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Development and application of a framework for assessing the vulnerability of aquatic species to multiple threats.

Barbara A. Cook, Benjamin M. Ford, Bronte E. Van Helden, Steve J. Beatty, Garry Ogston, Paul G. Close

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Acknowledgements

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Abstract

There are a number of frameworks that have been developed for assessing the vulnerability of species to climate change; however, those that address multiple threats are much rarer. We aimed to develop a framework for assessing the vulnerability of aquatic biota to multiple threats and to then apply it within a region that has multiple existing stressors and a severely drying climate. We selected south-western Australia as the model region as it is a global biodiversity hotspot with high rates of endemism, is already negatively impacted by multiple threatening processes, and its biota are highly likely to be impacted by decreasing rainfall and increasing temperatures associated with a changing climate. Moreover, faced with limited resources, conservation managers urgently need to prioritise these species for conservation management; and no robust framework has yet been developed for assessing the vulnerability of species to the projected change. Based on the integration of exposure, sensitivity and adaptive capacity, we develop a simple, points-based framework for assessing aquatic species vulnerability to multiple threatening processes, and apply this framework to aquatic invertebrate and fish species in the largest river system (by discharge) in south-western Australia. For each species and each threat assessed, the exposure score was multiplied by the sensitivity and the adaptive capacity scores to generate three separate threat vulnerability indices, one each for climate change, secondary salinization and nutrient enrichment, and these were summed to obtain an overall Threats Vulnerability Index. When the framework was applied to the Blackwood River, we determined which of the species assessed were at greatest risk, which threatening processes contributed most to their vulnerability, and where in the landscape vulnerable species were concentrated. The framework can be readily adapted and replicated in other regions where multiple stressors, including climate change, are acting simultaneously to threaten the viability of aquatic fauna.

1. Introduction

Early assessments of species vulnerability to projected climate change have relied heavily on the outputs of species distribution models (SDMs) (Dawson et al., 2011; Cabrelli et al., 2014). However, these changes in distribution due to climatic factors are an indicator of exposure to climate change only, and do not take into account other important aspects, such as sensitivity and adaptive capacity, that also influence a species vulnerability to a changing climate (Dickinson et al., 2014). Key ecological and evolutionary processes could allow species to persist despite high exposure to climate change, and thus species' biological traits should be used in combination with estimates of exposure in a trait-based vulnerability assessment approach (Williams et al., 2008; Bagne et al., 2011; Foden et al., 2013; Willis et al., 2015; Wilson et al., 2005). More recent studies aimed at assessing vulnerability to climate change have commonly scored three components: exposure (extent of climate change likely to be experienced by the species), sensitivity (degree to which the persistence of a species is dependent on climatic factors) and adaptive capacity (capacity of a species to adapt to climate change) (Williams et al., 2008; Chin et al., 2010; Dawson et al., 2011; Graham et al., 2011; Thomas et al., 2011; Young et al., 2011; Foden et al., 2013; Willis et al., 2015). However, while methods have been broadly consistent, specific approaches have varied; such as combining sensitivity and adaptive capacity (e.g. Gardali et al., 2012; Garnett et al., 2013). For example, Gardali et al. (2012) did not include criteria for determining adaptive capacity because of difficulties of scoring, but rather captured indirect proxies of adaptive capacity such as dispersal ability in their sensitivity component. They then scored sensitivity and exposure independently, and multiplied these two scores to generate a climate vulnerability index. Nonethless, in schemes based on the three components of exposure, sensitivity and adaptive capacity, species are considered to be highly vulnerable to climate change if they are found to be highly sensitive, highly exposed, but of lowest adaptive capacity (Foden et al., 2013; Willis et al., 2015).

Although several frameworks for assessing vulnerability to climate change exist, few authors have attempted to develop and implement a framework that addresses multiple threats (Moyle et al., 2013; Reece et al., 2013; Maggini et al., 2014). Moyle et al. (2013) assessed vulnerability of freshwater fish in California to climate change using 20 metrics, one of which was a combined rating of the fish species' vulnerability to multiple stressors such as water diversion, habitat degradation and harvest. Reece et al. (2013) assessed 300 plant and animal species in Florida for vulnerability to climate change, sea level rise and human land-use patterns. Their expert, opinion-based survey (the Standardized Index of Vulnerability and Value Assessment) consisted of 30 criteria distributed across modules of vulnerability, lack of adaptive capacity, conservation value and information availability. Maggini et al. (2014) developed a quantitative index of vulnerability based on the impact of climate change and land use change, and applied it to breeding birds in Switzerland. As far as we are aware, no framework has yet been developed that assesses the vulnerability of multiple aquatic faunal groups to multiple stressors, including climate change.

Fresh waters are increasingly recognised as hotspots for biodiversity (Strayer and Dudgeon, 2010), covering only 0.8% of the Earth's surface water, yet accounting for 9.5% of all known animal species (Dudgeon et al., 2006). Many of these species have small geographical ranges, resulting in high degrees of endemism. In a review of aquatic biodiversity of Mediterranean climate rivers in south-western Australia, Davies and Stewart (2013) reported that of the 662 species of plants and animals surveyed, 43% were endemic to the region. The freshwater fish fauna of the region is particularly unique, with nine of 11 native freshwater fish species endemic to south-western Australia (Morgan et al., 1998; Allen et al., 2002; Morgan and Beatty, 2013). Already threatened by salinization (e.g. Halse et al., 2003; Morgan et al., 2003; Beatty et al., 2011), nutrient enrichment (Weijters et al., 2009), overexploitation and flow modification (Bunn and Arthington, 2002), destruction and degradation of habitats (Davies, 2010), the presence of in-stream barriers (Morgan and Beatty, 2006; Beatty et al., 2007) and invasion by exotic species (e.g. Morgan et al., 2004; Beatty and Morgan, 2013), the aquatic biodiversity of south-western Australia is likely to be further negatively impacted by anthropogenic climate change (Davies, 2010). South-western Australia has already experienced considerable drying and warming over the past ~40 years and projections of its future climate are for a continued increase in temperature and decreases in rainfall in winter and spring (Hope et al., 2015). Mean annual warming is expected to be around 0.5 to 1.1^{o}C above the climate of 1986-2005 in the near future (2030) regardless of carbon emission scenario. Late in the 21st century (2090) mean annual warming is projected to vary from 1.2 to 2.0^{o}C for a low emissions scenario (Representative Concentration Pathway, RCP 4.5) and from 2.5 to 4.0^{o}C for a higher emissions scenario (RCP8.5) (Hope et al., 2015). Driven by the southward shift of winter systems and a greater prevalence of high pressure systems, annual rainfall is projected to decrease, with a decline of winter rainfall of 5-30% by 2090 under a low emissions scenario (RCP4.5) and a decline of 15-45% under a high emissions scenario (RCP8.5) (Hope et al., 2015).

Given that aquatic biodiversity in south-western Australian rivers are faced with multiple threats including ongoing climate change, it represents an ideal model region to assess the vulnerability of its aquatic fauna to environmental change. The aim of this study was to develop and apply a vulnerability framework that addresses three key threats (climate change, secondary salinization and nutrient enrichment) faced by these species. More specifically, the principle objectives of this study were (i) to develop a simple, points-based framework for assessing aquatic species vulnerability to multiple threatening processes in south-western Australian aquatic systems, and (ii) to apply the framework to selected species in a case study system (Blackwood River catchment). We intended the output from application of the framework to readily facilitate the selection of species (and areas) to be prioritised for management, i.e., to answer: Which of the species assessed may be at greatest risk in the future? What factors contribute most to their vulnerability? Where in the landscape they are located? Finally, we also aimed to ensure that the framework developed be repeatable for assessing aquatic species vulnerabilities in other catchments in south-western Australia.

2. Development of the framework

We have adopted a modified scheme based on existing climate change frameworks, but have tailored our framework for south-western Australian aquatic biodiversity. Recognising that assessing the vulnerability of species to threats requires consideration of all aspects of vulnerability (Williams et al., 2008; Dawson et al., 2011), we have developed a quantitative, points-based framework for scoring species for three selected threatening processes: climate change, secondary salinization, and nutrient enrichment (Figure 1). For each of these threats considered, we score species on a scale of ‘1’ (low vulnerability) to ‘3’ (high vulnerability) for exposure (extent to which a species is exposed to the threat), sensitivity (degree to which the species is likely to be affected) and adaptive capacity (opportunities that exist to ameliorate the sensitivity or exposure to a given threat). For each species and each threat assessed, we multiplied the exposure score by the sensitivity and the adaptive capacity scores to generate three separate threat vulnerability indices, one each for climate change (CCVI), secondary salinization (SSVI), and nutrient enrichment (NEVI). As each criterion was scored as either low (score of 1), moderate (2) or high (3) vulnerability, a higher index value (maximum possible value for each threat of ‘27’) indicates greater vulnerability. By summing the three indices, we obtain an overall Threats Vulnerability Index (TVI) for each species (maximum possible value for three threats combined is ‘81’), with equal weighting contributions from the three threats. Although we have not applied any weighting, it is possible that users of this framework might choose to weight particular threats for their target areas. Overall TVI scores were standardised, so that scores potentially ranged from ‘3.7’ (all criteria for all components of each threat scored a value of ‘1’) to ‘100’ (all criteria for all components of each threat scored a value of ‘3’).

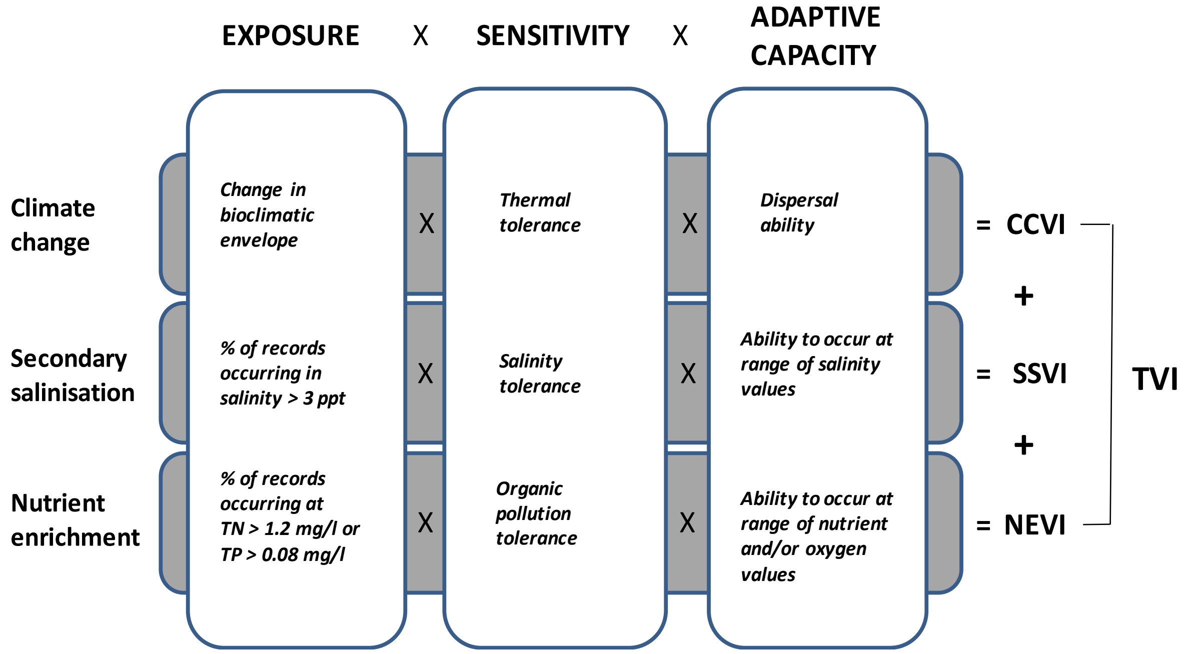

Figure 1. Outline of points-based framework for scoring the exposure, sensitivity and adaptive capacity of species to the threatening processes of climate change, secondary salinization, and nutrient enrichment.

2.1 Measuring vulnerability to climate change

2.1.1 Exposure

Species distribution modelling (SDM) has been used to assess exposure to climate change in many taxa, including aquatic invertebrates (e.g. Collins and McIntyre, 2015) and fish (e.g. Bond et al., 2011). This approach uses the current distribution of species and their environmental correlates (temperature and rainfall variables) to predict future distributions under future climate projections. Species predicted to experience the greatest loss or shift in geographical range are considered to be the most vulnerable to climate change. Species occurrence records for SDM were obtained through NatureMap (http://naturemap.dpaw.wa.gov.au/default.aspx), and the Atlas of Living Australia (ALA) (http://www.ala.org.au/); with only records from 1990 onwards with coordinate uncertainty of 5,000 m or less retained for SDM. Records were also obtained from previous studies (see online Appendix A: supplementary material for details of references used). A total of 868 records for eight fish species and 17,609 records of 452 invertebrate species were utilised in the SDM.

Current climate variables used in this study were 19 bioclimatic variables and altitude, sourced from WorldClim (http://www.worldclim.org/), in addition to soil type based on the “Geologic Unit Polygons 1M” polygon obtained from Geoscience Australia (http://mapconnect.ga.gov.au/MapConnect/). The future climate utilised was the high emissions, business as usual, RCP 8.5 scenario for 2080 based on the CSIRO Mk3.6 Global Climate Model (GCM). This GCM was selected as it was identified by the CSIRO Climate Futures Tool (http://www.climatechangeinaustralia.gov.au/en/) as being among the high consensus GCMs for south-western Australia for both the RCP4.5 and RCP8.5 scenarios by 2080. Future climate layers were obtained from the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) (http://ccafs-climate.org/data/). The grain of the climate layers was 2.5 minutes (≈ $5km^2$), and modelling was performed at the extent of the south-western Australian ecoregion (Figure 2).

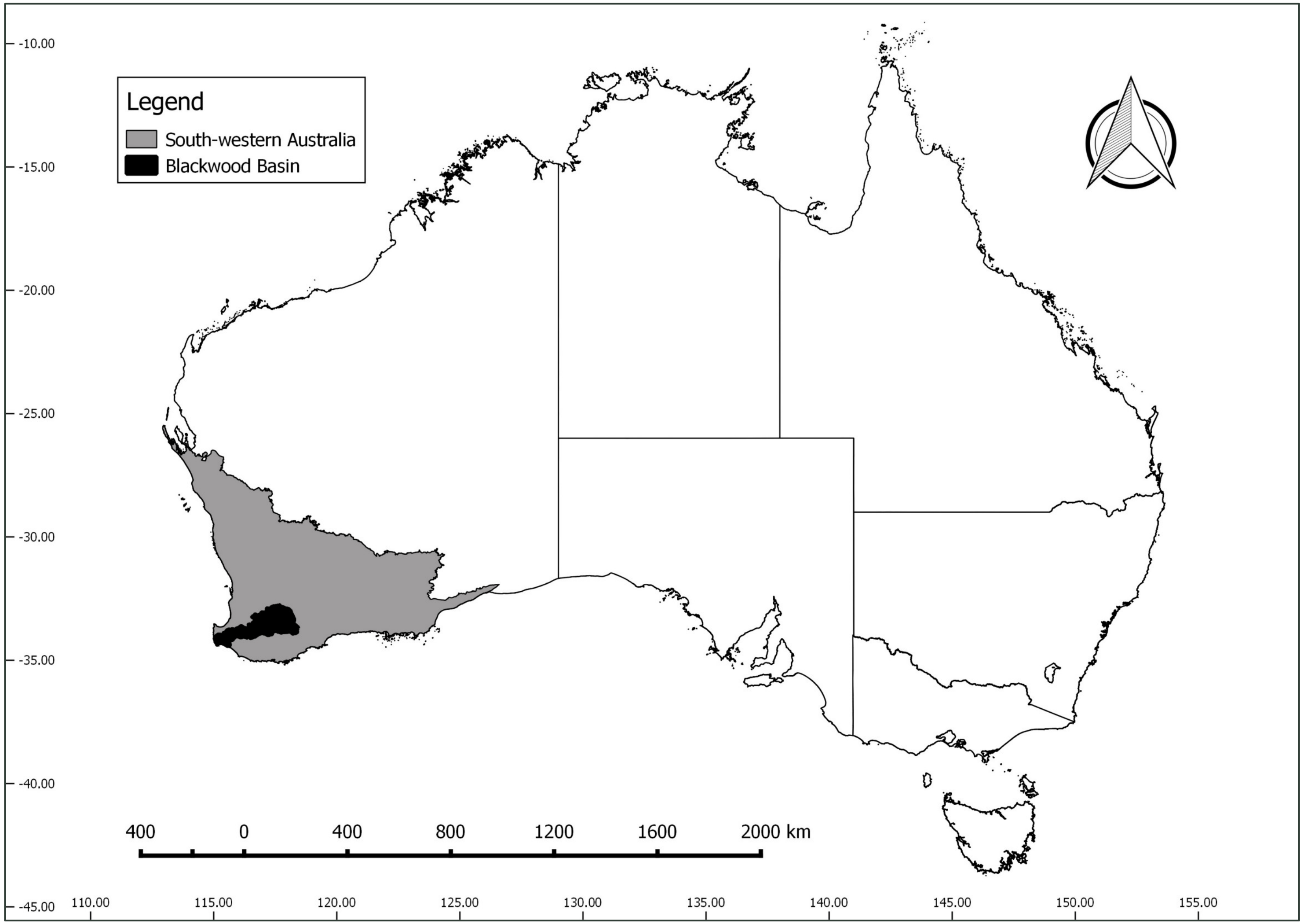

Figure 2. Location of the Blackwood Basin within south-western Australia.

Species distribution modelling was performed using MaxEnt V3.3.3 (Phillips and Dudik, 2008; Phillips et al., 2006). Of the suite of SDM methods currently available, the MaxEnt method has been determined to often provide the most accurate predictions (Elith et al., 2006, 2011; Merow et al., 2013). MaxEnt analyses were performed with the following settings - hinge features turned on to provide optimal environmental variable ranges, and thresholds off to provide continuous probability of occurrence. Random seed was utilised, with regularisation left as default. To account for sampling bias, invertebrate occurrence records were pooled and incorporated into the invertebrate modelling. No sample bias was incorporated into the fish SDM. Clamping was utilised to retain species future distributions within their current climatic envelopes. Cumulative output was selected as this is appropriate for determining range boundaries and avoids arbitrary or uncertain allocation of a value to τ (species probability of presence at "typical" sites) (Merow et al., 2013). Cross validation of 10 replicates was performed and the average of these was used as the final model for each species. The predictive accuracy of MaxEnt results was assessed through the area under the receiver operating characteristic curve (AUC). These scores range from 0 to 1, with a value of 0.5 indicating a performance no better than random. In our study, SDM results with AUC values <0.6 were deemed unreliable and discarded (Elith et al., 2006).

Species' climate suitability layers obtained through SDM were first converted to suitable/unsuitable climate based on the minimum training presence cumulative threshold (MTPCT - provided in the MaxEnt output). Cells with values above the MTPCT were considered as suitable climate, and cells with values below considered unsuitable (Figure 3). To estimate the effect of climate change on each species, percentage change in number of suitable cells between current and 2080 was utilised. A 50% decrease in number of presence cells was considered a proxy for 50% decrease in area of suitable climate. For the scoring of exposure to climate change (Tables 1, A1, A2), species with predictions of more than 75% reduction in suitable climate were considered as highly exposed (score of '3'), species with a predicted reduction in suitable climate of between 25 and 75% were considered as moderately exposed (score of '2'), and species with a predicted reduction less than 25% (or increase) in area of suitable climate were classed as low exposure to climate change (score of '1').

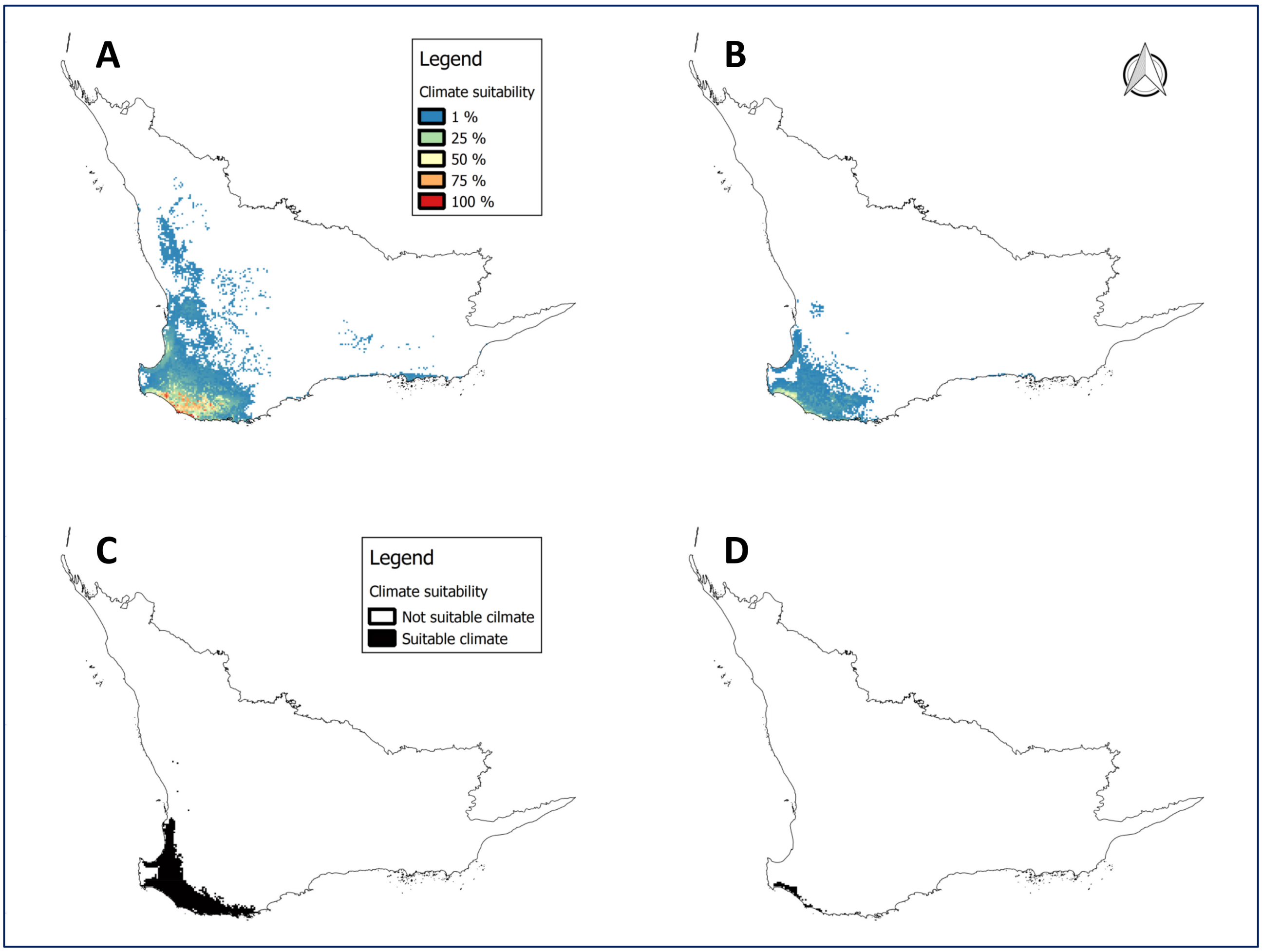

Figure 3. Example of SDM results showing climate suitability of *Galaxiella nigrostriata*. (A) Current climate suitability, (B) climate suitability by 2080 under high emissions scenario, (C) region of current suitable climate, and (D) region of suitable climate by 2080 under high emission scenario.

