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FINAL REPORT

Synthesis and gap assessment of fish dietary data required for modelling ecosystems in south-western Australia

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2002/016 Synthesis and gap assessment of fish dietary data required for modelling ecosystems in south-western Australia

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Objectives:

- 1. Develop a comprehensive database for the abundance, size compositions and diets of the fish fauna in the estuaries and marine waters of south-western Australia.
- 2. Describe the diets of the various fish species.
- 3. Identify where dietary and other relevant data are lacking.
- **4.** Determine appropriate sampling methods to obtain data for those areas where information is lacking.

Outcomes achieved to date:

- 1. A realisation amongst scientists, managers and the fishing community that dietary data is an essential part of management of fish species and their environment.
- 2. The multivariate approaches to dietary analyses and custom-designed database developed during this project have assisted dietary workers in more efficiently obtaining and better analysing their dietary data.

Non-technical summary

It has been recently recognised that dietary data for fish, including teleosts (bony fish), elasmobranchs, crustaceans and molluscs, in the marine and estuarine waters of south-western Australia, are essential for the development of appropriate ecosystem models. Thus, there is an urgent need to assess the current status of those dietary data and to identify the presence of any significant gaps.

The project initially addressed Objective 3 "Identify where dietary and other relevant data are lacking".

Thus, a collation of both research and commercial fishery data on the relative contributions of the different fish species to the overall biomass in shallow (nearshore) and deeper (offshore) waters, where appropriate, for each of the different selected systems, i.e. marine waters of south-western Australia, the Swan, Peel-Harvey and Leschenault estuaries and Wilson Inlet, identified which of those fish species for which dietary data is required for ecosystem modelling. For those species for which dietary data was shown to be needed, searches were made of published and unpublished material to assess whether or not dietary data were available and, if it was available, to assess the usefulness of that dietary data. A recommendation was then made as to the importance of collecting dietary information for that species. For example, if a species made either a high contribution to the overall biomass, or was of commercial or recreational importance, or was likely to represent a different feeding type, a higher priority was assigned for that species. The system for which dietary data were most lacking was the marine waters of south-western Australia, which is due partly to some of those species that contribute large amounts to the total biomass being relatively rare and/or difficult to sample. However, it should be noted that the western rock lobster (*Panulirus cygnus*), which is the largest and most lucrative single species fishery in Western Australia, is identified in this project as a species for which further scientific attention is warranted.

To address Objective 1 "Develop a comprehensive database for the abundance, size compositions and diets of the fish fauna in the estuaries and marine waers of south-western Australia", the following approaches were undertaken.

For all of those species which had been previously subjected to dietary analyses, the raw data for some fish species was entered into MS Excel TM and, in conjunction with dietary data for other species that were already in Excel, were re-coded into an appropriate format. Once recoding was completed, a Visual Basic TM routine was used to input the dietary and associated metadata into "Guts", which is a MS Access TM database that was developed during this project to collate the appropriate data. The development of this database, which is described in detail in Chapter 2, was required to account for differences in the ways in which dietary data were recorded and to optimise the usefulness of such data.

The "Guts" database also helped identify which species most urgently required scientific attention in terms of using the available data. Thus, dietary data were available for some species but had not been subjected to appropriate dietary analyses. These groups were therefore selected for re-analysis (see Chapters 3, 4 and 5) and thereby directly addressed Objective 2 "Describe the diets of the various fish species".

The diets of three fish species, which represented different feeding types in the lower and middle Swan Estuary, and were recorded in the early 1980s, were re-analysed in Chapter 3. These analyses demonstrated that *Apogon rueppellii* (common name gobbleguts), which was very abundant in this part of the Swan Estuary, fed mainly on small epibenthic and planktonic crustaceans, while the diets of two larger but less abundant and recreationally important teleosts *Pseudorhombus jenynsii* (small-tooth flounder) and *Platycephalus endrachtensis* (bar-tailed flathead) fed mainly on epibenthic teleosts and large crustaceans, such as carid and penaeid decapods. The last two species also ingested *A. rueppellii* (the other subject of this study) and the commercially and recreationally important *Engraulis australis* (anchovy) and *Argyrosomus japonicus* (mulloway) while *P. endrachtensis* also ingested *Hyperlophus vittatus* (sandy sprat), *Pseudocaranx dentex* (skipjack trevally) and two species of mullet (*Mugil cephalus* and *Aldrichetta forsteri*). Although little difference was

recorded in the dietary compositions of these species in that region of the Swan Estuary, seasonal differences were greater, presumably reflecting seasonal changes in the abundances of their prey. Size-related differences in diets could be determined for only *A. rueppellii*, with smaller individuals eating smaller and relatively fragile prey such as planktonic crustaceans, while the larger individuals were able to feed on larger, harder and/or more elusive prey such as bivalve siphons, hard-shelled crabs and large orbiniid and nereid polychaetes.

The above dietary data, which was collected in the 1980s, is of a sufficiently high quality to detect whether or not the diets of these three species have changed since that time, should another dietary study be carried out on those species. Such a study should ideally be carried out in the same locations and in each season to reduce any effect of spatial or temporal variation on the resultant comparisons. There is, as yet, no information on the types of size-related changes undergone by the two other species (*P. jenynsii* and *P. endrachtensis*).

When the diets of two mullet species (*A. forsteri* and *M. cephalus*) were compared, using data from both the Swan and Peel-Harvey estuaries (Chapter 4), it was evident that the diet of *A. forsteri* contained a wide variety of food, including macrophytes, crustaceans, polychaetes and molluscs. Although this species also ingested sediment and detritus, it was not to as great an extent as that of *M. cephalus*, which also ingested diatoms when small. The diets of these two species varied more with respect to distance from the sea within the two estuaries than between the Swan and Peel-Harvey estuaries, which lie less than 80 km apart on the west coast of Australia. However, their diets in an estuary on the south coast of this state (Wilson Inlet) differed from those in the other two west coast estuaries, in that they contained greater amounts of two polychaete species and the carid decapod *Palaemonetes australis*, which is particularly abundant in this system (Potter et al. 1993, Platell and Potter 1996).

The above results highlight the extent of dietary differences that can occur within a family of fish (Mugilidae), a situation which has also been shown for other confamilial species in marine waters of south-western Australia (e.g. Hyndes et al. 1997, Platell et al. 1998ab, Platell and Potter 1999). Furthermore, the influence of location within estuary for these two mugilid species, needs to be better explored in the future for estuaries such as the Leschenault Estuary.

The analyses of dietary data for six recreationally and/or commercially important fish species in Wilson Inlet, i.e. *M. cephalus, A. forsteri, Cnidoglanis macrocephalus* (cobbler), *Sillaginodes punctata* (King George whiting), *Arripis georgiana* (Australian herring) and *Platycephalus speculator* (blue-spotted flathead), have shown pronounced dietary differences between these species (Chapter 5). Thus, a wide variety of feeding types was represented in this estuary, ranging from predominantly detritivorous (*M. cephalus*) to feeding on small crustacean and polychaetes (*A. forsteri* and *S. punctata*), molluscs (*C. macrocephalus*) and fish and large crustaceans (*A. georgiana* and *P. speculator*). Although the extent to which the dietary composition of each species changes with increasing body size varied among species, this does not apparently reduce the extent of interspecific differences among those species. Little seasonal variation was detected in the diets of the six species, suggesting that their food sources are likely to remain sufficiently abundant throughout the year.

The dietary data from Wilson Inlet, which was collected in the 1980s, is of a standard appropriate to carrying out future comparisons, with the exception of certain of the dietary categories for *C. macrocephalus*, which were not recorded to a suitably low taxonomic level. Furthermore, the lack of site of capture information for *C. macrocephalus* and *P. speculator* has hindered the detection of any spatial differences in the diets for those two species. The extent of seasonality in the diets may also warrant further examination, due to the strongly seasonal abundance of macroinvertebrates and fish in this seasonally closed estuary (Potter et al. 1993, Platell and Potter 1996).

In order to make meaningful comparisons among the dietary data for the main fish species in a given system, in this case Wilson Inlet, an approach was developed that relied upon the allocation of the volumetric contributions of the different dietary categories for each fish species into a previously defined "food source" (Table 6.1), and analysis of that data in a multivariate framework (Chapter 6). This work demonstrates great potential for handling complex data sets in which dietary data is collected for a number of species by more than one dietician. It is able to use data summaries as well as the raw data for fish species, the former of which may be the only dietary data available for certain fish species.

The final objective of this project "Determine appropriate sampling methods to obtain data for those areas where information is lacking", was undertaken using the gap analysis coupled with the distribution of such species and known methods of capture. This showed that fish which were typically either rare, large and/or found in deeper waters were caught mainly by commercial and recreational fishers. It thus appears that any concerted efforts to address gaps in dietary information must involve the cooperation of such fishers.

Keywords: food sources, dietary compositions, multivariate analyses, size-related changes, resource partitioning, ecosystem modelling, estuaries, marine waters.

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Dr Colin Chalmers, Program Manager (Habitats), Fisheries WA

Mr Andrew Cribb, Program Manager (Recreational Fishing), Fisheries WA

Mr Frank Prokop, Executive Director, RecFishWest.

The following papers have been produced during and after this FRDC project

- Hourston, M., Platell, M.E., Potter, I.C. and Valesini, F.J. (2004). Factors influencing the diets of four morphologically divergent fish species in nearshore marine waters. *Journal of the Marine Biological Association of the United Kingdom* 84, 805-817.
- Platell, M.E., Orr, P.A. and Potter, I.C. (in press). Inter- and intraspecific partitioning of food resources by six large and abundant fish species in a seasonally-open estuary. *Journal of Fish Biology*
- Schafer, L.N., Platell, M.E., Valesini, F.J and Potter, I.C. (2002). Comparisons between the influence of habitat type, season and body size on the dietary compositions of fish species in nearshore marine waters. *Journal of Experimental Marine Biology and Ecology* 278, 67-92.
- White, W.T., Platell, M.E. and Potter, I.C. (2004). Comparisons between the diets of four abundant species of elasmobranchs in a subtropical embayment: implications for resource partitioning. *Marine Biology* 144, 439-448.

Benefits and adoption

The commercial and recreational fishers of south-western Australia will benefit from the results of this project as it will enable a better understanding of the interrelationships among fish species in the marine and estuarine waters of this large region. In particular, managers should be able to identify those species which are most at risk after environmental perturbations, including fishing activities. These benefits and beneficiaries are as outlined in the original project application. Thus, although dietary data was known to be present for some fish species, it is now clear as to which species have been studied and the quality of that data. The gap analyses have indicated precisely where scientific effort should be directed in the marine and estuarine waters of southwestern Australia.

Regular updates of our research have been provided to the Department of Fisheries Western Australia and the Water and Rivers Commission. A copy of the final report, once it is approved by FRDC, will be provided to these agencies and other members of the scientific, fishing and general community that have expressed an interest in this study. The application of the results of this research will be discussed with fishery and environmental managers to facilitate their adoption for the benefits of commercial and recreational fishers and other users of the aquatic environment.

Further development

The results of this research will be further disseminated by ongoing discussions with scientists and managers at the Department of Fisheries Western Australia. Seminars will also be provided to relevant community groups. A number of manuscripts will be submitted to international journals for publication. The database outputs will be modified and improved. An application has been recently submitted to the FRDC for an examination of the effect of algal blooms on fish food webs in the Swan Estuary, using traditional dietary techniques and stable isotope analyses.

Planned outcomes

- 1. A direction of scientific effort to collecting dietary data for important species.
- 2. The planned outcomes will be increasingly realised as management relies more on ecosystem rather than single species approaches to fisheries and environmental management.

Chapter 1 Introduction

1.1 Background: diets of fishes

Food resources are typically partitioned among the most abundant species of teleosts in coastal waters, thereby reducing the potential for interspecific competition for those resources (Ross 1986, Edgar and Shaw 1995, Platell and Potter 2001, Baldó and Drake 2002, Bulman et al. 2002). Such partitioning is facilitated by interspecific differences in the dimensions and orientation of the feeding apparatus, mode of feeding, location in the water column and swimming ability (Motta 1988, Labropoulou and Eleftheriou 1997). Furthermore, the potential for intraspecific competition for food by fish in coastal waters is reduced by changes in the type and size of their prey as those predators increase in size (e.g. Platell and Potter 2001, Baldó and Drake 2002).

Studies of the diets of fishes are typically restricted to the more abundant of the fish species that occur in a given area and are not necessarily aimed at those fish species that are of commercial and/or recreational importance (e.g. Fujita et al. 1995, Bulman et al. 2002). However, the national and international move to ensure long-term sustainability of fisheries and thus manage at an ecosystem, rather than species, level, requires a sound understanding of the feeding relationships between the various fish species, including those species of commercial and/or recreational importance, and of the extent of variability in those diets, i.e. size-related, spatial and/or temporal differences (Pauly et al. 1998). There is an obvious need to direct scientific effort in Australia towards quantifying such trophic relationships among fishes, and between their prey and predators.

Determination of the main dietary components of fish and crustacean species can be achieved using different techniques. Traditional approaches, which involve direct examination of recently ingested food items, produce data on the frequency of occurrence (%F), numbers (%N) and volume (%V) and/or weight (%W) of the different food items. Such values are also often adjusted to take into account gut fullness, which is typically scored on a scale of 1 (10% full) to 10 (100% full) (Hynes 1950, Hyslop 1980, Cortés 1997, Marshall and Elliot 1997). The dietary data derived using the traditional approaches can also be combined into an Index of Relative Importance (%IRI), a formula which uses %F, %N and %V or %W data (e.g. Hart et al. 2002). When such dietary data is available for juveniles and adults of a given species and over different spatial or temporal scales, the data can then be subjected to sophisticated

multivariate techniques to determine the extent to which those different factors influence the dietary compositions of fish (see e.g. Schafer et al. 2002, Hourston et al. 2004). Such data can also be analysed for interspecific differences and used to assign fish into broad feeding categories that can then form the basis for the construction of ecosystem models. The main drawbacks of traditional approaches to dietary analyses include (1) relatively large numbers of fish need to be collected to ascertain the influence of the various factors, (2) identification of food can be hindered by digestion or lack of taxonomic knowledge and (3) high prevalences of empty stomachs in certain species (see e.g. Linke et al. 2001). Furthermore, the data reflects only the composition of the ingested prey, and thus provides a "snapshot" of the last meal, and does not necessarily provide information on the longer-term contribution of the various food items.

