

Australian Government





MURRAY-DARLING BASIN AUTHORITY

Environmental Watering for Food Webs in The Living Murray Icon Sites

A literature review and identification of research priorities relevant to the environmental watering actions of flow enhancement and retaining floodwater on floodplains

Report to the Murray–Darling Basin Authority Project number MD1253

September 2009

Environmental Watering for Food Webs in The Living Murray Icon Sites

A literature review and identification of research priorities relevant to the environmental watering actions of flow enhancement and retaining floodwater on floodplains

Report to the Murray–Darling Basin Authority Project number MD1253

Justin Brookes, Kane Aldridge, George Ganf, David Paton, Russell Shiel, Scotte Wedderburn

University of Adelaide

September 2009

MDBA Publication No. 11/12 ISBN (on-line) 978-1-922068-12-5

© Copyright Murray-Darling Basin Authority (MDBA), on behalf of the Commonwealth of Australia 2012.

With the exception of the Commonwealth Coat of Arms, the MDBA logo, all photographs, graphics and trademarks, this publication is provided under a Creative Commons Attribution 3.0 Australia Licence.



http://creativecommons.org/licenses/by/3.0/au

The MDBA's preference is that you attribute this publication (and any material sourced from it) using the following wording:

- Title: Environmental Watering for Food Webs in The Living Murray Icon Sites — A literature review and identification of research priorities relevant to the environmental watering actions of flow enhancement and retaining floodwater on floodplains
- Source: Licensed from the Murray–Darling Basin Authority, under a Creative Commons Attribution 3.0 Australia Licence.

Authors: Justin Brookes, Kane Aldridge, George Ganf, David Paton, Russell Shiel, Scotte Wedderburn

The MDBA provides this information in good faith but to the extent permitted by law, the MDBA and the Commonwealth exclude all liability for adverse consequences arising directly or indirectly from using any information or material contained within this publication.

Cover images:

Sedge (*Eleocharis spatheolata*) in Barmah–Millewa Forest icon site (photo by Keith Ward, Goulburn Broken CMA)

Small mouthed hardyhead (photo by Gunther Schmida ©MDBA)

Royal spoonbill adult and chick (photo by Keith Ward, Goulburn Broken CMA)

River red gum in Gunbower–Koondrook–Perricoota Forest icon site (photo by David Kleinert ©MDBA)

Murray–Darling Basin Authority

Postal Address: GPO Box 1801, Canberra ACT 2601

Office location: Level 4, 51 Allara Street, Canberra City, Australian Capital Territory

Tel: (02) 6279 0100, international + 61 2 6279 0100 Fax: (02) 6248 8053, international + 61 2 6248 8053

E-mail: info@mdba.gov.au Website: www.mdba.gov.au

For further information contact the Murray–Darling Basin Authority office on (02) 6279 0100.

Contents

Bac	kground	1	
1.	Literature review	2	
	Food web studies in the Murray–Darling Basin		
	Zooplankton ecology—linking productivity to higher organisms	5	
	Fish, diets and habitat		
	Larval fish diets		
	Adult fish diets		
	Effects of flooding on fish food items, spawning and recruitment		
	Fish movement through connectivity between floodplain habitats and the river channel or Lower Lakes		
	Dietary response of native fish species to flooding		
	Fish water quality tolerances (e.g. salinity, pH, dissolved oxygen)	15	
	Diets and food resources of waterbirds		
	Aquatic and riparian vegetation; growth and distribution in relation to key environmental factors in the River Murray	17	
	Carbon sources, leaf litter inputs and phytoplankton primary productivity		
	Nutrient flux on inundated floodplains		
	Future flow, flooding and wetland response		
	Techniques for assessing food webs		
	Conclusions		
2.	Conceptual models: linking flow enhancement and water retention on floodplains with aquatic food sources response		
3.	Knowledge gaps and key hypotheses		
4.	Options to assess knowledge gaps during dry periods		
5.	Data sources to inform future projects		
6.	References		
Арр	Appendix 1		
Appendix 2			
Арр	Appendix 3		

Background

The Murray–Darling Basin is an environmentally, economically and culturally important region of Australia. However, water diversions and extractions from the river have compromised the condition of aquatic ecosystems. In response to a declining health of the River Murray system, The Living Murray Initiative was established by the Murray–Darling Basin Commission (role now taken over by Murray–Darling Basin Authority). This initiative aims to restore and preserve a healthy working river system for the benefit of all Australians. This will be achieved by returning water to the environment, with the first step focussing on delivering water to six icon sites, chosen for their high ecological value.

The Living Murray Initiative is undertaking a monitoring program to support environmental watering decisions at icon sites. There are a number of the monitoring programs established to document conditions of these wetlands, including:

- icon site condition monitoring
- intervention monitoring
- compliance and monitoring
- River Murray system scale assessment.

The intervention monitoring program has identified priority knowledge areas that require further information. These include "Evaluating the responses of food sources for fish and waterbirds to flow enhancement in both freshwater and estuarine systems" and "Evaluating the responses of food sources for fish and waterbirds to retaining floodwater on floodplains".

To adequately address these knowledge gaps it is necessary for the Murray–Darling Basin Authority to develop an understanding of the likely mechanisms to which fish and bird communities respond to flow enhancement and retaining floodwater on floodplains. This will assist in predicting and assessing the response of any future water provisions to aquatic ecosystems under The Living Murray Initiative. This aligns with The Living Murray Outcomes Evaluation Framework Objective 3—Determine the effectiveness of interventions in improving environmental condition.

The approach to evaluate the responses of food sources for fish and waterbirds to floodplain inundation was to:

- review food web ecology in the Murray–Darling Basin
- 2. develop conceptual models linking flow enhancement to food source response in both estuarine and freshwater systems
- 3. identify priorities for research and monitoring programs to examine ecosystem, productivity and food web response to flooding.

The literature review identified where knowledge was lacking and key hypotheses were constructed towards addressing these gaps.

1. Literature review

Food webs cannot be considered in isolation from nutrient dynamics, primary productivity, habitat and life cycle of populations. These features vary in their response to flooding and retention of water on floodplains. The aim of the review is to collate previous studies and critically assess these to frame the requirements of future monitoring to incorporate the role of floodplain inundation in enhancing aquatic food webs.

When assessing the role of flooding and floodplain inundation on aquatic food webs it is useful to describe the features of healthy and compromised river systems (Table 1). Healthy rivers have both longitudinal connectivity, allowing fish movement and delivery of food supply, and lateral connectivity linking the main river channel to its floodplain.

A diversity of morphology and flow creates a mosaic of habitat for flora and fauna. Relatively low nutrient conditions avoid excessive algal growth and maintain a light climate suitable for dominance by macrophytes. Diverse habitats can support a diversity of organisms at each trophic level of the food web. This provides redundancy in food options and so makes the food web more resilient to a decrease in abundance of a group of organisms should conditions become unfavourable.

Food web studies in the Murray-Darling Basin

The riverine-floodplain system

Food webs can be considered to be the flow of energy, or carbon, through ecosystems. Sources of energy that provide the basis of riverine ecosystems include allochthonous and autochthonous carbon. Allochthonous carbon is carbon that has been brought in from an external source and in riverine ecosystems includes terrestrial plant material such as logs, leaves and dissolved organic carbon. Autochthonous carbon is carbon fixed from the atmosphere by photosynthesis within the ecosystem by macrophytes, phytoplankton or periphytic algae.

An example of a generalised food web for floodplainriver ecosystems is shown in Figure 1, with allochthonous and autochthonous carbon providing a basis for the web. Energy is carried through trophic levels to invertebrates to fish and to predatory vertebrates and dead material entering the detrital pool, before being broken down by bacteria and recycling back into the food web.

Feature	Healthy River	Compromised River
Longitudinal connectivity	Few barriers to fish movement	Barriers to fish movement
	Upstream zooplankton sources fuelling downstream ecosystems	Low flow from tributaries contributing fewer zooplankton
Lateral connectivity	Connection between floodplain and river enabling exchange of water and resources	Restricted connection between floodplain and river
Morphology	Diverse morphology allowing a mosaic of habitats	Steep incised channel without benches and floodplain connection
Flow	Diversity of flow including high and low flows	Continuation of either high or low flow
Floodplain inundation	Regularly inundate the floodplain	Flow restricted to main channel
Nutrients	low	Either low or high
Dominant community	Dominance by macrophytes	Dominance by algae
Food web	Diversity at each trophic level of the food web providing redundancy should conditions become unsuitable for a particular population	Low diversity or abundance at one or more trophic levels

Table 1: Features of healthy and compromised rivers



Figure 1: Generalised food web for floodplain-river ecosystems (adapted from Winemiller 2003) Boxes are aggregate material pools and vectors represent consumer resource interactions with thick arrows representing dominant pathways (ml= microbial loop path, fp = nutrient pathways enhanced by flood pulses, iw = invertebrate web having complex trophic structure involving invertebrates and ? = poorly quantified pathways).

Along the length of a riverine ecosystem the major sources of energy are thought to change, thus altering the structure of the food web. This is described by the River Continuum Concept (Vannote *et al.* 1980; Minshall *et al.* 1985), whereby energy in the headwaters of a river is supplied predominately by allochthonous material since streams have dense, overhanging vegetation and there is little chance of autochthonous productivity due to shading.

However, as the river moves downstream, deposited coarse particulate organic matter is broken down into fine particles. The river broadens and slows providing greater opportunity for autotrophic organisms. In contrast, the Flood Pulse Concept (Junk *et al.* 1989; Bayley 1991) emphasises the importance of the connectivity between the river and the floodplain, with periodic changes in water level and flow resulting in the exchange of organic material between the river and the floodplain. Both models have relevance to the Murray–Darling Basin food webs; The River Continuum Concept because the Murray–Darling River is a long river and much of the water is sourced from headwaters. However, the Flood Pulse Concept is particularly relevant for rivers in variable climates which experience periodic inundation of the floodplain, resulting in increased productivity. It is not clear which model best fits the Murray–Darling River, but it is likely that is includes a combination of both models.

It is known that the flow of energy in the Murray–Darling is variable: longitudinally since the Murray–Darling Basin covers a range of climates, vegetation types and soil types all of which have a large influence upon primary and secondary productivity; temporally since flow, and thus the input of material, is highly variable; and laterally since the level of connectivity between the river and the floodplains varies considerably depending upon river flow. The complex structures of food webs and longitudinal, lateral and temporal variability that is experienced in the Murray–Darling Basin is perhaps why few have studied entire food webs of the Murray–Darling Basin in detail. Instead, studies within the Murray–Darling Basin have focussed on individual components of food webs. Differences between findings of these studies and the generalised food webs described above are discussed below.

This discussion is complemented with findings from studies of food webs in unregulated systems within Australia. Unfortunately, much of this information has been developed in arid regions since few temperate rivers remain unregulated in Australia.

 Allochthonous inputs are not the major driver of food webs in arid floodplain rivers—In arid areas, the input of terrestrial organic material is not considered to be as important to food webs as in more temperate and tropical regions (Bunn et al. 2006). There are a number of reasons for this and include the fact that extreme flooding events remove much of this material from the system.

In addition, in arid areas terrestrial material is considered to be of low nutritional quality. Consequently, macroinvertebrate shredders have been found to be in low abundances in these areas and microbial processing is thought to be more important. Indeed, macroinvertebrate abundance has been found to be related to chlorophyll concentrations rather than leaf litter (Bunn *et al.* 2003).

 High turbidity will disfavour macrophytes— Australian rivers have high turbidities and some are believed to have been this way prior to European settlement. This reduces light penetration and therefore limits the productivity of macrophyte communities within the main river channel (Bunn et al. 1999). An example of this is the Darling River (Bunn et al. 1999), and so it is likely that even prior to European settlement that under high Darling River inflows, the Murray–Darling River would have experienced high turbidities.

This has consequences for food webs and Bunn et al. (2003) found that in arid systems, high turbidities resulted in low macrophyte abundance, resulting in food webs that were primarily based upon algal material. A majority of the energy was found to be sourced from algae in dry periods and subsidies of algae following flooding, most likely due to their rapid colonisation. However, the inundation of floodplains is likely to result in the deposition of suspended material, resulting in conditions suitable for macrophyte growth on the floodplains, which are also shallower.

- Benthic algae are important sources of energy in arid floodplain rivers of Australia—It has been shown that in arid floodplain rivers of Australia, benthic algae are important components of the food web, making up large components of the diets of snails, crustaceans and fish (Bunn et al. 2003).
- Decapods feed primarily upon biofilms—The dominant macroinvertebrates of the Lower River Murray were found to be omnivorous, but feed primarily on cyanobacteria within biofilms (Burns and Walker 2000). It is believed that this omnivorous diet allows these species to thrive in this frequently disturbed system.
- In arid areas, the floodplain, and its connectivity with the river is integral for riverine food webs—Bunn et al. (2003) found that most of the food web of an arid floodplain river system was dependent upon productivity of the floodplain. Upon reflooding the floodplains represented a food rich environment which contained all components of the food web preferred by consumers.
- The microbial compartment might be an important component of the floodplain—Bunn and Boon (1993) found that in billabongs, crayfish were dependent upon detrital material and gastropods and Leptocerid caddis larvae were dependent upon epiphytes and macrophytes. However, stable isotopes could not be used to discriminate the sources of energy for a majority of the primary consumers (Bunn & Boon 1993). It was believed that much of the food web was fuelled by the consumption of methanotrophic bacteria (Bunn & Boon 1993).
- There is likely to be an export of material to the terrestrial environment—Most research has focussed on the flux of material from terrestrial to riverine ecosystems, but there is now substantial evidence for flux in the opposite direction (Ballinger and Lake 2006). Indeed, many have found that in arid streams, secondary production of insects contributes substantially to the food supply of insectivores, including birds, spiders and reptiles (e.g. Jackson & Fisher, 1986; Lynch et al., 2002; Sabo & Power, 2002).
- Birds are an important consumer—Australian waterbirds use floodplain wetlands shifting their distribution and abundance to productive habitat and breeding when flooding triggers sufficient food production (Kingsford et al., 1999; Dorfman & Kingsford, 2001; Roshier et al., 2002). In the Murray–Darling Basin, birds prey upon macrophytes, invertebrates and fish. This material can be transferred between regions of the Murray–Darling Basin and to and from other basins as the birds migrate during periods of drying and reflooding.

- Fish are opportunistic in arid areas—Most fish species within arid areas do not have specialised diets and are omnivorous (Humphries *et al.* 1999; Balcombe *et al.* 2005). This is thought to be a function of the variable conditions, allowing them to survive in these conditions. In dry periods, fish have broad diets and are sustained by both aquatic and terrestrial production, but in high flow, fish are sustained by aquatic productivity (Balcombe *et al.* 2005).
- The top fish predators are not completely piscivorous—Five fish species have been identified as top predators in the Murray–Darling Basin, including Murray cod, golden perch, freshwater catfish, bluenose cod and Hytrl's tandan (Harris 1995; Schiller and Harris 2001; Gehrke and Harris 2004). All these species are not completely piscivorous and some, including Hytrl's tandan, are better described as a benthic invertivores (Pusey et al. 2000).
- Murray cod are the Apex predator—Although five fish species are considered to be top predators in the Murray–Darling River, the Murray cod is considered to be the apex predator as it is more piscivorous than other top predators (Ebner 2006).
- The Murray–Darling Basin has no larger predatory mammals or reptiles—Unlike other large rivers, in the Murray–Darling Basin there are no large predatory mammals or reptiles, such as bears, alligators or crocodiles, that feed on fish (Walker 1986).
- The food web of the Murray–Darling Basin is not well structured—The Murray–Darling River is highly variable and so the availability of food for predators is also highly variable. Consequently, many predators are opportunistic, resulting in a dynamic food web structure that responds to variability in river-floodplain connectivity.

The Coorong as a unique food web in the Murray–Darling Basin

The Coorong is extremely valuable for the Murray–Darling Basin as it is the permanent water refuge for significant numbers of waterbirds. Following dry periods the Coorong can act as significant source of water birds to other wetlands within the Murray–Darling Basin. The Coorong relies on freshwater flow from the river to maintain salinity below the tolerance threshold for the organisms that inhabit the region. The rising salinity in the absence of freshwater flows in recent years has resulted in the decline of all taxonomic classes; fish, plants and benthic fauna. The Coorong differs from the rest of the river because it is a coastal lagoon with salinity grading from fresh through to hypermarine. The salinity gradient provides a range of aquatic habitats that support different communities. These can be broadly classified into estuarine, north lagoon, and south lagoon. Prior to the recent hypermarine condition, the estuarine system was characterised by the commercial fish species mulloway, bream and mullet and historically *Ruppia megacarpa*. The Southern Lagoon was characterised by extensive mud flats with polychaete infauna, *Ruppia* meadows, chironomids and small mouthed hardyhead. These communities supported large numbers of migratory birds.

Deegan *et al.* (2009) studied the food web of the Coorong and found a simplified food web structure in areas with elevated salinity levels. Under optimal conditions in the Coorong the trophic productivity supported a wide diversity of organisms across numerous trophic levels (Deegan *et al.* 2009).

However, under stressed conditions, organisms are forced to feed on food resources which are not optimal or optional but fundamental for their survival (Deegan *et al.* 2009). This was particularly apparent for larger bodied fish species (bream, mulloway and flounder), which decreased in trophic position as a result of the reduced biodiversity and potential food sources available. Omnivory increased the redundancy found within the food webs within the Coorong providing a buffering capacity to adjust to alterations in food sources (Deegan *et al.* 2009).

Zooplankton ecology—linking productivity to higher organisms

In marked contrast to the recent surge of research activity on macroinvertebrate taxonomy and ecology in the Murray–Darling Basin, spurred by river health initiatives and pressure for biodiversity information, the microfauna of Murray–Darling waters remains largely neglected. Microfauna regulate bacterial and algal abundance, and occupy important links in food chains for higher order consumers such as macroinvertebrates, fish and birds. In most Australian freshwater ecosystems, but particularly in the Murray–Darling system, these connections have been under-estimated or ignored (Green & Shiel 1992).

What little information exists on the microfaunal component of the River Murray and tributaries derives largely from a few local studies. Species composition and successional events in littoral microcrustacea from a year-long study of a Goulburn River billabong were documented by Shiel (1976). The zooplankton of Lake Hume was reported by Walker & Hillman (1977), that of several other impoundments by Powling (1980). A basin-wide survey, published in part by Shiel *et al.* (1982), demonstrated the disparate nature of the microbiota of the west-flowing River Murray and the south-flowing Darling River. The former contained a cool-temperate microcrustacean-dominated lacustrine (*limnoplankton*) assemblage, attributed to the serially-impounded nature of the River Murray, the latter a true riverine (*potamoplankton*) community dominated by rotifers, many of which are warm-stenotherms or tropical in affinity.

The role of turbidity in structuring zooplankton communities in Lake Alexandrina, at the Murray Mouth in S.A., was examined by Geddes (1984). Boon *et al.* (1990) reviewed information on upper Murray billabong ecology, including microbiota, for the Murray–Darling Basin Commission volume '*The Murray*'; information on riverine zooplankton was reviewed for the same volume (Shiel 1990).

Other relevant and more recent studies include: invertebrate emergence from flooded sediments (Boulton & Lloyd 1992), rapid responses to flood events by billabong rotifer assemblages (Tan & Shiel 1993), Lakes Hume and Dartmouth zooplankton in the context of biomanipulation (Matveev & Matveev 1997), heterogeneity of habitat and microfaunal biodiversity across ephemeral wetlands (Shiel *et al.* 1998), fish predation on zooplankton (Nielsen *et al.* 2000a, b) and the role of propagules in sediments (Langley *et al.* 2001, Nielsen *et al.* 2002, Shiel *et al.* 2001, Skinner *et al.* 2001). A series of studies on Paroo River microfauna include those by Timms (2001), Timms & Boulton (2001) and Timms & Hancock (2002).

More recently, the influence of flow regime on microfaunal community structure in three lowland rivers was reported by Nielsen *et al.* (2005), and Nielsen & Watson (2008). The influence of environmental flows to Barmah–Millewa Forest in structuring riverine plankton assemblages was investigated by Gigney *et al.* (2006). An upper Murray tributary, the Broken River, was the site of a study of 'slackwater' microinvertebrate communities relative to those of the main channel, demonstrating the importance of backwaters in maintaining in-channel microfaunal diversity (Ning *et al.* 2009).

Composition of River Murray microfauna

Three broad groups of microinvertebrates comprise the bulk of pelagic and littoral communities in Murray–Darling waters, *viz.* protists (Protista), rotifers (Rotifera) and a suite of microcrustacea dominated by copepods (Crustacea: Copepoda), cladocerans (Crustacea: Branchiopoda: Anomopoda/Ctenopoda) and (occasionally) ostracods (Crustacea: Ostracoda). Other groups occurring in microfaunal samples include larvae or small adults of various insects, particularly Diptera and Hemiptera, and water mites (most often Hydracarina or Oribatida). These latter groups may be abundant seasonally and be important in structuring microfaunal assemblages through food web interactions, however, for the purposes of this review, only the major groups are treated further.

Protista: Protists (or protozoa, unicellular heterotrophs) include flagellates, ciliates and amoebae, both naked and testate. They are commonly the numerically dominant animals in any sample taken from River Murray standing (*lentic*) or slow-flowing (*lotic*) waters. Protists are under-represented in rapidly-flowing lotic waters; they are relatively fragile, and do not survive.

Protists, remarkably, have received only cursory mention in River Murray ecological studies, if they are mentioned at all. The lack of study of Australian ciliates, for example, was regarded as 'regrettable and somewhat astonishing' when an endemic River Murray loricate ciliate was described (Foissner & O'Donoghue 1990). The age of the continent and the potential for isolation to drive speciation events, were seen as significant in predicting a diverse indigenous protist community.

A suggestion that Australian protist assemblages may differ from those of the northern hemisphere was made by Laybourn-Parry *et al.* (1997), who collected *Stentor*, a mixotrophic (photosynthetic) ciliate, from two Murray–Darling reservoirs (Tuggeranong, ACT and Hume, NSW). *Stentor* blooms colouring the water black have long been reported from River Murray waters (e.g. as 'cf. *Climacostomum*' in Walker & Hillman 1977), where densities >50,000 l⁻¹ have been recorded (cited in Laybourn-Parry 1997).

Stentor is uncommon in northern hemisphere waters, where it is subject to heavy predation by, *inter alia*, cyclopoid copepods. The latter are rare in River Murray reservoirs, which tend to be dominated by herbivorous calanoid copepods (see below); hence predation pressure on *Stentor* appears to be low. *Stentor* also reaches bloom populations seasonally in some River Murray billabongs (cf. Shiel 1990). Further evidence for distinctive protist assemblages comes from a study of testate amoebae in the upper Murray catchment (Meisterfeld & Tan 1998). They reported a rich testate community in the environs of Lake Catani, Mt Buffalo, with 89 taxa, 34 of them new to Australia, recorded from eight Sphagnum/sediment samples. Six of the testates were noted as 'strictly Gondwanan' in distribution. Several others were undescribed and possibly Australian endemics. New records of naked amoebae (Heliozoa) also were reported from ponds in the Mt Buffalo region (Mikrjukov & Croome 1998). Given that almost half of the amoebae reported in these two small surveys were new to the Australian fauna, it would seem that a diverse and unrecorded protist fauna awaits discovery!

The only group of protists which has been studied intensively in River Murray waters is the freshwater Acanthamoeba *Naegleria*, particularly in the lower Murray in South Australia, from which Adelaide and other regional centres draw drinking water. As the causative organism of amoebic meningitis, *Naegleria*, and other pathogenic protists such as *Giardia*, are continuously monitored by the Australian Water Quality Centre at Bolivar, S.A.

Given the paucity of studies on protists in Murray–Darling waters, little can be said of their potential for bioindication or their biodiversity in any of the Basin's waters, which is remarkable given the level of research effort applied to protists elsewhere (see, for example, Foissner & Berger, 1996).

Rotifera: Rotifers, the smallest metazoans, with most <200 µm in size, are commonly the most abundant microfauna after protists. More than 600 of the 720 rotifer species now known from Australia have been recorded from Murray–Darling waters (Shiel unpublished). The greatest rotifer biodiversity is found in ephemeral waters, where >100 co-occurring species have been collected in single net tows (Shiel

et al. 1998). Billabongs also support rich rotifer assemblages by virtue of the vegetated, partitioned habitat; >350 microfaunal species, including >200 rotifer spp., have been recorded from an ephemeral pool over 20+ years of sampling (Langley *et al.* 2001, Shiel *et al.* 2001). More commonly, a collection will contain 5–50 rotifer spp., depending on structural complexity of the habitat—densely vegetated and therefore partitioned billabongs have more species than does the open water of reservoirs and rivers.

Floating and submerged vegetation provides some protection from visual predators. Rotifers occupy all feeding niches in such partitioned habitats detritivores, bacteriovores, herbivores, carnivores and parasites. Suites of each of these feeding groups may co-occur. For example, several co-occurring species of *Brachionus, Filinia, Keratella* or *Trichocerca* may overcome the problem of competition for resources by taking different size food items. Experimental evidence suggests that even bacteria may be partitioned in a similar manner, by size, morphology or chemistry (Boon & Shiel 1990).

Rotifers are able to persist in ephemeral habitats by production of resistant resting eggs, which remain in dry sediment until rewetting and appropriate cues to hatching. All resting eggs do not respond to the same cues, hence there is a succession of hatching events, with concomitant compositional changes the longer a previously dry habitat is flooded (Tan & Shiel 1993). Collection of dry sediment from the previously wetted margin of Ryan's #3, a shallow ephemeral pool on the floodplain of the River Murray adjacent to Ryan's #1, a permanent billabong have been assessed for rotifer egg abundance and diversity. Resting stages counted from 1 mm slices of 1 cm diameter cores taken from these sites showed significant differences in density (Figure 2), up to 1,200 cm⁻³, with highest densities at the margin of Ryan's #3, the biennially flooded (ephemeral) site (Shiel et al. 2001).



Figure 2: Resting eggs counts in sediments from three flood-frequencies annual, biennial and every ca 25 years (from Shiel *et al.*, 2001).

Microcrustacea: Of the three main groups of microcrustaceans abundant in River Murray waters, copepods tend to predominate, with cladocerans either perennial in low numbers or markedly seasonal, when they may reach high densities. Ostracods, except in salinised waters, tend to be rare incursions from the littoral, their preferred habitat. Most abundant copepods in reservoirs and billabongs, and also often in weir pools and downstream reaches of the Murray and tributaries, are calanoids of the southern hemisphere family Centropagidae, commonly Boeckella and Calamoecia species, with Hemiboeckella species in ephemeral waters, and (rarely) the usually coastal *Gladioferens* in downstream sites such as Lake Cullulleraine. Two species of the northern affinity Diaptomidae occur across northern Australia, and may extend into the north of the Murray–Darling Basin (cf. Bayly 1966).

Of ca. 50 centropagid species known from Australia, the most common in River Murray waters and across southern Australia generally, is *Boeckella triarticulata*, which occurs across a wide range of habitat types (Bayly 1992). In fish-free ephemeral habitats the large (4 mm) *B. major* may be a seasonal predator on other plankters (Green *et al.* 1999), with *B. pseudochelae* and *Hemiboeckella searli* also common in ephemeral waters. Billabong species include *B. fluvialis B. minuta* and *B. symmetrica*, which may co-occur with one or more *Calamoecia* species, commonly *C. ampulla* or *C. lucasi.* Two or three co-occurring calanoids in a habitat is usual, 4–5 less so, and 6 is rare. Notably, salinised waters of mid-Murray regions around Kerang/Swan Hill have halophile calanoids, *Calamoecia salina* or *C. clitellata*, suggesting a much longer evolutionary history of salinization than that induced by human activities in the region in the last 200 years.

Cyclopoid copepods are less well known in River Murray waters. They are not common or abundant in the open water of reservoirs or rivers, but can be seasonally diverse and abundant in billabongs and ephemeral waters. They fill both herbivorous and carnivorous niches, prey including rotifers, other copepods, cladocerans and occasionally, small macroinvertebrates, e.g. mussel glochidia (juveniles). Most species are from the Family Cyclopidae, and ca. 100 spp. are known from the continent. Common genera are Australocyclops (a large predator), *Eucyclops, Mesocyclops* and *Microcyclops.* The latter two genera are the most species-rich based on present taxonomic information (e.g. Holynska 2000). As for calanoids, two or more species co-occurring at a site is common, often markedly different in size, thereby reducing competition.

A third group of copepods, the harpacticoids, are benthic in habit, rarely collected in open water, and poorly studied in Australasia. *Canthocamptus* species appear to be the most common in River Murray billabongs and ephemeral waters, associated with sediments and vegetation (cf. Hamond 1987). Plankton collections are usually dominated by juveniles of the resident copepods, both nauplii and copepodite stages, and this presents a major taxonomic impediment to biodiversity studies. Not only does a researcher has to determine the species present, but also may need to discriminate the life stages. This is not an easy task when 3–4 species co-occur, and samples may include several copepodite and sub-adult instars, with one sex or the other required for species determination. Juveniles also tend to predominate in downstream river reaches; adults apparently are able to avoid outflows from weir pools or reservoirs.

Cladocerans ('water fleas') may make up a significant part of microfaunal community diversity in shallow vegetated habitats, but less so in open water of reservoirs and rivers, where their size renders them subject to predation by macroinvertebrates and fish. More than half of the ca. 200 spp. of cladocerans now known from the continent occur in Murray–Darling waters.

The family Chydoridae is the most diverse, and in excess of 100 species have been recorded from Australia, with more than half of them endemic (Shiel & Dickson 1995). More than 20 spp. of chydorids co-occurred in a Goulburn billabong (Shiel 1976), where they filled detritivore and herbivore niches. Many chydorids are adapted to scraping biofilms from surfaces, hence are littoral or epiphytic in habit. Only species of *Chydorus* tend to be collected in open water, and then associated with filamentous algal blooms, where they collect food by scraping along filaments.

Only a few other cladoceran families have truly planktonic representatives in River Murray waters: *Bosmina* (Bosminidae) is common in reservoir and river plankton, as is *Diaphanosoma* (Sididae), and seasonally, *Moina* (Moinidae). *Daphnia* (Daphnidae), one of the larger cladocerans, tends to be seasonal in billabongs and ephemeral habitats, or perennial in low numbers in reservoirs, where it is probably subject to heavy predation pressure.

Smaller daphnids, such as *Ceriodaphnia*, are more often collected in plankton tows. Other daphnid genera—*Simocephalus, Scapholeberis*—are billabong/shallow water dwellers. One daphnid genus, *Daphniopsis* is a halophile, occurring in salinised waters throughout the Basin. Species of other families of cladocerans—Macrothricidae, Ilyocryptidae and larger sidids (e.g. *Latonopsis*) usually are found in shallow, vegetated habitats, particularly regularly inundated ephemeral pools. Notably absent from Australia, possibly evolving after the break-up of Gondwana, are the northern hemisphere predatory cladoceran families Cercopagidae, Leptodoridae and Polyphemidae, which are important 'structurers' of plankton communities in northern hemisphere waters (Shiel & Dickson 1995, cf. Rivier 1998). Species of Podonidae are reported from coastal/marine waters around Australia, but not from inland Australia (Smirnov & Timms 1983).

