A marine habitat and biodiversity inventory for AMLR region: chlorophyll *a* and fish

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Cover photo: Deep Creek estuary on Fleurieu Peninsula (Photo: Travis Elsdon)

Abstract

Estuaries are generally areas of exceptionally high primary and secondary productivity, but are also some of the most degraded habitats on earth. Chlorophyll *a* (an indicator of phytoplankton) and fish (higher trophic level organisms) were used as indicators of ecosystem health in this study. While 36 estuaries are recognised in the Adeladie Mt Lofty Ranges region only 8 to 11 estuaries were sampled between one and four times over a one year period. In addition, past studies were investigated and data compiled to determine fish species that inhabit estuaries within the Adelaide Mt Lofty Ranges region. A range of environmental and nutrient conditions were also measured in estuaries and over time. Chlorophyll *a* showed significant variation among estuaries and across time, with the mean values ranging from 0.3 to 5.2 μg/L. Thirty six species of fish were sampled from estuaries as part of this study, but this number increased to 81 when other studies were included. Five species made up over 90% of all individuals sampled. The most speciose family were the Gobiidae. No one species was found from all eleven of the estuaries sampled; the range size (or number of estuaries in which a species was found) ranged from 1 to 9 estuaries. Overall, seventeen estuaries within the region have had some sampling undertaken. The most speciose estuary was the Port River Barker Inlet (65 species) followed by Onkaparinga River (45 species), and the least speciose was Blowhole Creek (2 species), Deep Creek and Waitpinga estuary (3 species each). Yellow-eye mullet (*Aldrichetta forsteri*) occurred in 16 of the estuaries, blue spot goby (*Pseudogobius olorum*) were found in 15 and *Galaxias maculatus* were found in 14. Twenty species (25% of all species) were classed as duplicates (occurring in just two of the estuaries sampled) and twenty four species (30%) were classed as uniques (occurring in just one estuary). These data can now be utilised in conservation planning to decide important estuaries for protection.

Introduction

Estuaries are critical transition zones linking land, freshwater and the sea, but estuaries are spatially and temporally complex due to mixing of physico-chemical processes. Estuaries are generally regarded as areas of exceptionally high primary and secondary production (Beck et al. 2001), and as such are extremely important ecosystems. Many organisms utilise estuaries for the food sources and shelter, which they provide, for at least some part of their life history. Despite, the acknowledged importance of estuaries, they are some of the most degraded habitats on earth (Edgar et al. 2000).

Degradation of estuaries continues today, as most estuaries are situated close to human population centres, and the hydrology of their catchments has been significantly altered as native vegetation is cleared and freshwater flows are reduced. Estuaries are also likely to be greatly affected by global climate change, which will impact rainfall, causing increased frequency and severity of low flow in some regions particularly those that currently have low rainfall and intermittent periods of drought (Easterling et al. 2000, Lioubimtseva 2004). Pollution, sediment and nutrient levels have increased substantially within estuaries since European settlement, thereby altering water quality and affecting habitats such as seagrass, mangroves and saltmarsh (Edgar et al. 2000). Natural assemblages, particularly those of fish, have been compromised (Edgar et al. 2000).

A range of environmental indicators have been used to evaluate the condition of aquatic systems. These have typically included physical, chemical and biological measures (Harrison & Whitfield 2004). Biological measures are frequently regarded as good indicators because they integrate changes across a range of environmental parameters, and may be the only practical way of measuring certain impacts (Harrison & Whitfield 2004). Rarely is it possible to evaluate all biotic components, and therefore various groups of organisms have been proposed as good environmental indicators (Harrison & Whitfield 2004). Fishes and macroinvertebrates have generally received the greatest attention in estuarine systems (e.g. Deegan et al. 1997, Van Dolah et al. 1999). The advantages and disadvantages of using fish have been summarised by Harrison & Whitfield (2004) (see Table 1).

Table 1. Summary of advantages and disadvantages of using fish as indicators of ecosystem health in estuaries. Table summarised from Harrison & Whitfield (2004).

Advantages	Disadvantages
Present in most aquatic systems (except highly polluted waters)	Selective nature of sampling gear for certain habitats, and for certain sizes and species of fish
Relatively easy to identify	Mobility of fish on seasonal and diel time scales can lead to sampling bias
Most samples can be processed in the field and fish returned live to the water	Large sampling effort often required to adequately characterise fish assemblages
Life history and environmental response information more likely to be available for fish then other taxa	Some fish species may also be influenced by stocking, recreational and commercial fishing
Exhibit physiological, morphological or behavioural responses to stresses	Being highly mobile fish can move away from disturbance
Mobile therefore sensitive fish species may avoid stressful environments leading to measurable population changes	May be tolerant of substances chemically harmful to other life forms
Can range over considerable distances therefore have ability to integrate diverse aspects of relatively large scale habitats	Estuarine environments that have been physically altered may still contain diverse fish assemblages
Comparatively long-lived therefore provide long-term record of environmental stress	Represent higher trophic levels therefore lower level organisms may provide an earlier indication of water quality problems
Include species from a variety of trophic levels therefore reflect affects at all levels of food web	
Public likely to relate more directly to information about fish assemblages (because of recreational and commercial fishing)	

The widespread advantages of using fish as environmental indicators generally outweigh the disadvantages, and many of the disadvantages also apply to other groups (e.g. invertebrates) (Harrison & Whitfield 2004). A key disadvantage of using fish is that they represent higher trophic levels. This disadvantage can be overcome by also investigating chlorophyll *a*. Changes in chlorophyll *a* in estuaries are most likely to represent changes in phytoplankton abundance, distribution, or composition (Paerl et al. 2005). It can also be used as an indicator of trophic status, maximum photosynthetic rate and water quality (ANZECC/ARMCANZ 2000). High levels of chlorophyll *a* are generally used to indicate poor water quality, although more important is the persistence over time of high levels.

Within South Australia, estuaries have been defined by the South Australian Natural Resources Management Act (2004) as "a partially enclosed coastal body of water that is either permanently, periodically, intermittently or occasionally open to the sea within which there is a measurable variation in salinity due to the mixture of seawater with water derived from on or under the land". Most knowledge of South Australian estuarine systems is derived from a few large heavily populated estuaries, such as Port River Barker Inlet and Onkaparinga River. An extensive study is currently underway in the Coorong system (see Coorong Lower Lakes and Murray Mouth website: http://www.csiro.au/partnerships/CLLAMMecologyCluster.html), which is significantly larger than any of the other estuaries in South Australia. Less information exists for the smaller, more ephemeral systems that are common throughout the Adelaide Mt Lofty Ranges region, although this is starting to change.

The objective of this study was to determine chlorophyll *a* and small fish in estuaries of the Adelaide Mt Lofty Ranges. Species richness (the number of species) and abundance of fish were recorded since these parameters form the basis of numerous models on community structure (e.g. species-area relationship) (Magurran 2004). In addition, we also utilised past studies to ensure that the species list for each estuary was as comprehensive as possible.