Disadvantages of the traditional approaches can be partly overcome by using biochemical analytical techniques, such as stable isotope analyses (SIA), fatty acid composition analyses (FACA) or other techniques (Grisley and Boyle 1985, Gannes et al. 1997, Iverson et al. 1997, Fantle et al. 1999, Carmichael et al. 2002, Reñones et al. 2002). SIA, which relies on calculating ratios of heavy to light isotopes (signatures) for elements such as C, N or S, in the body tissue of the predator (fish), firstly provides information on the trophic level of that species (δN). Moreover, in conjunction with the signatures of the various food items for those fish species (δC and δS), information is also provided on the main food items that have been assimilated into the body of that fish (Carmichael et al. 2002, Davenport and Bax 2002, Reñones et al. 2002). FACA determines the contribution of the various fatty acids within different tissues or fluids in the body of the fish, and identifies those "marker" fatty acids which are not able to be produced by the fish, and must therefore be present in the body through assimilation of the prey that synthesise the marker fatty acids (Iverson et al. 1997). FACA therefore needs also to be carried out on the likely food sources for those species. The main disadvantages of the above approaches are that they are (1) time and cost-intensive and (2) rely on clearly distinguishable signatures from likely food sources. However, in those cases where fish are relatively scarce, or have large numbers of empty stomachs, such methods may be the preferred option for determining the dietary compositions of those species. The above approaches can also be extended to higher order predators, including elasmobranchs, avians and mammals, since they do not always involve euthanasia of the species in question (e.g. Pierce and Boyle 1991, Hobson and Clark 1992, Iverson et al. 1997).

1.2 Background: dietary data in south-western Australia

Detailed published data on the main components of the diets of fish species in south-western Australia, including those that are commercially and recreationally important, are essentially restricted to benthic fish and crustacean species over predominantly sandy substrates in coastal marine waters (Joll and Phillips 1984, Edgar 1990abc, Hyndes et al. 1997, Platell and Potter 1998, 1999, Platell et al. 1997, 1998ab, Schafer et al. 2002, Hourston et al. 2004) and for some fish species occurring in association with macrophytes (Robertson and Lenanton 1984, Lenanton and Caputi 1989). There are also published data for certain fish species in the Swan Estuary (Prince et al. 1982, Chrystal et al. 1985, Potter et al. 1988, Gill and Potter 1993, Wise et al. 1994, Sarre et al. 2000), the Peel-Harvey and Leschenault estuaries (Chalmer and Scott 1984, Potter et al. 2000, de Lestang et al. 2001) and Wilson Inlet (Humphries et al. 1992, Humphries and Potter 1993). A large amount of dietary data is also available in Honours (Chrystal 1983, Geijsel 1983, Shaw 1986, Goh 1992, MacArthur 1997, Stewart 1998, Whitehead 2000, Ang 2003, Lek 2004), Masters (Kanandjembo 1998) and PhD (Laurenson 1992, Orr 2000, Kendrick 2001) theses. Further information has been published on the feeding behaviour and fish predators of the western rock lobster P. cygnus (Joll 1982, Jernakoff 1987, Jernakoff et al. 1987, Howard 1988), on the feeding of the abalone Haliotis roei (Wells and Keesing 1989) and on the feeding of higher order predators, such as avians (Klomp and Wooller 1988, Trayler et al. 1989, Humphries et al. 1992). Although further unpublished dietary information does exist, it has either proved difficult to locate and/or not of sufficient quality for further analysis. At present, dietary studies are being undertaken or are about to commence on dhufish (Glaucosoma hebraicum), Australian herring (Arripis georgiana), skipjack trevally (Pseudocaranx dentex), breaksea cod (Ephinephelides coiodes), tuskfish (Choerodon rubescens and Choerodon schoennlenii), pink snapper (Pagrus auratus), nearshore fish species (Pelates humeralis, Cnidoglanis macrocephalus and Aldrichetta forsteri), rock lobster (Panulirus cygnus), various reef fishes and elasmobranch species in marine waters by students and research workers at Murdoch University, Edith Cowan University and the Western Australian Department of Fisheries. Future projects encompass analysis of the diets of northern fish species and of the main trophic interactions in the upper Swan Estuary.

The above dietary studies have essentially relied on the use of traditional approaches to determine the main dietary components, which would facilitate the use of sophisticated multivariate approaches to determine the relative importance of different

factors on the diets of those species. Although such approaches have been developing since the early 1990s, the introduction of new subroutines in the PRIMER v5 package (Clarke and Gorley 2001) and ongoing communications with the developer of that software package (K. Clarke, PRIMER-E), means that a new level of sophistication has recently been attained (see e.g. Hourston et al. 2004). Therefore, it stands to reason that, wherever possible, the raw data should be re-examined in the light of these new approaches so that the results can be more fully understood and compared with other dietary studies.

1.3 Objectives

- Develop a comprehensive database for the abundance, size compositions and diets of the fish fauna in the estuaries and marine waters of south-western Australia.
- 2. Describe the diets of the various fish species.
- 3. Identify where dietary and other relevant data are lacking.
- **4.** Determine appropriate sampling methods to obtain data for those areas where information is lacking.

1.4 Main approaches of the project

FRDC 2002/016 had identified six areas of priority for the collation of dietary data in south-western Australia, i.e. nearshore and offshore marine waters and the Swan, Peel-Harvey and Leschenault estuaries on the west coast and Wilson Inlet on the south coast. Lists of the fish species that had been subjected to dietary studies in those six areas were initially constructed. Once those species had been identified, searches were made of computer archived material to initially locate the data for individual fishes. If such data were not found, searches were then made for hardcopies of dietary data, such as the raw data sheets. The metadata for each of the fish species that was provided in the published or unpublished outputs of the various studies were then used to determine the quality of the data, and its appropriateness for the development of ecosystem models. Where possible, the data was re-analysed to help answer the above questions (see Chapters 3-6).

In order to ascertain precisely where the gaps lie in the dietary data sets available for finfish and crustaceans in south-western Australian waters, the first step involved tabulation of the relative contribution of each fish species to the overall biomass in each region, with the aim of including sufficient species to account for at least 80% of the biomass. Both scientific and fisheries data sets were used where appropriate. Each fish species was then assessed on the basis of whether there was any previously collected data and the localities from which the data was collected. A further assessment was made as to the quality of the dietary data. Thus the quality of the dietary data is defined as High (data were collected by an experienced dietician, from a range of sites and throughout at least a year, and included information on size-related change in dietary compositions), Moderate (data were collected less rigorously and from fewer sites and seasons) or Sparse (data were collected on only a few sampling occasions and from only one or two sites). Furthermore, "summary" means that the raw dietary data for individual fish have not yet been located. When making such assessments of the quality of dietary data, it should be borne in mind that any study which examines the effect of either site, season or size-related differences on the dietary compositions of a fish species, invariably finds that there are marked differences between these variables and thus a proper understanding of the diet of any fish species must encompass such variation. In the case of dietary differences among sites, this is particularly pronounced when these sites are known to represent different habitat types, the classification of which is based on an enduring suite of physical characteristics (FRDC 2000/159). Each fish species was then scored as to the requirement for data to be collected on its dietary compositions. These scores range from (1) High priority – species contributes a large amount to the overall biomass or is a commercially and/or recreationally important species for which very little is known, (2) Medium priority – species is moderately important to the biomass and/or information is available for this species in similar habitats and (3) Low priority – species makes only a low contribution to the overall biomass.

1.5 Gap analysis

1.5.1 Nearshore and offshore marine waters of south-western Australia

When the different species that contribute at least 80% to the overall biomass of fish faunas over sandy substrates in marine waters of 5-35 and <2 m depth along the lower west coast of Australia, based on studies that were conducted by Murdoch University, are determined, it is apparent that there is a very much greater number of species than in any of the estuaries (see later section) and that there is already a considerable amount of dietary data for those species in the marine waters (Tables 1.1 and 1.2, Edgar 1990ab, Hyndes et al. 1997, Platell et al. 1997, 1998ab, Platell and Potter 1999, 2000, Schafer et al. 2002, Hourston et al. 2004). For the offshore waters, more attention needs to be focussed on certain of the elasmobranchs and the western smooth boxfish Anoplocapros robustus (Table 1.1), while, in nearshore waters, dietary data needs to be collected for species such as tarwhine *Rhabdosargus sarba*, yellow-eye mullet *A. forsteri*, sea mullet *M. cephalus*, cobbler Cnidoglanis macrocephalus and sandy sprat Hyperlophus vittatus. There is some data available for the diets of C. macrocephalus and H. vittatus in similar environments, but these are only in the form of summaries (Robertson and Lenanton 1984, Lenanton and Caputi 1989, Goh 1992). It should also be noted that the diets of certain elasmobranchs in both nearshore and offshore waters and R. sarba are forming the basis of research projects at Murdoch University.

When the fish and crustacean species that are important in terms of the overall commercial catch (by weight) in the west coast bioregion, which comprises marine waters, were determined, it was immediately apparent that for many of these species, there was very little data that was of a sufficiently high quality for understanding the trophic relationships among these species (Table 1.3). For two of the species, pink snapper *P. auratus* and dhufish *G. hebraicum*, information is currently being collected on their diets as part of research projects at Murdoch University. A third species, the crystal crab *Hypothalassia acerba*, is present in very deep waters and the method of capture of these crustaceans means that the vast numbers of individuals have no food in their stomachs (K. Smith, Murdoch University, personal communication).

Table 1.1: List of species which collectively contribute at least 80% to the total biomass of fish recorded during a scientific study of the fish faunas over predominantly sandysubstrates in marine, offshore waters of 5-35 m depth along the lower west coast of Australia between 1991 and 1993 (Hyndes et al. 1999). N.B. In this and Tables 1.2-1.10, * denotes a species of commercial and/or recreational importance. Details are provided on the type of dietary data for each species and a decision made as to the type of scientific scrutiny that each species warrants, with (1) denoting high priority and (2) denoting medium priority.

	Marine offshore waters	Percent	Dietary data	Dietary data for	If no, then for which next	Data quality	Does this species
		biomass	present?	this environment?	most similar environment?		require attention?
	Parequula melbournensis	12.3	Yes	Yes		High	
*	Sillago bassensis	8.3	Yes	Yes		High	
	Squatina australis	7.0	No				Yes (1)
	Myliobatis australis	6.5	No				Yes (1)
	Anoplacopros robustus	5.8	Yes	Yes		Sparse	Yes (2)
*	Upeneichthys lineatus	5.3	Yes	Yes		High	
	Urolophus paucimaculatus	5.2	Yes	Yes		High	
	Trygonoptera mucosa	4.9	Yes	Yes		High	
	Urolophus lobatus	4.8	Yes	Yes		High	
	Trygonoptera personata	2.6	Yes	Yes		High	
	Pseudocaranx wrighti	2.5	Yes	Yes		High	
*	Platycephalus longispinis	2.4	Yes	Yes		High	
	Acanthaluteres vittiger	2.4	Yes	Yes		Sparse	Yes (2)
	Maxillicosta scabriceps	2.2	Yes	Yes		High	
	Heterodontus portjacksoni	2.1	No				Yes (1)
	Pempheris klunzingeri	1.6	Yes	Yes		High	
	Lepidotrigla papilio	0.8	Yes	Yes		High	
	Sillago robusta	0.4	Yes	Yes		High	
	Parapriacanthus elongatus	0.3	Yes	Yes		High	
	Lepidotrigla modesta	0.3	Yes	Yes		High	
	Sillago vittate	0.3	Yes	Yes		High	
	Sillago burrus	0.2	Yes	Yes		High	
	Upeneichthys stotti	0.2	Yes	Yes		High	
	Diodon nichthemerus	2.3	No				Yes (1)
	Total contribution to biomass	80.7					

	Marine nearshore waters	Percentage biomass	Dietary data present?	Dietary data for this environment?	If no, then for which next most similar environment?	Data quality	Does this species require attention?
	Atherinomorus ogilbyi	29.1	Yes	Yes		High	
*	Rhabdosargus sarba	20.1	Yes	Yes		Adequate	Yes (2)
*	Aldrichetta forsteri	5.8	Yes	No	Swan Estuary	High- summary	
	Leptatherina presbyteroides	5.0	Yes	No	Swan Estuary	High – summary	Yes (2)
*	Cnidoglanis macrocephalus	4.7	Yes	Yes	•	Adequate - summary	Yes (1)
*	Sillago schomburgkii	4.5	Yes	Yes		High	
	Trygonoptera mucosa	3.1	Yes	No	Marine offshore waters	High	
	Torquigener pleurogramma	3.0	Yes	No	Swan Estuary	Adequate – summary	Yes (1)
*	Sillago bassensis	2.9	Yes	Yes		High	
*	Arripis georgiana	2.3	Yes	Yes		High	Yes (2)
*	Spratelloides robustus	1.9	Yes	Yes		High	
	Sillago vittate	1.6	Yes	Yes		High	
	Gerres subfasciatus	1.3	Yes	No	Swan Estuary	Adequate – summary	Yes (2)
	Sillago burrus	1.2	Yes	Yes	-	High	
*	Mugil cephalus	1.1	Yes	No	Swan Estuary	High – summary	
	Myliobatis australis	1.1	No				Yes (1)
*	Hyperlophus vittatus	0.7	Yes	Yes		Adequate – summary	Yes (1)
*	Sillaginodes punctata	0.7	Yes	Yes		High	
	Apogon rueppellii	0.6	Yes	No	Swan Estuary	High – summary	
*	Platycephalus speculator	0.5	Yes	No	Wilson Inlet	High	
	Lesueurina platycephala	0.4	Yes	Yes		High	
*	Pseudorhombus jenynsii	0.4	Yes	Yes		High	
*	Argyrosomus japonicus	0.4	No			-	Yes (1)
	Favonigobius lateralis	0.2	Yes	No	Swan Estuary	High	
*	Ammotretis elongatus	0.1	Yes	Yes	-	High	
	Total contribution to biomass	92.7					

Table 1.2: List of species which collectively contribute at least 80% to the total biomass of fish recorded during a scientific study of the fish faunas over sandy substrates in nearshore, shallow marine waters along the lower west coast of Australia between 2001 and 2002 (Valesini unpublished data).

