abundance were significant.

The trajectory for *Capitella* spp. abundances identified three outcomes, with the majority of cases found in conditions of greater water depth (> 1.15 m), with moderate average abundances at 1335 individuals per m^2 and variability between the cases (SD = 3128.05) (Figure 4). A total of 14 cases fell within the outcome associated with shallower water depth (i.e. < 1.15 m) and greater levels of total phosphorus (< 0.20mg L^{-1}). Under such conditions, the average abundance of *Capitella* spp. and the variability between the cases were the highest of all the outcomes (15515 individuals per m^2, SD = 12376.79). Finally, under conditions of shallow water depth (< 1.15 m) and greater levels of phosphorus (> 0.20 mg L^{-1}), *Capitella* spp. were absent in the four cases which fell within this outcome.

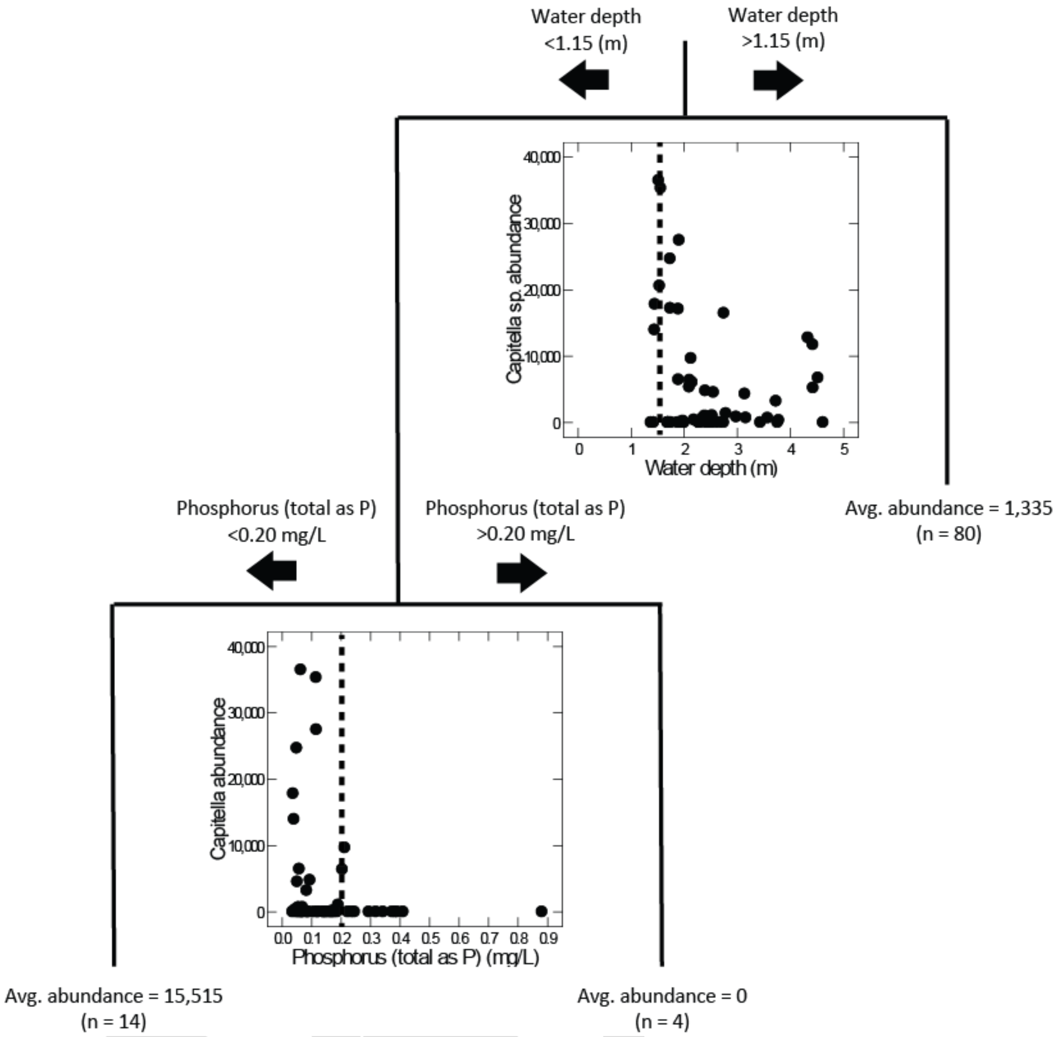

Figure 4: Regression tree output generated from *Capitella* spp. abundance data (response variable) and environmental variables (driving variables). See Figure 2 for further explanation.

TKN was the most influential variable on the midges Chironomidae abundance with an importance score of 100 (Figure 5). Other variables that were also considered important from the regression tree analysis, but of much lower importance, included total phosphorus (importance = 12.62), pH (importance = 9.25), water temperature (importance = 6.43) and turbidity (importance = 4.72). The two most important variables (i.e. TKN and total phosphorus) were represented in the tree, along with temperature. The key threshold identified for TKN was 2.31 mg L^{-1}, with a higher average abundance of Chironomidae found at greater concentrations of TKN (i.e. > 2.31 mg L^{-1}). The key thresholds identified for total phosphorus and temperature were 0.08 mg L^{-1} and 16.08 ^{o}C, respectively, with higher average abundances of Chironomidae found with lower levels of total phosphorus (i.e. < 0.08 mg L^{-1}) and temperatures (i.e. < 16.08 ^{o}C). Of the three key variables represented in the tree, linear regression analyses indicated that only TKN had a significant relationship with Chironomidae abundance ($r^2 = 0.190$, $p = 0.003$; Figure 5).

The regression tree analysis identified four outcomes for Chironomidae abundance (Figure 5). The majority of cases fell within the outcome associated with the combination of lower concentrations of TKN (i.e. <2.31 mg L^{-1}), higher levels of total phosphorus (>0.08 mg L^{-1}) and higher temperatures (> 16.08 ^{o}C), where the average abundance of Chironomidae was 249 individuals per m^2 and there was a moderate amount of variability between the cases (SD = 268.27). A total of eight cases fell within the outcome associated with lower concentrations of TKN (<2.31 mg L^{-1}) and lower levels of total phosphorus (< 0.08 mg L^{-1}). Under these conditions the average abundance of Chironomidae was 774.36 individuals per m^2 and the variability between the cases was moderate (SD = 843.59). Under higher concentrations of TKN (>2.31 mg L^{-1}), average abundance of Chironomidae was the highest of all the outcomes, at 2208 individuals per m^2, but the variability was also the greatest (SD = 1955.96). Two cases were associated with lower concentrations of TKN (<2.31 mg L^{-1}), higher levels of total phosphorus (>0.08 mg L^{-1}) and lower temperatures (<16.08 ^{o}C), where the average abundance of Chironomidae was reasonably high (944 individuals per m^2), and the variability between the cases was the lowest of all the outcomes identified (SD = 242.04).

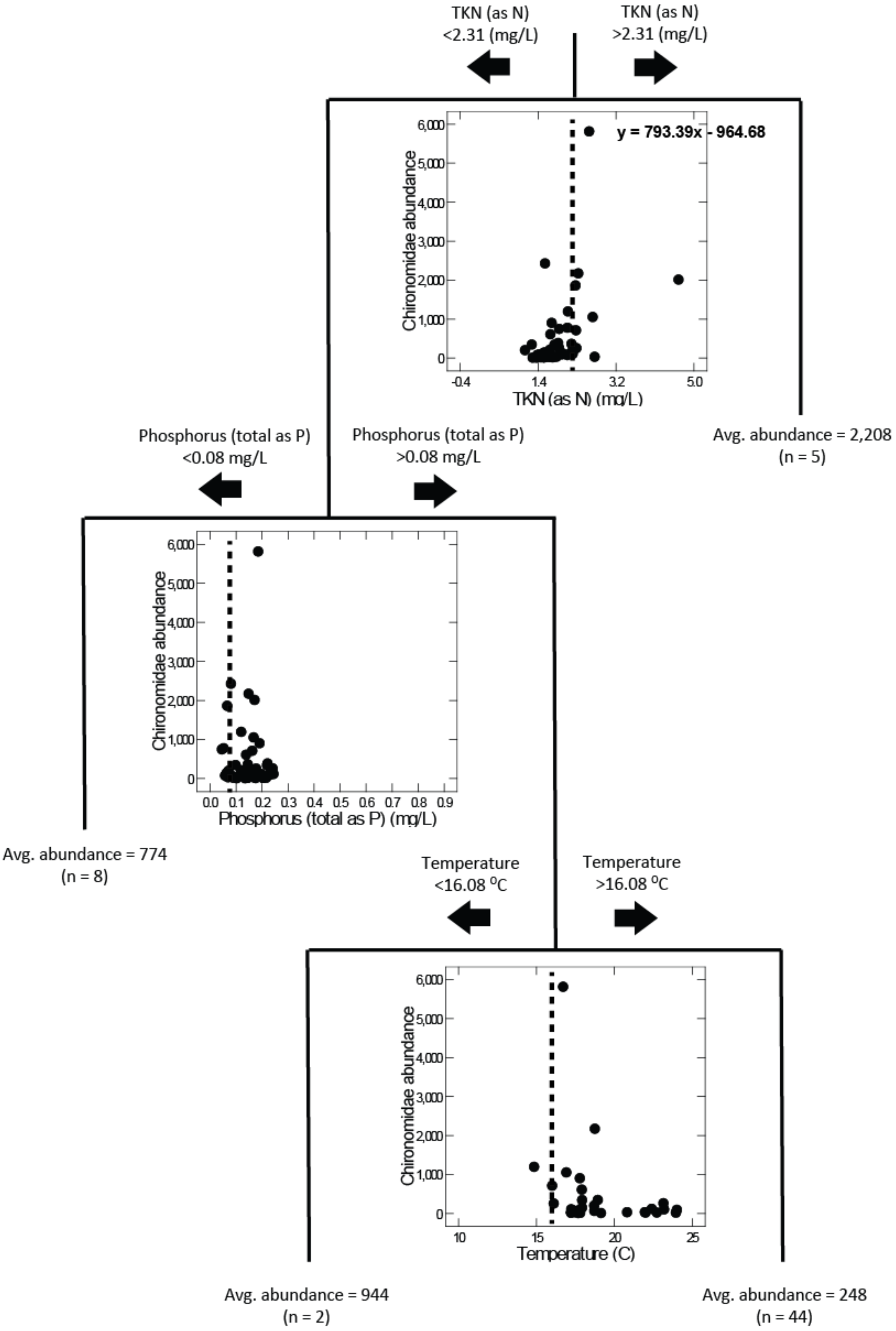

Figure 5: Regression tree output generated from Chironomidae abundance data (response variable) and environmental variables (driving variables). See Figure 2 for further explanation. The regression equation for the significant relationship between Chironomidae abundance and TKN is shown in the top right of the scatterplot.

Ammonia was the most influential variable on the springtail insects Collembola abundance, with an importance score of 100 (Figure 6). Other variables that were also considered important, but much less so, from the regression tree analysis included pH (importance = 6.12), TKN (importance= 0.10) and total nitrogen (importance = 0.04). The key threshold identified for ammonia was 0.05 mg L^{-1}, with higher average abundances of Collembola found with higher levels of ammonia (i.e. > 0.05 mg L^{-1}). The key threshold identified for pH was 8.10, with higher average abundances of Collembola found in waters with a pH of less than 8.10. Linear regression analyses indicated that of the two key variables, only ammonia had a significant relationship with Collembola abundance ($r^2 = 0.235$, $p = 0.026$; Figure 6).

The trajectory of Collembola abundance identified three outcomes, with the majority of cases ($n = 31$) found under lower levels of ammonia (i.e. <0.05 mg L^{-1}) and higher levels of pH (>8.1) (Figure 6). Under these conditions average abundance of Collembola was the lowest at 9 individuals per m^2 and moderate variability between the cases (SD = 24.98). A total of four cases fell within the outcome associated with lower levels of ammonia (<0.05 mg L^{-1}) and lower pH (<8.10), with a moderate (i.e. compared to the other outcomes) abundance of Collembola (24 individuals per m^2), and the highest variability (SD = 41.58). The least common outcome identified contained a single case, but had the highest abundance of Collembola and was associated with higher levels of ammonia (>0.05 mg L^{-1}).

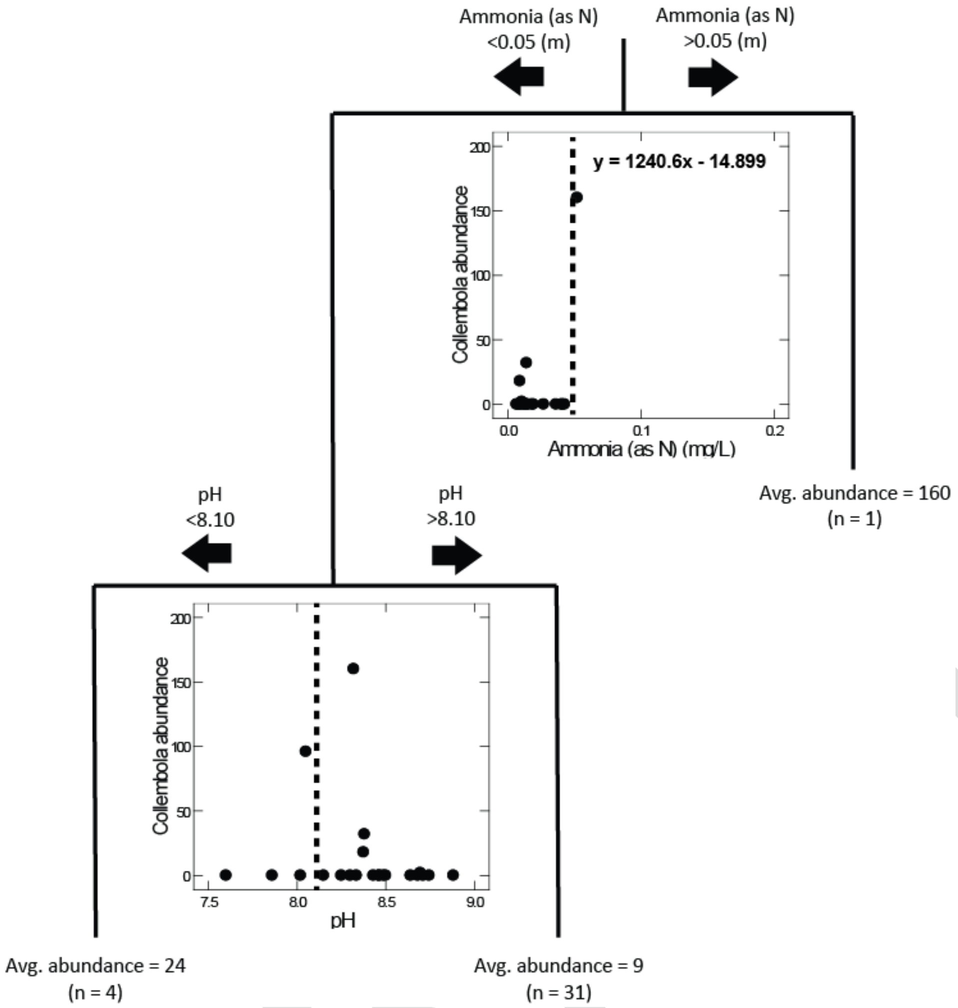

Figure 6: Regression tree output generated from Collembola abundance data (response variable) and environmental variables (driving variables). See Figure 2 for further explanation. The regression equation for the significant relationship between Collembola abundance and ammonia is shown in the top right of the scatterplot.

The most influential variable on the flies Ephydridae abundance was oxidised nitrogen (with an importance score of 100) (Figure 7). Ammonia was also important with an importance score of 73.11, but other variables including turbidity (importance = 1.04), total phosphorus (importance = 0.86), conductivity (importance = 0.56) and total nitrogen (importance = 0.07) had much lower scores of importance. Despite this, both turbidity and total nitrogen were represented in the tree, along with oxidised N, for Ephydridae abundance, with the other variables considered surrogates. The key threshold identified for oxidised nitrogen was 0.11 mg L^{-1}, where Ephydridae abundance, on average, was higher with increased levels of oxidised nitrogen (i.e. > 0.11 individuals per m^2) (Figure 7). The key thresholds identified for turbidity and total nitrogen were 6.91 NTU and 2.36 mg L^{-1}, respectively. On average, Ephydridae abundance was higher in less turbid (i.e. < 6.91 NTU) and less nitrogen-rich (< 2.36 mg L^{-1}) water. Linear regression analyses indicated that of the two key variables, only oxidised nitrogen had a significant relationship with Ephydridae abundance (r^2 = 0.138, p = 0.026; Figure 6).

The regression tree analysis identified four outcomes for Ephydridae abundance, with the majority of cases associated with the combination of lower concentrations of oxidised nitrogen (<0.11 mg L^{-1}), higher turbidity (>6.91 NTU) and lower concentrations of total nitrogen (<2.36 mg L^{-1}) (Figure 7). Under these conditions, the average abundance of Ephydridae was three indiviudals per m^2, with reasonably low variability between the cases (SD = 8.73). A total of six cases fell within the outcome associated with lower concentrations of oxidised nitrogen (<0.11 mg L^{-1}) and lower levels of turbidity (<6.91 NTU), with reasonably low average abundance of Ephydridae (7 individuals per m^2) and variability (SD = 8.78). Six cases also fell within the outcome associated with lower concentrations of oxidised nitrogen (<0.11 mg L^{-1}), higher levels of turbidity (>6.91 NTU) and higher concentrations of total nitrogen (>2.36 mg L^{-1}). Under these conditions, the average abundance of Ephydridae was two individuals per m^2 and the variability between the cases was the lowest (SD = 2.31). Finally, the lowest number of cases (n = 2) fell in the outcome associated with higher concentrations of oxidised nitrogen (>0.11 mg L^{-1}), where the highest average abundance of Ephydridae (127 individuals m^2) and highest variability between the cases (SD = 126.69) were found.

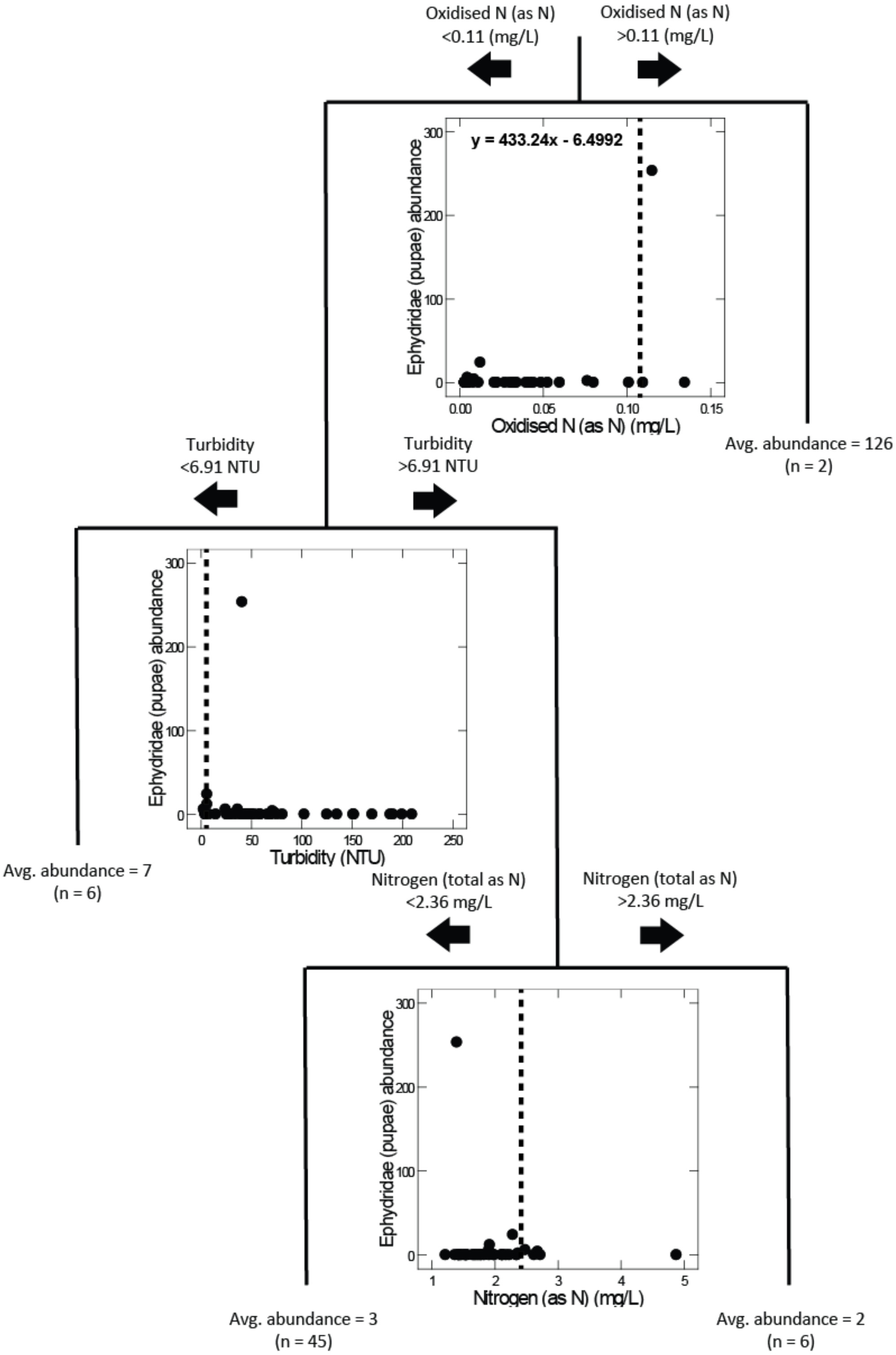

Figure 7: Regression tree output generated from Ephydridae abundance data (response variable) and environmental variables (driving variables). See Figure 2 for further explanation. The regression equation for the significant relationship between Ephydridae abundance and oxidised nitrogen is shown in the top right of the scatterplot.

TKN was the most influential variable on the abundance of the polychaete *Nephyts australiensis* with an importance score of 100 (Figure 8). Other variables that were also important from the regression tree analysis included EC (importance = 96.63), total nitrogen (importance = 41.04), turbidity (importance = 23.21), total phosphorus (importance = 2.50) and temperature (importance = 0.14). Despite the higher importance of variables like TKN and EC, only turbidity and pH were represented in the regression tree, with the other variables considered surrogates (Figure 8). The key thresholds identified for turbidity were 2.75 and 189.26 NTU, with higher *N. australiensis* abundances, on average, in less turbid waters (i.e. < 2.75 NTU and < 189.26 NTU). The key threshold identified for pH was 8.73, with average abundances of *N. australiensis* higher in more alkaline conditions (i.e. > 8.73). Of the two key variables represented in the tree, linear regression analyses indicated that neither of the relationships between the variables and *N. australiensis* abundance were significant.

The regression tree for *N. australiensis* abundance identified four outcomes (Figure 8). The majority of the cases (*n* = 108) fell within the outcome associated with the combination of higher initial levels of turbidity (>2.75 NTU), lower pH (<8.73) and lower levels of turbidity (189.26 NTU), where the average abundance of *N. australiensis* was the lowest (4 individuals per m^2) and the variability between the cases was also the lowest (SD = 16.34). A total of six cases fell within the outcome associated with lower levels of initial turbidity (<2.75 NTU), with reasonably high average abundance of *N. australiensis* (144 individuals per m^2) and variability (SD = 151.83). Under higher initial turbidity levels (>2.75 NTU) and higher pH (>8.73), the greatest average abundance of *N. australiensis* (151 individuals per m^2) and variability (SD = 260.72) were found. Finally, moderate average abundance (68 individuals m^2) and variability between the cases (SD = 62.24) were found for the three cases within the outcome associated with higher levels of initial turbidity (>2.75 NTU), lower ph (<8.73) and higher levels of turbidity (>189.26 NTU).

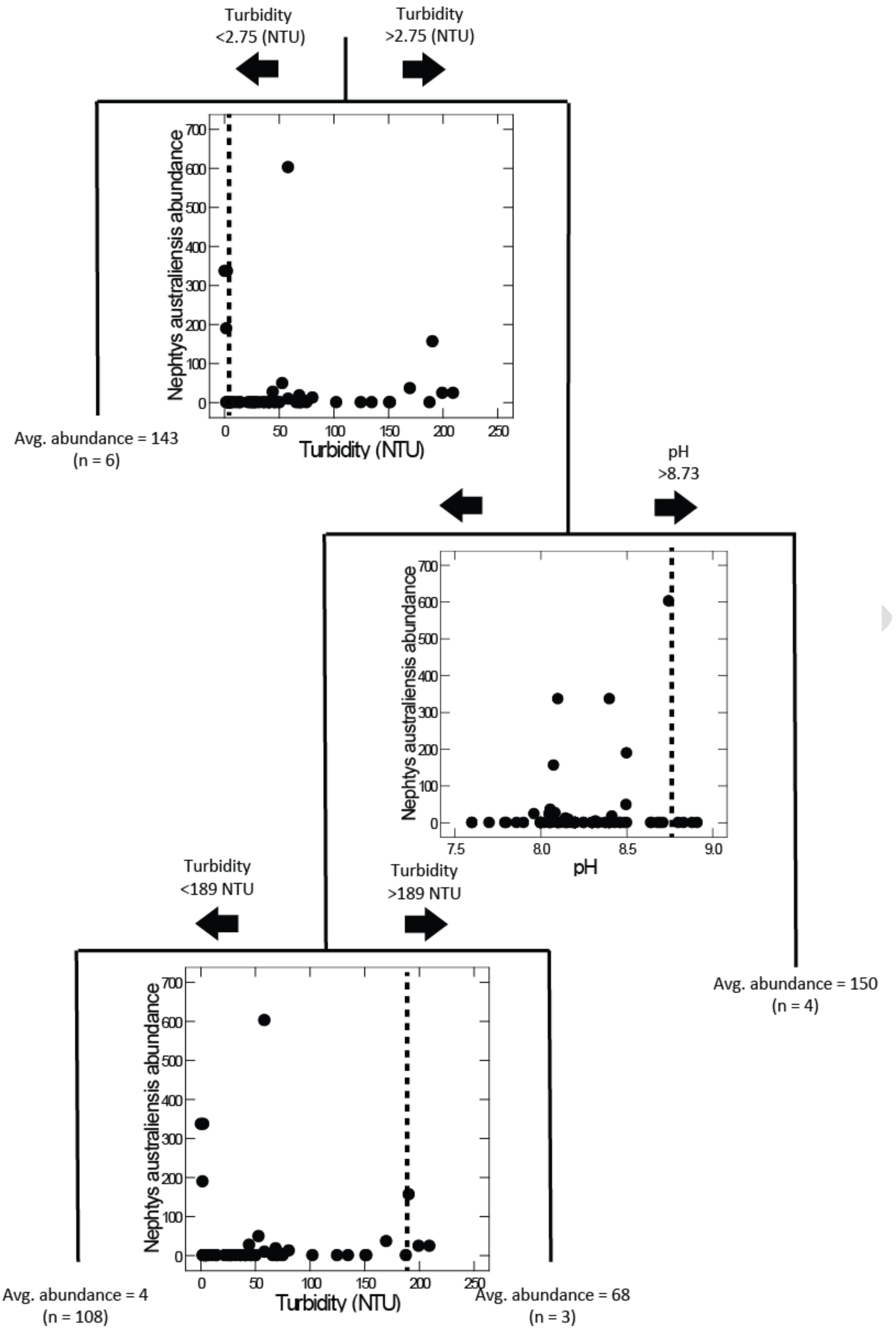

Figure 8: Regression tree output generated from *Nephtys australiensis* abundance data (response variable) and environmental variables (driving variables). See Figure 2 for further explanation.