2.1.2 Sensitivity

Upper thermal tolerance (UTT) level is a useful measure of sensitivity of species to the increasing temperatures predicted to be characteristic of future climate regimes. Many aquatic insect groups are believed to have ‘cool water ancestry’ (Ward and Stanford, 1982), and are likely to be intolerant of elevated water temperatures. As temperatures rise, these species will be approaching the upper limit of their thermal range (Davies, 2010). Davies et al. (2004) ranked orders of invertebrates according to their upper thermal limits, placing the Ephemeroptera (mayflies), Amphipoda (sideswimmers) and Plecoptera (stoneflies) as being most sensitive, and the Odonata (dragon- and damselflies) as being least sensitive. In a more comprehensive review of over 80 species in 40 invertebrate families, Stewart et al. (2013) reported mean UTT values of 22.3°C (Ephemeroptera) to 43.4°C (Coleoptera) for aquatic invertebrates, and suggested that a value of 21°C be used as a critical threshold temperature for sensitive taxa. The UTT value for the Ephemeroptera was significantly lower than UTT values for the Decapoda (crayfish and shrimps), Trichoptera (caddisflies) and Mollusca (snails, limpets and mussels), while values for the Coleoptera (beetles) and Odonata were significantly higher than values for the other groups assessed (Stewart et al., 2013). Dallas and Rivers-Moore (2012) also reported high median critical thermal maximum (CTmax) values for species of dragonflies and beetles in their investigation of the upper thermal limits of aquatic invertebrates occurring in South African rivers, and added the caddisflies to the list of 'most thermally sensitive' taxa. Based on Stewart et al. (2013), we scored invertebrates with mean UTT values less than 23°C as being highly sensitive (score of '3'), taxa with mean UTT values between 23°C and 33°C as being moderately sensitive (score of '2') and taxa with mean UTT values more than 33°C as having a low sensitivity to climate-induced temperature changes (score of '1'; Tables 1, A3).

Scoring of sensitivity to temperature for freshwater fish species was based on Beatty et al. (2013). These authors showed that there were significant differences among several freshwater fishes for temperature within their sites of occupancy in south-western Australia, inferring that these fish species have differing levels of sensitivity to temperature. These authors found that the temperature at sites occupied by the western minnow (*Galaxias occidentalis*) was significantly warmer than at sites occupied by the western mud minnow (*Galaxiella munda*) and Balston's pygmy perch (*Nannatherina balstoni*), and that the western mud minnow occupied significantly cooler sites than all other species except for Balstons's pygmy perch. Based on these results, we have scored fish species with mean temperature at sites of occupancy less than 17°C as being highly sensitive (score of '3'), taxa with mean temperatures of 17 to 19°C as being moderately sensitive (score of '2') and taxa with mean temperature values more than 19°C as having a low sensitivity to climate-induced temperature changes (score of '1'; Tables 1, A4).

2.1.3 Adaptive capacity

Dispersal ability was used as a measure of adaptive capacity. It is expected that species' ability to track shifts in suitable climates will differ; species that have high dispersal abilities are expected to successfully shift their distributions in response to climate change, whilst others will not be able to do so. For aquatic invertebrates, we classified families into dispersal trait groups according to Moran-Ordonez et al. (2015) and unpublished data. Assuming that species within a given family have the same dispersal type (Poff et al., 2006; Moran-Ordonez et al., 2015), these authors allocated invertebrate families into five dispersal trait groups based on information gleaned from the Murray Darling Freshwater Research Centre Bug Guide (Hawking et al., 2013) and the EPA Freshwater Biological Traits Database (US EPA, 2013). Organisms completely dependent on water for dispersal such as crustaceans and mussels ('obligate aquatic dispersers') were considered to have poor adaptive capacity, and thus would be most vulnerable, and given a score of '3', smaller invertebrates (e.g. mayflies) with adult stages capable of active flight ('weak active aerial dispersers') and those such as micro-crustaceans that are known to disperse passively by wind ('passive aerial dispersers') were considered to be moderately vulnerable (adaptive capacity score of '2'), while larger aquatic invertebrates (e.g. dragonflies) capable of active flight ('strong active aerial dispersers') and those organisms such as water mites that rely on invertebrate vectors for dispersal ('phoretic aerial dispersers') were considered to have high adaptive capacity, and would thus have low vulnerability, and were allocated an adaptive capacity score of '1' (Tables 1, A5). A sixth dispersal trait group was added in this study for invertebrate families, such as springtails, that actively dispersed via hopping or jumping ('active dispersers by hopping'). These families were also considered to have high adaptive capacity and were assigned an adaptive capacity score of '1'.

The majority of the nine endemic freshwater fish species occurring in south-western Australia are potamodromous, migrating within river systems usually into lower order tributaries for spawning and recruitment as stream discharge increases seasonally (Beatty et al., 2014). However, these species differ in their ability to migrate. By far the largest of the freshwater fish endemic to the region (Morgan et al., 1998; Beatty et al., 2010), the freshwater cobbler (*Tandanus bostocki*) actively migrates within the main channel of the Blackwood River, albeit at a localised, site-specific scale (Beatty et al., 2010). The streamlined body form (Kilsby and Walker, 2010, 2012), relatively larger body size and the migratory behaviour of galaxiids suggest that these fish are likely to be strong swimmers. The western minnow has been shown to be capable of extensive movements within the Canning and North Dandalup River (Pusey and Edward, 1990) and Blackwood River systems (Beatty et al., 2015). Moreover, it is the major user of all rock ramp fishways in the south-west including during the high-flow period when water velocities and turbulence on the structures is greatest (e.g. Morgan et al., 2005; Beatty et al., 2007, 2015). In contrast to the galaxiids, the pygmy perches are poorer migrators (Hammer et al., 2009; Beatty et al., 2014, 2015). Nevertheless, the western pygmy perch (*Nannoperca vittata*) has an extensive distribution in south-western Australia, and is known to migrate upstream for spawning associated with increased stream discharge (Beatty et al., 2015). Similarly, the nightfish (*Bostockia porosa*) also has a wide distribution and migrates upstream for spawning (Beatty et al., 2015). Balston's pygmy perch is known to recolonize previously dry pools on peat flats on inundation (Morgan et al., 1995) and can also migrate into tributaries to spawn (Beatty et al., 2015) thus demonstrating at least moderate swimming abilities. On the other hand, the newly described little pygmy perch (*Nannoperca pygmaea),* is small-bodied, has a restricted distribution (Morgan et al., 2013), and does not migrate as far upstream as sympatric species (Beatty et al. unpubl. data) and is thus likely to have a relatively poor swimming ability. Because of their small body sizes (Morgan et al., 1998; Morrongiello et al., 2011; Pusey and Edward, 1990), the salamanderfish (*Lepidogalaxias salamandroides*), the black-stripe minnow (*Galaxiella nigrostriata*) and the western mud minnow could be expected to have the poorest swimming ability. However, while the salamanderfish and black-stripe minnow are generally restricted to small, often temporary-water sites, aestivating during times of drought (Galleotti et al., 2010; Pusey and Edward, 1990), the western mud minnow moves seasonally between temporary and permanent waters (Pusey and Edward, 1990), suggesting that it has a moderate swimming ability. The two non-endemic species are likely to be strong swimmers. The common jollytail (*Galaxias maculatus*) and the trout minnow (*Galaxias truttaceus*) are both diadromous in eastern Australia (migrating downstream to estuaries to spawn), and are known to undertake considerable spawning migrations and to be efficient users of fishways (Morgan and Beatty, 2006; Close et al., 2014). However, unlike populations in eastern Australia, the south-western population of the trout minnow and some population of the common jollytail are presently landlocked (Chapman et al., 2006; Morgan and Beatty, 2006). Based on these observations, the smallest species that exhibited limited migratory behaviours were assigned a score of '3', species of moderate size, mostly non-streamline bodies but exhibiting migratory behaviours were assigned a score of '2', and larger species with streamlined bodies that showed extensive migratory behaviour were considered to have high adaptive capacity (and thus low vulnerability), and assigned a score of '1' (Tables 1, A6).

Table 1. Criteria used to score aquatic invertebrate and fish species occurring in south-western Australia for exposure, sensitivity and adaptive capacity to the threatening processes of climate change, secondary salinization and nutrient enrichment.

Threat	Component	Criteria	Scoring
Climate change	Exposure	Change in bioclimatic envelope	1 = < 25% reduction, or an increase in bioclimatic envelope 2 = 25-75% reduction in bioclimatic envelope 3 = > 75% reduction in bioclimatic envelope
	Sensitivity	Thermal tolerance	Aquatic-invertebrates: 1 = mean upper thermal tolerance (UTT) > 33^{o}C 2 = mean UTT between 23^{o}C - 33^{o}C 3 = mean UTT < 23^{o}C Fish: 1 = mean temperature at sites of occupancy > 19^{o}C 2 = mean temperature at sites of occupancy between 17^{o}C - 19^{o}C 3 = mean temperature at sites of occupancy < 17^{o}C
	Adaptive capacity	Dispersal ability	Aquatic invertebrates: 1 = strong active aerial dispersers, phoretic aerial dispersers, active dispersers by hopping 2 = weak active aerial dispersers, passive aerial dispersers 3 = obligate aquatic dispersers Fish: 1 = Larger, streamlined bodies, strong migratory behaviour 2 = Moderate size, mostly non-streamlined bodies, migratory behaviours 3 = Smallest, limited migratory behaviour
Salinisation	Exposure	Proportion of distribution occurring in water with salinity above threshold value	1 = < 25% of distribution within target area occurring in water with conductivity (salinity) > 4.8 mS.cm^{-1} (3 ppt) 2 = 25-75% of distribution within target area occurring in water with conductivity (salinity) > 4.8 mS.cm^{-1} 3 = > 75% of distribution within target area occurring in water with conductivity (salinity) > 4.8 mS.cm^{-1}
	Sensitivity	Salinity tolerance	Aquatic Invertebrates: 1 = Salinity tolerance > 30 mS.cm^{-1} 2 = Salinity tolerance between 10-30 mS.cm^{-1} 3 = Salinity tolerance < 10 mS.cm^{-1} Fish: 1 = Mean conductivity at sites of occupancy > 3000 µS.cm^{-1} 2 = Mean conductivity at sites of occupancy between 1000-3000 µS.cm^{-1} 3 = Mean conductivity at sites of occupancy < 1000 µS.cm^{-1}
	Adaptive capacity	Range of salinity levels tolerated	Aquatic Invertebrates: 1 = range of salinity levels at sites of occurrence >75th quartile of ranges across all families (> 26.88 mS.cm^{-1})

			2 = range of salinity levels at sites of occurrence between the 25th and 75th quartiles of ranges across all families (1.60-26.88 mS.cm^{-1}) 3 = range of salinity levels at sites of occurrence <25th quartile of ranges across all families (< 1.60 mS.cm^{-1}) Fish: 1 = range of salinity levels at sites of occurrence >75th quartile of ranges across all families (> 23348 µS.cm^{-1}) 2 = range of salinity levels at sites of occurrence between the 25th and 75th quartiles of ranges across all families (5218-23348 µS.cm^{-1}) 3 = range of salinity levels at sites of occurrence <25th quartile of ranges across all families (<5218 µS.cm^{-1})
Nutrient enrichment	Exposure	Proportion of distribution occurring in water with nutrients above threshold values	1 = < 25% of distribution within target area occurring in water with total nitrogen (TN) > 1.2 mg/L or total phosphorus (TP) > 0.08 mg/l 2 = 25-75% of distribution within target area occurring in water with TN > 1.2 mg/L or TP > 0.08 mg/l 3 = > 75% of distribution within target area occurring in water with TN > 1.2 mg/L or TP > 0.08 mg/l
	Sensitivity	Pollution tolerance	Aquatic invertebrates: 1 = SIGNAL score < 4 2 = SIGNAL score between 4 to 7 3 = SIGNAL score > 7 Fish: 1 = minimum oxygen level at sites of occupancy < 1.64mg/L 2 = minimum oxygen level at sites of occupancy between 1.64-2.79 mg/L 3 = minimum oxygen level at sites of occupancy > 2.79 mg/L
	Adaptive capacity	Range of TN, TP or oxygen levels tolerated	Aquatic invertebrates: 1 = range of TN and TP >75th quartile of ranges across all families (TN > 3.51 mg.l^{-1}, TP > 0.51 mg.l^{-1}) 2 = range of TN and TP at sites of occurrence between the 25th and 75th quartiles of ranges across all families (TN: 0.70-3.51 mg.l^{-1}; TP: 0.03-0.51 mg.l^{-1}) 3 = range of TN and TP at sites of occurrence <25th quartile of ranges across all families (TN < 0.70 mg.l^{-1}, TP < 0.03 mg.l^{-1}) Fish: 1 = ranges in dissolved oxygen at sites of occupancy > 75th quartile (> 14.25 mg.l^{-1}) 2 = ranges between the 25th and 75th quartiles (8.69-14.25 mg.l^{-1}) 3 = ranges of dissolved oxygen at sites of occupancy < 25th quartile (< 8.69 mg.l^{-1})

2.2 Measuring vulnerability to secondary salinisation

2.2.1 Exposure

Exposure to high salinity was assessed by considering the proportion of records of a selected species within a given area that occur in water with salinity values above an identified trigger value. The Framework for the Assessment of River and Wetland Health (FARWH) (Storer et al. 2011) for flowing rivers of south-western Australia was utilised to identify exposure trigger values for salinity. Storer et al. (2011) determined that at 4.8 mS.cm^{-1} (3000 mg.l^{-1}, equivalent to 3 ppt), multiple freshwater flora and fauna phyla reach their salinity tolerances. Taxa with > 75% of their records occurring in water with salinity values above 4.8 mS.cm^{-1} were considered to be highly exposed to salinity (score of ‘3’), taxa with between 25 to 75% of their records occurring in water with salinity values above 4.8 mS.cm^{-1} were considered to be moderately exposed (score of ‘2’), and taxa that had < 25% of their records within a given catchment area occurring in water with salinity values greater than 4.8 mS.cm^{-1} were considered to have low exposure, and thus low vulnerability to salinity (score of ‘1’). Regions within the Blackwood Catchment above and below the salinity threshold is displayed in Figure 4.

2.2.2 Sensitivity

The sensitivity of species to salinization was estimated using salinity tolerance data. The latter are usually determined either experimentally by means of acute toxicity tests (e.g. Kefford et al., 2004a, b), or by field studies that record the salinity at which species have been found (Kay et al., 2001; Pinder et al., 2005). Salinity tolerance data derived from LC$_{50}$ experiments have been shown to be significantly correlated with the maximum salinity at which species have been recorded in the field (maximum field distribution, MFD) (Kefford et al., 2004b). Although salinity tolerances of south-western Australian invertebrates have not been determined experimentally, relative salinity tolerances of a range of invertebrates from eastern Australia have been measured (Kefford et al., 2003; Dunlop et al., 2008). Kefford et al. (2003) recorded 72-h LC$_{50}$ values ranging from 5.5 to 52 mS.cm^{-1}, with non-arthropods having the lowest salinity tolerance (range 9-14 mS.cm^{-1}), insects and mites a higher salinity tolerance (5.5-55 mS.cm^{-1}), and crustaceans, the highest salinity tolerance (38-76 mS.cm^{-1}). Of the insects, baetid mayflies (Order Ephemeroptera) and chironomids (Diptera) were found to be particularly salt sensitive, stoneflies (Plecoptera) and caddisflies (Trichoptera) were moderately sensitive, and beetles (Coleoptera), true bugs (Hemiptera) and damselflies and dragonflies (Odonata) were variable (Kefford et al., 2003; 2005). Mean sensitivities recorded by Dunlop et al. (2008) at the order and suborder level in increasing order were Ephemeroptera (10.9 mS.cm^{-1}), Basommatophora (17.6 mS.cm^{-1}), Veneroidea (18.8 mS.cm^{-1}), Gastropoda (19.2 mS.cm^{-1}), Trichoptera (20.7 mS.cm^{-1}), Hemiptera (21.3 mS.cm^{-1}), Diptera (22.4 mS.cm^{-1}), Acariformes (22.5 mS.cm^{-1}), Anisoptera (23.3 mS.cm^{-1}), Zygoptera (32.4 mS.cm^{-1}), Coleoptera (35 mS.cm^{-1}), Decapoda (41.9 mS.cm^{-1}) and Isopoda (>55 mS.cm^{-1}). Broad similarities in salinity tolerances within most orders of aquatic invertebrates in south-eastern Australia and eastern South Africa suggest that in the absence of data for specific regions (e.g. south-western Australia), similar salinity tolerances to those reported in these locations can be assumed (Dunlop et al., 2008; Kefford et al., 2005). Based on data for eastern Australia, we scored taxa that have tolerance values less than 10.0 mS.cm^{-1} as being highly sensitive (score of ‘3’), taxa with values between 10 and 30 mS.cm^{-1} as being moderately sensitive (score of ‘2’), and taxa with salinity tolerance values more than 30 mS.cm^{-1} as having a low sensitivity to salinity (score of ‘1’; Tables 1, A7).

In contrast to aquatic invertebrates, there are few studies of salinity tolerance in freshwater fish species. Laboratory-based, acute salinity trials have been conducted for only three (Balston’s pygmy perch, western minnow and western pygmy perch) of the 11 native freshwater fish species known from south-western Australia (Beatty et al., 2011). Of these three species, Balston’s pygmy perch was found to be significantly more sensitive to salinity, with a median EC$_{50}$ value of 8.2 g.l^{-1} (CI: 8.1-8.3) being recorded, while EC$_{50}$ values for the western minnow and the western pygmy perch were similar (median values of 14.6-14.7 g.l^{-1}). Given the lack of data for the other eight species, we elected to use field-derived tolerance indicator values (TIVs). In an investigation of TIVs in seven species, Beatty et al. (2013) found that conductivities at sites of occupancy differed significantly among these species assessed, with the western mud minnow occupying significantly fresher sites than the other six species considered. Conductivities at sites occupied by the western pygmy perch, Baltson's pygmy perch and nightfish were similar. Based on these results, we have scored fish species with mean conductivity levels at sites of occupancy less than 1000 µS.cm^{-1} as being highly sensitive (score of '3'), taxa with mean conductivities at sites of occupancy of 1000 to 3000 µS.cm^{-1} as being moderately sensitive (score of '2'), and taxa with values more than 3000 µS.cm^{-1} as having low sensitivity to salinity changes (score of '1'; Tables 1, A8).

2.2.3 Adaptive capacity

The adaptive capacity of aquatic invertebrates and fish to high salinity levels was estimated by considering the range of salinities at which they had been recorded, with a wide range of salinities assumed to indicate a greater potential to cope with increasing salinity levels associated with secondary salinization. Aquatic invertebrate species and environmental conditions recorded at collection sites were compiled from several studies conducted in south-western Australia (see Sutcliffe, 2003; Pinder et al., 2004; Stewart, 2011a, b). For 218 invertebrate families occurring in south-western Australia, the median of species' conductivity ranges within the family was calculated and used as the salinity range for the family. Species level was utilised for the 11 freshwater fish species. For both groups, families (invertebrates) or species (fish) with salinity ranges <25th quartile of ranges across all taxa (invertebrates range < 1.60 mS.cm^{-1}, fish range 5218 µS.cm^{-1}) were deemed to have low adaptive capacity to salinity and therefore scored a value of '3', those with ranges between the 25th and 75th quartiles (invertebrates: 1.60-26.88 mS.cm^{-1}, fish: 5218-23348 µS.cm^{-1}) were scored '2', and those with ranges > 75th quartile of ranges (invertebrates: > 26.88 mS.cm^{-1}, fish: > 23348 µS.cm^{-1}) across all taxa were considered to have high adaptive capacity to salinity and thus were scored a value of '1'; Tables 1, A9, A10).