Ostracods, which include detritivores, herbivores and predators, occasionally are abundant in collections from billabongs and ephemeral pools. In some billabongs 5–6 species of ostracods is not unusual—large species (e.g. *Australocypris*, *Mytilocypris*) may co-occur with smaller (e.g. *Cypretta, Limnocythere, Newnhamia*). Ostracods rarely appear in open water collections.

Sources of Microfauna in the Mainstem Rivers

In River Murray waters there is no experimental evidence to demonstrate the contribution of headwater reservoir limnoplankton to downstream rivers, nor of contributions from floodplain lentic waters. From circumstantial evidence in the studies cited earlier, and from studies of river microfauna elsewhere (e.g. Baranyi et al. 2002) the persistent microfaunal community in downstream reaches reflects disparate contributions from upstream impoundments, floodplain waters which may at times have a connection to the river (Gigney et al. 2006), regions of slow-flow such as backwaters or braided channels (Ning et al. 2009), waste stabilisation ponds from riverside communities which may discharge into Murray tributaries, in fact any standing water which connects to the river at any time.

Geographical differences in source waters, regionalism in the microfauna and regional rainfall events will influence what particular assemblage is being inoculated into tributaries. Downstream weirs and locks on the River Murray provide low or no flow conditions and a longer retention time, which permits reconstitution of a microcrustacean assemblage. This is referred to in European studies as 'age' of the water, with rotifers dominating in waters of low 'age' (e.g. short retention time storages such as Lake Mulwala) and microcrustacean assemblages appearing in waters of greater 'age' (e.g. long retention time storages such as Lakes Dartmouth and Hume) (cf. Baranyi *et al.* 2002). What this phenomenon reflects is the life cycle of the respective microfauna. At ambient temperatures in River Murray tributaries, rotifers are reproducing in days, microcrustacea in weeks. Rotifers are able to get through their life cycles in the short retention time storages, microcrustacea are not. The latter require stable conditions for a longer period to reach adult reproductive stages and are unable to complete life cycles in turbulent or rapid through flow storages. This life cycle disparity is the basis for the differences noted earlier (Shiel *et al.* 1982) between Murray and Darling microfauna.

The microfauna of the Murray traverse a series of lentic or at least slow-flowing weir pools, those of the Darling below the headwater rivers a lotic system, at least until Menindee Lakes. Unlike the Murray system, which has an extensive network of lentic waters—a heterogeneous array of billabongs (Hillman 1986), intermittently flooded Barmah– Millewa Forest waters, the Macquarie Marshes, irrigation returns from tributary systems—the Darling is deeply incised (up to 10 m) into its floodplain, and lacks these sources of lentic microfauna. It remains a lotic, largely unimpeded system, albeit one of low flow.

Notably, a rotifer-dominated river microfauna (Brachionus, Keratella and Synchaeta dominants among 22 rotifer species) was collected from the River Murray near Morgan early in 2002 (M.C.Geddes, pers.com.), >20 years after a very similar autumn river plankton was reported from the same reaches of the lower Murray (Shiel et al. 1982). A comparably diverse rotifer potamoplankton was recorded from the River Murray at Swan Reach during undergraduate field camps early in 2008 and 2009 (Shiel, unpublished). Despite widely publicised alterations to the flow regime, abstractions, declining water quality during a protracted drought, the spread of carp and other deleterious effects of human interference with Murray waters, the microfauna appears remarkably little changed.

Biogeography/endemism

Microfaunal biogeography is subject to two interpretations—that of the 'cosmopolitanists', for whom everything is everywhere, and the 'regionalists', for whom it is not. Many of the microfauna species found throughout River Murray waters are the same species found in rivers and lakes everywhere; they are indeed cosmopolitan. But some are not. If they occurred worldwide, surely they would have been recorded in some 300 years of microfaunal research in the northern hemisphere. As noted earlier, the protists remain enigmatic. A small block of rotifers are more restricted, Gondwanan or Australasian on present distribution information. About 13–15% of rotifers are Australian endemics, or possibly more correctly 'Australasian'; some *Brachionus* species previously thought to be indigenous have been reported from Thailand (Sanoamuang *et al.* 1995). Most of the apparently indigenous rotifers are known from only one or a few habitats, primarily billabongs or small ephemeral waters, and appear to be restricted to them. The implication that they are thus endangered by loss of habitat is clear, but loss of species remains undocumented for the continent.

Cladocerans presently stand at ca. 48% endemism, but this figure is likely to increase when taxa carrying 'northern hemisphere' names are examined more closely using modern methods (Shiel & Dickson 1995). The work of Bayly (cited in Bayly 1992) indicates that the level of endemism in the Australian calanoids approaches 90%. Cyclopoids are less intensively studied, but evidence to date (e.g. Holynska 2000) suggests that greater endemism will be revealed as the Australian 'cosmopolitan' species shed their 'European' names.

The future?

In the Murray–Darling Basin, as in salinising wetlands in the southwest of Western Australia and in other degraded wetlands on continental Australia and Tasmania, species diversity is inversely related to salinity. The diverse microbiota of fresh waters is replaced by a halophile or halobiont assemblage tolerant of the new conditions. The new taxa may even be more abundant than the assemblage they replaced, but they are invariably less species rich. For example, the 100 species rotifer assemblage of upper Murray billabongs is replaced by one or two species of Brachionus/Hexarthra around Kerang, and the multispecies assemblage of *Boeckella/Calamoecia/ Hemiboeckella* of upper Murray billabongs is replaced by Calamoecia salina or C. clitellata in the salinised downstream lakes.

In the human time frame this decline in biodiversity is well documented for macrofauna. What is not documented is the loss of species at the microfaunal level due to loss of habitat. More than 70% of billabongs are now gone from some floodplain reaches (e.g. Goulburn River downstream of Eildon) and there is no data on how many species were previously found only in those billabongs. Persistence of propagules in sediments, despite the loss of wetlands, may be used to counter the suggestion that microfaunal species are being lost at an increasingly rapid rate. But as mentioned earlier, resting stages may have specific cues for emergence, and habitat changes such as salinization may remove these cues. Decreased flooding frequency may exceed the life expectancy of a propagule—resting stages have a finite life, be it decades or perhaps centuries. Further, propagules evolved to resist desiccation, not trampling by cattle, or tractor and plough. The introduction of exotic planktivorous fish (e.g. *Gambusia*), either deliberately or accidentally, must also have had a profound impact on microfaunal populations.

In summary, it is evident that microfaunal heterogeneity persists in the more pristine (upper) Murray–Darling floodplain waters—and it is the floodplain and sheltered backwaters which is the source of the biodiversity, not the reservoirs or mainstream rivers. The reservoirs are relatively recent in an evolutionary time-frame and the mainstem rivers transport microfauna and propagules. With loss of the more pristine wetlands due to agriculture, salinization, or other causes, the microfauna are lost, and if not replenished, the bank of cysts, resting eggs and ephippia in the sediments also disappear.

Functional role of macroinvertebrates in food web responses to inundation in the Murray–Darling Basin

Macroinvertebrate communities of the Murray–Darling Basin

Macroinvertebrates are an extremely diverse group of animals within inland water ecosystems and include worms, leeches, crustaceans, insects, molluscs, decapods and sponges. Boulton & Lloyd (1991) studied the macroinvertebrate community within different habitat types of the lower River Murray floodplain system and found that insects dominated the community. This is also the case for the Darling River, although crustaceans were more important in the lower River Murray than in the Darling River (Sheldon & Walker 1998). Quinn *et al.* (2000) also found that insects were dominant in the Ovens River (alpine region of Murray–Darling Basin), although oligochaetes and nematodes were also dominant (Quinn *et al.* 2000).

The macroinvertebrate community of the Murray–Darling Basin is considered to be diverse and heterogeneous, owing to the heterogeneous habitats that are available for macroinvertebrates on macro-(river channel, anabranch, billabong) and micro-(open water, macrophytes) scales (Boulton & Lloyd, 1991; Hillman & Quinn, 2002).

Functional roles of macroinvertebrates

Macroinvertebrates are herbivores, detritivores and predators (or a combination) and so they play a number of different functions within aquatic food webs. Herbivores are those species that feed on primary producers and so act to transfer energy to higher trophic levels, such as fish and birds. The most important food sources to macroinvertebrates within the Murray–Darling Basin appear to be periphyton and macrophytes (Bunn & Boon, 1993; Sheldon & Walker, 1997). Bunn and Boon (1993) found that in a billabong within the Murray–Darling Basin gastropods and leptocerid caddis larvae obtained their carbon from epiphytes and macrophytes.

Detritivores are those species that feed on dead organic matter, including dead organisms, woody material and leaf litter. Much of the dead organic material is sequentially broken down by shredders, scrapers and collectors, such that the organic material and nutrients are recycled back into the food web. The net result is reduced size of detrital material so that there is a large surface area available for further decomposition by heterotrophic microbial organisms.

Detritivores appear to be important components of the macroinvertebrate community of the Murray–Darling Basin. They were found to be the most abundant functional group in all macrohabitats of the Lower River Murray, except in temporary billabongs where predators predominated (Boulton and Lloyd 1991). Bunn & Boon (1993) found that in a billabong within the Murray–Darling Basin, freshwater crayfish was one of the few taxa that appeared to obtain its biomass carbon from detrital material.

Predatory macroinvertebrates are generally larger and feed on herbivores, detritivores or other predators. Consequently they also represent the transfer of energy through the food web. Another important function that macroinvertebrates play in food webs is as a food source for higher trophic levels such as fish and birds. The diverse range of macroinvertebrate sizes, high abundance and rapid colonisation mean that they are an important food source and integral to the functioning of aquatic ecosystems.

Unlike other floodplain river systems, few fishes of the Murray–Darling Basin are known to consume plant material or detritus (Merrick & Schmida, 1984). However, the floodplain contains a large number of insects available for consumption by fish (Humphries *et al.* 1999), with Murray–Darling fish considered to be opportunistic carnivores (Merrick & Schmida, 1984). Even top fish predators of the Murray–Darling Basin rely on macroinvertebrates as an important part of their diet (Ebner 2006). In arid areas secondary production of insects also contributes substantially to the food supply of terrestrial insectivores, including birds, spiders and reptiles (e.g. Jackson & Fisher, 1986; Lynch *et al.*, 2002; Sabo & Power, 2002; Ballinger and Lake 2006). Consequently, macroinvertebrates represent a connectivity of energy flow between aquatic and terrestrial ecosystems.

Responses to environmental flows in floodplain wetlands of the Murray-Darling Basin

The functioning of macroinvertebrate communities in floodplain wetlands of the Murray–Darling Basin is different to that of the Coorong. Temperature, flow, depth and substratum are considered to be important parameters structuring macroinvertebrate communities (Hillman & Quinn 2002), all of which differ considerably within the floodplain due to the complex geomorphic structure. These factors influence macroinvertebrates directly but also indirectly by influencing the quality and quantity of food sources (Sheldon & Walker 1997).

Owing to the variability in these factors across the riverine-floodplain gradient, Hillman and Quinn (2002) found that distinct macroinvertebrate assemblages developed in billabongs, backwaters and channels. In contrast Quinn *et al.* (2000) found that this was not the case for the unregulated wetlands of the Murray–Darling Basin. However, it is possible that this was associated with factors other than regulation, such as the mechanism of inundation, historical water regimes or climatic difference between the floodplains (Quinn *et al.* 2000). Boulton and Lloyd (1991) found that in the Lower River Murray temporary billabongs harboured the most species and individuals.

These wetlands are adapted to drying/reflooding cycles, with diverse and abundant biota flourishing when floods inundate and connect their diverse habitats (Jenkins *et al.* 2008). This is even the case in regulated systems with the burst in aquatic life evident in the macroinvertebrate communities recorded after an environmental allocation (Jenkins *et al.* 2008). This suggests that macroinvertebrates within the Murray–Darling Basin have successful strategies to deal with variability in inundation.

These strategies have been summarised by Hillman and Quinn (2002) following the work of Wiggins *et al.* (1980) and Batzer and Wissinger (1996). These include the production of desiccation resistant immature stages (eggs, larvae), desiccation resistant adults, cyclic colonisation by adults (often involving flight polymorphism), random dispersal, passive movement with incoming water and active migration during the period of connection. Since the macroinvertebrate communities of the Murray–Darling Basin depend partly on desiccation resistance, the period of time between flooding events is likely to play an important role in the ability of the macroinvertebrate community to recolonise following reinundation. Indeed frequent flooding is required to sustain resistant biota that survives dry periods as either dormant stages or in refugia (Jenkins *et al.* 2008).

Similarly, the macroinvertebrate community is dependent upon immigration for recolonisation following reinundation. Consequently, the connection to other habitats, either by water or by air, will also influence the ability of a wetland to be recolonised (Hillman & Quinn 2002). In fact, Marshall *et al.* (2002) found that proximity to other waterholes was the main factor structuring the observed macroinvertebrate communities in waterholes of an Australian dryland river system.

Following the initial connection or colonisation phase of reinundation there is a continuous change in the macroinvertebrate assemblage structure that is associated with community succession, as well as seasonal patterns (Hillman & Quinn 2002). The rate of change has been found to be greatest in temporary wetlands, most of which takes place in the first 6–8 weeks of inundation (Hillman & Quinn 2002).

In many systems it is thought that there is a decrease in diversity as the period of inundation decreases. However, Nielsen *et al.* (1999) found that in experimental billabongs on the floodplain of the River Murray that as the duration of flooding increased there was actually an increase in macroinvertebrate richness. This was associated with an increase in habitat complexity through time due to establishment and growth of macrophytes (Nielsen *et al.* 1999). However, the timing of flooding had little effect on the abundance and richness of the macroinvertebrate community with temperature being the driving force (Nielsen *et al.* 1999), highlighting the importance of the source of the water used for the provision of environmental flows.

It is clear that macroinvertebrates play integral roles in the response of food webs following inundation of wetlands of the Murray–Darling Basin. They colonise rapidly in response to inundation, filling a number of functional roles that result in the transfer of energy through the food web and recycling of dead material back into the food web. The communities and their responses to inundation are heterogeneous, but it appears that they are strongly dependent upon the frequency of flooding, duration of flooding, connectivity to refugia and the source of water for inundation.

Responses to environmental flows in the Murray–Darling estuary

Benthic macroinvertebrates have been shown to play an important role in the food webs of the Coorong, with many fish and birds dependent upon them for food (Deegan *et al.* 2009). The benthic macroinvertebrate assemblage of the Coorong varies considerably from those of the upstream river-floodplain system. In the Coorong, salinity is the primary driver of species diversity and community composition (Rolston & Dittmann 2009). Like other estuaries the Coorong is dominated by relatively few taxa, particularly the polychaete *Capitella* sp. and the micro-bivalve *Arthritica* (Rolston & Dittmann 2009).

Freshwater input into the Coorong will likely result in an increase in distribution abundance and diversity of macrobenthic invertebrates species with lower salinity tolerance (Rolston & Dittmann 2009). In addition, increased freshwater inflows will inundate currently exposed mudflats and create habitats suitable for colonisation, which will be fairly rapid due to the presence of juvenile macrobenthos in the Murray Mouth region (Rolston and Dittmann 2009). Such colonisation may take just a matter of weeks, but establishment of significant adult/reproductive populations or communities may take up to a year or more (Rolston and Dittmann 2009).

Fish, diets and habitat

Freshwater fishes often have the ability to switch life history styles during habitat disturbance events (Bruton 1995; Junk *et al.* 1989). The flexibility and opportunistic behaviour exhibited by many Australian fishes may relate to their adaptation to sporadic flow events (for example the flood recruitment model; Harris & Gehrke 1994) and the corresponding habitat disturbance (e.g. Tonkin *et al.* 2008), which at certain stages may produce a sudden increase in habitat complexity and prey items (Reid & Brooks 2000). The life history modes of most Murray–Darling Basin fishes are presented in Humphries *et al.* (1999).

This review found a patchy literature regarding the dietary needs of native fishes in the Murray–Darling Basin. Moreover, with few exceptions (e.g. Balcombe & Humphries 2009), there is little literature regarding the relationships between flow regimes with primary production and fish recruitment on Murray–Darling Basin floodplains.

Information regarding flood-induced changes in spawning and recruitment on floodplains is available for several species (e.g. King *et al.* 2003; King *et al.* 2008; Tonkin *et al.* 2008), however, the specific influencing factors remain unknown but are presumed to be largely related to increased productivity (e.g. zooplankton emergence) from flooding. There are other studies that test floodplain species in artificial ponds or tanks (e.g. Llewellyn 2005, 2006; Llewellyn 1973, 1974; Llewellyn 2008), and although these provide useful biological information, the specific factors influencing spawning and recruitment of the fishes still require testing in nature.

The following sub-sections present a review of the available literature from a search that was feasible under time constraints, so is not exhaustive.

Larval fish diets

Floodplains

Most of the approximately 40 native species in the Murray–Darling Basin (Appendix 1) inhabit the floodplain or estuary during some or all life stages. Approximately three quarters of these species are small-bodied (i.e. grow to <10 cm long). No studies of larval fish diets are known for the Murray estuary. Dietary research regarding small-bodied native fishes in Murray–Darling Basin floodplains is mostly on the Eleotridae (gudgeons) (e.g. Balcombe & Humphries 2009; Gehrke 1992; King 2005; Stoffels & Humphries 2003) (Appendix 2).

The studies on carp gudgeon species provide information regarding dietary shifts from juvenile to adult stages, influences of water level fluctuations on larval food availability, and interactions with the introduced eastern Gambusia. The other few published studies have examined the diets of larval carp (Vilizzi 1998), and larval Murray cod, Australian smelt, carp gudgeon, rainbowfish and carp (King 2005). It is likely that larvae of closely related fish species in the Murray–Darling Basin have differences in dietary preference. For example, experiments in artificial rearing ponds found that golden perch larvae included copepods in their diet whereas silver perch larvae did not (Culver & Geddes 1993).

The following points summarise some of the dietary research (see Appendix 2 for more information):

- Only two studies (Gehrke 1992; King 2005) have focused on the ontogenetic dietary shifts (changes in diet corresponding to changes in development) of several native species in Murray–Darling Basin floodplains.
- King (2005) found that the larval diets and feeding behaviour of Murray cod, Australian smelt, carp gudgeon and rainbowfish, and the alien eastern Gambusia and carp (collected from the lowland reaches of Broken River, Victoria) shifted throughout development from newly hatch larvae into juvenile stages, and to adulthood.

- Eleotrid larvae less than 5 mm in length consumed only rotifers, whereas larger larvae switched to larger prey, such as calanoid copepods and cladocerans (Gehrke 1992). Humphries *et al.* (1999) stated that, at the time, this is the only study of larval feeding of a fish species in its natural habitat.
- Results from a Victorian study imply that higher abundances of zooplankton in spring allow juvenile Murray hardyhead to forage more effectively and hence grow rapidly prior to decreases in zooplankton abundances over summer (Ellis 2006).

Adult fish diets

River floodplains

There are few publications regarding the adult diet of large native fishes (e.g. Murray cod and golden perch: Ebner 2006) (Appendix 2). An unpublished study by Lloyd (1987) examined the adult diet of approximately 15 small-bodied native and alien fish species from the lower River Murray and its estuary. All food items were identified to the lowest taxonomic level possible, at least to Family, but this detail is not presented in the thesis (Lloyd 1987). Dietary items were presented as taxonomic groups (aquatic insects, microcrustaceans, molluscs, aquatic plant, detritus, terrestrial insects, and fish) and ecological groups (nektonic organisms, Aufwuchs, benthic organisms, surface dwelling organisms, plant, detritus) (Lloyd 1987). The results are summarised in Appendix 2.

Estuary

There is only one known study (Lamontagne *et al.* 2007) regarding the diets of juvenile and adult fishes (small-mouthed hardyhead, gobies, yellow-eye mullet, mulloway) in the River Murray estuary (Appendix 2). Lloyd (1987) also analysed the diet of some species found at the estuary. There may be more information regarding the diets of commercial fish species in unpublished (and unavailable) fisheries reports.

Research from other catchments on species found at the Murray estuary includes a study from a Western Australian estuary found that blue-spot goby ingested predominantly algae, reflecting its differences from other goby species in terms of mouth morphology and feeding behaviour, rather than the type of food available (Gill & Potter 1993). A study in Tasmania (Hortle & White 1980) concluded that the diadromous congolli appear to be generalised carnivore eating a wide range of benthic animals. Information is given on the variation in diet with season and size. A comparison is made of the diets of fish from estuarine and freshwater sites on one river (Hortle & White 1980).

Effects of flooding on fish food items, spawning and recruitment

Ten years ago there was little evidence regarding the use of temporary floodplain habitats by larvae, juvenile or adult native fishes in the Murray–Darling Basin (Humphries *et al.* 1999). Since then only a few studies have been published that address this issue, and have demonstrated the benefits to spawning and/or recruitment in some native species (e.g. Australian smelt: Humphries *et al.* 2002; golden perch, silver perch, Murray cod, trout cod: King *et al.* 2008; southern pygmy perch: Tonkin *et al.* 2008).

Floods are not necessary to trigger spawning in all species, and instead may be induced by seasonal factors. For example, Puckridge & Walker (1990) demonstrated that spawning is not flood-cued for bony herring *Nematalosa erebi* (one of the most common native fish species in the Murray–Darling Basin), and suggested that a possible reason for the apparent success of the species is that larvae are not dependent on flooding-induced organisms. Bony herring and other species with a similar life cycle (e.g. Australian smelt) may be adapted to utilise food sources in the main river channel (cf. King 2004).

Other studies have demonstrated seasonal rather than flooding-induced spawning in small-bodied native fishes (e.g. Australian smelt: Humphries *et al.* 2002) and large native fish species (e.g. Murray cod: King *et al.* 2008), but flooding can increase recruitment success.

The aforementioned studies do not identify the factors that improve the success of spawning and recruitment during and after flooding. The reasons are probably largely related to increased prey abundances (e.g. zooplankton emergence from sediments). For example, Boulton and Lloyd (1992) showed that emergent invertebrates are a potentially significant contribution to the newly-inundated floodplain food web, and suggested that reducing the frequency of floodplain inundation probably reduces the food resource for young fish.

The physical changes derived from flooding (e.g. establishment of aquatic macrophytes) are likely to also play a significant role in spawning and recruitment success. For example, macroinvertebrate communities are highly structured by the presence and abundance of macrophytes (Brauns *et al.* 2008). Further, foraging profitability for fish is significantly enhanced by feeding in submerged aquatic vegetation (*Ceratophyllum demersum*), where they can consume larger prey, which can lead to higher growth rates, lower mortality and higher fecundity (Rozas & Odum 1988).

Estuary

The effects of freshwater inflows to estuaries on spawning and recruitment of fishes is derived mainly from overseas research. Generally, the rate, volume and duration of fresh water entering an estuary will determine the extent of the change in the fish community (Whitfield & Harrison 2003). However, a recent study at the Murray estuary found that during a period of freshwater inflows to the Coorong there was an increase in the diversity and abundance of zooplankton due to freshwater species being flushed over the barrage, predominately calanoids *Boeckella triarticulata* and *Calamoecia ampulla*, cladocerans *Ceriodapnnia cornuta* and *Daphnia lumholtzi* and rotifer *Ketatella australis* (Geddes & Wedderburn 2007).

Fish movement through connectivity between floodplain habitats and the river channel or Lower Lakes

- Gehrke et al.(1995) found reduced species diversity in increasingly regulated catchments of the Murray–Darling Basin The study showed that regulated catchments tend to have fewer native species, and those that are present are generally in high abundance, while introduced species flourish. Results showed discrete fish communities that reflect the geographical separation between catchments. The study concluded that river regulation may alter the relative abundance of native fishes and introduced fishes by desynchronising environmental cycles and the reproductive cycles of native species.
- Gehrke (1992) suggested that diel movements may be important in the exchange of fish larvae between the floodplain and channels during connectivity, by demonstrating significantly higher densities of flathead gudgeon or carp gudgeon larvae at night.
- Report that discusses movement and recruitment of common galaxias and congollis in Lake Alexandrina (Bice *et al.* 2007).
- During the current drought, the receded water levels at the Lower Lakes have dried or isolated fringing wetland habitats to the extent that one threatened species (Yarra pygmy perch) has become extinct from the MDB, and two others (southern pygmy perch, Murray hardyhead) now occur only as a few population isolates (Wedderburn & Barnes 2009). These species once

thrived at the Lower Lakes (Wedderburn and Hammer 2003), and the changes in water quality (especially increasing salinity) associated with the disconnection of habitats is the likely cause of extinction or rapid decline in the pygmy perch (Wedderburn & Barnes 2009).

 Low volumes of freshwater flow over the Murray barrage fishways in 2006–2007 attracted a suite of freshwater, marine and estuarine fish species, and facilitated spawning, recruitment and upstream migration of young-of-year and adult diadromous fishes

Dietary response of native fish species to flooding

There are few published studies regarding fish dietary responses to flooding in the Murray–Darling Basin (Balcombe & Humphries 2009). The findings of Balcombe & Humphries (2009), in a billabong c. 40 km downstream of Lake Hume, supported the hypothesis that "there will be greater volumes of high quality prey and fish [western carp gudgeon *Hypseleotris klunzingeri*] will have fuller stomachs during periods following stable water levels than during periods following fluctuating water levels". The findings also supported the hypothesis that "the higher quality food (in this case chironomids) would be reduced and lower quality food (in this case detritus) greater in times of fluctuating compared to stable water levels" (Balcombe & Humphries 2009).

Fish water quality tolerances (e.g. salinity, pH, dissolved oxygen)

Some studies regarding the influence of water quality on Murray–Darling Basin fishes:

- James et al. (2003) summarises upper salinity tolerances for approximately 20 native and six alien fishes of the Murray–Darling Basin, however, all fish were tested under laboratory conditions and upper limits will be lower in nature (e.g. unspecked hardyhead: Wedderburn et al. 2008).
- Gehrke (1990) demonstrated that larval golden perch may actively avoid inundated floodplains if water quality is unsuitable.
- A study examining larval development of golden perch in the Murray–Darling Basin and concluded that the presence of toxic leachates and low oxygen availability in flooded river red gum *Eucalyptus camaldulensis* forests may make these habitats unsuitable as nursery areas (i.e. larvae exposed to wood leachates at 20 g l⁻¹ for 30 mins suffered 97.5% mortality) (Gehrke *et al.* 1993).

- Silver perch can maintain a constant blood osmotic concentration to 6‰ salinity, but it is considered an obligate freshwater fish species because it has only been reported from <3% in nature (Guo *et al.* 1995).
- Fish species of the Ovens River floodplain indicate a generally high level of tolerance to periodic hypoxia, and species specific tolerance may have implications for billabong fish assemblage structures (McNeil & Closs 2007).

Diets and food resources of waterbirds

Studies on the diets of Australian waterbirds have largely consisted of inventories of the food items found in the crops, stomachs and or gizzards of birds, and to a much lesser extent observations of foraging birds. The collection of these largely ad hoc data has been ongoing for more than a hundred years, with few detailed studies from any one system or group of birds, the work of Vestjens (1977) on Lake Cowal and Frith (1959,1967) on waterfowl being exceptions.

There have been attempts to compile information throughout this period, with early compilations including the work of Cleland *et al.* (1918), and more recently Barker & Vestjens (1989), culminating in *The Handbook of Australian New Zealand and Antarctic Birds* (HANZAB) published from 1990 onwards. The first three volumes of HANZAB cover waterbirds (Marchant & Higgins 1990a, 1990b, 1993; Higgins & Davies 1996).

Appendix 3 provides details on the foods recorded in the diets of 80 species of waterbirds found within the Murray–Darling Basin based on material in Marchant & Higgins (1990a, 1990b, 1993) and Higgins & Davies (1996) and references within. Not all of the waterbirds recorded within the Murray–Darling region are covered in Appendix 3. A number of infrequently recorded or vagrant species (e.g. Large Sand Plover, Common Tern, and White-winged Black Tern) have not been included.

A precautionary note is required in assessing diets from stomach contents, in that soft bodied, easily digested foods are likely to be under represented because of more rapid digestion. Larger food items also take longer to be digested and or pass through the alimentary tract and so larger food items may be more often recorded, doubly so because larger items are usually easier to identify. Notwithstanding these potential biases, the available information (Appendix 3) shows that the vast majority of waterbirds consume a wide variety of foods, and only a few are restricted to one major food type. Even those species that feed almost entirely on one type of food (fish, plants) consume a diverse array of these foods. For example black swans *Cygnus atratus* feed almost entirely on plants but consume plants from at least 11 plant families (Appendix 3). Similarly fairy terns *Sterna nereis* specialise on fish, but take a diverse array of fish from at least 9 fish families (Appendix 3).

The great flexibility in the diets shown by most waterbirds is not unexpected. Birds have limited capacity to fast. If a particular food resource decreases birds have one of two choices—switch to an alternative food resource or fly to another wetland. Even if birds acquired reserves of fat, most fat stores provide at most a few days support. There are also added energetic costs for storing fat which relate to increased body masses, leading to elevated costs of flying. So, there is a disincentive (increased living costs) for birds to store fat, unless they are about to make a long distance migratory flight. Thus when faced with diminishing foods waterbirds modify diet or fly away.

Since there are risks associated with moving, strong selective pressures would favour birds that could switch to feed on other food(s). In some cases this may involve species shifting to adjacent terrestrial systems (e.g. Australian shelduck *Tadorna tadornoides* feeding on pasture). Importantly, although the details are not provided in Appendix 3, most stomachs of individual birds contained a variety of foods. This suggests that at the individual level birds are taking food as encountered and not specializing on any one prey.

The second key finding from the review of food resources consumed by waterbirds is that many are taking the same types of food items, and these are often the prominent or abundant foods in a wetland. Those birds that feed predominantly on plants are likely to consume a suite of common plants, such as Ceratophyllum, Myriophyllum, Vallisneria, Potamogeton, Polygonum, Ruppia, Azolla, Typha etc. Other species that feed on aquatic invertebrates often include the same items in their diets—such as the same species of annelids, gastropods, crustaceans (e.g. crabs, freshwater crayfish (Cherax)), as well as the same families of insects (chironomids, water-beetles etc). Those that take fish also overlap in the species of fish that are consumed (Appendix 3).

These patterns suggest that the food webs of the birds, and the bird community as a whole, contain redundancy. Irrespective of species, provided some species of aquatic plants, some species of aquatic invertebrates and or some species of fish are prospering in a wetland, then a broad range of waterbirds are likely to be present. Rogers & Paton (2008) reached a similar conclusion. A more important aspect of the waterbird community is that the majority of waterbirds forage in shallow water that is less than 1m deep, for some species it is <0.1m, or the birds forage on exposed mud surfaces (see Appendix 3 for some details). The only species foraging in deeper water are those that swim (cormorants, darter, grebes, some ducks). This means that the majority of waterbirds will forage around the margins of wetlands and that the key issue may be the provision or maintenance of suitable foraging habitats that in turn determines which bird species will use which wetlands.

Many birds have particular morphological features (upturned bill of an avocet; the spoon-shaped bills of spoonbills; the legs of stilts versus those of sandpipers) that aid harvesting food and or access to food, (e.g. the long neck of a swan can harvest aquatic plants from the sediment in water around the length of a swan's neck). These morphological differences may allow a wide variety of waterbirds to co-exist, with different species exploiting different parts of the wetland to feed on the same types of prey.