Environment	Dietary data present?	Dietary data for this environment?	If no, then for which next most similar I environment?	Data quality	Does this species require attention?
West coast bioregion					
Panulirus cygnus	Yes	Yes	S	Sparse	Yes (1)
Sardinella lemuru	?				Yes (1)
Sardinops sagax	?				Yes (1)
Carcharhinus brachyurus	?				Yes (1)
Pagrus auratus	Yes	No	Shark Bay, WA	Sparse	Yes (1)
Carcharhinus plumbeus	?				Yes (1)
Glaucosoma hebraicum	Yes	Yes	1	Adequate	Yes (1)
Arripis trutta	?				Yes (1)
Furgaleus macki	?				Yes (1)
Eutremeus teres	?				Yes (1)
Seriola hippos	?				Yes (1)
Portunus pelagicus	Yes	No	Peel-Harvey and Leschenault estuaries	High	No
Arripis georgiana	Yes	Yes		High	Yes (2)
Orectolobus spp.	No				Yes (1)
Hypothalassia acerba	No				Yes (2)
Peel-Harvey Estuary bioregion					
Portunus pelagicus	Yes	Yes		High	
Mugil cephalus	Yes	Yes		High - summary	Yes (2)
Sillaginodes punctata	Yes	Yes		Sparse - summary	Yes (1)
Sillago vittata	Yes	No	Marine nearshore waters	High	Yes (2)
Arripis georgiana	No				Yes (1)
Cnidoglanis macrocephalus	No				Yes (1)
Pomatomus saltatrix	No	Yes	Also combined with Leschenault	Sparse – summary	Yes (1)
Melicertus latisculcatus	No				Yes (1)

 Table 1.3: Summary of fish species and crustaceans that are important to commercial fisheries in the west coast and Peel-Harvey bioregions (data extracted from Western Australian Department of Fisheries CAES).

1.5.2 Estuaries in south-western Australia

For the Swan Estuary, two large scientifically-collected data sets on the fish fauna are available, with the most recent being recorded by Kanandjembo in 1995-1997 (Kanandjembo et al. 2001a) and which focussed on the upper estuary, and data that was collected in 1977-1981 in the lower, middle and upper region of this estuary (Loneragan et al. 1989) (Tables 1.4-1.7). The data sets were revisited in order to calculate the relative contributions of each species to the overall biomass, since such data was not presented in the published papers and the new calculations are provided in Tables 1.4 to 1.7. It should be noted that, since the biomass data for the various fish species in the upper estuary differed considerably during the two sampling periods (cf Tables 1.4-1.7), the data for the lower and the middle estuary that were collected in 1977-1981 are most probably not an accurate reflection of the present-day fish community. This view is consistent with the research that is currently being conducted by Murdoch University and Department of Fisheries WA on the impact of recent fish kills on the fish fauna of the Swan Estuary.

Tables 1.4-1.5, demonstrate that, in the upper Swan Estuary and Canning River, dietary information is completely lacking for large recreationally important species such as giant herring *Elops machnata* and mulloway *Argyrosomus japonicus* and for smaller species such as Perth herring Nematalosa vlaminghi, anchovy Engraulis australis, bartailed flathead Platycephalus endrachtensis and six-lined trumpeter Pelates sexlineatus, while for some other species, only summaries and/or data for the same species in different systems are present. For A. japonicus, this need becomes particularly urgent in that this species apparently has a high rate of gut regurgitation and stomachs are often empty (B. Farmer, Murdoch University, personal communication). In the case of the lower and middle Swan Estuary, more recent estimates of the contribution of each species to the overall biomass need to be obtained before an assessment can be made as to the level of understanding of the trophic interactions in those two regions. The dietary data that is available for atherinids, gobiids, A. forsteri, M. cephalus, blowfish Torquigener pleurogramma, yellow-tailed trumpeter A. caudavittata, gobbleguts A. rueppellii, P. endrachtensis and small-tooth flounder Pseudorhombus jenynsii (Prince et al. 1982, Geijsel 1983, Chrystal et al. 1985, Potter et al. 1988, Gill and Potter 1993, Wise et al. 1994) will probably pertain to important current contributers of the biomass, although other species are likely to also be important in terms of biomass (Valesini unpublished data).

In the Peel-Harvey Estuary, which lies ca 80 km to the south of the Swan Estuary, there is no direct information available on the diets of fish in that system (Table 1.8),

with the exception of very limited and unpublished data (T. Rose, Murdoch University). Similarly, in the case of the Leschenault Estuary, the dietary data that was collected by Chalmer and Scott (1984) and also presented in Potter et al. (2000) remains the only real source of information of the diets of fish in this estuary (Table 1.9). However, this data was based on a one-off sampling occasion in both this and the Peel-Harvey Estuary, with results combined for some fish species if they were present in both estuarine environments, Furthermore, at present, only data summaries exist for these species. Thus, most fish species in both the Peel-Harvey and Leschenault estuaries urgently require scientific attention, and this include commercially and recreationally important species such as the yellowfin whiting *Sillago schomburgkii*, *M. cephalus*, *A. forsteri*, tailor *Pomatomus saltatrix*, *A. georgiana*, *P. dentex* and black bream *Acanthopagrus butcheri*. However, for crustaceans, there are good published dietary data for the blue swimmer crab *Portunus pelagicus* (de Lestang et al. 2001).

In the case of Wilson Inlet, a study conducted by Murdoch University in 1988-1990, which included studies of the diets of many of the fish species that were important in terms of the overall biomass and abundance of fish within that seasonally closed estuary (Table 1.10), means that the dietary information for most species in Wilson Inlet is relatively well understood (Humphries et al. 1992, Humphries and Potter 1993, Laurenson 1992, Orr 2000). Some gaps exist in the case of *P. saltatrix, P. jenynsii*, garfish *Hyporhamphus melanochir, E. australis, R. sarba, A. butcheri*, leatherjacket *Meuschenia freycineti* and *P. sexlineatus*. However, the most important gap is probably that of *P. auratus*, which is a highly sought after commercial and recreational fish species but for which there are no substantial data in this or any other environment.

	Environment	Percentage biomass	Dietary data present?	Dietary data for this environment?	If not, then for which next most similar environment?	Data quality	Does this species require attention?
	Upper Swan Estuary						
	Nematalosa vlaminghi	80.2	No	Yes			Yes (1)
*	Acanthopagrus butcheri	10.0	Yes	Yes		High	
*	Mugil cephalus	3.1	Yes	Yes		Adequate – summary	
	Amniataba caudavittata	1.8	Yes	Yes		High	
*	Aldrichetta forsteri	1.1	Yes	Yes		Adequate-summary	
	Pelates sexlineatus	1.0	No				Yes (2)
	Torquigener pleurogramma	0.6	Yes	No	Lower Swan Estuary	High- summary	
	Engraulis australis	0.5	No				Yes (1)
*	Sillago burrus	0.4	Yes	No	South-western marine waters	High	
	Atherinomorus ogilbyi	0.3	Yes	Yes		High	
*	Platycephalus endrachtensis	0.1	Yes	Yes		Adequate	Yes (2)
	Total contribution to biomass	84.2					
	Canning River						
	Nematalosa vlaminghi	22.3	No	No			Yes (1)
*	Acanthopagrus butcheri	18.4	Yes	No	Upper Swan Estuary	High	
*	Mugil cephalus	15.4	Yes	Yes		High	
	Torquigener pleurogramma	15.4	Yes	Yes		High – summary	
	Amniataba caudavittata	8.1	Yes	No	Upper Swan Estuary	High	
*	Aldrichetta forsteri	5.8	Yes	Yes		Adequate – summary	
	Atherinomorus ogilbyi	4.3	Yes	No	Lower Swan Estuary	High – summary	
	Atherinosoma elongata	2.4	Yes	No	Lower and upper Swan Estuary	High	
	Leptatherina wallacei	1.7	Yes	No	Lower and upper Swan Estuary	High	
*	Sillago burrus	1.6	Yes	No	South-western marine waters	High	
	Gerres subfasciatus	1.3	Yes	No	Lower Swan Estuary	Adequate - summary	Yes (2)
	Total contribution to biomass	96.8					

Table 1.4: List of species which collectively contribute at least 80% to the total biomass of fish recorded during a scientific study of the fish faunas of nearshore, shallow waters in the upper Swan Estuary and Canning Rivers between 1995 and 1997 (Kanandjembo unpublished data from project detailed in Kanandjembo et al. 2001ab).

Table 1.5: List of species which collectively contribute at least 80% to the total biomass of fish recorded during a scientific study of the fish faunas of offshore, deeper waters in the
upper Swan Estuary between 1995 and 1997 (Kanandjembo unpublished data from project detailed in Kanandjembo et al. 2001ab).

	Environment	Percentage biomass	Dietary data present?	Dietary data for this environment?	If no, then for which next most similar environment?	Data quality	Does this species require attention?
	Upper Swan Estuary						
	Nematalosa vlaminghi	39.0	No	Yes			Yes (1)
*	Acanthopagrus butcheri	23.0	Yes	Yes		High	
	Amniataba caudavittata	17.9	Yes	Yes		High	
*	Mugil cephalus	8.8	Yes	Yes		Adequate-summary	
*	Arygrosoma japonicus	3.2	No				Yes (1)
*	Elops machnata	3.0	No				Yes (1)
*	Platycephalus endrachtensis	2.0	Yes	No	Lower Swan Estuary	Adequate - summary	Yes (2)
*	Pomatomus saltatrix	1.4	No				Yes (1)
*	Cnidoglanis macrocephalus	0.7	Yes	No	Wilson Inlet	High	
	Pelates sexlineatus	0.5	No				Yes (2)
	Total contribution to biomass	99.5					

Upper Swan Estuary Swan River	Percent biomass	Middle Swan Estuary	Percent biomass	Lower Swan Estuary	Percent biomass
Nematalosa vlaminghi	32.5	Amniataba caudavittata	31.7	Torquigener pleurogramma	77.6
Amniataba caudavittata	19.7	Nematalosa vlaminghi	15.6	Aldrichetta forsteri	13.9
Acanthopagrus butcheri	18.4	Aldrichetta forsteri	11.5	Mugil cephalus	2.9
Mugil cephalus	18.3	Torquigener pleurogramma	8.9	Pelates sexlineatus	2.8
Pomatomus saltatrix	0.6	Acanthopagrus butcheri	8.3	Platycephalus endrachtensis	0.7
Platycephalus endrachtensis	1.5	Mugil cephalus	7.3	Amniataba caudavittata	0.6
Pelates sexlineatus	1.4	Pelates sexlineatus	3.4	Apogon rueppellii	0.5
Pomatomus saltatrix	0.6	Cnidoglanis macrocephalus	2.9	Pseudorhombus jenynsii	0.3
Engraulis australis	0.5	Apogon rueppellii	2.2	Cnidoglanis macrocephalus	0.2
Trachurus mccullochi	0.5	Platycephalus endrachtensis	1.8		
Atherinomorus ogilbyi	0.3	Argyrosomus japonicus	1.5		
Gerres subfasciatus	0.3	Pomatomus saltatrix	1.5		
Cnidoglanis macrocephalus	0.2	Sillago vittata	1.4		
Amoya bifrenatus	0.2	Amoya bifrenatus	0.7		
		Portunus pelagicus	0.6		
Total contribution to biomass	84.2		83.7		99.5
Canning River					
Nematalosa vlaminghi	50.8				
Amniataba caudavittata	15.0				
Mugil cephalus	12.4				
Aldrichetta forsteri	9.8				
Acanthopagrus butcheri	4.5				
Torquigener pleurogramma	1.7				
Apogon rueppellii	1.1				
Engraulis australis	0.9				
Pomatomus saltatrix	0.8				
Platycephalus endrachtensis	0.6				
Pelates sexlineatus	0.5				
Atherinomorus ogilbyi	0.3				
Gerres subfasciatus	0.3				
Total contribution to biomass	98.8				

Table 1.6: List of species which collectively contribute at least 80% to the total biomass of fish recorded during a scientific study of the fish faunasof nearshore, shallow waters in the upper, middle and lower Swan Estuary and Canning River between 1977 and 1981 (Loneraganunpublished data from project detailed in Loneragan et al. 1989).

Table 1.7: List of species which collectively contribute at least 80% to the total biomass of fish recorded during a scientific study of the fish faunas of
offshore, deeper waters in the upper, middle and lower Swan Estuary and Canning River between 1977 and 1981 (Loneragan unpublished data
from project detailed in Loneragan et al. 1989).