The most influential variable on the polychaete *Simplisetia aequisetis* was TKN with an importance score of 100 (Figure 9). Other variables that were also important form the regression tree analysis, but were not represented in the regression tree, included total phosphorus (importance = 58.68), water temperature (importance = 22.65), water level (importance = 2.50), EC (importance = 0.51) and turbidity (importance = 0.02). The key threshold identified for TKN was 0.61 mg L^{-1}, and represented the only splitting variable (and threshold) within the regression tree for *S. aequisetis* abundance (Figure 9). The majority of the cases (*n* = 113) fell within the outcome associated with higher concentrations of TKN (>0.61 mg L^{-1}), where the average abundance of *S. aequisetis* was the lowest of the two outcomes identified (392 individuals per m^2) and the variability between the cases was also the lowest (SD = 1029.29) (Figure 9). The remaining eight cases fell within the outcome associated with lower concentrations of TKN (<0.61 mg L^{-1}), and had the highest average abundance of *S. aequisetis* (3277 individuals per m^2) and variability between the cases (SD = 2485.36). Linear regression analyses also indicated that there was a significant relationship between TKN and *S. aequesetis* abundance (r^2 = 0.065, *p* = 0.028).

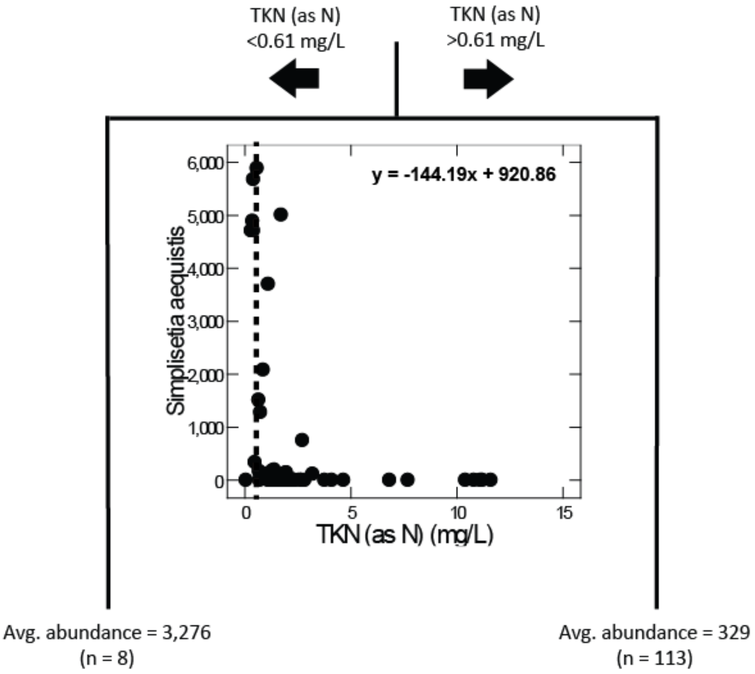

Figure 9: Regression tree output generated from *Simplisetia aequisetis* abundance data (response variable) and environmental variables (driving variables). See Figure 2 for further explanation. The regression equation for the significant relationship between *S. aequisetis* abundance and TKN is shown in the top right of the scatterplot.

3.3 Combining indicators to assess ecological condition in the CLLMM region

Table 9 outlines the species and assemblages selected for inclusion in the prototype spreadsheet model and the LACs for each that were defined by the project team, with the assistance of additional taxonomic experts (e.g. in birds, see Acknowledgments). These thresholds were based largely on salinity and water levels, as those are able to be simulated using existing hydrologic and hydrodynamic models across the site, and are often the variables for which thresholds are best understood based on previous literature. Selecting the LACs in this manner does not imply that the variables identified earlier in this report for macroinvertebrates are unimportant, but rather that further testing is needed to develop a better understanding of the relative importance of each variable. In addition, a much smaller number of taxa are considered here than were identified above. Again, this does not imply that the taxa omitted are of lower importance than those included here, but rather, the taxa selected here are simply a starting point used for the development of the prototype model.

In applying each of the LACs, some decisions were made (e.g. the use of surface or bottom salinity) and these are documented in Table 9. Some of these decisions may need revision with taxonomic experts, but were considered sufficient for the purposes of the prototype.

Table 9: List of indicator species used for the prototype spreadsheet model to combine multiple indicators. Limits of acceptable change were developed by experts and, where possible, informed by the analyses contained earlier in this report. Suitability criteria indicates how each LAC was incorporated into the model, including any limitations. Weightings are indicative of the relative importance of each taxon as an indicator in the Coorong example outlined in this report. They range between 0 for a taxon that should not be found in the Coorong to 1 for a taxon that represents an integral part of the ecological character of the Coorong.

Component/Process/Service (Weighting in Coorong)	Limit of Acceptable Change	Suitability criteria including notes
Birds		
Fairy tern (1)	Salinity 35-110 g L^{-1}	If salinity/EC from several depths was available, **surface** salinity was used Small-mouthed hardyhead presence was not included due to the lack of fish survey data available.
Black swan (0.8)	Water depth 0.2 - 1.3 m **AND** Salinity < 22 g L^{-1} **AND** Submerged vegetation is available	Water levels at site **AND** if salinity/EC from several depths was available (**surface** salinity was used) **AND** if site was suitable for *Ruppia megacarpa, Ruppia tuberosa, Lamprothamnium macropogon*, freshwater plant communities
	Reed cover < 30%	Was not able to be included due to a lack of vegetation cover data.
Fish		
Yarra pygmy perch (0.1)	Adequate coverage of submerged vegetation	If site was suitable for: *Ruppia megacarpa, Ruppia tuberosa, Lamprothamnium macropogon*, freshwater plant communities
Small-mouthed hardyhead (1)	Salinity 35 - 110 g L^{-1}	If salinity/EC from several depths was available, **surface** salinity was used due to potential oxygen requirement of this fish species. This did not take into account the possibility that fish could move within the water column, but oxygen is likely to be highest at the surface
Plants		
Freshwater submergent plant communities (0.1)	Water level > 0.2 m AHD in all areas other than Goolwa Channel **AND** salinity < 20,000 µS cm^{-1}	Water levels at site **AND bottom** salinity or from lowest available depths were used. Bottom salinity was used for vegetation due to their location in the water column.

Component/Process/Service (Weighting in Coorong)	**Limit of Acceptable Change**	**Suitability criteria including notes**
Phragmites australis (0.2), *Typha domingensis* (0.2), diverse reef beds *(0.2)*	Water level > 0 m AHD **AND** salinity < 22 g L^{-1}	Water levels at site **AND bottom** salinity or from lowest available depths were used
Muehlenbeckia florulenta (0.1)	Water level > 0.8 m AHD **AND** salinity < 4.4 g L^{-1}	Water levels at site **AND bottom** salinity or from lowest available depths were used
Melaleuca halmaturorum (0.5)	Water level > 0.2 m AHD downstream of barrages	Water level at site
Samphire and salt marsh communities (1)	Water level > 0.2 m AHD in the Coorong	Water level at site
Ruppia megacarpa (1)	Salinity < 46 g L^{-1}	**Bottom** salinity or from lowest available depths were used
Ruppia tuberosa (1)	Water level 0.3 > 0.9 m AHD **AND** salinity < 210 g L^{-1}	Water levels at site **AND bottom** salinity or from lowest available depths were used
Lamprothamnium macropogon (1)	Salinity < 230 g L^{-1}	**Bottom** salinity or from lowest available depths were used
Invertebrates:		
Amphipoda spp. (1) and *Nephtys australiensis* (1)	Salinity 10 - 60 g L^{-1}	**Bottom** salinity or from lowest available depths were used as these species are benthic
Arthritica helmsi (1) and *Capitella* spp. (1)	Salinity 10 - 55 g L^{-1}	**Bottom** salinity or from lowest available depths were used as these species are benthic
Chironomidae (1)	Salinity < 78 g L^{-1}	If salinity/EC from several depths was available, **surface** salinity was used as these species can be found on vegetation
Simplisetia aequisetis (1)	Salinity 10 - 35 g L^{-1}	**Bottom** salinity or from lowest available depths were used as these species are benthic

Each site was assessed for suitability for each species based on those rules for a period of 1995 to 2008 for the Coorong and 2010 to 2012 for Lakes Alexandrina and Albert. The relative proportion of sites within each management unit was then used to assess the likelihood that each site was in good, moderate or poor condition, based on the relationship shown in Figure 10. The proportion of suitable sites in the Coorong is presented in Appendix E as an example.

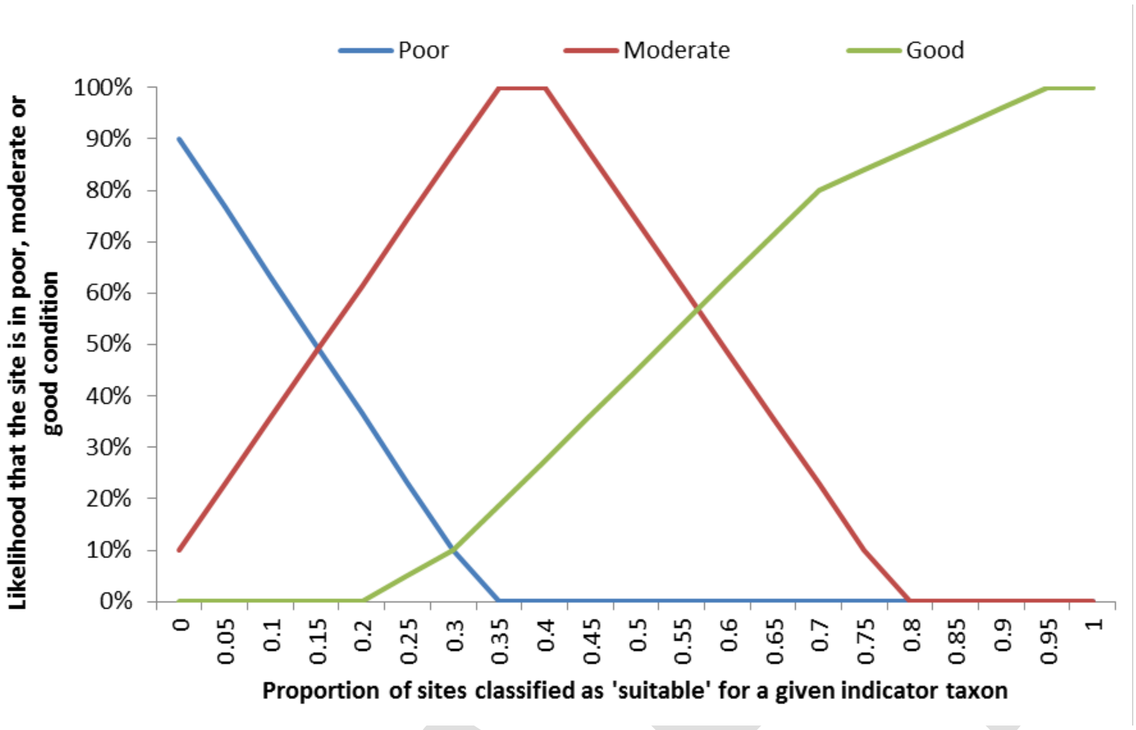

Figure 10: Relationship between the proportion of sites classified as suitable for a given indicator taxon, based on defined LACs, and the likelihood that that site is in poor, moderate or good condition. Note that the categories overlap, and it is possible for a site to have some likelihood that it is in poor condition as well as some likelihood it is in moderate condition, for example. The likelihoods do not add to 100%, to account for uncertainty in the LACs and monitoring data available.

The use of a fuzzy logic-based relationship to classify sites as being likely to be in good, moderate or poor condition means that the categories are not artificially sharp, and that some uncertainty is permitted in the classification. The relationships described here should be considered as a first iteration, and additional testing should be undertaken to ensure that the outcomes accord with expert opinion relating to overall site condition for past monitoring periods, before the tool is used on an ongoing basis for management.

Weightings were assigned to each indicator taxon to adjust the relative contribution of each to the overall assessment of ecological condition. This is because not all taxa are likely to be present in all locations and the absence of a freshwater specialist in the Coorong, for example, is consistent with the current ecological character, so should not result in a decrease in the likelihood that the Coorong is in good ecological condition. These weightings are listed in Table 9 above. The weightings were then used to multiply the likelihood score for each taxon, and these products were then averaged across all taxa for each year. This resulted in an average likelihood that the Coorong was in good, moderate or poor condition for each year between 1995 and 2008 (Figure 11). Likelihoods for each taxon in each year are presented in Appendix E. Because likelihoods are calculated separately for each category (e.g. poor, moderate), changes in the three categories are not necessarily proportional with changing environmental conditions. Based on the initial relationships and weightings used in the prototype, the Coorong was more likely to be in good ecological condition at the beginning of the period investigated than at the end. The likelihood that the region was in moderate ecological condition increased in 2003 and the likelihood that it was in poor condition increased in 2008. These changes are broadly consistent with the known decline in ecological condition in the region as a result of the Millenium Drought, which intensified during 2006-2008. The exact fit of this model with the ecological condition in the region has not been investigated, given that this is a prototype, rather than a validated model, so these results should be considered as indicative only.

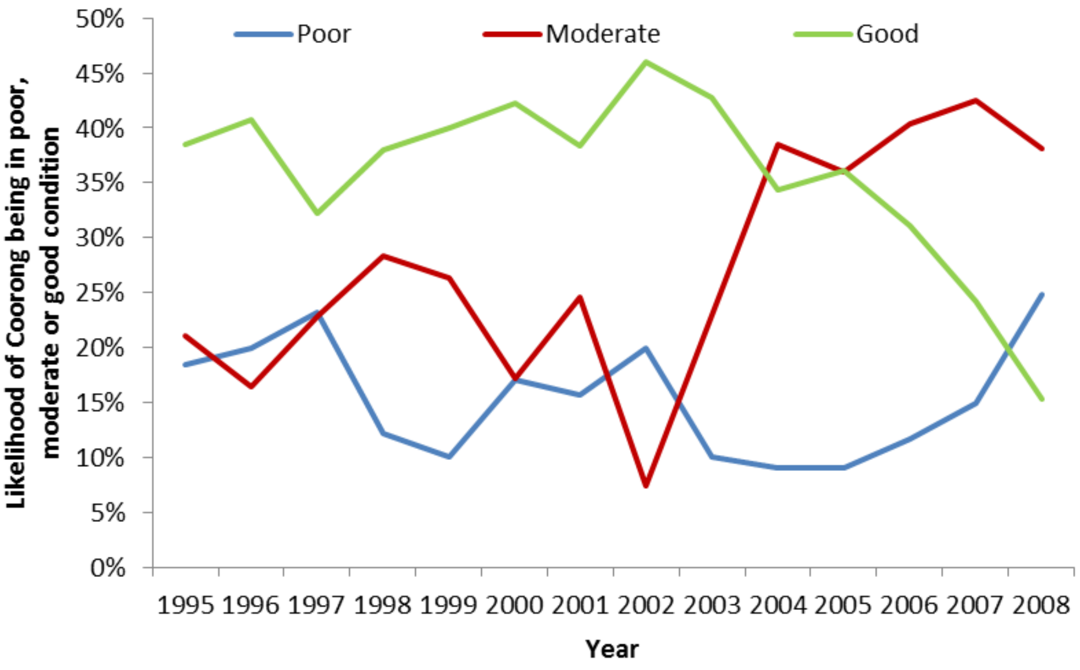

Figure 11: Example combination of scores across indicator taxa to provide an assessment of the likelihood that the Coorong is in poor, moderate or good ecological condition, based on LACs. Note that the categories overlap, and it is possible for a site to have some likelihood that it is in poor condition as well as some likelihood it is in moderate condition, for example. The likelihoods do not add to 100%, to account for uncertainty in the LACs and monitoring data available.

While the intention is that the tool be modified based on the available monitoring data for each indicator taxon, too few data were available at the time of development to adequately incorporate this feature. Where good monitoring data were available (e.g. birds), there were significant differences in the sites used for water quality and water level monitoring and bird surveys, so decisions will need to be made about where nearby sites are suitable to incorporate. To date, there were no inconsistencies between the presence of bird species foraging or resting in locations and the classified suitability of those sites for that particular bird species. This aspect will require further development and testing.

4 Discussion

The project aimed to suggest some pathways to develop data-informed LACs for each of the Ramsar-significant biota and processes identified for the region. Limits of acceptable change, or LACs, for Ramsar-listed wetlands are often compiled using the existing literature around species tolerances (often from different locations), but often enhanced by expert opinion. Such a set of LACs was developed for the CLLMM region by Phillips and Muller (2006) when the ecological character was described. However, many of those tolerances were breached during the Millennium Drought, with varying impacts on ecological character, so DEWNR considered that a review was needed. In order to assist DEWNR with that process, we attempted to develop new approaches to deriving LACs quantitatively from the available monitoring data, including data that had been collected during recent dry periods. The rationale was to provide a robust, scientific basis beyond that afforded by expert opinion to the final LACs.

A statistical method, known as BVSTEP or a 'peels' analysis (Clarke & Warwick 1998), identifying structural redundancy in a data set was used to provide an initial list of indicator taxa from all taxa identified in the available data sets. Multiple analyses were required as not all data sets covered the same locations across the same years. However, it was possible to compile a subset list of taxa that could be demonstrated to be representative of the patterns occurring in the ecosystem at that time. In many instances, the taxa selected were closely aligned with those that were considered to be key to the CLLMM ecological character (e.g. congolli and mulloway as fish indicators). In other instances, taxa that had not previously been considered as indicators were selected (e.g. several species of goby, and the introduced European carp). It is possible that these taxa have important ecological function in the ecosystem, or may represent undesirable conditions, and so should be considered as indicators in the future. Some taxa were selected for which we have very little life-history information or understanding of their distribution within the site (e.g. the macroinvertebrate Collembola). Finally, there were some iconic taxa that were not selected by the analysis as indicator taxa (e.g. Murray cod). This may be due to the sparse number of records for those taxa in the recent datasets used.

As a result, the list of taxa identified by the peels analysis as being representative of the patterns in the ecosystem was then modified by expert opinion, with some additional taxa added (e.g. due to their significance as a threatened species) or omitted (e.g. due to a lack of knowledge that would prevent LACs being set). Despite some taxa being omitted due to a lack of life-history and tolerance information, those taxa may be excellent candidates for further research and monitoring as future potential indicators of value. When used and vetted in this manner, the peels analysis approach appears to be a sound and useful method for the preliminary selection of a priority subset of indicator taxa in a Ramsar site. The method should be further developed and refined through time, but holds promise as a repeatable, objective manner by which to select indicator sets.

Another analytical approach was also used to set LACs for the macroinvertebrate taxa. This approach involved the use of regression trees (De'Ath & Fabricius 2000; Lester et al. 2011a). This technique identified thresholds in the available physicochemical data that corresponded with differences in measured abundances of the indicator taxa selected. Again, this technique relied on the collection and availability of environmental monitoring data that were matched to the biological data collected (in this case for macroinvertebrates). In developing these trees, we used linear regression to identify correlations among independent variables. There is an alternative theoretical viewpoint that logistic (or probit) regression may be a better choice, but given the continuous nature of both variables, we opted for the logistic regression option. Any differences due to this choice could be further investigated.

Once again, we had mixed success in applying this technique. Water quality variables, particularly relating to chemical concentrations, were commonly identified as variables correlated with breaks in the abundance of the macroinvertebrate taxa investigated. This indicates that pH and nutrients may be of critical importance to macroinvertebrate assemblages, particularly in the Lakes. This requires additional investigation to verify. It was unusual that salinity (or electrical conductivity) was not found to be a significant predictor for any taxon. This may be because measured (rather than modeled) salinity was included, and there were many instances in the data for which no measurement was taken (or was able to be aliased), rather than because salinity was unimportant. Water level was also frequently a variable of importance. In some instances, however, the optimal range for a particular group was very small (e.g. across only a few centimetres of water depth). Additional work is required to determine whether the bivalve in question for that example (*Arthritica helmsii*) is particularly sensitive to water depth, or whether the narrow range is an artefact of the data sampling or of the analysis technique.

One important point to note relating to this type of an analysis is that higher abundances of a taxon are not necessarily always a positive outcome for an ecosystem. For example, higher carp abundances would be considered to be detrimental to ecological character. Also some macroinvertebrates are able to withstand high levels of nutrient enrichment or low DO availability (e.g. some oligochaete worms) and so can be found in extremely high abundances, with very few other taxa present. This means that, depending upon the taxon, very high abundances, as well as very low abundances or the absence of a taxon, can signal a degraded ecosystem, or at least one that may require management intervention. Thus, a desirable range in abundance may need to be considered when LACs are set.

Process indicators were originally intended to be analysed much as we were able to do for the abundances of various taxonomic groups. We have previously advocated developing indicators based on ecological processes for various aquatic environments (Fairweather 1999a,b) or for this Ramsar site (Lester et al. 2009a,b, 2011a), as being closer to the essence of ecological health and as possible early warning systems. Thus we dutifully examined the availability and character of data sets that could be useful in this regard. Some were deemed to be quite important (e.g. rates of decomposition or recruitment) or had been measured somewhere within the CLLMM region (e.g. young-of-year fishes, aquatic plant germination) but it quickly became apparent that the availability of such data is very limited. We had to conclude that it is not yet possible to develop explicit LACs for any ecological processes until datasets on some ecological process measures are being routinely collected (see Lester et al. 2012).

Given the untested nature of the thresholds identified here for macroinvertebrates, the fact that similar analyses were not undertaken for fish, vegetation or birds, and the fact that many of the parameters identified (e.g. turbidity) are not able to be simulated using the present hydrological models for the region, we opted for a more traditional set of LACs to include in our prototype model to combine LACs across taxonomic groups, and based them on salinities. The rationale for using salinity was that tolerance thresholds were best understood for that variable across a range of taxa, while very little other information exists about the types of variables that were identified by the regression tree analyses, making them difficult to apply (Lester et al. 2011a).

The prototype tool we developed relies on several key principles. This includes the basic assumption that underpins the setting of LACs – that meeting basic habitat requirements (e.g. water quality, in the form of salinity, in this case study) will provide a suitable habitat for an indicator taxon of interest. In addition, however, we have also used the principle that taxa are often able to move within a site (e.g. directly via locomotion such as swimming, or indirectly, such as progressive colonisation of favourable habitats via seed), so it is not necessary to have the same location providing suitable habitat at all times, provided some habitat is available. Finally, we also rely on the principle that different taxonomic levels are linked. For example, small-bodied fish often require submerged vegetation as a habitat and refuge, while birds such as fairy terns require those same small-bodied fish as a food source. Thus, even if a habitat is directly suitable for fairy terns, if it is unsuitable for small-bodied fish (e.g. due to an absence of vegetation), then it is unlikely to be able to sustain fairy tern populations for any length of time, and may represent a population in decline or at risk.

Using those principles, we developed a tool whereby the habitat suitability was assessed for each of the identified taxa for the prototype, including assessing some links between taxa. This occurred for each site available within the dataset. Where possible, we also directly assessed monitoring data for the taxa of interest, to ensure that there were no inconsistencies between the habitat suitability assessment and the use of the site by the taxon. We had very few locations for where such a comparison was possible (all were for bird indicator taxa) but no such anomalies were identified. Additional work needs to be done to incorporate more monitoring data, particularly for vegetation and fish, to identify these anomalies. Such anomalies are important to note because they may represent gaps in our understanding, and could lead to the setting of more appropriate LACs, or they may indicate populations at risk and so act as management triggers. The latter may occur, for example, when conditions are marginal, and a taxon may be suffering sub-lethal impacts (e.g. failure to reproduce), which can impact the ecological character of the region in the medium to long term.

Once the suitability of each location was assessed for each taxon, we used the proportion of suitable sites (out of those included in the analysis) as the basis for combining the assessment across locations. As a starting point, we developed a relationship between the proportion of suitable sites and the likelihood that the region was in each of poor, moderate or good condition. Because of uncertainties in the monitoring data, the LACs and the method, we chose to use a fuzzy logic approach, whereby we simultaneously assess the likelihood that a site is in, say, good AND poor condition. High likelihood that a site is in good condition is likely to occur when there is low likelihood that a site is in poor condition, but this may not always change proportionally. This enables much more flexibility in the approach, akin to linguistic differences described with the words ‘very sure’ and ‘possible’. That is, if there is a high likelihood that the site is in good condition, we may be ‘quite sure’ that is the case, but there may still be ‘some possibility’ that it is in poor condition (Negnevitsky 2005). These types of ‘fuzzy’ categories can be more intuitive and more representative of a highly-variable system for which we have imperfect ecological knowledge, and so should be of use in the CLLMM Ramsar site.

These fuzzy categories were then combined across sites within each management unit by weighting the relative importance of each taxon to the ecological character of that region. Again, the actual values used here were a starting point, and should be further refined with experts on each taxonomic group and the site overall. These were then averaged across the various taxa to provide a single estimate for the likelihood that the region was in good, moderate or poor condition. Thus, the traditional problem, that different taxa are likely to give a different indication of the overall condition of the region, was overcome. By assuming that conditions will be suitable for most taxa at some point across the region, we get a more accurate assessment of overall ecosystem health than one based on a single taxon, and the weightings enable different taxa to have different relative impacts on that overall assessment. Additional constraints could also be added to ensure that all taxa are represented at least once across the site as a whole.

It is likely that further refinement of the relationships included in the model and the weightings is warranted. Additional testing should occur to ensure that the resultant likelihoods for existing data match the known ecological condition in the region at the time before any ongoing assessment is based on the tool. It may also be more appropriate to set these relationships separately for different taxa, or at least for smaller management units in the site (e.g. North Lagoon versus South Lagoon) to better capture the natural variability of the region. The tool is also likely to need additional refinement regarding the number and nature of the links that we have included among taxa. Some known relationships have not yet been able to be incorporated (e.g. the link between fairy terns relying on small-mouthed hardyhead as a food source) and the nature of those relationships may also need to be altered (e.g. there may be alternative food sources, so the absence of one fish at some time may not render the habitat completely unsuitable for fairy terns). Additional taxa also need to be added to better represent the ecological character of the region as a whole.

Despite this, and the usual limitations associated with inconsistencies in the monitoring data collected historically, the prototype appears to work well to give an overall assessment of ecological condition in a manner that, with some additional refinement and testing, will be of significant value to managers in the region.

5 Acknowledgements

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Appendix A – Summary of Structural Redundancy Analyses

Tables A1-A9 shows all of the species grouped by their functional feeding classifications for each of the peel analyses across each of the data sets.

Table A1: Taxonomic composition of species subsets from the peeling procedure on the Goolwa Barrage Water Release (Synthesis 1 – Macroinvertebrates, Zooplankton, Phytoplankton and Fish). The total number of species included within this analysis was 226, and those which did not get chosen in any of the five peels not included below. The total number of species which were included in each peel is shown below the taxa list for that peel. Peels that reached Rho > 0.95 have their Rho values given in bold.