There are also some species of waterbirds that are widespread across most of the wetlands (e.g. silver gull *Larus novaehollandiae*) and others that usually show preferences or restrict their use to wetlands that are fresh or brackish. There are also a few species that prefer the more saline wetlands of the southern Coorong (e.g. banded stilt *Cladorhyncus leucocaphalus*) or are limited to the estuarine and near coastal wetlands (e.g. Fairy Tern, most of the migratory waders) (e.g. Paton *et al.* (1994a,b)).

Most birds do not have significant salt glands that can concentrate and excrete the excess salt likely to be ingested when foraging in the South Lagoon (Baudinette et al., 1982). An alternative for getting rid of salt is drinking freshwater. The numerous freshwater soaks around the margins of the Coorong may provide waterbirds with freshwater to drink and so allow them to cope with the excess salt in their diets.

Recent counts of waterbirds in the Lower Lakes, Coorong and River Murray, have indicated that between 250,000 and a little over 400,000 waterbirds were using this Living Murray icon site in 2007 and 2008 during summer (Kingsford & Porter 2008; Paton & Rogers 2009; Rogers, Paton & Bailey 2009). In contrast very few birds were seen at the other Living Murray icon sites or within the channel of the River Murray (Kingsford & Porter 2008).

The large concentrations of birds in the Lakes and Coorong highlight the importance of this wetland system as habitat for waterbirds during droughts. Despite the deterioration in ecological condition during this period of no flow, the Coorong and Lower Lakes, remain a critically important wetland from a bird perspective. One of the key reasons for this is that these wetlands continue to provide extensive areas of shallow water that provide opportunities for the majority of bird species to forage that the River Channel does not.

Recently the quality of the Lower Lakes as waterbird habitat has diminished as the unprecedented low water levels have led to disconnection of the main water-body from the fringing vegetation, greatly reducing habitat quality for some species (e.g. Australasian bittern *Botaurus poicoloptilus*, purple swamphen *Porphyrio porphyrio*). Risks of acidification may lead to further deterioration of this wetland system for birds by affecting aquatic food resources.

Aquatic and riparian vegetation; growth and distribution in relation to key environmental factors in the River Murray

Aquatic macrophytes, riparian and flood plain vegetation are subject to water level fluctuations, both in Australia and overseas. As a result of water scarcity, water is diverted from rivers and lakes and either stored in reservoirs or used for domestic and irrigation purposes. In Australia total diversions from the Murray–Darling Basin rivers amounts to about one third of the total inflow (30,000 GL yr⁻¹ v 10,000 GL yr⁻¹).

As a consequence discharges and water levels in the rivers of the Murray–Darling Basin have fallen. This has resulted in significant changes to the extent, type and distribution of wetlands in the Murray Valley. For example, a comparison between natural conditions (e.g. removal of the infrastructure) and current conditions (e.g. with all infrastructure present) indicates that the number of wetlands that are never or rarely connected to the main river channel has increased from 2,468 to 3,116 whereas wetlands that would have been connected at least every three or four years has fallen from 1,305 to 657.

Of the 575 wetland complexes associated with Swan Hill Reach only 76 received water from the main channel during the period 1990 to 2000 because at no time did the discharge exceed the sill height for the remaining 499 wetlands so water did not enter them. Although these data specifically refer to wetlands they also indicate the loss of connectivity between the floodplain and the main channel.

Wetlands, billabongs and anabranches were the traditional habitat for wetland and riparian vegetation. The current conditions have greatly increased the potential terrestrial habitat and reduced areas suitable for aquatic and riparian vegetation. Blanch *et al.* (1999a, 2000) suggest that as a consequence the main channel and in particular the weir pools above locks have become the main refuge for aquatic plants.

However, the suitability of the main channel as a refuge for aquatic plants is heavily dependent upon water clarity.

The vertical extinction coefficient (K_{id}) in the main river channel varies from 1 to 25 m⁻¹ (Mackay *et al.* 1988, Oliver 1990, Westwood and Ganf 2004) resulting in euphotic zones from 4 m to less than 20 cm. When the Darling River is in flood the vertical attenuation coefficient of the Lower River Murray can reach 25 m⁻¹ (Mackay *et al.* 1988). This severely restricts the potential habitat for the growth of submerged aquatic plants.

Blanch et al. (1999a) demonstrated that an average daily water column irradiance (I) of < 21 μ mol m⁻² s⁻¹ was the light compensation for the growth of Vallisneria and growth rate increased as average irradiance increased according to the relationship: 38 x tanh(0.83 x I/38)-18.4; r²=0.896, n=81. Consistent with this in May 2009 the vertical attenuation coefficient at Swan Reach was 2.1 – 2.4 m⁻¹ and Vallisneria occupied a significant proportion of the benthic habitat. Other aquatic plants (Potamogeton crispus, P. tricariantus, Myriophyllum sp.) also proliferated. Indeed much of the river below Blanchetown had a depth of < 2m which has enabled the expansion of macrophyte beds. Oliver and Lorenz (2007) also noted that in the weir pool above Mildura there had been a significant increase in the abundance of aquatic macrophytes when compared with 1997/98.

Bunn *et al.* (1999) used the relationship between incoming irradiance canopy cover to predict the below canopy daily light (mol m^{-*} day⁻¹ = 48.1—0.48 x canopy (%); r²=0.90) and used this relationship to predict the optimal light threshold for diatoms (9 mol m^{-*2} day⁻¹), filamentous algae (26 mol m^{-*} day⁻¹) and macrophytes. Kalff (2002) also stresses the importance of irradiance in the distribution and productivity of aquatic plants and gives a range of equations that predict the fraction of the habitat that is likely to be colonised by either submerged or emergent macrophytes.

He also provides a numerical model that describes the relationship between the maximum depth of colonization (Z_c) and maximum biomass of submerged macrophytes (Z_{mb}) and the Secchi depth (Z_{sd}): Zc=0.62 x Z_{sd} + 1.95: r²=0.78, n = 24. Z_{mb}= 0.039 x Z_{sd} + 1.11; r²=0.79, n=22.

The growth of emergent macrophytes is dependent upon both the incoming irradiance but also upon the emergent photosynthetic area. As water levels rise a greater proportion of the photosynthetic area becomes submerged and the plant's access to atmospheric carbon dioxide is limited which in turn restricts the plants growth rate. For example, there was a linear relationship (r^2 = 0.979, n=24) between total plant dry weight (g) and emergent leaf area (m²) for *Bolboschoenus caldwellii* for plants grown between 0 and 60 cm depth.

Similarly there are strong relationships between emergent photosynthetic area (m²) and Relative Growth Rate (RGR mg g-1 day-1) for key emergent macrophytes (Table 2 The relationship between photosynthetic area and relative growth rate).

Species	Regression Equation	۲²	p-value
Bolboschoenus caldwelli	RGR =52 +7.8 x Ln emergent phs area	0.89	<0.0001
Cyperus gymnocaulos	RGR=40+6.1x Ln emergent phs area	0.90	<0.0001
Cyperus vaginatus	RGR=5.09 + 4.31 x Ln emergent phs area	0.72	<0.001
Juncus aridcola	RGR=37.4+4.4xLn emergent phs area	0.95	<0.0001
Schoenoplectus validus	RGR=24.9+5.2*Ln emergent phs area	0.85	<0.0001

Table 2: The relationship between photosynthetic area and relative growth rate

Light is also a key driver for the phytoplankton community of the River Murray. Oliver and Merrick (2006) report a strong relationship between the average daily irradiance of the water column and the planktonic gross primary production at Barmah and Hattah (y = 0.35x + 4.08; $r^2 = 0.86$).

Although light is an important driver of primary productivity other factors influence the distribution and composition of aquatic and floodplain species. Roberts and Ludwig (1990) studied the distribution of riparian vegetation in the wetlands of the Chowilla floodplain. They identified four vegetation types: *Eucalyptus* with *Phragmites; Eucalyptus* with mixtures of *Eleocharis, Juncus, Cyperus* and *Cynodon; Cyperus* plus riparian grasses; Riparian grasses. The dominant plants were *Cyperus gymnocaulos, Eleocharis acuta, Eucalyptus camaldulensis, Juncus aridicola, Phragmites australis, Cynodon dactylon* and *Paspalidium jubiflorum.* They were able to relate the main vegetation types to five wetland categories (Table 3) where rows represent decreasing gradient of current and connectivity to the main channel and the columns a decreasing gradient of current and exposure to wave action. They explain the distribution of riparian vegetation by reference to current, wave action and indirectly to bank slope, variables that are most likely to alter in response to river regulation (Walker 1985).

Unlike the zonation and distribution of aquatic vegetation in North America (Keddy and Rezenick 1986) the data of Roberts and Ludwig (1990) does not support the role played by water levels. This is surprising because irradiance, water clarity and water depth all influence plant growth. Furthermore, there is substantial evidence to suggest that plants occupy those areas that have a water regime that is most closely related to their morphology (Figure 3, Figure 4 and Figure 5).



Figure 3: Similarities in species distribution and cover/abundance in 21 littoral plants across four weir pools in the lower River Murray

Data for the four pools are overlain. Position along a weir pool is standardised across the four pools: 0% at the downstream end of the pool, and 100% at the upstream end of the pool. The direction of flow is left to right. Cover/ abundance scores are represented by ovals. Flooding and drying preferences are indicated by 25th, 50th (median) and 75th percentiles (proceeding down the page for each species, with medians in bold) for three water regime indices: numbers of days in the two preceding years flooded to \0 cm (any depth) and 0–30 cm, and exposed by \100 cm (max. days: 730). Dashed lines indicate the design weir pool level (from:Blanch et al. 2000).



Figure 4: Mean cover/abundance scores for perennial littoral plants in Pool 5 across seven water regime groups Water regime groups were determined from cluster analysis of sites based on indices of water regime. † indicates species for which few data exist (recorded in one or two quadrats). (From Blanch et al 1999a)

Submerged plants that have lost many of the acquired terrestrial characteristics such as functional stomata and thick cuticles occupy habitats that are permanently flooded whereas others that have retained many of the acquired characteristics (e.g. stomata, cuticle, strengthening tissues) occupy habitats where the water regime has a distinct annual variation from wet to dry.

Roberts *et al.* (2000) recognise that water regime does play an important role in the distribution and composition of riparian and aquatic vegetation and suggest for modelling purposes plant water regime should be considered as a time series of three states: inundated and submerged; inundated but not submerged and not inundated. The key statistics for each state would be the mean duration and the variability of the duration as well as the mean variability of the period between the occurrence of one state or another and the seasonal occurrence of the three states. This option is worth pursuing because it does take into account both spatial and temporal variations in both the light climate and the water regime and more truly reflects the response of aquatic plants to a regulated river system where wetlands may remain dry or permanently wet for decades. Furthermore it incorporates the concept that different plant life stages may require different water regimes. For example, a seedling of an emergent plant that relies upon access to atmospheric carbon dioxide will not survive permanent top-flooding but requires moist mud to germinate.

On the other hand a mature plant such as Typha, Phragmites or Schoenoplectus will thrive in a metre of water although their seeds require shallow mud flats to germinate (Nicol *et al.* 2003). Indeed Van der Valk (1981) suggests that falling water levels are ideal for the recruitment of new individuals and permanently deep water favours only a few species and stable water levels lessens the regeneration opportunities and this results in a loss of species diversity.

Table 3: Distribution of thirty-one sampling units among four vegetation types identified by classification and ordination and five wetland categories (explained in text) typical of the Chowilla floodplain on the River Murray, South-east Australia

Rows (wetlands represent a decreasing gradient of current and connectedness to the main river channel, from top to bottom. Columns (vegetation types) represent a decreasing gradient of current and exposure to wave action, from left to right.

	Vegetation types			
	Eucalyptus + Phragmites	Riparian Grasses	Cyperus + grasses	Eucalyptus mixture
Main river channel	4	0	0	0
Fas anabranch	0	4	0	0
Slow anabranch	1	3	7	0
Backwater	1	0	3	5
Billabong	0	0	0	3
Total	6	7	10	8



Figure 5: The probability of occurrence of 32 common aquatic plants in relation to water depth (<100cm = depth to water table >100cm; >100cm = water depth > 100cm) over the preceding two years (data from Blanch 1999, 2000, Siebentritt 2003)

Carbon sources, leaf litter inputs and phytoplankton primary productivity

The relative magnitude of allocthonous verses autochthonous carbon input to the River Murray and whether or not it fuels river metabolism is a crucial question that has recently been the subject of three publications, Oliver and Merrick (2006), Oliver and Lorenz (2007), Gawne *et al.* (2007). These authors agree that annual phytoplankton primary productivity is 775–1126 g $O_2 m^{-2} yr^{-1}$ (Oliver and Merrick 2006) or 221 to 376 g C m⁻² y⁻¹ (Gawne *et al.* 2007) which equates to 258–375 g C m⁻² y⁻¹ assuming a photosynthetic quotient of one. Both agree that planktonic gross primary productivity was least at the Albury site and greatest at Barmah and community respiration consumed significant amounts of oxygen. Gawne *et al.* (2007) indicates that phytoplankton dominate both primary productivity and community respiration, producing 157 to 383 g C m⁻² y⁻¹ (57–68%) and respiring 94–283 g C m⁻² y⁻¹ (52–66%). Planktonic bacteria have an annual growth of 77 to 257 g C m⁻² y⁻¹ and an annual energy consumption of 48 to 101 g C m⁻² y⁻¹. Their data show that the annual contributions of biofilms on the benthos, course woody debris and course detritus all contributed <10% of the annual gross primary production and community respiration.

Oliver and Merrick (2006) are rightly hesitant to convert the raw data collected as $g O_2 m^{-2} day^{-1}$ to annual figures because of the variability of climate and discharge over laying the relatively few sampling times and stations. Nevertheless, their data (Figure 6) show that estimates of whole system areal GGP, CR indicate that Net Ecosystem Production (NEP) is close to zero. They differentiate between the contributions made by the daily planktonic and benthic community GGP, CR and NEP (Figure 7 and Figure 8). Planktonic gross photosynthesis ranged from 0.2 to 4.2 g $O_2 m^{-2}$ day⁻¹ and community respiration from -0.4 to -4.5 g $O_2 m^{-2}$ day⁻¹ whereas benthic algal GPP contributed by the illuminated littoral zone and standardised to river surface area ranged from 0.005 to 0.71 g $O_2 m^{-2}$ day⁻¹ and CR -0.0.2 to -0.36 g $O_2 m^{-2}$ day⁻¹.

Benthic production is a small fraction of the whole system production. Annual estimates of the net phytoplankton production ranged from 25 to 36 g C m-2 yr⁻¹ or 6 to 11% of annual GPP. Although the ranges encompass an order of magnitude there was no overwhelming suggestion that rates were dependent upon season but rates were generally lower in winter and early spring.

The later study (March /April 2006 to March /April 2007) of Oliver and Lorenz (2007) re-enforce the findings of the 1998/1999 study that the system appears to be energy constrained with net production close to zero. The conclusions made by Oliver and Lorenz (2007) were:

- These results confirm earlier findings on the River Murray and indicate that for flowing sites phytoplankton are the major source of energy for the aquatic food webs and that the system appears to be energy constrained with NP close to zero (Oliver and Merrick 2006). In general benthic contributions were small in flowing reaches, although the positive net phytoplankton production within the riverine sites appears largely to be dissipated through the benthic compartment following sedimentation.
- The often large respiratory activity and negative *NP* within weir pools suggests that they are a significant site of organic material processing and a major contributor to food web energy capture within the river system. The dispersion of this energy is difficult to assess and appears to be small as flowing sites downstream of pools generally do not have significantly enhanced respiratory activity.

If dispersion is via larger organisms that distribute widely in downstream, and perhaps upstream directions in the case of fish, then enhancement of the metabolic signal will occur if the organic material making up the organisms is processed through respiration, or the increased concentration of organisms increases the total respiration due to processing of local material. The breakdown of individual organisms is unlikely to increase metabolic rates sufficiently to be observed in the oxygen time series. Enhanced respiration by increased population size can only occur if there is an excess of suitable organic material that can be metabolised and this appears not to be the case. Consequently the enhanced metabolism is confined to pools and its distribution through the river system curtailed. It is not known whether there is substantial exchange between pools.

These results suggest that the augmentation of riverine populations by enhanced growth and transport from metabolically active sites such as slow flowing reaches and connected wetlands could be constrained by the lack of energy supplies within the river channel. If this is the case then improving flow characteristics and wetland connectivity might not lead to enhanced river populations unless there is a concomitant increase in food supplies within the channel.

The interpretations reached in these three studies of river metabolism seem to differ in detail although not in the overall conclusions. Gawne et al. (2007) suggest that the net contribution of organic matter to the channel indicates that primary productivity is derived from a combination of phytoplankton, riparian vegetation and macrophytes but the major sources varies both spatially and temporally. Oliver and Merrick (2006) and Oliver and Lorenz (2007) emphasise the importance of phytoplankton but suggest that the slow moving weir pools are a major site for the processing of organic material associated with high rates of respiration and negative net productivities. Both agree that the contribution of flood plain derived organic carbon whether by riparian or terrestrial vegetation to overall river metabolism is largely unknown.

This conclusion is supported by Bunn *et al.* (2003) who make the observation when working on the arid Cooper Creek system that despite the presence of large amounts of terrestrial carbon there was no evidence of it being a significant contributor to the aquatic food web. They suggest that a conspicuous band of filamentous algae along the shallow littoral zone of the larger waterholes had a high GPP (1.7 to 3.6 g C m⁻² day⁻¹) and stable isotopes confirmed that this band was a major source of energy for the aquatic consumers.

Although measurements are scarce allochthonous carbon input is either unavailable or plays a minor role in river metabolism. Carbon derived from the floodplain is likely to be derived from the riparian vegetation and includes species such as *Eucalyptus camaudulensis*, *E. largiflorens*, *Acacia stenophylla*, *Typha domingensis*, *Phragmites australis*, *Juncus ingens* but in many regions the contribution by submerged and semi-emergent aquatic macrophytes is likely to be limited (Rees *et al.* 2005). The in stream processing of terrestrial derived carbon is primarily due to heterotrophic bacterial activity. It is perhaps significant that Rees *et al.* (2005) were unable to find any correlation between bacterial activity and carbon and nutrient concentrations in the Murray between Albury and Hattah. This was despite bacterial production rates that ranged from 1 to 25 μ g C L⁻¹ hr⁻¹. However they did substantiate a correlation between bacterial activity and carbon between the bacterial activity and chlorophyll, which may suggest the bacteria were dependent upon carbon excreted by the phytoplankton.

Measurements made by Webster *et al.* (2005) on the Daly River also indicate that there is a tight coupling between the photosynthetic fixation of carbon and the microbial degradation of photosynthetic products of plants and their exudates, in particular when nutrients are thought to be limiting the increase in plant biomass. This raises the question of whether or not the majority of the terrestrial derived carbon input to the main channel of the river is available. It may not be, because the riparian vegetation is carbon rich compared with the tissues concentration of nitrogen and or phosphorus (i.e. high C:N 50:1 and C:P 900:1 ratios).

In contrast, the C:N (<10:1) and C:P (<250:12) ratios in the semi-emergent and submerged vegetation are much lower (Elser *et al.* 2000). Deegan *et al.* (2008) used stable isotopes to suggest that primary consumers preferentially selected food sources that were closest to their body tissue C:N ratios which is more likely to be aquatic plants than terrestrial ones.



Figure 6: Whole system estimates of areal rates of GPP, CR and NEP measured on each sampling occasion at three sites on the River Murray (Oliver & Merrick 2006)



Figure 7: Daily planktonic GPP, CR and NEP measured on each sampling occasion at three sites on the River Murray (Oliver & Merrick 2006)



Figure 8: Daily benthic GPP, CR and NEP contributed by the illuminated littoral zone and standardised to river surface area (Oliver & Merrick 2006)

Nutrient flux on inundated floodplains

Nutrients are fundamental components of river and lake ecosystems that undergo continuous transformation as they pass downstream (Newbold *et al.* 1981). Aquatic primary productivity (macrophytes and algae), and therefore secondary productivity, is dependent upon the supply of nutrients as this determines both the magnitude of populations and the rate at which they grow (Wetzel 2001). Emergent macrophytes are thought to obtain a majority of their nutrients directly from interstitial sediment water (Reddy *et al.* 1999).

The source of nutrients to rooted submerged macrophytes and periphytic algae remains unclear, but it is likely that they obtain nutrients from both interstitial water and the water column, depending on relative nutrient availability (Denny 1972; Reddy *et al.* 1999). In contrast, floating macrophytes and phytoplankton obtain a majority of their nutrients from the water column (Reddy *et al.* 1999).

Although cycling of nutrients has been studied in great detail, much of this information has been developed in temperate regions, which are not subject to extreme changes in water level. Inland water ecosystems in arid and sub-tropical regions are subject to changes in water level and height of inundation on a range of spatial and temporal scales, owing largely to variability in rainfall (Gasith & Resh 1999). River, wetland and floodplain ecosystems of southern Australia are adapted to the intermittent frequency and variable period of inundation.

In fact, a considerable component of the primary and secondary productivity within these, and neighbouring ecosystems, is thought to be dependent upon the drying-reflooding cycles. Flood-pulsing of nutrient and carbon from wetland and floodplain sediment following drying-reflooding cycles provides resources to the food web within the floodplain and the main river channel (Junk *et al.* 1989).

Sediments contain a major portion of nutrients stored within inland water ecosystems (Marsden 1989; Martinova 1993; Søndergaard *et al.* 1993). Not only are sediments an important direct source of nutrients to plants but they also release nutrients into the overlying water column during anoxia, upon reflooding and by wind-driven resuspension. The drying-reflooding cycles that exist in Mediterranean and arid climates are important in controlling the flux of nutrients between sediments and the water column.

Along with external nutrient inputs, conditions within sediments largely control nutrient concentrations in the water column that ultimately drive productivity. Drying of sediments will result in changes to the physical, chemical and biological character of the sediments to which nutrient cycling is intrinsically linked (Baldwin and Mitchell 2000). Consequently, the cycling of nutrients following drying and reflooding cycles is different than under permanently inundated conditions. Despite this, only few have investigated the role of drying–reflooding cycles on nutrient cycling in aquatic ecosystems.

Baldwin and Mitchell (2000) have provided a comprehensive review of the likely effects of drying-reflooding on nutrient dynamics of inland water ecosystems. The major effects of drying of previously inundated sediments are to the mineralogy and microbial ecology, both of which respond to increasing oxygen concentrations within the sediment (Baldwin and Mitchell 2000). As water levels fall during the drying process, the oxygen penetration depth within sediments will increase. This is initially due to increased delivery of oxygen rich surface water to the sediments due to decreasing water depth.

As sediments begin to dry oxygen penetration will continue to increase due to contact with the atmosphere and finally through the development of cracks accompanying the loss of moisture content. The increasing oxygen concentrations will influence the mineralogy by causing the oxidation of reduced mineral phases (Baldwin and Mitchell 2000). The most notable change that influences nutrient cycling is the oxidation of ferrous sulphides into amorphous ferric oxyhydroxides which have a high affinity for phosphorus (De Groot and Van Wijck 1993). This is thought to be responsible for the increase in affinity of sediments for phosphorus of aerated sediments (De Groot and Fabre 1993; Baldwin 1996). However, as drying continues the affinity of sediments for phosphorus has been shown to reduce due to oxyhydroxides becoming crystalline (Lijklema 1980), reducing the number of binding sites for phosphorus (Sah et al. 1989; Qiu and McComb 1994; Baldwin 1996).

The penetration of oxygen into inundated sediments during drying will also influence nutrient cycling by altering the microbial composition and activity (Baldwin and Mitchell 2000). Initially, the expansion of the oxygen penetration depth may allow aerobic and anaerobic nutrient cycling processes to occur concurrently (Baldwin and Mitchell 2000). These process rates may be enhanced due to the coupling of processes such as nitrification and denitrification, with denitrification rates enhanced by the presence of nitrification through the provision of nitrate (Knowles 1982).

As oxidation continues however, obligate anaerobic heterotrophs will be killed or form resting stages (Lynch and Hobbie 1988), thus reducing the rate of the processes that they carry out. Furthermore, the loss of moisture from the soil as sediments continue to dry will result in a further decrease in bacterial biomass and activity (De Groot & Van Wijck 1993) and extreme drying will result in high bacterial mortality and cell lysis (West *et al.* 1988; Qiu and McComb 1994).

Upon re-inundation lysed cells may leach nutrients resulting in the flux of large amounts of nutrients into the porewater and overlying water column (Sah *et al.* 1989; Mitchell & Baldwin 1999; Baldwin & Mitchell 2000; Baldwin *et al.* 2005). This is thought to result in increased rates of microbial activity, including rates of nitrification and denitrification (Baldwin and Mitchell 2000) if microbial communities have survived the desiccation processes. Denitrifying bacteria are predominately facultative anaerobes (Knowles 1982) and so drying–reflooding cycles have been shown not to reduce denitrification rates (Kern *et al.* 1996). However, if obligate anaerobes are dominant then rates of microbial processes will presumably be lower upon inundation than prior to drying.

In addition to increasing microbial heterotrophic activity, an increase in the available nutrient pool may increase the productivity and standing biomass of phytoplankton or macrophytes within the wetland. In addition, if there is sufficient connectivity between inundated floodplain/wetlands, return flows to the river may deliver sufficient nutrients to drive significant primary productivity there. While we now have a basic understanding of the influence of dryingreflooding cycles on nutrient fluxes from sediments, how these nutrients are partitioned into various components of the ecosystem upon release from the sediments is largely unknown and is dependent upon a number of factors, including hydrodynamics and extent of sediment nutrient release.

The extent and form of nutrient release from sediments will depend upon a number of factors including:

- Nutrient concentrations within the sediment sediments with greater nutrient contents will tend to flux greater amounts of nutrients into the water column because of the equilibrium that exists between the two.
- The sediment character—this will influence rates of diffusion of nutrients from sediment to the water column.
- The extent of drying—sediments that have been dried for extended periods will contain more lysed cells and accumulate terrestrial organic material. This will result in greater nutrient fluxes upon reinundation.

 The extent of mixing upon reinundation mixing will enhance nutrient fluxes as released nutrients are dispersed through the water column, thus maintaining concentration gradients that drive diffusion.

The release of excessive nutrient concentrations coupled with low flow conditions is likely to stimulate the activity and growth of both heterotrophic microbial organisms. This may lead to consumption of oxygen and ultimately oxygen depletion, rendering them uninhabitable for most organisms, and resulting in further release of nutrients from anoxic sediments. Furthermore, this may lead to increased phytoplankton growth, including cyanobacteria, increased turbidity and loss of macrophytes and thus habitat and food for higher order organisms. The desired situation is for increased nutrient concentrations to promote both phytoplankton macrophyte growth, which requires sufficient water movement to inhibit the development of stratification and anoxia.

The inundation, either naturally or by environmental watering, of wetland and floodplain ecosystems of the River Murray is likely to release nutrients from sediment into interstitial water and the water column. This is likely to result in increased primary productivity within the wetland and floodplain ecosystems, but also in the main river channel if suitable connectivity exists. Ultimately, it is believed that the drying-reflooding cycles will lead to increased secondary productivity.

Gigney et al. (2006) investigated the exchange of material between the River Murray Channel and Barmah-Millewa Forest during a floodplain watering trial and found that there was extensive transfer of material between the floodplain and main river channel. Indeed, the water trial resulted in increased nitrogen, phosphorus and dissolved organic carbon concentrations in the River Murray as a result of the flux from newly inundated areas. In contrast, suspended solids and particulate organic carbon decreased in the River Murray, settling as the water dispersed through the floodplain. It was thought that the increased dissolved nutrients and organic carbon stimulated productivity of the system with plankton macroinvertebrates increasing rapidly after an initial decline following inundation.

These findings have been supported by findings elsewhere, including the Danube River (Tockner *et al.* 1999) and Solimoes River in the Amazon Basin (Bayley 1989); and a subtropical blackwater river system in Georgia (Cuffney 1984; Edwards & Meyer 1987). However, there remains considerable spatial and temporal variability in the lateral movement of resources between floodplains and rivers.

Future flow, flooding and wetland response

Examination of historical and current Murray–Darling Basin inflows and end-of-system flows can offer some insight into how river management and water allocation has altered the flow regime of the river. Historically the average flow into the Murray-Darling Basin was 29,639.6 GL per year, of which 12,232.8 GL flowed to the lakes, Coorong and Southern Ocean. Surface water availability was 14,493.4 GL/year which would have breached the banks and flooded vast tracts of floodplain. Current surface water diversions of 11,145.9 GL/year have reduced end of system flows to 4,732.6 GL/year on average (CSIRO, 2008), however, there have been negligible end of system flows since 2001. Recent climate end-of-system-flows are 2,367.4 GL/year.

Predicted future flows and anticipated flooded area under different flood volumes are significantly reduced from the historical flow but this is more due to water diversion than climate change. However, climate change by 2030 could lead to further reductions in inflow. River regulation and water allocation have altered the magnitude, duration and frequency of floodplain inundation. The Murray–Darling Basin Sustainable Yields Project (CSIRO, 2008) summarised the consequences of altered flow regime of the floodplain wetlands.

"Overall, consumptive water use in the Murray–Darling Basin has reduced average annual streamflow at the Murray mouth by 61 percent and has increased the incidence of cease-to-flow conditions from 1 percent of the time to 40 percent of the time. Severe drought inflows to the Lower Lakes (which would never occur in the absence of consumptive water use under the historical climate) prevail in 9 % of years at the current level of water resource development.

Water resource development has had major impacts for the flooding regimes of many important floodplain forests and wetlands, including for several Ramsar listed wetlands. For example, the proportion of years in which lakes in the Narran Lake Nature Reserve receive sufficient flooding to provide optimal waterbird breeding habitat has been more than halved; the average period between environmentally beneficial flooding of the Macquarie Marshes has more than doubled; and the average period between environmentally beneficial flooding of the major floodplains and wetland systems along the River Murray has approximately doubled. Prior to regulation, water levels in the Ramsar listed terminal Lake Albacutya in the Wimmera region never fell low enough to be deemed 'shallow' for more than 8 years. As a result of water resource development, Lake Albacutya is now shallow for periods of up to 33 years, which has fundamentally altered the natural character and habitat value of the lake."

"Climate change will impact water availability in South Eastern Australia. In the three highest water use regions (the Murray, Murrumbidgee and Goulburn–Broken) current water sharing arrangements would protect water users from much of the climate change impact and thus transfer a disproportionate share of the climate change impact to the environment. For the Murrumbidgee and Goulburn–Broken regions this means that much of the impact of climate change would effectively be transferred downstream to the Murray region.

In the south of the Murray–Darling Basin, current water sharing arrangements offer floodplain wetlands little protection from the expected impacts of climate change. Without changes to water sharing arrangements in these regions, climate change would be likely to lead to irreversible ecological degradation. The median 2030 climate would increase the duration of the dry periods between important flood events for all The Living Murray icon sites 4(e).