Materials and methods

Estuaries sampled

Between eight and eleven estuaries within the Adelaide Mt Lofty Ranges region were sampled from one to four times spanning a 1 year period (April 2007 – February 2008). In addition, fish that were sampled from 13 estuaries during November and December 2005 (Sautter 2006), and fish from 7 estuaries sampled during March and April 2004 (Rowntree 2004) were also included in presence/absence tables. A recent publication (Gillanders et al. 2008) on estuaries in Gulf St Vincent, Investigator Strait and Backstairs Passage also lists species found in various estuaries based on records lodged in the South Australian Museum, as well as from peer-reviewed literature and unpublished reports. Information from that publication was also utilised in the fish presence/absence table.

Environmental parameters (temperature, salinity, pH, dissolved oxygen, and chlorophyll *a*), and fish were sampled along the length of each estuary. Locations along the estuary were chosen to represent the freshwater (as far up the estuary as possible), brackish and marine (close to the estuary mouth) parts of the estuary such that 3 sites within each location were sampled.

Environmental and nutrient sampling

A YSI Sonde (model 6600) was used to sample temperature, salinity, pH and dissolved oxygen at each site within each estuary. At the same sites, water samples were collected for analysis of nutrients (n=2 per site), and chlorophyll *a*.

For chlorophyll *a*, a 1 L water sample was collected from each site, filtered through a Whatman GF/C filter and the filter frozen awaiting subsequent analysis. Chlorophyll *a* was determined by resuspending the GF/C filter in 10 mL of 100% ethanol at 70° C for 5 minutes and sonicating for 30 sec. Samples were then cooled rapidly on ice and analysed using a spectrophotometer at 665 and 750 nm, using a blank of 100% ethanol. Equations from Golterman et al. (1978) were used to determine the amount of chlorophyll *a* in each sample.

Fish sampling

Fish were sampled from each site using a 7 m seine net with a 1.7 m drop and 3.5 mm diameter fibreglass square mesh. The net had a cod end in the middle, float line at the top and heavily weighted lead line to increase sampling efficiency of bottom-dwellers and vegetated areas. After each seine, fish were collected from the net, and if identifiable in the field, fish were enumerated and returned to their collection site. Otherwise, fish were collected, cold euthanized and stored frozen prior to processing. In the laboratory, samples were defrosted and identified to the level of species.

Species richness (number of species) and abundance (total number of individuals) of each species were quantified for each site and enumerated for each estuary.

Statistical analyses

For chlorophyll *a* and fish, data were analysed using a two factor ANOVA with estuary and time as random factors. Only estuaries that were sampled during all four times were included. Thus, Gawler River, Port River Barker Inlet and Deep Creek were excluded for both chlorophyll *a* and fish, and Carrickalinga was also excluded for fish. Fish assemblages were analysed using a two factor PERMANOVA, that was the same design as the ANOVA analyses. Data were fourth root transformed and Bray-Curtis dissimilarity measures used for the PERMANOVA. If significant differences were found, post hoc tests were used to determine where differences lay.

Results & Discussion

The State estuaries policy recognises 36 estuaries within the Adelaide Mt Lofty Ranges region (Table 2). Most of these estuaries are small creeks that are frequently not connected to the ocean, and have relatively small catchment areas (>60% have catchment areas less than $50km^2$). Several estuaries (e.g. Patwalonga) have rock walls near the entrance preventing their mouths from silting over. With the exception of the estuaries with breakwalls near their mouths only three estuaries (Gawler River, Port River Barker Inlet and Onkaparinga) are permanently open. The entrance of several estuaries is unknown including ones on private land (e.g. Yohoe Creek, New Salt Creek) and those where there is no vehicle access (Balaparudda Creek, Coolawang Creek). The Mediterranean climate of South Australia (e.g. dry summer, wet winter but low rainfall) means that our estuaries are more similar to southern Africa and southwest Australia then to many European or North American estuaries.

The geomorphology of estuaries (e.g. whether the mouth is permanently open or not) plays a major role in whether fish can enter or exit estuaries. It also influences a number of environmental parameters especially salinity since the status of an estuarine mouth influences whether marine processes can influence the estuary and whether freshwater can exit the estuary. If the estuarine mouth is closed a considerable build-up of freshwater may occur within the estuary during flood events

(Gillanders 2007). Sand bars typically form over the estuary mouth during summer and autumn periods and are breached during late winter and early spring (see for example Figure 1).

Figure 1. Waitpinga estuary showing a build-up of sand over the entrance in April 2007 (Photo: Bronwyn Gillanders).

Environmental and nutrient data for 11 of the larger estuaries in the region is shown in Table 3. Temperature was lowest during winter ranging from 10.02 °C in Deep Creek to 14.17 °C in the Onkaparinga River. Intermediate values were generally found during autumn and spring (17.7-22.96 °C) and highest values were found in summer (21.67-26.11 °C). An exception was the Myponga River, which is spring fed, during summer where temperatures averaged 19.38 °C. Temporal variation in temperature is largely driven by seasonal patterns. Solar heating generally contributes to heating of estuarine waters especially in small, shallow estuaries such as many in the Adelaide Mt Lofty Ranges.

Salinity ranged from less than 1 (Carrickalinga River, Yankalilla River, Deep Creek and Hindmarsh River during winter) to greater than 40 (Gawler River, Port River Barker Inlet and Onkaparinga River) (Table 3). Yankalilla River had significantly higher salinity then these values during autumn (83), and whilst all sites had higher salinity values we recommend further sampling to check their accuracy. Whilst our results represent a summary of the overall salinity within each estuary, there can also be significant variation along an estuary, as well as from shallow to deeper waters (i.e. vertically stratified). Large standard errors around the mean (e.g. 1-5 for Onkaparinga, Bungala, Yankalilla, Inman and Hindmarsh at some times) likely indicate variation along the estuary.

A range of dissolved oxygen values were found including an average value at Yankalilla River during autumn that was less than 4 mg/L indicating hypoxic waters (Table 3). In general, however, waters were well oxygenated. Low oxygen is not usually a problem in well mixed estuarine waters. If primary production, nutrient concentrations or organic loading become excessive, bottom waters may become hypoxic (i.e. oxygen depleted where dissolved oxygen is less than 4 mg O_2 L^{-1}) (Paerl 2006). Such a scenario is more likely if the water column is stratified by temperature and salinity (Buzzelli et al. 2002). pH values ranged from 7.24 to 8.73 (Table 3). Most organisms are adapted to live in a pH from 5 to 9, and the pH of marine waters is close to 8.2, whereas freshwaters generally range from 6.5-8. An overabundance of algae in the system can cause pH levels to increase. Low pH values (e.g. 2-5) may represent acid sulphate drainage. If pH values are below 7 or above 9, then physiological processes may be adversely affected (Turner et al. 2004).

Table 2. Summary of latitude and longitude, entrance conditions and catchment area of Adelaide Mt Lofty Ranges estuaries. Entrance conditions are open (O), intermittently open (I) or possess breakwalls or training walls that keep the entrance open (T). Note the position of Cooalinga Creek and Urumbirra Creek is not marked on 1:50000 topographic maps.