Upper Swan Estuary	Percent biomass	Middle Swan Estuary	Percent biomass	Lower Swan Estuary	Percent biomass
Nematalosa vlaminghi	38.0	Nematalosa vlaminghi	22.0	Argyrosomus japonicus	83.6
Mugil cephalus	20.7	Argyrosomus japonicus	15.2	Portunus pelagicus	7.7
Argyrosomus japonicus	13.9	Platycephalus endrachtensis	11.5	Platycephalus endrachtensis	3.8
Amniataba caudavittata	13.4	Mugil cephalus	11.4	Nematalosa vlaminghi	3.3
Acanthopagrus butcheri	10.8	Sardinella lemuru	8.6		
Aldrichetta forsteri	1.2	Pomatomus saltatrix	7.8		
Platycephalus endrachtensis	1.1	Amniataba caudavittata	6.6		
Cnidoglanis macrocephalus	0.3	Melicertus latisculatus	6.1		
Portunus pelagicus	0.2	Pelates sexlineatus	5.6		
Pomatomus saltatrix	0.1	Aldrichetta forsteri	2.6		
		Cnidoglanis macrocephalus	1.5		
Total contribution to biomass	99.8		98.9		99.5

	Nearshore, shallow waters of Peel-Harvey Estuary	Percentage biomass	Dietary data present?	Dietary data for this environment?	If no, then for which next most similar environment?	Data quality	Does this species require attention?
	Torquigener pleurogramma	70.2	Yes	Yes		Low – summary	Yes (1)
*	Aldrichetta forsteri	11.9	Yes	Yes		High – summary	Yes (1)
*	Hyperlophus vittatus	5.1	Yes	No	Swan Estuary	Adequate – summary	Yes (1)
	Atherinosoma elongata	2.6	Yes	No	Swan Estuary and Wilson Inlet	High	Yes (2)
	Leptatherina presbyteroides	2.6	Yes	No	Swan Estuary and Wilson Inlet	High	Yes (2)
	Apogon rueppellii	1.6	Yes	No	Swan Estuary	High	Yes (2)
	Favonigobius lateralis	1.0	Yes	No	Swan Estuary and Wilson Inlet	High	Yes (2)
*	Pseudorhombus jenynsii	1.2	Yes	No	Marine nearshore waters	High	Yes (1)
	Total contribution to biomass	96.2					

 Table 1.8: List of species which collectively contribute at least 80% to the total biomass of fish recorded during a scientific study of the fish faunas in nearshore, shallow waters of the Peel-Harvey Estuary between 1995 and 1997 (Young 2000).

	Leschenault Estuary	Percentage biomass	Dietary data present?	Dietary data for this environment?	If no, then for which next most similar environment?	Data quality	Does this species require attention?
	Nearshore, shallow waters						
*	Aldrichetta forsteri	18.6	Yes	No	Swan Estuary and Wilson Inlet	High	
	Torquigener pleurogramma	17.3	Yes	No	Swan Estuary	High - summary	Yes (1)
	Favonigobius lateralis	11.6	Yes	No	Swan Estuary and Wilson Inlet	High	
	Contusus brevicaudus	11.4	No		·	-	Yes (1)
*	Sillaginodes punctata	8.6	Yes	No	Marine waters and Wilson Inlet	High	
	Pelates sexlineatus	6.4	Yes	Yes	Also combined with Peel-Harvey	Sparse - summary	Yes (1)
	Atherinosoma elongata	4.3	Yes	No	Swan Estuary and Wilson Inlet	High	
*	Hyperlophus vittatus	2.2	Yes	No	Swan Estuary	Adequate	
*	Cnidoglanis macrocephalus	1.7	Yes	No	Wilson Inlet	Adequate	
*	Sillago schomburgkii	1.6	Yes	Yes	Also combined with Peel-Harvey	Sparse - summary	Yes (1)
	Total contribution to biomass	83.7					
	Offshore, deeper waters						
	Myliobatis australis	44.0	No				Yes (1)
	Nematalosa vlaminghi	23.4	Yes	No	Swan Estuary	Adequate – summary	
*	Mugil cephalus	16.0	Yes	No	Swan Estuary and Wilson Inlet	High	Yes (2)
*	Aldrichetta forsteri	4.3	Yes	No	Swan Estuary and Wilson Inlet	High	Yes (2)
*	Pomatomus saltatrix	2.7	No		-	-	Yes (1)
	Carcharhinus leucas	2.1	No				Yes (1)
*	Arripis georgiana	2.0	Yes	No	Marine waters	High	Yes (2)
*	Pseudocaranx dentex	1.7	No				Yes (1)
*	Acanthopagrus butcheri	1.0	Yes	No	West and south coast estuaries	High	Yes (2)
	Total contribution to biomass	97.2					

 Table 1.9: List of species which collectively contribute at least 80% to the total biomass of fish recorded during a scientific study of the fish faunas in nearshore, shallow and offshore, deeper waters of the Leschenault Estuary between 1993 and 1994 (Tiivel unpublished data from project detailed in Potter et al. 1997).

	Wilson Inlet	Percentage biomass	Dietary data present?	Dietary data for this environment?	If no, then for which next most similar environment?	Data quality	Does this species require attention?
	Nearshore, shallow waters						
*	Aldrichetta forsteri	24.8	Yes	Yes		High	
*	Mugil cephalus	13.3	Yes	Yes		High	
	Atherinosoma elongata	14.1	Yes	Yes		High	
	Leptatherina wallacei	12.6	Yes	Yes		High	
*	Pomatomus saltatrix	10.2	No			-	Yes (1)
	Leptatherina presbyteroides	8.9	Yes	Yes		High	
	Favonigobius lateralis	5.0	Yes	Yes		High	
*	Pseudorhombus jenynsii	4.9	Yes	No	Marine waters		Yes (2)
*	Hyporhamphus melanochir	1.7	No				Yes (1)
	Engraulis australis	1.2	No				Yes (1)
	Favonigobius suppositus	1.1	Yes	Yes		High	
	Total contribution to biomass	97.8					
	Offshore, deeper waters						
*	Cnidoglanis macrocephalus	29.9	Yes	Yes		High	
*	Platycephalus speculator	17.6	Yes	Yes		High	
*	Arripis georgiana	14.1	Yes	yes		High	
*	Aldrichetta forsteri	11.0	Yes	yes		High	
*	Mugil cephalus	5.9	Yes	Yes		High	
*	Sillaginodes punctata	4.4	Yes	Yes		High	
*	Rhabdosargus sarba	4.0	Yes	No	Swan Estuary and marine waters	Adequate	Yes (2)
*	Pagrus auratus	3.7	No				Yes (1)
*	Acanthopagrus butcheri	2.1	Yes	No	South and west coast estuaries	High	Yes (1)
	Meuschenia freycineti	1.4	No				Yes (2)
	Pelates sexlineatus	1.2	No				Yes (2)
	Total contribution to biomass	88.1					

Table 1.10:	List of species which collectively contribute at least 80% to the total biomass of fish recorded during a scientific study of the fish faunas in nearshore, shallow and
	offshore, deeper waters of Wilson Inlet between 1988 and 1989 (Potter unpublished data from project detailed in Potter et al. 1993).

1.5.3 Future directions

In the case of marine coastal waters of south-western Australia, both research sampling and conversations with commercial and recreational fishers strongly indicate that, if a dietary study were to commence on those data-deficient species, sufficient numbers of those species could be collected from those environments to enable dietary analyses. Indeed, our ongoing work on certain of those species supports the above statement. In the case of the Swan Estuary, it is evident that certain of the species for which data is lacking will need to be sourced from recreational fishers, as well as from the research sampling which is being undertaken in that estuary by Murdoch University in conjunction with the Department of Fisheries WA. The limited sampling, employing seine and gill netting, that was carried out in two of the environments for which dietary data was particularly sparse (the Peel-Harvey and Leschenault estuaries) also indicates that individuals will need to be sourced from recreational and/or commercial fishers. In the case of Wilson Inlet, species such as pink snapper (P. auratus) can only be effectively sourced from commercial fishers. A senior fisher in that system has expressed interest in being involved in such a project and is willing to supply monthly samples should a study commence on the diets of those species.

1.6 Outline of final report

The background and gap analysis of dietary data for fish species in estuarine and marine waters of south-western Australia is provided in the preceding sections. The third and fourth objectives of the project "To identify where dietary and other relevant data are lacking" and "To determine appropriate sampling methods to obtain (dietary) data for those areas where information is lacking", are thus fully answered above. The raw data that is available for each of the different dietary studies at Murdoch University, where the bulk of the dietary work for fish has been carried out in the estuaries and marine waters of south-western Australia, has been reformatted and placed into an Microsoft AccessTM database "Guts" (Chapter 2) in order to facilitate the first main aim of this project. This aim "To develop a comprehensive database for the abundance, size compositions and diets of the fish fauna in the estuaries and marine waters" is directly addressed in Chapter 2. Data for the abundance, biomass and size composition of those fish species is available by request in Excel[™] spreadsheets with metadata attached, with the intellectual property belonging jointly between Murdoch University, Department of Fisheries WA and the Fisheries Research and Development Corporation. The second main aim of this project "To describe the diets of the various fish species" is directly

addressed in Chapters 3 to 5, in which dietary data for species which have not been appropriately interrogated, is re-analysed and discussed. Chapter 6 describes a new approach for interpreting complex dietary data in particular environments that can be that can be extended to other environments. The results in this chapter were given as an oral presentation at the September 21-23 2004 ASFB conference held in Adelaide and received extremely supportive feedback from a variety of conference delegates.

Chapter 2 Development of the "Guts" database

2.1 Introduction

Many workers use Microsoft ExcelTM as their database of choice to manage dietary information for different species, and use either this program or a more sophisticated statistical programme, such as SPSSTM for WindowsTM, to analyse the data. In the case of multivariate analyses, such as those provided in the PRIMER v5.2 software package (Clarke and Gorley 2001), the aforementioned programmes are used to provide input into PRIMER. However, one drawback of using ExcelTM as a database is that it is not easily able to account for differences in the way that data are recorded, nor is it designed to handle much of the related information. This drawback becomes more pronounced when attempting to collate dietary data that have been recorded by different workers and in different systems.

It was considered that, in order to collate dietary data, which have been previously recorded for fish species and collected by different workers, a method had to be developed that could account for any inconsistencies in such information. Such a method must also optimise the information that had been recorded and ensure that all appropriate related information was also included. It was therefore decided to develop a database system, using Microsoft Access[™] as a platform, which would meet the above main criteria. Such a dedicated database would facilitate the entry of data for individual fish and also ensure that information was maintained on the intellectual property of the dietary data. The advantage of storing data within a dedicated database is that it is possible to maintain a very flexible but comprehensive collation of all available data in a form that facilitates the extraction and use of the data yet ensures the integrity of the information in the database.

2.2 Approaches

The main feature of using Access TM is that data, which encompass a particular aspect of the information that is pertinent to any examination of the diets of fish, can be entered separately into different tables. Such data are typically those which are contained in a single record, such as that relating either to the project under which data was collected, sampling occasion or biological information, including fish length and part of digestive tract that was examined for dietary items. Certain key variables can then be used to link those tables together and queries can be used to extract data of the precise

type that are required for analyses. These queries can be used to interrogate the database for any inconsistencies and also used to provide outputs to different programs, such as statistical or multivariate analyses software.

The Access[™] database, which is termed "Guts", was developed by myself and Norm Hall and includes all of the important information pertaining to records of the dietary data for individuals of different fish species. A list of the different features of the main tables, followed by a pictorial representation of the relationships between the different tables (Figure 2.1) is presented below. For convenience, table names are highlighted in blue, while variable names are highlighted in red.

1. Project Details

Assigns an autonumber function to the project (AutProjectID) which is used to link to both the "Additional Funding Bodies" table and the "Trips" table. Includes main funding source and key project personnel.

2. Additional Funding Bodies

In those cases where more than one organisation has contributed to the research. Used in the assignation of intellectual property, where appropriate.

3. Project Personnel

Lists the role of each staff member or student whilst working on that project.

4. Trips

Each record is uniquely identified by an "AutTripID", which is assigned using an autonumber function, and which then links to the "Biologicals" table. Provides broad ecological information about the region of study within that project (Environment, Area and System, which links to the "System Codes" table), and specifically the way in which it relates to the fish that are collected for dietary analyses are also given. Detailed spatial information is provided in SiteCode (which links to the "Site Codes" table) and method of capture is provided in "MethodCode" (which links to the "Method Code" table).

5. System Codes, Site Codes and Method Codes

These codes are based on the initial code system developed by Fisheries WA and Murdoch University in the late 1980's, and which include most estuaries in south-western Australia. The initial codes have been expanded, and full documents are housed at Murdoch University. N.B. The site codes are provided as additional information in the sampling programmes that underly the results in Chapters 3, 4 and 5.
6. Biologicals

This table provides "SpeciesName" in full, which links to the "Fish Species" in the "Predator Type" table, and thereby associated phylogenetic information. It also provides "FishNumber", the unique fish number (e.g. YY####) that pertains to each individual of a species. Since fish numbers can be duplicated between species and projects, this table includes "AutFishID", a unique number assigned by an autonumber function. The name of the "Dietician", which may differ from that of the "DataCustodian" ("Project Details") is also provided. The "Biologicals" table includes all relevant biological information that may have been obtained for each individual fish that was collected as part of the sample collected during that trip – which is defined using the "TripID". The "DataQuality" and "DataAnalysed" variables are used to ascertain the usefulness of the dietary data.

7. Diets

This table contains the "ProjectID", "TripID" and "FishID" variables to link each record to the appropriate table. It also creates a new variable "PreyID" which refers to the "Prey Type" table. The measure of the percentage contribution of each dietary category to the overall diet of each individual fish is recorded in either "PreyVolume", "PreyWetWeight" or "PreyDryWeight" as a percentage value. A measure of numerical abundance was not included in this database due to inconsistencies in the estimation of that parameter by different workers.

8. Prey Type

The main obstacle to the development of this database was the need to encompass as much information as possible about the different species and categories that comprise the prey of fishes. A separate table was therefore created that includes all phylogenetic information about each prey taxa (Kingdom to CommonName), and which has space to add further functional or ecological information about the different taxa. It also includes dietary items such as sediment, detritus, etc. Each prey taxa and other items are assigned a unique identification code ("AutPreyID"), using an autonumber function. Although I had considered using CAAB codes for those numbers, insufficient representation of most of the invertebrates and other items means that it is not practical at present. The extensive list of prey categories in the prey table was devised using basic taxonomic works, as well as by referring to the published and non-published dietary data for different species of fish in south-western Australia.



Figure 2.1: Schematic representation of the data tables and accompanying relationships (1denotes single, ∞ denotes many) in the MS Access TM database "Guts", as at 9th December 2004. Database was developed by Margaret Platell and Norm Hall.