There would only be relatively small increases in the average period between flooding for most icon sites, but the average period would double for Chowilla Floodplain and Lindsay–Wallpolla Islands to be about every 18 years—almost eight times the without development period. The average annual volumes of environmentally beneficial floods would be close to halved for all the icon sites along the River Murray. On average they would only receive about one-tenth of the flooding volume they received under without-development conditions" (CSIRO, 2008)

To redress the water allocation to the environment The Living Murray initiative was instigated with the aim of securing 500 GL for environmental water by 2009. This target has almost been met although recent drought and historically low inflows to the system have meant only a fraction of this water is currently available. In the absence of floods, environmental watering programs have maintained aspects of floodplain health in very limited areas of the sites. The environmental watering reports of the Murray–Darling Basin Authority summarise these benefits but also highlight that the unprecedented drought has contributed to a general decline in flora and fauna. (Environmental Watering Report 2007–2008). A total of 16.522 GL was used at a number of icon sites to provide drought refuge for water birds, small fish and frogs but an allocation was also used to avoid acidification in the lower river wetlands.

As more typical flows are reinstated we can expect a greater area of floodplain flooding and increase in habitat area. The water recovered though The Living Murray will target restoration at the icon sites which include:

- 1. Barmah-Millewa forest
- 2. Gunbower-Koondrook-Perricoota Forests
- 3. Hattah lakes
- 4. Chowilla Floodplain and Lindsay Wallpolla Islands
- 5. Lower Lakes, Coorong and Murray Mouth
- 6. River Murray Channel

Other wetlands adjacent to the River Murray play critical roles in supporting food webs and providing habitat even though they may not support the abundance of fish, birds and vegetation as the icon sites.

Predicted response of the Coorong to flow provisions

Although in decline, much of the ecological function of the Coorong has been retained in the North Lagoon. Rising salinity, associated with the absence of freshwater inputs, is considered to be the major factors leading to the loss of biodiversity and the change in state from a system dominated by the macrophyte *Ruppia tuberosa* to a system dominated by microalgae. Consequently, in the Coorong environmental flow provisions should aim to reduce salinities to levels that maximise biodiversity. Identifying an appropriate salinity target can be achieved by determining salinity tolerance of the organisms that are in the system.

This is explored in a conceptual model for the Coorong later and informs a testable hypothesis that food webs could be re-established in the South Lagoon with the restoration of freshwater flows and lower salinity.

Techniques for assessing food webs

The focus of The Living Murray monitoring is on fish, birds and vegetation, which provide a good indication of the overall ecological health of the icon sites. The processes which are being influenced by flow manipulation and floodplain inundation include hydrodynamics, biogeochemistry and primary productivity. Higher order organisms respond to these habitat and primary productivity drivers.

When compared with terrestrial ecosystems, the food webs in aquatic environments are challenging to investigate. In terrestrial environments there are a range of techniques are available to examine food webs including direct observation of predation or ingestion, and faecal or pellet examination. Direct inspection of feeding and prey is possible for groups such as birds but almost impossible for fish. Dietary preference studies of zooplankton may also be possible but these are very labour intensive and require experimental manipulation rather than just monitoring. The nature of aquatic environments limits our ability to accurately determine predator-prey relationships (Hobson and Welch 1995).

Gut content analysis has been used to examine fish diet (Hyslop 1980), however, this only allows the stomach contents of a predator to be quantified for the specific taxa ingested, but not necessarily assimilated (Grey et al. 2002). It only provides information about feeding immediately prior to capture, and provides limited information regarding the source of those food items (e.g. pelagic, littoral, benthic, etc,). Moreover, ingested items can often be masticated or digested beyond recognition, and the softer body components of the diet may be significantly underestimated (Burns et al. 1998). Stable isotopes can be used to augment conventional dietary analysis techniques such as gut content analysis, providing additional information on diet over time periods of weeks to months.

Stable isotopes are a powerful and effective tool for tracing the movement of energy and nutrients from primary producers to consumers (Connolly *et al.* 2005). The stable isotope ratios of carbon (δ^{13} C) and nitrogen (δ^{15} N) differ among primary producers (Bouillon *et al.* 2002; Fry 1984) and these ratios, the isotopic signatures, are taken on by the consumers and reflected in their tissues at whatever trophic level they occur (Boon & Bunn 1994; Fry & Sherr 1984; Peterson 1999; Wada *et al.* 1991). Both the nitrogen and carbon in consumer tissues are derived exclusively from their diet, and therefore trophic estimates using stable isotopes are based on food that has been assimilated rather than just ingested (Gearing 1991).

Conclusions

There are notable differences in the feeding of key groups that need consideration when planning a flow regime for floodplain inundation and food web enhancement. Birds do not have the ability to fast and, for the majority of species, their feeding is restricted to water less than 1m deep. Consequently the main river channel is not a suitable refuge for them during dry periods without inundation and they rely almost exclusively on the shallow wetland areas.

During periods of extreme dry the Lower Lakes and Coorong is the major refuge for aquatic feeding birds in the Murray–Darling Basin. However, this habitat is also threatened by low freshwater flows. Fish on the other hand, may refuge and spawn in the main river channel although the success of recruitment is diminished relative to the flood conditions when there is a mosaic of habitat, dispersal of larvae and greater abundance of larval food sources. Therefore, the type of flood may also affect the relative value to the different groups and their contribution to the food web. Inundation of the floodplain creates the right habitat for bird feeding but transport of carbon or zooplankton into the river channel is required for food web benefits to be realised there. Changes to lateral and longitudinal connectivity have modified resource flow, reduced zooplankton contributions to the food web and meant the main river channel is a major refuge habitat. The importance of floodplain inundation for carbon input to the main channel and food web is largely unknown and constitutes a knowledge gap.

Limited water availability and the installation of regulators to manage floodplain inundation mean that flood plain watering is different from historical natural floods. Notable features of managed floodplain inundation are that the water has lower velocity and may not return nutrient and carbon resources to the main channel.

If the floodplain proves to be a valuable contributor of nutrients, carbon and zooplankton to the main river channel and hence important for food webs then managed floodplain inundation will need to consider this when designing artificial floods. 2. Conceptual models: linking flow enhancement and water retention on floodplains with aquatic food sources response

Food web models describe the transfer of energy through ecosystems. Carbon is the currency of energy in food webs but the macro-nutrients nitrogen and phosphorus are important components of nutrition and constraints on metabolism for plants. The rate and form of carbon transfer to aquatic ecosystems is not just a function of flooding but is also impacted by landuse, nutrient availability, turbidity and hydraulic connectivity. Energy input into food webs is ultimately derived from solar energy driving terrestrial and aquatic primary productivity. Energy flow through invertebrates, birds and fish may follow a number of routes or the carbon may be cycled internally through the microbial loop. The generalised food web model below (Figure 9) shows the vectors of resource flow between aggregate pools describing major functional groups.



Figure 9: Generalised food web for floodplain-river ecosystems (adapted from Winemiller 2003) Boxes are aggregate material pools and vectors represent consumer resource interactions with thick arrows representing dominant pathways (ml= microbial loop path, fp = nutrient pathways enhanced by flood pulses, iw = invertebrate web having complex trophic structure involving invertebrates and ? = poorly quantified pathways).
What the stylised food web models fail to describe are the physical and chemical drivers that support the organisms within the food web. Critical components that need consideration in aquatic food webs in the Murray–Darling Basin include:

- nutrient dynamics
- frequency and duration of flooding
- lifespan of individuals and breeding habitat requirements
- connectivity to the main river channel and system-wide benefits.

Carbon sources to the food webs include both allochthonous inputs from terrestrial vegetation and autochthonous inputs from phytoplankton, periphyton and macrophyte productivity (Figure 10). Water velocity, water depth, nutrient dynamics and the underwater light climate play roles in determining the type of autochthonous carbon that is fixed. Low flow in the main river channel can promote the growth of cyanobacteria at the expense of species that require turbulence to remain suspended in the water column. Inundation of the floodplain provides the habitat for macrophyte growth and herbland higher on the elevation gradient (Figure 10).

The mosaic of water velocity, vegetation architecture and water depth created in the heterogeneous river-floodplain system provide a suite of habitat types for utilisation by zooplankton, macroinvertebrates and fish (Figure 10). Furthermore, the shallow floodplain habitat opens up feeding grounds for waterbirds that require shallow water depths for feeding. Floodplain inundation is also central for recruitment of iconic fish species, not just spawning which appears to be seasonal. The mosaic of habitats created with flow and floodplain inundation maximises the potential for recruitment by both habitat provision and increased diversity of food sources (Figure 10).



Figure 10: Energy inputs and habitat diversity in a regulated river with an inundated floodplain

2. Conceptual models: linking flow enhancement and water retention on floodplains with aquatic food sources response

Maximising ecological benefits from floodplain inundation relies upon adequate flood frequency and duration for spawning/hatching/germination and recruitment to sexual maturity. This is rapid for zooplankton and there may be several generations produced in a single event with considerable community succession also occurring due to predation. Fish recruitment takes longer than for zooplankton. Unlike zooplankton that produce eggs that can persist for many years in the propagule bank, fish populations rely on the persistence of adults to ensure population success. Timelines for recruitment are summarised in Figure 11 highlighting the importance of both flood duration and flood timing.

The objective of environmental flow provisions in regulated rivers is to create resilient sustainable ecosystems. The main river channel lacks the mosaic of habitats that are found within the floodplain and so without adequate connectivity to the floodplain the river cannot function sustainably. Often inundation of floodplain wetlands are treated in isolation, but it is likely that benefits are provided to the river and so to the river-floodplain system. Floodplains play a number of important functions in Murray–Darling Basin, including a source of diverse and abundant food for fish and birds (invertebrates and primary producers); the provision of shallow habitat for birds; and the provision of habitat for fish recruitment.

While the floodplain is a recipient of resources from the river following flooding, it is also likely that the main river channel is a recipient of energy from floodplains. Much of this energy will be stored within organisms that will help support populations within the river and downstream wetlands. However, the impact of floodplain inundation upon the transfer of energy to the river, and to downstream wetlands, is largely unknown.



Figure 11: Conceptual timeline for fish and zooplankton responses to floodplain inundation

The Coorong food web model

The Coorong differs from the rest of the river because it is a coastal lagoon with salinity grading from fresh through to hypermarine (Figure 12 Map of Lower lakes and Coorong). However, the Coorong (in conjunction with the Lower Lakes) is extremely valuable as it is the permanent water refuge for significant numbers of waterbirds during dry years, and for migratory waders during the austral summer.



Figure 12: Map of Lower lakes and Coorong

The Coorong relies on freshwater flow from the river to maintain salinity below the tolerance threshold for the organisms that inhabit the region. The salinity gradient provides a range of aquatic habitats that support different communities. These can be broadly classified into estuarine, slightly hypermarine (1–2 x seawater); moderately hypermarine (2–4x seawater) and highly hypermarine (>4x seawater). The estuarine system, near the Murray Mouth, was characterised by commercial fish (mulloway, bream and mullet), abundant populations of polychaetes on the tidal mudflats, other benthic invertebrates (molluscs, crabs) and historically *Ruppia megacarpa*.

The slightly hypermarine system that exists in the North Lagoon supports a subset of the estuarine fauna that can tolerate the higher salinities and is an ecologically simpler, and less diverse system. This systems grades into the moderately hypermarine system that until recently dominated the South Lagoon. This moderately hypermarine system was dominated by the highly productive aquatic angiosperm *Ruppia tuberosa*, the chironomid *Tanytarsus barbitarsus* and a single fish species the small mouth hardyhead *Atherinosoma microstoma*. These communities supported large numbers of migratory waders, piscivores (terns, pelicans) and waterfowl (ducks).

In recent years, as a consequence of cessation of freshwater flows to the Murray Mouth because of over extraction from the River and drought, there have been no freshwater flows to the Coorong, and a new highly hypermarine system has established in the South Lagoon, with a single macroinvertebrate the brine shrimp *Parartemia zietziana* dominating the system. Chironomids and hardyhead fish were excluded from this system because the salinities exceeded their tolerances.

The loss of diversity with increasing salinity along the Coorong is common across all taxonomic classes: birds, fish, plants and benthic fauna, but the ecologically simplified highly hypermarine systems are still highly productive and can support vast numbers of birds but of only a few species (e.g. Over 200,000 banded stilts have been reporting using the South Lagoon of the Coorong, exploiting brine shrimps since 2006 (Wainwright & Christie 2008; Paton & Rogers 2009).

Fortunately the moderately hypermarine ecosystems of the South Lagoon are retained within the system but these have contracted into (or moved into) the southernmost sections of the North Lagoon. The consequence of this contraction is a loss of resilience for this system to cope with further change. If the northern lagoon experienced elevated water levels from freshwater flows down the Murray, the moderately hypermarine system may be vulnerable as the salinity will drop in the North Lagoon well before the salinity drops in the South Lagoon and the moderately hypermarine system will be trapped between two salinity states, neither of which can support that community. Importantly when there are flows to the Murray Mouth, the productive mudflats in the estuarine regions may be covered with water that is too deep to allow access to the migratory waders. Under these conditions the birds would have shifted to the southern Coorong and joined birds in this region exploiting chironomids along the shorelines.

Recovering the food webs of the Coorong

The food web within the South Lagoon will not recover until salinity levels are reduced to the typical levels of the moderately hypermarine system $(60-100g/L^{-1})$. The trajectory of recovery when freshwater flows are reinstated is unknown, but hydrological modelling suggest that unless there are significant flows the very high salinities in the South Lagoon may take up to 10 years to drop to those of a moderately hypermarine system. To speed recovery it has been suggested that the highly saline water should be pumped out to the Southern Ocean to improve the speed at which this system can be recovered (Paton *et al.* 2009).

It is likely that there will be a hysteresis and the return to *Ruppia* meadows may take several years of favourable salinity to recover. The chironomids and Small mouth Hardyhead will colonise fairly rapidly, however, the seed banks of *Ruppia tuberosa* are depleted in the South Lagoon and so recovery would rely upon seed or vegetative material being washed in from the North Lagoon refuge populations or for the plant to be translocated back into the South Lagoon

The volume of water extracted from the Darling and Murray rivers have proved to be unsustainable for both the irrigation industry and the environment, particularly during the extended drought. One approach to set sustainable diversion limits for maintenance of environmental values for the entire Murray–Darling Basin is to look at the most downstream ecosystem and determine what its flow requirements are. This sets the baseline flow that is required in the river at the estuary and from this base the upstream water can be allocated for irrigation and environmental benefit.

The Coorong region is characterised by a salinity gradient that ranges from fresh at the Murray Mouth, during periods of high flow, to moderately hypersaline in the South Lagoon. The system has been degraded with extended duration of no freshwater flows to have seawater salinity in the northern lagoon grading to five times seawater salinity in the southern lagoon. The rising salinity is considered to be the major factor leading to the loss of biodiversity and the change in state from a system dominated by the macrophyte *Ruppia tuberosa* to a system dominated by microalgae and the brine shrimp *Parartemia zietziana*.

In setting sustainable flow targets it is necessary to have clearly defined objectives and metrics against which to assess outcomes. In the case of the Coorong the key species that dominated the food webs of the South Lagoon (and supported a diverse array of bird species) are still present in the system, albeit restricted to the North Lagoon. However, salinity is currently constraining the reinstatement of these attributes in the South Lagoon and must be reduced before the system can be restored.

Identifying an appropriate salinity target can be achieved by determining the salinity tolerances of the organisms that are in the system. The salinity tolerance range of key organisms in the Coorong is summarised in Figure 13. The phytoplankton are a broad group of organisms with salinity tolerances ranging from fresh to saline and with a few species are able to tolerate the extreme salinities now found in the southern Coorong. *Ruppia tuberosa* also has a large salinity tolerance; however, its preferred salinity is within the range 60–90 mg/L TDS.

Although historically found in the Coorong, *Ruppia megacarpa* is currently not present, presumably because its salinity tolerance is less than current salinity. The upper limit for the invertebrate fauna and fish is between 30 and 60 mg/L although notably the Small-mouth Hardyhead and the Chironomids are able to tolerate higher salinities (e.g. Lui 1969; Kokkinn & Williams 1998) and have formed an important component of the community and food web in the South Lagoon. Achieving a salinity of 90–100 mg/L TDS in the southern most parts of the South Lagoon with the reestablishment of freshwater flows through the barrages would satisfy the criteria for reinstatement of the key system attributes:

- salinity within the preferred salinity range for *Ruppia tuberosa*
- establishment of a salinity gradient from fresh to moderately hypersaline
- the salinity gradient acceptable to key species allowing biodiversity and food web connections to be maintained.

Webster (2007) developed a one-dimensional hydrodynamic/salinity model that can be used to predict the salinity outcomes form various River Murray flow scenarios. The current concentration of extreme salinity must be rectified before environmental benefits can be achieved. The first iteration of the model has been used to predict the salinity benefits of high flow scenarios.

The five flow categories (see Table 4) describe the water entering the Coorong over the barrages (including the fishways) over a one year period. In order to model these flows over a 20 year period, four flow scenarios have been devised, using various combinations of these flow volumes (and an additional scenario with no flows). This allows the return intervals to be taken into account, and provides information on the cumulative benefit of each additional flow category over a 20 year flow regime.

Return time				Average	
Scenario	Category 1	Category 2	Category 3	Category 4	flow over barrages (GL/y)
1—'Do Nothing'	-	-	-	-	0
2—'Minimum flow'	1 in 1	-	-	-	304
3—'Low flow'	1 in 2	1 in 2	-	-	579
4—'Medium flood'	2 in 4	1 in 4	1 in 4	-	1,190
5—'Large flood'	2 in 5	1 in 5	1 in 5	1 in 5	2,952

Table 4: Description of flow scenarios modelled

The calculations of flow amounts assume that South Australia receives its entitlement allocation of 1,850 GL, and that the Lower Lakes are held above 0.5m above Australian Height Datum (AHD) to enable the delivery of water into the Coorong via the barrages. The Medium and High flow scenarios assume that The Living Murray (TLM) water allocations are supplemented by surplus unallocated flows. The modelling also assumes that there is no significant flow into the system via the Upper South East Drainage scheme through Salt Creek, and assumes that the system begins in the condition it was in as at March 2007. Modelling was conducted using a one-dimensional hydrodynamic model that is described in Webster (2007)

The range of salinities predicted in the North and South Lagoons in response to alternative flow scenarios are presented in Figure 14. Under a continuation of current conditions ('Do Nothing'), extremely high salinities, and low water levels will continue to be experienced in the South Lagoon. These conditions are well outside of the physiological tolerances of all of the organisms.

Compared to the 'Do Nothing' scenario, Minimum Flows provide little benefit in mitigating the current high salinities in the South Lagoon. However, even these small regular flows reduce the extreme summertime salinities currently experienced in both lagoons. Low Flows provide a small benefit in reducing extreme salinities, although under current conditions this reduction was not enough to bring salinities within the tolerance range of most organisms.

As the flow volumes increase beyond 579 GL/year the ecological benefits become more pronounced. Medium and large floods provide a significant reduction in salinity in the South Lagoon in particular, and provide an important estuarine signal in the North Lagoon during flood periods. This estuarine signal is critical in the life history of key organisms, particularly large-bodied fish, Black Bream, Mulloway.

Maintenance of water level in the Southern lagoon is another consideration for *Ruppia tuberosa* recruitment. Sufficiently high water levels are only maintained during the medium and large floods. Minimum water levels in the South Lagoon were only significantly affected under Medium and Large Flood conditions. The maintenance of high water levels under these conditions provided excellent recruitment conditions for the key aquatic plant *Ruppia tuberosa*. Water levels in the North Lagoon were typically more stable, spiking only during flooding conditions.

The modelling predicts that under the smaller flows (304–579 GL/y), salinity is maintained (ie not increasing), and would provide significant benefit for salinity maintenance if current South Lagoon salinities were significantly reduced using alternative methods (ie South Lagoon pumping).

Pumping of the Southern Lagoon was simulated using the Webster (2007) hydrodynamic model. It is evident that pumping at a rate of 400 ML/ day can remove salt from the Southern Lagoon and restore salinity concentrations amenable for colonisation of the key species in this region; Ruppia tuberosa, Smallmouth Hardyhead and chironomids. Maintenance of the low flow condition should then be sufficient to maintain this condition. However, it is evident from the salinity data set from 2001-2007 that the South Lagoon is vulnerable to salinity increases above the 100g/L threshold if there are two consecutive years of no freshwater flow. Ideally this condition would be avoided by astute allocation of water to this region in years of sufficient rainfall. This would avoid continued intervention (i.e. pumping) to remove salt from the South Lagoon.

Phytoplankton

Macrophytes

Ruppia tuberosa Ruppia megacarpa

Infauna

Capitella polychaete Chironomidae Bivalves Paragrapsus crab Other polychaetes

Fish

small-mouth hardyhead
Congoli
Yellow-eyed mullet
Tammar River goby
Mulloway
Black bream

Birds

Shorebirds
Piscivorous birds
Waterfowl (ducks, swans)

0 30 60 90 120 150 180

Figure 13: Salinity tolerance ranges (°/, TDS) for key species and ecosystem states in the Coorong

Dark green indicates the preferred range of salinities; light green indicates where a species may be found but where conditions are suboptimal (sub-lethal effects may be observed)

2. Conceptual models: linking flow enhancement and water retention on floodplains with aquatic food sources response



Figure 14: Predicted salinity responses in the Coorong North Lagoon and South Lagoon under five alternative flow scenarios over a 20-year period from March 2007

3. Knowledge gaps and key hypotheses

Knowled	ge Gap	Hypothesis
1 Lateral o wetland	connectivity and carbon transfer from the to the main channel	The in situ main channel processing of terrestrial derived carbon is unlikely to significantly increase community respiration rates if it is carbon rich with respect to both nitrogen and phosphorus, whereas, material that has a low C:N and C:P ratio is likely to increase community respiration above the control.
2 Decompo from diff	osition of autochthonous carbon in water ierent velocity	Areas of low flow (e.g. weir pools) are major sites of sedimentation and microbial decomposition of autochthonous carbon and in particular phytoplankton derived carbon.
3 The role biodivers	of water regime in promoting plant sity	Plant species diversity and wetland regeneration need a range of water regimes that vary both spatially and temporally to coincide with the requirements of the plants life history, whereas, productivity, diversity and regeneration will be limited by stable water regimes.
4 The role biodivers	of water regime in promoting plant sity (2)	Floodplain wetlands that have not received water for >5 years will have a depauperate seed bank, whereas those that have received water during past 5 years will have an intact seed bank.
5 How long ensure b	g should floodplains be inundated to enefits to the food web?	Environmental flows of short duration (<10days) and during winter are unlikely to have ecological benefit; whereas, environmental flows of longer duration (30+ days) or multiple rewetting during the spring (September, October) will result in a significant ecological benefit to a number or types of organisms.
6 Waterbir inundatio	d feeding habitat and floodplain on	Shallow (<50cm) wetland areas offer a major habitat for feeding of waterbirds and breeding floodplain fish, whereas the main river channel does not support the diversity of water regimes or extent of appropriate habitats and food needed to promote recruitment in fish and bird populations.
7 The role connecti promotic and zoop recruitm	of floodplain inundation and lateral vity to the river channel in the on and distribution of littoral microfauna vlankton, and to the spawning and vent success of fishes	Non-connectivity of the floodplain eliminates the replenishment of microbiota (protists, rotifers, microcrustaceans) to the river channel and reduces the recruitment potential of some riverine fish species.
8		Non-connectivity of the floodplain eliminates the replenishment of microbiota (protists, rotifers, microcrustaceans) to the river channel and reduces the recruitment potential of some riverine fish species.
9		Flood-induced increases in diversity and abundance of zooplankton (emergence, immigration, reproduction) promotes recruitment in some fish species on the floodplain.
10		Shifts in zooplankton composition from small (rotifer-dominant) to large (microcrustacean-dominant) species are positively correlated with ontogenetic dietary shifts in fishes.
11		Floodplain recruitment in native fish species is impacted by alien fish species due to competition for prey items during developmental life stages.
12 The effect from a la estuary	cts on fish recruitment and movement Irge freshwater inflow to the Murray	Freshwater inflows increase zooplankton abundance to the estuarine channels of the Coorong and combined with the created salinity gradient increase spawning and recruitment of native fishes.
13		Freshwater inflows increase zooplankton abundance to the estuarine channels of the Coorong and combined with the created salinity gradient increase spawning and recruitment of native fishes.
14		The movement of diadromous fish species (e.g. congolli, common galaxias, lampreys) through constructed fishways between the estuary and Lower Lakes is significantly increased by freshwater inflows.

Table 5: Knowledge gaps and key hypotheses for river food webs

Enhancement of existing monitoring to consider food web interactions

A coordinated approach should be taken to study all fish, zooplankton and invertebrate species through the Murray–Darling Basin so that data sets can be comparable and consistent for interpretation and modelling. A suite of hydrodynamic, hydrologic and floodplain models are available to advise flooding outcomes for use in experimental design. These can variously be used to estimate flooded area, return flows to the main river channel, water level and salinity. The appropriate model to use will vary depending upon the site and application. These models are summarised in Table 6, although this list may not be exhaustive.

Descriptive Name	Model name	Area covered	Custodian or developer	Parameters modelled	Limitations
Hydromodel	ELCOM-CAEDYM	River reach below Lock 1 and including Lower Lakes	SA Water and Centre for Water Research	3D Hydro-dynamics Bio-geochemistry Phytoplankton	Recently completed and validated but requires more targeted investigation to test scenarios
Coorong	Coorong hydrodynamic	Murray Mouth and Coorong	CSIRO (lan Webster)	Hydrodynamics and salinity	Good for current applications. Water quality components not included
River channel hydrological model	BIGMOD	Whole of river channel	MDBA and jurisdictions	Hydrology Salinity	Limited by current water accounting and is not a biogeochemical process model
Chowilla floodplain model	Chowilla Hydro- dynamic model	Chowilla Anabranch and floodplain	DWLBC	Chowilla Floodplain	Limited by data for validation
River Murray Floodplain Inundation Model	RiMFiM	Whole of river reach	CSIRO (Ian Overton)	Water level and vegetation response	GIS based, not dynamic but good for predicting flood

Table 6: Current surface water models used in the River Murray system and adjacent floodplain

4. Options to assess knowledge gaps during dry periods

The aim of floodplain inundation and retention of water on the floodplain is to enhance the resilience of the flood plain and river communities to subsequent dry periods to ensure a continuation of food supply and a healthy ecosystem. This means that what happens in dry periods and during dewatering is important and so monitoring or experimentation during these periods can provide considerable information about how the floodplain will respond to flooding.

Considerable diversity of a floodplain is contained and retained within the seedbank or propagule bank. Laboratory hatching or germination experiments can yield information on what is present in the seedbank, the species diversity and information on whether the seedbank/propagule bank has become depauperate with time. These hatching or germination experiments could prove particularly useful for prioritising wetland inundation for biodiversity outcomes when water is in short supply.

Fish recruitment within the main channel is also a topic of interest that can be addressed in the absence of floodplain inundation. How successful is fish recruitment during dry years and is the diversity of habitat available to support them to sexual maturity? For birds the question that needs addressing during dry periods is: where do the birds refuge during dry periods in the Murray–Darling Basin. This can be answered in part by basin scale monitoring of bird populations under the system monitoring program of the TLM. However, the other way to ask this question is where do birds migrate to as floodplain wetlands dry out? To answer this question radio tracking collars would be attached to birds and their migration from a receding wetland monitored. The distance to the next inhabitable wetland and feeding ground may play a large part in sustaining populations and aid in prioritising wetlands for inundation.

Modelling options, in the absence of environmental water can be used to determine the extent of floodplain inundation under different flow. Given the objectives of the flood inundation—food web studies, it is unlikely that one single model will provide the information that can be gathered during intense field investigation. However, components of the work could be achieved with modelling if data is available. These could include:

- modelling of lake/river metabolism from open water measurement
- modelling of carbon inputs from leaf litter from studies of leaf fall and canopy cover
- modelling of flood inundation and aquatic plant response
- population viability assessments to assess the viability of key components of the food web from time series abundance data, information on fertility and recruitment.

5. Data sources to inform future projects

Food web component	Region	Organisation
Bird food resources data	Coorong	The University of Adelaide
Bird foraging efforts	Coorong	The University of Adelaide
Bird foraging rates	Coorong	The University of Adelaide
Bird abundance	Coorong	The University of Adelaide
Bird abundance	MDB icon sites	MDBA/University of NSW
Food web stable isotope signatures	Coorong	The University of Adelaide
Fish stomach contents	Coorong	The University of Adelaide
Fish distribution	SA (MDB)	Native Fish SA, Aquasave, SARDI
Fish distribution	Victoria (MDB)	Arthur Rylan Institute
Fish distribution	New South Wales	NSW Fisheries
Fish mapping	MDB	MDBA

Table 7: List of data sources that may be available to inform future food web projects

6. References

Attiwell, P.M., H. B. Guthrie, and R. Leuning. (1978). Nutrient cycling in a Eucalyptus obiliqua (L'Herit.) forest. 1. Litter production and nutrient return. *Australian Journal of Botany* 26: 74–91.

Atkins, B. (1984). Feeding ecology of Nematalosa erebi in the lower River Murray. Department of Zoology. The University of Adelaide, Adelaide.

Balcombe, S. R., S. E. Bunn, F. J. McKenzie-Smith, and P. M. Davies. (2005). Variability of fish diets between dry and flood periods in an arid zone floodplain river. *Journal of Fish Biology* 67: 1552–1567

Balcombe, S. R., and P. Humphries. (2009). Diet of the western carp gudgeon (Hypseleotris klunzingeri Ogilby) in an Australian floodplain lake: the role of water level stability. *Journal of Fish Biology* 68: 1484–1493.

Baldwin, D. S. (1996). Effects of exposure to air and subsequent drying on the phosphate sorption characteristics of sediments from a eutrophic reservoir. *Limnology and Oceanography* 41: 1725–1732.

Baldwin, D. S., A. M. Mitchell. (2000). The effects of drying and re-flooding on the sediment and soil nutrient dynamics of lowland river-floodplain systems: a synthesis. *Regulated Rivers: Research and Management* 16: 457–467.

Baldwin, D. S., C. Rees, A. M. Mitchell, and G. Watson. (2005). Spatial and temporal variability of nitrogen dynamics in an upland stream before and after a drought. *Marine and Freshwater Research* 56: 457–464.

Ballinger, A., and P. S. Lake. (2006). Energy and nutrient fluxes from rivers and streams into terrestrial food webs. *Marine and Freshwater Research* 57: 15–28.

Baranyi, C., T. Hein, C. Holarek, S. Keckeis, and F. Schiemer. (2002). Zooplankton biomass and community structure in a Danube River floodplain system: effects of hydrology. *Freshwater Biology* 47: 473–482.

Barker, R. D., and W. J. M. Vestjens. (1989). The Food of Australian Birds 1 Non passerines. (CSIRO, Canberra)

Batzer, D. P. and S. A. Wissinger. (1996). Ecolgoy of insect communities in nontidal wetlands. *Annual Review of Entomology* 41: 75–100.

Baudinette, R.V., F. I. Norman, and J. Roberts. (1982). Salt-gland secretion in saline-acclimated Chestnut Teal, and its relevance to release programs. *Aust J. Zool*. 30: 407–415

Bayley, P. B. (1989). Aquatic environments in the Amazon Basin with an analysis of carbon sources, fish production and yield. *Canadian Special Publications of Fisheries and Aquatic Sciences* 106: 399–408.