Estuary	Latitude (S)	Longitude (E)	Entrance conditions	Catchment area (km^2)
Gawler River	34 4016.79	138 2612.08	O	1105
Port River Barker Inlet	34 4553.94	138 2854.97	O	346
West Lakes	34 5308.43	138 2915.51	T	130
Torrens River	34 5606.93	138 2954.56	I	500
Patwalonga Basin	34 5830.13	138 3043.74	T	212
Field River	35 0501.44	138 2937.19	I	55
Christie Creek	35 0742.47	138 2812.15	I	38
Onkaparinga River	35 0947.31	138 2814.52	O	554
Pedler Creek	35 1159.63	138 2815.72	I	106
Maslin Creek/Catchment	35 1404.00	138 2814.93	I	34
Willunga Creek/Catchment	35 1528.81	138 2744.07	I	30
Aldinga Catchment	35 1907.79	138 2654.16	I	49
Sellicks Creek/Catchment	35 2933.63	138 2636.63	I	7
Myponga River	35 2227.29	138 2249.02	I	139
Carrickalinga Creek	35 2546.01	138 1850.90	I	56
Bungala Creek	35 2651.49	138 1805.34	I	49
Yankalilla River	35 2759.22	138 1746.35	I	83
Congeratinga-Anacotilla Rivers	35 3006.07	138 1432.21	I	38
Yattagolinga River	35 3128.79	138 1125.42	I	25
Yohoe Creek	35 3228.84	138 0843.19	Unknown	18
New Salt Creek	35 3303.87	138 0802.40	Unknown	16
Fishery Creek	35 3758.21	138 0656.66	I	8
Cooalinga Creek			Unknown	4
Blowhole Creek	35 3914.70	138 0920.12	I	12
Deep Creek	35 3909.85	138 1441.21	I	41
Boat Harbour Creek	35 3820.10	138 1654.70	I	20
First Creek	35 3818.05	138 1900.76	I	5
Tunkalilla Creek	35 3820.99	138 2032.90	I	26
Callawonga Creek	35 3818.83	138 2315.59	I	19
Balaparudda Creek	35 3814.90	138 2405.62	Unknown	13
Coolawang Creek	35 3741.68	138 2552.48	Unknown	41
Waitpinga Creek	35 3758.40	138 2938.51	I	61
Inman River	35 3341.23	138 3638.35	I	192
Hindmarsh River	35 3239.31	138 3745.67	I	112
Urumbirra Creek			Unknown	15
Middleton catchment	35 3047.20	138 4234.75	I	16

Table 3. Summary of environmental data (mean ± SE) for Adelaide Mt Lofty Ranges estuaries sampled between Autumn 2007 and Summer 2008.

Estuary	Time	Temperature (°C)	Salinity	Dissolved oxygen (mg/L)	pH	Chl *a* (µg/L)
Gawler River	1 Aug 2007	13.26 ± 0.27	38.46 ± 0.20	6.80 ± 0.57	8.37 ± 0.03	0.32 ± 0.09
	21 Feb 2008	21.67 ± 0.46	42.53 ± 0.61	4.30 ± 0.16	8.15 ± 0.05	0.52 ± 0.09
Port River Barker Inlet	12 Jul 2007	13.08 ± 0.33	39.52 ± 0.08	12.18 ± 0.35	7.91 ± 0.09	0.34 ± 0.03
	20 Feb 2008	23.91 ± 0.31	42.62 ± 0.38	5.06 ± 0.39	8.18 ± 0.10	0.59 ± 0.11
Onkaparinga River	10 Apr 2007	21.50 ± 0.39	46.07 ± 0.51	6.28 ± 0.20	7.97 ± 0.04	0.54 ± 0.10
	15 Jun 2007	14.17 ± 0.45	22.20 ± 3.63	13.22 ± 1.11	8.21 ± 0.10	1.31 ± 0.59
	25 Oct 2007	18.52 ± 0.55	32.91 ± 0.83	12.51 ± 0.43	8.32 ± 0.13	0.37 ± 0.10
	16 Jan 2008	23.27 ± 0.17	36.65 ± 0.57	7.32 ± 0.51	8.05 ± 0.13	1.27 ± 0.57
Myponga River	16 Apr 2007	18.54 ± 0.31	2.45 ± 0.13	8.35 ± 0.35	7.99 ± 0.05	0.61 ± 0.14
	20 Jun 2007	13.22 ± 0.09	3.86 ± 0.24	13.79 ± 0.77	8.36 ± 0.04	1.45 ± 0.58
	11 Oct 2007	19.18 ± 0.16	5.42 ± 0.16	18.14 ± 0.48	8.45 ± 0.09	1.38 ± 0.47
	17 Jan 2008	19.38 ± 0.21	4.83 ± 0.19	11.83 ± 0.21	8.08 ± 0.06	0.42 ± 0.03
Carrickalinga River	9 Apr 2007	19.91 ± 0.08	82.97 ± 0.15	5.31 ± 0.14	7.85 ± 0.10	1.47 ± 0.18
	12 Jun 2007	12.22 ± 0.69	0.64 ± 0.13	11.82 ± 0.35	7.24 ± 0.45	0.90 ± 0.14
	18 Oct 2007	18.30 ± 0.25	10.33 ± 0.11	12.18 ± 0.62	8.15 ± 0.25	1.05 ± 0.36
	15 Jan 2008	26.11 ± 0.29	30.40 ± 0.63	8.71 ± 0.92	8.28 ± 0.04	0.74 ± 0.08
Bungala River	12 Apr 2007	19.91 ± 0.17	33.06 ± 0.13	5.52 ± 0.17	8.08 ± 0.01	2.56 ± 0.14
	21 Jun 2007	12.40 ± 0.22	5.67 ± 0.80	16.53 ± 1.19	8.35 ± 0.03	0.43 ± 0.13
	15 Oct 2007	22.96 ± 0.65	14.77 ± 2.10	10.65 ± 0.23	8.29 ± 0.09	1.40 ± 0.21
	19 Feb 2008	25.17 ± 0.34	35.55 ± 0.14	8.09 ± 0.61	8.64 ± 0.02	2.80 ± 0.21
Yankalilla River	17 Apr 2007	20.14 ± 0.78	37.20 ± 0.27	3.86 ± 0.98	7.57 ± 0.01	1.49 ± 0. 56

	13 Jun 2007	11.35 ± 0.27	0.55 ± 0.02	11.86 ± 0.20	7.73 ± 0.17	3.48 ± 2.45
	12 Nov 2007	21.16 ± 0.69	19.25 ± 1.25	10.05 ± 0.52	7.92 ± 0.07	0.76 ± 0.23
	15 Jan 2008	22.66 ± 0.44	33.74 ± 0.72	7.08 ± 0.63	7.55 ± 0.10	1.47 ± 0.16
Deep Creek	11 Jun 2007	10.02 ± 0.30	0.69 ± 0.02	12.72 ± 0.24	7.36 ± 0.07	0.46 ± 0.10
Waitpinga River	13 Apr 2007	20.31 ± 0.31	16.04 ± 0.04	8.81 ± 0.49	8.50 ± 0.03	3.07 ± 0.30
	20 Jun 2007	10.73 ± 0.10	4.52 ± 0.22	14.32 ± 0.31	8.62 ± 0.05	5.21 ± 0.22
	22 Oct 2007	18.22 ± 0.10	9.74 ± 0.04	13.26 ± 0.23	8.73 ± 0.01	4.75 ± 1.03
	13 Jan 2008	22.23 ± 0.09	11.23 ± 0.04	11.28 ± 0.12	8.56 ± 0.03	3.16 ± 0.24
Inman River	18 Apr 2007	19.93 ± 0.34	11.87 ± 0.22	4.96 ± 0.69	7.88 ± 0.07	1.86 ± 0.23
	21 Jun 2007	12.68 ± 0.16	7.20 ± 2.25	8.76 ± 1.38	7.71 ± 0.05	0.86 ± 0.19
	13 Nov 2007	21.71 ± 0.23	17.09 ± 1.80	8.22 ± 0.48	7.79 ± 0.08	1.92 ± 0.56
	18 Feb 2008	23.54 ± 0.36	16.56 ± 1.34	4.19 ± 0.36	7.97 ± 0.04	1.67 ± 0.46
Hindmarsh River	19 Apr 2007	17.70 ± 0.13	12.76 ± 0.37	5.69 ± 0.48	7.91 ± 0.04	3.24 ± 1.15
	6 Jul 2007	10.58 ± 0.05	0.73 ± 0.12	10.50 ± 0.21	7.54 ± 0.04	1.01± 0.04
	15 Nov 2007	21.68 ± 0.53	18.12 ± 4.26	8.26 ± 0.61	8.17 ± 0.17	2.19 ± 0.66
	18 Feb 2008	23.05 ± 0.42	10.41 ± 0.54	8.10 ± 076	8.25 ± 0.04	2.50 ± 0.21