At present, the dietary information in the Access database was imported via a Visual BasicTM routine from ExcelTM, that was developed by Norm Hall (Murdoch University) and the additional associated information has been entered via keyboard. The Query function in AccessTM is used to extract information, which is further treated in ExcelTM, for data analyses.

A CD copy of the latest version of "Guts", which contains records for 40 species in eight different environments, with a total of 14080 individuals for which dietary data is recorded, is included with this final report. This database is not to be used without express permission from either Margaret Platell or Norm Hall. Data within the database have been provided with the condition that they require the permission of the data custodian before they may be used in analyses or publications.

Chapter 3

Diets of three teleost species in the lower and middle Swan Estuary

3.1 Introduction and aims

The Swan Estuary is a permanently open and large estuary on the west coast of Western Australia and which runs through the city of Perth, the capital of that state. The estuary comprises three main regions, the lower region (entrance channel), which joins the sea to the middle estuary via a narrow channel, the middle estuary, which is the large basinlike region into which the tributary rivers empty and the upper estuary, which comprises the lower-most reaches of those tributary rivers (Potter and Hyndes 1999). The fish communities of this metropolitan estuary, which were studied intensively in the late 1970s and early 1980s (Loneragan et al. 1989), are considered to have changed since that time, as a consequence of anthropogenic activities that, inter alia, have resulted in the presence of more frequent and increasingly severe algal blooms in that system (Valesini et al. in preparation). Since these algal blooms have at least partly influenced the abundance of certain fish species, this would imply that the overall ecosystem functioning would have also been modified. Furthermore, since information on feeding relationships can provide indirect information on ecosystem stability, it would appear important to gain an understanding of those relationships in the Swan Estuary, so as to fully gauge the extent of any changes in this iconic estuary.

The published dietary information that is available for fish species in the upper Swan Estuary is relatively recent, with data available for the recreationally important sparid Acanthopagrus butcheri and three other abundant species of little or no commercial or recreational value, i.e. the teraponid Amniataba caudavitta, the atherinid Leptatherina wallacei and the gobiid *Pseudogobius olorum* (Kanandjembo 1998, Sarre et al. 2000). The dietary data for those species was subjected to appropriate multivariate analyses and the raw data for those species has been entered into "Guts". In contrast, although information for fish species in the lower and middle Swan Estuary is available for six species of atherinid (Prince et al. 1982), two species of gobiid (Gill and Potter 1993), one species of apogonid (Chrystal et al. 1985), one species of tetraodontid (Potter et al. 1988) and A. caudavittata (Wise et al. 1994), the dietary data for none of those species was subjected to the type of multivariate analyses that would enable the most important influences on the diets of those species to be determined (see e.g. Platell and Potter 2001, Hourston et al. 2004). Moreover, the raw data for the diets of individual fish, which would enable such comparisons to be made, could be located only in the case of the Honours study on the diets of the apogonid Apogon rueppellii (Chrystal 1983). That same author also provided detailed dietary data on two other fish species that were abundant in

the middle part of the Swan Estuary, namely the recreationally important *Pseudorhombus jenynsii* (Bothidae) and *Platycephalus endrachtensis* (Platycephalidae).

Since the raw data for the diets of the above three species could be located, with the exception of the length data for *P. jenynsii* and *P. endrachtensis*, this data was entered into "Guts" and re-analysed with a view to determining

- (1) the extent of any dietary differences among the three species,
- (2) whether or not the diets of those species vary between day and night, location and/or season and, if so, elucidate the reasons for such differences
- (3) for *A. rueppellii*, the influence of increasing size of fish on the dietary compositions of that apogonid, and
- (4) the usefulness of the above dietary data in terms of ecosystem modelling.

3.2 Materials and methods

Individuals of three species (*Apogon rueppellii*, *Pseudorhombus jenynsii* and *Platycephalus endrachtensis*) were obtained from sites located in the lower and middle regions of the Swan River Estuary on either a monthly or bimonthly basis between May 1981 and June 1983. Individuals of those three species were obtained by day and night-time otter trawling mainly at Blackwall Reach (Site No. 130), Freshwater Bay (Site No. 240), Melville 4 m depth (Site No. 335) and Melville 8 m depth (Site No. 336), with *A. rueppellii* and *P. jenynsii* being collected only from these four sites, while small numbers of *P. endrachtensis* were also obtained by night-time gillnetting at White Beach (Site No. 220), Point Walter (Site No. 230) and Melville 13 m depth (Site No. 337). N.B. The site names and accompanying codes are recorded in "Guts" and form part of the standardised data set for diets of fish in the Swan Estuary.

The otter trawl net, which was 5 m long, 2.6 m wide and 0.5 m in depth, comprised 51 mm mesh in the body of the net and 25 mm mesh in the bunt. The net was towed behind a small motor vessel at a speed of $3 - 4 \text{ km h}^{-1}$ for a 5 to 15 min period during each of the day and night. The composite sunken gill net, which contained 30 m panels that each comprised 13, 25, 38, 51, 63, 79, 89 or 102 mm mesh, was deployed soon after sunset and retrieved 3 h later.

Up to 25 individuals of each species, covering a wide size range, were removed from the day and night-time samples collected from each site in each season. Each fish was measured to the nearest 1 mm (total length) and its stomach removed and preserved in 70% ethanol. N.B. Although the lengths were recorded for all three species, the data for only *A. rueppellii* could be located.

The number of individuals of each species with empty stomachs, hereafter referred to as guts, was recorded and the fullness of each gut with food was scored on a scale of 1 (ca 10% full) to 10 (100% full). The contents of each gut were examined under a dissecting microscope using reflected light and its items identified to the lowest possible taxon. Each prey item was allocated to one of a number of taxonomic groups, subsequently referred to as dietary categories and also allocated into major taxa (see Table 3.1). The frequency of occurrence of each dietary category in the gut of each fish (%F) was recorded. The percentage contribution made by the volume of each dietary category to the total dietary volume of the gut of each fish (%V) was determined.

3.2.1 Dietary analyses

To examine the relative extents to which the dietary compositions of the three fish species were different, the mean percentage volumetric contributions of the various dietary categories in the guts of each species at each site and in each season and during both day and night were calculated, using those dietary categories and major taxa which are denoted by a superscript 1 in Table 3.1, and thereafter referred to as a dietary sample. N.B. Only those mean values which were represented by at least 3 guts were included. The dietary samples were then square root transformed and the Bray-Curtis similarity measure applied to those data to produce a matrix. This matrix was then subjected to a series of one-way Analyses of Similarities (ANOSIM) and non-metric multidimensional scaling (MDS) ordination (Clarke and Gorley 2001). The magnitude of the global R-statistic value were used to ascertain the extent to which dietary composition differed among species, sites and seasons and between day and night (Clarke 1993) and the significance level was recorded only for the most influential of those factors (K. Clarke, pers. comm.). Thus, R-statistic values range from 1, if the composition of all samples within each group are more similar to each other than to any of the samples from any other group, down to ca 0 if the average similarities between and within groups are the same (Clarke 1993). The null hypothesis for ANOSIM tests that the dietary compositions were not significantly different was rejected if the significance level (P)exceeded 5%. The results of pairwise ANOSIM comparisons are presented only when the number of possible permutations exceeded 35, i.e. the minimum number of permutations at which the significance level can be reliably interpreted (K. Clarke, pers. comm.). Here and subsequently, Similarity of Percentages (SIMPER) was used to determine which dietary categories either typify and/or distinguish between a priori groups that are shown to be significantly different (Clarke 1993). Multivariate dispersion (MVDISP) was used to ascertain the variability in the dietary samples of the three species (Somerfield and Clarke 1997).

As species exerted the greatest overall influence on dietary compositions, the dietary data for the three species were thus considered separately. The mean percentage volumetric contributions of the various dietary categories in the guts of each species at each site and in each season and during both day and night were calculated, using those dietary categories which are denoted by a superscript 2 in Table 3.1, and thereafter referred to as a dietary sample. As previously, only those mean values which were represented by at least 3 guts were included. The dietary data was then subjected to the various subroutines in PRIMER v5, i.e. ANOSIM, MDS ordination and SIMPER, which are described above. One-way ANOSIMs were used to determine whether the dietary composition of each of the three species was influenced most by site, season and/or time of day. The above dietary data was then separated by site (see results for explanation), subjected to MDS ordination and the resultant plots examined for any time of day and seasonal differences.

To explore whether the dietary compositions of *A. rueppellii* changed with increasing body size, the mean volumetric contributions of the various dietary categories to the diets of individuals in sequential length classes of 20 mm, i.e. 20-39, 40-59, 60-79 mm etc, derived from pooled data for time of day, but with dietary data for site and season kept separate, were subjected to ANOSIM, MDS ordination and SIMPER (Clarke and Gorley 2001). The mean volumetric contributions of the various dietary categories in each sequential length class were also pooled for both site and season and plotted separately as a histogram, in order to highlight those size-related changes that were shown to be most important (see results).

3.3 Results

3.3.1 Overall species patterns

A total of 1151, 297 and 504 guts were examined in the case of *Apogon rueppellii*, *Pseudorhombus jenynsii* and *Platycephalus endrachtensis*, respectively (Table 3.1). For the first species, 47.5% of the guts contained identifiable food while 59.6 and 46.8% of the guts of the second and third species, respectively, contained identifiable food. Of those guts that contained food, the mean fullness was least in *A. rueppellii* and greatest in *P. jenynsii* (Table 3.1).

Polychaetes occurred in 31.6% of the guts of *A. rueppellii* but in less than 1% of the guts of the other two species, while molluscs and macrophytes each occurred in between 1 and 4% of the guts of all three species (Table 3.1). Crustaceans occurred in 81.0, 43.5 and 31.4% of the guts of *A. rueppellii*, *P. jenynsii* and *P. endrachtensis*, respectively, and contributed 55.3, 35.6 and 20.4% to the overall dietary volume of these species, respectively. In contrast, teleosts only occurred in 4.9% of the guts of *A. rueppellii* but occurred in 65.5 and 83.5% of the guts of

P. jenynsii and *P. endrachtensis*, respectively. In the case of the last two species, teleosts contributed 66.4 and 78.0%, respectively, to their diets (Table 3.1).

For the polychaetes, these were mainly represented by nereids and orbiniids, which contributed 10.7 and 4.1%, respectively, to the overall dietary volume of *A. rueppellii* (Table 3.1). The crustaceans that were by far the most important to the overall dietary volume of *A. rueppellii* were gammarid amphipods (29.3%), with lesser contributions being made by copepods (10.4%) and mysids (6.5%). With *P. jenynsii*, the carid *Alpheus richardsoni* and two penaids (*Metapenaeus dallii* and *Melicertus latisulcatus*) collectively contributed 25.6% to the overall dietary volume while gammarids only contributed 3.6%. The important crustaceans in terms of dietary volume for *P. endrachtensis* were *A. richardsoni* (8.6%), *M. dallii* (3.8%), the carid *Palaemonetes australis* (2.0%), while crabs collectively contributed 3.7%.

Although each of the three species ingested fish to at least some extent, *P. endrachtensis* fed on the greatest number of species, including the other subject of this study (*A. rueppellii*) (Table 3.1). The contributions to the overall dietary volume of *P. endrachtensis* ranged downwards from 10.7% for *A. rueppellii*, to 8.1% for the clupeid *Engraulis australis* and 3.9% for the gobiid *Amoya bifrenatus*, with the collective contributions of gobiids and atherinids to the diet of this species being 8.8 and 4.8%, respectively. Although *P. endrachtensis* also consumed the recreationally and commercially important *Hyperlophus vittatus*, *Pseudocaranx dentex*, *Aldrichetta forsteri*, *Mugil cephalus* and *Arygrosomus japonicus*, the collective contributions of these species to the overall dietary volume were relatively low (3.1%). In terms of volume, *P. jenynsii* mainly ingested *E. australis* (12.9%), *Pseudogobius olorum* (10.1%), *A. rueppellii* (6.9%), *A. bifrenatus* (6.2%) and *A. japonicus* (5.0%) (Table 3.1). **Table 3.1:**The frequency of occurrence (%F) and mean percentage volumetric contribution (%V) of
the different major taxa (boldface) and dietary categories to the overall diets of *Apogon*
rueppellii, Pseudorhombus jenynsii and *Platycephalus endrachtensis* in the Swan Estuary.
N.B. For superscripts, 1, those major taxa or dietary categories used for inter-specific
comparisons, while 2 refers to those dietary categories that were used for intra-specific
comparisons. In the case of unidentifiable crabs, these were a valid dietary category for
intraspecific comparisons of the diets of A. *rueppellii*, in which no identifiable crab species
were recorded.