Bayley, P. B. (1991). The food pulse advantage and the restoration of river-floodplain systems. *Regulated Rivers: Research and Management* 6: 75–86.

Bayly, I. A. E. (1966). The Australian species of *Diaptomus* (Copepoda: Calanoida) and their distribution. *Australian Journal of Marine and Freshwater Research* 17: 123–134.

Bayly, I. A. E. (1992). The non-marine Centropagidae (Copepoda: Calanoida) of the world. *Guides to the identification of the microinvertebrates of the continental waters of the world* 2: 1–30. SPB Academic Publishers, The Hague.

Bice, C. M., P. R. Jennings, and B. P. Zampatti. (2007). Fish movement and recruitment in the Coorong and Lower Lakes 2006–07 progress report. SARDI Aquatic Sciences, Adelaide.

Blanch, S. J., G. G. Ganf, and K. F. Walker. (1999a). Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers Research and Management*. 15: 43–62.

Blanch, S. J., G. G. Ganf, and K. F. Walker. (1999b). Growth and resource allocation in response to flooding in the emergent sedge Bolboschoenus medianus. *Aquatic Botany* 63: 145–160.

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

Boon, P. I., and S. E. Bunn. (1994) Variations in the stable isotope composition of aquatic plants and their implications for food web analysis. *Aquatic Botany* 48: 99–108.

Boon, P.I., and R. J. Shiel. (1990). Grazing on bacteria by zooplankton in Australian billabongs. *Australian Journal of Marine and Freshwater Research* 41: 247–257. Boon, P. I., J. Frankenberg, T. J. Hillman, R. L. Oliver, and R. J. Shiel. (1990). Billabongs. In N. Mackay & D. Eastburn (Eds) *The Murray*. Murray–Darling Basin Commission, Canberra: 183–198.

Bouillon, S., N. Koedam, A. V. Raman, and F. Dehairs. (2002) Primary producers sustaining macroinvertebrate communities in intertidal mangrove forests. *Oecologia* 130: 441–448.

Boulton, A. J., and L. N. Lloyd. (1992). Flooding frequency and invertebrate emergence from dry floodplain sediments of the River Murray, Australia. *Regulated Rivers: Research and Management* 7:137–151.

Brauns, M., X. Garcia, and M. T. Pusch. (2008). Potential effects of water-level fluctuations on littoral invertebrates in lowland lakes. *Hydrobiologia* 613: 5–12.

Bruton, M. N. (1995). Have fishes had their chips? The dilemma of threatened fishes. *Environmental Biology of Fishes* 43:1–27.

Bunn, S. E., and P. I. Boon. (1993). What sources of organic carbon drive food webs in billabongs? A study based on stable isotope analysis. *Oecologia* 96: 85–94.

Bunn, S. E., P. M. Davies, and T. D. Mosisch. (1999). Ecosystem measures of river health and their response to riparian and catchment degradation. *Freshwater Biology* 41: 333–345.

Bunn, S. E., P. M. Davies, and M. Winning. (2003). Sources of organic carbon supporting the food web of an arid zone floodplain river. *Freshwater Biology* 48: 619–635.

Burns, J. M., S. J. Trumble, M. A. Castellini, and J. W. Testa. (1998). The diet of Weddell seals in McMurdo Sound, Antarctica as determined from scat collections and stable isotope analysis. *Polar Biology* 19: 272–282.

Burns, A. and K. F. Walker. (2000). Biofilms as food for decapods (Atyidae, Palaemonidae) in the River Murray, South Australia. *Hydrobiologia* 437: 83–90.

Cleland, J. B., J. H. Maiden, W. W. Froggatt, E. W. Ferguson, and C. T. Musson. (1918). *The food of Australian birds.* NSW Dept of Agric. Sci. Bulletin No. 15.

Clunie, P., and J. Koehn. (2001a). Freshwater Catfish: A Resource Document. Page 186. Department of Natural Resources and Environment, Heidelberg.

Clunie, P., and J. Koehn. (2001b). Silver Perch: A Resource Document. Page 172. Department of Natural Resources and Environment, Heidelberg. Connolly, R. M., J. S. Hindell, and D. Gorman. (2005) Seagrass and epiphytic algae support nutrition of a fisheries species, Sillago schomburgkii, in adjacent intertidal habitats. *Marine Ecology Progress Series* 286: 69–79.

Cuffney, T. F. (1984). Characteristics of riparian flooding and its impact upon the processing and exchange of organic matter in coastal plain streams of Georgia. PhD Thesis, University of Georgia

Culver, D. A., and M. C. Geddes. (1993). Limnology of rearing ponds for Australian fish larvae: relationships among water quality, phytoplankton, zooplankton, and the growth of larval fish. *Australian Journal of Marine and Freshwater Research* 44: 537–551.

CSIRO (2008) Water availability in the Murray–Darling Basin. A report to the Australian Government from the CSIRO Murray–Darling Basin Sustainable Yields Project. CSIRO. Australia 67pp

Deegan, B. M., and G. G. Ganf. (2008). The loss of aquatic and riparian communities: implications for their consumers in a riverine food web. *Austral Ecology* 33: 672–683.

Deegan B. M., S. Lamontagne, K. T. Aldridge, and J. D. Brookes. (2009). Trophodynamics of the Coorong. CSIRO: Water for a Healthy Country National Research Flagship.

De Groot, C. J., and A. Fabre. (1993). The impact of desiccation of a freshwater marsh (Garcines Nord, Camargue, France) on sediment-water-vegetation interactions. 3. The fractional composition and the phosphate adsorption characteristics of sediment. *Hydrobiologia* 252: 105–116.

De Groot, C. J., and C. Van Wijck. (1993). The impact of desiccation of a freshwater marsh (Garcines Nord, Camargue, France) on sediment-water-vegetation interactions. Part one: The sediment chemistry. *Hydrobiologia* 252.

Denny, P. (1972). Sites of nutrient absorption in aquatic macrophytes. *Journal of Ecology* 60: 819–829.

Dorfman, E. J., and R. T. Kingsford. (2001). Scale-dependent patterns of abundance and habitat use by cormorants in Australia and the importance of nomadism. *Journal of Arid Environments* 49: 677–694.

Ebner, B. (2006). Murray Cod an apex predator in the Murray River, Australia. *Ecology of Freshwater Fish* 15: 510–520.

Edwards, R. T., and J. L. Meyer. (1987). Metabolism of a subtropical low gradient blackwater river. *Freshwater Biology* 17: 251–63 Ellis, I. (2006). Age structure and dietary analysis of the Murray hardyhead Craterocephalus fluviatilis (McCulloch), Family Atherinidae, in two lakes near Mildura, Victoria. Page 44. The Murray–Darling Freshwater Research Centre, Mildura.

Elser, J.J., W.F. Fagan, R.F. Denno, D.R. Dobberfuhl, A. Folarin, A. Huberty, S. Interlandi, S.S. Kilham, E. McCauley, K. L. Schulz, E. H. Siemann and R.W. Sterner. (2000) Nutritional constraints in terrestrial and freshwater food webs. Nature 408: 578–580.

Frith, H. J. (1959). The ecology of wild ducks in inland New South Wales: III Food habits. *CSIRO Wildlife Res.* 4: 131–155

Frith, H. J. (1967). *Waterfowl in Australia*. (Angus & Robertson, Sydney)

Fry, B. (1984) 13C/12C ratios and the trophic importance of algae in Florida Syringodium filiforme seagrass meadows. *Marine Biology* 79: 11–19.

Fry, B., and E. B. Sherr. (1984). δ^{13} C measurements as indicators of carbon flow in marine and freshwater ecosystems. *Contrib Mar Sci* 27: 13–47.

Foissner, W., and H. Berger. (1996). A user-friendly guide to the ciliates (Protozoa, Ciliophora) commonly used by hydrobiologists as bioindicators in rivers, lakes and waste waters, with notes on their ecology. *Freshwater Biology* 35: 375–482.

Foissner, W. and P. J. O'Donoghue. (1990). Morphology and infraciliature of some freshwater ciliates (Protozoa : Ciliaphora) from Western and South Australia. *Invertebrate Taxonomy* 3: 661–69.

Gasith, A., and V. H. Resh. (1999). Streams in mediterranean climate regions: abiotic influences and biotic responses to predictable seasonal events. *Annual Review of Ecology and Systematics* 30: 51–81.

Gawne, B., C. Merrick, and D. G. Williams. (2007). Patterns of primary and heterotrophic productivity in an arid lowland river. *River Research and Applications* 23: 1070–1087

Gearing, J. N. (1991). The study of diet and trophic relationships through natural abundance ¹³C.D. C. Coleman and B. Fry. Carbon Isotope Techniques. Academic Press, London

Geddes, M. C. (1984). Seasonal studies on the zooplankton of Lake Alexandrina, River Murray, South Australia, and the role of turbidity in determining zooplankton community structure. *Australian Journal of Marine and Freshwater Research* 35: 417–426. Geddes, M. C., and S. D. Wedderburn. (2007). Fish monitoring below tidal barrages in Boundary Creek and Mundoo Channel during freshwater inflow to the River Murray estuary in 2005 and 2006. Page 29. The University of Adelaide, Adelaide.

Gehrke, P. C. (1990). Spatial and temporal dispersion patterns of golden perch, Macquaria ambigua, larvae in an artificial floodplain environment. *Journal of Fish Biology* 37: 225–236.

Gehrke, P. C. (1992). Diel abundance, migration and feeding of fish larvae (Eleotridae) in a flooplain billabong. *Journal of Fish Biology* 40: 695–707.

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

Gehrke, P., and J. Harris. (2004). Fish in the Darling River System. In: Breckwoldt, R, R. Boden, and J. Andrew. Ed. The Darling, Chap. 11. Canberra: Murray–Darling Basin Commission, pp. 260–277.

Gehrke, P. C., M. B. Revell, and A. W. Philby. (1993). Effects of river red gum, Eucalyptus camaldulensis, litter on golden perch, Macquaria ambigua. *Journal of Fish Biology* 43: 265–279.

Gigney, H., R. Petrie, B. Gawne, D. Nielsen, and L. Howitt. (2006). The exchange of material between the Murray River channel and Barmah–Millewa forest during the 2005/2006 floodplain watering. MDFRC Report to the Murray–Darling Basin Commission: 42 pp.

Gill, H. S., and I. C. Potter. (1993). Spatial segregation amongst goby species within an Australian estuary, with a comparison of the diets and salinity tolerance of the two most abundant species. *Marine Biology* 117: 515–526.

Gray, S. C., S. S. De Silva, B. A. Ingram, and G. J. Gooley. (2000). Effects of river impoundment on body condition and reproductive performance of the Australian native fish, Macquarie perch (Macquaria australasica). *Lakes and Reservoirs: Research and Management* 5: 281–291.

Green, J. D., and R. J. Shiel. (1992). Australia's neglected freshwater microfauna. *Australian Biologist* 5: 118–123.

Green, J. D., R. J. Shiel, and R. A. Littler. (1999). *Boeckella major* (Copepoda: Calanoida): a predator in Australian ephemeral pools. *Archiv für Hydrobiologie* 145: 181–196. Grey, J., S. J. Thackeray, R. I. Jones, and A. Shine. (2002) Ferox Trout (*Salmo trutta*) as 'Russian dolls': complementary gut content and stable isotope analyses of the Lock Ness food web. *Freshwater Biology* 47: 1235–1243.

Guo, R., P. B. Mather, and M. F. Capra. (1995). Salinity tolerance and osmoregulation in the silver perch, Bidyanus bidyanus Mitchell (Teraponidae), an endemic Australian freshwater teleost. *Marine and Freshwater Research* 46: 947–952.

Hamond, R. (1987). Non-marine harpacticoid copepods of Australia. I. Canthocamptidae of the genus *Canthocamptus* Westwood, s. lat. and *Fibulacamptus*, gen. nov., and including the description of a related new species of *Canthocamptus* from New Caledonia. *Invertebrate Taxonomy* 1: 1023–1247.

Harris, J. H. (1995). The use of fish in ecological assessments. *Australian Journal of Ecology* 20: 65–80.

Harris, J. H., and P. C. Gehrke. (1994). Modelling the relationship between streamflow and population recruitment to manage freshwater fisheries. *Australian Fisheries* 6: 28–30.

Higgins, P. J., and J. J. F. Davies. (1996). Handbook of Australian, New Zealand & Antarctic Birds. Volume 3 Snipe to Pigeons. (Oxford University Press, Melbourne)

Hillman, T. J. (1986). Billabongs. In P. De Deckker & W.D. Williams (eds) *Limnology in Australia.* CSIRO/ Junk B.V., Melbourne/Dordrecht: 457–470.

Hillman, T. J., and G. P. Quinn. (2002). Temporal changes in macroinvertebrate assemblages following experimental flooding in permanent and temporary wetlands in an Australian floodplain forest. *River Research and Applications* 18: 137–154.

Hobson, K. A., and B. A. Welch. (1995) Cannibalism and trophic structure in a high Arctic lake: insights from stable-isotope analysis. *Canadian journal of Fisheries and Aquatic Sciences* 52: 1195–1201.

Holynska, M. (2000). Revision of the Australasian species of the genus *Mesocyclops* Sars, 1914 (Copepoda, Cyclopidae). *Annales Zoologici* 50: 363–447.

Hortle, M. E., and R. W. G. White. (1980). Diet of Pseudaphritis urvillii (Cuvier & Valenciennes) (Pisces: Bovichthyidae) from south-eastern Tasmania. Australian *Journal of Marine and Freshwater Research* 31: 533–539. Humphries, P., A. J. King and J. D. Koehn. (1999). Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray–Darling River system, Australia. *Environmental Biology of Fishes* 56: 129–151.

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

Hyslop, E. J. (1980) Stomach content analysis - a review of methods and their applications. *Journal of Fish Biology* 17: 411–429.

Jackson, J. K., and S. G. Fisher. (1986). Secondary production, emergence, and export of aquatic insects of a Sonoran desert stream. *Ecology* 67: 629–638.

James, K. R., B. Cant, and T. Ryan. (2003). Responses of freshwater biota to rising salinity levels and implications for saline water management: a review. *Australian Journal of Botany* 51: 703–713.

Jenkins, K., B. Wolfenden, J. Davies, A. Boulton, and R. Rolls. (2008). Macroinvertebrate and fish communities of the Macquarie Marshes: responses to low flows and floods. Draft Final Report to the Environmental Trust. University of New South Wales, Sydney, NSW, Australia. 81 pages.

Jennings, P. R., B. P. Zampatti, I. G. Stuart, and L. J. Baumgartner. 2008.Fish passage at the Murray River barrages. Page 85 in J. Barrett, editor. The Sea to Hume Dam: Restoring Fish Passage in the Murray River. Murray–Darling Basin Commission, Canberra.

Junk, W. J., P. B. Bayley, and R. E. Sparks. (1989). The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 110–127.

Kalff, J. (2002). Limnology Inland water ecosystem. Publ: Pretice Hall New Jersey USA pp. 591.

Keddy, P. A., and A. A. Reznicek. (1986). Great Lakes vegetation dynamics: the role of fluctuating water levels and buried seeds. *Journal of the Great Lakes Research.* 12, 25–36.

Kelly, D. J., and D. J. Jellyman. (2007). Changes in trophic linkages to shortfin eels (Anguilla australis) since the collapse of submerged macrophytes in Lake Ellesmere, New Zealand. *Hydrobiologia* 579: 161–173.

Kern, J., A. Darwich, K. Furch, and W. J. Junk. (1996). Seasonal denitrification in flooded and exposed sediments from the Amazon floodplain at Lago Camaleao. *Microbial Ecology* 32: 47–57. King, A. J. (2004). Density and distribution of potential prey for larval fish in the main channel of a floodplain river: pelagic versus epibenthic meiofauna. *River Research and Applications* 20: 882–897.

King, A. J. (2005). Ontogenetic dietary shifts of fishes in an Australian floodplain river. *Marine and Freshwater Research* 56: 215–225.

King, A. J., P. Humphries, and P. S. Lake. (2003). Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Science* 60: 773–786.

King, A. J., Z. Tonkin, and J. Mahoney. (2008). Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. *River Research and Applications*.

Kingsford, R. T., A. L. Curtin, and J. L. Porter. (1999). Water flows on Cooper Creek in arid Australia determine "boom and bust" periods for waterbirds. *Biological Conservation* 88: 231–248.

Kingsford, R. T., and J. L. Porter. (2008). Survey of waterbird communities of The Living Murray icon sites—November 2007. Report to MDBC, Canberra

Kokkinn, M.J. and W.D. Williams. (1988). Adaptations to life in a hypersaline water–body: adaptations at the egg and early embryonic stage of *Tanytarsus barbitarsis* Freeman (Diptera, Chironomidae). *Aquatic Insects* 10: 205–214.

Knowles, R. (1982). Denitrification. *Microbiological Reviews* 46: 43–70.

Lake, P. S. (1995). Of floods and droughts: river and stream ecosystems of Australia. Pp 659–694. In CE Cushing, KW Cummins and GW Minshall (ed.) Ecosystems of the World 22, River and stream Ecosystems, Elsevier Press, London.

Lamontagne, S., M. C. Geddes, M. Fernandes, and E. Krull. (2007). Analysis of fish diet from the Murray Estuary using C, N, and S stable isotopes. Page 17. Water for a Healthy Country National Research Flagship, CSIRO, Adelaide.

Langley, J. M., R. J. Shiel, D. L. Nielsen, and J. D. Green. (2001). Hatching from the sediment eggbank or aerial-dispersing? - the use of mesocosms in assessing rotifer biodiversity. *Hydrobiologia* 446: 203–211.

Laybourn-Parry, J., S. J. Perriss, G. G. R. Seaton, and J. Rohozinski. (1997). A mixotrophic ciliate as a major contributor to plankton photosynthesis in Australian lakes. *Limnology & Oceanography* 42: 1463–1467.

Lieschke, J. A., and G. P. Closs. (1999). Regulation of zooplankton composition and distribution by a zooplanktivorous fish in a shallow, eutrophic flooplain lake in south east Australia. *Archiv für Hydrobiologie* 146: 397–412.

Lijklema, L. (1980). Interaction of orthophosphate with iron (III) and aluminium hydroxides. *Environmental Science and Technology* 14: 537–541.

Llewellyn, D. W. (2005). Breeding biology, and egg and larval development of Galaxias rostratus Klunzinger, the Murray Jollytail from inland New South Wales. *Australian Zoologist* 33: 141–165.

Llewellyn, D. W. (2006). Breeding and development of the endangered Purple-spotted Gudgeon Mogurnda adspersa population from the Murray–Darling. *Australian Zoologist* 33: 480–510.

Llewellyn, L. C. (1973). Spawning, development, and temperature tolerance of the spangled perch, Madigania unicolor (Günther) from inland waters in Australia. *Australian Journal of Marine and Freshwater Research* 24: 73–94.

Llewellyn, L. C. (1974). Spawning, development and distribution of the southern pigmy perch Nannoperca australis australis Günther from inland waters in eastern Australia. *Australian Journal of Marine and Freshwater Research* 25: 121–149.

Llewellyn, L. C. (2008). Observations on the breeding biology of Ambassis agassizii Steindachner, 1867 (Teleostei:Ambassidae) from the Murray–Darling Basin in New South Wales. *Australian Zoologist* 34: 476–498.

Lloyd, L. N. (1987). Ecology and distribution of the small native fish of the lower River Murray, South Australia and their interactions with the exotic mosquitofish, Gambusia affinis holbrooki. Department of Zoology. The University of Adelaide, Adelaide.

Lui, L.C. 1969. Salinity tolerance and osmoregulation of *Taeniomembras microstomus* (Gunther 1861) (Pisces: Mugiliformes: Atherinidae) from Australian salt lakes. *Australian Journal of Marine and Freshwater Research* 20: 157–162.

Lynch, R. J., S. E. Bunn, and C. P. Catterall. (2002). Adult aquatic insects: potential contributors to riparian food webs in Australia's wet-dry tropics. *Austral Ecology* 27: 515–526.

Lynch, J. M., and J. E. Hobbie. Ed. (1988). 'Microorganisms in Action: Concepts and Applications in Microbial Ecology (Second edn).' (Blackwell: Melbourne) Mackay, N. J., T. J. Hillman, and J. Rolls. (1988). Water quality of the River Murray. Review of monitoring 1978 to 1986; Water quality report 3. Murray–Darling Basin Commission, Canberra.

Marshall, J. C., F. Sheldon, R. J. Lynch, S. E. Bunn, and C. P. Catterall. (2002). Adult aquatic insects: potential contributors to riparian food webs in Australia's wet-dry tropics. *Austral Ecology* 27: 525–526.

Marchant, S., and P. J. Higgins. (1990a). Handbook of Australian, New Zealand & Antarctic Birds. Volume 1 Ratites to Ducks. Part A. Ratites to Petrels. (Oxford University Press, Melbourne)

Marchant, S., and P. J. Higgins. (1990b). Handbook of Australian, New Zealand & Antarctic Birds. Volume 1 Ratites to Ducks. Part B. Australian Pelican to Ducks (Oxford University Press, Melbourne)

Marchant, S., and P. J. Higgins. (1993). Handbook of Australian, New Zealand & Antarctic Birds. Volume 2 Raptors to Lapwings. (Oxford University Press, Melbourne)

Marsden, M. W. (1989). Lake restoration by reducing external phosphorus loading: the influence of sediment phosphorus release. *Freshwater Biology* 21: 139–162.

Martinova, M. V. (1993). Nitrogen and phosphor compounds in bottom sediments: mechanisms of accumulation, transformation and release. *Hydrobiologia* 252: 1–22.

Matveev, V., and L. Matveev. (1997). Grazer control and nutrient limitation of phytoplankton biomass in two Australian reservoirs. *Freshwater Biology* 38: 49–65.

McNeil, D. G., and G. P. Closs. (2007). Behavioural responses of a south-east Australian floodplain fish community to gradual hypoxia. *Freshwater Biology* 52: 412–420.

Meisterfeld, R., and L. –W. Tan. (1998). First records of testate amoebae (Protozoa: Rhizopoda) from Mount Buffalo National Park, Victoria: preliminary notes. *The Victorian Naturalist* 115: 231–238.

Merrick, J. R., and G. E. Schmida. (1984). Austrlain freshwater fishes: biology and management. Griffin, Adelaide 409p.

Mikrjukov, K., and R. Croome. (1998). Observations of heliozoans in ice-covered ponds on Mount Buffalo. *The Victorian Naturalist* 115: 239–241. Milward, N. E. (1965). Comparison of weightlength ratios between Murray cod from the Murray and Darling River systems. *Australian Society for Limnology Newsletter* 4: 11–12.

Minshall, G. W., K. W. Cummins, R. C. Petersen, C. E. Cushing, D. A. Bruns, J. R. Sedell, and R. L. Vannote. (1985). Developments in stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1045–55.

Mitchell, A. M., and D. S. Baldwin. (1999). The effects of sediment desiccation on the potential for nitrification, denitrification, and methanogenesis in an Australian reservoir. *Hydrobiologia* 392: 3–11.

Newbold, J. D., J. W. Elwood, J. O'Neill, and W. Van Winkle. (1981). Measuring nutrient spiralling in streams. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 860–863.

Nicol, J. M., and G. G. Ganf and G. A. Pelton. (2003). Seed banks of a southern Australian wetland: the influence of water regime on the final floristic composition. *Plant Ecology* 168: 191–205.

Nielsen, D. L., T. J. Hillman, and F. J. Smith. (1999). Effects of hydrological variation and planktivorous competition on macroinvertebrate community structure in experimental billabongs. *Freshwater Biology* 42: 427–444.

Nielsen, D. L., and G. O. Watson. (2008). The response of epibenthic rotifers and microcrustacean communities to flow manipulation in lowland rivers. *Hydrobiologia* 603: 117–128.

Nielsen, D. L., G. O. Watson, and R. Petrie. (2005). Microfaunal communities in three lowland rivers under differing flow regimes. *Hydrobiologia* 543: 101–111.

Nielsen, D. L., F. J. Smith, T. J. Hillman, and R. J. Shiel. (2000a). Impact of water regime and fish predation on zooplankton resting egg production and emergence. *Journal of Plankton Research* 22: 433–446.

Nielsen, D. L., F. J. Smith, T. J. Hillman, and R. J. Shiel. (2000b). The influence of a planktivorous fish on zooplankton assemblages in experimental billabongs. *Hydrobiologia* 434: 1–9.

Nielsen, D. L., F. J. Smith, T. J. Hillman, and R. J. Shiel. (2002). The influence of seasonality and duration of flooding on zooplankton in experimental billabongs. *River Research and Applications* 18: 227–237.

Ning, N. S. P., D. L. Nielsen, W. L. Paul, T. J. Hillman, and P.J. Suter. (2009). Microinvertebrate dynamics in riverine slackwater and mid-channel habitats in relation to physico-chemical parameters and food availability. *River Res.& Applic.* 18 pp. [Published online Apr '09].

Oliver, R. L. (1990). Optical properties of the waters in the Murray–Darling Basin, South-eastern Australia. *Australian Journal of Marine and Freshwater Research* 41: 581–601.

Oliver, R. L., and Lorenz (2007) Murray River metabolism quantifying the food supplies that support riverine food webs. CSIRO: Water for a Healthy Country National Research Flagship.

Oliver, R. L., and C. J. Merrick. (2006). Partitioning of river metabolism identifies phytoplankton as a major contributor in the regulated Murray River (Australia). *Freshwater Biology* 51: 1131–1148.

Paton, D. C., G. Carpenter, and R. G. Sinclair. (1994a). A second bird atlas of the Adelaide region. Part 1: Changes in the distribution of birds: 1974–5 vs 1984–5. *S.Aust.Orn.* 31: 151–194

Paton, D. C., G. Carpenter, and R. G. Sinclair. (1994b). A second bird atlas of the Adelaide region. Part 2: Distribution maps 1984–5. *S.Aust. Orn.* 31:195–264

Paton, D. C., and D. J. Rogers. (2009). Condition monitoring of indicator bird species in the Lower Lakes, Coorong & Murray Mouth Icon Site: Coorong and Murray Mouth estuary 2009. Report to SA MDB NRM (University of Adelaide, Adelaide)

Paton, D. C., D. J. Rogers, K. Aldridge, B. Deegan, and J. Brookes. (2009). A future for the Coorong and Lower Lakes. *Pacific Conservation Biology* 15: 7–10

Pen, L. J., I. C. Potter, and M. C. Calver. (1993). Comparisons of the food niches of three native and two introduced fish species in an Australian river. *Environmental Biology of Fishes* 36: 167–182.

Peterson, B. J. (1999) Stable isotopes as tracers of organic matter input and transfer in benthic food webs: a review. *Acta Oecologia* 20: 479–487.

Powling, I. J. (1980). Limnological features of some Victorian reservoirs. pp. 332–342 In: *An ecological basis for water resource management*. (Ed. W. D. Williams). ANU Press, Canberra.

Puckridge, J. T., and K. F. Walker. (1990). Reproductive biology and larval development of a gizzard shad, Nematalosa erebi (Günther) (Dorosomatinae: Teleostei), in the River Murray, South Australia. *Australian Journal of Marine and Freshwater Research* 41: 695–712. Pusey, B. J., A. H. Arlington, and M. G. Reid. (2000). The dry-seasonal diet of freshwater fishes in monsoonal tropical rivers of Cape York Peninsula, Australia. *Ecology of Freshwater Fishes* 9: 177–190.

Qiu, S., and A. J. McComb. (1994). Effects of oxygen concentration on phosphorus release from fresh and air-dried wetland sediments. *Australian Journal of Marine and Freshwater Research* 45: 1319–1328.

Quinn, G. P., T. J. Hillman, and R. Cook. (2000). The response of macroinvertebrates to inundation in floodplain wetlands: a possible effect of river regulation. *Regulated Rivers: Research and Management* 16: 469–477.

Reddy, K. R., R. H. Kadlec, E. Flaig, and P. M. Gale. (1999). Phosphorus retention in streams and wetlands: a review. *Critical Reviews in Environmental Science and Technology* 29: 83–146.

Rees, G. N., G. Beattie, P. M. Bowan, and B. T. Hart. (2005). Heterotrophic production in the lower Murray River, south-eastern Australia. *Marine and Freshwater Research* 56: 835–841.

Reid, M. A., and J. J. Brooks. (2000). Detecting effects of environmental water allocations in wetlands of the Murray–Darling Basin, Australia. *Regulated Rivers: Research and Management* 16: 479–496.

Rivier, I. K. (1998). The predatory Cladocera (Onychopoda: Podonidae, Polyphemidae, Cercopagidae) and Leptodorida of the world. *Guides* to the identification of the microinvertebrates of the continental waters of the world 13: 1–213. Backhuys Publishers, Leiden.

Roberts, J., and J. A. Ludwig. (1991). Riparian vegetation along current-exposure gradients in floodplain wetlands of the River Murray, Australia. *Journal of Ecology* 79: 117–127.

Roberts, J., B. Young, and F. Marston. (2000). Estimating the water requirements for plants of floodplain wetlands: a guide. Land and Water Resources Research and Development Corporation, Occasional paper 04/00.

Rolston, A., and S. Dittmann. (2009). The Distribution and Abundance of Macrobenthic Invertebrates in the Murray Mouth and Coorong Lagoons 2006 to 2008. CSIRO: Water for a Healthy Country National Research Flagship.

Rogers, D. J., and D. C. Paton. (2008). An evaluation of the proposed Chowilla Creek environmental regulator on waterbird and woodland bird populations. Report for SA MDB NRM. (University of Adelaide, Adelaide) Rogers, D. J., D. C. Paton, and C. P. Bailey. (2009). Monitoring the waterbirds of Lakes Albert and Alexandrina, for The Living Murray LLCMM Icon Site Condition Monitoring program. Report to SA MDB NRM (University of Adelaide, Adelaide)

Roshier, D. A., A. I. Robertson, and R. T. Kingsford. (2002). Responses of waterbirds to flooding in an arid region of Australia and implications for conservation. *Biological Conservation* 106: 399–411.

Rozas, L. P., and W. E. Odum. (1988). Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. *Oecologia* 77: 101–106.

Sabo, J. L., and M. E. Power. (2002). River-watershed exchange: effects of riverine subsidies on riparian lizards and their terrestrial prey. *Ecology* 87: 1860– 1869.

Sah, R. N., D. S. Mikkelsen, and A. A. Hafez. (1989). Phosphorus behaviour in flooded-drained soils. 2. Iron transformations and phosphorus sorption. *Soil Science of America Journal* 53: 1723–1729.

Sanger, A. C. (1978). Aspects of the ecology and evolution of the pigmy perches (Teleostei: Kuhlidae). Department of Zoology. University of Melbourne, Victoria.

Sanoamuang, L., H. Segers, and H. Dumont. (1995). Additions to the rotifer fauna of south-east Asia: new and rare species from north-east Thailand. *Hydrobiologia* 313/314: 35–45.

Schiller, C. B., and J. H. Harris. (2001). Native and alien fish. In: Young, W. J. Ed. Rivers as ecological systems: The Murray–Darling Basin. Canberra: Murray–Darling Basin Commission, pp. 229–258.