Subset 1 **Rho = 0.951** *n* = 20	**Subset 2** Rho = 0.889 *n* = 12	**Subset 3** Rho = 0.774 *n* = 11	**Subset 4** Rho = 0.653 *n* = 10	**Subset 5** Rho = 0.605 *n* = 7
Autotrophic *Aphanizomeno* (Cyanobacteria) *Chaetoceros* (Diatom) *Closterium* (Algae) *Cyclotella* (Small) (Diatom) *Cyphoderia ampulla* (Protist) *Pediastrum* (Cladoceran) *Pseudanabaena* (Cyanobacteria) **Heterotroph** *Arcella hemisphaerica* (Amoebozoa) *Difflugia* sp. C (Amoebozoa) **Omnivore** Bridled Goby (*Arenigobius bifrenatus*) European Carp (*Cyprinus carpio)* River Garfish (*Hyporhamphus regularis*) **Planktivore/Herbivore/Detritivore** *Keratella tropica* (Rotifer) *Filinia pejleri* (Rotifer) *Filinia australiensis* (Rotifer) *Boeckella triarticulata* (Copepod) *Ephydridae* (Pupae) (Diptera) *Moina micrura* (Cladoceran) **Macrobenthivore** Lagoon Goby (*Tasmanogobius lasti*) *Nephtys australiensis* (Polychaete)	**Autotrophic** *Cryptomonas* (Algae) *Geitlerinema* (Cyanobacteria) *Cosmarium* (Algae) *Microcystis aeruginosa* (Cyanobacteria) **Planktivore/Herbivore/Detritivore** Chironomidae (Larvae & Pupae) Centropagidae (copepodites) (Copepoda) Mysidacea (indet.) (Crustacea) *Hexarthra intermedia* (Rotifer) *Polyarthra dolichoptera* (Rotifer) *Stentor sp.* (Ciliate) **Macrobenthivore** Congolli *(Pseudaphritis urvillii)* **Unallocated** *Protoperidinium* (Dinoflagellate)	**Autotrophic** *Schroedaria* (Algae) *Anabaena* (Straight) (Cyanobacteria) *Aulacoseira* (Diatom) *Romeria* (Cyanobacteria) *Sphaerocystis* (Algae) **Omnivore/Opportunist** Amphipoda (Crustacea) *Simplisetia aequisetis* (Polychaete) Yellow-eye Mullet (*Aldrichetta forsteri)* **Planktivore/Herbivore/Detritivore** *Bosmina meridionalis* (Cladoceran) *Proalides tentaculatus* (Rotifer) **Macrobenthivores** Flathead Gudgeon *(Philypnodon grandiceps)*	**Autotrophic** *Dictyosphaerium* (Algae) *Elakatothrix* (Algae) *Oocystis* (Large) (Algae) *Coscinodiscus* (Diatom) **Planktivore/Herbivore/ Detritivore** *Brachionus calyciflorus amphiceros* (Rotifer) *Ceriodaphnia cornuta* (Cladoceran) *Conochilus* (Colonial Rotifer) *Daphnia lumholtzi* (Cladoceran) *Filina opoliensis* (Rotifer)	**Autotrophic** *Cyclotella* (Large) (Diatom) *Tetraspora* (Algae) *Oedogonium* (Algae) **Omnivore** Goldfish (*Carassius auratus)* **Planktivore/Herbivore/ Detritivore** Harpacticoida copepodites (Copepoda) *Stenosemella lacustris* (Ciliate) *Cypretta* (Ostracoda)

Table A2: Taxonomic composition of species subsets from the peeling procedure on the Goolwa Barrage Water Release (Synthesis 2 – Macroinvertebrates, Zooplankton and Phytoplankton). The total number of species included within this analysis was 197, and those which did not get chosen in any of the five peels not included below. The total number of species which were included in each peel is shown below the taxa list for that peel. Peels that reached Rho > 0.95 have their Rho values given in bold.

Subset 1 **Rho = 0.951** *n* = 7	**Subset 2** Rho = 0.814 *n* = 18	**Subset 3** Rho = 0.728 *n* = 9	**Subset 4** Rho = 0.634 *n* = 4	**Subset 5** Rho = 0.610 *n* = 5
Autotrophic *Oocycstis* (Algae) *Planctonema* (Algae) *Tetrastrum* (Algae) *Ankistrodesmus* sp. 2 (Algae) *Aphanocapsa* (Cyanobacteria) *Planktolyngbya* (Cyanobacteria) *Staurosira* (Diatom)	**Autotrophic** *Ankistrodesmus* (Algae) *Closterium* (Algae) *Dictyosphaerium* (Algae) *Elakatothrix* (Algae) *Actinastrum* (Algae) Chlorophyceae (Algae) *Oocystis* (Small) (Algae) *Oocystis* (Large) (Algae) *Scenedesmus* (Algae) *Cyclotella* (Diatom) *Aulacoseira* (Diatom) *Coscinodiscus* (Diatom) *Planktothrix* (Cyanobacteria) *Geitlerinema* (Cyanobacteria) *Pseudanabaena* (Cyanobacteria) **Heterotroph** *Difflugia* sp. C (Amoebozoa) **Planktivore/Herbivore/Detritivore** Centropagidae nauplii (Copepoda) *Stenosemella lacustris* (Ciliate)	**Autotrophic** *Sphaerocystis* (Algae) *Tetraspora* (Algae) *Crucigenia* (Algae) *Coelosphaerium* (Cyanobacteria) *Cyanogranis* (Cyanobacteria) *Merismopedia* (Cyanobacteria) *Chaetoceros* (Diatom) **Heterotroph** *Arcella hemisphaerica* (Amoebozoa) **Planktivore/Herbivore/Detritivore** *Brachinonus calyciflorus amphiceros* (Rotifer)	**Autotrophic** *Chlamydomonas* (Algae) *Microcystis aeruginosa* (Cyanobacteria) **Planktivore/Herbivores/Detritivores** *Brachionus sp.* (Rotifer) *Keratella australis* (Rotifer)	**Autotrophic** *Chodatella* (Algae) **Planktivore/Herbivores/Detritivores** *Arthritica helmsi* (Bivalve) *Brachionus rubens* (Rotifer) Harpacticoida (Adult) (Copepod) *Proales daphnicola* (Rotifer)

Table A3: Taxonomic composition of species subsets from the peeling procedure on the Goolwa Barrage Water Release (Synthesis 3 – Zooplankton and Phytoplankton). The total number of species included within this analysis was 185, and those which did not get chosen in any of the five peels not included below. The total number of species which were included in each peel is shown below the taxa list for that peel. Peels that reached Rho > 0.95 have their Rho values given in bold.

Subset 1	**Subset 2**	**Subset 3**	**Subset 4**	**Subset 5**
Rho = 0.950	Rho = 0.841	Rho = 0.609	Rho = 0.575	Rho = 0.480
n = 8	*n* = 18	*n* = 5	*n* = 8	*n* = 8
Autotrophic *Ankistrodesmus* sp. 2 (Algae) *Aphanocapsa* (Cyanobacteria) *Coelosphaerium* (Cyanobacteria) *Oocycstis* (Algae) *Planctonema* (Algae) *Planktolyngbya* (Cyanobacteria) *Staurosira* (Diatom) *Tetrastrum* (Algae)	**Autotrophic** *Actinastrum* (Algae) *Ankistrodesmus* (Algae) *Aulacoseira* (Diatom) *Elakatothrix* (Algae) *Geitlerinema* (Cyanobacteria) *Oocycstis* (Large) (Algae) *Closterium* (Algae) *Coscinodiscus* (Diatom) *Cryptomonas* (Algae) *Planktothrix* (Cyanobacteria) *Pseudanabaena* (Cyanobacteria) *Scenedesmus* (Algae) *Tetraspora* (Algae) *Pseudo-nitzschia* (Diatom) *Skeletonema* (Diatom) **Heterotroph** *Difflugia* sp. C (Amoebozoa) **Planktivore/Herbivore/Detritivore** *Stenosemella lacustris* (Ciliate) *Moina micrura* (Cladoceran)	**Autotrophic** *Schroedaria* (Algae) *Sphaerocystis* (Algae) **Planktivore/Herbivore/Detritivore** *Harpacticoida* (Adult) (Copepod) *Keratella australis* (Rotifer) **Unallocated** *Prorocentrum* (Dinoflagellate)	**Autotrophic** *Chaetoceros* (Diatom) *Chlamydomonas* (Algae) Chlorophyceae (Algae) *Crucigenia* (Algae) *Cyclotella* (Diatom) *Merismopedia* (Cyanobacteria) **Planktivore/Herbivores/Detritivores** *Daphnia carinata* (Cladoceran) *Keratella tropica* (Rotifer)	**Autotrophic** *Chodatella* (Lagerheimia) (Algae) *Synedra* (Diatom) **Planktivore/Herbivores/ Detritivores** *Brachionus calyciflorus* s.l. (Rotifer) *Brachionus rubens* (Rotifer) *Cypretta* (Ostracoda) *Alona* (Cladoceran) *Anthalona* sp. (Cladoceran) *Calamoecia ampulla* (Copepoda)

Table A4: Taxonomic composition of species subsets from the peeling procedure on the Goolwa Channel Water Level Management Project (GCWLMP) (Synthesis 1 – Macroinvertebrates, Fish and Vegetation). The total number of species included within this analysis was 142, and those which did not get chosen in any of the five peels not included below. The total number of species which were included in each peel is shown below the taxa list for that peel. Peels that reached Rho > 0.95 have their Rho values given in bold.

Subset 1 **Rho = 0.956** *n* = 9	**Subset 2** Rho = 0.943 *n* = 10	**Subset 3** Rho = 0.935 *n* = 15	**Subset 4** Rho = 0.848 *n* = 3	**Subset 5** Rho = 0.815 *n* = 11
Autotrophic *Paspalum distichum* (Water Couch) *Potamogeton pectinatus* (Pondweed) **Herbivore/Detritivore** Collembola (Springtails) **Omnivore** Amphipoda spp. (Crustacea) Blue-spot Goby (*Pseudogobius olorum*) **Macrobenthivores** Small-mouthed Hardyhead *(Atherinosoma microstoma*) Carp Gudgeon complex (*Hypseleotris spp.*) Common Galaxias (*Galaxias maculatus*) **Predatory** Mysidacea (Larvae)	**Autotrophic** *Lemna* sp. (Duckweed) *Chenopodium glaucum* (Saltbush) *Lycopus australis* (Australian Gypsywort) **Herbivore/Detritivore** Chironomidae (Larvae & Pupae) Dolichopodidae (March flies) **Macrobenthivores** Australian Smelt (*Retropinna semoni*) Congolli *(Pseudaphritis urvillii)* Callop (*Macquaria ambigua*) *Nephtys australiensis* (Polychaete) **Parasite** Ceratopogonidae (Biting Midge)	**Autotrophic** *Phragmites australis* (Common reed) *Calystegia sepium* (Great Bindweed) *Mentha* spp. (Mint/Peppermint) *Muehlenbeckia florulenta* (Lignum) *Persicaria lapathifolia* (Pale Knotweed) **Herbivore/Detritivore** *Capitella* spp. (Polychaete) *Ephydridae* (Pupae) (Diptera) Spionidae (Polychaete) Bony Bream (*Nematalosa erebi*) **Omnivore** Bridled Goby (*Arenigobius bifrenatus*) Murray hardyhead (*Craterocephalus fluviatilis*) **Planktivore** Anostraca (Brine shrimp) Sandy sprat (*Hyperlophus vittatus*) **Macrobenthivores** Lagoon Goby (*Tasmanogobius lasti*) Eastern Gambusia (*Gambusia holbrooki*)	**Herbivore/Detritivore** Ostracoda spp. (Seed Shrimp) **Omnivore/Opportunist** *Simplisetia aequisetis* (Polychaete) **Macrobenthivores** Tamar River Goby (*Afurcagobius tamarensis*)	**Autotrophic** *Cyperus gymnocaulos* (Spiny flat-hedge) *Pennisetum clandestinum* (Kikuyu grass) *Senecio pterophorus* (African daisy) *Triglochin procerum* (Ribbon weed) **Detritivore** *Boccardiella novaehollandiae* (Spionidae) **Herbivore/Detritivore** Chrysomelidae sp. 2 (Leaf beetle) **Omnivore** Goldfish (*Carassius auratus*) **Macrobenthivores** Flathead Gudgeon (*Philypnodon grandiceps*) **Predator** Pisauridae (Fishing spider) Staphylinidae (Beetle) **Unallocated** Coleoptera spp. (Beetle)

Table A5: Taxonomic composition of species subset from the peeling procedure of the Coorong (Subset 1: Birds, Commercial Fish and Ruppia – long term data set). The total number of species included within this analysis was 51, and those which did not get chosen in any of the five peels not included below. The total number of species which were included in each peel is shown below the taxa list for that peel. Peels that reached Rho > 0.95 have their Rho values given in bold.

Subset 1 Rho = 0.950 *n* = 13	**Subset 2** Rho = 0.732 *n* = 13	**Subset 3** Rho = 0.565 *n* = 11	**Subset 4** Rho = 0.479 *n* = 4	**Subset 5** Rho = 0.272 *n* = 3
Herbivore Black swan (*Cygnus atratus*) Chestnut teal (*Anas castanea*) **Omnivore/Opportunist** Australian Shelduck (*Tadorna tadornoides*) Banded stilt (*Cladorhynchus leucocephalus*) Curlew sandpiper (*Calidris ferruginea*) Grey teal (*Anas gracilis*) Red-necked stint (*Calidris ruficollis*) Sharp-tailed sandpiper (*Calidris acuminata)* Silver gull (*Larus novaehollandiae*) **Piscivore** Australian pelican (*Pelecanus conspicillatus*) Crested tern (*Sterna bergii*) Little pied cormorant (*Phalacrocorax melanoleucos*) Whiskered tern (*Chlidonias hybridus*)	**Autotrophic** Number of *Ruppia tuberosa* shoots **Detritivore** Bony bream (*Nematalosa erebi*) **Herbivore** Pacific black duck (*Anas superciliosa*) **Omnivore/Opportunist** White-faced heron (*Ardea novaehollandiae)* Yellow-eye mullet (*Aldrichetta forsteri*) Australian salmon (*Arripis truttacea*) **Macrobenthivore** Australian white ibis (*Threskiornis molucca*) Common greenshank (*Tringa nebularia*) **Macrobenthivore/Piscivore** Pied cormorant (*Phalacrocorax varius*) Mulloway (*Argyrosomus hololepidotus*) Pied oystercatcher (*Haematopus longirostris*) **Piscivore** Fairy tern (*Sterna nereis*) Great crested grebe (*Podiceps cristatus*)	**Omnivore/Opportunist** Australasian shoveler (*Anas rhynchotis*) Black-winged stilt (*Himantopus himatopus*) Hoary-headed grebe (*Poliocephalus poliocephalus*) Musk duck (*Biziura lobata*) Masked lapwing (*Vanellus miles*) Black Bream (*Acanthopagrus butcheri*) **Macrobenthivore/Piscivore** Little black cormorant (*Phalacrocorax sulcirostris*) Red-capped plover (*Charadrius ruficapillus*) **Piscivore** Black-faced cormorant (*Phalacrocorax fuscescens*) Caspian tern (*Sterna caspia*) Great cormorant (*Phalacrocorax carbo*)	**Herbivore** Cape barren goose (*Cereopsis novaehollandiae*) **Planktivore/Macrobenthivore** Redfin Perch (*Perca fluviatilis*) **Hyperbenthivore/Piscivore** Gummy Shark (*Mustelus antarcticus*) Mixed ray species (Ray spp./ skate spp.)	**Omnivore/Opportunist** European Carp (*Cyprinus carpio*) **Macrobenthivores** Callop (*Macquaria ambigua*) **Piscivore** Bronze Whaler Shark (*Carcharhinus brachyurus*)

Table A6: Taxonomic composition of species subset from the peeling procedure of the Coorong (Subset 2: Birds and Commercial Fish – long term data set). N The total number of species included within this analysis was 48, and those which did not get chosen in any of the five peels not included below. The total number of species which were included in each peel is shown below the taxa list for that peel. Peels that reached Rho > 0.95 have their Rho values given in bold.

Subset 1	**Subset 2**	**Subset 3**	**Subset 4**	**Subset 5**
Rho = 0.950	Rho = 0. 732	Rho = 0.579	Rho = 0.473	Rho = 0.263
n = 13	*n* = 12	*n* = 13	*n* = 3	*n* = 1
Herbivore Australian shelduck (*Tadorna tadornoides*) Black swan (*Cygnus atratus*) Chestnut teal (*Anas castanea*) **Omnivore/Opportunist** Banded stilt (*Cladorhynchus leucocephalus*) Curlew sandpiper (*Calidris ferruginea*) Grey teal (*Anas gracilis*) Red-necked stint (*Calidris ruficollis*) Sharp-tailed sandpiper (*Calidris acuminata)* Silver gull (*Larus novaehollandiae*) **Piscivore** Australian pelican (*Pelecanus conspicillatus*) Crested tern (*Sterna bergii*) Little pied cormorant (*Phalacrocorax melanoleucos*) Whiskered tern (*Chlidonias hybridus*)	**Detritivore** Bony bream (*Nematalosa erebi*) **Herbivore** Pacific black duck (*Anas superciliosa*) **Omnivore/Opportunist** White-faced heron (*Ardea novaehollandiae)* Yellow-eye mullet (*Aldrichetta forsteri*) Australian salmon (*Arripis truttacea*) **Macrobenthivore** Australian white ibis (*Threskiornis molucca*) Common greenshank (*Tringa nebularia*) **Macrobenthivore/Piscivore** Mulloway (*Argyrosomus hololepidotus*) Pied oystercatcher (*Haematopus longirostris*) Gummy shark (*Mustelus antarcticus*) **Piscivore** Fairy tern (*Sterna nereis*) Great crested grebe (*Podiceps cristatus*)	**Omnivore/Opportunist** Australasian shoveler (*Anas rhynchotis*) Black-winged stilt (*Himantopus himatopus*) Hoary-headed grebe (*Poliocephalus poliocephalus*) Musk duck (*Biziura lobata*) Masked lapwing (*Vanellus miles*) Black bream (*Acanthopagrus butcheri*) **Macrobenthivore/Piscivore** Little black cormorant (*Phalacrocorax sulcirostris*) Pied cormorant (*Phalacrocorax varius*) **Hyperbenthivore/Piscivore** Red-capped plover (*Charadrius ruficapillus*) **Piscivore** Black-faced cormorant (*Phalacrocorax fuscescens*) Caspian tern (*Sterna caspia*) Great cormorant (*Phalacrocorax carbo*) Bronze-whaler shark (*Carcharhinus brachyurus*)	**Herbivore** Cape barren goose (*Cereopsis novaehollandiae*) **Planktivore** Jumping mullet (*Liza argentea*) **Planktivore/Hyperbenthivore** Greenback flounder (*Rhombosolea tapirina*)	**Hyperbenthivore/Piscivore** Mixed ray species (Ray spp./ skate spp.)

Table A7: Taxonomic composition of species subset from the peeling procedure of the Coorong (Subset 3: Commercial Fish – long term data set). The total number of species included within this analysis was 14, and those which did not get chosen in any of the five peels not included below. The total number of species which were included in each peel is shown below the taxa list for that peel. Subsets 4 and 5are not available because all of the species within the data set had fallen out in the previous peels. Peels that reached Rho > 0.95 have their Rho values given in bold.

Subset 1 Rho = 0.963 *n* = 2	**Subset 2** Rho = 0.759 *n* = 9	**Subset 3** Rho = 0.324 *n* = 3	**Subset 4** Not available	**Subset 5** Not available
Omnivore/Opportunist Yellow-eye mullet (*Aldrichetta forsteri*)	**Detritivore** Bony Bream (*Nematalosa erebi*)	**Hyperbenthivore/Piscivore** Mixed species Rays (Ray spp/ skate spp.)		
Hyperbenthivore/Piscivore Mulloway (*Argyrosomus hololepidotus*)	**Omnivore/Opportunist** Black bream (*Acanthopagrus butcheri*) Australian salmon (*Arripis truttacea*)	**Piscivore** Bronze-whaler shark (*Carcharhinus brachyurus*)		
	Planktivore Jumping mullet (*Liza argentea*)			
	Planktivore/ Macrobenthivores Greenback flounder (*Rhombosolea tapirina*) European Carp (*Cyprinus carpio*) Redfin Perch (*Perca fluviatilis*)			
	Macrobenthivore Callop (*Macquaria ambigua*)			
	Hyperbenthivore/Piscivore Gummy shark (*Mustelus antarcticus*)			

Table A8: Taxonomic composition of species subset from the peeling procedure of the Coorong (Birds, Commercial Fish and Invertebrates – short term data set). The total number of species included within this analysis was 56, and those which did not get chosen in any of the five peels not included below. The total number of species which were included in each peel is shown below the taxa list for that peel. Peels that reached Rho > 0.95 have their Rho values given in bold.

Subset 1 Rho = 0.956 *n* = 8	**Subset 2** Rho = 0.772 *n* = 20	**Subset 3** Rho = 0.504 *n* = 7	**Subset 4** Rho = 0.457 *n* = 7	**Subset 5** Rho = 0.390 *n* = 3
Detritivore *Capitella capitata* **Herbivore** Australian shelduck (*Tadorna tadornoides*) **Omnivore/Opportunist** Banded stilt (*Cladorhynchus leucocephalus*) Grey teal (*Anas gracilis*) Masked lapwing (*Vanellus miles*) Silver gull (*Larus novaehollandiae*) *Simplisetia aequisetis* (Polychaete) **Planktivore** *Arthritica helmsi*	**Herbivore** Chestnut teal (*Anas castanea*) Black swan (*Cygnus atratus*) Pacific black duck (*Anas superciliosa*) **Omnivore/Opportunist** Black-winged stilt (*Himantopus himatopus*) Hoary-headed grebe (*Poliocephalus poliocephalus*) Pink-eared duck (*Malacorhynchus membranaceus*) **Macrobenthivore** Australian white ibis (*Threskiornis molucca*) **Macrobenthivore/Piscivore** Little black cormorant (*Phalacrocorax sulcirostris*) **Hyperbenthivore/Piscivore** Red-capped plover (*Charadrius ruficapillus*) **Piscivore** Australian pelican (*Pelecanus conspicillatus*) Caspian tern (*Sterna caspia*) Fairy tern (*Sterna nereis*) Great cormorant (*Phalacrocorax carbo*) Great crested grebe (*Podiceps cristatus*) Great egret (*Ardea alba*) Little pied cormorant (*Phalacrocorax melanoleucos*) Pied Cormorant (*Phalacrocorax varius*) Whiskered tern (*Chlidonias hybridus*) **Unallocated** Juvenile Insect	**Detritivore** Bony bream (*Nematalosa erebi*) **Omnivore/Opportunist** Godwit spp. (*Limosa* spp.) Black bream (*Acanthopagrus butcheri*) **Planktivore/Hyperbenthivore** Greenback flounder (*Rhombosolea tapirina*) **Macrobenthivore** Eastern curlew (*Numenius madagascariensis*) **Hyperbenthivore/Piscivore** Gummy shark (*Mustelus antarcticus*) **Piscivore** Bronze-whaler shark (*Carcharhinus brachyurus*)	**Herbivore** Cape Barren goose (*Cereopsis novaehollandiae*) Oligochaetes **Omnivore/Opportunist** European carp (*Cyprinus carpio*) Red-necked stint (*Calidris ruficollis*) **Macrobenthivore** Black-tailed godwit (*Limosa limosa*) **Hyperbenthivore/Piscivore** Mulloway (*Argyrosomus hololepidotus*) **Piscivore** Little egret (*Egretta garzetta*)	**Macrobenthivore** Callop (*Macquaria ambigua*) *Nepthys australiensis* (Polychaete) **Piscivore** Crested tern (*Sterna bergii*)

Table A9: Taxonomic composition of species subset from the peeling procedure of the Coorong (Birds and Commercial Fish – short term data set). The total number of species included within this analysis was 49, and those which did not get chosen in any of the five peels not included below. The total number of species which were included in each peel is shown below the taxa list for that peel. Peels that reached Rho > 0.95 have their Rho values given in bold.

Subset 1 Rho = 0.956 *n* = 10	**Subset 2** Rho = 0.711 *n* = 18	**Subset 3** Rho = 0.289 *n* = 5	**Subset 4** Rho = 0.242 *n* = 9	**Subset 5** Rho = 0.115 *n* = 1
Herbivore Australian shelduck (*Tadorna tadornoides*) Black swan (*Cygnus atratus*) Chestnut teal (*Anas castanea*) **Omnivore/Opportunist** Banded stilt (*Cladorhynchus leucocephalus*) Grey teal (*Anas gracilis*) Hoary-headed grebe (*Poliocephalus poliocephalus*) Masked lapwing (*Vanellus miles*) Silver gull (*Larus novaehollandiae*) **Piscivore** Australian pelican (*Pelecanus conspicillatus*) Crested tern (*Sterna bergii*)	**Herbivore** Pacific black duck (*Anas superciliosa*) **Omnivore/Opportunist** Black-winged stilt (*Himantopus himatopus*) Musk duck (*Biziura lobata*) White-faced heron (*Ardea novaehollandiae)* Yellow-eye mullet *(Aldrichetta forsteri)* Royal spoonbill (*Platalea regia*) Pink-eared duck (*Malacorhynchus membranaceus*) **Macrobenthivore** Black-tailed godwit (*Limosa limosa*) Eastern curlew (*Numenius madagascariensis*) **Macrobenthivore/ Piscivore** Pied cormorant (*Phalacrocorax varius*) Pied oystercatcher (*Haematopus longirostris*) Red-capped plover (*Charadrius ruficapillus*) **Hyperbenthivore/Piscivore** Gummy shark (*Mustelus antarcticus*) Greater sand plover (*Charadrius leschenaultia*) **Piscivore** Black-faced cormorant (*Phalacrocorax fuscescens*) Great cormorant (*Phalacrocorax carbo*) Little pied cormorant (*Phalacrocorax melanoleucos*) Whiskered tern (*Chlidonias hybridus*)	**Omnivore/Opportunist** Black bream (*Acanthopagrus butcheri*) **Planktivore/Hyperbenthivore** Greenback flounder (*Rhombosolea tapirina*) **Macrobenthivore** Australian white ibis (*Threskiornis molucca*) Callop (*Macquaria ambigua*) **Hyperbenthivore/Piscivore** Mulloway (*Argyrosomus hololepidotus*)	**Herbivore** Cape barren goose (*Cereopsis novaehollandiae*) **Omnivore/Opportunist** Australasian shoveler (*Anas rhynchotis*) Australian salmon (*Arripis truttacea*) **Planktivore** Jumping mullet (*Liza argentea*) **Piscivore** Caspian tern (*Sterna caspia*) Fairy tern (*Sterna nereis*) Great crested grebe (*Podiceps cristatus*) Great egret (*Ardea alba*) Little egret (*Egretta garzetta*)	**Herbivore** Eurasian coot (*Fulica atra*)

Appendix B – Further Justification for Indicator Selections

Further species have been added to the initial list of indicator species generated from the peels analysis, based upon expert opinion. Species were selected for inclusion based upon either their conservation status (i.e. threatened species), unique life-history strategy (e.g. anadromous species such as lampreys), reliance on specific habitats or conditions and perceived importance to higher trophic levels.

Exclusion of indicators

Mysidacea was excluded as a useful indicator due to the paucity of life-history knowledge for the taxon, and the lack of data relating to its prevalence and distribution in the CLLMM region.

Inclusion of additional indicators

Short-headed lamprey (*Mordacia mordax*) and pouched lamprey (*Geotria australis*)

These two species are unique in the Murray-Darling Basin in that they are the only representatives of the form of diadromy known as anadromy. The anadromous life history strategy is characterised by adult marine residence and upstream migration into freshwater environments for spawning. In the case of lamprey, spawning is followed by mortality (Lintermans 2007). Juveniles or ammocoetes reside in freshwater for 3 – 4 years before metamorphosis and downstream migrations to marine environments (McDowall 1996). The persistence of these species is entirely dependent upon freshwater inflows and connectivity between the Lower Lakes and Coorong. These species' could be included as one group – lamprey spp.

Yarra pygmy perch (*Nannoperca obscura)*

Yarra pygmy perch is nationally listed as vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act* (1999) due to its restricted range and habitat degradation. This species was formerly common in the Hindmarsh Island and Goolwa Channel area of Lake Alexandrina (Wedderburn and Hammer 2003; Bice and Ye 2006; Bice and Ye 2007). Following diminished inflows to the Lower Lakes and significant water level recession, Yarra pygmy perch underwent significant declines and eventual extirpation from the region between 2006 and 2010 (Hammer 2008; Wedderburn *et al.* 2012). The presence of this species in Lake Alexandrina is now reliant upon a captive breeding and reintroduction program (Bice *et al.* Unpublished data). Declines in distribution and abundance, and eventual extirpation, resulted in the underrepresentation of this species in data sets used for peels analysis.

Yarra pygmy perch are likely to be an indicator of a healthy freshwater environment in Lake Alexandrina. The species is a habitat specialist preferring sheltered, well-vegetated habitats (particularly submerged vegetation, e.g. *Myriophyllum* spp., *Ceratophyllum demersum,* but also emergent, e.g. *Schoenoplectus validus*) of low salinity. Additionally, many sites where this species was formerly common were off-channel irrigation drains and wetlands that are relatively high on the elevation gradient (0.3 – 0.8 m AHD). Yarra pygmy perch's affiliation with vegetated aquatic habitat high on the elevation gradient dictates it is reliant on adequate inflows to Lake Alexandrina to maintain favourable water levels and habitat, as evidenced by recent extirpation from Lake Alexandrina during low water levels.