Major taxa and dietary categories	Apo ruepj	gon pellii	Pseudor jeny	hombus nsii	Platycep endrach	ohalus utensis
	%F	%V	%F	%V	%F	%V
Polychaetes ¹ Orbiniids ² Capitellids ²	31.6 5.9 1.6	17.6 4.1 0.8	0.6	0.3	0.8	0.3
Sabellids ⁻ Nereids ² Funicids ²	0.9 20.3 0.2	0.4 10.7 0.1			0.4	0.2
Unidentifiable polychaetes	1.6	1.4			0.4	<0.1
Molluscs Gastropods ¹	3.3	2.7	1.1 0.6	<0.1	1.3	0.2
Musculista senhausia ¹ Bivalve siphons ¹	0.2 3.1	0.2 2.5	0.0	1011	0.4	<0.1
Other bivalves ¹			0.6	<0.1	0.8	<0.1
Crustaceans Copepods ¹	81.0 15.7	55.3 10.4	43.5	35.6	31.4	20.4
Mysids ¹ Tanaids ¹	15.7 0.2	6.5 0.2			0.4	0.4
Gammarid amphipods ¹ Caprellid amphipods ¹ Elaballifaran isonods ¹	51.4 6.4	29.3 2.4	5.6 0.6	3.6 0.1	3.0	1.6
Squilla laevis ¹ Palaemonetes	1.8	1.6	0.0	<0.1	0.4 3.4	<0.1 2.0
australis ¹ Alpheus richardsoni ¹ Metapenaeus dallii ¹ Melicertus	3.7	3.0	16.9 9.0 4.5	12.9 8.2 4.5	14.4 4.2	8.6 3.8
Halicarcinus australis ¹ Portunus pelagicus ¹ Unidentifiable crabs ² Unidentifiable crustaceans	0.5	0.4	1.2 0.6 2.8 5.1	0.9 0.3 2.5 2.6	3.0 0.8 2.1 0.4	1.5 0.3 1.9 <0.1
Teleosts	4.9	4.1	65.5	66.4	83.5	78.0
Hyperlophus vittatus ¹ Engraulis australis ¹ Pelates sexlineatus ¹	0.9	1.7	11.3	12.9	1.3 8.5 1.3	0.9 8.1 1.0
Apogon rueppellii ¹ Sillago burrus ¹ Pseudocaranx dentex ¹ Aldrichetta forsteri ¹ Mugil genhalur ¹	1.8	0.5	7.9 0.6	6.9 0.6	11.4 0.4 1.7 0.4	10.7 0.4 1.2 0.3
Argyrosomus japonicus ¹			5.6	5.0	0.4	0.3
Amoya bifrenatus ¹ Callogobius mucosus ¹ Favonigobius lateralis ¹ Pseudogobius olorum ¹			6.2 0.6 1.1 11.3	6.2 0.3 0.6 10.1	5.1 0.8 2.5 4.2	3.9 0.7 1.8 3.3
Tridentiger triginocephalus ¹					0.8	0.9

Table 3.1:continued

Major taxa and dietary categories	Apo ruepj	gon vellii	Pseudor jeny	hombus msii	Platyce _l endrach	ohalus tensis
	%F	%V	%F	%V	%F	%V
Unidentifiable gobiids			3.9	3.9	5.9	4.8
Unidentifiable atherinids ¹	0.2	0.2			0.4	<0.1
Unidentifiable fish	1.5	1.1	26.0	20.0	45.3	39.3
Fish larvae ¹	0.9	0.6				
Macrophytes ¹	0.5	0.2	1.7	0.3	2.1	1.3
Gracilaria verrucosa	0.2	< 0.1	1.7	0.3	1.7	0.5^{2}
Polysiphonia sp.					0.8	0.5^{2}
Halophila ovalis					1.3	0.2^{2}
Plant material	0.4	0.1				
Other material						
Sediment	0.4	< 0.1			0.4	0.4
Shell fragments					0.8	< 0.1
Foraminiferans ¹					0.4	< 0.1
Eggs ¹	0.6	0.9				
Unidentifiable material	42.2	19.2			0.4	<0.1
Number of guts	1	1151		297		504
Number of guts with		813		179		236
food						
Numbers of guts with		547		177		236
identifiable food						
Mean and SE fullness of guts that contained food	2.5+	0.1	4.9+	0.2	2.9 +	- 0.1

3.3.2 Multivariate analyses of the dietary compositions of the three species

The mean percentage volumetric contributions of each dietary category (as denoted by a superscript 1 in Table 3.1) to the diets of each species and being kept separate for site, season and time of day, were subjected to the Bray-Curtis similarity measure and the resultant matrix tested using ANOSIM. ANOSIM revealed that the dietary compositions were influenced by far the most by species (Global R-statistic value=0.629, P=0.1%), and then by season (R=0.069), site (R=0.039) and time of day (R=-0.027). Pairwise ANOSIM comparisons also demonstrated that the diets of each species differed significantly from each other, with the R-statistic value ranging from 0.159 (P=0.5%) for P. jenynsii vs P. endrachtensis to 0.691 for A. rueppellii vs P. jenynsii (P=0.1%) and 0.893 for A. rueppellii vs P. endrachtensis. When the dietary data was ordinated and the dietary samples coded for species, the points for each species lay in a different part of the plot, with those for A. rueppellii forming a discrete and tight group on the left of the plot and those of *P. endrachtensis* lying on the right part of the plot, with those for P. jenynsii lying in the middle of the plot and grouping away from most of the points for P. endrachtensis (Figure 3.1). The relative dispersion was least for A. rueppellii (MVDISP=0.620) and far greater for both P. jenynsii and P. endrachtensis (MVDISP=1.141 and 1.146, respectively).



Figure 3.1: MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of *Apogon rueppellii*, *Platycephalus endrachtensis*, and *Pseudorhombus jenynsii* in the Swan Estuary.

SIMPER showed that relatively large volumes of gammarid amphipods, polychaetes, copepods and mysids both typified the diet of *A. rueppellii* and distinguished it from those of the other two species (Table 3.2). For *P. jenynsii*, the ingestion of relatively greater amounts of *A. richardsoni*, *P. olorum*, *M. dallii*, *A. rueppellii* and *A. bifrenatus* distinguished the diet of this bothid from that of *P. endrachtensis*, which consumed relatively greater amounts of *E. australis*.

3.3.3 Multivariate analyses of the dietary compositions of Apogon rueppellii

When the dietary data for *A. rueppellii* was separately subjected to ANOSIM to determine the relative influence of site, time of day and season on those diets, season had by far the greatest influence (Global R=0.339, P=0.1%), followed by time of day (Global R=0.095, ns) and site (Global R=0.075, ns). Pairwise comparisons demonstrated that, with the exception of summer vs autumn, the diets differed significantly between season, with R-statistic values ranging from 0.209 (autumn vs winter) to 0.704 (summer vs spring) (Table 3.3). When the points on the ordination plot were coded for season, those for summer and autumn were interspersed on the upper part of the plot, while those for winter and spring tended to form groups on the bottom part of the plot (Figure 3.2a).

Table 3.2: Dietary categories determined by SIMPER as those most responsible for typifying the dietary compositions of *Apogon rueppellii*, *Pseudorhombus jenynsii* and *Platycephalus endrachtensis* (non-shaded boxes) and distinguishing between the diets of each pair of those species. In this and Tables 3.4-3.8, asterisks denote that the dietary category makes a greater contribution to the diets recorded at the species at the top of the column.

Species	A. rueppellii	P. jenynsii	P. endrachtensis
A. rueppellii	Gammarids Polychaetes Copepods Mysids		
P. jenynsii	Gammarids* Polychaetes* A. richardsoni Copepods* P. olorum	A. richardsoni P. olorum M. dallii A. rueppellii A. bifrenatus A. japonicus	
P. endrachtensis	Gammarids* Polychaetes* Copepods* Mysids* <i>A. richardsoni</i> <i>E. australis</i>	A. richardsoni* P. olorum* M. dallii* A. rueppellii* A. bifrenatus* E. australis	A. richardsoni E. australis A. rueppellii M. dallii P. olorum

Table 3.3:Results of ANOSIM pairwise comparisons between the dietary compositions of Apogon
rueppellii in different seasons in the Swan Estuary. *p<5%, **p<1%, ***p<0.1%</th>

Season	Summer	Autumn	Winter
Autumn Winter Spring	0.028 0.539** 0.704**	0.209* 0.358**	0.233*

When those same points were coded for either time of day (Figure 3.2b) or sampling location (Figure 3.2c), the points for the different samples were largely interspersed on both of those plots.

SIMPER demonstrated that, although some small crustaceans, such as gammarids, mysids and copepods, were consumed in either three or four of the seasons, they were most important in the diets of *A. rueppellii* in summer and typically declined thereafter (Table 3.4). Unlike the situation with gammarid amphipods and copepods, mysids became important in the diets during spring. Relatively large volumes of orbiniid polychaetes and fish were consumed by this apogonid in autumn, while, in the winter diets, nereid polychaetes and bivalve siphons were relatively important. Gammarid amphipods were most important in summer and least important in winter. The larger carid crustaceans, *P. australis* and *A. richardsoni*, were largely ingested during the spring (Table 3.4).



Figure 3.2: MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of *Apogon rueppellii*, with the dietary samples coded separately for (a) season, (b) time of day and (c) site of capture.

Table 3.4:	Species determined by SIMPER as those most responsible for typifying the dietary
	compositions of Apogon rueppellii in the different seasons (non-shaded boxes) and
	distinguishing between the diets of each pair of those seasons.

Season	Summer	Autumn	Winter	Spring
Summer	Gammarids Copepods Mysids Orbiniids Nereids			
Autumn	Copepods* Gammarids* Orbiniids* Mysids* Fish	Gammarids Copepods Mysids Orbiniids Fish		
Winter	Copepods* Nereids Orbiniids* Mysids* Bivalve siphons	Nereids Copepods* Gammarids Bivalve siphons	Gammarids Nereids Copepods Bivalve siphons	
Spring	Copepods* Nereids Orbiniids* Mysids <i>P. australis</i> <i>A. richardsoni</i>	Nereids Gammarids Copepods* Mysids P. australis A. richardsoni	Nereids Gammarids Copepods* Mysids P. australis A. richardsoni	Nereids Gammarids Mysids <i>P. australis</i> <i>A. richardsoni</i>

In order to better visually depict the possible influence on season on the diets of *A. rueppellii*, the dietary data were separated by sampling location (site) and time of day and then ordinated. The plots for the diets are shown in Figures 3.3 a-d with the different points coded for day or night and for season. At Freshwater Bay the three points for night lay to the left or above the single point for spring (Figure 3.3a). For Blackwall Reach the points for each of day and night lay in different parts of the plot and, within each the points for summer and autumn lay on the top of the plot, while those for winter and spring occurred on the bottom of the plot (Figures 3.3c,d), with the points for the day lying to the left of those for night in all seasons except spring, in which the reverse was true. At Melville 4 m, the points for day and night were widely separated in autumn, and separated less during the spring, while there was little separation in summer and especially winter (Figure 3.3c,d), with the exception of the summer samples from day and night lying close together and further upwards on the plot (Figure 3.3d).



Figure 3.3: MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of *Apogon rueppellii* and kept separate for site (a) 130 (Blackwall Reach), (b) 240 (Freshwater Bay), (c) 335 (Melville 4m depth) and (d) 336 (Melville 8m depth), with the dietary samples coded for both season and time of day.

SIMPER was used to highlight the dietary categories which typified the dietary compositions of *A. rueppellii* during different seasons and times of day for each of the four sites (Table 3.5). At Freshwater Bay, in which both day and night-time samples showed the same seasonal progression, SIMPER showed that the main difference between the diets during the day and night-time was that greater amounts of fish larvae and the carid *A. richardsoni* were ingested during the day and relatively more gammarid amphipods, orbiniid and capitellid polychaetes, the clupeid *H. vittatus*, and the carid *P. australis* were found in the night-time diets. For both Melville 4 and 8 m, in which the day/night samples showed the most extreme difference in autumn, SIMPER demonstrated that, although gammarids were found during both day and night, they were more prevalent in the night-time samples. Moreover, copepods and fish were mainly ingested during the day and both caprellid amphipods and flabelliferan isopods were ingested at Melville 4 m during the night, while orbiniid polychaetes and mysids were consumed by *A. rueppellii* at Melville 8 m.

Table 3.5:	Dietary categories, in order of decreasing importance, that are determined by SIMPER as
	those most responsible for typifying the dietary compositions of Apogon rueppellii during
	the day and night in the different seasons at Blackwall Reach, Freshwater Bay, Melville 4 m
	and Melville 8 m, the Swan Estuary between 1981 and 1983

Season	Blackwall Reach	Freshwater Bay	Melville 4 m	Melville 8 m
Summer Day	Copepods Eggs Gammarids	Copepods Gammarids Fish larvae	Copepods Gammarids Eggs	Copepods Orbiniids Mysids
Summer Night		Gammarids Orbiniids <i>H. vittatus</i>	Gammarids Copepods Mysids	Gammarids Copepods Orbiniids
Autumn Day	Orbiniids Gammarids	Copepods Nereids	Copepods Fish Gammarids	Fish Gammarids Copepods
Autumn Night		Gammarids <i>H. vittatus</i> Capitellids	Gammarids Caprellids Flabelliferans	Gammarids Orbiniids Mysids
Winter Day	Gammarids Copepods	Nereids <i>A. richardsoni</i> Gammarids	Gammarids Nereids Caprellids	Nereids Gammarids Bivalve siphons
Winter Night		Gammarids Nereids A. richardsoni	Gammarids Bivalve siphons Nereids	Gammarids Nereids Bivalve siphons
Spring Day	Nereids Orbiniids Caprellids	Mysids Nereids <i>A. richardsoni</i>	Gammarids Nereids <i>P. australis</i>	Gammarids Mysids Nereids
Spring Night		Gammarids Nereids <i>P. australis</i>	Gammarids Nereids Copepods	Nereids Gammarids <i>P. australis</i>

3.3.4 Multivariate analyses of the dietary compositions of Pseudorhombus jenynsii

When the dietary data for *P. jenynsii* was separately subjected to ANOSIM to determine the relative influence of site, time of day and season on those diets, season had the greatest influence (Global R=0.240, P=2.3%), followed by time of day (Global R=-0.124, ns) and site (Global R=0.075, ns). Pairwise comparisons demonstrated that the diets of *P. jenynsii* differed significantly only with summer vs autumn (R=0.328, P=3.9%) and winter (R=0.612, P=0.6%). When the points on the ordination plot were coded for season, those for summer lay in a relatively discrete group on the upper middle part of the plot, while those for autumn were in the bottom part of the plot and for winter on the right-hand side of the plot (Figure 3.4a). When those same points were coded for either time of day (Figure 3.4b) or sampling location (Figure 3.4c), the points for the different samples were largely interspersed on both of those plots.



Figure 3.4: MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of *Pseudorhombus jenynsii*, coded separately for (a) season, (b) time of day and (c) site of capture.

SIMPER demonstrated that the diets of *P. jenynsii* in summer were distinguished by the relatively large contributions of the carid *A. richardsoni*, penaeid *M. dallii* and sciaenid *A. japonicus* from those of autumn and winter, in which relatively greater amounts of the engraulid *E. australis* (autumn) and the gobiids *A. bifrenatus* (winter) and *P. olorum* (autumn and winter) and the apogonid *A. rueppellii* (winter) were consumed (Table 3.6). Large crustaceans such as crabs and the penaeid *M. latisulcatus* also contributed to the diets of this bothid in autumn.