Sheldon, F., and K. F. Walker. (1997). Changes in biofilms induced by flow regulation could explain extinctions of aquatic snails in the lower River Murray, Australia. *Hydrobiologia* 347: 97–108.

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

Shiel, R. J. (1976). Associations of Entomostraca with weedbed habitats in a billabong of the Goulburn River, Victoria. *Australian Journal of Marine and Freshwater Research* 27: 533–49.

Shiel, R. J. (1990). Zooplankton. In N. Mackay & D. Eastburn (Eds) *The Murray*. Murray–Darling Basin Commission, Canberra: 275–284. Shiel, R. J., and J. A. Dickson. (1995). Cladocera recorded from Australia. *Transactions of the Royal Society of South Australia* 119: 29–40.

Shiel, R. J., J. D. Green, and D. L. Nielsen. (1998). Floodplain biodiversity: Why are there so many species? *Hydrobiologia* 387: 39–46.

Shiel, R. J., J. D. Green, and L. W. Tan. (2001). Microfaunal and resting stage heterogeneity in ephemeral pools, upper River Murray floodplain. International Vereinigung für Theoretische und Angewandte Limnologie, Verhandlungen 27: 3738–3741.

Shiel, R. J., K. F. Walker, and W. D. Williams. (1982). Plankton of the lower River Murray, South Australia. *Australian Journal of Marine and Freshwater Research* 33: 301–327.

Siebentritt, M. (2003). The influence of water regime upon vegetation in lower River Murray wetlands. PhD Thesis, the University of Adelaide.

Skinner, R., F. Sheldon, and K. F. Walker. (2001). Propagules in dry wetland sediments as indicators of ecological health: effects of salinity. *Regulated Rivers: Research and Management* 17: 191–197.

Smirnov, N. N., and B. V. Timms. (1983). A revision of the Australian Cladocera (Crustacea). *Records of the Australian Museum*, *Supplement* 1: 1–132.

Søndergaard, M., P. Kristensen, and E. Jeppesen. (1993). Eight years of internal phosphorus loading and changes in the sediment phosphorus profile of Lake Søbygaard, Denmark. *Hydrobiologia* 253: 345–356.

Stoffels, R., and P. Humphries. (2003). Ontogenetic variation in the diurnal food and habitat associations of an endemic and an exotic fish in floodplain ponds: consequences for niche partitioning. *Environmental Biology of Fishes* 66: 293–305.

Tan, L. W., and R. J. Shiel. (1993). Responses of billabong rotifer communities to inundation. *Hydrobiologia* 255/256: 361–369.

Timms, B. V. (2001). Limnology of intermittent pools of Bells Creek, Paroo, arid Australia, with special reference to biodiversity of invertebrates and succession. *Proc. Linn. Soc. N.S.W.* 123: 193–213.

Timms, B. V., and A. J. Boulton. (2001). Typology of arid-zone floodplain wetlands of the Paroo River (inland Australia) and the influence of water regime, turbidity and salinity on their aquatic invertebrate assemblages. *Arch. Hydrobiol.* 153: 1–27. Timms, B. V., and M. A. Hancock. (2002). Ecology of four turbid clay pans during a filling-drying cycle in the Paroo, semi-arid Australia. *Hydrobiologia* 479: 95–107.

Tockner, K., D. Pennetzdorfer, N. Reiner, F. Scheimer, and J. V. Ward. (1999). Hydrological connectivity, and the exchange of organic matter and nutrients in a dynamic river-floodplain system (Danube, Austria). *Freshwater Biology* 41: 521–535.

Tonkin, Z., A. J. King, and J. Mahoney. (2008). Effects of flooding on recruitment and dispersal of the Southern Pygmy Perch (Nannoperca australis) at a Murray River floodplain wetland. *Ecological Management and Restoration* 9: 196–201.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130–137.

Van der Valk, A. G. (1981). Succession in wetlands: a Gleasonian approach. *Ecology* 62: 688–696.

Vestjens, W. J. M. (1977). *Status habitats and food of vertebrates at Lake Cowal*. CSIRO Division of Wildlife Research Technical Memorandum No. 12.

Vilizzi, L. (1998). Observation on ontogenetic habitat shifts in the diet of 0+ carp, Cyprinus carpio, from the River Murray, Australia. *Folia Zoologica* 47: 225–229.

Wada, E. H., H. Mizutani, and M. Minagawa. (1991) The use of stable isotopes for food web analysis. *Crit Rev Food Sci Nutr* 30: 361–371.

Wainwright P. and M. Christie (2008). Wader surveys at the Coorong and S.E. coastal lakes, South Australia, February 2008. *Stilt* 54: 31–47

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

Walker, K. F. (1986). The Murray–Darling River system. In: Davies, B. R., and K. F. Walker. Ed. The ecology of river systems. Dordrecht: Dr W. Junk Publishers, Dordrecht, pp. 631–659.

Walker, K. F. and T. J. Hillman. (1977). *Limnological* survey of the River Murray in relation to Albury Wodonga. A. W. D. C. Albury 256 pp.

Webster IT, 2007. Hydrodynamic modelling of the Coorong. Water for a Healthy Country National Research Flagship, CSIRO. 53 pp. Webster, I. T., N. Rea, and A. V. Padovan. (2005). An analysis of primary production in the Daly River, a relatively unimpacted river in Northern Australia. *Marine and Freshwater Research* 56: 303–316.

Wedderburn, S., and M. Hammer. 2003. The Lower Lakes fish inventory: distribution and conservation of freshwater fishes of the Ramsar Convention wetland at the terminus of the Murray–Darling Basin, South Australia. Page 38. Native Fish Australia (SA), Adelaide.

Wedderburn, S. D., K. F. Walker, and B. P. Zampatti. 2008. Salinity may cause fragmentation of hardyhead (Atherinidae) populations in the River Murray, Australia. *Marine and Freshwater Research* 59:254– 258.

Wedderburn, S. and Barnes, T. 2009. Condition monitoring of threatened fish species at Lake Alexandrina and Lake Albert (2008–2009). Report to the South Australian Murray–Darling Basin Natural Resources Management Board and the Murray–Darling Basin Authority. The University of Adelaide, Adelaide.

West, A. W., G. P. Sparling, T. W. Speir, and J. M. Wood. (1988). Comparison of microbial C, N–flush and ATP, and certain enzyme activities of different textured soils subject to gradual drying. *Australian Journal of Soil Research* 26: 217–229.

Westwood, K. J., and G. G. Ganf (2004). Effect of mixing patterns and light dose on growth of Anabaena circinalis in a turbid, lowland river. *River Research and Applications 20*: 115–126.

Wetzel, R. G. (2001). 'Limnology: Lake and River Ecosystems.' (Elsevier Science: San Diego)

Whitfield, A. K., and T. D. Harrison. (2003). River flow and fish abundance in a South African estuary. *Journal of Fish Biology* 62: 1467–1472.

Winemiller K. O. (2003) Floodplain river food webs: generalizations and implications for fisheries management. In R.Welcome and T Petr (eds) *Proceedings of the second international symposium on the management of large rivers for fisheries* Volume II Sustaining livelihoods and biodiversity in the new millennium 11–14 Feb 2003. Phnom Pen, Cambodia.

Wiggins, G. B., R. J.Mackay, and Smith (1980). Evolutionary and ecological strategies of animals in annual temporary pools. *Archives of Hydrobiology/ Supplement* 58: 97–206.

Appendix 1

Fishes of the Murray-Darling Basin, and their national conservation status under the *Environment Protection and Biodiversity Conservation Act 1999*.

Common name	Taxonomic name	Conservation status
common galaxias	Galaxias maculatus	
flat-headed galaxias	Galaxias rostratus	
mountain galaxias	Galaxias olidus	
barred galaxias	Galaxias fuscus	Endangered
Australian smelt	Retropinna semoni	
bony herring	Nematalosa erebi	
Murray rainbowfish	Melanotaenia fluviatilis	
desert rainbowfish	Melanoatenia splendida tatei	
small-mouthed hardyhead	Atherinosoma microstoma	
unspecked hardyhead	Craterocephalus stercusmuscarum fulvus	
Murray hardyhead	Craterocephalus fluviatilis	Vulnerable
Darling River hardyhead	Craterocephalus amniculus	
southern pygmy perch	Nannoperca australis	
Yarra pygmy perch	Nannoperca obscura	Vulnerable
chanda perch	Ambassis agassizii	
purple-spotted gudgeon	Mogurnda adspersa	
Murray–Darling carp gudgeon	Hypseleotris sp.	
Midgley's carp gudgeon	Hypseleotris sp.	
western carp gudgeon	Hypseleotris klunzingeri	
hybrid carp gudgeon	Hypseleotris spp.	
flathead gudgeon	Philypnodon grandiceps	
dwarf flathead gudgeon	Philypnodon macrostomus	
lagoon Goby	Tasmanogobius lasti	
tamar goby	Afurcagobius tamarensis	
western blue spot goby	Pseudogobius olorum	
congolli	Pseudaphritis urvillii	
short-finned eel	Anguilla australis	
long-finned eel	Anguilla reinhardtii	
river blackfish	Gadopsis marmoratus	
two-spined blackfish	Gadopsis bispinosus	
Murray cod	Maccullochella peelii peelii	Vulnerable
Macquarie perch	Macquaria australasica	Endangered
estuary perch	Macquaria colonorum	
golden perch	Macquaria ambigua	
trout cod	Maccullochella macquariensis	Endangered
silver perch	Bidyanus bidyanus	Vulnerable
spangled grunter	Leiopotherapon unicolor	
freshwater catfish	Tandanus tandanus	
Hyrlt's tandan	Neosilurus hyrtlii	
pouched lamprey	Geotris australis	
shorthead lamprey	Mordacia mordax	

Common name	Taxonomic name	Conservation status
Alien species		
сагр	Cyprinus carpio	
goldfish	Carassius auratus	
roach	Rutilus rutilus	
tench	Tinca tinca	
Gambusia	Gambusia holbrooki	
redfin	Perca fluviatilis	
brown trout	Salmo trutta	
rainbow trout	Oncorhynchus mykiss	

Appendix 2

Summary of some studies that include dietary analyses of floodplain, estuarine and diadromous fishes of the Murray-Darling Basin. Species are removed from the table if no information was collected in this literature review.

Species	Description of diet or study findings	Source
Freshwater		
Australian smelt	Adult fish consume predominately aquatic insect larvae, terrestrial insects, microcrustaceans and algae, mostly from nekton, water surface and macrophytes	(Lloyd 1987)
	Changed from predominantly pelagic feeding as larvae to surface feeding as adult in channel habitat	(King 2005)
	Diet of adult fish is predominantly cladocerans in billabong habitat	Lieschke & Closs (1999)
bony herring	Juvenile fish consume predominately microcrustaceans, dipteran larvae, algae and detritus	(Lloyd 1987)
	Juvenile fish are primarily zooplanktivores and adult fish are omnivorous detritovores	(Atkins 1984)
	Describes larval development, but has no information regarding diet	(Puckridge & Walker 1990)
Murray rainbowfish	Adult fish consume predominately crustaceans (cladocerans, amphipods), aquatic insect larvae (large numbers of mosquito larvae) and algae from macrophytes, nekton and water surface	(Lloyd 1987)
unspecked hardyhead	Adult fish consume predominately microcrustaceans, algae and aquatic insect larvae from macrophytes, nekton and plant matter	(Lloyd 1987)
Murray hardyhead	Adult fish consume predominately zooplankton, aquatic insect larvae, detritus and algae, from nekton, plant matter, macrophytes and detritus	(Lloyd 1987)
	Study at Victorian lakes found diet consisted largely of cladoceran and copepods, but also ostracods, dipteran larvae and algae (predominantly diatom <i>Campylodiscus</i>)	(Ellis 2006)
southern pygmy perch	Adult fish consume predominately aquatic insects (beetles) and to a lesser extent chironomid larvae, amphipods and detritus, mostly from or around macrophytes	(Lloyd 1987)
Yarra pygmy perch	Diet not studied in the MDB, but fish in Deep Creek, Victoria had totally carnivorous diet: Diptera (40%), mobile insect larva (18%) and Brachiopoda (17.4%) - ~7% each of Ostracods, Copepods and Mollusca	(Sanger 1978)
chanda perch	Diet includes mosquito larvae and microcrustaceans, probably mostly from water surface but also from macrophytes and nekton	(Lloyd 1987)
carp gudgeon (species complex)	Adult fish consume predominately microcrustaceans, macrocrustaceans, and aquatic insect larvae, and smaller amounts of algae and fish, mostly from macrophytes, benthos and nekton	(Lloyd 1987)
	New larvae consume mainly rotifers before switching to calanoid copepods and cladocerans after preflexion	(Gehrke 1992)
	Newly hatched fish consumed only copepod nauplii before adding rotifers and cyclopoids to diet after preflexion	(King 2005)
	Chironomids dominated the diet of large (>25 mm) and small (<25 mm) western carp gudgeon (<i>H. klunzingeri</i>), and also included zooplankton and detritus. Large fish also fed on shrimps.	(Balcombe & Humphries 2009)
	Juvenile fish (<21 mm) showed specialised diet on cladocerans (Chydoridae), but rotifers were also important. Adult fish (>27 mm) diet predominantly chironominae and algae (<i>Oscillatoria</i> spp.)	(Stoffels & Humphries 2003)

Species	Description of diet or study findings	Source
flathead gudgeon	Adult fish consume predominately microcrustaceans, macrocrustaceans and aquatic insect larvae and smaller amounts of fish and detritus, mostly from macrophytes, nekton and benthos	(Lloyd 1987)
	New larvae consume mainly rotifers before switching to calanoid copepods and cladocerans after preflexion	(Gehrke 1992)
dwarf flathead gudgeon	Adult fish consume predominately aquatic insect larvae and microcrustaceans from the benthos, macrophytes and nekton	(Lloyd 1987)
Macquarie perch	Body condition and spawning performance was greater at initial filling of Lake Dartmouth before primary production reduced	(Gray <i>et al</i> . 2000)
golden perch	Adult gut content of fish (carp, bony herring, golden perch), Decapoda (<i>Macrobrachium, Paratya, Cherax</i>), Insecta (Corixidae, Diptera) and Crustacea (Austroargathona)	(Ebner 2006)
Murray cod	Diet of larval fish consisted mostly of cyclopoids and cladocerans	(King 2005)
	Bony herring constitute a part of adult diet	(Milward 1965)
	Adult gut content of fish (carp, bony bream, silver perch), Decapoda (<i>Macrobrachium, Cherax, Euastacus</i>), Mollusca and Crustacea (Austroargathona)	(Ebner 2006)
silver perch	Omnivorous, larvae feed on zooplankton and aquatic insects, adults consume zooplankton, shrimps, filamentous algae and aquatic plants	(Clunie & Koehn 2001b)
freshwater catfish	Summary of diet studies in source: a carnivorous bottom feeder, and benthic organisms the major aquatic component of diet (detritus, molluscs and macrocrustacea, terrestrial and planktonic invertebrates, terrestrial and aquatic vegetation and algae, fish)	(Clunie & Koehn 2001a)
Estuarine/diadromo	us	
small-mouthed hardyhead	Main food items in diet were amphipods and polychaetes	(Lamontagne <i>et al</i> . 2007)
common galaxias	Adult fish consume predominately small invertebrates such as surface insects, crustaceans, insect larvae and mollusks, mostly from the nekton but smaller amounts from macrophytes, plant matter, detritus and benthos	(Lloyd 1987)
western blue spot goby	Adult fish consume predominantly microcrustaceans and aquatic insect larvae (midges, mosquitoes), mostly from the benthos, nekton and macrophytes	(Lloyd 1987)
	Predominantly algae, but can vary depending on levels of interspecific competition	(Gill & Potter 1993)
congolli	Adult fish consume predominately macrocrustaceans, fish and aquatic insect larvae, from on or around macrophytes and nekton	(Lloyd 1987)
	Generalised carnivore eating a wide range of benthic animals. Information is given on variation in diet with season and size	(Hortle & White 1980)
short-finned eel	<i>Chironomus</i> larvae comprised 65% of the diets of juveniles in a New Zealand coastal brackish lake	(Kelly & Jellyman 2007)
yellow-eye mullet	Main food items in diet of juveniles was polychaetes (<i>Australonereis</i>), and in adults polychaetes (<i>Capitella</i>)	(Lamontagne <i>et al</i> . 2007)
mulloway	Main food items in diet were crabs, mullet and small-mouth hardyhead	(Lamontagne <i>et al.</i> 2007)
Introduced		
carp	Early larvae consumed algae and chydorids then fed on epibenthic prey (chronomid larvae, chydorids) as larvae developed into juveniles	(King 2005)
	Diet consisted of predominantly cladocerans (mainly <i>Daphnia</i>) throughout larval development, and feeding behaviour became more benthic in juveniles	Vilizzi (1998), as cited by King (2005)
goldfish	Adult fish consume predominately microcrustaceans, aquatic insect larvae, detritus and algae from macrophytes, detritus, nekton, plant material and benthos	(Lloyd 1987)

Species	Description of diet or study findings	Source
gambusia	Adult fish consume predominately aquatic insect larvae, terrestrial insects and crustaceans mostly from macrophytes, nekton, benthos and water surface	(Lloyd 1987)
	Opportunistic carnivore: diet sometimes dominated by terrestrial insects, but at other times by benthic organisms	(Pen <i>et al.</i> 1993)
	Chironomids, microcrustacea, planktonic algae, blue-green algae (<i>Oscillatoria</i> spp.) and detritus made the greatest average volumetric contribution to the diet	(Stoffels & Humphries 2003)
redfin	In a WA study, juvenile diet dominated by copepods, but after it grows beyond about 120 mm long it feeds mainly on large benthic organisms	(Pen <i>et al</i> . 1993)

Appendix 3

Diets of 80 species of waterbirds that frequent wetlands within the Murray–Darling Basin. The information provided is taken from Marchant & Higgins (1990a); Marchant & Higgins (1993), Higgins & Davies (1996) and references within. Some additional unpublished information on food resources used by birds within the estuarine-hypermarine systems of the Coorong is also incorporated. Much of the information on the diets of Australian birds is limited to inventories of the food resources found in stomachs or gizzards, and much less frequently from field observations of foraging birds. There are few quantitative or detailed studies of the diets of birds. For a few species the relative proportions of food types is provided below (where they have been estimated), as well as brief statements on the extent to which each species uses of different wetlands, including specific information on foraging habitats.

Species	Food items	Habitat needs	Summary/Comments
Australasian	Fish, snails and aquatic invertebrates	Variety of mainly fresh	Predominantly small fish
grebe Tachybaptus novaehollandiae	Molluscs; gastropods (<i>Glyptophysa, Isidorella, Thiara</i>)	to brackish wetlands— entirely aquatic. May avoid	(~80% by weight), Snails may be taken when preferred prey scarce
	Crustaceans: cladocerans (<i>Daphnia</i>); ostracods; amphipods	large open wetlands	
	Insects: Odonata (larvae); mayfly & stonefly nymphs;Hmeiptera; Homoptera; Coleoptera (Hydrophilidae,Staphylidinidae; Curculionidae etc); Diptera (Chironomidae; Ephydridae etc)		
	Fish: Gambusia, Philypnodon		
Hoary-headed	Chiefly aquatic arthropods but also fish.	May prefer large open	Although reported
grebe	Annelids: earthworms	wetlands (>100 m across) up to 3 m deep with some	as chiefly aquatic arthropods, in
Poliocephalus poliocephalus	Molluscs: Glyptophysa	submerged vegetation,	the Coorong fish
penecephatae	Arachnids: water mites	but can use all types of wetlands from fresh to	(Atherinosoma microstoma) and brine shrimps (Parartemia zietziana) prominent Males have larger bills than females—may reflect a difference in diet
	Crustaceans: cladocerans (<i>Daphnia</i>);ostracods; amphipods; decapods (shrimps, yabbies, <i>Paratya</i>);	wettands from fresh to estuarine to hypersaline. May use areas with sparse submerged vegetative growth (<i>Ruppia</i> , <i>Vallisneria</i>) where foliage- gleaning easier than from <i>Myriophyllum</i> . Most food harvested by deep diving (?to 3m)	
	Insects: Odonata ; Anisoptera; Hemiptera (Corixidae etc); Coleoptera (Carabidae; Hydrophilidae, Curculionidae etc); Diptera (Chironomidae; Ephydridae; Tipulidae); Lepidoptera; Hymenoptera (Formicidae) Eisb: Gambusia: Atherinosoma		
	rish. oumbusia, Anermosoma		
Great crested grebe <i>Podiceps cristatus</i>	Mainly fish with some plant and aquatic invertebrates. Plant: algae; <i>Myriophyllum</i> ; Polygonaceae seeds Molluscs: (no details)	Wide range of wetlands from rivers, swamps, lakes, salt fields, estuaries and lagoons	Small fish (1–5.5 cm long) main food fed to chicks
	Crustaceans: decapod shrimps	favouring large deep open	
	Insects: Orthoptera; Hemiptera (Corixidae); Coleoptera (Hydrophilidae); Diptera (Chironomidae);	Some literature suggests restricted to salinities < 30 ppt TDS but clearly uses hypermarine salinities in Coorong	
	Fish: Onchorynchus spp., Salmo, Philypnodon		
		Although prefer clear water will use wetlands with reduced visibility to ~ 0.2 m	
		Observed to catch fish up to 6 cm in length	

Species	Food items	Habitat needs	Summary/Comments
Australian pelican <i>Pelecanus</i>	Mostly fish but occasionally small crustaceans	Terrestrial, estuarine and marine wetlands, areas of open water free of dense aquatic vogetation	Also observed catching
	Crustaceans: decapods shrimps (<i>Macrobrachium</i> , <i>Cherax destructor</i>), crabs		crabs in Coorong
conspicillatus	Insects: (no details)	Poported as using	
	Fish: Cyprinus carpio, Leiopotherapon unicolour, Perca pluviatulus, Carassius, auratus, Tinca tinca,Macquaria australasica, bream, whitebait (Atherinostoma) etc	hypersaline wetlands upto 130 ppt TDS (which is the upper tolerance of fish)	
	Other vertebrates: reptile; birds; mammal (small dog)		
Darter Anhinga	Predominantly fish and occasional aquatic invertebrate and plant material	Widespread across terrestrial wetlands, in	Piscivorous. Mean fish length ~13 cm but will
melanogaster	Plant: Hydrilla, Naja (foliage),and Nymphaea etc (seeds)	sheltered coastal waters particularly in tropics and	take fish up to ~20 cm
	Insects: Hemiptera (Belostomatidae, Notonectidae, Corixidae); Coleoptera (Dytiscidae, Hydrophilidae)	subtropics	Plant material accounts for <10% food by weight
	Fish: (many species) major species in SE Aust include Nematolosa erebi. Carassius auratus, Perca fluviatilis, Perca grandiceps, Retropinna semoni, Gallaxius, Nannoperca australis, Philypnodon	Most common on permanent water-bodies (lakes, estuaries, rivers) with water at least 0.5 m deep without dense	
	Other vertebrates (very occasional): turtle (<i>Chelidonia</i>)		
Great cormorant	Mainly fish and some crustaceans	Widespread—terrestrial	Mean fish length ~15 cm
Phalacrocorax carbo	Crustaceans: decapods (Cherax, , Paratya, Macrobrachium, crabs Paragrapsus)	wetlands and coastal waters	~50 cm
	Insects: Hemiptera; Coleoptera	very turbid water (secchi <10 cm)	
	auratus, Perca fluviatilis, Salmo, Tinca tinca, Anguilla		
	australis, Hyporhamphus regularis, Engraulis australis, Aldrichetta forsteri, Acanthopagrus butcheri, Atherinidae, Gobiidae etc	May favour areas of deep open and permanent water and major rivers but also use estuaries and	
	Other vertebrates (very occasional): frog (<i>Neobatrachus</i>); turtle (<i>Chelidonia</i>); duckling	protected coastal marine waters	
		Nest in trees (eucalypts, melaleucas), bushes (<i>Muehlenbeckia</i>) or reeds (<i>Phragmites</i>) in or near water	
Pied cormorant	Mostly fish with a few crustaceans	Mainly marine, but will use lakes, swamps, estuaries and rivers. Prefers large open water wetlands. Birds unaffected by turbidy and salinity	Fish account for >90% of food intake.
Phalacrocorax varius	Molluscs: (marine waters: squid, shrimps, prawns, crabs		
	Crustaceans: decapods (Cherax destructor)		
	Fish: many species of marine fish but prominent inland and estuary species include <i>Carassius auratus,</i> <i>Nematalosa erebi, Retropinna semonia, Perca fluviatilis,</i> <i>Philypnodon, Cyprinus carpio</i> , Galaxiidae, Aldrichetta forsteri		
		estuaries, tidal creeks or near shore islands. Nests built in mangroves, Melaleuca, Nitraria etc, or on rocky or bare cliffs around coast	

Species	Food items	Habitat needs	Summary/Comments
Little black cormorant	Mostly fish particularly smelt, carp, perch and some crustaceans	Widespread on sheltered coastal waters and inland	Fish account for >90% of intake
Phalacrocorax sulcirostris	ax Crustaceans: Cherax destructor, Paratya australiensis, Macrobrachium australiensis waters	wetlands, as well as estuaries and brackish waters	Taking fish 4–18cm in length
	Insects: Hemiptera; Coleoptera (trivial volumes)	Breeds in vegetated	
	Fish: Carassius auratus, Perca fluviatilis, Retropinna semoni, Philypnodon, Gambusia affinis, Craterocephalus,	swamps and lakes mainly fresh in flooded trees	
	Ambassis agassizi, Tandanus tandanus, Hypseleotris, Cyprinus carpio, Macquaria ambigua, Nannoperca australis, Nepatolosa erebi in estuaries take Aldrichetta	<i>Carassius</i> and <i>Perca</i> the prominent species in inland wetlands	
		Often forages collectively in large flocks involving more than 1,000 birds	
Black-faced shag	Fish	A coastal marine and	Unlikely to respond to
Phalacrocorax fuscescens	Fish: variety of largely marine fish, but includes Atherinidae, Clinidae, Monacanthidae, Plotosidae, Triglidae	estuarine species that in the MDB is limited to the Murray Mouth estuary and Coorong	improved environmental allocations
Little pied cormorant	Mostly freshwater crayfish and crustaceans and fish, particularly carp and perch	Terrestrial wetlands and sheltered coastal waters	Fish account for ca 38– 55% of diet by wet weight,
Phalacrocorax melanoleucos	Crustaceans: Decapods (Cherax destructor, Macrobrachium australiense, Paratya australiensis)	Feed in open water. Does not feed cooperatively	crustaceans 45–61%
	Insects: Orthoptera; Coleoptera		
	Fish: Carassius auratus, Perca fluviatilis, Retropinna semoni, Philypnodon, Gambusia affinis, Craterocephalus, Ambassis agassizi, Tandanus tandanus, Hypseleotris, Cyprinus carpio, Nannoperca australis		
	From estuarine and coastal marine waters (<i>Gymnapistes</i> marmoratus, Ambassis, Macquaria ambigua, Acanthopagrus butcheri, Atherinidae, Gobiidae)		
Pacific heron	Mainly small aquatic and terrestrial animals, some fish	Predominantly terrestrial	
Ardea pacifica	Molluscs: freshwater mussels	wetlands rarely estuaries	
	Crustaceans: shrimps, freshwater crayfish	Mainly freshwater and opportunistic	
	Arachnids: spiders		
	Insects: Mantodea (praying mantids), Anisoptera (dragonfly nymphs); Zygoptera (damselfly nymphs), Orthoptera, Hemiptera, Coleoptera (Hydrophilidae, Staphylinidae, Dynastinae), Diptera, Lepidoptera		
	Fish: Carassius auratus, Neosilurus		
	Other vertebrates: frogs, lizards, young mammals		
Great egret <i>Ardea alba</i>	Principally fish but also frogs, insects and occasionally birds	Terrestrial wetlands, estuarine, littoral habitats	Take fish up to 15 cm but fish > 12 cm handled with
	Molluscs: freshwater snails	and moist grasslands	difficulty
	Crustaceans: freshwater shrimp and crayfish; crabs		
	Insects: Anisoptera; Zygoptera; Hemiptera (Corixidae); Orthoptera; Coleoptera (water beetles); Diptera	Usually feed alone	
	Fish: Carassius auratus, Gambusia affinis, Philypnodon, eel		
	Other vertebrates: frogs & tadpoles, snake, various small birds (crakes, silvereye, sparrow)		

			a 1a i
Species	Food items	Habitat needs	Summary/Comments
White-faced heron	Wide variety of aquatic invertebrates and vertebrates	Widespread across temperate and tropical wetlands including littoral	In southern Coorong observed taking <i>Atherinosoma microstoma</i> and crabs
	Annelids: earthworms		
novaehollandiae	Molluscs: cephalopods (Sepiolidae); gastropods	and estuarine systems.	
	Crustacea: amphipods, isopods, shrimps (<i>Macrobrachium , Cherax</i> , etc), crabs (<i>Paragrapsis</i> etc)	Also forage in pastures near wetlands	
	Arachnids: spiders (Lycosidae)	Forage in water up to	
	Insects: Odonata; Orthoptera (Tettigoniidae, Gryllidae etc); Hemiptera (Corixidae); Coleoptera (Dytisicidae, Hydrophilidae, Scarabaeidae) Lepidoptera: Diptera	to shallow water areas around margins of wetlands	
	Fish: Sygnathidae; Clinidae; Gobiidae; Monacanthidae; <i>Galaxia, Tandanus</i>		
	Other vertebrates: frogs (<i>Littoria, Heleioporus</i>), lizards <i>Lampropholis</i> , mice		
Little egret	Fish, crustaceans and aquatic insects	Terrestrial freshwater	Fish caught typically <2
Ardea garzetta	Crustaceans: freshwater crayfish; shrimps; prawns; crabs (<i>Heliograspis haswelli</i>)	and saline wetlands, plus littoral and estuarine	cm but can be >10 cm
	Arachnids: spiders	Forage mainly in shallow	
	Insects: Orthoptera (crickets); Zygoptera; Hemiptera (Corixidae); Coleoptera (water beetles)	open water	
	Fish: Gambusia affinis, Hypseleotris gallii		
Cattle egret Ardea ibis	Wide variety of pasture invertebrates, plus frogs and lizards if available. Any fish taken likely to be scavenged	Temperate grasslands including stock pastures,	Insects accounted for 60–80% by weight of
	Arachnids: spiders (Lycosa),ticks	and terrestrial wetlands. Wetlands used are	nestling foods, mainly
	Insects: Orthoptera (Gryllidae, Tettigoniidae, Acrididae, Pyrgomorphidae); Hemiptera (Cicada-idae, Corixidae, Parkalla muelleri): Dintera, Hymepontera (Formicidae)	predominantly fresh Usually follow stock, taking disturbed	10–20%, frogs 2–3% and spiders 2–3% were the prominent foods
	Frogs: Littoria spp. Lympodynastes		
	Reptiles: LampropholisAmphibolurus, Ctenotus, Egernia, Eremiascincus, Delma		
	Mammals: Antechinus, Mus		
Rufous night	Mainly fish, frogs, crustaceans, and aquatic insects	Littoral, estuarine and terrestrial wetlands. Forage along banks, shores with still or slow- moving water. In inland areas prefers wetlands with tall emergents or with wooded edges	
heron Nycticorax	Crustaceans: freshwater crayfish (<i>Cherax</i>), shrimps, crabs (<i>Holthuisiana</i>)		
caledonicus	Insects: Dermaptera (earwigs) Anisoptera, Orthoptera (Gryllotalpidae), Coleoptera (Carabidae); Hymenoptera (Formicidae)		
	Fish: Carassius; Gambusia		
	Frogs: <i>Littoria</i>	Opportunistic forager. Mainly pocturnal	
	Reptiles: turtles Chelidonia	Mainly nocturnal. Suggestion that breeding timed to coincide with emergence of hatchling turtles, but also breed when colonial waterbirds breed	
	Birds: ducklings, eggs of cormorants, ibis, spoonbills		
	Mammals: <i>Mus</i>		