Southern pygmy perch (*Nannoperca australis*)

Southern pygmy perch are considered threatened in South Australia and are protected under the *Fisheries Management Act* (2007). Similar to the congeneric Yarra pygmy perch, southern pygmy perch experienced extensive reductions in distribution and abundance between 2006 and 2010 (Bice *et al.* 2011; Wedderburn *et al.* 2012), related to loss of preferred vegetated wetland habitat and increased salinity. This species is also part of a current reintroduction program (Bice *et al.* Unpublished data). Declines in distribution and abundance resulted in the underrepresentation of this species in data sets used for Peel's analysis.

Southern pygmy perch have similar habitat associations to Yarra pygmy perch and are thus likely to be an indicator of a healthy freshwater environment in Lake Alexandrina.

Murray hardyhead (*Craterocephalus fluviatilis*)

Murray hardyhead are nationally listed as endangered under the Commonwealth *EPBC Act* (1999). This species was typically patchily distributed in the Lower Lakes and often locally abundant (Wedderburn and Hammer 2003; Bice and Ye 2006; Wedderburn *et al.* 2012). It shows a preference for sheltered, vegetated habitats (Wedderburn *et al.* 2007; Wedderburn *et al.* 2008) and is highly tolerant of saline conditions (≤25 $g.L^{-1}$). Abundance can be positively related with salinity, when this species has a competitive advantage over less tolerant species (Wedderburn *et al.* 2008). During initial water level recession in the Lower Lakes, this species was abundant in saline, off-channel habitats, until these sites became hypersaline (Bice *et al.* 2011; Wedderburn and Barnes 2011).

Following the return of typical water levels to Lake Alexandrina, the status of Murray hardyhead was unknown. The species is highly mobile and together with increased water levels, likely increased the difficultly of sampling Murray hardyhead. Records of Murray hardyhead in Lake Alexandrina since 2010 have been sporadic and only low numbers have been detected (SARDI unpublished data). This species is also part of a current reintroduction program (Bice *et al.* unpublished data).

In other areas of the Murray-Darling Basin Murray hardyhead appear to exhibit a greater affiliation with saline conditions than in the Lower Lakes and rarely co-occur in species rich assemblages. Conversely in the Lower Lakes, whilst in the past this species has been found to be abundant at saline sites with few other species, it has also been found at some sites co-occurring with over ten other fish species (Bice *et al.* 2011). Murray hardyhead's affiliation with saline and vegetated wetland habitat means its presence may indicate the provision of a diversity of different habitats (i.e. varying salinities and vegetation cover) within Lake Alexandrina.

Golden perch (*Macquaria ambigua*)

Golden perch likely represent the most abundant native large-bodied fish species (adult length >300 mm) in the Lower Lakes and comprise a significant proportion of the Lower Lakes and Coorong commercial fishery (Ferguson 2008). During times of freshwater flow to the Coorong, golden perch are also regularly captured in the Coorong (Zampatti *et al.* 2012).

Golden perch are a flow-cued spawner, spawning and recruiting on increased within channel flows and floods (Mallen-Cooper and Stuart 2003). The presence of healthy golden perch populations and in particular, newly recruited juvenile golden perch is an indication of favourable River Murray flows.

Murray cod (*Maccullochella peellii peellii*)

Murray cod are nationally listed as vulnerable under the Commonwealth *EPBC Act* (1999). The current status of this species within Lake Alexandrina is unknown, for a number of reasons. Firstly, the majority of research projects in the region in recent years have focused on small-bodied threatened species (e.g. Bice *et al.* 2008; Wedderburn and Hillyard 2010; Bice *et al.* 2011; Wedderburn and Barnes 2011) and thus have targeted habitats where Murray cod are unlikely to be present and utilised sampling gear types that are unlikely to capture Murray cod. Secondly, given poor recruitment of Murray cod below Lock 1 over the last two decades (Ye and Zampatti 2007), the majority of the population is likely comprised of large individuals (>1 m), which are unlikely to be captured in the selective fishing gear (i.e. particular gill net mesh sizes) used within the Lakes and

Coorong commercial fishery. Nonetheless, following increased flows below Lock 1 in 2010, two juvenile Murray cod were sampled in Lake Alexandrina (Karl Hillyard pers. comm.).

Historical fishery data suggests a strong correlation between Murray cod recruitment and river flow (Ye *et al.* 2000). Little inference can be drawn from the absence of Murray cod from monitoring programs in the Lower Lakes due to the difficultly in sampling this species, however, its presence (particularly juveniles) is undoubtedly evidence of a healthy freshwater system and favourable regional flow regime.

Australian smelt (*Retropinna semoni*)

Australian smelt is a small-bodied (max length ~80 mm) freshwater species that is highly abundant in the Lower Lakes and lower River Murray. The species is highly tolerant of elevated salinity (Williams and Williams 1991) and during times of freshwater inflow and connectivity between the Coorong and Lower Lakes is commonly captured in large abundances in the Coorong. Being highly abundant, this species is likely to be an important prey item for higher trophic levels.

Whilst generally common, the distribution and abundance of Australian smelt may be indicative of certain ecosystem states or trajectories in both the Lower Lakes and the Coorong. During low water levels in the Lower lakes from 2007 – 2009 this species numerically predominated, most likely due to its broad salinity tolerance and generalist ecological habit (Wedderburn *et al.* 2012). Conversely, its presence and abundance in the Coorong is associated with favourable freshwater inflows to the Coorong.

Sandy sprat (*Hyperlophus vittatus*)

Sandy sprat is a small-bodied (max length ~100 mm) marine clupeid found in the inshore waters of both gulfs and the Coorong in South Australia. Within the estuary section of the Coorong (i.e. from Goolwa Barrage to Pelican Point), this species is amoung the most abundant fish species (Zampatti *et al.* 2011; Zampatti *et al.* 2012). Importantly, it has been found to be a significant prey item for larger fishes, both in the Coorong and elsewhere, including mulloway, black bream and Australian salmon (Hoedt and Dimmlich 1994; Deegan *et al.* 2010). It is also likely to be an important prey item of small piscivorous birds. Sandy sprat is similar in size and morphology to small-mouthed hardyhead and is likely to play a similar role in the trophic ecology of the Coorong Estuary to that of small-mouthed hardyhead in the northern and southern lagoons.

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Appendix C – Potential vegetation indicators for limits of acceptable change for the CLLMM Ramsar site

Indicators

Eleven indicators of Levels of Acceptable Change (LAC) for vegetation were identified (largely by expert opinion) for the Coorong, Lower Lakes and Murray Mouth Ramsar site. The plant species identified by peels analysis (Section 3.1) were obtained using data from The Living Murray (TLM) condition monitoring of the Lower Lakes between 2008 and 2011 during a period of drought with extreme low water levels in the Lower Lakes and high salinity in the Coorong and Murray Estuary and the very early recovery from drought and a return to historical water levels and lower salinity in the Coorong and Murray Estuary. The species identified were either highly abundant at a particular site (or sites), exclusive to a particular site or changed dramatically in abundance between 2008 and 2011. However, the majority of the species identified are probably poor indicators for limits of acceptable change, not because the peels analysis was an inappropriate method to identify indicators but the data set was used was an inappropriate data set. Water levels below sea level in the Lower Lakes and the extreme salinities experienced in the Coorong between 2007 and 2010 have never been encountered in the system. Basing indicators of acceptable change using data from period when the system has clearly exceeded the limits of acceptable change will result in indicators of a degraded system, not the "canary in the coal mine" type indicators that will allow management actions to prevent limits of acceptable change being exceeded. If the peels analysis was undertaken on vegetation data from the late 1980s to the mid 1990s a good list of indicators may have been produced; however, there is little data available from this period. Running peels analysis on data from 2011 to 2015 (and beyond) may produce a list of good indicators.

The indicators chosen represent species and communities that were deemed functionally important (by expert opinion) for the system, which include: freshwater submergent plant communities, *Phragmites australis, Typha domingensis, Duma florulenta* and diverse reed beds for the Lower Lakes; *Ruppia megacarpa* for the North Lagoon of the Coorong; *Ruppia tuberosa and Lamprothamnium macropogon* for the South Lagoon of the Coorong; *Melaleuca halmaturorum* and samphire and salt marsh communities for the whole of the system (Table C1). Figure C1 to Figure C7 present conceptual models that outline the key external drivers, physico-chemical and biotic processes that determine the distribution and abundance of the selected indicator. A summary of the drivers, processes and thresholds (where data exists) outlined in the conceptual models is presented in Table C2.

Table C1: List of potential vegetation indicators, the area of the system where they are appropriate indicators and metrics that could be used to set targets to inform limits of acceptable change.

Indicator	Area	Metrics
Freshwater submergent plant communities	Lower Lakes	Spatial extent, abundance, distribution, diversity, propagule bank
Phragmites australis	Lower Lakes	Spatial extent, distribution
Typha domingensis	Lower Lakes	Spatial extent, distribution
Duma florulenta	Lower Lakes	Spatial extent, distribution
Diverse reed beds	Lower Lakes	Spatial extent, abundance, distribution, diversity, propagule bank
Melaleuca halmaturorum	Whole of system	Spatial extent, distribution, abundance, recruitment, reproduction, demographics
Samphire and salt marsh communities	Whole of system	Spatial extent, abundance, distribution, recruitment, reproduction, propagule bank, demographics
Ruppia megacarpa	North Lagoon and Murray Estuary	Spatial extent, distribution, recruitment, biomass, abundance, reproduction, propagule bank
Ruppia tuberosa	South Lagoon and Saline Lakes	Spatial extent, distribution, recruitment, biomass, abundance, reproduction, propagule bank
Lamprothamnium macropogon	South Lagoon and Saline Lakes	Spatial extent, distribution, recruitment, biomass, abundance, reproduction, propagule bank
Phragmites australis	Coorong	Spatial extent

Table C2: List of potential vegetation indicators with a summary of the (a.) the external drivers (b.) physico chemical processes (including thresholds where data exists) and (c.) biological processes outlined in the conceptual models.

a.

	External drivers						
Indicator	**Climate**	**E-water**	**Barrage operations**	**Elevation (m AHD)**	**Nutrients**	**Wave action**	**USE flows**
Freshwater submergent plant communities	Drives River Murray Flows and Lake Levels	Supplements flows	Controls lake levels	0.4 to 0 (-0.5 in Goolwa Channel)	Low	Low tolerance	NA
Phragmites australis (Lower Lakes)	Drives River Murray Flows and Lake Levels	Supplements flows	Controls lake levels	0.9 to 0 (-0.5 in some areas)	High	Data deficient	NA
Typha domingensis	Drives River Murray Flows and Lake Levels	Supplements flows	Controls lake levels	0.8 to 0 (-0.2 in some areas)	High	Data deficient	NA
Muehlenbeckia florulenta	Drives River Murray Flows and Lake Levels	Supplements flows	Controls lake levels	>0.8	Data deficient	Data deficient	NA
Diverse reed beds	Drives River Murray Flows and Lake Levels	Supplements flows	Controls lake levels	0.9 to 0	Low	Data deficient	NA
Melaleuca halmaturorum	Drives River Murray Flows and Lake Levels	Supplements flows	Controls lake levels	>0.8	Data deficient	Data deficient	NA
Samphire and salt marsh communities	Drives River Murray Flows and Lake Levels	Supplements flows	Controls lake levels	>0.8	Data deficient	Data deficient	NA
Ruppia megacarpa	Drives River Murray Flows and Barrage Outflows	Supplements flows	Influences Murray Estuary and North Lagoon salinities	>0	Low	Low tolerance	NA
Ruppia tuberosa	Drives River Murray Flows, Barrage Outflows and Upper South East Flows	Supplements flows	Influences South Lagoon water levels and salinities	>0	Low	Low tolerance	Data deficient
Lamprothamnium macropogon	Drives River Murray Flows, Barrage Outflows and Upper South East Flows	Supplements flows	Influences South Lagoon water levels and salinities	>0	Low	Low tolerance	Data deficient
Phragmites australis (Coorong)	Drives local recharge	NA	NA	Data deficient	Data deficient	Data deficient	Data deficient

b.

	Physicochemical process					
Indicator	**River Murray Flow**	**Salinity (EC $\mu S.cm^{-1}$)**	**Water level (m AHD)**	**Soil Moisture**	**Light Availability**	**Shear force**
Freshwater submergent plant communities	Drives lake levels	<2,000	+0.8 to +0.4 m , +0.2 m minimum	Inundation	Maximum depth determined by light availability	Low
Phragmites australis (Lower Lakes)	Drives lake levels	<5,000	+0.8 to +0.4 m , +0.2 m minimum	High	NA	Data deficient
Typha domingensis	Drives lake levels	<5,000	+0.8 to +0.4 m , +0.2 m minimum	High	NA	Data deficient
Muehlenbeckia florulenta	Drives lake levels	<5,000	+0.8 to +0.4 m , +0.2 m minimum	High to low	NA	Data deficient
Diverse reed beds	Drives lake levels	<2,000	+0.8 to +0.4 m , +0.2 m minimum	High	Maximum depth of submergent species present is determined by light availability	Data deficient
Melaleuca halmaturorum	Drives lake levels and Barrage outflows	High	+0.8 to +0.4 m , +0.2 m minimum	High to moderate	NA	Data deficient
Samphire and salt marsh communities	Drives lake levels and Barrage outflows	High although	+0.8 to +0.4 m , +0.2 m minimum	High	NA	Data deficient
Ruppia megacarpa	Drives lake levels and Barrage outflows	<35 gL^{-1} TDS	>0 m	Inundation	High, Maximum depth determined by light availability	Low
Ruppia tuberosa	Drives lake levels and Barrage outflows	40 to 80 gL^{-1} TDS	>+0.2 m between May and January	Inundation	High, Maximum depth determined by light availability	Low
Lamprothamnium macropogon	Drives lake levels and Barrage outflows	40 to 80 gL^{-1} TDS	>+0.2 m between May and January	Inundation	High, Maximum depth determined by light availability	Low
Phragmites australis (Coorong)	NA	Localised freshening	Data deficient	High	NA	Data deficient

c.

Indicator	Biological Process							
	Herbivory	**Competition**	**Dispersal**	**Sexual reproduction**	**Asexual reproduction**	**Soil propagule bank**	**Recruitment**	**Critical Habitat**
Freshwater submergent plant communities	Swans	Data deficient	Water, animals	Yes	Yes	Yes	Inundation with freshwater	Threatened fish
Phragmites australis (Lower Lakes)	Domestic stock	Data deficient	Wind	Limited	Yes	No	Data deficient	Data deficient
Typha domingensis	Domestic stock	Data deficient	Wind	Yes	Yes	Yes	Wet soil or shallow inundation	
Muehlenbeckia florulenta	Domestic stock	Data deficient	Water, animals	Yes	Yes	No	Wet Soil	Data deficient
Diverse reed beds	Swans/domestic stock	Data deficient	Wind, water, animals	Yes	Yes	Yes	Wet soil or shallow inundation	Threatened fish
Melaleuca halmaturorum	Domestic stock	Data deficient	Water, animals	Yes	No	No	Wet Soil	Data deficient
Samphire and salt marsh communities	Domestic stock	Data deficient	Water, animals	Yes	Samphire no, some salt marsh species yes	Yes	Wet Soil	Orange Bellied Parrot
Ruppia megacarpa	Swans	Data deficient	Water, animals	Yes	Yes	Yes	Inundation with fresh to brackish water	Data deficient
Ruppia tuberosa	Swans, waders (propagule bank)	Data deficient	Water, animals	Yes	Yes	Yes	Inundation with water <100 gL^{-1}	Data deficient
Lamprothamnium macropogon	Swans	Data deficient	Water, animals	Yes	Yes	Yes	Inundation with water <100 gL^{-1}	Data deficient
Phragmites australis (Coorong)	Data deficient	Data deficient	Wind	Limited	Yes	No	Data deficient	Data deficient

Submergent freshwater plant communities

Submergent plants play important roles in freshwater ecosystems; they are food for herbivorous waterfowl (e.g. Schmieder *et al.* 2006; Chaichana *et al.* 2011; Wood *et al.* 2012), provide fish (e.g. Wedderburn *et al.* 2007) and invertebrate habitat (e.g. Wright *et al.* 2002; Larned *et al.* 2006; Walker *et al.* 2013), oxygenate the sediment and water column (e.g. Thursby 1984) and improve water quality (e.g. Findlay *et al.* 2006; Dai *et al.* 2012). Submergent plants were historically abundant in areas that are protected from wave action in the Lower Lakes, such as shoreline wetlands, bays, channels and throughout the Lower Reaches of the Murray River between Clayton and Goolwa Barrage (including the lower Finniss River and lower Currency Creek) (referred to as Goolwa Channel from herein) (Renfrey *et al.* 1989; Holt *et al.* 2005; Nicol *et al.* 2006). Between 2007 and 2010 submergent vegetation was lost from the system (except in Goolwa Channel after August 2009 due to the Clayton regulator) but has returned (albeit in reduced abundance and distribution) since August 2010 (Gehrig *et al.* 2011; Gehrig *et al.* 2012). The submergent plant taxa present in the Lower Lakes are: *Myriophyllum salsugineum, Myriophyllum caput-medusae, Potamogeton crispus, Potamogeton pectinatus, Ruppia polycarpa, Ruppia tuberosa, Ruppia megacarpa, Ceratophyllum demersum, Vallisneria australis, Chara* spp., *Nitella* spp. and *Lamprothamnium macropogon* (Gehrig *et al.* 2012).

The main factors that influence the distribution and abundance of submergent plants in the Lower Lakes are water level and salinity. Water level in the Lower Lakes is dependent on River Murray flow and barrage operations and salinity on River Murray flow (Figure C1). Submergent plants generally do not colonise areas below sea level, except in Goolwa Channel where plants often grow in areas as low as -0.5 to -1 m AHD (Gehrig *et al.* 2012). Therefore, water levels in the lakes need to be maintained at a minimum of +0.2 m AHD, preferably +0.4 m AHD and above. The impact of salinity is less well understood, species that were reported to have low salinity tolerances (e.g. *Vallisneria australis, Ceratophyllum demersum*) (Bailey *et al.* 2002) colonized and persisted in Goolwa Channel between August 2009 and August 2010 when salinities exceeded 230,000 µS.cm^{-1} at times (Gehrig *et al.* 2011). However, whilst salinities were elevated, *Potamogeton pectinatus* dominated and formed large and almost monospecific beds throughout Goolwa Channel (Gehrig *et al.* 2011). In contrast, after water levels were reinstated and salinities lowered, the submergent plant community has become more diverse (Gehrig *et al.* 2012). Therefore, it would be desirable to maintain salinities as low as possible to maximize diversity and prevent dominance of one salt tolerant species.

There is very little available information regarding the impact of other physicochemical factors on the distribution and abundance of submergent plants in the Lower Lakes. The current and historical distribution of submergent plants, which are restricted to areas protected from wave action (Renfrey *et al.* 1989; Holt *et al.* 2005; Nicol *et al.* 2006; Gehrig *et al.* 2011; Gehrig *et al.* 2012), suggests that they are sensitive to mechanical disturbance and stress. The absence of submergent plants in areas where the elevation is lower than sea level is probably due to a combination of factors. Most areas sheltered from wave action are shallow fringing wetlands and channels with beds higher then sea level, except areas in Goolwa Channel. The Lower Lakes are turbid water bodies; therefore, the maximum depth that submergent plants can grow in Goolwa Channel is probably controlled by light availability. However, sediment physicochemistry (e.g. sulfide concentration) may also influence the distribution of submergent species (Koch 2001).

Similarly, there is little information available regarding the biotic interactions that influence the distribution and abundance of submergent species. All of the species present in submergent plant communities in the Lower Lakes have evolved desiccation resistant seed banks (Nicol and Ward 2010b; Nicol and Ward 2010a); however, the longevity of the seed bank under different condition is not known. Sub-lethal salinity probably reduces growth rates (e.g. Blindow and Schutte 2007; Obrador and Pretus 2010) but also delays germination in *Myriophyllum salsugineum* and *Ruppia tuberosa* (Nicol and Ward 2010b; Nicol and Ward 2010a). All of the submergent species present in the Lower Lakes reproduce asexually, which under favourable conditions, is probably the dominant mode of reproduction and source of recruitment (e.g. Grace 1993). Nevertheless, sexual reproduction (flowering or spore production) has been observed in all submergent species (except *Ceratophyllum demersum*) in the Lower Lakes (J. Nicol pers. obs.) and is required for the production of desiccation resistant propagules and for the formation of a seed bank. Dispersal is also poorly understood but all of the submergent species found in the Lower Lakes have cosmopolitan distributions (Sainty and Jacobs 1981; Jessop and Tolken 1986; Romanowski 1998; Sainty and Jacobs 2003); therefore, are probably very good dispersers (Santamaria 2002). Hydrochory is probably the dominant dispersal mode for short-distance dispersal (Merritt and Wohlb 2002; Merritt and Wohl 2006; Greet *et al.* 2012). However, they require a vector (usually an animal, probably a migratory water bird) for long-distance dispersal between catchments (Vivian-Smith and Stiles 1994; Clausen *et al.* 2002; Pakeman and Small 2009; Raulings *et al.* 2011).

The effects of competition and herbivory are also not well understood. Given the limited area suitable for colonization by submergent species, space is probably the limiting resource; however, as depth increases there would be increasing competition for light. The main herbivore of submergent plants in the Lower Lakes is probably the back swam (*Cygnus atratus*); however, there no information available regarding the impact of herbivory on submergent plant communities in the Lower Lakes.

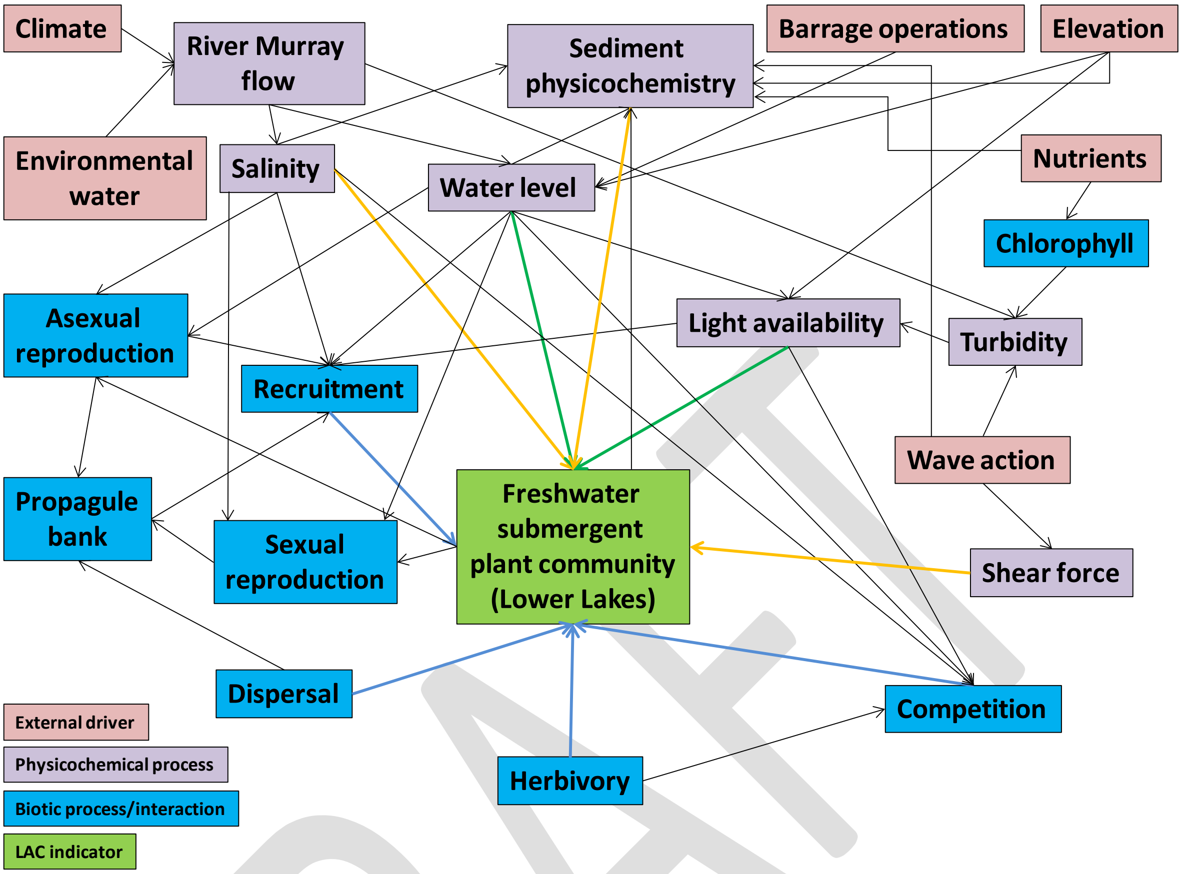

Figure C1: Conceptual model showing the key external drivers, physico-chemical and biotic processes that determine the distribution and abundance of submergent freshwater plant communities in the Lower Lakes.

Emergent freshwater plant communities

The conceptual model presented in Figure C2 outlines the key external drivers, physicochemical and biotic processes that determine the distribution and abundance of diverse reed beds*, Typha domingensis*, *Phragmites australis* and *Duma florulenta* (emergent freshwater plant communities) in the Lower Lakes. The factors that influence the distribution and abundance of the aforementioned community and species are the very similar with small differences in a small number of factors that will determine floristic composition of the emergent plant community.

Emergent plants are important components of freshwater ecosystems; they are important primary producers (e.g. Roberts and Ganf 1986; Froend and McComb 1994), improve water quality (e.g. Kadlec and Wallace 2009; Maddison *et al.* 2009; Li *et al.* 2010; Borin and Salvato 2012), oxygenate the sediment and water column (e.g. Blom *et al.* 1990; Sorrell and Hawes 2010; Dickopp *et al.* 2011) provide habitat for fish (e.g. Beyer *et al.* 2010; Marsland *et al.* 2010; Zampatti *et al.* 2011; Leigh *et al.* 2012), water birds (e.g. Jansen and Robertson 2001; Kapa and Clarkson 2009) and invertebrates (e.g. Papas 2007; Walker *et al.* 2013) and stabilise shorelines (e.g. Abernethy and Rutherfurd 1998). In the Lower Lakes extensive stands of emergent macrophytes are present around the shorelines throughout the system. Often stands are monospecific *Typha domingensis* or *Phragmites australis*; however, in some areas there is distinctive zonation of *Duma florulenta, Phragmites australis* (at the top of the elevation gradient), *Typha domingensis* (middle elevations) and *Schoenoplectus validus* (low elevation) or there is a diverse assemblage of emergent, floating and submergent plants (diverse red beds) (Gehrig *et al.* 2011; Gehrig *et al.* 2012).

The main factors that determine the distribution and abundance of emergent freshwater plant communities (similar to submergent plants) are water level and salinity. Emergent plants tend to occupy elevations between +0.9 m AHD to sea level; hence, water levels need to be maintained at a minimum of +0.2 m AHD, preferably +0.4 m AHD to maintain hydrological connection with the lakes and ensure there is sufficient water for plants growing at higher elevations. Furthermore, most emergent species require high soil moisture in the root zone when growing out of the water (Sainty and Jacobs 1981; Romanowski 1998; Sainty and Jacobs 2003; Roberts and Marston 2011). Between 2007 and 2010 when water levels were low, most emergent plants persisted but did not recruit further down the elevation gradient and were hydrologically disconnected from the lakes (Gehrig *et al.* 2012). Therefore, did not provide the same function (e.g. aquatic habitat) as emergent vegetation that is hydrologically connected. The effect of salinity is less well understood, species that were reported to have low salinity tolerances (e.g. *Typha domingensis, Schoenoplectus validus*) (Bailey *et al.* 2002) persisted in Goolwa Channel between August 2009 and August 2010 whilst salinities exceeded 30,000 µS.cm^{-1} at times (Gehrig *et al.* 2011). Nevertheless, whilst salinities were elevated there was no recruitment from seed by the aforementioned species and abundances were lower compared to after water levels were reinstated and salinity reduced (Gehrig *et al.* 2012). Therefore, it would be desirable to maintain salinities as low as possible to maximize abundance, allow recruitment from seed and provide conditions that will allow the greatest number of species to recruit.