Chlorophyll **a**

Significant variation in chlorophyll *a* was found among estuaries and times, although not all estuaries showed significant variation across all times (Figure 2, Table 4). For example, Onkaparinga and Myponga estuaries showed no variation among sampling times, whereas Bungala River showed significant variation among all sampling times except Autumn and Summer. Other estuaries showed variation between one or two of the sampling times. Most variation among estuaries was found during autumn (15 out of 28 comparisons significant) and summer (17 out of 28 comparisons significant), and least variation was during winter (only 8 out of 28 comparisons significant).

Water quality guidelines suggest that chlorophyll *a* levels less than 1 µg/L indicate good water quality, those between 1 and 10 µg/L indicate moderate water quality, whereas values greater than 10 µg/L indicate poor water quality (ANZECC/ARMCANZ 2000). Using these values, several estuaries had good chlorophyll *a* levels, but most were in the moderate range. Chlorophyll *a* levels often fluctuate through time and may increase after rainfall since nutrients are often flushed into the system. Chlorophyll *a* can be higher during summer (as seen for Gawler River and Port River Barker Inlet) since water temperatures and light levels are often increased. It can also be dependent on tidal regimes that may influence turbidity, as well as flushing rates and levels of nutrients.

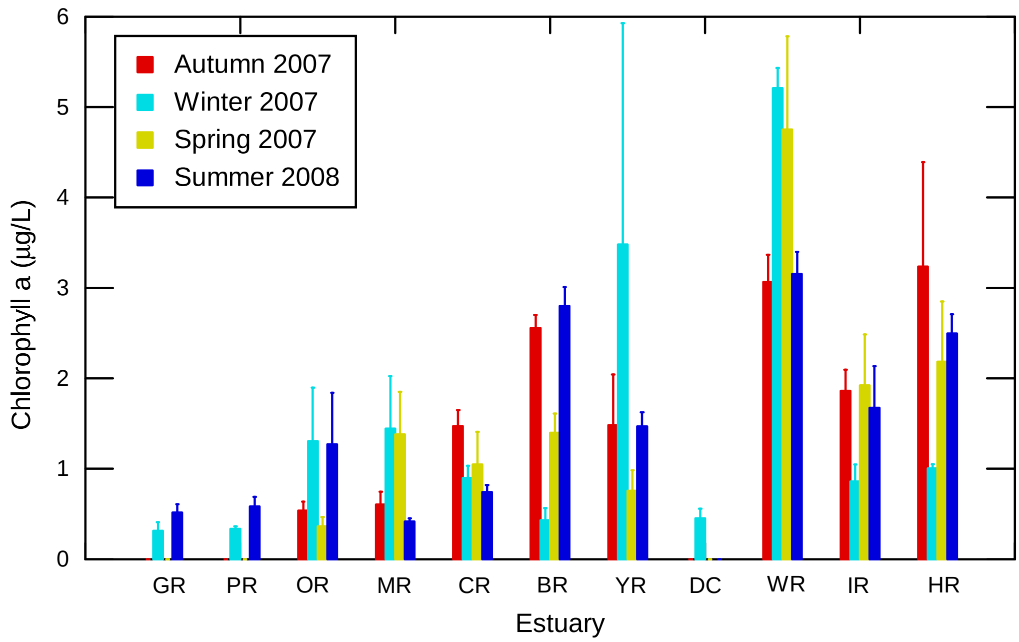

Figure 2. Chlorophyll *a* (mean ± standard error) for each estuary and sampling time. Note Gawler River and Port River Barker Inlet were only sampled in winter and summer, and Deep Creek was only sampled in Winter. Estuary codes: Gawler River (GR), Port River Barker Inlet (PR), Onkaparinga River (OR), Myponga River (MR), Carrickalinga River (CR), Bungala River (BR), Yankalilla River (YR), Deep Creek (DC), Waitpinga River (WR), Inman River (IR) and Hindmarsh River (HR).

Table 4. Analysis of variance results for chlorophyll *a* sampled from different estuaries across four sampling times.

Source	df	MS	*F*	*P*
Estuary	7	33.693	5.019	0.002
Time	3	0.259	0.003	0.993
Estuary x time	21	6.731	2.023	0.007
Residual	252			

Fish

A total of 26,044 fish encompassing 20 families and 36 species were recorded (Table 5). The most abundant families were the Gobiidae (*n*=7 species), Syngnathidae and Atherinidae (3 species each). Six other families were each represented by 2 species. One species, *Atherinosoma microstoma* represented 41.1% of all individuals recorded, and together with four other species (*Acanthopagrus butcheri, Galaxias maculatus, Gobiopterus semivestitus* and *Pseudogobius olorum*) made up over 90% of all individuals (Figure 3). Numbers of fish and species depends on sampling intensity, as well as the spatial and temporal extent. In this study estuaries were sampled along their length and generally at multiple times in an effort to sample as many species as possible.

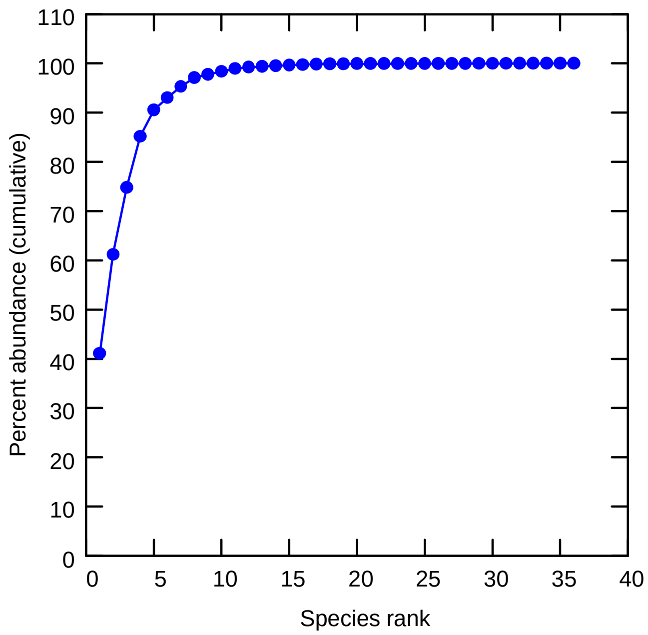

Figure 3. Cumulative percent abundance versus species rank.