Species	Food items	Habitat needs	Summary/Comments
Australasian bittern <i>Botaurus</i>	Crustaceans, aquatic invertebrates, vertebrates that inhabit aquatic areas (fish, amphibians,reptiles, birds,mammals)	Fresh terrestrial wetlands and estuaries with tall dense fringing and	No detailed studies of diet. Will be disadvantaged when wetlands dry and dewater dense fringing vegetation
poicoloptilus	Arachnids: spiders	emergent vegetation, particularly those	
	Crustaceans: freshwater crayfish (Cherax).	dominated by sedges,	
	Insects: Orthoptera, Coleoptera	rush, reeds or cutting grass	
	Fish: Carassius auratus	Forage in still shallow	
	Amphibians: frogs	water to 0.3 m	
	Reptiles: snake (<i>Pseudechis</i>), lizards		
	Birds: Zosterops		
	Mammals: rats, mice		
Glossy ibis	Mainly aquatic invertebrates (crustaceans, insects)	Terrestrial wetlands,	Only limited data on food
Plegadis falcinellus	Molluscs: freshwater mussels, freshwater snails (<i>Lymnaea</i>)	occasional wet grasslands and sheltered estuaries	resources in se Australia
	Crustaceans: freshwater crayfish	Avoids dry ground, foraging in shallow water or on damp, soft mudflats. Often feed in dense lines	
	Arachnids: aquatic mites; spiders		
	Insects: Orthoptera (crickets, grasshoppers); Hemiptera (Corixidae); Coleoptera (Hydrophilidae, Scarabaeidae etc) Diptera (larvae)		
	Fish: no details		
	Amphibians: frogs		
Australian white ibis	Aquatic invertebrates (crustaceans, insects) and some fish when foraging in wetlands	Terrestrial wetlands, sheltered marine habitats and grasslands Diet depends on habitat Major dietary components by weight (depending on foraging habitat) probably frogs, fish, freshwater crayfish, beetles, crickets, grasshoppers	
Threskiornis	Annelids: earthworms		
molucca	Molluscs: bivalves, freshwater mussels, gastropods (freshwater snails)		
	Arachnids: spiders		
	Crustaceans: isopods, freshwater crayfish (Cherax spp, Paratephusa leichardti); shrimps (Alpheus, Macrobrachium); crab Paragrapsis, Macrophthalmus ect)		
	Insects: Dermaptera, Anisoptera, Orthoptera (Gryllidae, Acrididae, etc), Hemiptera (Cicadidae, Nepidae, Notonectidae, Corixidae); Coleoptera (Carabidae, water- beetles, Scarabaeidae, Curculionidae etc); Diptera; Lepidoptera (Noctuidae),; Hymenoptera		
	Fish: <i>Gambusia affinis, Perca fluviatilis</i> , Gobiidae, eel		
	Amphibians: frog		
	Other vertebrates: (rarely) snake, bird		

Species	Food items	Habitat needs	Summary/Comments
Straw-necked ibis <i>Threskiornis</i>	Varies with habitat—wide range of prey items including freshwater crayfish, frogs, fish, beetles, crickets, caterpillars, spiders and freshwater snails	Grasslands and cultivated land and terrestrial wetlands	
spinicollis	Annelids: earthworm	Often feed away from	
	Molluscs: bivalves, gastropods (water snail, Helix)	wetlands in dry or damp grassland	
	Crustaceans: isopods, freshwater crayfish (Cherax), crabs (Holthuisiana)	Breed in fresh, brackish or saline wetlands in reeds, shrubs or trees	
	Millipedes & centipedes; scorpions		
	Arachnids: spiders (<i>Lycosa</i>)		
	Insects: Anisoptera; Dermaptera; Orthoptera (Gryllidae, Gryllacrididae, Tettigoniidae, Acrididae); Hemiptera (Cicadidae, Corixidae, Notonectidae); Coleoptera (Carabidae, Dytiscidae, Hydrophilidae, Scarabaeidae, Staphylinidae, Tenebrionidae, Curculionidae),Lepidoptera (NoctuidaeSphingidae); Diptera Tipulidae Syrphidae); Hymenoptera (wasps, bees, ants)		
	Fish: no details		
	Amphibians: frogs		
	Reptiles: lizard and snake		
	Mammals: mice, rats		
Royal spoonbill	Fish, crustaceans and aquatic insects	Terrestrial wetlands,	
Platalea regia	Molluscs: Sepiolidae; gastropods (<i>Lymnaea, Bullinus</i>)	sheltered marine habitats	
, , , , , , , , , , , , , , , , , , ,	Crustaceans: amphipods, isopods , decapods (shrimps Atyidae, <i>Macrobrachium , Euastacus armatus Cherax</i> <i>destructor</i> , crabs <i>Brachynotus</i>)	both fresh and saline systems used, but prefer freshwater wetlands	
	Insects: Orthoptera, Anisoptera; Hemiptera (Corixidae, Notonectidae), Coleoptera (Dytiscidae, Hydrophilidae, Curculionidae)	Structure of bill limits foraging to shallow water <0.4 m deep	
	Fish: Carassius auratus, Retropinna semoni, Gambusia affinis, Perca fluviatilis Philypnodon , Gobiidae		
	Amphibians; tadpoles		
Yellow-billed	Mainly aquatic insects, with some crustaceans and fish	Terrestrial wetlands, wet	
Spoonbill Distalas flavinas	Molluscs: Lymnaea etc	sheltered marine habitats	
Plalalea navipes	Crustaceans: <i>Cherax destructor, Macrobrachium,</i> <i>Euastacus</i> shrimps (Atyidae)	Mainly inland at fresh or brackish wetlands with	
	Arachnids: spiders	abundant aquatic flora	
	Insects: Zygoptera, Anisoptera, Orthoptera (Gryllidae,Tereogryllidae), Hemiptera (Corixidae, Notonectidae etc), Coleoptera (Dytiscidae, Hydrophilidae), Hymenoptera (Formicidae)		
	Fish: Gambusia affinis, Retropinna semoni , Carassius auratus, Philypnodon		
Plumed whistling	Almost entirely herbivorous	Tropical and temperate	Unlikely to respond to
аиск Dendrocygna eytoni	Plants: Fabaceae, Polygonacae, Potamogetonaceae, Cyperaceae, Poaceae, Marsileaceae, Amaranthaceae, Menyanthaceae	grassiands but visits a range of freshwater wetlands and rarely tidal systems (in northern Aust). Will move into flooded inland wetlands. Generally avoid wetlands with fringing vegetation	 Numerical watering in Murray–Darling system >98% of diet is plant material of which 50–100% composed of Poaceae
		Graze on native grassland and pastures dabble in shallow water at edges of wetland. Mainly feed at night	

Species	Food items	Habitat needs	Summary/Comments
Blue-billed duck	Seeds and foliage of aquatic plants, and aquatic insects	Wholly aquatic, preferring deep water in large permanent wetlands with abundant aquatic flora	Unlikely to use
Oxyura australis	Plants: Ceratophyllum, Myriophyllum, Vallisneria, Potamogeton, Polygonum, Azolla, Chara, Spirogyra, Fabaceae, Chenopodiaceae, Cyperaceae		ephemeral floodplains Diet about 50% plant and 50% aquatic insects
	Molluscs: bivalves (<i>Corbiculina</i>), gastropods (<i>Glyptophysa, Gyraulus, Physa</i>)	Prefers freshwater wetlands; does not use marine systems, may use	
	Crustaceans: copepods, cladocerans	saline wetlands in winter	
	Arachnids: mites Hydracrina	Dives to forage	
	Insects: Odonata, Ephemeroptera, Zygoptera, Anisoptera, Hemiptera, Trichoptera, Coleoptera, Diptera (Chironomidae)		
Musk duck <i>Biziura lobata</i>	Mainly aquatic invertebrates (crustaceans, insects) supplemented with aquatic plants	Widespread on terrestrial wetland, estuaries and sheltered inshore	Aquatic invertebrates accounted for 73%
	Plants: Ceratophyllum, Myriophyllum, Vallisneria, Potamogeton, Polygonum, Runnia, Azolla, Chara	wetlands	votume, plants 2770
	Spirogyra, Typha, Fabaceae, Chenopodiaceae,	Can dive to at least 6 m.	
	Cyperaceae, Convolvulaceae, Ranunculaceae, Asteraceae, Juncaceae, Poaceae	Birds prefer deep exposed water far from shore	
	Annelids: leech	Deep freshwater swamps	
	Molluscs: Corbiculina, Physastra	preferred, with fringing	
	Crustaceans: copepods, cladocerans, ostracods, decapods (Cherax), <i>Caridinia</i> , crabs (Macrophthalmus)	Eleocharis, Melaleuca, Muehlenbeckia) for	
	Insects: Odonata; Zygopytera; Anisoptera, Hemiptera (Corixidae etc); Coleoptera, Trichoptera, Diptera (Chironomidae), Hymenoptera	breeding	
	Vertebrates (rarely)		
	Fish: Retropinna semoni, Tandanus tandanus, Gambusia affinis		
	Amphibians: frogs, tadpoles		
	Birds: ducklings		
Freckled duck	Aquatic plants and aquatic invertebrates (crustaceans, insects)	Prefer fresh, densely vegetated waters	Published dietary analyses may over
naevosa	Plants: <i>Ceratopyllum</i> (fruits), <i>Lepilaena</i> , Potamogetonaceae, Ruppiaceae, Najadaceae, Cyperaceae, Poaceae, Thyphaceae, Portulaceae, Haloragaceae, Polygonaceae, Fabaceae, Asteraceae, Marsileaceae, Chlorophyacaee, Characeae, Azollaceae	particularly floodwater swamps and creeks vegetated with lignum (<i>Muehlenbeckia</i>) or canegrass (<i>Eragrostis</i> Feeds by filtering and dabbling so limited to shallow productive waters or soft mud at wetland edges	estimate importance of plant material
	Nematodes: (no details)		
	Molluscs: (no details)		
	Crustaceans: cladocerans, ostracods		
	Insects: Ephemeroptera; Zygoptera; Hemiptera; Diptera (Ceratopogonidae, Chironomidae); Coleoptera		
Black swan	Almost entirely herbivorous, usually leaves and shoots of aquatic plants, sometimes pasture	Widespread over temperate and tropical	
сygnus atratus	Plants: Vallisneria, Potamogeton, Typha, Azolla, Chara, Ruppia, Myriophyllum, Ceratophyllum, Najas, Chlorophyta, Poaceae, Chenopodiaceae, Lempaceae	terrestrial wetlands, sheltered estuarine and maritime habitats	
	Juncaceae, Fabaceae	Generally favour permanent wetlands with floating, submerged or emergent vegetation. May avoid turbid water (limited plant growth) and wetlands with salinities > ~60 ppt TDS	
		Use of underwater habitat limited to depths reached by upending ca 1m	

Species	Food items	Habitat needs	Summary/Comments
Cape Barren goose <i>Cereopsis</i> novaehollandiae	Mostly green herbage including pasture grasses and	Graze terrestrial pastures	Mainly grass. Unlikely to respond to environmental watering, may respond to changes in irrigated and non-irrigated pastures around Lower Lakes
	legumes Plants: Poaceae; Juncaceae; Geraniaceae Plantaginacesae, Asteracea, Fabaceae, Aizoaceae	Can persist in areas without free water because of well- developed salt secreting glands.	
Australian shelduck Tadorna tadornoides	Aquatic and terrestrial plants, aquatic invertebrates Plants: Vallisneria, Potamogeton, Azolla, Chara, Arthrocnemum, Ruppia (seeds, turions), Lamprothamnium (tubers), Lepilaena (seeds), Poaceae, Fabaceae Molluscs: mussels, gastropod Coxiella Crustaceans: cladocerans, anostracans, Parartemia , ostracods Insects: Ephemeroptera; Zygoptera; Hemiptera (Corixidae); Coleoptera (water beetles); Diptera (Tanytarsus barbitarsus. Ephydra (larvae, pupae)); Hymenoptera (Formicidae)	Grasslands, croplands, terrestrial wetlands, estuaries, and saline systems Can tolerate high salinities Forages by grazing, surface dabbling, up- ending in shallow water, sifting soft sediments	Diet poorly documented, but influenced by presence of rich-dryland pastures, rather than flooding of wetlands
Maned duck Chenonetta jubata	Predominantly plants, taking grain and insects when herbage in short supply Plants: Poaceae, Fabaceae, Polygonaceae, Asteracee, Cyperaceae, Typhaceae, Marsileaceae, etc Insects: Collembola, Ephemeroptera; Hemiptera; Orthoptera; Coleoptera (Hydrophilidae); Diptera (Sciaridae); Hymenoptera	Widespread use of grasslands, terrestrial wetlands, particularly in farming areas Prefer grassland and pastures	Plant material accounts for 99% of diet, and 50% from Poaceae
Pink-eared duck Malacorhynchus membranaceus	Aquatic insects and crustaceans, sometimes supplemented with aquatic plants Plants: Chenopiodaceae, Portulaceae, Polygonaceae, Fabaceae, Poaceae, Cyperaceae, Marsileaceae, Lemnaceae Chlorophyta , <i>Myriophyllum, Ceratophyllum</i> <i>Azolla</i> , etc Molluscs: gastropods (Glyptophysa) Crustaceans: ostracods (Cyprinotus, copepods, cladocerans (Daphnia) clam shrimps; freshwater crayfish (Cherax) Arachnids: Hydracarina Insects: Ephemeroptera; Hemiptera (Corixidae, Notonectidae); Neuroptera; Coleoptera (Dytiscidae, Hydrophilidae, Carabidae); Diptera (Chironomidae, Ceratonogonidae)	Inland terrestrial wetlands, occasionally reaching coastal wetlands Avoids fast-moving water.	Aquatic invertebrates account for 60–99% of intake, plants 1–40%. Aquatic insects more important than crustaceans

Species	Food items	Habitat needs	Summary/Comments
Grey teal <i>Anas gracilis</i>	Aquatic plants including seeds and tubers, and aquatic invertebrates (molluscs, crustaceans & insects)	Terrestrial wetlands and sheltered estuaries,	Plant material 2–88% by dry weight, aquatic invertebrates 12–40%, mainly insects and molluscs
	Plants: algae (Chlorophyta), Ranunculaceae, Chenopodiaceae, Portulacaceae, Polygonaceae, Cyperaceae, Poaceae, Malvaceae, Boraginaceae, Lemnaceae, Fabaceae, Haloragaceae, Solanaceae, Liliaceae, Marsileaceae, Asteraceae, Azollaceae etc. In Coorong Ruppia (tuber, seed, foliage) Mainly foraging in shal open water <1m deep, except in wetlands with floating vegetation. Fas Lamprothamnium papulosum (tuber) Lepilaena cylindrocarpa (seed)	Including fresh, brackish and saline wetlands Mainly foraging in shallow open water <1m deep, except in wetlands with floating vegetation. Favour large shallow productive inland wetlands when available	
	Molluscs: bivalves, gastropods (Columbellidae,	Forage by up-ending, dabbling and dredging	
	Pyramellidae, <i>Glyptophysa, Gyraulus</i>) Crustaceans: cladocerans, ostracods (<i>Euphilomedes</i>), isopods, amphipods, etc	mud at edge of wetland, and by stripping seeds off plants	
	Insects: Anisoptera, Ephemeroptera, Hemiptera (Corixidae, Notonectidae), Coleoptera (Dytiscidae, Hydrophilidae), Trichoptera, Diptera (Tipiludae, Culicidae, Chironomidae, Simuliidae, Ceratopogonidae), Lepidoptera		
Chestnut teal Anas castanea	Aquatic plants and invertebrates (molluscs, crustaceans, insects)	Inhabits terrestrial, fresh and saline, wetlands	10–75% diet is the foliage and seeds of plants, 25–90% invertebrates
Ands Castanea	Plants: Chlorophyta, <i>Ruppia, Bulboschoenus</i> , Cyperaceae Chenopodiaceae, <i>Myriophyllum, Potamogeton</i> . In hypersaline Coorong - <i>Ruppia</i> (seeds, turions) <i>Lamprothamnium papulosum</i>	Food taken from water surface or just below it by either up-ending, or dabbling around the	
	Polychaetes: Ceratonereis	edges of wetlands	
	Molluscs: bivalves, chitons, gastropods (Columbellidae, <i>Aschoris, Tatea, Coxiella</i>)	Can exploit highly saline wetlands provided have source of freshwater,	
	Crustaceans: copepods, cladocerans, isopods, amphipods, crabs etc	salt gland is not well developed	
	Arachnids: spiders (Anyphaenidae)		
	Insects: Hemiptera (Corixidae), Lepidoptera, Neuroptera, Diptera (Tipulidae)		
Pacific black duck	Mostly plant material particularly seeds, plus aquatic insects and crustaceans	Temperate and tropical terrestrial wetlands, sheltered estuaries and marine waters. Will also forage in wet pastures away from water Prefer shallow productive wetlands with low salinity, but also prominent in deeper vegetated swamps with fringing and emergent vegetation Forages by dabbling at surface and up-ending to reach submerged food. Also grazes in flood paddocks	Plant material accounts for 70–96% of food,
Anas superciliosa	Plants: Families accounting for than 3% of volume include: Nymphaeceae, Ceratophyllaceae, Ranunculaceae, Chenopodiaceae, Polygonaceae, Cucurbitaceae, Haloragaceae, Menyanthaceae, Asteraceae, Potamonetonaceae, Azollaceae		aquatic invertebrates 4–30%
	Lemnaceae, Cyperaceae, Poaceae, Typhaceae, Marsileaceae, Characeae		
	Important genera: Myriophyllum, Echinocloa, Ceratophyllum, Polygonum, Vallisneria, Potamogeton, Najas		
	Molluscs: bivalves <i>Corbiculina</i> , gastropod <i>Glyptophysa,</i> <i>Gyraulus</i>		
	Crustaceeans: copepods, ostracods, shrimps (<i>Caridinia</i>), freshwater crayfish (<i>Cherax</i>)		
	Arachnids: spiders (Arctosa) water mites (Hydrocarina)		
	Insects: Orthoptera (Tettigoniidae), Zygoptera, Anisoptera, Ephemeroptera, Hemiptera (Corixidae, Belostomatidae), Trichoptera, Coleoptera (Dytiscidae, Hydrophilidae), Diptera (Chironomidae), Lepidoptera		

Species	Food items	Habitat needs	Summary/Comments
Australasian shoveller	Predominantly aquatic invertebrates and aquatic plant foliage and seeds	Predominantly temperate terrestrial wetlands, occasionally sheltered estuaries and inshore waters Prefer large deep permanent lakes and swamps where small seasonal fluctuations	Aquatic invertebrates account for 46–76% of
Anas rhynchotis	Plants: Chenopodiaceae, Polygonaceae, Ceratophyllaceae, Cucurbitaceae, Haloragaceae Hydrochaitaceae, (<i>Vallieneria</i>), Runpiaceae (<i>Runpia</i>)		tood by volume, plants 24–54%
	Fabaceae, , Typhaceae (<i>Typha</i>), Boraginaceae, Asteraceae, Cyperaceae, Poaceae, Marsileaceae (<i>Marsilea</i>), Azollaceae (<i>Azolla</i>), Potamogetonaceae (<i>Potamogeton</i>), Najas		
	Molluscs: bivalves (<i>Corbiculina</i>), gastropods (<i>Glyptophysa, Pygmanisus</i>)	in water level promote aquatic flora and fauna	
	Crustaceans: ostracods (<i>Cyprinotus</i>),cladocerans, copepods	Forage by dabbling in surface water or mud.	
	Insects: Odonata, Hemiptera (Notonectidae) Coleoptera (Carabidae), Trichoptera	dive	
Hardhead Aythya australis	Aquatic plants and invertebrates (mainly molluscs and insects).	Terrestrial wetlands, occasionally sheltered	Plants account for 57–96% of food volume,
	Plants: Chenopodiaceae, Nympahaeaeceae, Polygonaceae, Fabaceae, Myriophyllaceae (<i>Myriophyllum</i>), Cyperaceae (<i>Carex, Eleocharis,</i> <i>Scirpus</i>), Poaceae, Potamogetonaceae (<i>Potamogeton</i>), Lemnaceae, Characeae, Chlorophyta, other genera Najas, Typha, Vallisneria, Azolla, Ruppia	estuaries and inshore waters. Uses a diversity of freshwater swamps and lakes. Avoids main streams of rivers except calm reaches with aquatic	aquatic invertebrates 4-43%
	Molluscs: bivalves (Alathyia, Corbiculina, Velesunio); gastropods (Glyptophysa, Isidorella,Gabbia, Plotiopsus)	Dive to forage	
	Crustaceans: ostracods, copepods, shrimps (<i>Caridina</i>) freshwater crayfish (<i>Cherax</i>)		
	Insects: Zygoptera, Hemiptera (Belastomatidae), Coleoptera (Dytiscidae), Trichoptera, Diptera (Chironomidae)		
Baillon's crake Porzana pusilla	Mostly aquatic insects but also seeds, snails, crustaceans	Use fresh, brackish and saline wetlands	
	Plants (seeds): Cyperaceae (<i>Carex</i>)	Forage on mud around	
	Molluscs: small freshwater snails	reeds and tringing vegetation and in water	
	Crustaceans: copepods	< 3 cm, including areas	
	Insects: Odonata (Xanthocnemis); Hemiptera (belastomids); Coleoptera (Hydrophylidae); Diptera (Drosphilidae)	with floating vegetation (e.g. <i>Azolla</i>)	
Australian crake	Seeds, molluscs, insects, crustaceans and spiders.	Use fresh, estuarine and marine wetland shorelines with good cover of terrestrial vegetation (samphire,	Aquatic and terrestrial
Porzana fluminea	Plants (seeds) : Cyperaceae, Fabaceae (<i>Medicago</i> , <i>Trifolium</i>)		Invertebrates
	Molluscs: freshwater snails		
	Crustaceans: ostracods	reeds etc) Forage on damp mudflats to shallow water (<5 cm)	
	Arachnids: spiders		
	Insects: Dermaptera; Orthoptera (Acrididae); Hemiptera; Coleoptera (Carabidae, water-beetles, Chrysomelidae, Curculionidae); Diptera (Chironomidae); Lepidoptera; Hymenoptera (Formicidae)	Nests may be abandoned if water levels drop	
Spotless crake	Seeds, fruit and shoots of grasses and aquatic plants, insects (larvae & adults), molluscs, crustaceans	Uses wetlands with continuous stands of emergent vegetation (e.g. reeds, rushes, sedges). May prefer wetlands with flowing water Usually forage from mud surface or in shallow water	
	Plants: seeds (not specified); fruit (<i>Rubus</i> spp.); foliage (Poaceae (blades); reeds (tillers))		
	Molluscs: Gastropoda		
	Crustaceans: Ostracoda, Amphipoda		
	Collembola:		
	Insects: Ephemeroptera; Coleoptera (water beetles; Chrysomelidae); Diptera (Calliphoridae)		
Creation	Food items	Habitat peode	Summany/Commonte
---	---	---	--
Species		Habitat needs	Summary/Comments
Purple swamphen	Mainly aquatic vegetation lleaves, rhizomes, tillers, plus seeds, fruits) some invertebrates and vertebrates	Wide diversity of usually fresh or brackish wetland systems used. Rarely forages on open mudflats, but readily forages in pasture fringing wetlands Numbers reduced by clearance of the marginal wetland venetation. Will	Primarily forage on emergent riparian plants
Porphyrio porphyrio	Plants: Chlorophyaceae; Lemnaceae (duckweed leaves); Hydrocharitaceae (<i>Vallisneria</i>) Ruppiaceae (<i>Ruppia</i>); Juncaginaceae (<i>Triglochin</i>); Juncaceae (<i>Juncus</i> seeds); Cyperaceae (Scirpus leaves, sedge-weed, seeds of <i>Carex, Eleocharis</i> spp); Typhaceae (<i>Typha</i>)_Poaceae (leaves, rhizomes & seeds, <i>Phragmites australis,</i> <i>Alopercus, Lolium, Poa, Hemarthria</i> etc); Ranunculaceae;		In NZ species plays a role in transfer of minerals from swamp to
	Fabaceae; Haloragaceae (<i>Myriophylium</i>), Polygonaceae (<i>Polygonum</i>) Chenopodiaceae (<i>Chenopodium album</i> leaves); etc	occupy weltands provided enough cover and sufficient water	pasiure
	Crustaceans: Amphipoda	Will pull out monocot	
	Arachnids: (not specified)	tillers or nip them off at base and chew fleshy	
	Insects: Hemiptera; Coleoptera (Hydrophilidae; Scarabaeidae; Chrysomelidae; etc); Diptera (larvae):(Chironomidae & Tipulidae); Hymenoptera (Formicidae); also the sugary caps (lerp) of selected Pysillidae (DCP pers obs)	bases. Also dig for subterranean rhizomes	
	Vertebrates: eels, flounder, dead carp; frogs; and duck eggs		
Dusky moorhen Gallinula tenebrosa	Plant material (leaves, as well as seeds, fruit), plus molluscs, spiders and aquatic insects	Usually uses fresh wetlands. Occasionally in brackish to saline wetlands (e.g. estuaries). Prefer foraging in shallow water where there much vegetation	No quantitative data
	Plants: algae; Pteriodophyta; Azollaceae (<i>Azolla</i>); Hydrocharitaceae (<i>Ottelia</i>); Potomogetonaceae (<i>Potomogeton</i>); Lemnaceae (<i>Spirodela</i>); Poaceae (<i>Pennisetum</i>); Typhaceae (<i>Typha</i>); Polygonaceae (Polygonum): Portulacaceae (<i>Portulaca</i>): Solanaceae		
	(Lycium); Nymphaeaceae (water lilies)	Food taken from up to 30	
	Annelids: oligochaetes	cm below the surface (will up-end but not dive)	
	Molluscs: gastropods, river shells, bivalves; Hydriidae	Young although pecking	
	Arachnids: Araneae	in the water column in	
	Insects (mainly aquatic): Odonata; Orthoptera (Gryllidae, Acrididae, grasshoppers); Hemiptera; Coleoptera (water beetles); Lepidoptera; Hymenoptera (Formicidae)	first 10 days take no food. Animals dominate the diet during first few weeks, taking annelids, molluscs	
	Frogs (adults & larvae)	and insects	
Black-tailed	Plant material (young plants), seeds, insects	Irruptive species.	Omnivorous but may be
native-hen Gallinula ventralis	Plants: young plants of cereal crops (<i>Triticum, Hordeum, Avena, Zea, Medicago</i>), short lengths of aquatic plants	Permanent and ephemeral terrestrial wetlands in low rainfall	predominantly vegetarian
	Molluscs: (no details)	areas. Favours fresh or	
	Insects (adults & larvae):	brackish wetlands. Can	
	Orthoptera (Gryllacrididae, Tettogoniidae); Coleoptera (Carabidae, Chrysomelidae; Scarabaeidae); Lepidoptera; Hymenoptera (Formicidae)	Irruptions to southern and coastal areas may follow after floods as resources in the inland systems diminish	
		Glean from ground and surface of water	

Species	Food items	Habitat needs	Summary/Comments	
Eurasian coot <i>Fulica atra</i>	Almost entirely herbivorous but also some aquatic insects, crustaceans and molluscs Plants: algae. Chlorophycaceae (<i>Nitella</i>):	Fresh, estuarine and rarely marine wetlands used. May prefer wetlands with a high diversity of submerged or emergent aquatic vegetation often with deeper (> 2 m), open areas that permit diving	rarely marine wetlands vegetation used. May prefer wetlands	Predominantly takes vegetation
	Poaceae (Pennisetum, Paspalum, lawn grasses); Pomatogetonaceae (Pomatogeton;) Ruppiaceae (Ruppia); Hydrocharitaceae (Vallisneria, Elodea); Nymphaeaceae (Nymphaea); Ranunuculaceae (Ranunculus): Salicaceae (Salix): Haloragaceae			
	(Myriophyllum)	Will feed in water and on		
	Molluscs: (no details)	land (green pasture)		
	Crustaceans: freshwater shrimps			
	Insects: aquatic (no details)			
Pied	Molluscs, worms, crabs and small fish	Prefers tidal mudflats,	Within the	
oystercatcher	Echinoderms: (Echinocardium cordatum);	ocean beaches and marine embayments.	Murray–Darling system restricted to the Murray	
Haematopus Iongirostris	Annelids (3mm in length):	Forage across mudflats	Mouth region and	
longh cours	earthworms, polychaetes, sandworms (<i>Nerinides</i>)	and beaches to about 15	Coorong	
	Molluscs: gastropods—Pulmonata (<i>Paphes, Anapella</i>); Plecypoda (small bivalves); mussels; <i>Mytilus, Codackia,</i> pipis (<i>Donax</i>), cockles (<i>Chione</i>))			
	Crustaceans: prawns, crabs, <i>Macropthalamus</i> , Grapsidae)			
	Insects: (no details) but Diptera larvae taken in Coorong (DCP pers. obs.)			
	Fish (no details)			
Sooty oystercatcher	Molluscs, crustaceans, polychaetes, ascidians, coastlines and marine	Generally prefers rocky coastlines and marine		
Haematopus	Echinodermata: sea-urchins	use the Murray Mouth region of the Coorong at times		
fuliginosus	Molluscs: gastropods (10+ species); polyplacophorans (4+ sp, including Chiton); bivalves;			
	Crustaceans: barnacles			
	Insects: Diptera			
Black-winged stilt	Aquatic and terrestrial invertebrates; molluscs, crustaceans, insects and occasionally seeds	Prefers shallow, open freshwater wetlands	Very broad range of aquatic invertebrates	
Himantopus himantopus	Plants: Pteridophyta (<i>Marsilea</i> sporophytes); Ruppiaceae (<i>Ruppia</i> seeds); Portulacaceae (<i>Vitis</i> seeds)	emergent or floating vegetation, but will use	habitats that species can use	
	Annelids: oligochaetes (earthworms)	most wetlands including		
	Molluscs: freshwater gastropods (Hydrobiidae; Bullinidae)	lagoons, salt marsnes, protected tidal wetlands and will use hypersaline		
	Crustaceans: freshwater shrimps; <i>Parartemia; Mysidacea</i> ; amphipods	systems (e.g. Coorong)		
	Arachnidas: Araneae			
	Insects (adults & larvae): Ephemeroptera (mayfly nymphs)			
	Odonata (dragonfly larvae); Orthoptera: Hemiptera (cicada, Notonectidae etc); Neuroptera: (no details) Coleoptera: (Carabidae; Dytiscidae; Hydrophilidae; Scarabaedidae; Curculionidae)			
	Diptera:(Culicidae; Chironomidae; Ephydridae; Calliphoridae)			
	Trichoptera (Hydropsychidae, Odontoceridae, Sericostomatidae)			
	Hymenoptera (Formicidae)			
	Fish (Salmoniformes (<i>Galaxias</i>); Gobiesociformes (<i>Gobiomorphus</i>)			