Diverse reed beds

Diverse reed beds are characterised by a diverse assemblage of emergent, floating and submergent plants. Taxa present include: *Phragmites australis, Typha domingensis, Schoenoplectus validus, Duma florulenta, Schoenoplectus pungens, Juncus* spp., *Berula erecta, Calystegia sepium, Eleocharis acuta, Azolla* spp. *Lemna* spp. *Triglochin procera, Rumex bidens, Lycopus australis, Hydrocotyle verticillata, Centella asiatica, Bolboschoenus caldwellii, Cyperus gymnocaulos, Persicaria lapathifolium, Myriophyllum* spp., *Potamogeton* spp,. *Vallisneria americana* and *Ceratophyllum demersum* (Gehrig *et al.* 2012). Diverse reed beds are found at similar elevations to *Typha domingensis* and *Phragmites australis* monocultures (+0.9 to 0 m AHD) but generally in areas protected from wave action in areas with gentle sloping shorelines (Gehrig *et al.* 2012). It is unclear why the diversity in these areas is higher because there are protected areas with gentle sloping shorelines where there are *Typha domingensis* or *Phragmites australis* monocultures (Gehrig *et al.* 2012); hence, there is little information regarding physicochemical processes and biotic interactions.

Diverse reed beds require shallow inundation or high soil moisture (Sainty and Jacobs 1981; Romanowski 1998; Sainty and Jacobs 2003; Roberts and Marston 2011) and are restricted to areas with low salinity, protected from wave action (Gehrig *et al.* 2012). Most species present reproduce sexually and asexually (Sainty and Jacobs 1981; Romanowski 1998; Sainty and Jacobs 2003) and form a desiccation resistant seed bank (Nicol and Ward 2010b; Nicol and Ward 2010a). *Typha domingensis* and *Phragmites australis* are wind dispersed (Sainty and Jacobs 1981; Sainty and Jacobs 2003) but there is little information regarding the other species, which are probably dispersed by water and/or animals.

Phragmites australis

Phragmites australis plants often form extensive, dense monospecific stands around the edges of lakes Alexandrina and Albert (Seaman 2003). *Phragmites australis* tend to be present at upper elevations (+09 to +0.4 m AHD) but will colonise deeper water (0 m AHD or deeper) especially in areas with steep banks that are protected from wave action (e.g. the lower Finniss River) (Gehrig *et al.* 2012). On exposed shorelines plants are restricted to the upper elevations (Gehrig *et al.* 2011) and are important for controlling shoreline erosion (Hocking *et al.* 1983).

Phragmites australis primary mode of reproduction in the Lower Lakes is by rhizomes (asexual) (Koch 2001) and seeds have not been detected in the seed bank (Nicol and Ward 2010b; Nicol and Ward 2010a); however, a small number of seedlings were observed when water levels were drawn down (J. Nicol pers. obs.). Bailey *et al.* (2002) reported that *Phragmites australis* died at 15 gL^{-1} TDS; however, Gehrig *et al.* (2011) observed healthy plants growing in areas where the surface water salinity exceeded 22 gL^{-1} (over 30,000 $\mu S.cm^{-1}$) in Goolwa Channel. *Phragmites australis* are good competitors and able to rapidly colonise large areas clonally excluding other species, they oxygenate the sediment and water column but are susceptible to grazing and trampling by domestic stock (Hocking *et al.* 1983). When viable seed is produced it is dispersed by wind; hence, its cosmopolitan distribution (Sainty and Jacobs 1981; Hocking *et al.* 1983; Romanowski 1998; Sainty and Jacobs 2003). *Phragmites australis* prefers high soil moisture when not inundated but will persist for short periods when subjected to low soil moisture and senesce to rhizomes when subjected to extended desiccation (Hocking *et al.* 1983); however, the longevity of rhizomes is unknown.

Typha domingensis

Similar to *Phragmites australis, Typha domingensis* plants also form extensive monospecific stands around the shorelines of lakes Alexandrina and Albert (Seaman 2003). *Typha domingensis* generally colonise areas between +0.8 and 0 m AHD but will colonise slightly deeper water (around -0.2 m AHD) especially in areas with steep banks that are protected from wave action (e.g. the lower Finniss River, Clayton Bay, Dunns Lagoon) (Gehrig *et al.* 2012). They are probably more susceptible to wave action than *Phragmites australis* as they rarely form for large stands in areas with high wave action (Gehrig *et al.* 2012).

Typha domingensis reproduce both sexually and asexually (Sainty and Jacobs 1981; Finlayson *et al.* 1983; Romanowski 1998; Sainty and Jacobs 2003). Plants produce large numbers of seeds (>250,000 seeds in a single inflorescence) that are dispersed long distances by the wind (Finlayson *et al.* 1983) and form a soil seed bank (Nicol and Ward 2010b; Nicol and Ward 2010a). Seeds germinate on wet soil and when inundated to at least 70 cm (Nicol and Ganf 2000). In addition, *Typha domingensis* forms an extensive rhizome network and once established that can rapidly colonise areas excluding other species (Finlayson *et al.* 1983). *Typha domingensis* also aerates the sediment and water column (e.g. Sorrell and Hawes 2010) and will grow in areas with high nutrient concentrations (Kadlec and Wallace 2009). Bailey *et al.* (2002) reported that *Typha domingensis* died when exposed to surface water salinity of 15 gL^{-1}; however, Gehrig *et al.* (2011) observed healthy plants growing in areas where the surface water salinity exceeded 22 gL^{-1} in Goolwa Channel.

Duma florulenta

Duma florulenta (syn. *Muehlenbeckia florulenta*) can also form large stands but at higher elevations than *Typha domingensis* and *Phragmites australis* (>+1 to +0.8 m AHD) (Gehrig *et al.* 2012). This species is widespread around the shoreline of lakes Alexandrina and Albert in sheltered areas and areas subjected to wave action (Seaman 2003). Plants are intolerant of long-term inundation but will tolerate short-term inundation, and extended water logging and desiccation (Roberts and Marston 2011).

Duma florulenta reproduce sexually and asexually by fragmentation and layering; however they do not form a long-lived soil seed bank (Chong and Walker 2005). Bailey *et al.* (2002) reported the maximum salinity tolerance of this species as 4.4 gL^{-1}; however, it grows on the River Murray floodplain in areas with much higher soil salinity (Craig *et al.* 1991) and persisted in Goolwa Channel whilst the Clayton regulator was in operation and surface water salinities exceeded its reported maximum salinity tolerance (Gehrig and Nicol 2010).

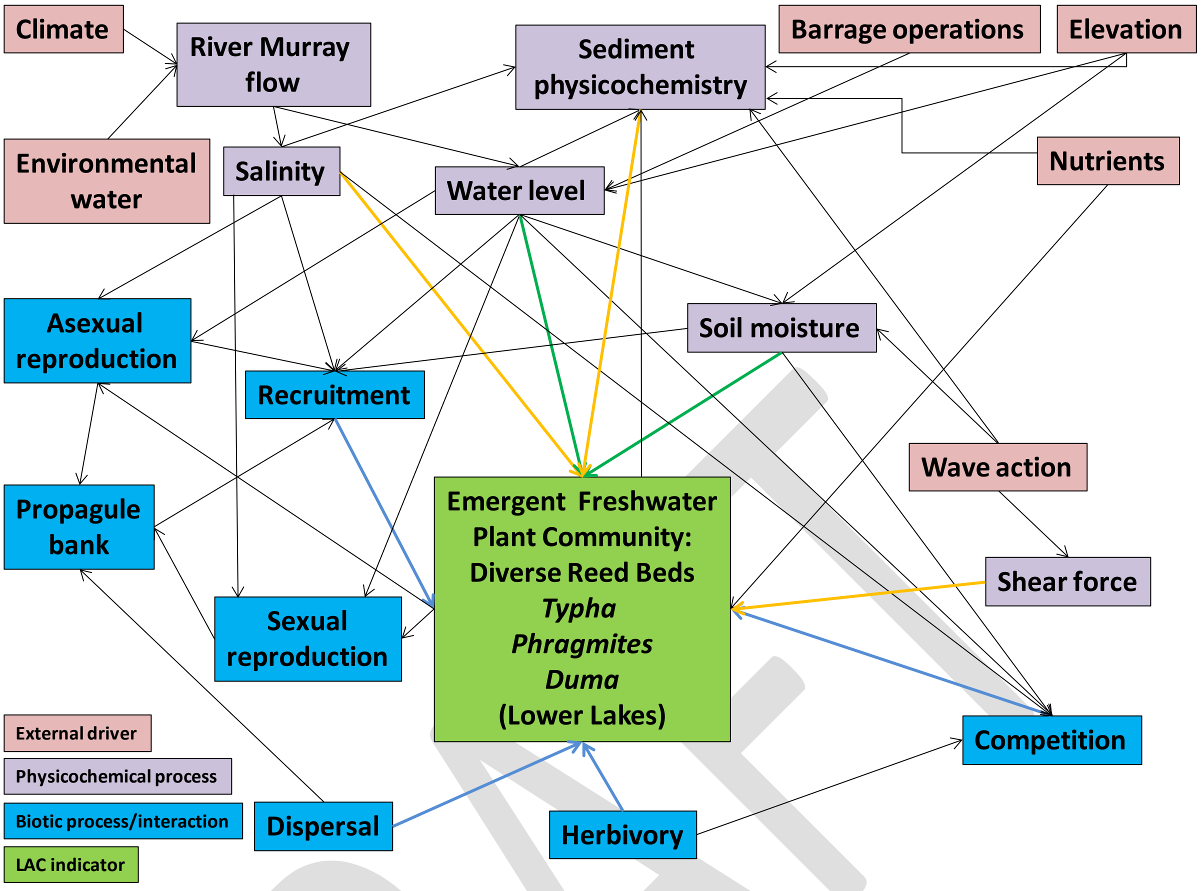

Figure C2: Conceptual model showing the key external drivers, physico-chemical and biotic processes that determine the distribution and abundance of emergent freshwater plant communities: diverse reed beds, *Typha domingensis, Phragmites australis* and *Duma florulenta* in the Lower Lakes.

Melaleuca halmaturorum

The conceptual model presented in Figure C3 outlines the key external drivers, physicochemical and biotic processes that determine the distribution and abundance of *Melaleuca halmaturorum* throughout the Coorong, Lower Lakes and Murray Mouth region. *Melaleuca halmaturorum* is the dominant tree species in the Coorong, Lower Lakes and Murray Mouth area and forms small areas of closed woodlands downstream of Point Sturt (Seaman 2003; Marsland and Nicol 2009). *Melaleuca halmaturorum* is intolerant of medium-term flooding (Denton and Ganf 1994); therefore is restricted to areas above +0.8 m AHD upstream of the barrages and +0.2 m AHD downstream of the barrages.

Reproduction is by seed, which germinates on exposed soil with high soil moisture (Nicol and Ganf 2000). Seed will not germinate under water and will lose viability when inundated for longer than four weeks (Nicol and Ganf 2000). This species does not form a soil seed bank but holds the seed in the canopy (an aerial seed bank or serotiny) (Rayamajhi *et al.* 2002). *Melaleuca halmaturorum* are highly salt tolerant and widespread throughout fresh to saline wetlands in south eastern Australia (Holliday 2004). However, it is not known whether lower salinity is required for germination and juvenile survivorship. The impact of other processes is not well understood but Cooke (1987) reported it was susceptible to herbivory by rabbits as juveniles.

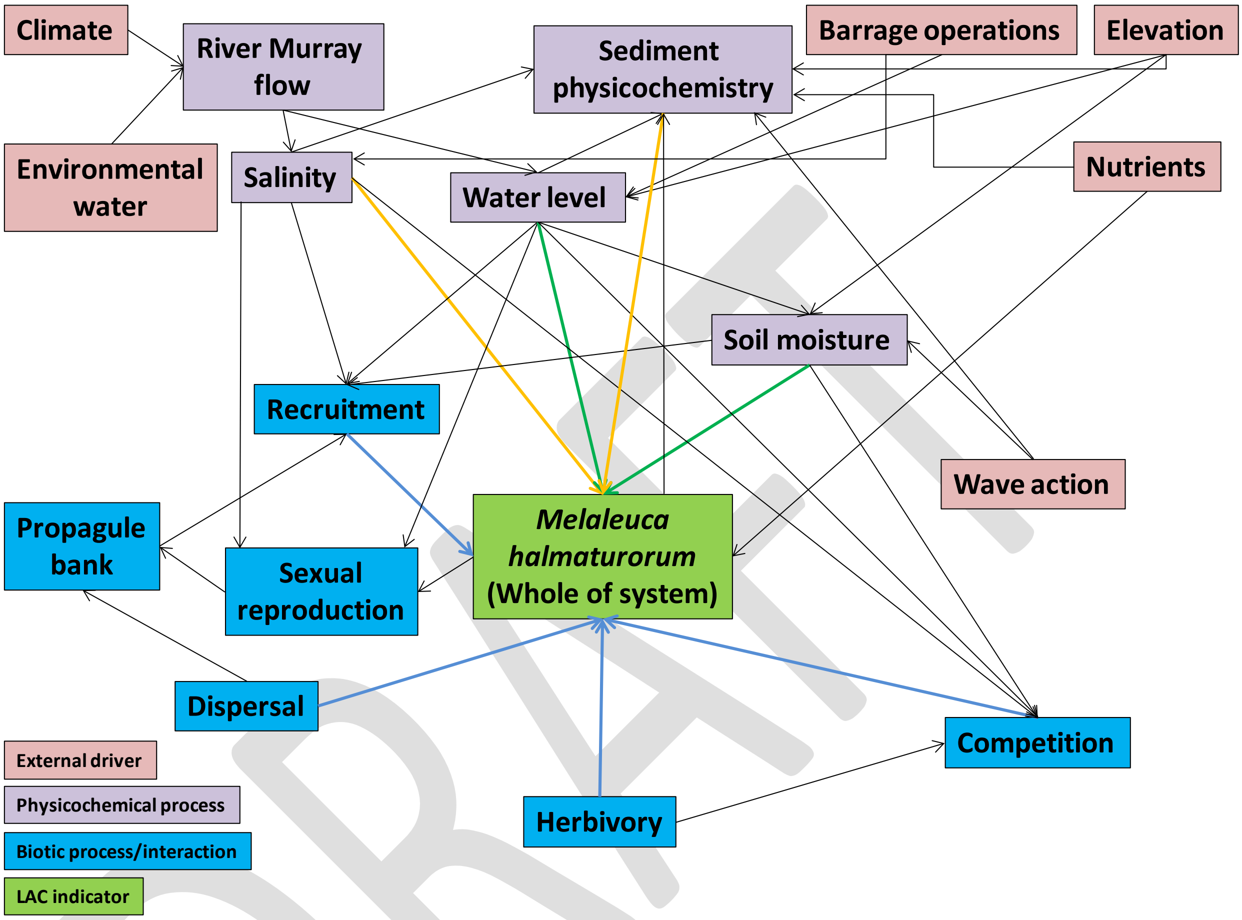

Figure C3: Conceptual model showing the key external drivers, physico-chemical and biotic processes that determine the distribution and abundance of *Melaleuca halmaturorum* in the Coorong, Lower Lakes and Murray Mouth Ramsar site.

Samphire and salt marsh communities

The conceptual model presented in Figure C4 outlines the key external drivers, physicochemical and biotic processes that determine the distribution and abundance of samphire and salt marsh communities throughout the Coorong, Lower Lakes and Murray Mouth region. Samphire and salt marsh communities are widespread throughout the region in areas where there is moderate to high salinity (Seaman 2003). Most samphire and salt marsh species do not require high salinity (in fact they have higher growth rates when grown at low salinities) but are out competed by species such as *Typha domingensis* or *Phragmites australis*; therefore, are restricted to areas with high salinity in nature (Ungar 1991). Taxa present in samphire and salt marsh communities in the Coorong, Lower Lakes and Murray Mouth region include: *Tecticornia* spp., *Sarcocornia* spp., *Suaeda australis,* *Triglochin striatum, Juncus kraussii, Wilsonia rotundifolia* and *Samolus repens* (Gehrig *et al.* 2012). Species are generally intolerant of long-term flooding but grow well in waterlogged soil (Sainty and Jacobs 1981; Romanowski 1998; Sainty and Jacobs 2003); hence, they are restricted to areas above +0.8 m AHD in the Lower Lakes and above +0.2 m AHD in the Coorong.

With the exception of *Juncus kraussii* (which reproduces asexually with rhizomes), reproduction is by seed and all species form a soil seed bank (Nicol *et al.* 2003; Nicol and Ward 2010b; Nicol and Ward 2010a). Germination occurs on wet soil and some species (e.g. *Juncus kraussii*) require salinities lower than they can tolerate as adults to germinate and survive while juveniles (Greenwood and MacFarlane 2006; Naidoo and Kift 2006). Little is known about the dispersal of samphire and salt marsh plants; however, it is likely they are dispersed by water and animals. The seeds of the samphire *Sarcocornia quinqueflora* are an important component of the diet of the EPBC listed orange bellied parrot (Mondon *et al.* 2009).

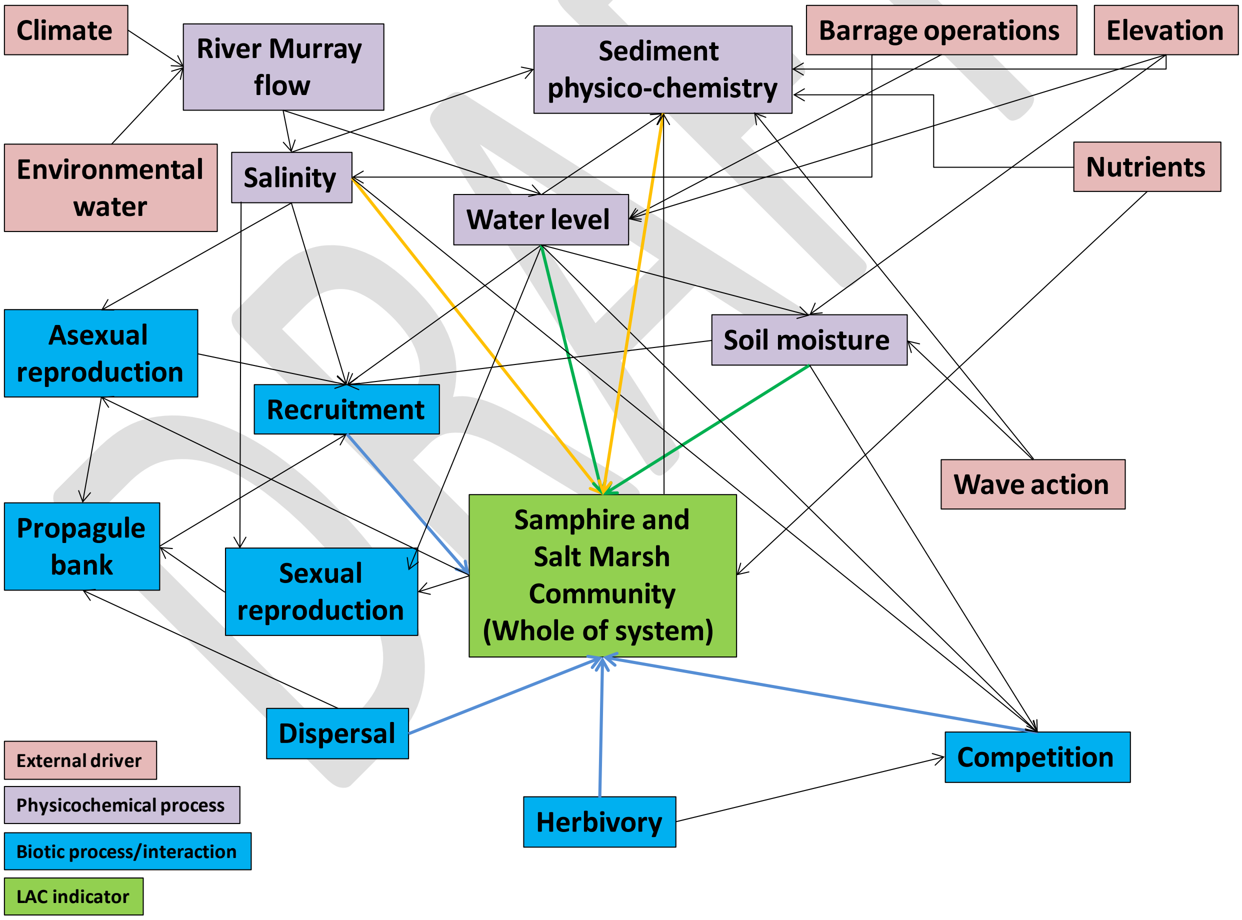

Figure C4: Conceptual model showing the key external drivers, physico-chemical and biotic processes that determine the distribution and abundance of samphire and salt marsh communities in the Coorong, Lower Lakes and Murray Mouth Ramsar site.

Ruppia megacarpa

The conceptual model presented in Figure C5 outlines the key external drivers, physicochemical and biotic processes that determine the distribution and abundance of *Ruppia megacarpa* in the Murray Estuary and North Lagoon of the Coorong. In the 1980s *Ruppia megacarpa* was the dominant submergent macrophyte in the North Lagoon of the Coorong and Murray Estuary forming extensive beds throughout the aforementioned areas (Geddes and Butler 1984; Geddes 1987; Geddes and Hall 1990). Abundance declined throughout the 1990s and was distribution was restricted the Murray Estuary (Edyvane *et al.* 1996), by 2002 it had become locally extinct (Nicol 2005) and there was no seed bank present in 2007 (Nicol 2007).

Ruppia megacarpa reproduces sexually and asexually (rhizomes) and will develop a desiccation resistant propagule bank (Nicol and Ward 2010b; Nicol and Ward 2010a). The longevity of seed in the propagule bank under different conditions is unknown. *Ruppia* spp. plants are intolerant of desiccation and exposure of five hours will result mortality (Adams and Bate 1994); hence, they require permanent water. The maximum salinity tolerance of *Ruppia megacarpa* is 46 gL^{-1}; however, plants did not flower when growing in water with salinity over 35 gL^{-1} and probably require lower salinity for germination and survival as juveniles (Brock 1979; Brock 1982a; Brock 1983). Therefore, flow through the barrages is required to lower salinity in the Murray Estuary and North Lagoon of the Coorong to enable recruitment and reproduction. *Ruppia megacarpa* has cosmopolitan distribution that suggests it is a good disperser, with waterbirds and water the most likely vectors (Santamaria 2002; Nicol 2005; Triest and Sierens 2013).

Congdon and McComb (1979) reported that *Ruppia megacarpa* had a high light requirement and is restricted to shallow areas in turbid water bodies. During periods of high barrage outflows the turbidity in the Murray Estuary and North Lagoon is higher compared with periods of low or no discharge; therefore, *Ruppia megacarpa* is probably restricted to shallow areas. (Higginson 1965; Congdon and McComb 1979); Congdon and McComb (1981) reported that *Ruppia megacarpa* preferred areas with fine sediment and high organic matter content in areas with low current and wave action. In contrast, Carruthers and Walker (1999) reported that *Ruppia megacarpa* was restricted to areas with coarse sediment but this may have been due to the areas with fine sediments being anoxic with high sulphide concentrations or in water too deep to support photosynthesis.

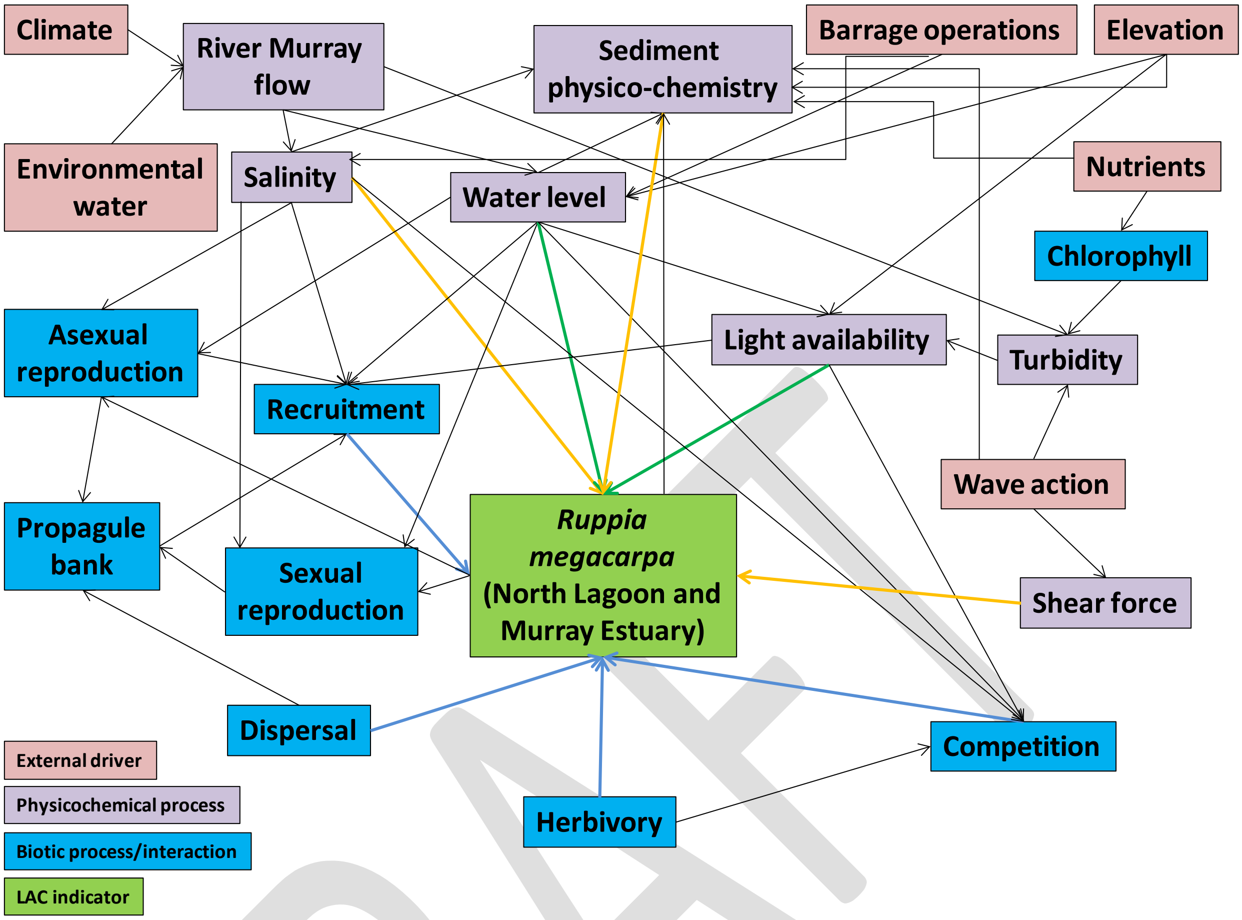

Figure C5: Conceptual model showing the key external drivers, physico-chemical and biotic processes that determine the distribution and abundance of *Ruppia megacarpa* in the North Lagoon of the Coorong, and Murray Estuary.

Submergent halophytes

The conceptual model presented in Figure C6 outlines the key external drivers, physicochemical and biotic processes that determine the distribution and abundance of submergent halophytes in the South Lagoon of the Coorong. *Ruppia tuberosa* and *Lamprothamnium macropogon* are extremely salt tolerant submergent plants and the only two species recorded in the South Lagoon of the Coorong (Womersley 1975; Paton 1982).