2.3 Measuring vulnerability to nutrient enrichment

2.3.1 Exposure

Total nitrogen (TN) and total phosphorus (TP) in Blackwood River were used as measurements of exposure to nutrient enrichment. More specifically, exposure to nutrient enrichment was assessed by determining the proportion of records for a selected species in a given area that exceeded an identified trigger value in either TN or TP. During the development of the FARWH, Storer et al. (2011) determined that values of TN in excess of 1.2 mg.l^{-1}, and values of TP in excess of 0.08 mg.l^{-1} would become detrimental to biodiversity. These values were used as trigger values in the framework. Taxa with > 75% of their records occurring in water with TN values above 1.2 mg.l^{-1} and TP values above 0.08 mg.l^{-1} were considered to be highly vulnerable to nutrient enrichment (score of '3'), taxa with between 25 to 75% of their records occurring in water with TN values above 1.2 mg.l^{-1} and TP values in excess of 0.08 mg.l^{-1} were considered to be moderately vulnerable (score of '2'), and taxa that had < 25% of their records within a given catchment area occurring in water with TN values greater than 1.2 mg.l^{-1}, and TP values greater than 0.08 mg.l^{-1} were considered to have low vulnerability to nutrient enrichment (exposure to nutrients score of '1'). Each species' exposure to nutrient enrichment was calculated by taking the rounded up average of TN exposure and TP exposure. Regions within the Blackwood Catchment above and below the TN and TP thresholds are displayed in Figures Figure ***5*** & Figure ***6*** respectively.

2.3.2 Sensitivity

For the assessment of sensitivity of aquatic invertebrates to nutrient enrichment, we used the Stream Invertebrate Grade Number Average Level (SIGNAL) biotic index developed initially for application in eastern Australia (Chessman, 1995, 2003). This index assigns each macroinvertebrate family a pollution sensitivity grade ranging from 10 (most sensitive) to 1 (most tolerant). To date, the applicability of SIGNAL has been broadened geographically by deriving grades at the family level for 210 taxa from the whole of Australia, covering 171 families, six chironomid subfamilies and 33 higher taxa, and testing of the relationship between SIGNAL scores and TN and TP found these to be strongly and significantly correlated (Chessman, 2003). Taxa with SIGNAL scores > 7 were considered to be very sensitive to nutrient enrichment, and assigned a score of '3', taxa with SIGNAL scores of 4 to 7 were considered to be moderately tolerant of nutrient enrichment, and assigned a sensitivity score of '2', and taxa that have SIGNAL scores less than 4 were considered to be tolerant of nutrient enrichment, and were assigned a sensitivity score of '1' (Tables 1, A11).

To assess the sensitivity of freshwater fish species to nutrient enrichment, minimum dissolved oxygen (mg.l^{-1}) levels at collection sites of each species was utilised as a proxy for tolerance to organic pollution associated with nutrient enrichment. Levels of dissolved oxygen and fish occurrence records were collated from Beatty et al. (2011), Beatty et al. (2013), and unpublished data. To score fish species sensitivity to nutrient enrichment, quartiles of minimum values were calculated across the species. Species with minimum dissolved oxygen values greater than the 75th quartile (> 2.79 mg.l^{-1}) were scored '3' for nutrient enrichment sensitivity as this was taken to represent low tolerance to locations subject to anoxic conditions. Species with minimum dissolved oxygen values between the 25th and 75th quartiles (1.64-2.79 mg.l^{-1}) were scored a value of '2', and species with minimum dissolved oxygen levels less than the 25th quartile (< 1.64 mg.l^{-1}) were scored a value of '1' (Table 1, A12).

2.3.3 Adaptive capacity

The adaptive capacity of aquatic invertebrates and fish to high nutrient levels was estimated by considering the range of TN and TP levels for aquatic invertebrates or the range of dissolved oxygen for fishes at which they had been recorded, with a wider range of TN and/or TP or dissolved oxygen assumed to indicate a greater potential to cope with increasing nutrient levels, and consequently, organic pollution. The values of TN and TP at locations where aquatic invertebrate species had been collected were collated from various studies (e.g. Sutcliffe, 2003; Pinder et al., 2004; Stewart, 2011a, b), and the range in TN and TP was calculated for each species. For each family of aquatic invertebrates, for both TN and TP, the median value of ranges across species was calculated and utilised as a proxy for nutrient enrichment adaptive capacity across all families. Families with median range values less than the 25th quartile (TN < 0.70 mg.l^{-1}, TP < 0.03 mg.l^{-1}) of median ranges were scored a value of '3' to indicate low adaptive capacity to nutrient enrichment. Families with median range values between the 25th and 75th quartiles (TN: 0.70-3.51 mg.l^{-1}; TP: 0.03-0.51 mg.l^{-1}) were scored a value of '2' for nutrient enrichment adaptive capacity. Families with median range values greater than the 75th quartile (TN > 3.51 mg.l^{-1}, TP > 0.51 mg.l^{-1}) were scored a value of '1'. To calculate aquatic invertebrate nutrient enrichment adaptive capacity at the family level, the average of TN and TP adaptive scores was calculated and rounded up to the nearest whole number (Tables 1, A13).

As TN and TP were not readily available from fish records, dissolved oxygen was utilised to represent the fish fauna nutrient enrichment adaptive capacity. Data on ranges of dissolved oxygen for each of the species of fish were collated from Beatty et al. (2011), Beatty et al. (2013) and unpublished sources. Across all freshwater fish species considered, species with ranges of dissolved oxygen less than the 25th quartile (< 8.69 mg.l^{-1}) were scored '3' for nutrient enrichment adaptive capacity. Species with ranges between the 25th and 75th quartiles (8.69-14.25 mg.l^{-1}) were scored '2', and species with ranges in dissolved oxygen greater than the 75th quartile (> 14.25 mg.l^{-1}) were scored '1' (Tables 1, A14).

3. Application of framework

3.1 Study site and target species

The Blackwood River Basin occupies an area of approximately 22 000 km^2 and is located within south-western Australia in a recognised global biodiversity hotspot (Myers et al., 2000; Ali et al., 2012) (Figure 2). The region experiences a typical Mediterranean climate, with cool, wet winters and hot, dry summers. Annual rainfall varies from 350 mm in the upper catchment to 1400 mm near the coast. The catchment has sustained extensive land clearing for agricultural purposes with 78% of land used for agriculture, resulting in nutrient enrichment and salinity issues (Ali et al., 2012; Hodgson et al., 2004). However, the catchment has many significant water resources including the Blackwood River (the largest in the region in terms of discharge) and over 1000 wetlands, one of which (Toolibin Lake) is an Australian listed Ramsar site. The Blackwood River itself stretches 280 km with one section in its lower reach (with a largely pristine riparian zone) recently being nominated as a Ramsar site. The river and its numerous tributaries are a sanctuary for aquatic species and have been identified to contain a high degree of diversity of both invertebrate and vertebrate species. Many of the species that inhabit Blackwood River are endemic, restricted, rare or threatened, making the river highly important for biodiversity and conservation purposes.

A comprehensive list of freshwater faunal species occurring in the Blackwood River catchment was compiled from a number of sources (see online Appendix A). Based on this collation of distribution records, 8 freshwater fish, 18 frogs, 8 crayfish species, and a further 60 invertebrate families were found to occur in the Blackwood River system. Four species are listed as threatened by the Wildlife Conservation Act (1950): two freshwater fish (the western mud minnow and Balston's pygmy perch)*;* and two frogs (white-bellied frog (*Geocrinia alba)* and orange-bellied frog (*G. vitellina*))*.* In addition to supporting these threatened species, the Blackwood River provides critical habitat for a large proportion of endemic south-western Australian species. Eight of the eleven native freshwater fish in south-western Australia are found in the Blackwood River; the system is also a "hotspot" of freshwater crayfish biodiversity with five of six endemic *Cherax* species and one of the four *Engaewa* species (*E. similis*) occupying the area (Morgan and Beatty, 2005). Data were available for 100 aquatic invertebrate taxa and the eight freshwater fish species occurring in the Blackwood River. A total of 59 macroinvertebrate and four fish families were represented in the threats vulnerability analyses.

3.2 Threats vulnerability analysis

Climate change exposure scores for taxa occurring in the Blackwood River were sourced from Table A1 for aquatic invertebrates and Table A2 for fish. To score species for exposure to secondary salinization and nutrient enrichment, water quality data for TN ($mg.l^{-1}$), TP ($mg.l^{-1}$), and salinity/conductivity ($mS.cm^{-1}$) were obtained from the Western Australian State government, Department of Water website (www.dow.wa.gov.au) and other unpublished sources. A total of 250, 219, and 408 sites were used for TN, TP, and salinity respectively throughout the Blackwood Basin. These parameters were estimated for the whole of the Blackwood River system using the "krige.conv" function in the geoR package (Ribeiro and Diggle, 2015) in R V3.2.0 (R Core Team 2015). Kriging was performed only within the Blackwood Basin by including a mask polygon of the basin in the analysis. Kriging results were then cropped using a buffered Blackwood River and tributaries layer. This process was applied to each of TN, TP, and salinity records. To assess each species' exposure to each of these water quality variables, species records from 1990 onwards with coordinate certainty of 10 000 m or less were utilised. A total of 223 fish and 3315 invertebrate records were located in the Blackwood Basin and utilised in the water quality exposure analyses. The "point sampling tool" plug in (http://hub.qgis.org/projects/pointsamplingtool) in QGIS 2.8.1 (Quantum GIS Development Team 2014) was used to extract counts of records of each species above and below the threshold values for each of TN, TP, and salinity.

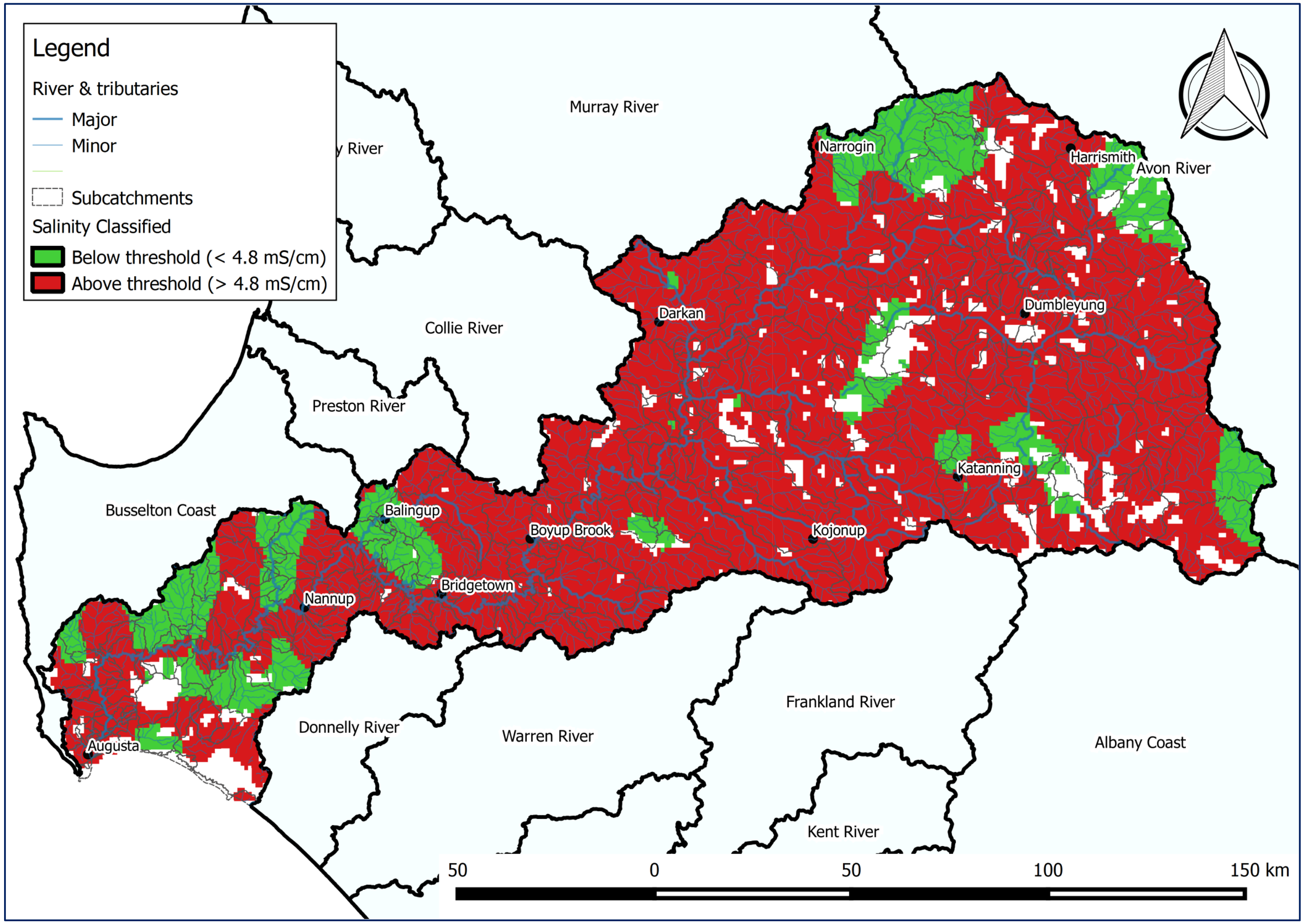

Figure 4. Interpolated salinity through the Blackwood Basin. Areas below threshold (4.8 mS.cm^{-1}) are green, areas above threshold are red.

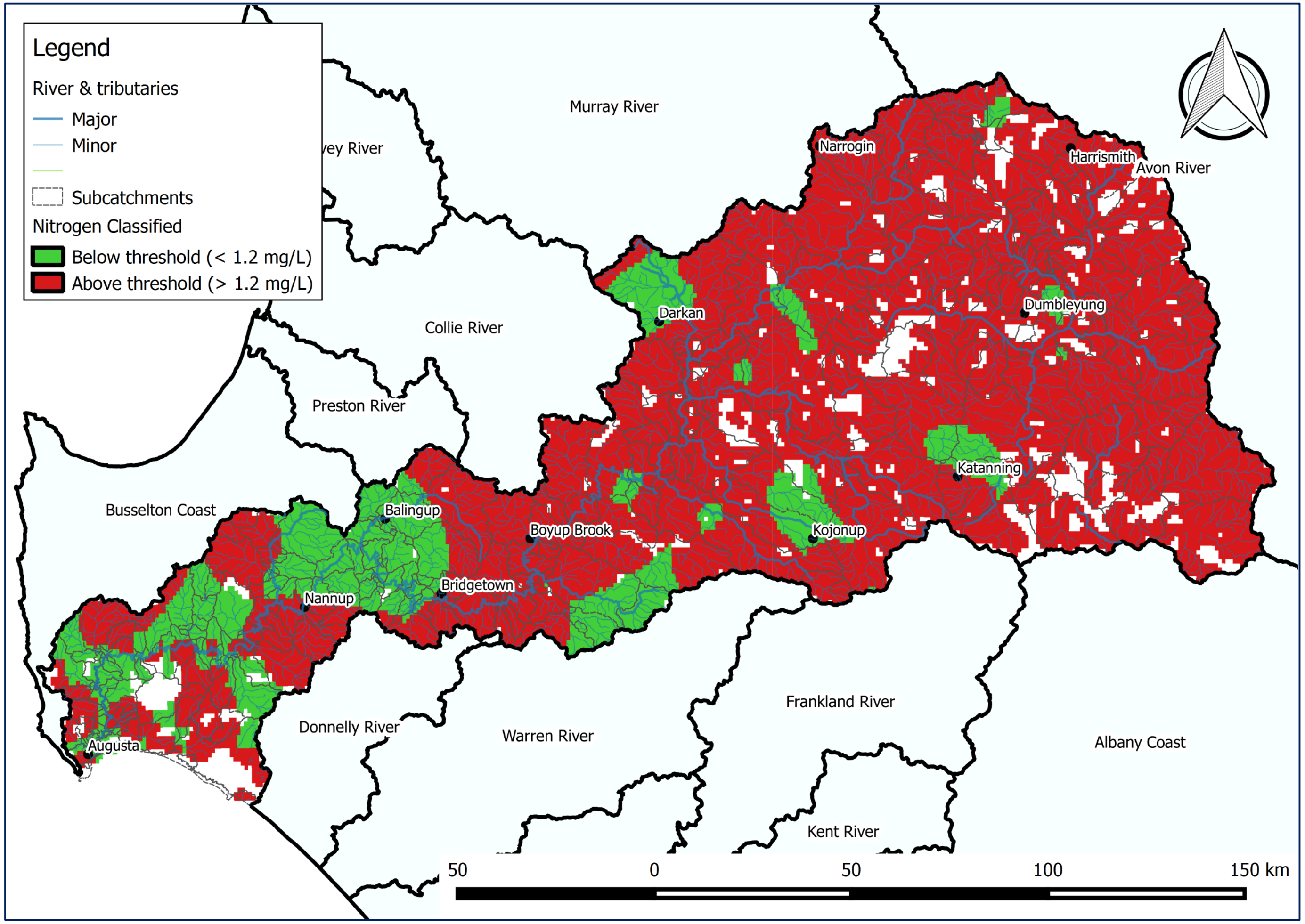

Figure 5. Interpolated total nitrogen through the Blackwood Basin. Areas below threshold (1.2mg.L^{-1}) are green, areas above threshold are red.

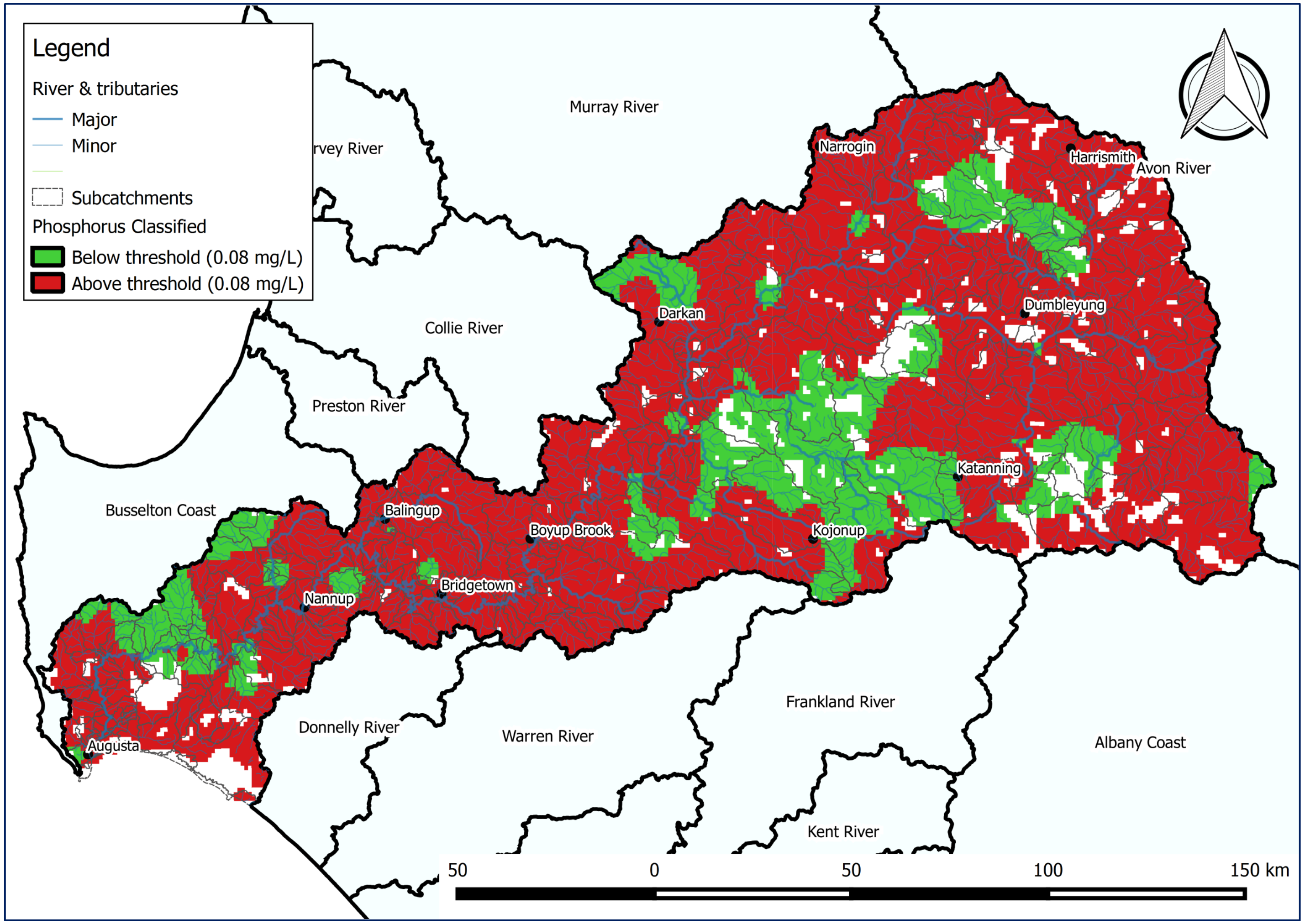

Figure 6. Interpolated total phosphorus through the Blackwood Basin. Areas below threshold (0.08 mg.L^{-1}) are green, areas above threshold are red.

Invertebrate sensitivity scores to climate change, secondary salinization, and nutrient enrichment were sourced from Tables A3, A9, and A13 respectively. Fish sensitivity scores to climate change, secondary salinization, and nutrient enrichment were sourced from Appendix Tables A4, A8, and A12 respectively. Tables A5, A7, and A11 provided invertebrate adaptive capacity scores to climate change, secondary salinization, and nutrient enrichment respectively. Fish adaptive capacity scores to climate change, secondary salinization, and nutrient enrichment were obtained from Appendix Tables A6, A10, and A14 respectively. For the three vulnerability measures (exposure, sensitivity, and adaptive capacity) to all threat categories (climate change, secondary salinisation, and nutrient enrichment), threat vulnerability scores were assigned to invertebrates at various taxonomic levels, while fish were assigned scores at the species level.