Table 5. Presence absence table of species occurring in different estuaries in the Adelaide Mt Lofty Ranges region. Data were obtained as part of the current study as well as from other studies (summarised in Gillanders et al. 2008). Only 17 of the estuaries have been sampled. Please note that each estuary has had different sampling effort. For more information on each species please see Table 9. * indicates introduced species

Scientific name	Gawler River	Port River Barker Inlet	West Lakes	Torrens River	Patawalonga Creek & lake	Field River	Onkaparinga River	Pedler Creek	Myponga River	Carrickalinga Creek	Bungala Creek	Yankalilla Creek	Blowhole Creek	Deep Creek	Waitpinga creek	Inman River	Hindmarsh River
Vincentia conspersa		1															
Arripis truttaceus		1			1		1										
Arripis georgianus	1	1					1										
Atherinosoma elongata		1															
Kestratherina brevirostris	1	1															
Kestratherina esox	1	1															
Atherinosoma microstoma	1	1		1	1	1	1	1	1	1	1	1			1		
Atherinosoma spp.		1	1	1	1												
Omobranchus anolius	1	1	1														
Parablennius tasmanianus							1										
Pseudocaranx dentex		1			1												
Dactylophora nigricans		1															
Cristiceps australis		1	1														
Heteroclinus adelaidae	1	1															
Heteroclinus spp.		1	1														
Etrumeus teres		1															
Hyperlophus vittatus		1			1												
Spratelloides robustus		1	1				1										
Sardinops sagax		1	1		1												
Diodon nicthemerus		1															
Philypnodon grandiceps	1			1	1	1	1										1
Engraulis australis		1	1		1												
Enoplosus armatus	1	1			1		1										
Galaxias brevipinnis							1										
Galaxias maculatus	1			1	1	1	1	1	1	1	1	1	1	1		1	1
Geotria australis				1			1										
Gobiopterus semivestitus	1	1					1					1					
Afurcagobius tamarensis	1	1	1	1	1		1		1	1	1	1			1		1
Mugilogobius stigmaticus		1															
Pseudogobius olorum	1	1	1	1	1	1	1	1	1	1	1	1			1	1	1
*Tridentiger trigonocephalus**			1														
Acentrogobius bifrenatus	1	1	1		1		1	1		1	1						1
Redigobius macrostomus			1		1		1										
Favonigobius lateralis	1	1	1		1		1		1	1	1	1		1			1
Callogobius mucosus			1														
Bathygobius kreftii		1	1				1										

Nesogobius sp.		1															
Nesogobius sp. 5		1															
Gonorynchus greyi		1															
Hyporhamphus melanochir	1	1	1		1		1										
Hyporhamphus regularis		1			1		1										
Meuschenia freycineti		1					1										
Brachaluteres jacksonianus		1															
Acanthaluteres spilomelanurus		1					1										
Mordacia mordax				1	1		1										
Mugil cephalus			1		1												
Liza argentea	1	1	1	1			1		1								1
Aldrichetta forsteri	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1
Upeneichthys vlamingii		1															
Haletta semifasciata		1	1														
Siphonognathus argyrophanes		1			1												
Pseudorhombus jenynsii			1				1										
Pempheris klunzingeri							1										
Platycephalus bassensis		1	1														
Platycephalus fuscus				1			1										
Platycephalus speculator		1															
Platycephalus laevigatus		1															
Ammotretis rostratus		1					1										
Ammotretis elongatus							1										
Rhombosolea tapirina		1	1		1		1										1
Cnidoglanis macrocephalus		1	1														
*Gambusia holbrooki**				1	1		1	1									
Pseudaphritis urvillii	1	1	1	1	1		1	1	1	1	1	1				1	1
Argyrosomus japonicus		1	1	1	1												
Sillaginodes punctata	1	1	1		1		1		1		1						
Sillago bassensis		1					1										
Sillago schomburgkii		1	1	1	1		1										
Cynoglossus broadhursti		1															
Acanthopagrus butcheri		1	1	1	1		1	1	1	1	1	1			1		1
Acanthopagrus australis							1										
Sphyraena novaehollandiae		1															
Kaupus costatus	1	1															
Pugnaso curtirostris	1	1					1		1	1							
Stigmatopora argus	1	1	1				1										
Stigmatopora nigra	1	1	1		1		1										
Pelates octolineatus	1	1	1		1		1										
Contusus brevicaudus	1	1			1		1		1								
Torquigener pleurogramma							1										
Tetractenos glaber	1	1	1		1	1	1		1								
Gymnapistes marmoratus	1	1	1		1		1										
Chelidonichthys kumu		1															
Total number of species	27	64	34	16	33	6	45	8	13	10	10	8	2	3	3	4	11

Two estuaries had no fish for one of the sampling times: Myponga River in autumn 2007 and Yankalilla River in summer 2008. Excluding these samples fish species richness ranged from an average (± standard error) of 0.2 (± 0.15) in Yankalilla during autumn 2007 to 5.9 (± 0.8) in Onkaparinga River during summer 2008. More species were found during summer than during the other sampling periods. Autumn and/or winter tended to have fewer species. More species are commonly found in summer since many species that utilise estuaries as juveniles recruit to estuarine systems at this time. Four estuaries were excluded from analyses because they were not sampled at all four times (Gawler River, Port River Barker Inlet, Carrickalinga River and Deep Creek). There was a significant interaction between estuary and time largely because the magnitude of differences among estuaries and times differed (Figure 4a, Table 6). Inman River showed no significant difference in number of species among the four sampling times (Figure 4a). The other estuaries showed significant differences between most of the sampling times. For each time period, pairwise comparisons between estuaries showed that most estuaries (60-80% of comparisons) were significantly different numbers of species.

Total abundance of fish ranged from an average (± standard error) of 0.2 (± 0.15) individuals in Deep Creek during winter 2007 to 557 (± 150) individuals in Bungala River during spring 2007. The large numbers in the Bungala River were due to high abundances of black bream (*Acanthopagrus butcheri*) at this time (range 22 to 1060 per seine). The ANOVA analysis showed a similar pattern to that of species richness, namely an interaction between estuary and time (Table 6b). Onkaparinga River showed no significant difference among the four sampling times, although there was reasonably large variation in abundances among replicates during the spring sampling period. Bungala River was the only estuary that had significantly different abundances of fish during the four sampling periods, with reduced abundances in winter and increased abundances during spring. During the summer sampling period, around two-thirds of estuaries were significantly different, whereas in the other sampling periods fewer between estuary differences in abundance were observed. Abundances of fish can be variable depending on whether schools of fish are caught.