Table 3.6: Dietary categories determined by SIMPER as those most responsible for typifying the dietary compositions of *Pseudorhombus jenynsii* in summer, autumn and winter (non-shaded boxes) and distinguishing between the diets of summer and the two other seasons.

Season	Summer	Autumn	Winter
Summer	A. richardsoni M. dallii A. japonicus E. australis		
Autumn	A. richardsoni* E. australis M. dallii* A. japonicus*	E. australis P. olorum Crabs M. latisculcatus	
Winter	A. bifrenatus A. richardsoni* M. dallii* A. rueppellii P. olorum A. japonicus*	Ns	A. bifrenatus A. rueppellii P. olorum

In order to gain a better understanding of the possible influence on season on the diets of *P. jenynsii*, the dietary data were separated by sampling location (site) and time of day and then ordinated. The plots for two sampling locations where sufficient numbers of individuals were captured, i.e. Freshwater Bay and Melville 4 m are shown in Figures 3.5a,b, with the different points coded for time of day and for season. In the case of both locations, the points form a seasonal progression in an anticlockwise direction. Although the points for day and night lie on the upper and lower parts of the plot, respectively, there are insufficient day/night comparisons to ascertain the likely diel effect during the different seasons.



Figure 3.5: MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of *Pseudorhombus jenynsii* and kept separate for site (a) 240 (Freshwater Bay) and (b) 335 (Melville 4m depth), with the dietary samples coded for both season and time of day.

3.3.5 Multivariate analyses of the diets of Platycephalus endrachtensis

When the dietary data for *P. endrachtensis* were subjected to ANOSIM to determine the relative influence of site, time of day and season on those diets, site and season had the greatest influence (Global R=0.211, P=2.6% and Global R=0.167, P=2.6%, respectively), followed by time of day (Global R=-0.072, ns). Pairwise comparisons, for those cases when the number of permutations exceeded 35, demonstrated that the diets of *P. endrachtensis* at Melville 4 m differed significantly from both Blackwall Reach (R=0.759, P=1.8%) and Freshwater Bay (R=0.628, P=1.6%). When the points on the ordination plot were coded for sampling location, those for Melville 4 m lay in a tight group in the centre of the plot, above those for Blackwall Reach and to the right and/or above those for Freshwater Bay (Figure 3.6c). When those same points were coded for season, the point for autumn and most of those for summer lay on the upper part of the plot, while those for winter and spring were interspersed on the bottom half of the plot (Figure 3.6a). In the case of time of day, the points for the day and night-time samples were largely interspersed on the plot (Figure 3.6b).

SIMPER demonstrated that, although *P. endrachtensis* ingested large amounts of the engraulid *E. australis* at both Blackwall Reach and Freshwater Bay, the presence of the penaeid *M. dallii* in the diets at Blackwall Reach distinguished the diet of *P. endrachtensis* from that of Freshwater Bay, and also of that from Melville 4 m (Table 3.7). The ingestion of large amounts of *A. richardsoni* and *A. rueppellii* at Melville 4 m distinguished the diets of this platycephalid from the other two sites. Relatively greater amounts of *A. bifrenatus* were recorded in the diets of fish at Melville 4 m than Freshwater Bay (Table 3.7).



Figure 3.6: MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of *Platycephalus endrachtensis*, coded separately for (a) season, (b) time of day and (c) site of capture.

 Table 3.7:
 Dietary categories determined by SIMPER as those most responsible for typifying the dietary compositions of *Platycephalus endrachtensis* at Freshwater Bay, Blackwall Reach and Melville 4 m (non-shaded boxes) and distinguishing between the diets at those sites.

Site	Blackwall Reach	Freshwater Bay	Melville 4 m
Blackwall Reach	E. australis M. dallii		
Freshwater Bay	E. australis M. dallii*	E. australis	
Melville 4 m	E. australis A. richardsoni M. dallii* A. rueppellii	E. australis* A. richardsoni A. rueppellii A. bifrenatus	A. richardsoni A. rueppellii

In order to gain a better understanding of the possible influence of season and time of day on the diets of *P. endrachtensis*, the dietary data were separated by site and time of day and then ordinated. The plots for two sampling locations where sufficient numbers of individuals were captured, i.e. Melville 4 m and Melville 8 m, are shown in Figures 3.7a,b, with the different points coded for day or night and for season. For Melville 4 m, the diets in summer during the day lie on the far left and upper part of the plot, while that for night in the same season lies at the bottom of the plot (Figure 3.7a). The points for all other seasons form a relatively tight group on the far right of the plot. In the case of Melville 8 m, the day-time point for autumn lies on the left of the plot, with the other points all lying on the right of the plot. Within that latter group of samples, the day samples lie beneath and to the left of the night-time samples for the corresponding season (Figure 3.7b).





SIMPER was used to highlight the dietary categories which typified the dietary compositions of *P. endrachtensis* during different seasons and time of day for the two sites. At Melville 4 m, the distinct diets in summer were due to the ingestion of large amounts of *A. richardsoni* and *A. bifrenatus* during the day and the crab *H. australis* during the night. The night-time diets during spring comprised mainly *A. richardsoni* and smaller amounts of the teleosts *A. bifrenatus*, *A. rueppellii* and *A. japonicus*. In contrast, the diets during the day and in other seasons comprised mainly *A. bifrenatus*, *A. richardsoni* and the sillaginid *S. burrus*.

At Melville 8 m, the distinct diets during the autumn were due to ingestion of *P. dentex* during the day. In the other seasons, larger amounts of *A. rueppellii, A. richardsoni, A. bifrenatus* and *E. australis* were consumed by *P. endrachtensis* during the night than day, with the main dietary categories during the day being *M. dallii* and *P. olorum*.

3.3.6 Does increasing body size affect the dietary compositions of Apogon rueppellii?

When the dietary data for *A. rueppellii* was analysed, this time taking size of fish into consideration, the data were initially pooled for the other factors (site, season and time of day). Thus, the dietary data were separated into sequential size classes of 20 mm and plotted as a histogram (Figure 3.8a). The smallest *A. rueppellii* consumed mainly copepods and amphipods, with mysids making a smaller contribution. With increasing size, the contribution of copepods declined sharply, while that of mysids and amphipods decreased more slowly. The larger fish, i.e. > 60 mm, consumed substantial amounts of fish and the carid *A. richardsoni* and the very largest fish also consumed moderate amounts of crabs and polychaetes (Figure 3.8a).

When the dietary data was then separated by site and season, but not for time of day, the mean percentage volumetric contributions of the different dietary categories determined, and then subjected to ordination, there was a clear movement from left to right with increasing fish size (Figure 3.8b). SIMPER confirmed the above broad differences, i.e. when not taking site, season and time of day into account, and further demonstrated that the presence of orbiniids distinguished the diets of 40-59 mm individuals (cf Figure 3.8), as did the contributions of *P. australis* to the diets of 60-79 mm fish and bivalve siphons to the diets of the largest fish (< 80 mm) (Table 3.8).

Length class (mm)	20-39	40-59	60-79	$\geq \! 80$
20-39	Copepods Gammarids Mysids			
40-59	Copepods* Gammarids Mysids* Nereids	Gammarids Mysids Nereids Orbiniids		
60-79	Copepods* Nereids Gammarids Mysids*	Nereids Orbiniids* Mysids*	Gammarids Nereids <i>A. richardsoni</i> Caprellids <i>P. australis</i>	
≥80	Copepods* Gammarids* A. richardsoni Mysids* Fish Bivalve siphons	Gammarids* <i>A. richardsoni</i> Mysids*	Gammarids* <i>A. richardsoni</i> Nereids* Fish Bivalve siphons	Gammarids <i>A. richardsoni</i> Fish Crabs Bivalve siphons

Table 3.8:	Species determined by SIMPER as those most responsible for typifying the dietary
	compositions of 20-39, 40-59, 60-79 and >80 mm size classes of Apogon rueppellii (non-
	shaded boxes) and distinguishing between the diets of each pair of those size classes.



Figure 3.8: Mean percentage volumetric contributions of the different dietary categories to the diets of sequential size classes of *Apogon rueppellii*, presented as (a) stacked histograms and (b) an MDS ordination. N.B. Some of the dietary categories used to construct (b) have been combined in (a) to increase the perspicuity of the histograms.

3.4 Discussion

3.4.1 Interspecific comparisons

The multivariate approaches employed in this study demonstrate that the diets of *Apogon rueppellii, Pseudorhombus jenynsii* and *Platycephalus endrachtensis* significantly differed from each other, with the differences being greatest between *A. rueppellii* vs the other two species. Thus, the apogonid *A. rueppellii* mainly ingested small epibenthic and planktonic crustaceans, such as gammarid amphipods, copepods and mysids, and polychaetes, while the diets of the bothid *P. jenynsii* and the platycephalid *P. endrachtensis* were dominated by epibenthic teleosts and large crustaceans, such as carid and penaeid decapods. Thus, although the main method of capture of these three species was trawling, and these three species must therefore be occurring less than 0.5 m from the substrate, there is obviously partitioning of the food resources in that area. The terminal mouth and lateral compression of *A. rueppellii* also provides further circumstantial evidence for their feeding higher in the water column than the bothid or platycephalid, which are extremely flattened and can be observed lying on or just beneath the substrate surface. The presence of nereid polychaetes, which presumably migrate into the water column at night, also supports the view that this apogonid does feed higher in the water column than the other two species.

Although both *P. jenynsii* and *P. endrachtensis* ingested large amounts of fish, each ingesting *A. rueppellii* (the other subject of this study), the clupeid *Engraulis australis* and the sciaenid *Argyrosomus japonicus*, *P. endrachtensis* also ingested other commercially and recreationally important species, including the clupeid *Hyperlophus vittatus*, the carangid *Pseudocaranx dentex* and the mugilids *Aldrichetta forsteri* and *Mugil cephalus*. It would thus appear that, of these two ambush predators, *P. endrachtensis* is a more effective piscivore than *P. jenynsii*, which may be due to its greater swimming speed and/or greater size.

The greater variability in the diets of *P. jenynsii* and *P. endrachtensis* in comparison to that of *A. rueppellii*, reflects both the relative abundance and size of the prey and the prey capture behaviour of these three species. Thus, since *A. rueppellii* particulate feeds on a relatively prey that are particularly abundant in the water column and in the substrate (Kanandjembo et al. 2001b, Valesini et al. 2004), there is an increased likelihood of a number of these different prey being found in the stomach contents, which reduce the overall variability in their diets. For *P. jenynsii* and *P. endrachtensis*, their ambush feeding on large prey, such as fish or decapods, means that the stomach contents frequently contain only one or two of the many different prey types, which would act to increase the overall variability in the diets.

3.4.2 Influence of site, season and time of day on dietary compositions

The overall influence of site on the diets of any of the three species was found to be relatively unimportant. Although a site difference was expected, given the large differences of diets of nearshore fish between different habitat types (Schafer et al. 2002, Hourston et al. 2004), it would thus seem that the four sites (Blackwall Reach, Freshwater Bay, Melville 4 m and Melville 8 m) did not differ largely in their habitat characteristics and thus food sources. It is also probably relevant that these sites are located within a 5 km distance on the Swan Estuary. At present, there is no available information to assess whether or not these sampling locations do comprise the same or different habitat types, nor on their invertebrate food sources. Certainly, the compositions of the fish faunas sampled during an intensive study of the Swan Estuary did not differ greatly between those sites, which imply that variation in the fish food sources would be unlikely to produce large differences in the diets of those species which prey upon them, such as *P. jenynsii* and *P. endrachtensis*.

Time of day was also found to have little overall influence on the dietary compositions of any of the species, except during certain seasons at certain sites. Thus, for *A. rueppellii*, there was an overall difference between day and night at Freshwater Bay, which reflects the greater contribution of fish larvae and the carid *Alpheus richardsoni* during the day and relatively more gammarid amphipods, orbiniid and capitellid polychaetes, *Hyperlophus vittatus* and the carid *Palaemonetes australis* during the night. Likewise, for *P. endrachtensis* at Melville 4 m, the day/night differences in the diets during summer were due mainly to the ingestion of the gobiid *Amoya bifrenatus* and carid *A. richardsoni* during the day and of the crab *Halocarcinus australis* during the night. Such differences, which occur in only a few circumstances, reflect either differences in prey behaviour between day and night (see also Valesini et al. 2004) or of foraging behaviour in those species (see Linke et al. 2001, Hourston et al. 2004).

Season was shown to have by far the greatest influence on the diets of each of the three species, with clear seasonal progressions occurring on more than a few occasions. Thus, gammarid amphipods were most important in the diets of *A. rueppellii* during summer, while mysids and carid decapods were most important in spring, orbiniids and fish in autumn and nereid polychaetes and bivalve siphons in winter. Since there is no direct information available on the abundances of these prey types, it is difficult to determine whether such seasonal differences reflect either hyper-abundance or reduced abundances of "preferred" prey. However, nereid polychaetes have been shown to vary seasonally in an estuary on the south coast of Western Australia (Platell and Potter 1996). For the piscivorous *P. jenynsii*, the summer diets were dominated by crustaceans, such as the carid *A. richardsoni* and penaeid

Metapenaeus dallii, which are presumably more active in warmer temperatures, and of small individuals of the marine-spawning teleost *Argyrosomus japonicus* while, during the winter, greater amounts of estuarine fish species, such as gobiids and *A. rueppellii*, were ingested during this time.