Mean vulnerability to the threats were tested for differences among vulnerability indicies using a Kruskal-Wallis test. Subsequent pair-wise comparisons were performed using the "coin" package (Hothorn et al., 2008) and supplementary code from Mangiafico (2015). Both tests were performed in R V 3.2.0 (R Core Team, 2015).

In order to identify ‘hotspots’ of vulnerable species within the Blackwood Basin, we used species occurrence records and species TVI scores to create an interpolated layer. This layer was then classified into three categories, (i) areas dominated by species which had been classified according to their TVI scores as being of ‘low vulnerability’ (interpolated values of 0-33), (ii) areas where there were concentrations of species classified as being of ‘medium vulnerability’ (interpolated values of 33-66), and (iii) areas where there were concentrations of species classified as being of ‘high vulnerability’ (interpolated values > 66). Interpolation and classification was performed using QGIS 2.8.1 (Quantum GIS Development Team 2014).

4. Results

The standardised TVI values for the 101 species (93 invertebrate and eight fish species) scored for the Blackwood River catchment ranged from 6.2 to 70.4, with 71.3% considered as being of ‘low vulnerability’ (TVI < 33), 27.7% as being of ‘moderate vulnerability’ (TVI between 33 and 66) and only one species as being of ‘high vulnerability’ (TVI > 66) to the threats assessed (Figure 7). The 28 species that were considered either ‘moderately’ or ‘highly’ vulnerable included four of the eight freshwater fish species assessed (black-stripe minnow, Balston’s pygmy perch, western mud minnow and the salamanderfish), 11 caddisfly taxa (order Trichoptera), and six freshwater crayfish species.

Post hoc permutational pairwise comparisons revealed that the mean secondary salinization vulnerability index (SSVI) value of 10.65 across all species was significantly higher than both the mean climate change vulnerability index (CCVI) value of 6.85 ($P < 0.001$) and the nutrient enrichment vulnerability index (NEVI) value of 7.80 ($P < 0.001$) (Kruskal-Wallis rank sum test, Chi square = 27.98, d.f. = 2, $P < 0.001$), but mean CCVI and NEVI were not significantly different from each other ($p = 0.215$; Figure 8).

Areas with concentrations of species with moderate TVI scores (33-66) occurred in the lower reaches of the Blackwood Basin (
Figure 10 and Figure 10). Tributaries within these lower reaches that were classified as areas dominated by species that were of ‘medium vulnerability’ were the Scott River, McLeod Creek, Chapman Brook, Upper Chapman Brook, Rosa Brook, Milyeannup Brook, McAtee Brook, St John Brook, Maranup, Ballajup Brook, Gnowergerup Brook, the Hillman River, and the region between Maranup Brook to Balingup Brook. There were no areas classified as ‘high vulnerability’.

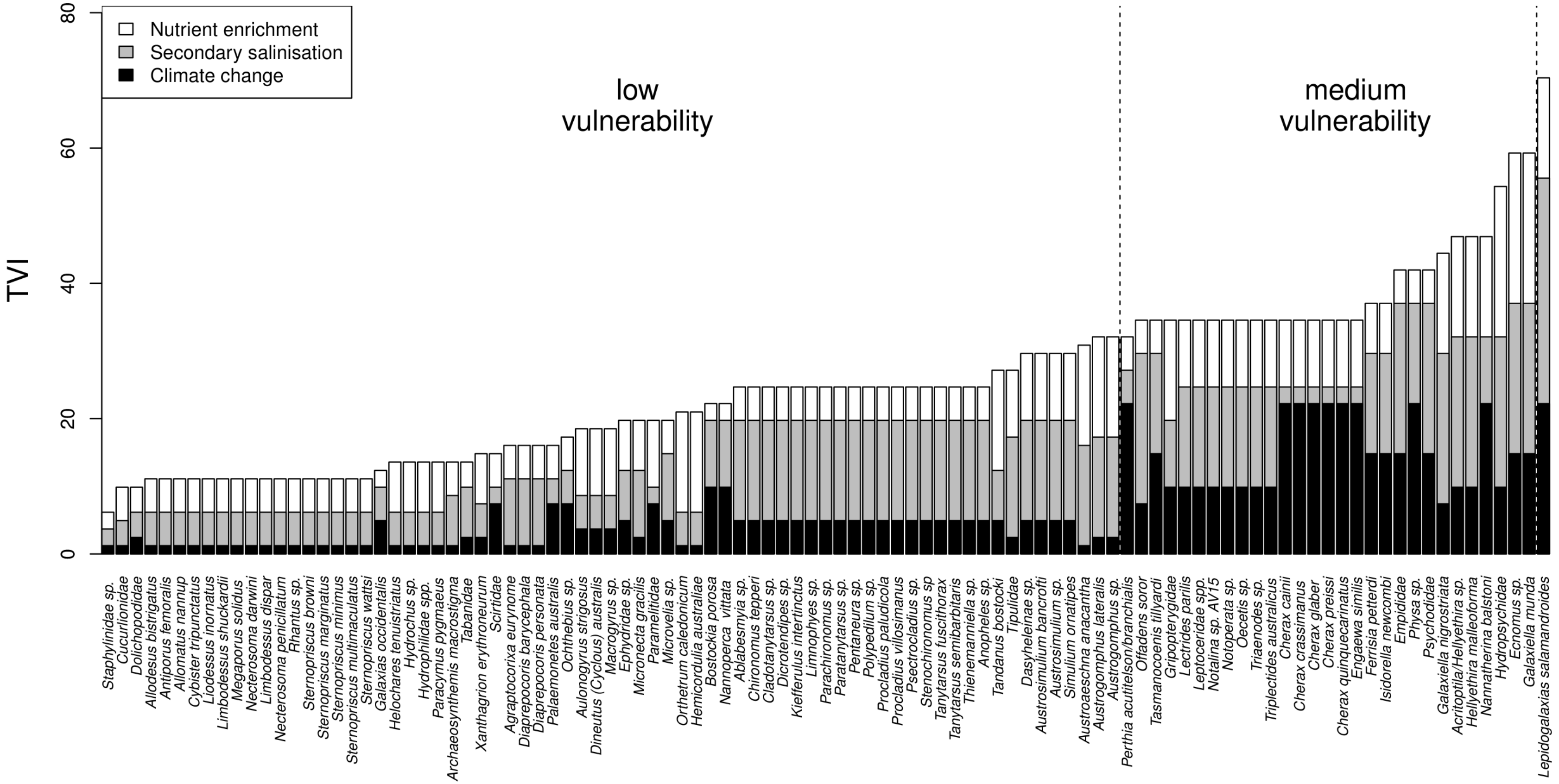

Figure 7. Standardised Threat Vulnerability Index (TVI) scores for 101 species of aquatic invertebrates and freshwater fish in the Blackwood River catchment. Species are arranged from smallest to largest values. Broken lines indicate groups of species that were considered of ‘low vulnerability’ (TVI < 33), ‘moderate vulnerability’ (33 < TVI < 66) and ‘high vulnerability’ (TVI > 66).

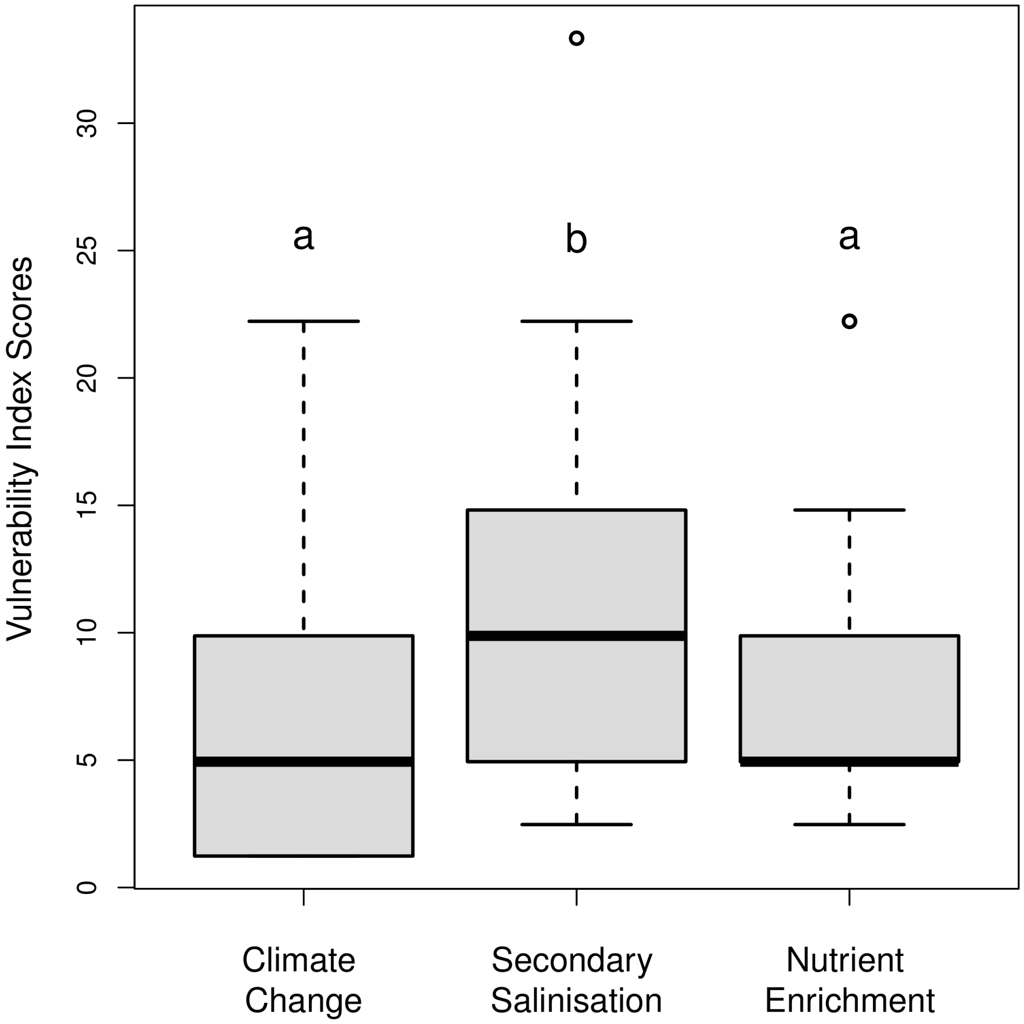

Figure 8. Box plots of vulnerability index scores for climate change, secondary salinization and nutrient enrichment. Lower case letters indicate results of statistical tests with different letters indicating significant differences at the 5% level.

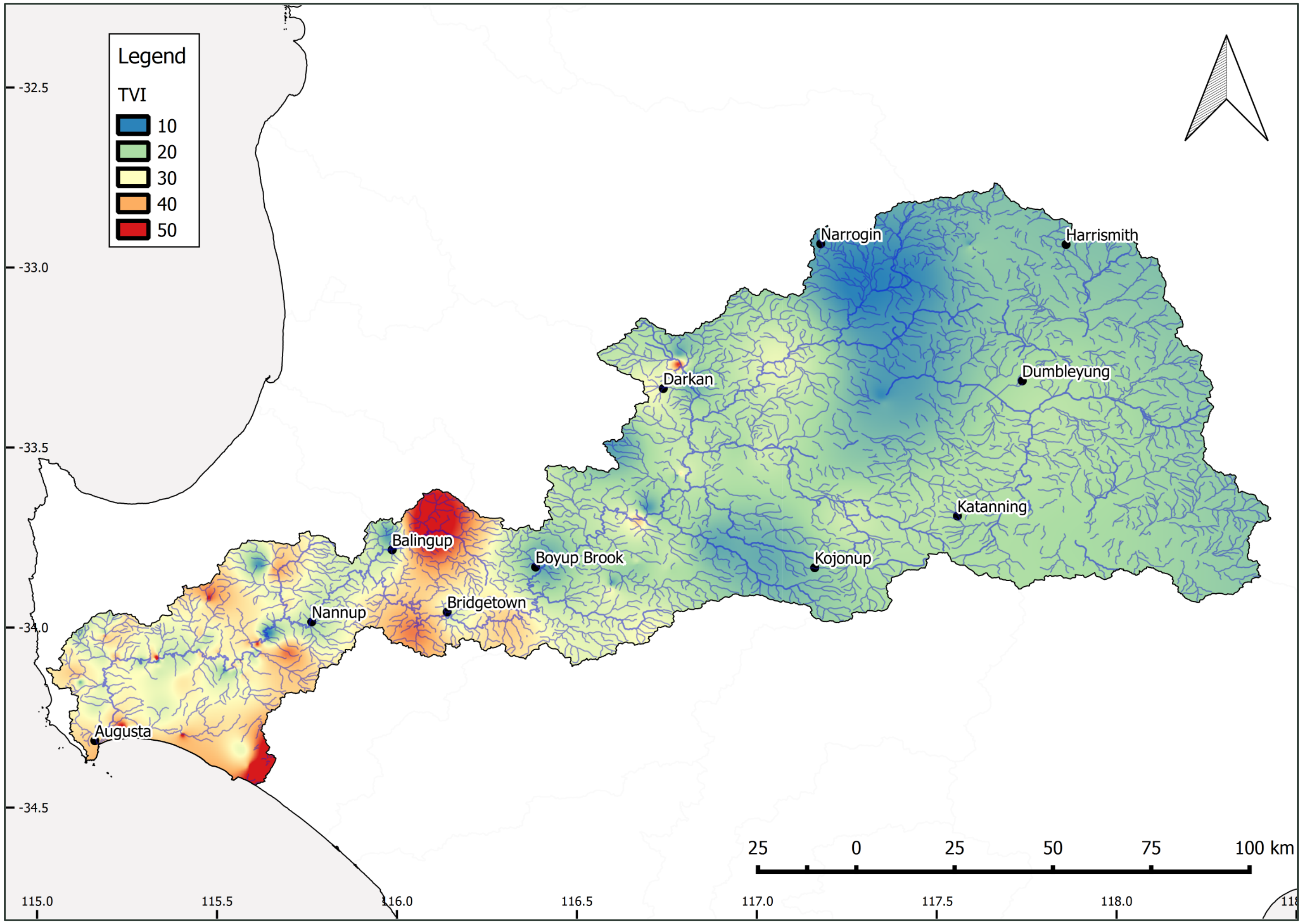

Figure 9. Map of Blackwood River catchment showing interpolated TVI scores

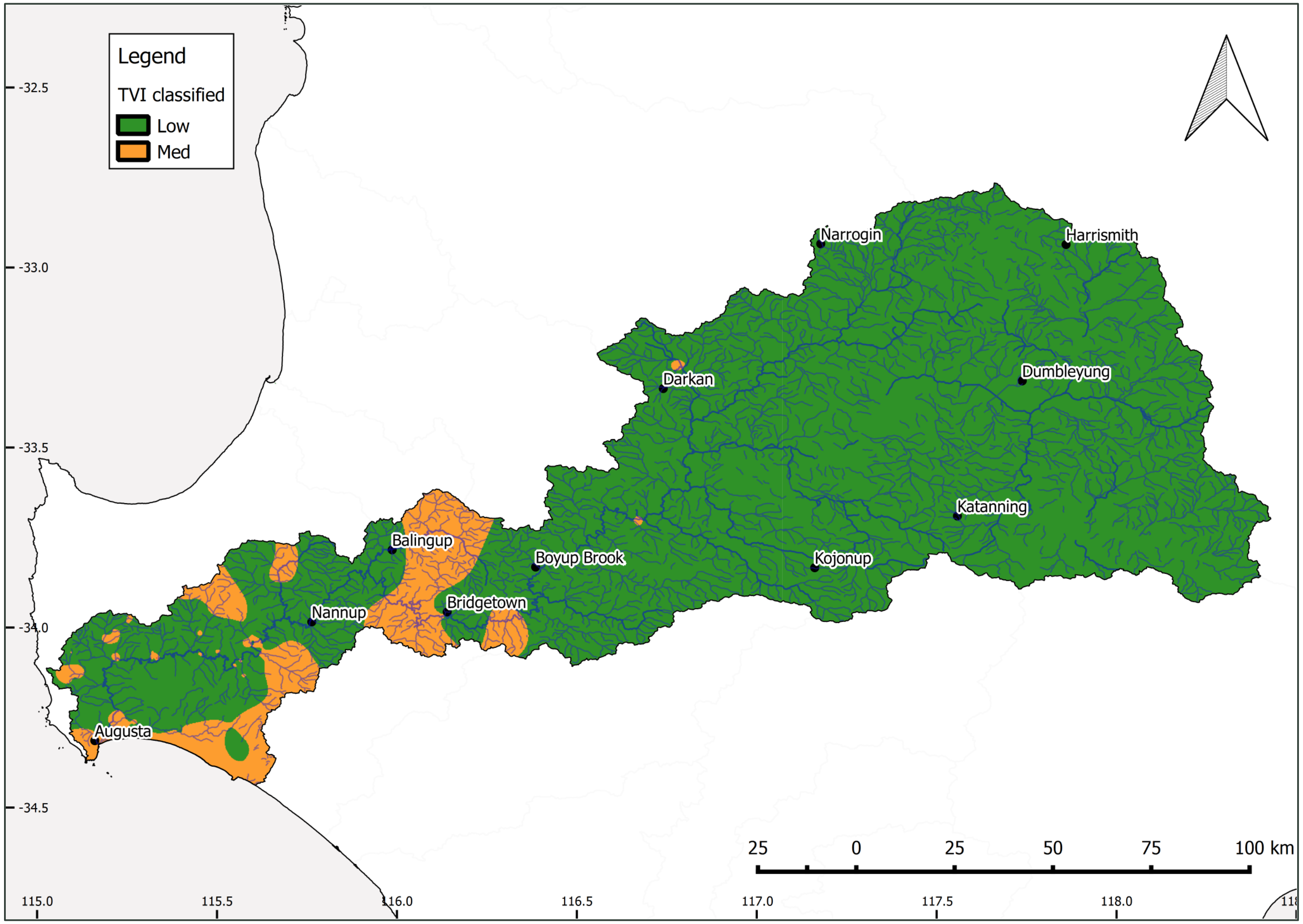

Figure 10. Map of Blackwood River catchment showing areas dominated by species which had been classified according to their TVI scores as being either of low vulnerability’ (green; interpolated values of 0-33), or of ‘medium vulnerability’ (orange; interpolated values of 33-66).

5. Discussion

The framework outlined here represents a robust, replicable approach for assessing the vulnerability of aquatic fauna to multiple threatening processes, including climate change. The framework can be readily adapted and applied to other regions where fauna are subjected to multiple threats. Using similar tables as provided in the online supplementary material, users will be able to score taxa occurring in rivers and wetlands for exposure, sensitivity and adaptive capacity; in the current example, to climate change, secondary salinization and nutrient enrichment. Results of these analyses can then be used for prioritising investment aimed at mitigating the negative impacts of multiple stressors on aquatic fauna.

We successfully applied the framework to a selected catchment in south-western Australia, scoring over 100 species of freshwater fish and aquatic invertebrates based on exposure, sensitivity and adaptive capacity to climate change, secondary salinization and nutrient enrichment. This enabled us to (i) identify the most vulnerable species worthy of continued conservation efforts and possible recognition as 'flagship' species, (ii) determine which threats contributed most to their vulnerability, and (iii) map the spatial distribution of vulnerable species to identify areas of the catchment that can be prioritised for restoration and conservation measures.

Firstly, we identified a number of species that were either 'highly vulnerable' or 'moderately vulnerable' to threatening processes, and thus could be suitable for focal species conservation measures. Only one species, the salamanderfish, belonging to the south-western Australian endemic family, Lepidogalaxiidae, was classified as 'highly vulnerable' (scoring more than 66 out of a possible 100). The salamanderfish typically occurs in ephemeral freshwater streams and pools on heathland peat flats between the Blackwood and Kent Rivers (Berra and Pusey, 1997), raising concern that reductions in rainfall, resulting in lowered groundwater levels, could seriously threaten this aestivating species (Morrongiello et al., 2011). Considered to be the sole representative of an early divergent lineage (divergence estimated at about 230 million years ago; Morgan et al., 2014a), this unique species would make a good candidate as a 'flagship' species for encouraging support for wetland and river restoration activities.

Our results also identified that three of the remaining seven freshwater fish known to occur in the Blackwood River catchment (including the Scott River) were 'moderately vulnerable' to the threats assessed (TVI values between 33 and 66). These included two *Galaxiella* species (western mud minnow and black-stripe minnow) listed by the International Union for the Conservation of Nature (IUCN) as 'lower risk/near threatened', and Balston's pygmy perch, listed as 'vulnerable' under the Australian Federal Government's *Environmental Protection and Biodiversity Conservation Act 1999* and as 'Schedule 1' (rare or likely to become extinct) under the Western Australian State Government's *Wildlife Conservation Act 1950*. Like the salamanderfish, both *Galaxiella* species have highly restricted distributions, while Balston's pygmy perch has experienced a 31% reduction in range (Morgan et al., 2014b).

A significant proportion of the 28 species classified as of 'moderate vulnerability' were caddisflies, with 11 species assessed as having TVI scores of 34.6 to 59.3. Many of these vulnerable species are likely to be of conservation concern. Applying the IUCN criteria for listing of threatened species, Sutcliffe (2003) concluded that 41 of the 71 known species of caddisfly in south-western Australia could be classed as threatened, with 12 classed as 'vulnerable', 20 as 'endangered', and nine as 'critically endangered'. Although arguably less suitable as 'flagship' species because of their small size and drab colours, these species would nevertheless be useful as indicators of environmental degradation.