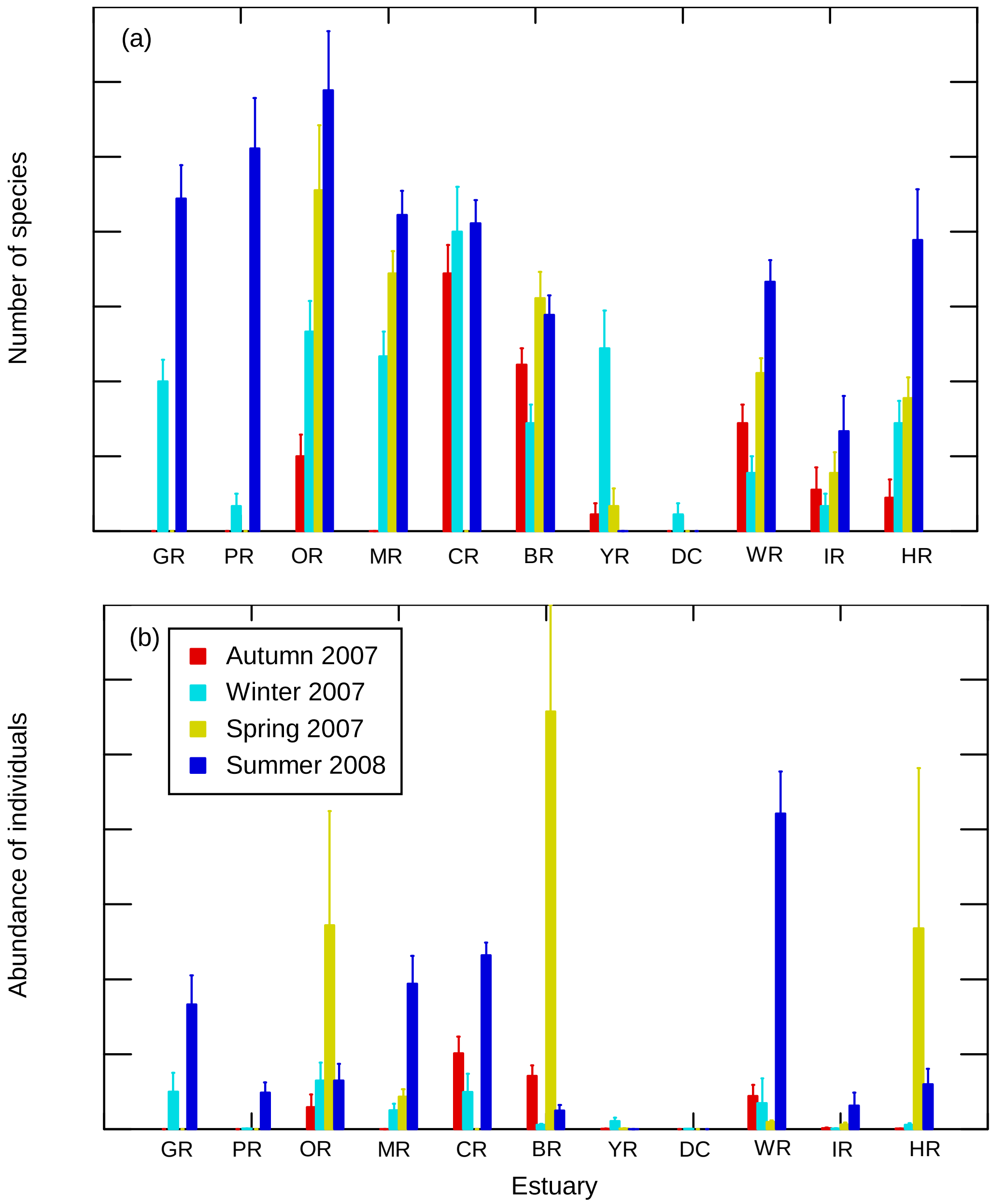

Figure 4. Number of species (a) and abundance of individuals (b) in different AMLR estuaries for each of the four sampling periods. Shown are means ± standard error. See caption of Figure 1 for estuary names.

Table 6. Results of ANOVA for (a) species richness and (b) abundance of individuals in seven of the estuaries for the four sampling times.

Source	df	MS	*F*	*P*
(a)				
Estuary	6	35.358	3.4002	0.015
Time	3	57.263	5.5066	0.012
Estuary x time	18	10.399	8.3325	0.001
Residual	224	1.248		
(b)				
Estuary	6	127390	0.7866	0.611
Time	3	323070	1.9948	0.137
Estuary x time	18	161960	5.0412	0.001
Residual	224	32127		

The range size of species (or number of estuaries where a species was recorded) was between 1 and 9 across the 11 estuaries sampled in this study (Figure 5). Nineteen species occurred in just one estuary (referred to as uniques, 53% of species) and a further four species occurred in just two estuaries (duplicates, 11% of species). Together these species represent less than 1% of total abundance. The three species found in nine estuaries (*Atherinosoma microstoma*, *Favonogobius tamarensis*, and *Pseudogobius olorum*) made up almost 50% of the total abundance.

Six estuaries had species that were unique to that estuary (Table 7). The Onkaparinga River had 8 unique species (*Arripis truttaceus, Enoplosus armatus*, *Galaxias brevipinnis, Tasmanogobius lasti*, *Ammotretis rostratus, Stigmatopora argus, Tetractenos glaber, Gymnapistes marmoratus*) and the Port River-Barker Inlet had 5 unique species (*Spratelloides robustus, Sardinops sagax, Hyporhamphus melanochir, Platycephalus laevigatus, Pelates octolineatus*). Seven of these unique species were represented by single individuals. Four species were classified as duplicates (*Kestractherina brevirostris, Philypnodon grandiceps, Bathygobius kreftii, Stigmatopora nigra*). When additional studies were incorporated many of these species where also found in other estuaries (see below).

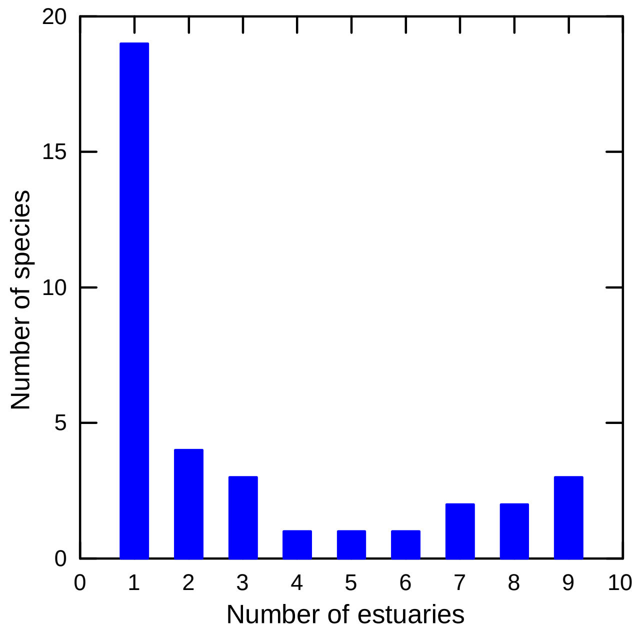

Figure 5. Frequency distribution showing the number of estuaries where a species was recorded.

Table 7. Summary of species richness, number of uniques (occur in just one estuary), duplicates (occur in two estuaries) and singletons (occur as a single individual in an estuary) for estuaries sampled in the AMLR. See caption of Figure 1 for estuary names.

Estuary	No of seines & sampling occasions	No of species	Uniques	Duplicates	Singletons
GR	9 x 2	14	3	2	1
PR	9 x 2	16	5	1	3
OR	9 x 4	23	8	3	3
MR	9 x 2	9	1	0	0
CR	9 x 3	8	1	1	0
BR	9 x 4	8	0	0	0
YR	9 x 4	9	0	0	0
DC	9 x 1	1	0	0	0
WR	9 x 4	5	0	0	0
IR	9 x 4	5	1	0	0
HR	9 x 4	10	0	0	1

Fish assemblage data also showed a significant estuary x time interaction (Table 8). Post hoc tests showed that significant differences occurred between all four sampling times for Bungala River and Hindmarsh River. The other five estuaries showed significant differences between sampling times for some of the sampling times. All estuaries were significantly different from one another during summer 2008. For the other sampling times, most estuaries differed in assemblage structure during spring (exceptions Yankalilla and Inman Rivers, and Inman and Hindmarsh Rivers), but fewer differences were observed during Autumn and winter.