Ruppia tuberosa

Ruppia tuberosa is a highly salt tolerant angiosperm (maximum reported salinity tolerance 210 gL^{-1}) (Bailey *et al.* 2002) that is widely distributed in hypersaline temporary waterbodies (Nicol 2005). It is an annual or short-lived perennial species (Brock 1979; Brock 1982b) well adapted to temporary water bodies, germinating rapidly once sediment is inundated (Porter 2007) although the length of time to break dormancy increases with increasing salinity (J. Nicol unpublished data). *Ruppia tuberosa* was historically abundant throughout the South Lagoon of the Coorong in water depths ranging from 0.3 to 0.9 m (Womersley 1975; Paton 1982; Paton 1996; Triest and Sierens 2013). Since 2000 the abundance of *Ruppia tuberosa* has declined and by 2008 was largely absent from the South Lagoon of the Coorong (Paton and Rogers 2008; Brookes *et al.* 2009; Whipp 2010). Frahn *et al.* (2012) reported the presence of *Ruppia tuberosa* in the South Lagoon of the Coorong during December 2011; however, water levels fell in early January 2012 exposing plants and preventing them from completing their life cycle.

Ruppia tuberosa seeds germinate in late autumn/early winter in the South Lagoon of the Coorong as water levels rise and inundate mudflats (Nicol 2005). Water levels need to be maintained at above +0.2 m AHD until plants are able to produce seed and replenish the seed bank as plants are intolerant of exposure for more than a five hours (Adams and Bate 1994; Nicol 2005). Therefore, barrage flows need to be maintained into early summer to ensure water levels remain at a suitable level to enable reproduction to prevent depletion of the propagule bank. *Ruppia tuberosa* reproduce sexually and asexually (rhizomes and turions) and forms a desiccation resistant propagule bank of seeds and turions (Nicol 2005). The seeds and turions in the propagule bank are an important food source for migratory waters and shoots are grazed by black swans (Paton *et al.* 2001). *Ruppia tuberosa* has a cosmopolitan distribution; hence, is a good disperser with the vectors most likely waterbirds and water (Nicol 2005).

Despite the high salinity tolerance of *Ruppia tuberosa*, salinity (which exceeded 160 gL^{-1} in 2009 (Brookes *et al.* 2009) has been implicated as the major factor in the decline in abundance in the South Lagoon of the Coorong (Whipp 2010). Salinity ranging from 40 to 80 gL^{-1} is probably most suitable because it is sufficiently low not to stress *Ruppia tuberosa* plants but not so low that filamentous green algae (which smothers plants) will be absent. The majority of the freshwater required to maintain salinities in the aforementioned range needs to come from barrage releases; however, localised freshening around the mouth of Salt Creek may be achieved by releases from Morella Basin with water from the Upper South East Drainage Scheme. In addition to salinity, mud flats need to be inundated until at least late spring to enable *Ruppia tuberosa* to complete its life cycle and replenish the propagule bank. During the drought barrage flows were absent and flows through Tauwitchere Barrage in late spring are required to maintain levels in the South Lagoon of the Coorong that will enable *Ruppia tuberosa* to reproduce. *Ruppia tuberosa* also have high light requirements and are generally found no deeper than 90 cm in the South Lagoon of the Coorong due to high turbidity caused by phytoplankton (Womersley 1975). There is no available information regarding the effects of sediment physicochemistry or wave action; however, it unlikely that *Ruppia tuberosa* is tolerant to wave action.

Lamprothamnium macropogon

Lamprothamnium macropogon is a highly salt tolerant charophyte (230 gL^{-1} (Bailey *et al.* 2002) that is widely distributed in inland saline waterbodies (Porter 2007). This species was present in the South Lagoon of the Coorong in the 1970s and 1980s (Womersley 1975; Paton 1982; Geddes and Butler 1984) but has not been recorded since. Porter (2007) reported that *Lamprothamnium macropogon* spores require 350 days inundation before germination occurs; therefore, was probably present lower on the elevation gradient than *Ruppia tuberosa*.

The optimum ranges for salinity for *Lamprothamnium macropogon* are probably similar to *Ruppia tuberosa* because it was present whilst *Ruppia tuberosa* was abundant (Womersley 1975; Paton 1982; Geddes and Butler 1984). Similarly, other physicochemical and biotic processes that result in high abundances of *Ruppia tuberosa* probably result in high abundances of *Lamprothamnium macropogon*.

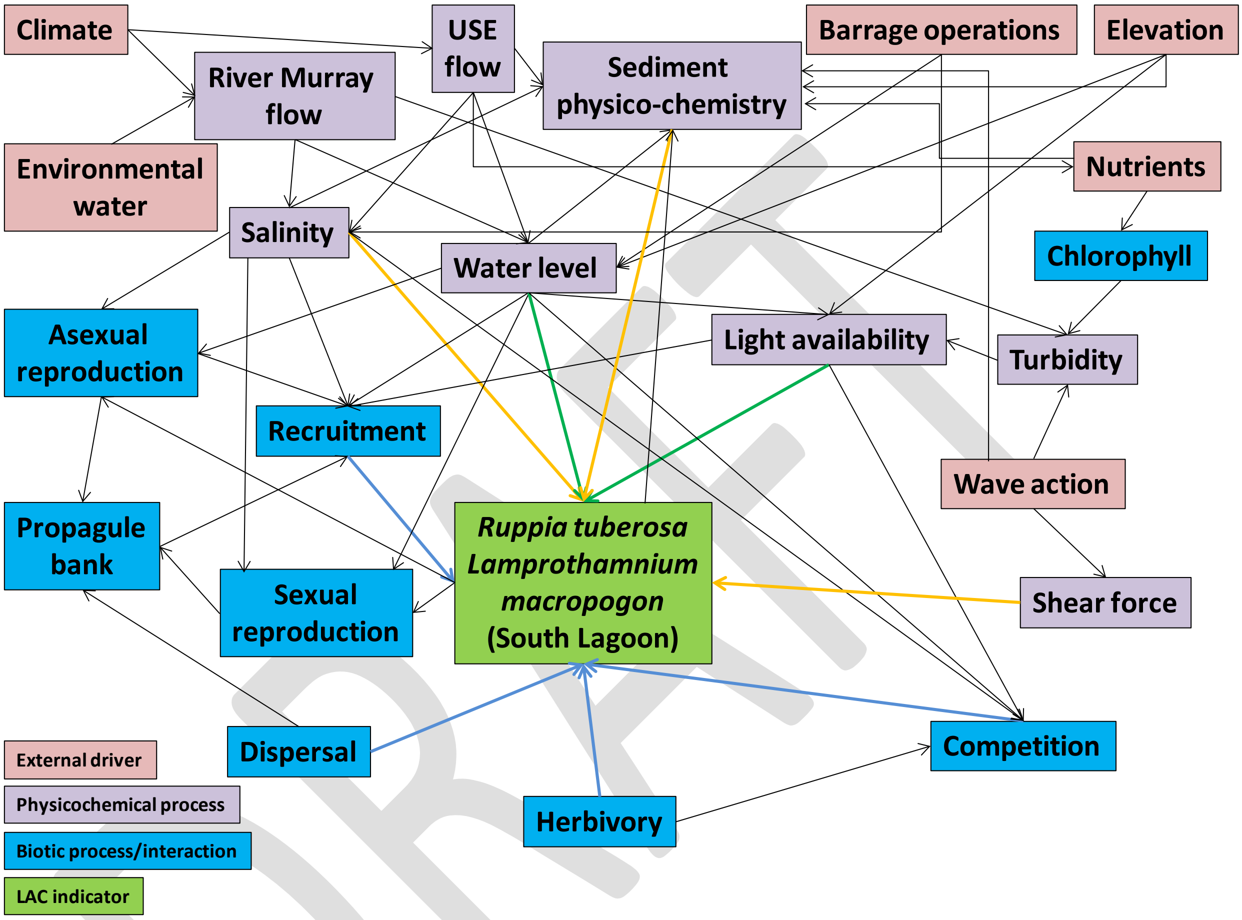

Figure C6: Conceptual model showing the key external drivers, physico-chemical and biotic processes that determine the distribution and abundance of *Ruppia tuberosa* and *Lamprothamnium macropogon* (submergent halophytes) in the South Lagoon of the Coorong.

Phragmites australis (Coorong)

Numerous freshwater soaks occur along the western shoreline of the Coorong (Sir Richard and Younghusband Peninsulas) in areas where fresh groundwater discharges. There is a localised freshening of the surface water adjacent to the freshwater soaks, where *Phragmites australis* are often present. The main factor that influences the distribution and abundance of *Phragmites australis* is groundwater discharge, which needs to be sufficient to maintain the localised freshening to enable this species to persist. The main factor that influences discharge is recharge, which is from local rainfall that percolates through the sand dunes before it reaches an aquitard that causes it to discharge into the Coorong along the western shoreline. If there is a significant reduction in rainfall, recharge will also decrease leading to a decrease in discharge. However, there is no information regarding the relationship between rainfall, recharge and discharge for freshwater soaks or the time taken for water move through the aquifer.

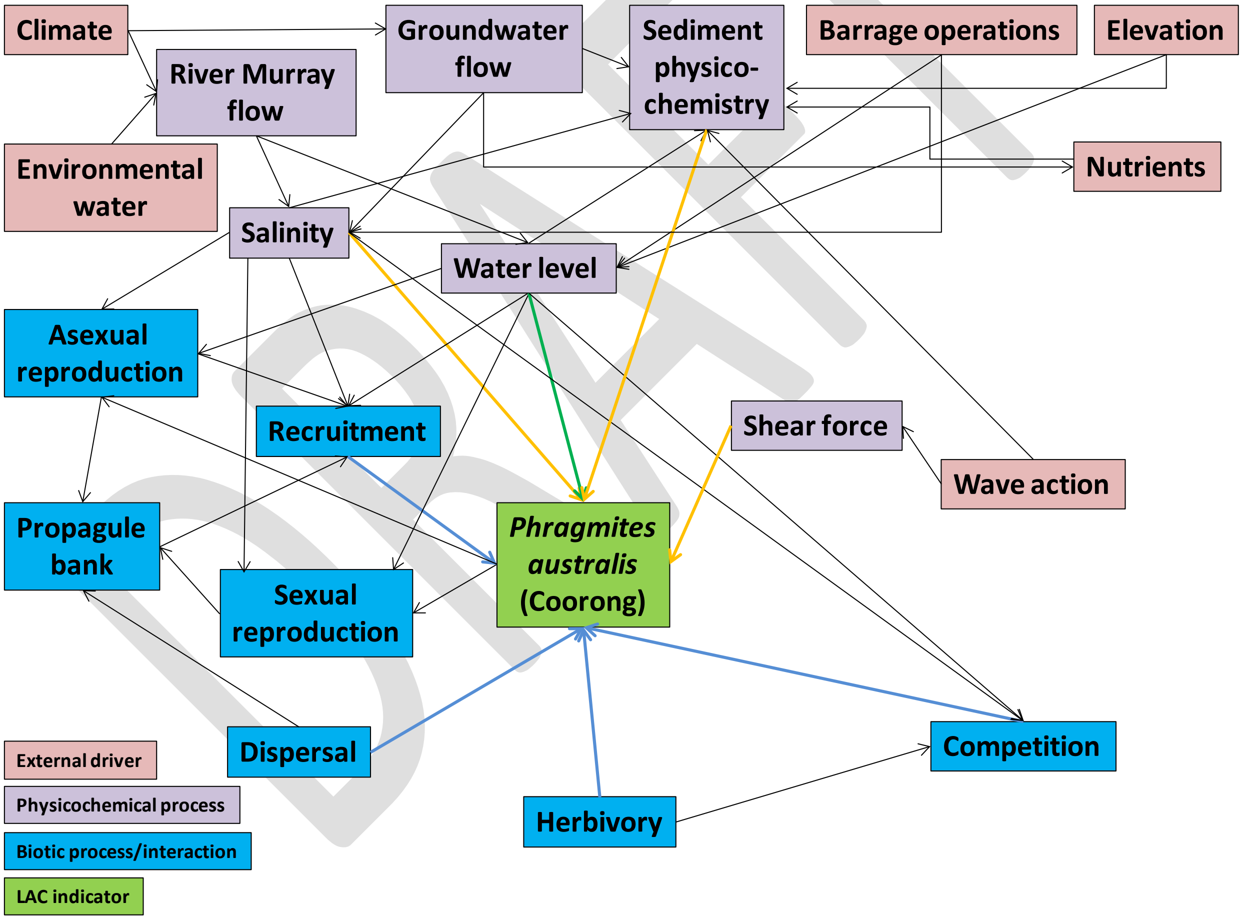

Figure C7: Conceptual model showing the key external drivers, physico-chemical and biotic processes that determine the distribution and abundance of *Phragmites australis* in the Coorong.

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Appendix D – Potential fish indicators for limits of acceptable change for the CLLMM Ramsar site

Indicator species

The final list of fish indicator species was derived from a combination of redundancy analyses (see Section 3.1) and those included based upon expert opinion (Table D1). Several species were likely underrepresented in the datasets used for redundancy analysis either due to low abundance during the time of data collection, difficulty in sampling these species or only seasonal occurrence within the site. The Goolwa dataset utilised was collected between 2009 and 2011 (Bice and Zampatti 2011) during irregularly low water levels in the Lower Lakes and thus several small-bodied freshwater species (e.g. Yarra pygmy perch) had already undergone significant declines such they were not collected and were thus absent from the dataset. Additionally, other species, such as lamprey's, are difficult to sample and potentially are only present within the site seasonally during migration. The fish monitoring techniques (e.g. fyke and gill netting) utilised in the projects from which the datasets were derived, are not effective in sampling these species, probably accounting from their absence from redundancy analysis. The absence of particular species from the utilised datasets however does not preclude their importance to system function or the ecological character description of the region. Thus a further group of species, not identified during redundancy analyses, was included in the final indicator list using expert opinion and based upon three considerations;

1) conservation status
    - Species listed as threatened at either national or state level
2) Uniqueness of life-history strategy (i.e. anadromous species – lamprey spp.)
    - Species representative of a life history strategy that was not represented by indicator species as determined by redundancy analyses. It is important that all life history strategies exhibited by fishes within the CLLMM region are represented in the indicator species list.
3) Reliance on specific habitats or conditions and/or perceived importance to other biotic groups or system function.
    - Species, that through their reliance on specific habitats (e.g. vegetated habitat) or conditions (e.g. connectivity) are potentially valid indicators of ecosystem change.
    - Species believed to have important relationships with other biota (e.g. small-bodied fishes as prey for higher trophic levels).

The final list of fish indicator species, incorporating species identified during redundancy analyses and using expert opinion, is presented in Table D1. Justification for inclusion of species based upon expert opinion are presented below.

Table D3. Final list of fish indicator species derived from both redundancy analyses and expert opinion (indicated in bold).

Species	Functional feeding category	Life-cycle categories
Fish – 23 chosen		
Australian Salmon (*Arripis truttacea*)	Omnivore/Opportunist	Marine migrant
Australian Smelt (*Retropinna semoni*)	**Macrobenthivore**	**Freshwater migrant**
Blue-spot Goby (*Pseudogobius olorum)*	Omnivore	Estuarine
Bony Bream (*Nematalosa erebi*)	Detritivore	Freshwater migrant
Bridled Goby (*Arenigobius bifrenatus*)	Omnivore/Opportunist	Estuarine
Carp Gudgeon complex (*Hypseleotris spp.)*	Macrobenthivore	Freshwater straggler
Common Galaxias (*Galaxias maculatus*)	Macrobenthivore	Catadromous
Congolli (*Pseudaphritis urvillii*)	Macrobenthivore	Catadromous
European Carp (*Cyprinus carpio*)	Omnivore	Freshwater straggler
Golden Perch (*Macquaria ambigua*)	**Macrobenthivore**	**Freshwater migrant**
Lagoon Goby (*Tasmanogobius lasti*)	Macrobenthivore	Estuarine
Mulloway (*Argyrosomus hololepidotus*)	Hyperbenthivore/Piscivore	Marine migrant
Murray Cod (*Maccullochella peelii peelii*)	**Opportunist**	**Freshwater straggler**
Murray Hardyhead (*Craterocephalus fluviatilis*)	**Omnivore**	**Freshwater straggler**
Pouched lamprey (*Geotria australis*)	**Detritivore/Piscivore**	**Anadromous**
River Garfish (*Hyporhamphus regularis*)	Herbivore	Estuarine
Sandy Sprat (*Hyperlophus vittatus*)	**Planktivore**	**Marine migrant**
Short-headed Lamprey (*Mordacia mordax*)	**Detritivore**	**Anadromous**
Small-mouthed Hardyhead (*Artherinosoma microstoma)*	Macrobenthivore	Estuarine
Southern Pygmy Perch (*Nannoperca australis*)	**Macrobenthivore**	**Freshwater straggler**
Yarra Pygmy Perch (*Nannoperca obscura*)	**Macrobenthivore**	**Freshwater straggler**
Yellow eye Mullet (*Aldrichetta forsteri*	Omnivore/opportunist	Marine migrant

Short-headed lamprey (*Mordacia mordax*) and pouched lamprey (*Geotria australis*)

These two species are unique in the Murray-Darling Basin in that they are the only representatives of the form of diadromy known as anadromy. The anadromous life history strategy is characterised by adult marine residence and upstream migration into freshwater environments for spawning. In the case of lamprey, spawning is followed by mortality (Lintermans 2007). Juveniles or ammocoetes reside in freshwater for 3 – 4 years before metamorphosis and downstream migrations to marine environments (McDowall 1996).

Lamprey species were not collected during sampling from which the datasets used for redundancy analyses were derived. As migratory species, sampling individuals during migration and passage through fishways appears the most effective way of monitoring these species with both pouched and short-headed lamprey sampled from the barrage fishways in 2006/07 and most recently in 2011/12 (Bice et al. 2012b). The persistence of these species is entirely dependent upon freshwater inflows and connectivity between the Lower Lakes and Coorong.

Yarra pygmy perch (*Nannoperca obscura)*

Yarra pygmy perch is nationally listed as vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act* (1999) due to its restricted range and habitat degradation. This species was formerly common in the Hindmarsh Island and Goolwa Channel area of Lake Alexandrina (Wedderburn and Hammer 2003; Bice and Ye 2006; Bice and Ye 2007). Following diminished inflows to the Lower Lakes and significant water level recession, Yarra pygmy perch underwent significant declines and eventual extirpation from the region between 2006 and 2010 (Hammer 2008; Wedderburn et al. 2012). The presence of this species in Lake Alexandrina is now reliant upon a captive breeding and reintroduction program (Bice et al. 2012a). Declines in distribution and abundance, and eventual extirpation, resulted in the underrepresentation of this species in datasets used for redundancy analyses.

Yarra pygmy perch are likely to be an indicator of a healthy freshwater environment in Lake Alexandrina. The species is a habitat specialist preferring sheltered, well-vegetated habitats (particularly submerged vegetation, e.g. *Myriophyllum* spp, *Ceratophyllum demersum,* but also emergent, e.g. *Schoenoplectus validis*) of low salinity. Additionally, many sites where this species was formerly common were off-channel irrigation drains and wetlands that are relatively high on the elevation gradient (0.3 – 0.8 m AHD). Yarra pygmy perch's affiliation with vegetated aquatic habitat high on the elevation gradient dictates it is reliant on adequate inflows to Lake Alexandrina to maintain favourable water levels and habitat, as evidenced by recent extirpation from Lake Alexandrina during low water levels. Additionally, whilst the species could not have been considered abundant in the region in the last decade, its size dictates that it is likely preyed upon by piscivorous fishes and birds and may have been an important prey item in the past.

Southern pygmy perch (*Nannoperca australis*)

Southern pygmy perch are considered threatened in South Australia and are protected under the *Fisheries Management Act* (2007). Similar to the congeneric Yarra pygmy perch, southern pygmy perch experienced extensive reductions in distribution and abundance between 2006 and 2010 (Bice et al. 2011; Wedderburn et al. 2012), related to loss of preferred vegetated wetland habitat and increased salinity. This species is also part of a current reintroduction program (Bice et al. 2012a). Declines in distribution and abundance resulted in the underrepresentation of this species in data sets used for redundancy analysis. Southern pygmy perch have similar habitat associations to Yarra pygmy perch and are thus likely to be an indicator of a healthy freshwater environment in Lake Alexandrina.

Murray hardyhead (*Craterocephalus fluviatilis*)

Murray hardyhead are nationally listed as endangered under the Commonwealth *EPBC Act* (1999). This species was typically patchily distributed in the Lower Lakes and often locally abundant (Wedderburn and Hammer 2003; Bice and Ye 2006; Wedderburn et al. 2012). It shows a preference for sheltered, vegetated habitats (Wedderburn et al. 2007; Wedderburn et al. 2008) and is highly tolerant of saline conditions (≤25 $g.L^{-1}$). Abundance can be positively related with salinity, when this species has a competitive advantage over less tolerant species (Wedderburn et al. 2008). During initial water level recession in the Lower Lakes, this species was abundant in saline, off-channel habitats, until these sites became hypersaline (Bice et al. 2011; Wedderburn and Barnes 2011). Following the return of typical water levels to Lake Alexandrina, the status of Murray hardyhead was unknown. The species is highly mobile and together with increased water levels, likely increased the difficultly of sampling Murray hardyhead. Records of Murray hardyhead in Lake Alexandrina since 2010 have been sporadic and typically low numbers have been detected (Bice et al. 2012a; Bice et al. in prep). This species is also part of a current reintroduction program.

In other areas of the Murray-Darling Basin Murray hardyhead appear to exhibit a greater affiliation with saline conditions than in the Lower Lakes and rarely co-occur in species rich assemblages. Conversely in the Lower Lakes, whilst in the past this species has been found to be abundant at saline sites with few other species, it has also been found at some sites co-occurring with over ten other fish species (Bice et al. 2011). Murray hardyheads' affiliation with saline and vegetated wetland habitat means its presence may indicate the provision of a diversity of different habitats (i.e. varying salinities and vegetation cover) within Lake Alexandrina.

Golden perch (*Macquaria ambigua*)

Golden perch likely represent the most abundant native large-bodied fish species (adult length >300 mm) in the Lower Lakes and comprise a significant proportion of the Lower Lakes and Coorong commercial fishery (Ferguson 2008). During times of high freshwater flow to the Coorong, golden perch are also regularly captured in the Coorong (Zampatti et al. 2012). Golden perch are a flow-cued spawner, spawning and recruiting on increased within channel flows and floods (Mallen-Cooper and Stuart 2003). The presence of healthy golden perch populations and in particular, newly recruited juvenile golden perch is an indication of favourable River Murray flows. Additionally, the species is likely to be important as a higher order consumer of macroinvertebrates (e.g. *Macrobrachium*) and other fish (e.g. bony herring).

Murray cod (*Maccullochella peellii peellii*)

Murray cod are nationally listed as vulnerable under the Commonwealth *EPBC Act* (1999). The current status of this species within Lake Alexandrina is unknown, for a number of reasons. Firstly, the majority of research projects in the region in recent years have focused on small-bodied threatened species (e.g. Bice et al. 2008; Wedderburn and Hillyard 2010; Bice et al. 2011; Wedderburn and Barnes 2011) and thus have targeted habitats where Murray cod are unlikely to be present and utilised sampling gear types that are unlikely to capture Murray cod. Secondly, given poor recruitment of Murray cod below Lock 1 over the last two decades (Ye and Zampatti 2007), the majority of the population is likely comprised of large individuals (>1 m), which are unlikely to be captured in the selective fishing gear (i.e. particular gill net mesh sizes) used within the Lakes and Coorong commercial fishery. Nonetheless, following increased flows below Lock 1 in 2010, two juvenile Murray cod were sampled in Lake Alexandrina (Karl Hillyard Pers. Comm.).

Historical fishery data suggests a strong correlation between Murray cod recruitment and river flow (Ye et al. 2000). Little inference can be drawn from the absence of Murray cod from monitoring programs in the Lower Lakes due to the difficultly in sampling this species, however, its presence (particularly juveniles) is undoubtedly evidence of a healthy freshwater system and favourable regional flow regime.

Australian smelt (*Retropinna semoni*)

Australian smelt is a small-bodied (max length ~80 mm) freshwater species that is highly abundant in the Lower Lakes and lower River Murray. The species is highly tolerant of elevated salinity (Williams and Williams 1991) and during times of freshwater inflow and connectivity between the Coorong and Lower Lakes is commonly captured in large abundances in the Coorong. Being highly abundant, this species is likely to be an important prey item for higher trophic levels.

Whilst generally common, the distribution and abundance of Australian smelt may be indicative of certain ecosystem states or trajectories in both the Lower Lakes and the Coorong. During low water levels in the Lower lakes from 2007 – 2009 this species numerically predominated, most likely due to its broad salinity tolerance and generalist ecological habit (Wedderburn et al. 2012). Conversely, its presence and abundance in the Coorong is associated with high freshwater inflows to the Coorong.

Sandy sprat (*Hyperlophus vittatus*)

Sandy sprat is a small-bodied (max length ~100 mm) marine clupeid found in the inshore waters of both gulfs and the Coorong in South Australia. Within the estuary section of the Coorong (i.e. from Goolwa Barrage to Pelican Point), this species is among the most abundant fish species (Zampatti et al. 2011a; Zampatti et al. 2012). Importantly, it has been found to be a significant prey item for larger fishes, both in the Coorong and elsewhere, including mulloway, black bream and Australian salmon (Hoedt and Dimmlich 1994; Deegan et al. 2010). It is also likely to be an important prey item of small piscivorous birds (Klomp and Wooller 1988). Sandy sprat is similar in size and morphology to small-mouthed hardyhead and is likely to play a similar role in the trophic ecology of the Coorong Estuary to that of small-mouthed hardyhead in the northern and southern lagoons. Whilst considered a marine species, the abundance of sandy sprat in the Coorong Estuary appears highly correlated with freshwater inflow (Bice et al. 2012b).

Conceptual models

We have adopted a generic conceptual model for fishes of the Coorong and Lower Lakes (Figure D1) highlighting key drivers that structure abiotic factors within the CLLMM region, and ultimately, these directly or indirectly influence (through biotic interactions) the life histories of fish. Abiotic and biotic factors effect the survival and growth of different life history stages (i.e. egg, larvae, young-of-year, juvenile, adult, spawning adult) and importantly, the transitions (i.e. survival, spawning, egg development, recruitment, movement, gonad development) between life history stages. Whilst a generic 'graphical' conceptual model is adopted for all indicator species, individual species or 'guild' conceptual models will be expanding using tables.