Secondly, our results showed that over all species assessed, vulnerability to secondary salinization was significantly higher than vulnerability to climate change and nutrient enrichment, suggesting that this threatening process could continue to compromise the conservation of aquatic biodiversity in the Blackwood River catchment and the region as a whole. Beatty et al (2011) have attributed the current distributions of freshwater fish in the Blackwood River to range reductions resulting from secondary salinization, with freshwater species such as the western pygmy perch and

Balston's pygmy perch restricted to parts of the catchment where salinity values are lower. Historically, the upper parts of the Blackwood River catchment have been characterised by elevated salinity levels (Morrissy, 1974; Williams et al., 1991), and this has been attributed largely to land clearing for agriculture. It has been suggested that the present fauna of these salinized reaches may represent the halotolerant remnants of a once more diverse fauna (Williams et al., 1991), leaving the fresher lower reaches of the system acting as a refuge for salt sensitive species.

Thirdly, we identified a number of areas within the Blackwood River catchment that could be considered as 'hotspots' for vulnerable species. In particular, our results suggest that restoration and conservation efforts should be focussed in the lower part of the catchment. The Blackwood River Foundation, through its 'Strategic Investment Plan' is already targeting the lower Blackwood River, including the Scott River; supporting activities such as riparian restoration, stock exclusion, and nutrient and drainage management. Overall, application of the framework to this case study system confirms that an integrated approach to threat mitigation, where efforts are concentrated on riparian restoration aimed at controlling temperatures, salinity and nutrient enrichment should continue, and that potential 'flagship' species, such as the salamanderfish could be used to win community support.

The fact that this study identified only one species as being highly vulnerable, in a system which has been subjected to anthropogenic impacts, may be because species with lower tolerances are only found in less disturbed areas of the system. Being confined to these less disturbed areas, these species are not exposed to high salinity and nutrient levels. This would reduce the TVI scores possible, as the likelihood of a species scoring high for both exposure and sensitivity is reduced. Despite this, the species and areas of the Blackwood which were identified as being of 'medium vulnerability' can still be considered as priorities for management and conservation in this catchment.

The current framework enables the user to quantify the relative vulnerability to multiple threats of multiple groups of aquatic organisms. It would be readily adaptable to other regions, stressors and faunal groups provided there are adequate data to classify the level of exposure, sensitivity and adaptive capacity of the taxa being assessed. Therefore, there is an ongoing need for fundamental ecological data (such as species distributions, physicochemical tolerances, and life-cycles) to be obtained for aquatic organisms in order to increase the robustness of such assessments of species vulnerability to environmental change.

6. References

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Appendix A Supplementary Tables

Table A1. Median percentage change in climate envelope and climate change exposure scores for aquatic invertebrate families occurring in south-western Australia. Families with median envelope change < -75% were scored "3", families with median envelope change between -25 to -75% were scored "2", and families with median envelope change > -25% were scored "1". Aquatic invertebrate family median envelope percentage change summary: min = -100, 25th quartile = -50.03, median = -22.38, 75th quartile = 29.34, max = 260.42. NA indicates insufficient records for modelling.

Family	Description	Number of Species utilised	Family median percentage change in climate envelope	Exposure score
Aeolosomatidae	Worm	NA	NA	NA
Aeshnidae	Dragonfly	2	-15.20	1
Ameridae	Zooplankton	1	-84.47	3
Amphisopidae	Isopod	NA	NA	NA
Amphisopodidae	Isopod	1	-100.00	3
Ancylidae	Snail	1	-98.44	3
Anisitsiellidae	Water mite	NA	NA	NA
Arcellidae	Zooplankton	NA	NA	NA
Arrenuridae	Water mite	2	22.37	1
Artemiidae	Fairy shrimp	NA	NA	NA
Asplanchnidae	Zooplankton	NA	NA	NA
Assimineidae	Snail	NA	NA	NA
Athericidae	True Fly	NA	NA	NA
Atriplectididae	Caddisfly	1	-50.51	2
Aturidae	Water mite	1	-75.84	3
Atyidae	Shrimp	NA	NA	NA
Australomedusidae	Cnidaria	NA	NA	NA
Austrocorduliidae	Dragonfly	1	6.63	1
Baetidae	Mayfly	1	106.71	1
Bdellididae	Water mite	3	56.51	1
Belostomatidae	Water bug	NA	NA	NA
Bithynnidae	Snail	NA	NA	NA
Bosminidae	Zooplankton	NA	NA	NA
Brachionidae	Zooplankton	5	56.11	1
Branchiopodidae	Fairy shrimp	1	54.99	1
Brentidae	Beetle	NA	NA	NA
Caenidae	Mayfly	2	-44.68	2
Candonidae	Seed shrimp	NA	NA	NA
Canthocamptidae	Zooplankton	3	-38.62	2

Family	Description	Number of Species utilised	Family median percentage change in climate envelope	Exposure score
Capitellidae	Worm	NA	NA	NA
Carabidae	Beetle	NA	NA	NA
Ceinidae	Amphipod	1	-35.46	2
Centropagidae	Zooplankton	5	-31.25	2
Centropyxidae	Amoebae	NA	NA	NA
Ceratopogonidae	Biting midge	13	-5.51	1
Chaoboridae	Phantom midge	NA	NA	NA
Chiltoniidae	Amphipod	1	-47.01	2
Chironomidae	Midge	30	-2.88	1
Chrysomelidae	Beetle	1	-72.24	2
Chydoridae	Zooplankton	9	39.94	1
Cirolanidae	Isopod	NA	NA	NA
Coenagrionidae	Damselfly	9	-57.61	2
Conochilidae	Zooplankton	NA	NA	NA
Conoesucidae	Caddisfly	NA	NA	NA
Corixidae	Water bug	5	-9.70	1
Corophiidae	Amphipod	NA	NA	NA
Corydalidae	Fly	NA	NA	NA
Crambidae	Moth	NA	NA	NA
Culicidae	Mosquito	6	-0.54	1
Curculionidae	Beetle	1	-4.07	1
Cyclopidae	Zooplankton	1	-42.79	2
Cyclopoidae	Zooplankton	10	-5.23	1
Cyprididae	Seed shrimp	23	28.28	1
Cypridopsidae	Seed shrimp	2	13.86	1
Cytherideidae	Seed shrimp	NA	NA	NA
Cyzicidae	Clam shrimp	1	14.15	1
Daphniidae	Zooplankton	9	24.75	1
Darwinulidae	Seed shrimp	NA	NA	NA
Dicranophoridae	Zooplankton	NA	NA	NA
Difflugiidae	Amoebae	NA	NA	NA
Diosaccidae	Zooplankton	NA	NA	NA
Dolichopodidae	True fly	3	147.67	1
Dugesiidae	Worm	NA	NA	NA
Dytiscidae	Beetle	28	-6.62	1
Ecnomidae	Caddisfly	3	-90.12	3
Elmidae	Beetle	NA	NA	NA
Empididae	True fly	1	-77.12	3
Enchytraeidae	Worm	1	-2.96	1
Ephydridae	Shore Fly	5	-23.57	1

Family	Description	Number of Species utilised	Family median percentage change in climate envelope	Exposure score
Epiphanidae	Zooplankton	2	18.21	1
Euchlanidae	Zooplankton	NA	NA	NA
Euglyphidae	Amoebae	NA	NA	NA
Eusiridae	Amphipod	NA	NA	NA
Eylaidae	Water mite	1	55.36	1
Filiniidae	Zooplankton	NA	NA	NA
Flosculariidae	Zooplankton	NA	NA	NA
Galeommatidae	Mussel	NA	NA	NA
Gastropodidae	Zooplankton	NA	NA	NA
Gelastocoridae	Water bug	NA	NA	NA
Gerridae	Water bug	NA	NA	NA
Glacidorbidae	Snail	NA	NA	NA
Glossiphoniidae	Leech	1	-97.08	3
Gomphidae	Dragonfly	3	-48.54	2
Gordiidae	Worm	NA	NA	NA
Grapsidae	Crab	NA	NA	NA
Gripopterygidae	Stonefly	4	-43.73	2
Gyrinidae	Beetle	2	-90.78	3
Habrotrochidae	Water mite	NA	NA	NA
Halacaridae	Water mite	NA	NA	NA
Haliplidae	Beetle	4	4.63	1
Hebridae	Water bug	NA	NA	NA
Heleidae	Fly	NA	NA	NA
Hemicorduliidae	Dragonfly	2	198.29	1
Heteroceridae	Beetle	NA	NA	NA
Hexarthridae	Zooplankton	2	46.02	1
Hirudinidae	Leech	NA	NA	NA
Hydrachnidae	Water mite	1	21.41	1
Hydraenidae	Beetle	4	-85.36	3
Hydridae	Cnidaria	NA	NA	NA
Hydrobiidae	Snail	NA	NA	NA
Hydrobiosidae	Caddisfly	2	-68.27	2
Hydrochidae	Beetle	1	-100.00	3
Hydrodromidae	Water mite	1	19.27	1
Hydrometridae	Water bug	1	2.33	1
Hydrophilidae	Beetle	14	26.19	1
Hydropsychidae	Caddisfly	2	-53.42	2
Hydroptilidae	Caddisfly	5	-38.05	2
Hydryphantidae	Water mite	1	-85.29	3
Hygrobatidae	Water mite	1	-99.86	3

Family	Description	Number of Species utilised	Family median percentage change in climate envelope	Exposure score
Hygrobiidae	Beetle	NA	NA	NA
Hymenosomatidae	Crab	NA	NA	NA
Hypogastruridae	Springtail	1	-100.00	3
Hyriidae	Mussel	1	-76.40	3
Ilyocryptidae	Zooplankton	NA	NA	NA
Ilyocypridae	Seed shrimp	1	0.32	1
Ilyocyprididae	Seed shrimp	NA	NA	NA
Isostictidae	Damselfly	NA	NA	NA
Isotomidae	Springtail	1	-98.75	3
Laophontidae	Zooplankton	1	-83.80	3
Lecanidae	Zooplankton	5	98.91	1
Lepadellidae	Zooplankton	1	139.97	1
Leptoceridae	Caddisfly	17	-55.68	2
Leptocytheridae	Seed shrimp	NA	NA	NA
Leptophlebiidae	Mayfly	4	-100.00	3
Lestidae	Damselfly	4	26.90	1
Libellulidae	Dragonfly	3	114.61	1
Limnadiidae	Clam shrimp	1	2.71	1
Limnesiidae	Water mite	2	-61.11	2
Limnichidae	Beetle	NA	NA	NA
Limnocharidae	Water mite	1	-57.85	2
Limnocytheridae	Seed shrimp	2	-26.01	2
Lindeniidae	Dragonfly	NA	NA	NA
Lindiidae	Zooplankton	NA	NA	NA
Lymnaeidae	Snail	NA	NA	NA
Lynceidae	Clam shrimp	1	88.63	1
Macromiidae	Dragonfly	NA	NA	NA
Macrothricidae	Zooplankton	2	103.84	1
Megapodagrionidae	Damselfly	2	47.83	1
Melitidae	Amphipod	NA	NA	NA
Mesoveliidae	Water bug	NA	NA	NA
Micronectidae	Water bug	2	-9.70	1
Microsporidae	Beetle	NA	NA	NA
Mideopsidae	Water mite	NA	NA	NA
Moinidae	Zooplankton	1	-2.51	1
Momoniidae	Water mite	1	791.89	1
Munnidae	Isopod	NA	NA	NA
Muscidae	Fly	2	55.16	1
Mytilinidae	Zooplankton	NA	NA	NA
Naididae	Worm	2	404.36	1

Family	Description	Number of Species utilised	Family median percentage change in climate envelope	Exposure score
Nannochoristidae	Scorpionfly	NA	NA	NA
Naucoridae	Water bug	NA	NA	NA
Nebelidae	Amoeba	NA	NA	NA
Neoniphargidae	Amphipod	NA	NA	NA
Neothricidae	Zooplankton	1	52.36	1
Nepidae	Water bug	NA	NA	NA
Nereididae	Worm	NA	NA	NA
Noctuidae	Moth	NA	NA	NA
Noteridae	Beetle	1	-75.98	3
Notodromadidae	Seed shrimp	2	-87.01	3
Notommatidae	Zooplankton	1	39.68	1
Notonectidae	Water bug	6	-28.21	2
Oceaniidae	Cnidaria	NA	NA	NA
Ochteridae	Water bug	NA	NA	NA
Olindiidae	Cnidaria	NA	NA	NA
Oniscidae	Woodlice	1	-52.34	2
Orbatidadae	Mite	1	-100.00	3
Orbatidae	Mite	NA	NA	NA
Osmylidae	Spongefly	NA	NA	NA
Oxidae	Water mite	2	-47.18	2
Oxygastridae	Dragonfly	1	-73.22	2
Palaemonidae	Shrimp	2	85.51	1
Paramelitidae	Sideswimmer	1	-22.38	1
Parasitidae	Mite	NA	NA	NA
Parastacidae	Crayfish	6	-94.23	3
Parastenocarididae	Zooplankton	NA	NA	NA
Pelecorhynchidae	Fly	NA	NA	NA
Perthiidae	Amphipod	3	-83.90	3
Petaluridae	Dragonfly	1	127.22	1
Pezidae	Mite	1	-95.16	3
Philodinidae	Zooplankton	NA	NA	NA
Philopotamidae	Caddisfly	1	-47.90	2
Philorheithridae	Caddisfly	NA	NA	NA
Phreatoicidae	Isopod	NA	NA	NA
Phreatoicopsidae	Isopod	NA	NA	NA
Phreodrilidae	Worm	2	-3.34	1
Physidae	Snail	1	-99.83	3
Pionidae	Water mite	1	-49.85	2
Planorbidae	Snail	6	-27.95	2
Pleidae	Water bug	NA	NA	NA

Family	Description	Number of Species utilised	Family median percentage change in climate envelope	Exposure score
Plumatellidae	Zooid	NA	NA	NA
Poduridae	Springtail	1	-100.00	3
Polycentropodidae	Caddisfly	NA	NA	NA
Pomatiopsidae	Snail	3	-64.23	2
Proalidae	Zooplankton	NA	NA	NA
Protoneuridae	Damselfly	NA	NA	NA
Pseudodifflugiidae	Amoeba	NA	NA	NA
Psychodidae	True fly	2	-92.83	3
Ptiliidae	Beetle	NA	NA	NA
Ptilodactylidae	Beetle	NA	NA	NA
Pychodidae	Moth fly	NA	NA	NA
Pyralidae	Moth	1	37.15	1
Richardsonianidae	Leech	NA	NA	NA
Sabellidae	Worm	NA	NA	NA
Saldidae	Shore bug	NA	NA	NA
Scaridiidae	Zooplankton	NA	NA	NA
Scatopsidae	Midge	1	15.27	1
Sciomyzidae	True fly	1	16.56	1
Scirtidae	Beetle	1	-100.00	3
Serpulidae	Worm	NA	NA	NA
Sididae	Zooplankton	NA	NA	NA
Simuliidae	Black fly	2	-23.23	1
Sisyridae	Spongefly	NA	NA	NA
Sminthuridae	Springtail	1	-100.00	3
Spercheidae	Beetle	NA	NA	NA
Sphaeriidae	Pea clam	NA	NA	NA
Sphaeromatidae	Isopod	NA	NA	NA
Spongillidae	Sponge	NA	NA	NA
Staphylinidae	Beetle	1	3.13	1
Stratiomyidae	True fly	1	-14.13	1
Styloniscidae	Woodlice	NA	NA	NA
Sulcaniidae	Copepod	NA	NA	NA
Synchaetidae	Zooplankton	1	25.57	1
Synthemistidae	Dragonfly	4	115.42	1
Syrphidae	Hoverfly	NA	NA	NA
Tabanidae	Horsefly	1	8.06	1
Talitridae	Amphipod	NA	NA	NA
Tanyderidae	Cranefly	1	-100.00	3
Tanypodinae	Midge	1	-100.00	3
Telephlebiidae	Dragonfly	1	-13.09	1

Family	Description	Number of Species utilised	Family median percentage change in climate envelope	Exposure score
Temnocephalidae	Worm	1	-47.99	2
Tenebrionidae	Beetle	NA	NA	NA
Testudinellidae	Zooplankton	1	66.55	1
Tettigoniidae	Cricket	1	-100.00	3
Thamnocephalidae	Fairy shrimp	NA	NA	NA
Thaumeliidae	Midge	NA	NA	NA
Thiaridae	Snail	NA	NA	NA
Tipulidae	Cranefly	4	-19.07	1
Trapeziidae	Crab	NA	NA	NA
Trichocercidae	Zooplankton	NA	NA	NA
Trichotriidae	Zooplankton	NA	NA	NA
Triopsidae	Shield shrimp	NA	NA	NA
Trombidioidea	Water mite	1	31.21	1
Tubificidae	Worm	2	-28.22	2
Turbellaria	Worm	1	17.05	1
Unionicolidae	Water mite	1	-44.51	2
Urothemistidae	Dragonfly	NA	NA	NA
Veliidae	Water bug	1	-52.06	2

Table A2. Percentage change in climate envelope and climate change exposure scores for freshwater fish occurring in south-western Australia. Species with envelope change < -75% were scored "3", species with envelope change between -25 to -75% were scored "2", and species with median envelope change > -25% were scored "1". Freshwater fish envelope percentage change summary: min = -100, 25th quartile = -72.97, median = -54.02, 75th quartile = -36.67, max = 303.81. NA indicates insufficient records for modelling.

Species	Percent change in climate envelope	Exposure score
Bostockia porosa	-33.02	2
Galaxias maculatus	-70.96	2
Galaxias occidentalis	-48.02	2
Galaxias truttaceus	303.81	1
Galaxiella munda	-47.62	2
Galaxiella nigrostriata	-73.64	2
Lepidogalaxias salamandroides	-100.00	3
Nannatherina balstoni	-100.00	3
Nannoperca pygmaea	NA	NA
Nannoperca vittata	-60.01	2
Tandanus bostocki	58.62	1

Table A3. Mean upper thermal tolerance (UTT, °C) and climate change sensitivity scores for major aquatic invertebrate taxa in south-western Australia. Data sourced from Stewart et al. (2013) and Dallas and Rivers-Moore (2012). Invertebrate orders with a mean UTT < 23°C were scored "3", orders with a mean UTT between 23-33°C were scored "2", and orders with a mean UTT > 33°C were scored "1".

Taxon	**Mean UTT**	**Sensitivity score**
Planaria (flatworms)	32.2	2
Oligochaeta (segmented worms)	26.7	2
Mollusca (snails, limpets and mussels)	31.5	2
Amphipoda (sideswimmers)	24.3	2
Decapoda (crayfish and shrimps)	29.6	2
Ephemeroptera (mayflies)	22.3	3
Odonata (dragonflies and damselflies)	41.9	1
Plecoptera (stoneflies)	27.2	2
Hemiptera (true bugs)	39.7	1
Trichoptera (caddisflies)	30.1	2
Diptera (flies)	27.2	2
Coleoptera (beetles)	43.4	1

Table A4. Mean water temperature (°C) at sites of occupancy and climate change sensitivity scores of native freshwater fish in south-western Australia. Data sourced from Beatty et al. (2013) and unpublished sources. Freshwater fish with a mean water temperature at sites of occupancy < 17°C were scored "3", species with a mean water temperature at sites of occupancy between 17-19°C were scored "2", and species with a mean water temperature at sites of occupancy > 19°C were scored "1".

Species	**Mean (S.E.)**	**Max.-Min.**	**Range**	**75th percentile**	**Sensitivity score**
Bostockia porosa	17.65 (0.23)	29.30-8.33	20.97	20.80	2
Galaxias maculatus	15.14 (0.46)	21.53-11.1	10.43	17.00	3
Galaxias occidentalis	18.46 (0.22)	32.80-8.33	24.47	21.72	2
Galaxias truttaceus	15.94 (0.26)	23.50-8.54	14.96	17.95	3
Galaxiella munda	15.76 (0.41)	22.50-8.40	14.10	18.60	3
Galaxiella nigrostriata	20.01 (1.05)	33.47-12.17	21.30	24.57	1
Lepidogalaxias salamandroides	17.25 (0.76)	32.70-9.63	23.07	21.47	2
Nannatherina balstoni	16.56 (0.37)	24.73-8.33	16.40	19.43	3
Nannoperca pygmaea	15.74 (0.52)	26.63-10.67	15.96	18.30	3
Nannoperca vittata	18.22 (0.24)	34.83-8.33)	26.50	21.18	2
Tandanus bostocki	17.76 (0.31)	25.70-8.33	17.37	21.40	2

Table A5. Dispersal trait group and adaptive capacity score for families of aquatic invertebrates in south-western Australia. Dispersal trait groups were assigned according to Moran-Ordonez et al. (2015) and unpublished data. Families that are obligate aquatic dispersers were given a score of “3”, families that are weak active aerial dispersers or passive aerial dispersers were given a score of “2”, and families that are strong active aerial dispersers, phoretic aerial dispersers or are active aerials dispersers by hopping were given a score of “1”.