Table 8. Results from analysis of multivariate assemblage data based on fourth root transformed data.

Source	df	MS	*F*	*P*
Estuary	6	28669	3.143	0.001
Time	3	16836	1.846	0.003
Estuary x time	18	9123	3.148	0.001
Residual	224	2898		

Incorporating past fish studies

Around 81 species have been recorded from Adelaide Mount Lofty Ranges estuaries (Table 9). This number is likely to increase since some estuaries have not been sampled at all, others have had limited sampling and limited gear types have been used in most. The most speciose family were the Gobiidae with 12 species followed by the Atherinidae with 5 species. Three families each had four species (Clupeidae, Platycephalidae, and Syngnathidae) while a further six families had 3 species. Twenty two families were each represented by one species.

The most speciose estuary was the Port River Barker Inlet with 65 species followed by Onkaparinga River with 45 species. Three estuaries (Gawler River, West Lakes and Patawalonga Creek) had over 20 species. These numbers may represent greater sampling with these estuaries, or their larger size and diversity of microhabitats, or alternatively, that they do actually support more species due to geographic, habitat, or food web differences. Few species have been recorded in Blowhole Creek (2 species), Deep Creek and Waitpinga estuary (3 species each) – again this is likely to represent less sampling within these systems, and their ephemeral nature. For example, no sampling of fish was possible in Deep Creek during summer due to the small amount of water present.

Seventeen of the estuaries have been sampled for fish. Yellow-eye mullet (*Aldrichetta forsteri*) were found in 16 of these estuaries (exception Waitpinga Creek), blue spot goby (*Pseudogobius olorum*) were found in 15 (exceptions Deep Creek and Blowhole Creek) and *Galaxias maculatus* were found in 14 (exceptions Port River Barker Inlet, West Lakes and Yankalilla Creek) (Table 5). Twenty species (25% of all species) were classed as duplicates (occurring in just two of the estuaries sampled) and twenty four species (30%) were classed as uniques (occurring in just one estuary). Unique species were found in three estuaries, Port River Barker Inlet (*n*=14), West Lakes (*n*=2) and the Onkaparinga River (*n*=6), although this is likely to reflect more intensive sampling in these estuaries (see Table 5). Unique species may represent just one specimen being collected (referred to as singletons) or many individuals being collected. It is often difficult to determine which of these scenarios may be the case since many studies just provide a species list with no indication of abundance.

Our sampling used a small seine net (7 m long with a 1.7 m drop and 3.5 mm mesh) and generally sampled over seagrass or non-vegetated habitats. Such a net is especially suitable for small individuals and the small estuaries commonly found in the Adelaide Mt Lofty Ranges. In many of these estuaries we were able to sample cross the width of the estuary. This is not possible in some of the larger (e.g. Port River Barker Inlet) and deeper (e.g. upper parts of the Hindmarsh) estuaries. In these estuaries some of the larger individuals and species may have been able to avoid the net and therefore larger seines or gill nets may also be needed to fully characterise the fish assemblage. In addition, seines are not suitable for sampling mangrove habitats due to the extensive pneumatophores present. Previous sampling of mangrove habitats in the region has utilised either pop nets (Bloomfield & Gillanders 2005) or fyke nets (Payne and Gillanders unpublished data). Several estuaries also have rocky entrances and/or breakwalls and additional methods will be required to sample these areas.

In summary, over 80 species have been recorded from estuaries in the region. Our sampling showed that there are a number of abundant species occurring in many estuaries, as well as a number of species which occur in only one estuary. Many of our estuaries are classified as in modified or extensively modified condition and therefore data from this study could now be utilised in conservation planning to ensure that species utilising estuaries are protected.

Table 9. List of species found in the Adelaide Mount Lofty Ranges region including their family, scientific name and authority, and common name. Also shown are (A) the habitats (freshwater, brackish, marine) that the fish are found in, (B) their dominant habitat and (C) whether they are regarded as a migrant, straggler, resident or diadromous. Please note that there is some flexibility in the life cycles of many species of fish, and that in many cases little is known on the local biology of the species to aid accurate classifications. * indicates introduced species.

Family	Scientific name		Common name	(A)	(B)	(C)
APOGONIDAE	*Vincentia conspersa*	(Klunzinger 1872)	Southern gobbleguts	M	M	S
ARRIPIDAE	*Arripis truttaceus*	(Cuvier 1829)	Western Australian salmon	B, M	M	
ARRIPIDAE	*Arripis georgianus*	(Valenciennes 1831)	Australian herring (tommy rough)	B, M		
ATHERINIDAE	*Atherinosoma elongata*	(Klunzinger 1879)	Elongate hardyhead	B, M		
ATHERINIDAE	*Kestratherina brevirostris*	(Pavlov et al, 1988)	Short-snout hardyhead	B,M		
ATHERINIDAE	*Kestratherina esox*	(Klunzinger 1872)	Pike-head hardyhead	B,M		
ATHERINIDAE	*Atherinosoma microstoma*	(Günther 1861)	Small-mouth hardyhead	F, B, M		
ATHERINIDAE	*Atherinosoma* spp.	Castelnau 1872	Hardyhead unidentified	F, B, M		
BLENNIIDAE	*Omobranchus anolius*	(Valenciennes 1836)	Oyster blenny	B,M		S
BLENNIIDAE	*Parablennius tasmanianus*	(Richardson 1842)	Tasmanian blenny	B,M		
CARANGIDAE	*Pseudocaranx dentex*	(Bloch & Schneider 1801)	White trevally	B,M	M	S
CHEILODACTYLIDAE	*Dactylophora nigricans*	(Richardson 1850)	Dusky morwong	M	M	S
CLINIDAE	*Cristiceps australis*	Valenciennes 1836	Crested weedfish	M	M	S
CLINIDAE	*Heteroclinus adelaidae*	Castelnau 1872	Adelaide's weedfish	M	M	S
CLINIDAE	*Heteroclinus* spp.	Castelnau 1872	Weedfishes	M	M	S
CLUPEIDAE	*Etrumeus teres*	(DeKay 1842)	Round herring	M	M	S
CLUPEIDAE	*Hyperlophus vittatus*	(Castelnau 1875)	Sandy sprat	B,M		
CLUPEIDAE	*Spratelloides robustus*	Ogilby 1897	Blue sprat	B,M		
CLUPEIDAE	*Sardinops sagax*	(Jenyns 1842)	Australian pilchard	M		
DIODONTIDAE	*Diodon nicthemerus*	Cuvier 1818	Globe fish	M	M	S
ELEOTRIDAE	*Philypnodon grandiceps*	(Krefft 1864)	Flathead gudgeon	F	F	S
ENGRAULIDAE	*Engraulis australis*	(White 1790)	Australian anchovy	B, M	E	
ENOPLOSIDAE	*Enoplosus armatus*	(White 1790)	Old wife	B,M	M	S