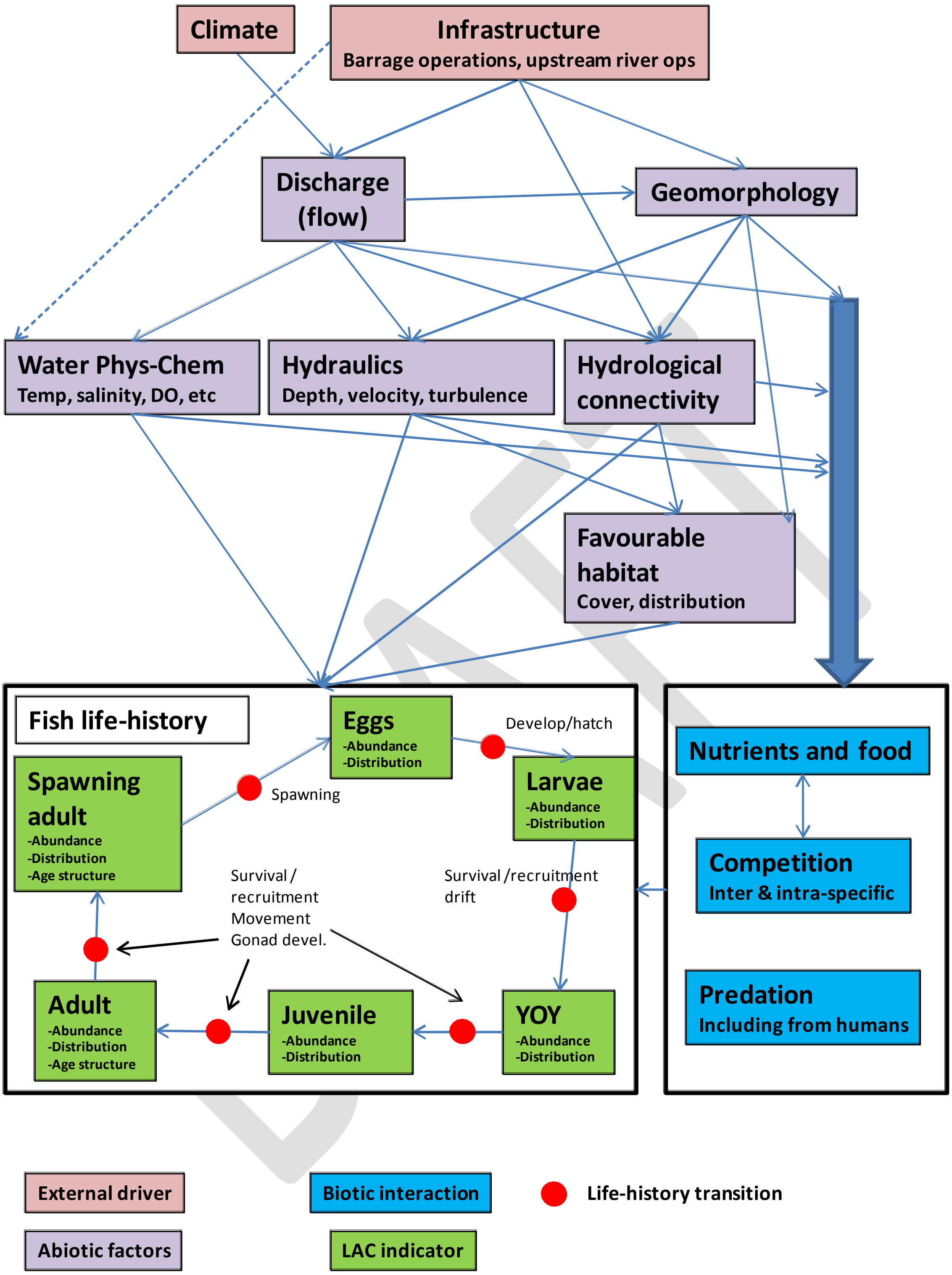

Figure D8. Generic conceptual model for fish of the Coorong, Lower Lakes and Murray Mouth Region. This model will be adapted for all species and explained with a table to be viewed alongside the diagram. The importance of different factors and interactions will differ between species.

The importance of different abiotic and biotic factors differs between species, whilst others have similar life-histories and habitat requirements and may thus respond to variability in abiotic and biotic factors in a similar fashion, and may be grouped together as ‘guilds’ (e.g. large-bodied freshwater fish, diadromous fish). Thus we have adopted a ‘guild’ and ‘representative species’ approach, adapted from that used by Bice (2010). Guilds are defined by the ‘ecological similarity’ of constituent species largely based upon life-history characteristics, habitat requirements, size and conservation status. Fish guilds and representative species are as follows,

1. *Large-bodied freshwater species*: Life-cycle is typically completed within freshwater. Adult length at maturity typically >150 mm. Most species are highly mobile. Includes threatened species (i.e. Murray cod), species that spawn on increased flows and floods (i.e. golden perch), and commercially important species. Likely important higher level consumers. Representative species: golden perch (*Macquaria ambigua ambigua*)
2. *Common small-bodied freshwater species*: Life-cycle is typically completed within freshwater. Adult length at maturity <150 mm. Generally abundant and widespread in the Lower Lakes. Likely important prey items for higher trophic levels. Representative species: Australian smelt (*Retropinna semoni*)
3. *Rare small-bodied freshwater species*: Life-cycle is typically completed within freshwater. Adult length at maturity <150 mm. Includes several threatened species (i.e. Yarra pygmy perch, southern pygmy perch, Murray hardyhead). All species have specialist habitat requirements. Representative species: Yarra pygmy perch (*Nannoperca obscura*)
4. *Alien freshwater species*: Life-cycle is typically completed within freshwater. Size at maturity varies. Representative species: common carp (Cyprinus carpio)
5. *Catadromous species*: Lifecycle characterised by adult freshwater residence, downstream migration and marine spawning, marine larval and juvenile development, followed by upstream juvenile migration into freshwater. Connectivity between freshwater and estuarine/marine environments is vital for both downstream and upstream migrations. Representative species: congolli (*Pseudaphritis urvillii*)
6. *Anadromous species*: Lifecycle characterised by adult marine residence, upstream migration and freshwater spawning, freshwater larval and juvenile development, followed by downstream juvenile migration to the marine environment. Connectivity between freshwater and estuarine/marine environments is vital for both downstream and upstream migrations. Representative species: pouched lamprey (*Geotria australis*)

7. *Estuarine species*: Life-cycle is typically completed within estuaries, adult length at maturity varies. Many of the smaller species are highly abundant and widely distributed in the CLLMM region. Many are highly tolerant of variable salinity regimes. Small-bodied species are important prey items for higher trophic levels, whilst larger species are important higher order consumers and commercially exploited species (e.g. black bream). Representative species: small-mouthed hardyhead (*Atherinosoma microstoma*)
8. *Small-bodied marine migrant*: Found in a range of marine and estuarine environments, when available, estuaries are often used during a particular life history phase (most commonly as juveniles). Adult length at maturity <150 mm. These species are often highly abundant and distributed widely in the Coorong, but commonly in the Coorong estuary. Likely important prey item for higher trophic levels. Representative species: sandy sprat (*Hyperlophus vitattus*)
9. Large-bodied marine migrant – Found in a range of marine and estuarine environments, when available, estuaries are often used during a particular life history phase (most commonly as juveniles). Adult length at maturity >150 mm. Some species may be important as prey for higher trophic levels during juvenile and even adult life stages (e.g. yellow-eyed mullet), whilst other are important higher order consumers (e.g. Australian salmon and mulloway). Representative species: mulloway (*Argyrosomus japonicus*)

Conceptual models were developed for the representative species of each guild utilising the same generic model template (Figure D1) together with species-specific tables of text (Table D2–Table D18), which highlight the differing importance of different abiotic and biotic factors, and their impact on different life-history stages and transitions. Where possible, values of abiotic and biotic variables critical to the survival of specific life stages and completion of life history transitions are included. Preliminary discussion of interactions or links to other biota is also undertaken for each representative species (Table D2–Table D18).

Table D4. Conceptual model of golden perch (as a representative of large-bodied freshwater fishes) in the Coorong and Lower Lakes. Model details critical values and/or thresholds of abiotic and biotic factors that influence specific life-history stages and transitions. DD = data deficient. * Indicates a significant link to another biotic group/model

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values/thresholds	Comments and spatial/temporal considerations
Adult survival/spawning adult/movement	Hydrological connectivity	Connectivity between Lakes and upstream reaches	Large-scale upstream migration common for this species (O'Connor et al. 2005; Leigh and Zampatti 2011). Downstream larval drift is also important. No specific data from Lower Lakes. In other regions upstream migration typically greatest in spring/summer and at elevated flows.
	Salinity	>14 g.L^{-1}	Represents LC50 value so likely not conservative. Adult fish moderate tolerance. Salinities above value across a given area (e.g. ~50%) of adult habitat for any given time, may result in unsustainable reductions in adult population
	Dissolved oxygen (DO)	2.0 mg.L^{-1} (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat may result in unsustainable reductions in adult population
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	N/A	Resides in variety of habitats in Lower Lakes – not a habitat specialist. In riverine environments typically favours complex habitats, woody debris and often fast flowing habitats in anabranch systems.
	Food resources*	Presence, abundance	Recent research (Wedderburn unpublished data) suggests that in the Lower Lakes *Macrobrachium* and small fishes, particularly juvenile bony herring, constitute the majority of adult diet.
Spawning	Discharge (hydraulics)	≥15,000 ML.day^{-1} (DD)	This species spawns and recruits on increases of within channel flow and floods. Current consensus is that flows of ≥15,000 ML.day^{-1} at the SA border are required to initiate spawning in the lower River Murray. Flows required for spawning response in the CLLMM region are unknown. Also temperature dependent

Life-history stage/transition	**Abiotic factor/Biotic factor**	**Critical values/thresholds**	**Comments and spatial/temporal considerations**
	Temperature	>20˚C	Spawning may occur at any time if discharge is high enough and water temperatures exceed 20˚C
Egg/Larval survival and recruitment to juvenile stage	Discharge (hydraulics)	≥15,000 ML.day^{-1} (DD)	Produce pelagic drifting eggs and larvae with limited swimming ability. Lack of hydraulic conditions to facilitate egg/larval drift may result in a lack of dispersal from conspecifics (e.g. siblings) and failure to find favourable nursery habitat. Recruitment typically not observed in the absence of elevated flow. Acceptance of ≥15,000 ML.day^{-1}
	Salinity	>12 g.L^{-1}	Represents LC50 value so likely not conservative. Slightly less tolerant than adults
	Dissolved oxygen (DO)	2.7 mg.L^{-1}	Appear susceptible to low DO
	pH		As per adult
	Food resources*	Presence, abundance	Zooplankton likely important – specific species unknown, likely cladocerans, copopods and rotifers as well as macroinvertebrate larvae such as chironomids
Recruitment to adult stage	Salinity	>14 g.L^{-1}	Likely as per adult
	Dissolved oxygen (DO)	2.0 mg.L^{-1} (DD)	Likely as per adult
	pH	pH <5, >10 (DD)	Likely as per adult
	Favourable habitat	N/A	Likely as per adult
	Food resources*	Presence, abundance	DD, likely macroinvertebrates

Table D5. Details of potentially significant biotic interactions between golden perch and other biota (includes other fishes and unrelated taxonomic groups)

Life-history stage/transition	Biotic group	Interaction	Comments and spatial/temporal considerations
Adult (survival)	Large macroinvertebrates (*Cherax, Macrobrachium)* Small-medium bodied fishes	Food resources (GP as predator)	Recent research (Wedderburn unpubl data) suggests that in the Lower Lakes *Macrobrachium* and small fish, particularly juvenile bony herring, constitute the majority of adult diet.
	Humans	Predation (GP as prey) (commercial fishing pressure)	Commercial catch from Lower Lakes is regularly >100 t.year^{-1} (Ferguson 2008)
	Birds	Predation (GP as prey)	Likely predated upon by piscivorous birds such as Australian pelican and great cormorant. Larger individuals likely not at risk
Larvae (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources (larval GP as predator)	Zooplankton likely important – specific species unknown, likely cladocerans, copopods and rotifers as well as macroinvertebrate larvae such as chironomids
	Fishes, Macroinvertebrates, Birds	Predation (GP as prey)	Other fishes and predacious macroinvertebrates prey upon larvae
	Fishes	Competition	Both intra and inter-specific competition between fish is believed to be greatest during the larval phase as most species are reliant on similar prey items at this stage of life
Juvenile (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources (juvenile GP as predator)	Zooplankton likely important but an increasing importance of macroinvertebrates. Specific species of greatest importance unknown but given the often variable data of adults is likely opportunistic
	Fishes, Macroinvertebrates, Birds	Predation (GP as prey)	Other fishes and birds likely prey upon juvenile GP. Species of importance likely include Australian pelican, cormorant spp, tern spp and potentially other piscivorous spp

Table D6. Conceptual model of Australian smelt (as a representative of common small-bodied freshwater fishes) in the Coorong and Lower Lakes. Model details critical values and/or thresholds of abiotic and biotic factors that influence specific life-history stages and transitions. DD = data deficient. * Indicates a significant link to another biotic group/model.

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
Adult survival/spawning adult	Salinity	>50 g.L^{-1}	Represents LC50 value so likely not conservative. Adult fish have high tolerance to elevated salinity. Salinities above value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Dissolved oxygen (DO)	2.0 mg.L^{-1}	DO tolerance considered moderate (McNeil and Closs 2007). DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	None	Considered a generalist in regards to habitat use. A pelagic species, adults are found in a range of habitats
	Food resources*	Presence, abundance	Diet includes primarily terrestrial insects and zooplankton, as well as a range of small aquatic macroinvertebrates (Lintermans 2007)
Spawning	Temperature	>11˚C	Spawning occurs over a protracted season from winter-summer. Most likely related to water temperature.
Egg development/hatching, larval survival and recruitment to juvenile stage	Salinity	DD	Egg and larval tolerance unknown
	Dissolved oxygen (DO)	2.0 mg.L^{-1} (DD)	Egg and larval tolerance unknown. Adopt adult value
	pH	pH <5, >10 (DD)	As per adult
	Food resources*	Presence, abundance	Zooplankton likely important – specific species unknown, likely cladocerans, copopods and rotifers

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
Recruitment to adult stage	Salinity	>28 $g.L^{-1}$	Represents juvenile LC50 so likely not conservative (Williams and Williams 1991). Juveniles possess a high tolerance to elevated salinity relative to other freshwater species.
	Dissolved oxygen (DO)	2.0 $mg.L^{-1}$ (DD)	Likely as per adult
	pH	pH <5, >10 (DD)	Likely as per adult
	Favourable habitat	N/A	As per adult
	Food resources*	Presence, abundance	As per adult

Table D7. Details of potentially significant biotic interactions between Australian smelt and other biota (includes other fishes and unrelated taxonomic groups)

Life-history stage/transition	**Biotic group**	**Interaction**	**Comments/spatial and temporal considerations**
Adult (survival)	Terrestrial insects, zooplankton, aquatic macroinvertebrates	Food resources (as predator)	
	Large-bodied freshwater fishes (native and alien)	Predation (as prey)	Likely preyed upon by large-bodied fishes (e.g. golden perch, redfin perch)
	Birds	Predation (as prey)	Likely predated upon by piscivorous birds. Species of importance likely include Australian pelican, cormorant spp, tern spp and potentially other piscivorous spp
Larvae (survival and recruitment)	Zooplankton	Food resources (larvae as predator)	Zooplankton likely important – specific species unknown, likely cladocerans, copopods and rotifers
	Fishes, Macroinvertebrates,	Predation (as prey)	Other fishes and predacious macroinvertebrates prey upon larvae
	Fishes	Competition	Both intra and inter-specific competition between fish is believed to be greatest during the larval phase as most species are reliant on similar prey items at this stage of life
Juvenile (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources (juvenile as predator)	Zooplankton likely important but an increasing importance of terrestrial insects. Specific species of greatest importance unknown but given the often variable data of adults is likely opportunistic
	Fishes, Macroinvertebrates, Birds	Predation (as prey)	Other fishes and birds likely prey upon juvenile AS. Species of importance likely include Australian pelican, cormorant spp, tern spp and potentially other piscivorous spp

Table D8. Conceptual model of Yarra pygmy perch (as a representative of rare small-bodied freshwater fishes) in the Coorong and Lower Lakes. Model details critical values and/or thresholds of abiotic and biotic factors that influence specific life-history stages and transitions. DD = data deficient. * Indicates a significant link to another biotic group/model

Life-history stage/transition	**Abiotic factor/Biotic factor**	**Critical values**	**Comments/spatial and temporal considerations**
Adult survival/spawning adult	Salinity	>10 $g.L^{-1}$ (DD)	Specific adult tolerance unknown. Likely not tolerant to elevated salinity
	Dissolved oxygen (DO)	2.0 $mg.L^{-1}$ (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	Presence of diverse submerged and emergent species	Habitat specialist. Previously most abundant in well-vegetated wetland habitat on Hindmarsh and Mundoo Islands, also lower Finniss (Wedderburn and Hammer 2003; Bice et al. 2011). Appears to be associated with the submergents *Myriophyllum* and *Ceratophyllum* and emergent *Schoenoplectus*
	Food resources*	Presence, abundance	Diet likely to include zooplankton and a range of small macroinvertebrates, e.g. chironomids, paratya, nymphs of other aquatic insects
	Discharge (Depth)	Lake height >0.3 m AHD	Favoured wetland habitat is high on the elevation gradient. Reduced lake level sees these sites dry first
Spawning	Temperature	>15˚C (DD)	Spawning occurs during late winter/spring (Bice and Ye 2007). Most likely related to water temperature.
Egg development/hatching, larval survival and recruitment to juvenile stage	Discharge (depth)	Lake height >0.5 m AHD	Recruitment appears greatest when lake levels are elevated and fringing vegetation (grasses) are inundated (Bice and Ye 2007)
	Salinity	>6.3 $g.L^{-1}$	Represents larval LC50 value so likely not conservative (McNeil et al. 2010).
	Dissolved oxygen (DO)	2.0 $mg.L^{-1}$ (DD)	As per adult

Life-history stage/transition	**Abiotic factor/Biotic factor**	**Critical values**	**Comments/spatial and temporal considerations**
	pH		As per adult
	Favourable habitat	Presence of diverse submerged and emergent species	Habitat specialist. Previously most abundant in well-vegetated wetland habitat on Hindmarsh and Mundoo Islands, also lower Finniss (Wedderburn and Hammer 2003; Bice et al. 2011). Appears to be associated with the submergents *Myriophyllum* and *Ceratophyllum* and emergent *Schoenoplectus*
	Food resources*	Presence, abundance	Zooplankton likely important – specific species unknown, likely cladocerans, copopods and rotifers as well as macroinvertebrate larvae such as chironomids
Recruitment to adult stage	Salinity	>14 $g.L^{-1}$	Likely as per adult
	Dissolved oxygen (DO)	2.0 $mg.L^{-1}$ (DD)	Likely as per adult
	pH	pH <5, >10 (DD)	Likely as per adult
	Favourable habitat	N/A	Likely as per adult
	Food resources*	Presence, abundance	DD, likely macroinvertebrates (e.g. amphipods, chironomids, etc).

Table D9. Details of potentially significant biotic interactions between Yarra pygmy perch and other biota (includes other fishes and unrelated taxonomic groups)

Life-history stage/transition	**Biotic group**	**Interaction**	**Comments/spatial and temporal considerations**
Adult (survival)	Macroinvertebrates, zooplankton	Food resources – predation (as predator)	Likely prey upon a variety of macroinvertebrates and zooplankton (e.g. copopods) (Sanger 1978). Important macroinvertebrates would potentially include amphipods, chironomids, nymphs of terrestrial insects and other macroinvertebrates.
	Fishes, birds	Predation (as prey)	Likely predated upon by piscivorous fishes such as redfin perch and golden perch. The high affinity of this species for well vegetated habitats is likely related to the protection from predation provided by this type of habitat. May be highly susceptible to predation when favourable habitat lacking
	Submerged and emergent vegetation	Favourable habitat (all life stages)	YPP are highly associated with submerged and emergent vegetation (Woodward and Malone 2002). In particular the submerged *Myriophyllum* spp and *Ceratophyllum* spp together with the emergent *Schoenoplectus validus* appear important. Such habitat provides protection from predation but also represents foraging habitat and spawning substrate
Egg/Larvae (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources – predation (larvae as predator)	Zooplankton likely important – specific species unknown
	Fishes	Predation (prey)	A variety of other fishes likely prey upon eggs and larvae
	Fishes	Competition	Both intra and inter-specific competition between fish is believed to be greatest during the larval phase as most species are reliant on similar prey items at this stage of life
	Submerged and emergent vegetation	Favourable habitat (all life stages)	As above. Additionally, greatest abundance of YPP in the past has been recorded following winter/spring with surcharged lake levels. Several experts believe increased inundation of littoral grasses may enhance egg and larval survival and thus recruitment in this species

Life-history stage/transition	Biotic group	Interaction	Comments/spatial and temporal considerations
Juvenile (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources – predation (juvenile as predator)	Zooplankton likely important but an increasing importance of macroinvertebrates. Specific species of greatest importance unknown but is likely somewhat opportunistic
	Fishes, Macroinvertebrates, Birds	Predation (as prey)	Other fishes and birds likely prey upon juvenile YPP. A variety of fishes may prey upon juvenile YPP due to their small size.

Table D10. Conceptual model of common carp (as a representative of alien freshwater fishes) in the Coorong and Lower Lakes. Model details critical values and/or thresholds of abiotic and biotic factors that influence specific life-history stages and transitions. DD = data deficient. * Indicates a significant link to another biotic group/model

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
Adult survival/spawning adult/movement	Hydrological connectivity	Connectivity between Lakes and upstream reaches (DD)	This species is highly mobile (Jones and Stuart 2009) although there are no specific investigations from the Lower Lakes.
	Salinity	>12.8 g.L^{-1}	Represents LC50 value so likely not conservative (Whiterod and Walker 2006).
	Dissolved oxygen (DO)	1.0 mg.L^{-1}	Highly tolerant of low DO tolerance (McNeil 2004).
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	none	Resides in variety of habitats, although appears to favour slow-flowing streams, rivers and lakes.
	Food resources*	Presence, abundance	Omnivore, feeds on a wide variety plant material and animals (e.g. terrestrial insects, aquatic macroinvertebrates, zooplankton, fish) (Lintermans 2007)
Spawning	Discharge (depth)	Lake height (>0.75 m AHD)	Prefers shallow, warm, well-vegetated areas for spawning (Crivelli 1981; Koehn et al. 2000). Such areas are common in the Lower Lakes at elevated water levels.
	Temperature	>17˚C	Spawning may occur at any when water temperature >17˚C. Typically late winter - summer
Egg/Larval survival and recruitment to juvenile stage	Salinity	>8.3 g.L^{-1} >12 g.L^{-1}	Sperm motility and thus fertilisation impacted at salinity >8.3 g.L^{-1}. Juvenile LC50 >12 g.L^{-1} (Karimov and Keyser 1998).
	Dissolved oxygen (DO)	1.0 mg.L^{-1} (DD)	Tolerance unknown, acceptance of adult value
	pH		As per adult
	Food resources*	Presence, abundance	Zooplankton likely important – specific species unknown, likely cladocerans, copopods and rotifers as well as macroinvertebrate larvae such as chironomids

Life-history stage/transition	**Abiotic factor/Biotic factor**	**Critical values**	**Comments/spatial and temporal considerations**
Recruitment to adult stage	Salinity	>12.8 g.L^{-1}	Likely as per adult
	Dissolved oxygen (DO)	1.0 mg.L^{-1} (DD)	Likely as per adult
	pH	pH <5, >10 (DD)	Likely as per adult
	Favourable habitat	Presence of vegetated wetland, floodplain habitats	Whilst habitat use is variable, vegetated wetland habitat appears preferred
	Food resources*	Presence, abundance	Likely omnivorous consuming a variety of food items as in adults

Table D11. Details of potentially significant biotic interactions between common carp and other biota (includes other fishes and unrelated taxonomic groups)

Life-history stage/transition	**Biotic group**	**Interaction**	**Comments/spatial and temporal considerations**
Adult (survival)	Macroinvertebrates (various spp.), small-bodied fishes, terrestrial insects	Food resources (as predator)	Likely consumes a wide variety of food items
	Humans	Predation (as prey) (commercial fishing pressure)	Targeted in commercial catch from Lower Lakes
Larvae (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources (larvae as predator)	Zooplankton likely important – specific species unknown, likely cladocerans, copopods and rotifers as well as macroinvertebrate larvae such as chironomids
	Fishes, Macroinvertebrates, Birds	Predation (as prey)	Other fishes and predacious macroinvertebrates likely prey upon larvae
	Fishes	Competition	Both intra and inter-specific competition between fish is believed to be greatest during the larval phase as most species are reliant on similar prey items at this stage of life
Juvenile (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources (juvenile as predator)	As per adult, likely consumes a variety food items
	Fishes, Macroinvertebrates, Birds	Predation (as prey)	Other fishes and birds likely prey upon juvenile CC. Species of importance likely include Australian pelican, cormorant spp, tern spp and potentially other piscivorous spp

Table D12. Conceptual model of congolli (as a representative of catadromous fishes) in the Coorong and Lower Lakes. Model details critical values and/or thresholds of abiotic and biotic factors that influence specific life-history stages and transitions. DD = data deficient. * Indicates a significant link to another biotic group

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
Adult survival	Salinity	>100 g.L^{-1}	Adult fish highly tolerant. Salinities above value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Dissolved oxygen (DO)	<2.0 mg.L^{-1} (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	N/A (DD)	Resides in variety of habitats – not a habitat specialist
	Food resources*	N/A	Data deficient on diet. Likely generalist feeding on various macroinvertebrates and small-bodied fishes
Spawning - Downstream migration	Hydrological connectivity	April - August	Requires connectivity between Lake Alexandrina and Coorong and, Coorong and Southern Ocean from April – August. Adults migrate downstream to spawn (Crook et al. 2010; Zampatti et al. 2011b). Adult populations may persist during conditions of disconnection of freshwater and estuarine habitats for a period of at least three years (Zampatti et al. 2011b).
Recruitment to YOY/early juvenile stage	Salinity	DD	Larval tolerant unknown. Salinities above critical value within the Coorong Estuary may result in recruitment failure. Recruitment failure may occur for a period of at least 3 years (see above)
	Dissolved oxygen (DO)		As per adult
	pH		As per adult
	Food resources*	DD	Zooplankton likely important – specific species unknown. This relates to larval food resources in ocean and Coorong

Life-history stage/transition	**Abiotic factor/Biotic factor**	**Critical values**	**Comments/spatial and temporal considerations**
Recruitment to juvenile/adult (upstream migration)	Hydrological connectivity	October - January	Juvenile fish migrate upstream during spring/summer (Zampatti et al. 2011a). Failed recruitment to the adult population may occur for a period of at least 3 years with population still remaining viable
	Salinity	>92 $g.L^{-1}$	Juvenile fish highly tolerant (SARDI unpublished data). Salinities above value within the Coorong Estuary will result in recruitment failure. Recruitment failure may occur for a period of at least 3 years (see above)
	Dissolved oxygen (DO)	<2.0 $mg.L^{-1}$ (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of juvenile habitat will result in unsustainable reductions in adult population
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	N/A	Resides in variety of habitats – not a habitat specialist
	Food resources*	N/A	Data deficient on diet. Likely generalist feeding on various zooplankton and macroinvertebrates. Relates to prey abundance within Lower Lakes

Table D13. Details of potentially significant biotic interactions between congolli and other biota (includes other fishes and unrelated taxonomic groups)

Life-history stage/transition	**Biotic group**	**Interaction**	**Comments/spatial and temporal considerations**
Adult (survival)	Macroinvertebrates (various?) Small-bodied fishes	Food resources – predation (as predator)	Likely prey upon a variety of organisms
	Birds, seals	Predation (as prey)	Likely predated upon by piscivorous birds such as Australian pelican and great cormorant and seals. Larger individuals likely not at risk
Larvae (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources – predation (larvae as predator)	Zooplankton likely important – specific species unknown
	Fishes, Birds	Predation (as prey)	Other fishes likely prey upon larvae
	Fishes	Competition	Both intra and inter-specific competition between fish is believed to be greatest during the larval phase as most species are reliant on similar prey items at this stage of life
Juvenile (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources – predation (juvenile as predator)	Zooplankton likely important but an increasing importance of macroinvertebrates. Specific species of greatest importance unknown but is likely opportunistic
	Fishes, Macroinvertebrates, Birds	Predation (as prey)	Other fishes and birds likely prey upon juvenile congolli. Species of importance likely include Australian pelican, cormorant spp, tern spp and potentially other piscivorous spp (including con-specifics)

Table D14. Conceptual model of pouched lamprey (as a representative of anadromous fishes) in the Coorong and Lower Lakes. Model details critical values and/or thresholds of abiotic and biotic factors that influence specific life-history stages and transitions. DD = data deficient. * Indicates a significant link to another biotic group

Life-history stage/transition	Driver/Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
Adult survival	Salinity	>35 $g.L^{-1}$ (DD)	Adult tolerance unknown. Typically marine so a marine value used.
	Dissolved oxygen (DO)	<2.0 $mg.L^{-1}$ (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	N/A	Resides in marine environment. CLLMM region represents a 'conduit' to spawning habitats
	Food resources*	N/A	Parasite of teleost fish in marine environment. Does not feed on spawning migration
Spawning - Upstream migration	Hydrological connectivity	June (?) - November	Requires connectivity between Southern Ocean and Coorong, Coorong and lake Alexandrina, and within the Lower River Murray from June – November (Bice et al. 2012b). Adults migrate upstream to spawn. Adult populations may persist during conditions of disconnection of freshwater and estuarine habitats for a period of at least three years.
Recruitment to YOY/early juvenile stage	Salinity	DD	Specific tolerance unknown
	Dissolved oxygen (DO)	<2.0 $mg.L^{-1}$ (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across (xx%) of adult habitat will result in unsustainable reductions in adult population

Life-history stage/transition	**Driver/Abiotic factor/Biotic factor**	**Critical values**	**Comments/spatial and temporal considerations**
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Food resources*	Presence/absence	Filter feeder of detritus, algae and other microorganisms (Lintermans 2007)
	Favourable habitat	Presence of soft substrates in slow-flowing waters	Specific habitats in CLLMM region unknown. Ammocoetes have been collected in the River Murray below Lock 1 (SARDI unpublished data).
Recruitment to juvenile/adult (downstream migration)	Hydrological connectivity	Spring (DD)	Migrates downstream to marine habitats. Specific timing in the CLLMM region unknown but connectivity is vital
	Salinity	DD	
	Dissolved oxygen (DO)	<2.0 mg.L^{-1} (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of juvenile habitat will result in unsustainable reductions in adult population

NOTE: There are no data on significant biotic interactions of this species within the CLLMM region.