Family	Description	Dispersal trait group	Adaptive capacity score
Aeolosomatidae	Worm	Obligate aquatic disperser	3
Aeshnidae	Dragonfly	Strong active aerial disperser	1
Ameridae	Zooplankton	Passive aerial dispersers	2
Amphisopidae	Isopod	Obligate aquatic disperser	3
Amphisopodidae	Isopod	Obligate aquatic disperser	3
Ancylidae	Snail	Obligate aquatic disperser	3
Anisitsiellidae	Water mite	Phoretic aerial disperser	1
Arcellidae	Zooplankton	Passive aerial dispersers	2
Arrenuridae	Water mite	Phoretic aerial disperser	1
Artemiidae	Fairy shrimp	Obligate aquatic disperser	3
Asplanchnidae	Zooplankton	Passive aerial dispersers	2
Assimineidae	Snail	Obligate aquatic disperser	3
Athericidae	True Fly	Weak active aerial disperser	2
Atriplectididae	Caddisfly	Weak active aerial disperser	2
Aturidae	Water mite	Phoretic aerial disperser	1
Atyidae	Shrimp	Obligate aquatic disperser	3
Australomedusidae	Cnidaria	Obligate aquatic disperser	3
Austrocorduliidae	Dragonfly	Strong active aerial disperser	1
Baetidae	Mayfly	Weak active aerial disperser	2
Bdellididae	Water mite	Phoretic aerial disperser	1
Belostomatidae	Water bug	Strong active aerial disperser	1
Bithynnidae	Snail	Obligate aquatic disperser	3
Bosminidae	Zooplankton	Passive aerial dispersers	2
Brachionidae	Zooplankton	Passive aerial dispersers	2
Branchiopodidae	Fairy shrimp	Obligate aquatic disperser	3
Brentidae	Beetle	Weak active aerial disperser	2
Caenidae	Mayfly	Weak active aerial disperser	2
Candonidae	Seed shrimp	Passive aerial dispersers	2
Canthocamptidae	Zooplankton	Passive aerial dispersers	2
Capitellidae	Worm	Obligate aquatic disperser	3
Carabidae	Beetle	Strong active aerial disperser	1
Ceinidae	Amphipod	Obligate aquatic disperser	3
Centropagidae	Zooplankton	Passive aerial dispersers	2
Centropyxidae	Amoebae	Obligate aquatic disperser	3
Ceratopogonidae	Biting midge	Weak active aerial disperser	2
Chaoboridae	Phantom midge	Weak active aerial disperser	2
Chiltoniidae	Amphipod	Obligate aquatic disperser	3
Chironomidae	Midge	Weak active aerial disperser	2

Family	Description	Dispersal trait group	Adaptive capacity score
Chrysomelidae	Beetle	Weak active aerial disperser	2
Chydoridae	Zooplankton	Passive aerial dispersers	2
Cirolanidae	Isopod	Obligate aquatic disperser	3
Coenagrionidae	Damselfly	Strong active aerial disperser	1
Conochilidae	Zooplankton	Passive aerial dispersers	2
Conoesucidae	Caddisfly	Weak active aerial disperser	2
Corixidae	Water bug	Strong active aerial disperser	1
Corophiidae	Amphipod	Obligate aquatic disperser	3
Corydalidae	Fly	Weak active aerial disperser	2
Crambidae	Moth	Weak active aerial disperser	2
Culicidae	Mosquito	Weak active aerial disperser	2
Curculionidae	Beetle	Strong active aerial disperser	1
Cyclopidae	Zooplankton	Passive aerial dispersers	2
Cyclopoidae	Zooplankton	Passive aerial dispersers	2
Cyprididae	Seed shrimp	Passive aerial dispersers	2
Cypridopsidae	Seed shrimp	Passive aerial dispersers	2
Cytherideidae	Seed shrimp	Passive aerial dispersers	2
Cyzicidae	Clam shrimp	Passive aerial dispersers	2
Daphniidae	Zooplankton	Passive aerial dispersers	2
Darwinulidae	Seed shrimp	Passive aerial dispersers	2
Dicranophoridae	Zooplankton	Passive aerial dispersers	2
Difflugiidae	Amoebae	Obligate aquatic disperser	3
Diosaccidae	Zooplankton	Passive aerial dispersers	2
Dolichopodidae	True fly	Strong active aerial disperser	1
Dugesiidae	Worm	Obligate aquatic disperser	3
Dytiscidae	Beetle	Strong active aerial disperser	1
Ecnomidae	Caddisfly	Weak active aerial disperser	2
Elmidae	Beetle	Weak active aerial disperser	2
Empididae	True fly	Weak active aerial disperser	2
Enchytraeidae	Worm	Obligate aquatic disperser	3
Ephydridae	Shore Fly	Weak active aerial disperser	2
Epiphanidae	Zooplankton	Passive aerial dispersers	2
Euchlanidae	Zooplankton	Passive aerial dispersers	2
Euglyphidae	Amoebae	Obligate aquatic disperser	3
Eusiridae	Amphipod	Obligate aquatic disperser	3
Eylaidae	Water mite	Phoretic aerial disperser	1
Filiniidae	Zooplankton	Passive aerial dispersers	2
Flosculariidae	Zooplankton	Passive aerial dispersers	2
Galeommatidae	Mussel	Obligate aquatic disperser	3
Gastropodidae	Zooplankton	Passive aerial dispersers	2
Gelastocoridae	Water bug	Obligate aquatic disperser	3
Gerridae	Water bug	Strong active aerial disperser	1
Glacidorbidae	Snail	Obligate aquatic disperser	3
Glossiphoniidae	Leech	Obligate aquatic disperser	3

Family	Description	Dispersal trait group	Adaptive capacity score
Gomphidae	Dragonfly	Strong active aerial disperser	1
Gordiidae	Worm	Obligate aquatic disperser	3
Grapsidae	Crab	Obligate aquatic disperser	3
Gripopterygidae	Stonefly	Weak active aerial disperser	2
Gyrinidae	Beetle	Strong active aerial disperser	1
Habrotrochidae	Water mite	Phoretic aerial disperser	1
Halacaridae	Water mite	Phoretic aerial disperser	1
Haliplidae	Beetle	Weak active aerial disperser	2
Hebridae	Water bug	Weak active aerial disperser	2
Heleidae	Fly	Weak active aerial disperser	2
Hemicorduliidae	Dragonfly	Strong active aerial disperser	1
Heteroceridae	Beetle	Strong active aerial disperser	1
Hexarthridae	Zooplankton	Passive aerial dispersers	2
Hirudinidae	Leech	Obligate aquatic disperser	3
Hydrachnidae	Water mite	Phoretic aerial disperser	1
Hydraenidae	Beetle	Weak active aerial disperser	2
Hydridae	Cnidaria	Obligate aquatic disperser	3
Hydrobiidae	Snail	Obligate aquatic disperser	3
Hydrobiosidae	Caddisfly	Weak active aerial disperser	2
Hydrochidae	Beetle	Weak active aerial disperser	2
Hydrodromidae	Water mite	Phoretic aerial disperser	1
Hydrometridae	Water bug	Weak active aerial disperser	2
Hydrophilidae	Beetle	Strong active aerial disperser	1
Hydropsychidae	Caddisfly	Weak active aerial disperser	2
Hydroptilidae	Caddisfly	Weak active aerial disperser	2
Hydryphantidae	Water mite	Phoretic aerial disperser	1
Hygrobatidae	Water mite	Phoretic aerial disperser	1
Hygrobiidae	Beetle	Weak active aerial disperser	2
Hymenosomatidae	Crab	Obligate aquatic disperser	3
Hypogastruridae	Springtail	Active disperser by hopping	1
Hyriidae	Mussel	Obligate aquatic disperser	3
Ilyocryptidae	Zooplankton	Passive aerial dispersers	2
Ilyocypridae	Seed shrimp	Passive aerial dispersers	2
Ilyocyprididae	Seed shrimp	Passive aerial dispersers	2
Isostictidae	Damselfly	Strong active aerial disperser	1
Isotomidae	Springtail	Active disperser by hopping	1
Laophontidae	Zooplankton	Passive aerial dispersers	2
Lecanidae	Zooplankton	Passive aerial dispersers	2
Lepadellidae	Zooplankton	Passive aerial dispersers	2
Leptoceridae	Caddisfly	Weak active aerial disperser	2
Leptocytheridae	Seed shrimp	Passive aerial dispersers	2
Leptophlebiidae	Mayfly	Weak active aerial disperser	2
Lestidae	Damselfly	Strong active aerial disperser	1
Libellulidae	Dragonfly	Strong active aerial disperser	1

Family	Description	Dispersal trait group	Adaptive capacity score
Limnadiidae	Clam shrimp	Passive aerial dispersers	2
Limnesiidae	Water mite	Phoretic aerial disperser	1
Limnichidae	Beetle	Weak active aerial disperser	2
Limnocharidae	Water mite	Phoretic aerial disperser	1
Limnocytheridae	Seed shrimp	Passive aerial dispersers	2
Lindeniidae	Dragonfly	Strong active aerial disperser	1
Lindiidae	Zooplankton	Passive aerial dispersers	2
Lymnaeidae	Snail	Obligate aquatic disperser	3
Lynceidae	Clam shrimp	Passive aerial disperser	2
Macromiidae	Dragonfly	Strong active aerial disperser	1
Macrothricidae	Zooplankton	Passive aerial dispersers	2
Megapodagrionidae	Damselfly	Strong active aerial disperser	1
Melitidae	Amphipod	Obligate aquatic disperser	3
Mesoveliidae	Water bug	Weak active aerial disperser	2
Micronectidae	Water bug	Weak active aerial disperser	2
Microsporidae	Beetle	Weak active aerial disperser	2
Mideopsidae	Water mite	Phoretic aerial disperser	1
Moinidae	Zooplankton	Passive aerial dispersers	2
Momoniidae	Water mite	Phoretic aerial disperser	1
Munnidae	Isopod	Obligate aquatic disperser	3
Muscidae	Fly	Strong active aerial disperser	1
Mytilinidae	Zooplankton	Passive aerial dispersers	2
Naididae	Worm	Obligate aquatic disperser	3
Nannochoristidae	Scorpionfly	Strong active aerial disperser	1
Naucoridae	Water bug	Weak active aerial disperser	2
Nebelidae	Amoeba	Obligate aquatic disperser	3
Neoniphargidae	Amphipod	Obligate aquatic disperser	3
Neothricidae	Zooplankton	Passive aerial dispersers	2
Nepidae	Water bug	Strong active aerial disperser	1
Nereididae	Worm	Obligate aquatic disperser	3
Noctuidae	Moth	Strong active aerial disperser	1
Noteridae	Beetle	Weak active aerial disperser	2
Notodromadidae	Seed shrimp	Passive aerial dispersers	2
Notommatidae	Zooplankton	Passive aerial dispersers	2
Notonectidae	Water bug	Strong active aerial disperser	1
Oceaniidae	Cnidaria	Obligate aquatic disperser	3
Ochteridae	Water bug	Weak active aerial disperser	2
Olindiidae	Cnidaria	Obligate aquatic disperser	3
Oniscidae	Woodlice	Obligate aquatic disperser	3
Orbatidadae	Mite	Phoretic aerial disperser	1
Orbatidae	Mite	Phoretic aerial disperser	1
Osmylidae	Spongefly	Weak active aerial disperser	2
Oxidae	Water mite	Phoretic aerial disperser	1
Oxygastridae	Dragonfly	Strong active aerial disperser	1

Family	Description	Dispersal trait group	Adaptive capacity score
Palaemonidae	Shrimp	Obligate aquatic disperser	3
Paramelitidae	Sideswimmer	Obligate aquatic disperser	3
Parasitidae	Mite	Phoretic aerial disperser	1
Parastacidae	Crayfish	Obligate aquatic disperser	3
Parastenocarididae	Zooplankton	Passive aerial dispersers	2
Pelecorhynchidae	Fly	Strong active aerial disperser	1
Perthiidae	Amphipod	Obligate aquatic disperser	3
Petaluridae	Dragonfly	Strong active aerial disperser	1
Pezidae	Mite	Phoretic aerial disperser	1
Philodinidae	Zooplankton	Passive aerial dispersers	2
Philopotamidae	Caddisfly	Weak active aerial disperser	2
Philorheithridae	Caddisfly	Weak active aerial disperser	2
Phreatoicidae	Isopod	Obligate aquatic disperser	3
Phreatoicopsidae	Isopod	Obligate aquatic disperser	3
Phreodrilidae	Worm	Obligate aquatic disperser	3
Physidae	Snail	Obligate aquatic disperser	3
Pionidae	Water mite	Phoretic aerial disperser	1
Planorbidae	Snail	Obligate aquatic disperser	3
Pleidae	Water bug	Weak active aerial disperser	2
Plumatellidae	Zooid	Obligate aquatic disperser	3
Poduridae	Springtail	Active disperser by hopping	1
Polycentropodidae	Caddisfly	Weak active aerial disperser	2
Pomatiopsidae	Snail	Obligate aquatic disperser	3
Proalidae	Zooplankton	Passive aerial dispersers	2
Protoneuridae	Damselfly	Strong active aerial disperser	1
Pseudodifflugiidae	Amoeba	Obligate aquatic disperser	3
Psychodidae	True fly	Weak active aerial disperser	2
Ptiliidae	Beetle	Weak active aerial disperser	2
Ptilodactylidae	Beetle	Weak active aerial disperser	2
Pychodidae	Moth fly	Weak active aerial disperser	2
Pyralidae	Moth	Strong active aerial disperser	1
Richardsonianidae	Leech	Obligate aquatic disperser	3
Sabellidae	Worm	Obligate aquatic disperser	3
Saldidae	Shore bug	Strong active aerial disperser	1
Scaridiidae	Zooplankton	Passive aerial dispersers	2
Scatopsidae	Midge	Weak active aerial disperser	2
Sciomyzidae	True fly	Weak active aerial disperser	2
Scirtidae	Beetle	Weak active aerial disperser	2
Serpulidae	Worm	Obligate aquatic disperser	3
Sididae	Zooplankton	Passive aerial dispersers	2
Simuliidae	Black fly	Weak active aerial disperser	2
Sisyridae	Spongefly	Weak active aerial disperser	2
Sminthuridae	Springtail	Active disperser by hopping	1
Spercheidae	Beetle	Strong active aerial disperser	1

Family	Description	Dispersal trait group	Adaptive capacity score
Sphaeriidae	Pea clam	Obligate aquatic disperser	3
Sphaeromatidae	Isopod	Obligate aquatic disperser	3
Spongillidae	Sponge	Obligate aquatic disperser	3
Staphylinidae	Beetle	Strong active aerial disperser	1
Stratiomyidae	True fly	Weak active aerial disperser	2
Styloniscidae	Woodlice	Obligate aquatic disperser	3
Sulcaniidae	Copepod	Obligate aquatic disperser	3
Synchaetidae	Zooplankton	Passive aerial dispersers	2
Synthemistidae	Dragonfly	Strong active aerial disperser	1
Syrphidae	Hoverfly	Strong active aerial disperser	1
Tabanidae	Horsefly	Strong active aerial disperser	1
Talitridae	Amphipod	Obligate aquatic disperser	3
Tanyderidae	Cranefly	Strong active aerial disperser	1
Tanypodinae	Midge	Weak active aerial disperser	2
Telephlebiidae	Dragonfly	Strong active aerial disperser	1
Temnocephalidae	Worm	Obligate aquatic disperser	3
Tenebrionidae	Beetle	Strong active aerial disperser	1
Testudinellidae	Zooplankton	Passive aerial dispersers	2
Tettigoniidae	Cricket	Strong active aerial disperser	1
Thamnocephalidae	Fairy shrimp	Passive aerial dispersers	2
Thaumeliidae	Midge	Weak active aerial disperser	2
Thiaridae	Snail	Obligate aquatic disperser	3
Tipulidae	Cranefly	Strong active aerial disperser	1
Trapeziidae	Crab	Obligate aquatic disperser	3
Trichocercidae	Zooplankton	Passive aerial dispersers	2
Trichotriidae	Zooplankton	Passive aerial dispersers	2
Triopsidae	Shield shrimp	Obligate aquatic disperser	3
Trombidioidea	Water mite	Phoretic aerial disperser	1
Tubificidae	Worm	Obligate aquatic disperser	3
Turbellaria	Worm	Obligate aquatic disperser	3
Unionicolidae	Water mite	Phoretic aerial disperser	1
Urothemistidae	Dragonfly	Strong active aerial disperser	1
Veliidae	Water bug	Weak active aerial disperser	2

Table A6. Inferred dispersal abilities and adaptive capacity score of the native freshwater species occurring in south-western Australia. Measurements of maximum total length (TL) were taken from Morgan et al. (1998) and unpublished sources. Freshwater fish species smallest in size with limited migratory behaviour were given a score of “3”, species moderate in size with mostly non-streamlined bodies and migratory behaviours were given a score of “2”, and species larger in size with streamlined bodies and strong migratory behaviours were given a score of “1”.

Species	Description	Adaptive capacity score
Bostockia porosa	170 mm, potamodromous, widespread distribution in SW Australia	2
Galaxias maculatus	190 mm, diadromous, widespread distribution in southern Australia and Southern Hemisphere	1
Galaxias occidentalis	190 mm, potamodromous, extensive in-stream migratory behaviour	1
Galaxias truttaceus	200 mm, diadromous, southern Australian distribution, SW population landlocked	1
Galaxiella munda	60 mm, potamodromous, moves seasonally between temporary and permanent waters	2
Galaxiella nigrostriata	50 mm largely restricted to wetlands, aestivate in times of drought	3
Lepidogalaxias salamandroides	80 mm, restricted to wetlands, aestivate in times of drought	3
Nannatherina balstoni	90 mm, potamodromous, colonises acid pools on peat flats during inundation	2
Nannoperca pygmaea	65 mm, potamodromous, restricted geographical range	3
Nannoperca vittata	80 mm, potamodromous, widespread distribution in SW Australia	2
Tandanus bostocki	550 mm, undertakes localised upstream migration through riffles while feeding	2

Table A7. Salinity tolerance (mS cm^{-1}) levels based on LC$_{50}$ experiments and sensitivity scores for aquatic invertebrates. Data sourced from Kefford et al. (2003, 2005, 2006) and Dunlop et al. (2008). Invertebrate groups with salinity tolerances < 10 mS.cm^{-1} were given a score of “3”, invertebrate groups with salinity tolerances between 10-30 mS.cm^{-1} were given a score of “2”, and invertebrate groups with salinity tolerances > 30 mS.cm^{-1} were given a score of “1”.

Taxon	Salinity tolerances	Sensitivity score
Turbellaria (flatworms)	3-16	3
Hirudinea (leeches)	13-15	2
Annelida (Lumbriculidae)	15-20	2
Annelida (other segmented worms)	9	3
Bivalvia (mussels)	18-23	2
Gastropoda (snails, limpets)	3-20	3
Hydracarina (Limnesiidae, Unionicolidae)	3-47	3
Hydracarina (other water mites)	22-39	2
Amphipoda (Ceinidae)	49-52	1
Isopoda (Sphaeromatidae)	70-75	1
Decapoda (Atyidae)	29-41	1
Decapoda (Parastacidae)	40-50	1
Decapoda (Palaemonidae)	43	1
Ephemeroptera (Baetidae, Leptophlebiidae)	6-15	3
Ephemeroptera (Caenidae)	13	2
Odonata (Gomphidae, Libellulidae, Telephlebiidae)	13-47	2
Odonata (other dragonflies and damselflies)	34-60	1
Plecoptera (Stoneflies)	15-20	2
Hemiptera (Notonectidae)	6-40	3
Hemiptera (other water bugs)	13-30	2
Trichoptera (caddisflies)	3-47	3
Diptera (Chironomidae)	10	3
Coleoptera (beetles)	15-60	1

Table A8. The mean and 75th percentile of conductivity (µS.cm^{-1}) levels at sites of occupancy of freshwater fish in south-western Australia, with sensitivity scores assigned. Data sourced from Beatty et al. (2013) and Beatty et al. (2011). Freshwater fish species with the mean conductivity at sites of occupancy < 1000 µS.cm^{-1} were given a score of "3", species with mean conductivity at sites of occupancy between 1000-3000 µS.cm^{-1} were given a score of "2", and species with mean conductivity at sites of occupancy > 3000 µS.cm^{-1} were given a score of "1".

Species	**n**	**Mean (S.E.)**	**75th percentile**	**Median EC$_{50}$ (g.L^{-1})**	**Sensitivity score**
Bostockia porosa	366	1882.1 (143.8)	2543	-	2
Galaxias maculatus	30	30778.0 (3166)	45480	-	1
Galaxias occidentalis	563	2522.5 (178.4)	3413	14.7	2
Galaxias truttaceus	105	1057.0 (66.6)	1342	-	2
Galaxiella munda	75	738.6 (109.4)	720	-	3
Galaxiella nigrostriata	33	486.4 (57.8)	598	-	3
Lepidogalaxias salamandroides	53	375.6 (30.0)	485	-	3
Nannatherina balstoni	94	2146.0 (220.6)	4039	8.2	2
Nannoperca pygmaea	47	3667.7 (559.4)	8454	-	1
Nannoperca vittata	382	1641.6 (112.5)	2066	14.6	2
Tandanus bostocki	194	3135.9 (182.8)	4567	-	1

Table A9. The minimum, maximum and median of the ranges of conductivity (mS.cm^{-1}) at which aquatic invertebrate species occurred, with adaptive capacity scores assigned at the family level. Aquatic invertebrate families with a range of salinity levels at site of occupany < 1.60 mS.cm^{-1} were given a score of “3”, families with a range of salinity tolerances between 1.60-26.88 mS.cm^{-1} were given a score of “2”, and families with a range of salinity levels at sites of occurrence > 26.88 mS.cm^{-1} were given a score of “1”. Aquatic invertebrate salinity summary (mS.cm^{-1}): min = 0.002, 25th quartile = 1.60, median = 8.70, 75th quartile = 26.88, max = 479.95. NA indicates data not available.