GALAXIIDAE	*Galaxias brevipinnis*	Günther 1866	Climbing galaxias	F, B, M	F	D
GALAXIIDAE	*Galaxias maculatus*	(Jenyns 1842)	Common galaxias	F, B, M	F	D
GEOTRIIDAE	*Geotria australis*	Gray 1851	Pouched lamprey	F, B, M	F	D
GOBIIDAE	*Gobiopterus semivestitus*	(Munro 1949)	Glass goby	F, B	E	R
GOBIIDAE	*Afurcagobius tamarensis*	(Johnston 1883)	Tamar River goby	F,B	E	R
GOBIIDAE	*Mugilogobius stigmaticus*	(De Vis, 1884)	Mangrove goby	F,B	E	R
GOBIIDAE	*Pseudogobius olorum*	(Sauvage 1880)	Western bluepsot goby	F,B	E	R
GOBIIDAE	*Tridentiger trigonocephalus**	(Gill, 1859)	Trident goby	B, M		R
GOBIIDAE	*Acentrogobius bifrenatus*	(Kner 1865)	Bridled goby	B,M		R
GOBIIDAE	*Redigobius macrostomus*	(Günther 1861)	Largemouth goby	F,B,M		R
GOBIIDAE	*Favonigobius lateralis*	(Macleay 1881)	Long-finned goby	B, M		S
GOBIIDAE	*Callogobius mucosus*	(Günther 1872)	Sculptured goby	M	M	S
GOBIIDAE	*Bathygobius kreftii*	(Steindachner 1866)	Krefft's frillgoby (frayfin goby)	B, M		
GOBIIDAE	*Nesogobius* sp.	undescribed	Unidentified Nesogobius	M		
GOBIIDAE	*Nesogobius* sp. 5	undescribed (after Hoese and Larson 1994)	Sicklefin sand-goby	M		
GONORYNCHIDAE	*Gonorynchus greyi*	(Richardson 1845)	Beaked salmon	B,M	M	S
HEMIRAMPHIDAE	*Hyporhamphus melanochir*	(Valenciennes 1847)	Southern sea garfish	B,M	E	
HEMIRAMPHIDAE	*Hyporhamphus regularis*	(Günther 1866)	River garfish	F,B		
MONACANTHIDAE	*Meuschenia freycineti*	(Quoy & Gaimard 1824)	Six-spine leatherjacket	M	M	M
MONACANTHIDAE	*Brachaluteres jacksonianus*	(Quoy & Gaimard 1824)	Pigmy leatherjacket	B, M	M	S
MONACANTHIDAE	*Acanthaluteres spilomelanurus*	(Quoy & Gaimard 1824)	Bridled leatherjacket	B,M	E	
MORDACIIDAE	*Mordacia mordax*	(Richardson 1846)	Shorthead lamprey	F,B,M	F	D
MUGILIDAE	*Mugil cephalus*	Linnaeus 1758	Sea mullet	F,B,M	M	D
MUGILIDAE	*Liza argentea*	(Quoy & Gaimard 1825)	Flat-tail (jumping) mullet	F,B,M	M	M
MUGILIDAE	*Aldrichetta forsteri*	(Valenciennes 1836)	Yellow-eye mullet	F,B,M	E	
MULLIDAE	*Upeneichthys vlamingii*	(Cuvier 1829)	Southern goatfish	M	M	S
ODACIDAE	*Haletta semifasciata*	(Valenciennes 1840)	Blue weed whiting	B,M	M	S
ODACIDAE	*Siphonognathus argyrophanes*	Richardson 1858	Tubemouth	M	M	S
PARALICHTHYIDAE	*Pseudorhombus jenynsii*	(Bleeker 1855)	Small-toothed flounder	B,M		

PEMPHERIDAE	*Pempheris klunzingeri*	McCulloch 1911	Klunzinger's bullseye	M	M	S
PLATYCEPHALIDAE	*Platycephalus bassensis*	Cuvier 1829	Sand flathead	B,M	M	M
PLATYCEPHALIDAE	*Platycephalus fuscus*	Cuvier 1829	Dusky flathead	B,M	M	M
PLATYCEPHALIDAE	*Platycephalus speculator*	Klunzinger 1872	Blue-spotted flathead	B,M	M	M
PLATYCEPHALIDAE	*Platycephalus laevigatus*	Cuvier 1829	Grass flathead	M	M	S
PLEURONECTIDAE	*Ammotretis rostratus*	Günther 1862	Long-snout flounder	B,M	M	S
PLEURONECTIDAE	*Ammotretis elongatus*	McCulloch 1914	Elongate flounder	M	M	S
PLEURONECTIDAE	*Rhombosolea tapirina*	Günther 1862	Greenback flounder	B,M	E	
PLOTOSIDAE	*Cnidoglanis macrocephalus*	(Valenciennes 1840)	Estuary catfish	B, M	M	S
POECILIIDAE	*Gambusia holbrooki**	Girard 1859	Eastern mosquito fish	F,B	F	S
PSEUDAPHRITIDAE	*Pseudaphritis urvillii*	(Valenciennes 1832)	Congolli	F,B,M		D
SCIAENIDAE	*Argyrosomus japonicus*	(Temminck & Schlegel 1843)	Mulloway (jewfish)	B, M	M	M
SILLAGINIDAE	*Sillaginodes punctata*	(Cuvier 1829)	King George whiting	B,M	M	M
SILLAGINIDAE	*Sillago bassensis*	Cuvier 1829	Silver whiting	M	M	M
SILLAGINIDAE	*Sillago schomburgkii*	Peters 1864	Yellowfin whiting	B,M		
SOLEIDAE	*Cynoglossus broadhursti*	Waite 1905	Southern tongue sole	M	M	S
SPARIDAE	*Acanthopagrus butcheri*	(Munro 1949)	Black bream	F,B,M	E	M
SPARIDAE	*Acanthopagrus australis*	(Günther 1859)	Yellowfin bream	B,M	E	
SPHYRAENIDAE	*Sphyraena novaehollandiae*	Günther 1860	Snook	M	M	S
SYNGNATHIDAE	*Kaupus costatus*	(Waite & Hale 1921)	Deep-body pipefish	M	M	S
SYNGNATHIDAE	*Pugnaso curtirostris*	(Castelnau 1872)	Pug-nose pipefish	B,M		
SYNGNATHIDAE	*Stigmatopora argus*	(Richardson 1840)	Spotted pipefish	B,M		
SYNGNATHIDAE	*Stigmatopora nigra*	Kaup 1856	Wide-bodied pipefish	B,M		
TERAPONTIDAE	*Pelates octolineatus*	(Jenyns 1840)	Western striped grunter	M	M	M
TETRAODONTIDAE	*Contusus brevicaudus*	Hardy 1981	Prickly toadfish	B, M	E	
TETRAODONTIDAE	*Torquigener pleurogramma*	(Regan 1903)	Weeping toadfish	B,M		
TETRAODONTIDAE	*Tetractenos glaber*	(Fréminville 1813)	Smooth toadfish	F,B,M		
TETRAROGIDAE	*Gymnapistes marmoratus*	(Cuvier 1829)	Cobbler	B, M	E	
TRIGLIDAE	*Chelidonichthys kumu*	(Cuvier 1829)	Red gurnard	B, M		

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