Species	Food items	Habitat needs	Summary/Comments
Banded stilt	Mainly crustaceans (including branchipods and ostracods), molluscs, insects, seeds and small fish	Mainly uses inland ephemeral salt lakes	
leucocephalus	Plants: seeds and turions of Ruppia	when filled and the more	
	Molluscs: Gastropoda (<i>Salinator fragilis, Coxiella</i> spp); bivalves	and hypersaline wetlands particularly larger	
	Crustaceans: brine shrimps <i>Parartemia</i> ; ostracods; isopods <i>Haloniscus</i> .	waterbodies Mainly forage by wading	
	Arachnids: (no details)	in shallow water (to 15 cm	
	Insects: Hemiptera (Corixidae); Coleoptera (Carabidae (<i>Clivinia</i>); Anthicidae; Staphylinidae); Hymenoptera (Formicidae); Diptera (Culicidae, Chironomidae)	forage in the upper 5 cm of the water column	
	Fish: Atheriniformes (Atherinosoma microstoma)		
Red-necked	Insects, crustaceans, fish, occasional seeds.	Wide variety of wetlands—	
avocet	Plants: (no details)	from fresh to hypersaline	
Recurvirostra novaehollandiae	Annelids: (no details)	salt lakes, but will move	
nordenettanalde	Molluscs: (no details)	to tidal mudflats and sheltered estuaries but	
	Crustaceans: Parartemia	avoid ocean shorelines	
	Insects (aquatic):	Forage in shallow water wading up to belly	
	Coleoptera (Dytiscidae, Scarabaeidae)		
	Diptera (Chironomidae (<i>Tanytarsus</i>)		
	Fish:		
	Antheriniformes (Craterocephalus)		
Pacific golden	Molluscs, worms, insects, crustaceans, spiders	Migratory—breed in Arctic	In the Murray–Darling Basin largely confined to the coastal regions of the Coorong and Lower Lakes and rarely wetlands along the lower
plover	Plants: leaves (no detals)	regions	
Pluvialis fulva	Annelids: polychaetes	Usually close to coastline using sandy and rocky	
	Molluscs: freshwater gastropods (Acmaeidae, Neritidae, Turbinidae)	shorelines, estuaries and lagoons. Will also	
	Crustaceans: crabs (<i>Helice</i>)	use grassland areas (paddocks, crops) where	reaches of the Murray.
	Insects: Hemiptera (Aphidae); Coleoptera (water beetles, Carabidae, Scarabaeidae, Chrysomelidae, Curculidae (beach weevils)); Diptera (larvae); Lepidoptera (caterpillars); Hymenoptera (Formicidae)	grass is short	
Grey plover Pluvialis	Molluscs, insects, crustaceans, polchaete worms and occasionally seeds and vegetation	Migratory—breeds in Arctic regions	Largely limited to the Murray Mouth estuary
squatarola	Plants: (mosses)	Mainly uses marine	and Coorong region
	Annelids: (no details)	shores, inlets and	
	Molluscs: gastropods (Littorinidae (periwinkles))	mudflats	
	Crustaceans: crabs		
	Insects: (adults, larvae)		
	Isoptera: (Termitidae; Curculionidae; Cryptorrhynchinae)		
	Hymenoptera (Formicidae)		

Species	Food items	Habitat needs	Summary/Comments
Red-capped plover	Annelids, molluscs, small crustaceans, dipterans, some vegetation	Prefer saline and brackish wetlands but will use	May depend at times on terrestrial invertebrates
Charadrius ruficapillus	Plants: seeds (<i>Ruppia</i>)	fresh, brackish, marine	blown on to water bodies
	Annelids: (no details)	Lice areas with wide open	and then washed ashore
	Molluscs: Gastropoda (<i>Coxiella</i>)	bare mudflats	
	Crustaceans: ostracods; isopods (<i>Asellus</i>); amphipods (<i>Parhyadella</i> ; small crabs	Largely forage on exposed mud surfaces, venturing	
	Insects (larvae & adults):	into shallow water	
	Coleoptera (Anthicidae; Carabidae; Dytiscidae;Staphylinidae; Scarabaeidae; Curculidionidae)	occasionary to recu	
	Neuroptera (larvae)		
	Diptera (Chironomidae; Ephydrella (brine flies);Coelopidae; Tipulidae)		
	Hymenoptera (Formicidae)		
	Fish: (no details)		
Double-banded plover	Molluscs, insects crustaceans, spiders, occasionally seeds and fruit	Trans Tasman migrant— autumn-winter visitor to	Within MDB small numbers limited to
Charadrius	Plants: seeds (not details)	SE Australia Wide range of littoral, estuarine, fresh or saline wetlands used, as well as grasslands and pastures. Not limited to coastal area	lower reaches Murray, including Lower Lakes, Murray Mouth and Coorong
bicinctus	Molluscs: gastropods (<i>Polinices</i>)		
	Arachnids: spiders		
	Insects: Dermaptera (earwigs); Hemiptera; Coleoptera (Carabidae; Dytiscidae; Staphylinidae; Curculidae); Diptera (larvae); Hymenoptera (Formicidae)		
Black-fronted	Molluscs, crustaceans, and insects, occasionally seeds	Largely uses freshwater	
Plover	Plants: Fabaceae (Trifolium seeds)	wetlands, sometimes using brackish wetlands and very rarely saline wetlands Largely forage on wet mud surface. May probe	
Elseyornis melanops	Annelids: oligochaetes (earthworms)		
	Molluscs: gastropods (freshwater snails)		
	Crustaceans: ostracods, isopods (wood slaters)		
	Arachnids: mites	into surface up to about	
	Insects: Collembola; Odonata; Anisoptera (dragonflies);	5mm	
	Dermaptera; Hemiptera (Corixidae);Orthoptera (Acrididae.Grvllidae (crickets)): Lepidoptera	Widespread in small	
	(larvae);Diptera (Ephydridae, Tipulidae,Chironomidae (<i>Chironomus</i> , Muscidae); Coleoptera (water beetles, Carabidae, Dytisicdae, Hydrophilidae, Tenebrionidae, Chrysomelidae, Curculionidae); Hyemnoptera (Formicidae)	Murray–Darling Basin	
Hooded plover Thinornis rubricollis	Polychaetes, molluscs, crustaceans, insects, seeds and turions	Widespread around the southern coasts of	
	Plants: algae; Ruppia tuberosa seeds, turions	Australia, exploiting ocean beaches and adjacent	
	Annelids: polychaetes	coastal salt-lakes,	
	Molluscs: gastropods (Patelloidae, <i>Coxiella striata</i> ; bivalves (Mytilidae)	including Coorong On beaches forage in the wave wash zone, and around the exposed shoreline and into shallow water of coastal saline lagoons	
	Crustaceans: amphipods (Gammaridae; Talitridae); crabs		
	Insects: Odonata; Anisoptera; Coleoptera (Scarabaeidae; Staphylinidae; Curculionidae); Hemiptera; Diptera		

Species	Food items	Habitat needs	Summary/Comments
Red-kneed dotterel <i>Erythrogonys</i> <i>cinctus</i>	Seeds, molluscs, annelids, spiders and insects Plants: Ferns (<i>Marsilea</i> spores; <i>Lotus, Medicago,</i> <i>Trifolium</i> seeds) Annelids: (no details)	Margins of terrestrial wetlands, prefers freshwater wetlands with fine sediments over mudflats, particularly those inundated by rain or	Move to coastal areas when inland areas dry
Banded Janwing	Molluscs: gastropods (treshwater snails); bivalves Crustaceans: no details Arachnids; small spider Insects (aquatic): Ephemeroptera (nymphs); Odonata (nymphs); Dermaptera (Labiduridae); Hemiptera (Corixidae); Orthoptera (Cayllidae); Coleoptera (water beetles; Dytiscidae; Hydrophilidae; Tenebrionidae; Curculionidae) Diptera (Chironomidae); Lepidoptera; Hymenoptera (Formicidae)	floodwaters. May show a predilection to wetlands scattered with fringing or emergent vegetation but tends to avoid tree lined wetlands Forage around margins of wetlands gleaning or probing into surface of wet mudflats venturing into water no deeper than 15 mm. Does not feed on dry exposed mudflats	Widosproad across
Banded lapwing Vanellus tricolor	Seeds, foliage, molluscs, worms, insects, spiders Plants: Poaceae; Iridaceae; Liliaceae; Caryophyllaceae; Fabaceae; Asteraceae Molluscs: gastropods Annelids: oligochaetes Arachnids: Aranacae Insects: Blattodea; Isoptera (Termitidae); Orthoptera (Gryllidae, Acrididae, Tettigoniidae); Dermoptera; Hemiptera; Coleoptera (Carabidae- Clivinia, Scarabaeidae ; Elateridae; Tenebrionidae; Curculionidae; etc); Lepidoptera (Noctuidae caterpillars); Hymenoptera (Formicidae)	Generally on open short grasslands including agricultural lands used for grazing, including bluebush, saltbush areas Will occasionally forage in shallow water	Widespread across Murray–Darling Basin but rarely near wetlands, except visiting Lower Lakes and Coorong shorelines during hot summer weather
Masked lapwing Vanellus miles	Molluscs, worms, millipedes, centipedes, insects, crustaceans, occasionally seeds, foliage and frogs Plants: Poaceae, Panicoideae, Cyperaceae (seeds), Polygonaceae (seeds); Chenopodiaceae (seeds); Fabaceae (seeds) etc Annelids: oligochaetes Molluscs: freshwater gastropods Crustaceans: (no details) Arachnids: spiders Insects:Thysanura; Blattodea; Dermaptera; Hemiptera; Coleoptera Carabidae, Scarabaeidae, Elateridae; Tenebrionidae; Chrysomelidae; Curculionidae); Lepidoptera; Hymenoptera (wasps) Frogs (Hylidae)	Short grassed areas and at margins of swamps and wetlands, both fresh and saline Forage in short pasture on mud flats and in shallow water	

Species	Food items	Habitat needs	Summary/Comments	
Latham's snipe	Plants seeds, worms,spiders & insects, occasional other invertebrates	Migratory, breeds predominantly in Japan	Plant material accounts for about 44% diet by	
hardwickii	Plants: (seeds)Poaceae, Juncaceae, Cyperaceae, Polygonaceae, Boraginaceae, Fabaceae, Ranunculaceae, Caryophyllaceae, Onagraceae	In Australia, prefers freshwater wetlands with cover nearby. Will occupy	volume	
	Annelids: oligocaheates (earthworms)	any vegetation around wetlands including		
	Arachnids: spiders	tussock grasslands,		
	Insects: Odonata (Anisoptera); Ephemeroptera; Plecoptera; Orthoptera (Acrididae, Tettigoniidae, Gryllidae, Gryllacrididae)	reeds, sedges, lignum, saltmarshes, coastal scrubs, heaths and	reeds, sedges, lignum, saltmarshes, coastal scrubs, heaths and	
	Diptera (Stratiomyidae, Muscidae, Culicidae, Tipulidae), Lepidoptera, Coleoptera (Carabidae, Hydrophilidae, Dytiscidae, Scarabaeidae, Tenebrionidae, Curculionidae, Staphylinidae, Heteroceridae, Stratiomyidae, Tabanidae); Dermaptera; Hymenoptera (Formicidae)			
Black-tailed godwit	In Australia, limited data on diet—but primarily aquatic invertebrates	Migratory. Breeds northern hemisphere	Limited to the estuary region of the Murray	
Limosa limosa	Molluscs: bivalves (Hyriidae)	(Palaearctic)	Mouth, recorded in Lower Lakes occasionally	
	Insects: Coleoptera (Dytiscidae, Hydrophilidae)	Mainly coastal sheltered bavs. estuaries and	,	
	Outside Australian known to take annelids, crustaceans, arachnids, fish eggs and tadpoles	lagoons with intertidal mudflats. Infrequently reported far from coast		
		Will forage in water up to 15 cm deep		
Bar-tailed godwit <i>Limosa lapponica</i>	In Australia, limited data on diet—but primarily aquatic invertebrates	Migratory. Breeds northern Scandinavia, Duggia, Alagka	Limited to the estuary region of the Murray	
	Annelids: polychaetes (<i>Nerinides</i>); oligochaetes	Russid, Aldska	Mouth	
	Crustaceans : crabs (<i>Macrothalmus</i>)	intertidal mudflats and		
	Insects: Lepidoptera (Noctuidae larvae)	estuaries in Australia		
	Probably also takes molluscs	Probe into mud or glean mud surface for food in water up to 15 cm deep.		
		When breeding mainly takes insects		
Whimbrel	Mainly annelids and crustaceans	Migratory. Breeds	Essentially a marine	
Numenius	Annelids: polycheates	Alaska and Iceland, also Scandinavia etc	species, infrequently recorded in Murray Mouth	
phaeopus	Crustaceans: shrimps (Alpheidae, Synalpheus, Alpheus), crabs (Goneplacidae, <i>Litocheira</i> ; Hymenosomatidae, <i>Paragrapsis</i> ; Portunidae, <i>Nectocarcinus</i> ; Grapsidae, <i>Helice</i> ; Ocypodidae <i>Macrophthalmus, Ocypodes</i> ; Pilumnidae <i>Pliumnus</i> ;	In Australia uses intertidal mudflats along sheltered coasts and estuaries	estuary and Coorong	
	Leucosidae, <i>Philyra</i>)	Rarely recorded inland on		
	Fish: no details	saline lakes		
	Bird: tern chick			
Eastern curlew	Mainly crabs, small molluscs and insects	Migratory. Breeds Russia and north-east China In Australia—sheltered coasts and lagoons with extensive intertidal mudflats	Limited to the estuarine	
Numenius	Limited data for Australia		areas near Murray Mouth	
mauayascariensis	Molluscs: (no details)			
	Crustaceans: decapods (<i>Cherax</i> , Trypae) crabs (Heliciidae (<i>Helice, Paragrapsis</i>); shrimps (<i>Callinassa</i>)			
	Insects: Orthoptera (grasshoppers)			

Species	Food items	Habitat needs	Summary/Comments
Marsh sandpiper Tringa stragnatilis	No detailed studies. Aquatic insects, molluscs and crustaceans	Migratory. Breeds Palaearctic.	
ninga sa agnatais	Molluscs: no details	Wetlands of varying salinity including swamps,	
	Crustaceans: (taken ex-Australia)		
	Insects: Odonata; Anisoptera; Coleoptera (Carabidae); Hymenoptera (Formicidae)	on inundated floodplains, intertidal mudflats. In the Murray–Darling Basin mainly found along shores of Coorong, Lower Lakes and small numbers inland along Murray	
		Forage in shallow water wading up to thighs, generally picking prey off the surface of the water or mud	
Common	Molluscs, crustaceans, insects and fish	Migratory. Breeds in	Prominent in the Coorong
greenshank	Limited data from Australia		and around the shores of the Lower Lakes.
Tringa nebularia	Molluscs: bivalves; gastropods	of inland wetlands and	Small numbers along the Murray–Darling river valleys
	Crustaceans: cladocerans, ostracods, malocostracans (shrimps); anisostracans (<i>Parartemi</i> a); copepods	sheltered coastal habitats including estuaries and lagoons. Forage around edges of wetlands in shallow water	
	Insects: Zygoptera, Anisoptera, Orthoptera (Gryllidae, Acrididae) Hemiptera (Corixidae, Hydrophilidae); Coleoptera (Dytiscidae),Diptera, Lepidoptera (Noctuidae); Hymenoptera (Formicidae)		
	Fish: Galaxiidae (<i>Galaxis</i>); in Coorong Atherinidae (<i>Atherinosoma microstoma</i>)		
	Amphibians: frogs		
	Also take annelids outside Australia, also occasional reptile and small mammal		
Wood sandpiper <i>Tringa glareola</i>	Aquatic insects and molluscs reported for Australia— but no detailed studies. Also known to take seeds,	Migratory. Breeds Palaearctic	
	Algae, worms, crusiaceans, arachinus, iish anu nogs Mollusce: (no detaile)	Well-vegetated, shallow	
	Insects: Orthoptera (Acrididae); Hemiptera (Corixidae); Coleoptera; Diptera (Coelopidae); Hymenoptera (Formicidae)	typically with emergent plants and dense fringing habitat. Only rarely reported from brackish waters	
		Small numbers reported along the Murray	
		Forage on moist to dry mud at edge of wetland	
Terek sandpiper	Crustaceans and aquatic invertebrates. Known to take	Migratory, breeds Eurasia	 Only small numbers visit the Murray estuary, Coorong and Lower Lake area. Given propensity to forage on intertidal mudflats, unlikely to respond to environmental watering
Xenus cinereus	seeds, molluscs and arachnids elsewhere	Coastal, mostly intertidal	
	Incerte: Coleontera Dintera	estuaries, occasionally on	
	insects: Coteoptera, Diptera	brackish coastal swamps and lakes	

Species	Food items	Habitat needs	Summary/Comments
Common sandpiper	Molluscs, crustaceans and aquatic insects, but known to take seeds, worms, arachnids, fish and frogs and	Migratory. Breeds in Europe and Asia	
Actitis hypoleucos	tadpoles elsewhere	Wide variety of wetlands with varying salinities, often at estuaries	
	No detailed studies of diet in Australia		
	Molluscs: bivalves	Only small numbers in	
	Crustaceans: amphipods; crabs	Murray–Darling system,	
	Myrmeleontidae); Coleoptera (Staphylinidae); (Myrmeleontidae); Coleoptera (Staphylinidae, Scarabaeidae, Tenebrionidae, Chrysomelidae, Curculionidae); Diptera (Coelopidae, Tabanidae); Hymenoptera (Formicidae)	most reports from Murray Mouth estuary and around Lakes	
Ruddy turnstone	Mainly aquatic invertebrates	Migratory. Breeds	
Arenaria interpres	Echinodermata: no details	northern coasts of Furone, Asia and North	
	Annelids:no details	America	
	Molluscs: gastropods (<i>Littorina, Modiolus</i>); bivalves Mytiliodae (mussels)	Mainly uses rocky coastal areas, occasionally in	
	Crustaceans: barnacles; amphipods (Talitridae); isopods; crabs (Helice)	estuaries Only small numbers	
	Insects: Coleoptera (Curculionidae); Hymenoptera (Formicidae)	reported from Murray estuary	
	Fish: Exocoetidae		
Red knot <i>Calidris canutus</i>	Wide variety of aquatic invertebrates (worms, molluscs, crustaceans) while in Australia, but also takes seeds, bulbs etc of plants elsewhere	s, Migratory. Breeds high Arctic Mainly tidal mudflats and sheltered bays, and	Only small numbers recorded in Murray–Darling Basin—
	Annelids: polychaetes (<i>Abarenicola</i>); oligochaetes		mainly in Coorong and Murray estuary
	Molluscs: bivalves (Macoma, Siliqua); gastropods (Nassiridae, <i>Nassarius</i>)	estuaries, occasionally on terrestrial saline lagoons,	
	Crustaceeans: amphipods, decapods (prawns)	Tarety freshwater swamps	
	Insects: Diptera		
	Fish: small flounder		
Sanderling	No detailed studies in Australia	Migratory. Breeds	In Murray–Darling Basin,
Calidris alba	Annelids: no details	While in Australia mostly	beaches opposite the
	Arachnids: spiders	coastal and on exposed	Coorong, and the Murray
	Insects: Coleoptera (Scarabaeidae <i>Aphodus</i>); Lepidoptera (larvae); Hymenoptera (Formicidae)	ocean beaches, but also using sheltered estuaries. Rarely moves away from coast	estuary
		Foraging on ocean beaches mainly in wave wash zone	
Red-necked stint	Mainly aquatic invertebrates and seeds of plants	Migratory, breeds in	Within the
Calidris ruficollis	Plants: (seeds): Ruppia, Polygonum, Heliotropium, Trifolium	Siberia and northwestern Alaska. Mostly coastal in sheltered bays. lagoons	Murray–Darling Basin, majority of birds along shorelines of the Coorong
	Annelids: polychaetes (Orbiniidae; Nereidae, <i>Ceratonereis</i>)	and estuaries with and without tidal mudflats	and Lower Lakes
	Molluscs: bivalves, gastropods (Coxiella, Assiminea)	Forage primarily along	
	Crustaceans: amphipods (Paryalella), ostracods (Australocypris), amphipods (<i>Paracorphium</i>)	water line and into water ca 2.5 m deep, and within 30 cm of the shoreline	
	Arachnids: spiders	Jab and probe with bill	
	Insects (mainly larvae): Diptera (Tipulidae, Chironomidae, Blephariceridae), Neuroptera; Hemiptera (Aphidae); Coleoptera (Scarabaeidae, Dytiscidae); Lepidoptera (Noctuidae); Hymenoptera (Formicidae)	into sediment—upto 2 cm, also taking prey from water column	

Species	Food items	Habitat needs	Summary/Comments
Long-toed stint Calidris subminuta	No data on diet in Australia Diet assumed to be similar to Red-necked Stint, consisting of aquatic molluscs, crustaceans and insects, plus seeds of plants	Migratory, breeds in Palaearctic. Prefers freshwater or brackish wetlands, including river floodplains	Only very small numbers in Australia
Sharp-tailed sandpiper <i>Calidris acuminata</i>	Aquatic invertebrates (worms, molluscs, crustaceans, insects) and seeds of plants Plants (seeds): Ruppiaceae (<i>Ruppia</i>); Poaceae (<i>Paspalum</i>); Fabaceae (<i>Trifolium, Medicago</i>), Polygonaceae (<i>Polygonum</i>), Chenopodiaceae (<i>Chenopodium</i>) Annelids: polychaetes (Nereidae, <i>Ceratonereis</i>) Molluscs: bivalves (Hyriidae) gastropods (<i>Smargadella, Coxiella</i>) Crustaceans: ostracods (<i>Australocypris</i>); amphipods (<i>Parhyadella</i>) Insects: Odonata, Orthoptera (Acrididae); Dermaptera; Hemiptera: Coleoptera (Carabidae, Dytiscidae, Hydrophilidae, Tenebrionidae, Chrysomelidae, Curculionidae]; Diptera (Tipulidae, Chironomidae, Anisopodidae); Hymenoptera (Formicidae)	Migratory. Breed north- eastern Siberia Feed mostly at edge of water on mudflats, out to water up to 5 cm deep. Probe into sift sediments to about 1.3 cm Within the Murray-Darling Basin, majority of birds found along shorelines of Coorong and Lower Lakes in fresh, brackish, estuarine and hypermarine systems	
Curlew sandpiper Calidris ferruginea	Mainly aquatic invertebrates, occasionally seeds of plants Plants: Ruppiaceae (<i>Ruppia</i> seeds) Annelids: polychaetes (Nereidae, <i>Ceratonereis</i>) Molluscs: bivalves; gastropods (Hydrobiidae) Crustaceans: amphipods (Paracorophium), crabs Insects(larvae, pupa): Coleoptera (Dytiscidae, Scarabaeidae); Diptera Stratiomyidae, Chironomidae)	Migratory, breeds in Siberia. Mainly uses intertidal mudflats, in sheltered coastal areas, estuaries, also non-tidal lagoons, swamps and lakes near coasts Usually forage in water 1–3 cm deep but up to belly (6cm). Also forage on bare wet mud at water's edge. Glean from mud surface or pick from water column, but will insert bill to 4 cm into mud sediments Size of prey taken— molluscs 3–5mm x 1–3 mm; annelids up to 80 mm in length	Dietary information largely from marine systems. In Murray–Darling Basin the majority of birds use the Coorong and to a lesser extent the Lower Lakes Polychaetes, chironomids and other aquatic invertebrates (molluscs, crustaceans) key foods in these areas

Species	Food items	Habitat needs	Summary/Comments
Species Silver gull Larus novaehollandiae	Food itemsOpportunistic scavengers, taking a wide variety of aquatic and terrestrial foods both plant and animal, including human refusePlants: Monocots: Iridaceae (Romulea corms); Juncaceae (Juncus seeds) Poaceae (seeds, foliage); Dicots: - corms Oxalidaceae - seeds: Polygonaceae; Asteraceae; Crayophyllaceae; Fabaceae; Papavaeraceae; Portulacaceae; Rosaceae; Solanaceae; Aizocaceae; fruits: Araliaceae; Chenopodiaceae; Epacridaceae; Myoporaceae; RubiaceaeCnidarians: hydrozoansAnnelids: polychaetes (Nereis); oligochaetes [Lumbricus]Molluscs: gastropods; bivalvesCrustaceans: barnacles; ostracods; notostracans; 	Habitat needs Widespread across marine and freshwater systems, but largest concentrations around coasts near human settlements Some fish and crustaceans caught when other birds drive birds to surface or into shallows, steal fish and other prey from other birds	Summary/Comments
	Reptiles: turtle (eggs & young), snake, skinks Birds: eggs nestlings		
	Mammals: Mus		
Gull-billed tern Sterna nilotica	Terrestrial and aquatic invertebrates, fish, reptiles and mammals	Only small numbers spread along the River Murray	
	Annelids: worms	Forage by hawking insects	
	Crustaceans: decapods treshwater crayfish, prawns, crabs	in the air, by dipping to take items off the surface of the water or ground; and only occasionally	
	Incoste, Orthontora (grasshonnore, Gryllidao,		
	Acrididae); Hemiptera (Corixidae, Gerridae); Coleoptera (Dytiscidae); Lepidoptera (moths); Diptera; Hymenoptera (Formicidae)	plunging	
	Fish: Anguillidae: Clupeidae		
	Reptiles: lizards		
	Mammals: rodents Mus		
Caspian tern	Predominantly fish, but also some crustaceans	Mainly found around	Given small numbers
Sterna caspia	Crustaceans: decapods (Alpheidae, Penaeidae)	coasts in protected bays and coastal ladoons and	along the Murray, unlikely to respond dramatically to environmental
	Insects: Orthoptera (Gryllidae)	lakes, both fresh and	
	Fish: Apogonidae; Antherinidae; Exocaetidae; Lutjanidae; Salmonidae; Hemiramphidae: Pomacentridae, Clupeidae, Melanotaeniidae; Mugilidae, Cyprinidae (<i>Cyprinus carpio</i>), Pleuronectidae, Terapontidae	saune systems. Small numbers along the lower Murray. Will visit inland ephemeral salt lakes	watering of individual wetlands
		When foraging prefers open sheltered shallow water near margins. May avoid turbid water	

Species	Food items	Habitat needs	Summary/Comments
Crested tern Sterna bergii	Predominantly marine fish, but also takes squid and occasionally prawns	Widely distributed around the Australian coast and	Essentially a marine species that is unlikely to
	Molluscs: cephalopods Sepiidae (<i>Sepia</i>); Ommastrrephidae (<i>Stenoteuthis</i>)	beyond. A largely marine species that also fishes in estuaries and coastal	environmental flows
	Crustaceans: decapods (crabs, euphasid prawns)	lagoons	
	Insects: Coleoptera, Diptera, Hymenoptera (rarely)	Fishes by plunging into	
	Fish: wide variety of largely marine fish from 32 families. Amongst the fish were Anguillididae; Atherinidae (incl. <i>Atherinosoma microstoma</i>); Engraulididae (anchovy); Hemirhampihidae (garfish); Clupeidae (<i>Sardinops</i>), Gobiidae, Mugilidae (mullet <i>Aldrichetta forsteri</i>)	the water from 7–10 m, penetrating to 0.5 m	
Fairy tern	Entirely fish	Sheltered coastal	Within the
Sterna nereis	Fish: Anguillidae (elvers, <i>Anguilla</i>),; Carangidae (skipjack); Clupeidae (sardines); Hemiramphidae (garfish), Mugilidae (mullet); Pleuronectidae (flounder, <i>Rhombosolea</i>); Retropinnidae (smelt); Engraulididae (anchovy <i>Engraulis</i>); Gobiidae (<i>Favonigobius</i>); also Atheriniformes (hardyhead, <i>Atherinosoma microstoma</i> in Coorong)	wetlands—estuaries, lagoons and ocean beaches. Will visit fresh and saline wetlands close to coast	Murray–Darling Basin limited to the Coorong and Murray Mouth region, occasionally in Lower Lakes
		Take fish from surface of water by plunging from heights of 5–10 m	
		Presence of occasional mollusc, crustacean in stomachs probably from their fish prey	
Whiskered tern Chlidonias	Mainly fish, aquatic and terrestrial invertebrates, some frogs	Prefers shallow terrestrial freshwater swamps,	Mobile species with very flexible diet with some propensity to respond to floodwaters
hybridus	Crustaceans: shrimps <i>Macrobrachium</i> , freshwater crayfish, notostracans	lagoons and lakes usually with much submerged or	
	Arachnids: Aranae (spiders)	use flooded paddocks,	
	Insects: Odonata; Zygoptera; Anisoptera; Orthoptera (Acrididae); Hemiptera (Cicadellidae; Corixidae; Gerridae; Notonectidae; Belostomatidae); Coleoptera (Carabidae, Dytiscidae, Hydrophyllidae, Scarabaeidae,	saline and hypersaline lakes, and forage over terrestrial vegetation (pastures)	
	Chrysomelidae, Curculidae); Diptera; Lepidoptera (Noctuidae); Hymenoptera (Formicidae)	Forage by plunging into water, by skimming	
	Fish: Ambassidae (<i>Ambassis</i>) Atherinidae; Plotosidae; Cyprindae (<i>Carassius auratus</i>); Poecilidae (<i>Gambusia</i> <i>affinis</i>)	the surface to take invertebrates from on or just below the surface of the water, and by hawking	
	Amphibians: frogs (Hylidae, <i>Litoria</i>) tadpoles	insects in air or off	
	Other vertebrates (rarely); lizard, bird, mammal (<i>Mus</i>)	vegetation of terrestrial systems	

Species	Food items	Habitat needs	Summary/Comments
Sacred kingfisher	Wide variety of terrestrial invertebrates, but also	Inhabits a wide variety of	Flexible diet—not dependent on aquatic resources, but often forages around margins of wetlands along River
Todiramphus sanctus	odiramphus frogs, tadpoles, lizards, etc Plunge dive into shallow	Plunge dive into shallow	
Sanotas	Annelids: oligochaetes	water for aquatic prey	
	Crustaceans: decapods Helice, isopods, branchiopods,	Uses freshwater habitats	
	Chilopods: centipedes	with fringing woodland vegetation, and intertidal	
	Arcahnids: spiders	Absent from hypersaline systems	
	Insects: Odonata; Orthoptera; Hemiptera; Coleoptera; Dermaptera; Diptera; Lepidoptersa; Hymenoptera; Neuroptera		
	Fish: Cyprinidae (<i>Carassius auratis</i>); Poeciliidae (<i>Gambusia</i>)		
	Amphibians: frogs, tadpoles		
	Reptiles: Scincidae (<i>Leiolopisma, Lampropholis;</i> <i>Bassiana; Sphenomorphus</i>); Agamidae (<i>Amphibolurus</i>); snakes		
	Mammals: <i>Mus</i>		