Family	Description	Minimum range	Maximum range	Median Range	Adaptive capacity score
Aeolosomatidae	Worm	9.54	9.54	9.54	2
Aeshnidae	Dragonfly	1.44	65.55	13.35	2
Ameridae	Zooplankton	2.08	36.93	3.12	2
Amphisopidae	Isopod	4.61	4.61	4.61	2
Amphisopodidae	Isopod	10.26	10.26	10.26	2
Ancylidae	Snail	7.25	8.70	7.97	2
Anisitsiellidae	Water mite	NA	NA	NA	NA
Arcellidae	Zooplankton	0.91	6.40	0.91	3
Arrenuridae	Water mite	10.77	22.08	10.77	2
Artemiidae	Fairy shrimp	328.83	328.83	328.83	1
Asplanchnidae	Zooplankton	1.55	1.55	1.55	3
Assimineidae	Snail	8.90	8.90	8.90	2
Athericidae	True Fly	NA	NA	NA	NA
Atriplectididae	Caddisfly	0.40	0.40	0.40	3
Aturidae	Water mite	6.23	6.23	6.23	2
Atyidae	Shrimp	NA	NA	NA	NA
Australomedusidae	Cnidaria	NA	NA	NA	NA
Austrocorduliidae	Dragonfly	3.40	3.40	3.40	2
Baetidae	Mayfly	0.60	7.47	0.60	3
Bdellididae	Water mite	36.50	36.50	36.50	1
Belostomatidae	Water bug	NA	NA	NA	NA
Bithynnidae	Snail	NA	NA	NA	NA
Bosminidae	Zooplankton	NA	NA	NA	NA
Brachionidae	Zooplankton	1.58	126.32	10.15	2
Branchiopodidae	Fairy shrimp	6.40	304.00	112.00	1
Brentidae	Beetle	NA	NA	NA	NA
Caenidae	Mayfly	10.04	10.04	10.04	2
Candonidae	Seed shrimp	5.49	5.49	5.49	2
Canthocamptidae	Zooplankton	0.10	207.84	0.10	3
Capitellidae	Worm	6.40	6.40	6.40	2
Carabidae	Beetle	191.73	191.73	191.73	1
Ceinidae	Amphipod	NA	NA	NA	NA
Centropagidae	Zooplankton	0.04	331.44	7.30	2
Centropyxidae	Amoebae	1.26	9.12	6.41	2
Ceratopogonidae	Biting midge	0.64	479.95	14.36	2
Chaoboridae	Phantom midge	5.62	5.62	5.62	2
Chiltoniidae	Amphipod	123.41	123.41	123.41	1
Chironomidae	Midge	0.08	384.19	5.28	2
Chrysomelidae	Beetle	62.90	62.90	62.90	1

Family	Description	Minimum range	Maximum range	Median Range	Adaptive capacity score
Chydoridae	Zooplankton	0.15	191.73	0.29	3
Cirolanidae	Isopod	NA	NA	NA	NA
Coenagrionidae	Damselfly	0.65	65.55	15.24	2
Conochilidae	Zooplankton	0.17	0.59	0.38	3
Conoesucidae	Caddisfly	NA	NA	NA	NA
Corixidae	Water bug	4.30	65.25	15.79	2
Corophiidae	Amphipod	NA	NA	NA	NA
Corydalidae	Fly	NA	NA	NA	NA
Crambidae	Moth	0.50	19.90	0.50	3
Culicidae	Mosquito	0.02	145.25	7.86	2
Curculionidae	Beetle	255.87	255.87	255.87	1
Cyclopidae	Zooplankton	53.18	53.18	53.18	1
Cyclopoidae	Zooplankton	0.43	374.64	7.88	2
Cyprididae	Seed shrimp	0.02	331.44	8.16	2
Cypridopsidae	Seed shrimp	0.02	73.04	10.09	2
Cytherideidae	Seed shrimp	48.58	48.58	48.58	1
Cyzicidae	Clam shrimp	2.16	7.76	2.16	2
Daphniidae	Zooplankton	0.03	254.24	3.90	2
Darwinulidae	Seed shrimp	NA	NA	NA	NA
Dicranophoridae	Zooplankton	NA	NA	NA	NA
Difflugiidae	Amoebae	0.19	0.68	0.22	3
Diosaccidae	Zooplankton	57.60	78.69	68.14	1
Dolichopodidae	True fly	75.94	349.57	207.66	1
Dugesiidae	Worm	NA	NA	NA	NA
Dytiscidae	Beetle	0.08	255.86	11.48	2
Ecnomidae	Caddisfly	1.60	65.26	1.60	2
Elmidae	Beetle	0.23	0.23	0.23	3
Empididae	True fly	0.93	34.98	17.95	2
Enchytraeidae	Worm	31.62	479.94	255.78	1
Ephydridae	Shore Fly	0.59	349.57	52.75	1
Epiphanidae	Zooplankton	1.25	64.70	1.59	3
Euchlanidae	Zooplankton	1.84	1.84	1.84	2
Euglyphidae	Amoebae	NA	NA	NA	NA
Eusiridae	Amphipod	NA	NA	NA	NA
Eylaidae	Water mite	0.73	23.94	12.33	2
Filiniidae	Zooplankton	3.44	3.44	3.44	2
Flosculariidae	Zooplankton	0.42	39.47	0.52	3
Galeommatidae	Mussel	26.08	26.08	26.08	2
Gastropodidae	Zooplankton	NA	NA	NA	NA
Gelastocoridae	Water bug	0.37	1.07	0.72	3
Gerridae	Water bug	0.10	0.10	0.10	3
Glacidorbidae	Snail	0.06	0.06	0.06	3
Glossiphoniidae	Leech	0.02	3.86	0.02	3
Gomphidae	Dragonfly	0.46	16.10	0.46	3
Gordiidae	Worm	NA	NA	NA	NA
Grapsidae	Crab	NA	NA	NA	NA
Gripopterygidae	Stonefly	0.10	14.70	12.05	2
Gyrinidae	Beetle	8.02	17.20	11.90	2
Habrotrochidae	Water mite	NA	NA	NA	NA

Family	Description	Minimum range	Maximum range	Median Range	Adaptive capacity score
Halacaridae	Water mite	65.10	65.10	65.10	1
Haliplidae	Beetle	7.70	21.56	9.40	2
Hebridae	Water bug	2.08	2.08	2.08	2
Heleidae	Fly	NA	NA	NA	NA
Hemicorduliidae	Dragonfly	10.73	65.55	14.60	2
Heteroceridae	Beetle	12.16	12.16	12.16	2
Hexarthridae	Zooplankton	4.46	384.08	7.76	2
Hirudinidae	Leech	0.34	0.34	0.34	3
Hydrachnidae	Water mite	5.41	65.52	8.30	2
Hydraenidae	Beetle	0.08	101.40	7.43	2
Hydridae	Cnidaria	5.14	36.60	5.14	2
Hydrobiidae	Snail	1.60	1.60	1.60	2
Hydrobiosidae	Caddisfly	9.40	9.40	9.40	2
Hydrochidae	Beetle	8.96	57.04	8.96	2
Hydrodromidae	Water mite	6.26	14.70	10.48	2
Hydrometridae	Water bug	33.50	33.50	33.50	1
Hydrophilidae	Beetle	0.14	384.19	17.14	2
Hydropsychidae	Caddisfly	3.40	12.90	3.40	2
Hydroptilidae	Caddisfly	0.40	17.40	1.11	3
Hydryphantidae	Water mite	1.60	20.80	14.90	2
Hygrobatidae	Water mite	17.40	17.40	17.40	2
Hygrobiidae	Beetle	0.86	7.00	3.93	2
Hymenosomatidae	Crab	NA	NA	NA	NA
Hypogastruridae	Springtail	105.36	105.36	105.36	1
Hyriidae	Mussel	43.20	43.20	43.20	1
Ilyocryptidae	Zooplankton	0.85	5.71	3.28	2
Ilyocypridae	Seed shrimp	9.36	51.68	9.36	2
Ilyocyprididae	Seed shrimp	12.23	12.23	12.23	2
Isostictidae	Damselfly	NA	NA	NA	NA
Isotomidae	Springtail	55.00	55.00	55.00	1
Laophontidae	Zooplankton	30.85	30.85	40.85	1
Lecanidae	Zooplankton	NA	NA	NA	NA
Lepadellidae	Zooplankton	1.31	189.92	11.73	2
Leptoceridae	Caddisfly	0.10	109.24	6.83	2
Leptocytheridae	Seed shrimp	48.58	48.58	48.58	1
Leptophlebiidae	Mayfly	0.97	12.90	1.20	3
Lestidae	Damselfly	0.32	73.12	52.48	1
Libellulidae	Dragonfly	0.66	17.56	1.82	2
Limnadiidae	Clam shrimp	1.65	7.76	3.15	2
Limnesiidae	Water mite	5.46	8.32	6.68	2
Limnichidae	Beetle	95.92	95.92	95.92	1
Limnocharidae	Water mite	13.10	13.10	13.10	2
Limnocytheridae	Seed shrimp	0.10	44.12	1.28	3
Lindeniidae	Dragonfly	NA	NA	NA	NA
Lindiidae	Zooplankton	NA	NA	NA	NA
Lymnaeidae	Snail	14.10	67.60	40.85	1
Lynceidae	Clam shrimp	7.78	7.78	7.78	2
Macromiidae	Dragonfly	NA	NA	NA	NA
Macrothricidae	Zooplankton	0.10	22.22	1.09	3

Family	Description	Minimum range	Maximum range	Median Range	Adaptive capacity score
Megapodagrionidae	Damselfly	0.21	9.80	0.42	3
Melitidae	Amphipod	22.88	22.88	22.88	2
Mesoveliidae	Water bug	9.95	102.70	56.33	1
Micronectidae	Water bug	5.07	104.56	13.71	2
Microsporidae	Beetle	NA	NA	NA	NA
Mideopsidae	Water mite	0.40	0.40	0.40	3
Moinidae	Zooplankton	0.35	11.95	3.09	2
Momoniidae	Water mite	8.50	8.50	8.50	2
Munnidae	Isopod	NA	NA	NA	NA
Muscidae	Fly	17.28	479.78	56.50	1
Mytilinidae	Zooplankton	0.78	1.78	1.28	3
Naididae	Worm	0.16	10.66	0.85	3
Nannochoristidae	Scorpionfly	NA	NA	NA	NA
Naucoridae	Water bug	NA	NA	NA	NA
Nebelidae	Amoeba	0.02	0.02	0.02	3
Neoniphargidae	Amphipod	NA	NA	NA	NA
Neothricidae	Zooplankton	2.19	2.19	2.19	2
Nepidae	Water bug	0.26	0.26	0.26	3
Nereididae	Worm	NA	NA	NA	NA
Noctuidae	Moth	1.08	1.08	1.08	3
Noteridae	Beetle	NA	NA	NA	NA
Notodromadidae	Seed shrimp	0.32	105.10	4.15	2
Notommatidae	Zooplankton	NA	NA	NA	NA
Notonectidae	Water bug	2.05	95.95	19.55	2
Oceaniidae	Cnidaria	NA	NA	NA	NA
Ochteridae	Water bug	NA	NA	NA	NA
Olindiidae	Cnidaria	2.20	2.20	2.20	2
Oniscidae	Woodlice	0.79	202.35	57.60	1
Orbatidadae	Mite	66.20	66.20	66.20	1
Orbatidae	Mite	2.54	2.54	2.54	2
Osmylidae	Spongefly	NA	NA	NA	NA
Oxidae	Water mite	0.38	28.06	1.58	3
Oxygastridae	Dragonfly	0.70	0.70	0.70	3
Palaemonidae	Shrimp	44.40	44.40	44.40	1
Paramelitidae	Sideswimmer	44.50	44.50	44.50	1
Parasitidae	Mite	0.37	0.37	0.37	3
Parastacidae	Crayfish	11.97	65.54	27.70	1
Parastenocarididae	Zooplankton	5.44	5.44	5.44	2
Pelecorhynchidae	Fly	NA	NA	NA	NA
Perthiidae	Amphipod	0.10	27.80	18.52	2
Petaluridae	Dragonfly	NA	NA	NA	NA
Pezidae	Mite	25.33	25.33	25.33	2
Philodinidae	Zooplankton	0.50	207.66	0.56	3
Philopotamidae	Caddisfly	0.80	7.49	4.15	2
Philorheithridae	Caddisfly	NA	NA	NA	NA
Phreatoicidae	Isopod	NA	NA	NA	NA
Phreatoicopsidae	Isopod	NA	NA	NA	NA
Phreodrilidae	Worm	0.59	2.51	1.31	3
Physidae	Snail	11.68	11.68	11.68	2

Family	Description	Minimum range	Maximum range	Median Range	Adaptive capacity score
Pionidae	Water mite	5.41	64.62	5.41	2
Planorbidae	Snail	0.59	34.80	7.01	2
Pleidae	Water bug	0.82	6.70	0.82	3
Plumatellidae	Zooid	NA	NA	NA	NA
Poduridae	Springtail	NA	NA	NA	NA
Polycentropodidae	Caddisfly	NA	NA	NA	NA
Pomatiopsidae	Snail	60.80	198.11	116.60	1
Proalidae	Zooplankton	NA	NA	NA	NA
Protoneuridae	Damselfly	NA	NA	NA	NA
Pseudodifflugiidae	Amoeba	NA	NA	NA	NA
Psychodidae	True fly	8.22	11.14	8.22	2
Ptiliidae	Beetle	11.10	11.10	11.10	2
Ptilodactylidae	Beetle	NA	NA	NA	NA
Pychodidae	Moth fly	1.00	1.00	1.00	3
Pyralidae	Moth	0.50	84.65	42.58	1
Richardsonianidae	Leech	NA	NA	NA	NA
Sabellidae	Worm	160.00	160.00	160.00	1
Saldidae	Shore bug	10.08	101.30	64.93	1
Scaridiidae	Zooplankton	0.68	0.68	0.68	3
Scatopsidae	Midge	101.10	478.40	289.75	1
Sciomyzidae	True fly	1.10	126.27	43.60	1
Scirtidae	Beetle	17.14	51.86	34.50	1
Serpulidae	Worm	NA	NA	NA	NA
Sididae	Zooplankton	NA	NA	NA	NA
Simuliidae	Black fly	11.17	28.06	11.17	2
Sisyridae	Spongefly	NA	NA	NA	NA
Sminthuridae	Springtail	105.36	105.36	105.36	1
Spercheidae	Beetle	NA	NA	NA	NA
Sphaeriidae	Pea clam	1.69	57.00	1.69	2
Sphaeromatidae	Isopod	22.88	44.50	33.69	1
Spongillidae	Sponge	1.28	1.28	1.28	3
Staphylinidae	Beetle	479.95	479.95	479.95	1
Stratiomyidae	True fly	479.87	479.87	479.87	1
Styloniscidae	Woodlice	26.60	26.60	26.60	2
Sulcaniidae	Copepod	11.23	11.23	11.23	2
Synchaetidae	Zooplankton	0.54	10.40	7.79	2
Synthemistidae	Dragonfly	0.10	12.90	0.52	3
Syrphidae	Hoverfly	17.39	17.39	17.39	2
Tabanidae	Horsefly	1.33	479.87	240.60	1
Talitridae	Amphipod	25.10	25.10	25.10	2
Tanyderidae	Cranefly	12.90	12.90	12.90	2
Tanypodinae	Midge	128.70	128.70	128.70	1
Telephlebiidae	Dragonfly	12.90	12.90	12.90	2
Temnocephalidae	Worm	0.40	4.11	0.95	3
Tenebrionidae	Beetle	NA	NA	NA	NA
Testudinellidae	Zooplankton	NA	NA	NA	NA
Tettigoniidae	Cricket	13.88	13.88	13.88	2
Thamnocephalidae	Fairy shrimp	NA	NA	NA	NA
Thaumeliidae	Midge	NA	NA	NA	NA

Family	Description	Minimum range	Maximum range	Median Range	Adaptive capacity score
Thiaridae	Snail	NA	NA	NA	NA
Tipulidae	Cranefly	3.46	255.90	3.63	2
Trapeziidae	Crab	NA	NA	NA	NA
Trichocercidae	Zooplankton	0.07	191.44	0.35	3
Trichotriidae	Zooplankton	0.50	1.78	0.89	3
Triopsidae	Shield shrimp	1.41	2.21	1.81	2
Trombidioidea	Water mite	65.54	65.54	65.54	1
Tubificidae	Worm	NA	NA	NA	NA
Turbellaria	Worm	95.95	95.95	95.95	1
Unionicolidae	Water mite	10.32	32.01	10.32	2
Urothemistidae	Dragonfly	NA	NA	NA	NA
Veliidae	Water bug	6.51	8.99	7.47	2

Table A10. Range of conductivity (µS.cm^{-1}) levels at sites of occupancy and adaptive capacity scores for freshwater fish in south-western Australia. Data sourced from Beatty et al. (2013) and Beatty et al. (2011). Freshwater fish species with a range of salinity levels at sites of occurrence < 5218 µS.cm^{-1} were given a score of "3", species with a range of salinity levels at sites of occurrence between 5218–23348 µS.cm^{-1} were given a score of "2", and species with a range of salinity levels at sites of occurrence > 23348 µS.cm^{-1} were given a score of "1". Freshwater fish salinity summary (µS.cm^{-1}): min = 945, 25th quartile = 5218, median = 9371, 75th quartile = 23348, max = 62960.

Species	**n**	**Max-Min**	**Range**	**Adaptive capacity score**
Bostockia porosa	366	29500-168	29332	1
Galaxias maculatus	30	64000-1040	62960	1
Galaxias occidentalis	563	41100-108	40992	1
Galaxias truttaceus	105	6070-178	5892	2
Galaxiella munda	75	4805-261	4544	3
Galaxiella nigrostriata	33	1668-194	1474	3
Lepidogalaxias salamandroides	53	1027-82	945	3
Nannatherina balstoni	94	8700-190	8510	2
Nannoperca pygmaea	47	347-9718	9371	2
Nannoperca vittata	382	17500-136	17364	2
Tandanus bostocki	194	17500-185	17315	2

Table A11. Sensitivity of aquatic invertebrates to nutrient enrichment based on SIGNAL scores derived from Chessman (2003). Aquatic invertebrate families with a SIGNAL score > 7 were given a score of “3”, families with a SIGNAL scores between 4-7 were given a score of “2”, and families with a SIGNAL score < 4 were given a score of “1”.

Family	SIGNAL	Sensitivity score
Aeshnidae (*sensu lato*)	4	2
Amphisopidae	1	1
Ancylidae	4	2
Athericidae	8	3
Atriplectididae	7	2
Atyidae	3	1
Austrocorduliidae	10	3
Baetidae	5	2
Belostomatidae	1	1
Bithyniidae	3	1
Branchipodidae	1	1
Brentidae	3	1
Caenidae	4	2
Calamoceratidae	7	2
Carabidae	3	1
Cecidomyidae	1	1
Ceinidae	2	1
Ceratopogonidae	4	2
Chaoboridae	2	1
Chironominae	3	1
Chrysomelidae	2	1
Cirolanidae	2	1
Coenagrionidae	2	1
Corbiculidae	4	2
Corduliidae	5	2
Corixidae	2	1
Corophiidae	4	2
Corydalidae	7	2
Culicidae	1	1
Curculionidae	2	1
Dolichopodidae	3	1
Dugesiidae	2	1
Dytiscidae	2	1
Ecnomidae	4	2
Elmidae	7	2
Empididae	5	2
Ephydridae	2	1
Gelastocoridae	5	2
Gerridae	4	2

Family	SIGNAL	Sensitivity score
Glacidorbidae	5	2
Glossiphoniidae	1	1
Gomphidae	5	2
Gordiidae	5	2
Gripopterygidae	8	3
Gyrinidae	4	2
Haliplidae	2	1
Hebridae	3	1
Hemicorduliidae	5	2
Heteroceridae	1	1
Hydraenidae	3	1
Hydridae	2	1
Hydrobiidae	4	2
Hydrobiosidae	8	3
Hydrochidae	4	2
Hydrometridae	3	1
Hydrophilidae	2	1
Hydropsychidae	6	2
Hydroptilidae	4	2
Hygrobiidae	1	1
Hyriidae	5	2
Leptoceridae	6	2
Leptophlebiidae	8	3
Lestidae	1	1
Libellulidae	4	2
Limnichidae	4	2
Lymnaeidae	1	1
Megapodagrionidae	5	2
Melitidae	7	2
Mesoveliidae	2	1
Muscidae	1	1
Nannochoristidae	9	3
Naucoridae	2	1
Nepidae	3	1
Noteridae	4	2
Notonectidae	1	1
Notonemouridae	6	2
Oniscidae	2	1
Orthocladiinae	4	2
Palaemonidae	4	2
Paramelitidae	4	2
Parastacidae	4	2
Perthiidae	4	2
Philopotamidae	8	3

Family	SIGNAL	Sensitivity score
Physidae	1	1
Planorbidae	2	1
Pleidae	2	1
Polycentropodidae	7	2
Pomatiopsidae	1	1
Psychodidae	3	1
Ptilidae	3	1
Pyralidae	3	1
Saldidae	1	1
Scatopsidae	1	1
Sciomyzidae	2	1
Scirtidae	6	2
Simuliidae	5	2
Sisyridae	3	1
Sphaeriidae	5	2
Sphaeromatidae	1	1
Spongillidae	3	1
Staphylinidae	3	1
Stratiomyidae	2	1
Synthemistidae	2	1
Syrphidae	2	1
Tabanidae	3	1
Talitridae	3	1
Tanyderidae	6	2
Tanypodinae	4	2
Telephlebiidae	9	3
Temnocephalidae	5	2
Thaumaleidae	7	2
Tipulidae	5	2
Triopsidae	1	1
Veliidae	3	1

Table A12. The minimum dissolved oxygen (mg/L) levels at sites of occupancy of freshwater fish in south-western Australia, with sensitivity scores assigned. Data from Morgan et al. (2006), Beatty et al. (2011), Beatty et al. (2013), and unpublished sources. Freshwater fish species with a minimum oxygen level at site of occupancy > 2.7 mg/L were given a score of “3”, species with a minimum oxygen level at site of occupancy between 1.64-2.79 mg/L were given a score of “2”, and species with a minimum oxygen level at site of occupancy < 1.64 mg/L were given a score of “1”. Dissolved oxygen summary (mg/L): min = 0.3, 25th quartile = 1.64, median = 2.42, 75th quartile = 2.79, max = 3.44.