Table D15. Conceptual model of small-mouthed hardyhead (as a representative of small-bodied estuarine fishes) in the Coorong and Lower Lakes. Model details critical values and/or thresholds of abiotic and biotic factors that influence specific life-history stages and transitions. DD = data deficient. * Indicates a significant link to another biotic group/model

Life-history stage/transition	**Abiotic factor/Biotic factor**	**Critical values**	**Comments/spatial and temporal considerations**
Adult survival/spawning adult	Salinity	>100 $g.L^{-1}$	Adults are extremely tolerant to both low and elevated salinity. 108 $g.L^{-1}$ represents a laboratory LC50 (Lui 1969), but individuals have in fact been sampled at greater salinities in the wild. 100 $g.L^{-1}$ however represents a more conservative figure
	Dissolved oxygen (DO)	2.0 $mg.L^{-1}$ (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	Presence of submerged estuarine vegetation (e.g. *Ruppia* spp, *Lamprothamnium*) (DD)	Data deficient. Little is known of the habitat associations of this species. Atherinids, however, are commonly associated with vegetation. Probably more important for spawning and recruitment
	Food resources*	Presence, abundance	Deegan et al. (2010) suggest that *Capitella* is the key dietary item of adult SMHH as well as amphipods, small crustaceans (e.g. amphipods) and other polychaetes
Spawning	Temperature	(DD)	Spawning occur during late spring/summer. Most likely related to water temperature (Molsher et al. 1994).

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
	Favourable habitat*	Presence of submerged estuarine vegetation (e.g. *Ruppia* spp, *Lamprothamnium*) (DD)	Data deficient. Has adhesive eggs. Most atherinids attach eggs to vegetation and SMHH thought to do the same. *Ruppia* spp likely to be of key importance and potentially in the past other species such as *Lamprothamnium, Potamogeton pectinatus* and *Lepoleana cylindricarpa*. Significant losses of submerged vegetation in the Coorong lagoons may have had a great impact on this species
Egg development/hatching, larval survival and recruitment to juvenile stage	Salinity	>80 g.L^{-1} (DD)	Data deficient. Eggs and larvae are undoubtedly highly tolerant based on observations of YOY in saline waters
	Dissolved oxygen (DO)	2.0 mg.L^{-1} (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	pH		As per adult
	Favourable habitat*	Presence of submerged estuarine vegetation (e.g. *Ruppia* spp, *Lamprothamnium*) (DD)	Data deficient. Larvae and juveniles may favour such habitat. Likely increased survival due to shelter from predation.
	Food resources*	Presence, abundance	Zooplankton likely important – specific species unknown, likely cladocerans, copopods and rotifers as well as macroinvertebrate such as chironomids
Recruitment to adult stage	Salinity	>100 g.L^{-1}	Likely as per adult
	Dissolved oxygen (DO)	2.0 mg.L^{-1} (DD)	Likely as per adult
	pH	pH <5, >10 (DD)	Likely as per adult
	Favourable habitat	N/A	Likely as per adult
	Food resources*	Presence, abundance	DD, likely macroinvertebrates (e.g. amphipods, chironomids, etc).

Table D16. Details of potentially significant biotic interactions between small-mouthed hardyhead and other biota (includes other fishes and unrelated taxonomic groups)

Life-history stage/transition	Biotic group	Interaction	Comments/spatial and temporal considerations
Adult (survival)	Macroinvertebrates (various)	Food resources – predation (as predator)	Likely prey upon a variety of macroinvertebrates. Stable isotope work suggests *Capitella* is highly important (Deegan et al. 2010). Also crustaceans (e.g. amphipods) and other polychaetes. Chironomids and other macroinvertebrates also likely constitute part of diet.
	Fishes, birds	Predation (as prey)	Heavily predated upon by a range of piscivorous birds (particularly in the north and south lagoons) particularly fairy terns and other tern species. Also predated upon by piscivorous fishes, i.e. black bream, mulloway and Australian salmon (Deegan et al. 2010)
	Submerged estuarine vegetation	Favourable habitat (all life stages)	Submerged estuarine vegetation is likely preferred habitat for this species. Broad-scale loss of this habitat in the Coorong has had an unknown impact on this species.
Egg/Larvae (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources – predation (larvae as predator)	Zooplankton and various small macroinvertebrates likely important – specific species unknown
	Fishes	Predation (as prey)	A variety of other fishes likely prey upon eggs and larvae
	Fishes	Competition	Both intra and inter-specific competition between fish is believed to be greatest during the larval phase as most species are reliant on similar prey items at this stage of life
	Submerged estuarine vegetation vegetation	Favourable habitat	As above. Additionally, vegetation likely utilised as spawning substrate and nursery area for larvae/juveniles
Juvenile (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources – predation (juvenile as predator)	Zooplankton likely important but an increasing importance of macroinvertebrates. Specific species of greatest importance unknown but is likely somewhat opportunistic
	Fishes, Birds	Predation (as prey)	As per adult

Table D17. Conceptual model of sandy sprat (as a representative of marine migrant fishes) in the Coorong and Lower Lakes. Model details critical values and/or thresholds of abiotic and biotic factors that influence specific life-history stages and transitions. DD = data deficient. * Indicates a significant link to another biotic group/model

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
Adult survival/spawning adult	Salinity	>40 $g.L^{-1}$ (DD)	Data deficient. As a marine migrant, tolerance likely close to marine salinity levels. Typically not abundant in North or South Lagoons during times of elevated salinity (Noell et al. 2009).
	Dissolved oxygen (DO)	2.0 $mg.L^{-1}$ (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population within the region.
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	N/A	Species is pelagic and thus appears to not have a specific microhabitat affinity
	Food resources*	Presence, abundance	No published literature but likely pelagic zooplanktivore
Spawning	Temperature	(DD)	Spawning occur during through spring/summer potentially related to water temperature (Rogers and Ward 2007).
	Favourable habitat*	(DD)	Pelagic spawning species
Egg development/hatching, larval survival and recruitment to juvenile stage	Salinity	>40 $g.L^{-1}$ (DD)	Data deficient. Adopt near marine value
	Dissolved oxygen (DO)	2.0 $mg.L^{-1}$ (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	pH		As per adult
	Favourable habitat		Data deficient. Larvae and juveniles may favour such habitat. Likely increased survival due to shelter from predation.

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
	Food resources*	Presence, abundance	No published literature but likely pelagic zooplanktivore
Recruitment to adult stage	Salinity	>40 g.L^{-1}	Likely as per adult
	Dissolved oxygen (DO)	2.0 mg.L^{-1} (DD)	Likely as per adult
	pH	pH <5, >10 (DD)	Likely as per adult
	Favourable habitat	N/A	Likely as per adult
	Food resources*	Presence, abundance	No published literature but likely pelagic zooplanktivore

Table D18. Details of potentially significant biotic interactions between sandy sprat and other biota (includes other fishes and unrelated taxonomic groups)

Life-history stage/transition	Biotic group	Interaction	Comments and spatial/temporal considerations
Adult (survival)	Zooplankton	Food resources – predation (as predator)	Likely preys upon a variety of zooplankton.
	Fishes, birds	Predation (as prey)	Typically an important food source of piscivourous fishes (e.g. black bream, mulloway and Australian salmon) and birds (e.g. tern spp, little penguin) (Klomp and Wooller 1988; Hoedt and Dimmlich 1994; Deegan et al. 2010). Likely important prey for higher trophic levels in the Coorong Estuary where it is often the most abundant small-bodied fish species (Bice et al. 2012b)
Egg/Larvae (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources – predation (larvae as predator)	Likely preys upon a variety of zooplankton.
	Fishes	Predation (as prey)	A variety of other fishes likely prey upon eggs and larvae
Juvenile (survival and recruitment)	Zooplankton	Food resources – predation (juvenile as predator)	Likely preys upon a variety of zooplankton.
	Fishes, Birds	Predation (as prey)	As per adult but potentially even more important as juveniles are typically more abundant within the Coorong than adults.

Table D19. Conceptual model of mulloway (as a representative of marine migrant fishes) in the Coorong and Lower Lakes. Model details critical values and/or thresholds of abiotic and biotic factors that influence specific life-history stages and transitions. DD = data deficient. * Indicates a significant link to another biotic group/model

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
Adult survival/spawning adult	Salinity	>40 $g.L^{-1}$ (DD)	Data deficient. As a marine migrant, tolerance likely close to marine salinity levels. Typically not abundant in North or South Lagoons during times of elevated salinity (Noell et al. 2009).
	Dissolved oxygen (DO)	2.0 $mg.L^{-1}$ (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population within the region.
	pH	pH <5, >10 (DD)	Data deficient on tolerance to low or high pH. Acceptance of generic value for fish tolerance. pH above or below tolerance values across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	Favourable habitat	N/A	Adults are more common outside of CLLMM region. Resides in inshore habitats of Coorong ocean beach. Aggregate at Murray Mouth under certain conditions
	Food resources*	Presence, abundance	Carnivore consuming a range of fishes and crustaceans (crabs, prawns, etc) (Taylor et al. 2006).
Spawning	Hydrology (flow at Murray Mouth)	(DD)	Specifics of local spawning are unknown but what appear to be spawning aggregations often occur at the Murray Mouth in spring/summer coinciding with elevated river discharge
	Favourable habitat*	(DD)	Pelagic spawning species
Egg development/hatching, larval survival and recruitment to juvenile stage	Salinity	>40 $g.L^{-1}$ (DD)	Data deficient. Adopt near marine value
	Dissolved oxygen (DO)	2.0 $mg.L^{-1}$ (DD)	Data deficient on DO tolerance. Acceptance of generic value for fish tolerance. DO below tolerance value across a given area (e.g. ~50%) of adult habitat will result in unsustainable reductions in adult population
	pH		As per adult

Life-history stage/transition	Abiotic factor/Biotic factor	Critical values	Comments/spatial and temporal considerations
	Favourable habitat (hydrology, barrage discharge)	Brackish (10–35 g.L^{-1}) estuarine salinity	Juveniles prefer estuarine habitat of brackish salinity. Years of elevated freshwater inflow are correlated with enhanced recruitment (Ferguson et al. 2008)
	Food resources*	Presence, abundance	Carnivore consuming a range of fishes and crustaceans (crabs, prawns, etc) (Taylor et al. 2006; Deegan et al. 2010).
Recruitment to adult stage	Salinity	>40 g.L^{-1} (DD)	Likely as per adult
	Dissolved oxygen (DO)	2.0 mg.L^{-1} (DD)	Likely as per adult
	pH	pH <5, >10 (DD)	Likely as per adult
	Favourable habitat (hydrology, barrage discharge)	Brackish (10–35 g.L^{-1}) estuarine salinity	Juveniles prefer estuarine habitat of brackish salinity. Years of elevated freshwater inflow are correlated with enhanced recruitment (Ferguson et al. 2008)
	Food resources*	Presence, abundance	Carnivore consuming a range of fishes and crustaceans (crabs, prawns, etc) (Taylor et al. 2006).

Table D20. Details of potentially significant biotic interactions between mulloway and other biota (includes other fishes and unrelated taxonomic groups)

Life-history stage/transition	Biotic group	Interaction	Comments and spatial/temporal considerations
Adult (survival)	Fishes, crustaceans (crabs, etc)	Food resources – predation (as predator)	Preys upon a variety of fishes and crustaceans (Taylor et al. 2006).
	Man	Predation (as prey)	Commercial catch from CLLMM region is regularly >50 $t.year^{-1}$ (Ferguson et al. 2013)
Egg/Larvae (survival and recruitment)	Zooplankton, macroinvertebrates	Food resources – predation (larvae as predator)	Likely preys upon a variety of marine zooplankton.
	Fishes	Predation (as prey)	A variety of other fishes (including conspecifics) likely prey upon eggs and larvae
Juvenile (survival and recruitment)	Fishes, crustaceans (crabs, etc)	Food resources – predation (juvenile as predator)	Preys upon a variety of fishes and crustaceans (Taylor et al. 2006; Deegan et al. 2010). Important species likely include sandy sprat, small-mouthed hardyhead, yellow-eyed mullet and Australian salmon.
	Man	Predation (as prey)	Commercial catch from CLLMM region is regularly >50 $t.year^{-1}$. Importantly close to 100% of commercial take from within the Coorong represent juvenile individuals (Ferguson et al. 2013)

Key thresholds

To aid in the development of Limits of Acceptable Change for the CLLMM it is vital to understand thresholds that once breached, may induce changes in indicator species populations. Whilst a variety of factors may influence the persistence and population dynamics of species within the region, one or two factors may be highlighted that disproportionately influence critical life-history stages and/or transitions. Thus, utilising the information provided in the conceptual model tables, key thresholds (for abiotic and/or biotic factors) of greatest importance for each of the representative species were determined and are presented in Table D19. Key thresholds take both spatial and temporal scales into consideration. For instance, connectivity is vitally important in the life-history of diadromous fish (both catadromous and anadromous representatives) that require migration in both upstream and downstream directions at given times of year. Nonetheless, disruption of connectivity and migratory pathways for short periods (e.g. <3 years) are unlikely to result in irreversible changes to an indicator species populations if the species is long-lived. Alternatively, the breaching of other thresholds (e.g. salinity or pH), which result in immediate and considerable population loss, or impact short-lived species, must consider shorter temporal scales. Ultimately, these key thresholds will lead to the development of suitable LACs for the determined indicator species.

Table D21. Key thresholds for critical life-history stages and transitions of indicator species representatives

Species	**Critical life-history stage/transition**	**Key threshold**	**Comments/links**	**Potential metrics**
Golden perch	Spawning and recruitment	Hydrological variability (River discharge) - Sufficient to stimulate spawning and enhance recruitment (≥15,000 ML.d^{-1} in the lower River Murray) - At least every 5–8 years	Population age structure of golden perch is often characterised by a small number of dominant age classes (Zampatti and Leigh 2013). The presence of several age classes provides population resilience particularly if younger age classes are regularly recruiting to the population. Golden perch is a long-lived species and as such recruitment does not need to occur every year. Nonetheless no recruitment for 5-8 years may unsustainably reduce population resilience	- Population age structure (multiple year classes present with ≤5 years between cohorts)
Yarra pygmy perch	All life history stages and transitions	-Presence of wetland and littoral habitat with diverse submerged (i.e. *Myriophyllum, Ceratophyllum, Vallisneria*) and, to a lesser degree, emergent (i.e. *Schoenoplectus*, grasses) vegetation	YPP are highly associated with submerged and emergent vegetation in fringing wetlands of the Lower Lakes. Yarra pygmy perch resides in these habitats throughout ontogeny and thus favourable vegetated habitat is vital for all life stages and transitions between life stages. Provides shelter from predation, foraging habitat and spawning substrate. Favoured wetland habitat is typically high on the elevation gradient and is thus affected by water level. Unlikely to survive prolonged loss of favourable habitat	- Presence of Yarra pygmy perch - Continued presence of a given area of favourable habitat

Species	**Critical life-history stage/transition**	**Key threshold**	**Comments/links**	**Potential metrics**
Australian smelt	Spawning and recruitment	Salinity - >25 g.L^{-1} throughout the region for any period of time	Salinity above juvenile tolerance would likely result in recruitment failure and significant population decline given the species is short-lived (1–2 years). Nonetheless, source populations exist upstream.	-Abundance & distribution -Salinity regime
Congolli	Downstream migration (spawning) followed by upstream migration (recruitment)	Hydrological connectivity between the Lower Lakes, Coorong and Southern Ocean - required during winter (downstream spawning migration) and following summer (upstream juvenile migration) - At least 1 year out of every 3	Downstream spawning migration occurs in winter followed by an upstream juvenile migration in summer. Hydrological connectivity in winter must be followed by connectivity in summer. During the recent drought the population became dominated by fish >4 years of age (SARDI unpublished data) with no younger fish present due to hydrological disconnection and failed recruitment. Longevity of species unknown but appears species may persist through 3 years of failed or minimal recruitment.	- Population age structure (youngest age classes in freshwater habitats <4 years of age) -Hydrological connectivity (1 in 3 years).
Pouched lamprey	Upstream migration (spawning) followed by downstream migration (recruitment)	Hydrological connectivity between the Lower Lakes, Coorong and Southern Ocean - required during winter/spring for upstream spawning migrations and downstream juvenile migrations - Connectivity at least 1 year out of every 3	Lamprey were detected at the Murray Barrages in 2006/07 but were absent for the entire period 2007–2010. Nonetheless the species was detected at the Murray Barrages in 2011 (Bice et al. 2012b), suggesting population persistence is not effected by periods of disconnection of up to 3 years	- Presence of upstream migrants (at least once every three years)

Species	**Critical life-history stage/transition**	**Key threshold**	**Comments/links**	**Potential metrics**
Small-mouthed hardyhead	All life history stages and transitions	Coorong salinity - Salinity >100 g.L^{-1}	Highly tolerant species but prefers salinity <100 g.L^{-1}. Salinity above this level restricts distribution. May impact higher trophic levels which prey upon this species.	-Abundance & distribution -Salinity regime
Sandy sprat	Juvenile	No critical threshold Secondary threshold - Hydrological variability (barrage discharge)	Abundance greatest in years of freshwater inflow (Bice et al. 2012b). Important as prey item for higher trophic levels.	-Abundance & distribution
Mulloway	Juvenile (survival and recruitment to adult population)	Hydrological variability (barrage discharge) -Salinity <35 g.L^{-1} in Coorong Estuary - Significant barrage discharge at least every 5 years	Spawning and enhanced recruitment (i.e. strong year classes) are correlated with years of high freshwater discharge and brackish salinities within the Coorong (Ferguson et al. 2008). Mulloway are a long-lived species and thus do not require strong annual recruitment. Nonetheless, diverse population age structure provides population resilience.	- Population age structure (multiple year classes present with ≤5 years between strong cohorts)

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Appendix E – Proportion of suitable sites in the Coorong for vegetation, invertebrate, fish and bird indicators and likelihood of poor, moderate and good ecological condition

Table E1. Proportion of suitable sites out of those surveyed for vegetation, invertebrate, fish and bird indicators selected for inclusion in a prototype model of condition. Coorong sites only are included as an illustration. A total of 14 sites were used in each year, corresponding with the salinity cells in the hydrodynamic model for the Coorong (Webster 2010). Sites were considered suitable for each taxon where environmental conditions at least met the limit of acceptable change (LAC) as documented below.

		Year													
Taxon	**LAC**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Invertebrates															
Arthritica helmsi	Salinity 10-55 g/L	57%	50%	57%	57%	64%	57%	43%	86%	71%	36%	36%	50%	29%	21%
Capitella spp.	Salinity 5-55 g/L	64%	64%	71%	71%	79%	64%	64%	100%	79%	43%	50%	57%	36%	21%
Nephtys australiensis	Salinity 10-60 g/L	57%	50%	57%	57%	64%	57%	43%	86%	71%	57%	43%	50%	36%	29%
Amphipoda	Salinity 10-60 g/L	57%	50%	57%	57%	64%	57%	43%	86%	71%	57%	43%	50%	36%	29%
Chironomidae	Salinity <78 g/L	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	57%	50%
Simplisetia aequisetis	Salinity 10-35 g/L	14%	0%	14%	7%	14%	14%	7%	36%	21%	14%	14%	29%	0%	0%
Plants															
Phragmites australis, Typha domingensis	Water level > 0 m AHD and Salinity < 22 g/L	0%	0%	0%	0%	21%	14%	29%	0%	0%	0%	0%	0%	0%	0%
Diverse reed beds	Water level > 0 m AHD	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Muehlenbeckia florulenta	Water level > 0.8 m AHD and Salinity < 4.4 g/L	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ruppia megacarpa	Salinity < 46 g/L	100%	93%	100%	64%	64%	100%	100%	100%	57%	57%	57%	50%	14%	14%
Ruppia tuberosa	Water level 0.3 - 0.9 m AHD and Salinity < 210 g/L	43%	100%	0%	43%	50%	100%	100%	0%	50%	43%	93%	0%	50%	0%

		Year													
Taxon	**LAC**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Lamprothamnium macropogon	Salinity < 230 g/L	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Freshwater submergent plant communities	Water level > 0.2 m AHD and Salinity < 20,000 µS/cm	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Melaleuca halmaturorum	Water level > 0.2 m AHD downstream of barrages	100%	100%	43%	100%	100%	100%	100%	100%	100%	100%	100%	50%	57%	50%
Samphire and salt marsh communities	Water level > 0.2 m AHD in the Coorong	100%	100%	43%	100%	100%	100%	100%	100%	100%	100%	100%	50%	57%	50%
Fish															
Yarra pygmy perch	Adequate coverage of submerged vegetation	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Small-mouthed hardyhead	Salinity 35 - 110 g/L	0%	0%	0%	29%	21%	0%	0%	0%	29%	36%	36%	43%	50%	36%
Birds															
Fairy tern	Salinity 35-110 g/L	0%	0%	0%	29%	21%	0%	0%	0%	29%	36%	36%	43%	50%	36%
Black swan	Water depth 20 - 130 cm / 0.2 - 1.3 m and Salinity < 22 g/L and links to submerged plants	0%	0%	0%	0%	21%	14%	29%	0%	0%	0%	0%	0%	0%	0%

Table E2. Likelihood that the Coorong is in poor ecological condition based on a fuzzy-logic classifier assessing the proportion of suitable sites. Coorong sites only are included as an illustration. A total of 14 sites were used in each year, corresponding with the salinity cells in the hydrodynamic model for the Coorong (Webster 2010). Sites were considered suitable for each taxon where environmental conditions at least met the limit of acceptable change (LAC) as documented in Table E1.

	Year													
Taxon	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Invertebrates														
Arthritica helmsi	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	23%	37%
Capitella spp.	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	37%
Nephtys australiensis	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	23%
Amphipoda	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	23%
Chironomidae	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Simplisetia aequisetis	63%	90%	63%	77%	63%	63%	77%	0%	37%	63%	63%	23%	90%	90%
Plants														
Phragmites australis, Typha domingensis	90%	90%	90%	90%	37%	63%	23%	90%	90%	90%	90%	90%	90%	90%
Diverse reed beds	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Muehlenbeckia florulenta	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Ruppia megacarpa	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	63%	63%
Ruppia tuberosa	0%	0%	90%	0%	0%	0%	0%	90%	0%	0%	0%	90%	0%	90%
Lamprothamnium macropogon	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Freshwater submergent plant communities	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Melaleuca halmaturorum	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Samphire and salt marsh communities	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fish														
Yarra pygmy perch	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Small-mouthed hardyhead	90%	90%	90%	23%	37%	90%	90%	90%	23%	0%	0%	0%	0%	0%

	Year													
Taxon	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Birds														
Fairy tern	90%	90%	90%	23%	37%	90%	90%	90%	23%	0%	0%	0%	0%	0%
Black swan	90%	90%	90%	90%	37%	63%	23%	90%	90%	90%	90%	90%	90%	90%

Table E3. Likelihood that the Coorong is in moderate ecological condition based on a fuzzy-logic classifier assessing the proportion of suitable sites. Coorong sites only are included as an illustration. A total of 14 sites were used in each year, corresponding with the salinity cells in the hydrodynamic model for the Coorong (Webster 2010). Sites were considered suitable for each taxon where environmental conditions at least met the limit of acceptable change (LAC) as documented in Table E1.

	Year													
Taxon	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Invertebrates														
Arthritica helmsi	61%	74%	61%	61%	49%	61%	100%	0%	23%	100%	100%	74%	74%	61%
Capitella spp.	49%	49%	23%	23%	10%	49%	49%	0%	10%	100%	74%	61%	100%	61%
Nephtys australiensis	61%	74%	61%	61%	49%	61%	100%	0%	23%	61%	100%	74%	100%	74%
Amphipoda	61%	74%	61%	61%	49%	61%	100%	0%	23%	61%	100%	74%	100%	74%
Chironomidae	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	61%	74%
Simplisetia aequisetis	36%	10%	36%	23%	36%	36%	23%	100%	61%	36%	36%	74%	10%	10%
Plants														
Phragmites australis, Typha domingensis	10%	10%	10%	10%	61%	36%	74%	10%	10%	10%	10%	10%	10%	10%
Diverse reed beds	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Muehlenbeckia florulenta	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Ruppia megacarpa	0%	0%	0%	49%	49%	0%	0%	0%	61%	61%	61%	74%	36%	36%
Ruppia tuberosa	100%	0%	10%	100%	74%	0%	0%	10%	74%	100%	0%	10%	74%	10%
Lamprothamnium macropogon	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Freshwater submergent plant communities	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Melaleuca halmaturorum	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	74%	61%	74%
Samphire and salt marsh communities	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	74%	61%	74%
Fish														
Yarra pygmy perch	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Small-mouthed hardyhead	10%	10%	10%	74%	61%	10%	10%	10%	74%	100%	100%	100%	74%	100%

	Year													
Taxon	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Birds														
Fairy tern	10%	10%	10%	74%	61%	10%	10%	10%	74%	100%	100%	100%	74%	100%
Black swan	10%	10%	10%	10%	61%	36%	74%	10%	10%	10%	10%	10%	10%	10%

Table E3. Likelihood that the Coorong is in good ecological condition based on a fuzzy-logic classifier assessing the proportion of suitable sites. Coorong sites only are included as an illustration. A total of 14 sites were used in each year, corresponding with the salinity cells in the hydrodynamic model for the Coorong (Webster 2010). Sites were considered suitable for each taxon where environmental conditions at least met the limit of acceptable change (LAC) as documented in Table E1.

	Year													
Taxon	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Invertebrates														
Arthritica helmsi	54%	45%	54%	54%	63%	54%	28%	92%	80%	19%	19%	45%	5%	0%
Capitella spp.	63%	63%	80%	80%	84%	63%	63%	100%	84%	28%	45%	54%	19%	0%
Nephtys australiensis	54%	45%	54%	54%	63%	54%	28%	92%	80%	54%	28%	45%	19%	5%
Amphipoda	54%	45%	54%	54%	63%	54%	28%	92%	80%	54%	28%	45%	19%	5%
Chironomidae	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	54%	45%
Simplisetia aequisetis	0%	0%	0%	0%	0%	0%	0%	19%	0%	0%	0%	5%	0%	0%
Plants														
Phragmites australis, Typha domingensis	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%
Diverse reed beds	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Muehlenbeckia florulenta	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ruppia megacarpa	100%	96%	100%	63%	63%	100%	100%	100%	54%	54%	54%	45%	0%	0%
Ruppia tuberosa	28%	100%	0%	28%	45%	100%	100%	0%	45%	28%	96%	0%	45%	0%
Lamprothamnium macropogon	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Freshwater submergent plant communities	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Melaleuca halmaturorum	100%	100%	28%	100%	100%	100%	100%	100%	100%	100%	100%	45%	54%	45%
Samphire and salt marsh communities	100%	100%	28%	100%	100%	100%	100%	100%	100%	100%	100%	45%	54%	45%
Fish														
Yarra pygmy perch	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Small-mouthed hardyhead	0%	0%	0%	5%	0%	0%	0%	0%	5%	19%	19%	28%	45%	19%

	Year													
Taxon	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Birds														
Fairy tern	0%	0%	0%	5%	0%	0%	0%	0%	5%	19%	19%	28%	45%	19%
Black swan	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%