Species	n	Minimum D.O.	Sensitivity score
Bostockia porosa	264	0.30	1
Galaxias maculatus	50	1.50	1
Galaxias occidentalis	361	0.30	1
Galaxias truttaceus	153	2.60	2
Galaxiella munda	16	1.70	2
Galaxiella nigrostriata	33	2.68	2
Lepidogalaxias salamandroides	53	2.42	2
Nannatherina balstoni	89	2.90	3
Nannoperca pygmaea	47	1.76	2
Nannoperca vittata	263	1.57	1
Tandanus bostocki	164	3.44	3

Table A13. Macroinvertebrate family median total nitrogen (mg/L) and total phosphorus (mg/L) values, with assigned adaptive capacity scores for aquatic invertebrates. Aquatic invertebrate families were given a score for both nitrogen adaptive capacity and phosphorus adaptive capacity. These scores were then averaged and rounded up to determine the nutrient enrichment score. Families with total nitrogen (TN) < 0.70 mg/L and total phosphorus (TP) < 0.03 mg/L were given a score of “3”, families with TN between 0.70-3.51 mg/L and TP between 0.03-0.51 mg/L were given a score of “2”, and families with TN > 3.51 mg/L and TP > 0.51 mg/L were given a score of “1”. TN summary (mg/L): min = 0.02, 25th quartile = 0.7, median = 1.47, 75th quartile = 3.50, max = 27.98. TP summary (mg/L): min = 0.001, 25th quartile = 0.03, median = 0.13, 75th quartile = 0.51, max = 6.99. NA indicates data not available.

Family	Description	Median total nitrogen	Nitrogen adaptive capacity score	Median total phosphorus	Phosphorus adaptive capacity score	Nutrient enrichment score
Aeolosomatidae	Worm	1.14	2	0.13	2	2
Aeshnidae	Dragonfly	1.66	2	0.67	1	2
Ameridae	Zooplankton	1.04	2	0.01	3	3
Amphisopidae	Isopod	1.45	2	0.07	2	2
Amphisopodidae	Isopod	27.98	1	3.49	1	1
Ancylidae	Snail	2.93	2	0.42	2	2
Anisitsiellidae	Water mite	NA	NA	NA	NA	NA
Arcellidae	Zooplankton	0.30	3	0.01	3	3
Arrenuridae	Water mite	1.35	2	0.02	3	3
Artemiidae	Fairy shrimp	2.60	2	0.01	3	3
Asplanchnidae	Zooplankton	1.30	2	0.02	3	3
Assimineidae	Snail	0.20	3	0.01	3	3
Athericidae	True Fly	NA	NA	NA	NA	NA
Atriplectididae	Caddisfly	0.03	3	0.01	3	3
Aturidae	Water mite	0.82	2	0.21	2	2
Atyidae	Shrimp	NA	NA	NA	NA	NA
Australomedusidae	Cnidaria	0.61	3	0.01	3	3
Austrocorduliidae	Dragonfly	1.50	2	0.42	2	2
Baetidae	Mayfly	1.45	2	0.57	1	2
Bdellididae	Water mite	0.91	2	0.07	2	2
Belostomatidae	Water bug	NA	NA	NA	NA	NA
Bithynnidae	Snail	NA	NA	NA	NA	NA
Bosminidae	Zooplankton	NA	NA	NA	NA	NA
Brachionidae	Zooplankton	1.79	2	0.18	2	2
Branchiopodidae	Fairy shrimp	0.30	3	0.01	3	3
Brentidae	Beetle	4.30	2	0.01	3	3
Caenidae	Mayfly	4.39	1	0.57	1	1
Candonidae	Seed shrimp	1.44	2	0.01	3	3
Canthocamptidae	Zooplankton	0.07	3	0.01	3	3
Capitellidae	Worm	0.69	3	0.02	3	3
Carabidae	Beetle	5.24	1	1.69	1	1

Family	Description	Median total nitrogen	Nitrogen adaptive capacity score	Median total phosphorus	Phosphorus adaptive capacity score	Nutrient enrichment score
Ceinidae	Amphipod	NA	NA	NA	NA	NA
Centropagidae	Zooplankton	1.63	2	0.09	2	2
Centropyxidae	Amoebae	0.65	3	0.01	3	3
Ceratopogonidae	Biting midge	2.24	2	0.14	2	2
Chaoboridae	Phantom	1.52	2	0.08	2	2
Chiltoniidae	Amphipod	25.88	1	0.79	1	1
Chironomidae	Midge	1.51	2	0.10	2	2
Chrysomelidae	Beetle	2.09	2	0.52	1	2
Chydoridae	Zooplankton	0.10	3	0.02	3	3
Cirolanidae	Isopod	NA	NA	NA	NA	NA
Coenagrionidae	Damselfly	1.84	2	0.25	2	2
Conochilidae	Zooplankton	0.20	3	0.04	2	3
Conoesucidae	Caddisfly	NA	NA	NA	NA	NA
Corixidae	Water bug	1.86	2	0.15	2	2
Corophiidae	Amphipod	0.61	3	0.01	3	3
Corydalidae	Fly	NA	NA	NA	NA	NA
Crambidae	Moth	1.51	2	0.13	2	2
Culicidae	Mosquito	1.56	2	0.03	2	2
Curculionidae	Beetle	3.72	1	0.42	2	2
Cyclopidae	Zooplankton	2.11	2	0.28	2	2
Cyclopoidae	Zooplankton	2.17	2	0.11	2	2
Cyprididae	Seed shrimp	2.49	2	0.06	2	2
Cypridopsidae	Seed shrimp	1.42	2	0.09	2	2
Cytherideidae	Seed shrimp	1.89	2	0.01	3	3
Cyzicidae	Clam shrimp	3.85	1	1.38	1	1
Daphniidae	Zooplankton	1.37	2	0.07	2	2
Darwinulidae	Seed shrimp	NA	NA	NA	NA	NA
Dicranophoridae	Zooplankton	1.70	2	0.01	3	3
Difflugiidae	Amoebae	0.87	2	0.01	3	3
Diosaccidae	Zooplankton	0.19	3	0.01	3	3
Dolichopodidae	True fly	6.24	1	0.96	1	1
Dugesiidae	Worm	NA	NA	NA	NA	NA
Dytiscidae	Beetle	2.59	2	0.29	2	2
Ecnomidae	Caddisfly	1.24	2	0.001	3	3
Elmidae	Beetle	0.14	3	0.001	3	3
Empididae	True fly	6.94	1	0.93	1	1
Enchytraeidae	Worm	6.26	1	0.69	1	1
Ephydridae	Shore Fly	2.59	2	0.38	2	2
Epiphanidae	Zooplankton	3.85	1	0.35	2	2
Euchlanidae	Zooplankton	4.14	1	0.09	2	2
Euglyphidae	Amoebae	0.57	3	0.03	2	3

Family	Description	Median total nitrogen	Nitrogen adaptive capacity score	Median total phosphorus	Phosphorus adaptive capacity score	Nutrient enrichment score
Eusiridae	Amphipod	NA	NA	NA	NA	NA
Eylaidae	Water mite	5.16	1	3.40	1	1
Filiniidae	Zooplankton	1.20	2	0.02	3	3
Flosculariidae	Zooplankton	0.30	3	0.05	2	3
Galeommatidae	Mussel	0.28	3	0.01	3	3
Gastropodidae	Zooplankton	2.80	2	0.01	3	3
Gelastocoridae	Water bug	1.22	2	0.01	3	3
Gerridae	Water bug	0.05	3	0.03	2	3
Glacidorbidae	Snail	0.03	3	0.01	3	3
Glossiphoniidae	Leech	0.70	2	0.03	2	2
Gomphidae	Dragonfly	0.32	3	0.02	3	3
Gordiidae	Worm	0.41	3	0.01	3	3
Grapsidae	Crab	NA	NA	NA	NA	NA
Gripopterygidae	Stonefly	1.38	2	0.30	2	2
Gyrinidae	Beetle	1.17	2	0.03	2	2
Habrotrochidae	Water mite	0.39	3	0.01	3	3
Halacaridae	Water mite	1.90	2	0.01	3	3
Haliplidae	Beetle	1.47	2	0.04	2	2
Hebridae	Water bug	0.25	3	0.06	2	3
Heleidae	Fly	1.40	2	0.01	3	3
Hemicorduliidae	Dragonfly	1.34	2	0.09	2	2
Heteroceridae	Beetle	1.84	2	0.27	2	2
Hexarthridae	Zooplankton	0.70	2	0.02	3	3
Hirudinidae	Leech	0.81	2	0.01	3	3
Hydrachnidae	Water mite	0.29	3	0.11	2	3
Hydraenidae	Beetle	1.24	2	0.05	2	2
Hydridae	Cnidaria	1.27	2	0.26	2	2
Hydrobiidae	Snail	1.01	2	0.01	3	3
Hydrobiosidae	Caddisfly	2.13	2	0.57	1	2
Hydrochidae	Beetle	1.48	2	0.14	2	2
Hydrodromidae	Water mite	0.80	2	0.09	2	2
Hydrometridae	Water bug	9.56	1	0.96	1	1
Hydrophilidae	Beetle	2.15	2	0.20	2	2
Hydropsychidae	Caddisfly	0.02	3	0.02	3	3
Hydroptilidae	Caddisfly	0.22	3	0.03	2	3
Hydryphantidae	Water mite	0.41	3	0.01	3	3
Hygrobatidae	Water mite	0.69	3	0.03	2	3
Hygrobiidae	Beetle	0.33	3	0.00	3	3
Hymenosomatidae	Crab	NA	NA	NA	NA	NA
Hypogastruridae	Springtail	10.99	1	6.99	1	1
Hyriidae	Mussel	0.64	3	0.13	2	3

Family	Description	Median total nitrogen	Nitrogen adaptive capacity score	Median total phosphorus	Phosphorus adaptive capacity score	Nutrient enrichment score
Ilyocryptidae	Zooplankton	0.42	3	0.01	3	3
Ilyocypridae	Seed shrimp	3.00	2	0.11	2	2
Ilyocyprididae	Seed shrimp	0.80	2	0.08	2	2
Isostictidae	Damselfly	NA	NA	NA	NA	NA
Isotomidae	Springtail	10.99	1	1.69	1	1
Laophontidae	Zooplankton	1.07	2	0.14	2	2
Lecanidae	Zooplankton	1.30	2	0.02	3	3
Lepadellidae	Zooplankton	1.40	2	0.01	3	3
Leptoceridae	Caddisfly	1.37	2	0.26	2	2
Leptocytheridae	Seed shrimp	0.79	2	0.01	3	3
Leptophlebiidae	Mayfly	2.17	2	0.96	1	2
Lestidae	Damselfly	3.50	2	0.47	2	2
Libellulidae	Dragonfly	0.84	2	0.03	2	2
Limnadiidae	Clam shrimp	0.05	3	0.01	3	3
Limnesiidae	Water mite	2.33	2	0.49	2	2
Limnichidae	Beetle	3.76	1	0.31	2	2
Limnocharidae	Water mite	2.54	2	0.12	2	2
Limnocytheridae	Seed shrimp	1.10	2	0.05	2	2
Lindeniidae	Dragonfly	NA	NA	NA	NA	NA
Lindiidae	Zooplankton	1.80	2	0.02	3	3
Lymnaeidae	Snail	1.52	2	0.19	2	2
Lynceidae	Clam shrimp	4.25	1	0.58	1	1
Macromiidae	Dragonfly	NA	NA	NA	NA	NA
Macrothricidae	Zooplankton	0.26	3	0.01	3	3
Megapodagrionidae	Damselfly	0.94	2	0.17	2	2
Melitidae	Amphipod	1.89	2	0.01	3	3
Mesoveliidae	Water bug	1.48	2	0.15	2	2
Micronectidae	Water bug	4.31	1	0.35	2	2
Microsporidae	Beetle	NA	NA	NA	NA	NA
Mideopsidae	Water mite	0.23	3	0.14	2	3
Moinidae	Zooplankton	6.06	1	0.56	1	1
Momoniidae	Water mite	0.40	3	0.01	3	3
Munnidae	Isopod	NA	NA	NA	NA	NA
Muscidae	Fly	3.51	1	0.01	3	2
Mytilinidae	Zooplankton	0.20	3	0.04	2	3
Naididae	Worm	1.13	2	0.08	2	2
Nannochoristidae	Scorpionfly	0.73	2	0.01	3	3
Naucoridae	Water bug	NA	NA	NA	NA	NA
Nebelidae	Amoeba	0.91	2	0.01	3	3
Neoniphargidae	Amphipod	NA	NA	NA	NA	NA
Neothricidae	Zooplankton	1.30	2	0.03	2	2

Family	Description	Median total nitrogen	Nitrogen adaptive capacity score	Median total phosphorus	Phosphorus adaptive capacity score	Nutrient enrichment score
Nepidae	Water bug	0.20	3	0.66	1	2
Nereididae	Worm	NA	NA	NA	NA	NA
Noctuidae	Moth	0.46	3	0.26	2	3
Noteridae	Beetle	0.68	3	0.03	2	3
Notodromadidae	Seed shrimp	0.40	3	0.01	3	3
Notommatidae	Zooplankton	1.30	2	0.02	3	3
Notonectidae	Water bug	2.47	2	0.16	2	2
Oceaniidae	Cnidaria	2.50	2	0.02	3	3
Ochteridae	Water bug	NA	NA	NA	NA	NA
Olindiidae	Cnidaria	0.49	3	0.01	3	3
Oniscidae	Woodlice	5.31	1	0.58	1	1
Orbatidadae	Mite	9.59	1	0.66	1	1
Orbatidae	Mite	7.27	1	5.59	1	1
Osmylidae	Spongefly	NA	NA	NA	NA	NA
Oxidae	Water mite	1.24	2	0.06	2	2
Oxygastridae	Dragonfly	0.15	3	0.01	3	3
Palaemonidae	Shrimp	7.08	1	1.23	1	1
Paramelitidae	Sideswimmer	0.88	2	0.06	2	2
Parasitidae	Mite	0.21	3	0.07	2	3
Parastacidae	Crayfish	6.17	1	0.50	2	2
Parastenocarididae	Zooplankton	0.36	3	0.01	3	3
Pelecorhynchidae	Fly	NA	NA	NA	NA	NA
Perthiidae	Amphipod	9.59	1	1.23	1	1
Petaluridae	Dragonfly	NA	NA	NA	NA	NA
Pezidae	Mite	2.32	2	0.02	3	3
Philodinidae	Zooplankton	0.68	3	0.02	3	3
Philopotamidae	Caddisfly	1.42	2	0.46	2	2
Philorheithridae	Caddisfly	NA	NA	NA	NA	NA
Phreatoicidae	Isopod	NA	NA	NA	NA	NA
Phreatoicopsidae	Isopod	NA	NA	NA	NA	NA
Phreodrilidae	Worm	0.51	3	0.01	3	3
Physidae	Snail	3.04	2	0.79	1	2
Pionidae	Water mite	1.36	2	0.08	2	2
Planorbidae	Snail	1.31	2	0.19	2	2
Pleidae	Water bug	0.10	3	0.01	3	3
Plumatellidae	Zooid	1.80	2	0.07	2	2
Poduridae	Springtail	NA	NA	NA	NA	NA
Polycentropodidae	Caddisfly	1.10	2	0.05	2	2
Pomatiopsidae	Snail	4.44	1	0.01	3	2
Proalidae	Zooplankton	2.15	2	0.3	2	2
Protoneuridae	Damselfly	NA	NA	NA	NA	NA

Family	Description	Median total nitrogen	Nitrogen adaptive capacity score	Median total phosphorus	Phosphorus adaptive capacity score	Nutrient enrichment score
Pseudodifflugiidae	Amoeba	0.94	2	0.01	3	3
Psychodidae	True fly	2.37	2	0.50	2	2
Ptiliidae	Beetle	6.09	1	6.99	1	1
Ptilodactylidae	Beetle	NA	NA	NA	NA	NA
Pychodidae	Moth fly	1.40	2	0.27	2	2
Pyralidae	Moth	1.29	2	0.01	3	3
Richardsonianidae	Leech	NA	NA	NA	NA	NA
Sabellidae	Worm	5.91	1	0.03	2	2
Saldidae	Shore bug	2.62	2	0.14	2	2
Scaridiidae	Zooplankton	1.01	2	0.11	2	2
Scatopsidae	Midge	2.98	2	0.30	2	2
Sciomyzidae	True fly	0.91	2	0.12	2	2
Scirtidae	Beetle	7.21	1	3.98	1	1
Serpulidae	Worm	0.33	3	0.01	3	3
Sididae	Zooplankton	1.50	2	0.04	2	2
Simuliidae	Black fly	2.14	2	0.28	2	2
Sisyridae	Spongefly	3.10	2	0.51	2	2
Sminthuridae	Springtail	10.99	1	5.59	1	1
Spercheidae	Beetle	1.00	2	0.07	2	2
Sphaeriidae	Pea clam	0.62	3	0.07	2	3
Sphaeromatidae	Isopod	1.44	2	0.03	2	2
Spongillidae	Sponge	1.90	2	0.50	2	2
Staphylinidae	Beetle	11.99	1	1.69	1	1
Stratiomyidae	True fly	25.92	1	0.58	1	1
Styloniscidae	Woodlice	0.46	3	0.01	3	3
Sulcaniidae	Copepod	1.28	2	0.01	3	3
Synchaetidae	Zooplankton	0.70	2	0.01	3	3
Synthemistidae	Dragonfly	0.75	2	0.09	2	2
Syrphidae	Hoverfly	7.12	1	3.49	1	1
Tabanidae	Horsefly	14.18	1	0.63	1	1
Talitridae	Amphipod	6.96	1	1.23	1	1
Tanyderidae	Cranefly	3.93	1	0.48	2	2
Tanypodinae	Midge	9.61	1	1.59	1	1
Telephlebiidae	Dragonfly	3.94	1	0.29	2	2
Temnocephalidae	Worm	0.80	2	0.02	3	3
Tenebrionidae	Beetle	NA	NA	NA	NA	NA
Testudinellidae	Zooplankton	1.35	2	0.01	3	3
Tettigoniidae	Cricket	1.79	2	0.93	1	2
Thamnocephalidae	Fairy shrimp	1.40	2	0.06	2	2
Thaumeliidae	Midge	1.80	2	0.03	2	2
Thiaridae	Snail	NA	NA	NA	NA	NA

Family	Description	Median total nitrogen	Nitrogen adaptive capacity score	Median total phosphorus	Phosphorus adaptive capacity score	Nutrient enrichment score
Tipulidae	Cranefly	1.33	2	0.04	2	2
Trapeziidae	Crab	1.30	2	0.01	3	3
Trichocercidae	Zooplankton	0.18	3	0.02	3	3
Trichotriidae	Zooplankton	0.77	2	0.05	2	2
Triopsidae	Shield	4.90	1	0.90	1	1
Trombidioidea	Water mite	25.74	1	0.79	1	1
Tubificidae	Worm	1.40	2	0.01	3	3
Turbellaria	Worm	25.61	1	1.39	1	1
Unionicolidae	Water mite	2.14	2	0.01	3	3
Urothemistidae	Dragonfly	NA	NA	NA	NA	NA
Veliidae	Water bug	1.62	2	0.08	2	2

Table A14. Range of dissolved oxygen (mg/L) levels at sites of occupancy and adaptive capacity scores for freshwater fish in south-western Australia. Data from Beatty et al. (2013), Beatty et al. (2011) and unpublished sources. Freshwater fish species with a range of dissolved oxygen at site of occupancy < 8.69 mg/L were given a score of “3”, species with a range of dissolved oxygen at site of occupancy between 8.69-14.25 mg/L were given a score of “2”, and species with a range of dissolved oxygen at site of occupancy > 14.25 mg/L were give a score of “1”. Freshwater fish dissolved oxygen summary (mg/L): min = 6.02, 25th quartile = 8.69, median = 11.73, 75th quartile = 14.25, max = 17.17.

Species	n	Max.-Min.	Range	Adaptive capacity score
Bostockia porosa	264	17.47-0.30	17.17	1
Galaxias maculatus	50	16.04-3.04	13.00	2
Galaxias occidentalis	361	17.47-0.30	17.17	1
Galaxias truttaceus	153	12.35-2.60	9.75	2
Galaxiella munda	16	10.60-1.70	8.90	2
Galaxiella nigrostriata	33	8.70-2.68	6.02	3
Lepidogalaxias salamandroides	53	9.21-2.42	6.79	3
Nannatherina balstoni	89	14.63-2.90	11.73	2
Nannoperca pygmaea	47	10.24-1.76	8.48	3
Nannoperca vittata	263	16.04-1.57	14.47	1
Tandanus bostocki	164	17.47-3.44	14.03	2

Appendix B References used for collation of distribution records for SDMs

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Contact Details

Barbara Cook
Centre of Excellence in Natural Resource Management, UWA
Barbara.Cook@uwa.edu.au

Ben Ford
Centre of Excellence in Natural Resource Management, UWA
benjamin.ford@uwa.edu.au

Bronte Van Helden
Centre of Excellence in Natural Resource Management, UWA
21306019@student.uwa.edu.au

Steve Beatty
Freshwater Fish Group and Fish Health Unit, Murdoch University
S.Beatty@murdoch.edu.au

Garry Ogston
Freshwater Fish Group and Fish Health Unit, Murdoch University
gogston@our.ecu.edu.au

Paul Close
Centre of Excellence in Natural Resource Management, UWA
Paul.Close@uwa.edu.au

Contact Details

Centre of Excellence in Natural Resource Management

(+61 8) 9842 0838
cenrm@uwa.edu.au
www.cenrm.uwa.edu.au/