3.4.3 Size-related changes in the diets of Apogon rueppellii.

The collection of a full size range of the very abundant A. rueppellii enabled the precise influence of fish size on the dietary compositions of that apogonid to be determined. MDS ordination highlighted the dramatic changes that are undergone with increasing fish size, which overrode those influences of site, season or time of day. Thus, the diets of the smaller individuals, i.e. 20-39 mm, contained mainly very small crustaceans (copepods), whose contributions decreased sharply with increasing fish size, while that of gammarid amphipods and mysids, which are slightly greater in size than copepods, increased. The diets of the larger individuals included orbiniid and nereid polychaetes, the carids A. richardsoni and P. australis, which are all relatively large in size, while the largest fish also ingested hard-shelled crabs and bivalve siphons. Thus, the changes in the dietary compositions of fish between 20 and 79 mm in size apparently reflect increases in mouth gape and a better ability to capture and ingest larger prey. With the very largest individuals, their consumption of crabs implies that their dentition and digestive abilities can cope with "difficult" prey. However, the ingestion of bivalve siphons, which typically belong to the venerid Tellina deltoidalis, and which extend from the substrate surface yet can very quickly retract back into that substrate, also directly implies that A. rueppellii is capable of feeding at the substrate surface and with extreme rapidity.

3.4.4 How can this data be used for ecosystem modelling?

The scientific skill of the dietician in this study, with most prey being identified to the lowest possible taxonomic level (species) means that, if this study were to be repeated in the near future, any differences in the diets of these species could be quickly detected. Since these species all feed on a wide variety of prey, with both *P. jenynsii* and *P. endrachtensis* being sought after by recreational fishers, such dietary comparisons may prove very useful when assessing long-term ecosystem changes. The main deficit in this data set is the lack of information on the lengths of the two species which reach a relatively large size, i.e. *P. jenynsii* and *P. endrachtensis*. However, it is possible that such data may be located at a later date.

The relatively unimportant influence of site (on those locations in the middle and lower estuary) and time of day on the diets of all three species, implies that scientifically rigorous determination of the diets of these species may not have to include all of those sites and could also restrict sampling to either the day or the night. However, the strong seasonal differences in the diets of each species, where sufficient data were collected, strongly suggests that any such sampling must be carried out in each season. The strong seasonality in the diets of fishes parallels that shown for fish and invertebrate communities in the Swan Estuary (Loneragan et al. 1989, Kanandjembo et al. 2001ab) and for the diets of the recreationally important sparid *Acanthopagrus butcheri* in the upper Swan Estuary (Sarre et al. 2000).

Although the dietary data in the above study can provide good input to ecosystem models, there is a lack of such detailed information for many of the other species in the study area, which would act to limit the usefulness of the dietary data for these three species. There is a clear need for an overall examination of the diets of the most important species, in terms of biomass, to be used as a standardised input to ecosystem models of the type being developed by Norm Hall at Murdoch University.

Chapter 4

Dietary compositions of *Aldrichetta forsteri* and *Mugil cephalus* in different estuaries

4.1 Introduction

Although different species of mugilid are important recreational and commercial fish species worldwide, they are relatively poorly valued in Australian waters (Kailola et al. 1993). In south-western Australia, two species of mugilid (yellow-eye mullet *Aldrichetta forsteri* and sea mullet *Mugil cephalus*) complete their life cycles in marine waters and use estuaries as nursery areas, growing to relatively large sizes in those estuaries (Ayvazian and Hyndes 1995, Potter and Hyndes 1999, Young 2000). Small commercial and recreational net fisheries exist for *A. forsteri* and *M. cephalus* in the Peel-Harvey and other estuaries (Department of Fisheries WA).

The diets of mugilids have received a great deal of attention worldwide (e.g. Thomson 1954, Zismann et al. 1975, Blaber 1977, Eggold and Motta 1992, Kailola et al. 1993, Blay 1995), with most studies concluding the representatives of this family are predominantly detritivorous. However, very few of those papers have elucidated quantitatively and concomitantly the main influences on dietary compositions of mugilids. The only investigations of the dietary compositions of mugilid species in south-western Australia are those carried out by P. Orr nee Geijsel, as part of her under- and post-graduate studies at Murdoch University.

The main aim of this chapter is to subject the dietary data, that was recorded by Pia Orr nee Geijsel for two species of mugilid (*A. forsteri* and *M. cephalus*) in the Peel-Harvey and Swan estuaries (Geijsel 1983) and in Wilson Inlet (Orr 2000), to contemporary multivariate analyses in order to elucidate the relative influence of species, estuary, site within estuary and season on the dietary compositions of those mugilid species. The data used for the Swan and Peel-Harvey estuaries were summaries for either small (< 40 mm total length) or larger (\geq 40 mm) individuals of the two species in each season, and thus not the raw data for individuals, since that data could not be located. The analyses will be conducted with a view to the use of those data in ecosystem models of the type that are currently being developed by Norm Hall (FRDC 2000/311).

4.2 Materials and methods

4.2.1 Sampling regime in Peel-Harvey and Swan estuaries

Samples of *Aldrichetta forsteri* and *Mugil cephalus* were obtained at monthly intervals from January to October 1983 at sites in the Swan Estuary (Stirling Bridge (Site No. 110), Applecross (Site No. 360), Perth Water (Site No. 620), Joel Terrace (Site No. 711), Mt Henry Bridge (Site No. 410) and Kent St Weir (Site No. 910)), which represent site 1, 3, 4, 5, 9 and 11, respectively, in Loneragan and Potter (1990) and are thereafter referred to as sites 1-6. Sampling for fish was undertaken at the same time at three sites, i.e. (Soldiers Cove (Site No. 500), Serpentine River (Site No. 400) and Murray River (Site No. 300)), in the Peel-Harvey Estuary (sites 1, 8 and 9 in Loneragan et al. (1986)), thereafter referred to as sites 7-9.

A 102.5 m seine net, with wings that contained 44.5 m of 25.4 mm mesh and 5.5 m of 15.9 mm mesh, and a cod end of 9.5 mm mesh, fished to a maximum depth of 1.83 m and swept an approximate area of 1600 m². This net was deployed during the day (0800 to 1700 h) at each site and typically at high tide. All individuals of both mugilid species that were retained by the seine net were sorted and then euthanased in an ice slurry.

4.2.2 Sampling regime in Wilson Inlet

Samples of both mugilid species were obtained at monthly or bimonthly intervals between April 1988 and April 1990 from sites in the basin of Wilson Inlet (Potter et al. 1993). A 21.5 m seine net, with 6 m of 9 mm mesh and 4 m of 6 mm mesh and a 1.5 m pocket containing 3 mm mesh, which fished to a depth of 1.5 m and swept an area of 116 m², was deployed monthly in the shallow waters at Site No. 100 (Entrance channel), thereafter referred to site 1. A 40.5 m long seine net, with 25 mm mesh in the wings and 9.5 mm mesh in the pocket, which also fished to a depth of 1.5 m, was deployed bimonthly at the Landing (Site No. 260), Honeymoon Island (Site No. 230), Denmark River mouth (Site No. 360), Pelican Island 2 m depth (Site No. 335), Youngs Rocks (Site No. 530) and Hay River mouth (Site No. 520), hereafter referred to as sites 2-5, 7 and 9.

Composite multifilament gillnets, that comprised six 30 m panels each consisting of a different mesh size, i.e. 38, 51, 63, 76, 89 and 102 mm, were used monthly at site 2 until August 1989 and bimonthly thereafter. The same gillnets were

used at sites 3, 4 and 10 (Hay River upstream, Site No. 610) between April 1988 and April 1989, site 6 (Pelican Island 2 m depth, Site No. 330) between April 1988 and April 1990 and at site 9 from October 1989 to April 1990. See Potter et al. (1993) for further details of the sampling regime undertaken in Wilson Inlet.

4.2.3 Laboratory analyses

A total of up to 20 individuals of each species, that was retained for dietary analyses, were measured (TL) to the nearest 1 mm. The entire gut was removed, stored in 10% formalin and then transferred to 70% ethanol. The degree of fullness of the cardiac stomach (gut) was estimated on a scale of 1 (10% full) to 10 (100% full). The gut were examined under a dissecting microscope and sorted to the lowest taxonomic level, i.e. prey item. Each prey item was allocated to one of a number of broader taxonomic groups, subsequently referred to as dietary categories and also allocated into major taxa (see Table 4.1). The frequency of occurrence of each dietary category in the gut of each fish (%F) was recorded. The percentage contribution made by the volume of each dietary category to the total dietary volume of the gut of each fish was determined (%V).

4.2.4 Data analyses

Mugilids in the Swan and Peel-Harvey estuaries

The mean percentage contribution of each dietary category to the overall volume of the diets of both mugilid species in the Swan and Peel-Harvey estuaries, recorded at the different sites and times of year, and kept separate wherever possible for fish of <40 and \geq 40 mm, that were presented in Geijsel (1983), were entered directly into Microsoft Excel TM and then PRIMER v5.2 so that the data could be subjected to the various subroutines in this software package (Clarke and Gorley 2001).

SIMPER was firstly used to calculate the mean percentage contribution of each dietary category to the overall volume of the diets of *A. forsteri* and *M. cephalus* (Clarke 1993). The dietary data were then separated by size of fish, site and season, square-root transformed and subjected to the Bray-Curtis similarity measure, with the resultant matrix being tested using one and two-way ANOSIMs to ascertain the most important influence on the diets, i.e. species, size of fish, estuary and site within estuary, and season (Clarke 1993). The magnitude of the R-statistic value in the

ANOSIM test, which ranges from 0, when the similarities between the samples within a factor (group) is less than that between other factors, to 1, when the similarities between the samples within a factor is greater than that between other factors (Clarke 1993). The data was then separated according to the most important factor, i.e species (see later), and SIMPER used to determine which dietary categories either typified and/or contributed the most to the dissimilarities in the diets of the two species. One-way ANOSIMs, which tested for differences with both size of fish and month, and a two-way ANOSIM, with site nested within estuary, were then applied to the dietary data and the next most important factor determined using the magnitude of the Global R-statistic value. Since size of fish was shown to be next most important, SIMPER was firstly used to elucidate which dietary categories typified and distinguished between the diets of fish of < or ≥ 40 mm for each mugilid species. Since the numbers of samples of fish <40 mm were low, focus was then placed on ascertaining the extent of any differences between estuary, site within estuary and season of fish ≥ 40 mm, using a combination of both one and two-way ANOSIM tests. Multivariate dispersion (MVDISP) was used, where appropriate, to determine the extent of the variability in the dietary samples among different groups of samples (Somerfield and Clarke 1997).

Mugilids in the three different estuaries

The mean percentage volumetric contributions of the dietary categories to the overall diets of *A. forsteri* and *M. cephalus*, that were recorded during each season at the different sites in Wilson Inlet (= dietary sample) were initially analysed using ANOSIM to determine the relative influence of site and season on those dietary samples (see also Chapter 5). Before comparisons of the diets of these two mugilids among the three estuaries were undertaken, the dietary categories for each species were re-defined so that the information could be maximised among the three estuaries. This approach is particularly useful when large differences exist between previously defined dietary categories in different environments. Thus, for example, several dietary categories belonging to the Macrophyta were important in the diets of *A. forsteri* in the Swan and Peel-Harvey estuaries, while the contribution of macrophytes was very low in Wilson Inlet. In such a case, analyses can be considered as being more conservative if a single dietary category of "macrophytes" was used to compare the diets of mugilids between those estuaries. In the case of

Wilson Inlet, a restricted set of dietary categories was calculated and matched with the appropriate dietary category in the other two estuaries. The above dietary data was then appended to the dietary data recorded for each of *A. forsteri* and *M. cephalus* in the Swan and Peel-Harvey estuaries (see earlier section), square-root transformed and subjected to the Bray Curtis similarity measure (Clarke 1993). The resultant similarity matrices were then tested for the influence of estuary on the diets of the two species using ANOSIM and SIMPER where appropriate (see above for further details). MVDISP was also used to ascertain the variability of the dietary samples in each of the three estuaries for each species (Somerfield and Clarke 1997).

4.3 Results

4.3.1 Overall comparisons

SIMPER was used to determine the mean percentage volumetric contributions of the different dietary categories to the overall diets of both *A. forsteri* and *M. cephalus* (Table 4.1). The dietary volumes of *M. cephalus* was dominated, in order of importance, by sediment (41.9%), Chrysophyta (29.1%) and detritus (22.7%), with two small crustaceans contributing 6.4% to the overall gut contents. In contrast, the diets of *A. forsteri* contained representatives of macrophytes (38.2%), arthropods (23.5%), polychaetes (17.9%) and molluscs (4.4%), along with sediment and detritus (Table 4.1). The most important macrophytes in the diets of *A. forsteri* were *Cladophora* sp., *Enteromorpha* sp. and *Polysiphonia subtillisima*, collectively contributing 25.7% to the overall dietary volume, while the majority of crustaceans were gammarid amphipods, which collectively contributed 12.5% to the diet and two small planktonic crustaceans (*Daphnia carinata* and *Gladioferens imparipes*). Of the polychaetes, the nereid *Ceratonereis aequisetis* (7.8%) and the eunicid *Marphysa sanguinea* (6.0%) were the most important (Table 4.1). Table 4.1:The mean percentage volumetric contribution (%V) of the different major taxa
(boldface) and dietary categories to the overall diets of Aldrichetta forsteri and
Mugil cephalus, in the Swan and Peel-Harvey estuaries, derived using
SIMPER. N.B. For superscripts, 1, denotes a dietary category that was not
included in further analyses, as it could have contained representatives of other
dietary categories.

Major taxa and dietary categories	Aldrichetta forsteri	Mugil cephalus
Polychaetes	17.9	
Scoloplos simplex	3.8	
Capitella "capitata"	0.2	
Ceratonereis aequisetis	7.8	
Marphysa sanguinea	6.0	
Molluscs	4.4	
Arthritica semen	4.4	
Arthropods	23.5	6.4
Daphnia carinata	3.7	5.7
Gladioferens imparipes	3.6	0.7
Corophium minor	8.9	
Paracorophium excavatum	0.7	
Talorchestia sp.	1.5	
Melita matilda	0.7	
Melita zeylanica kaurti	0.2	
Melita spp. ¹	0.4	
Caprella scaura	0.1	
Crab zoea	0.1	
Diptera spp	3.4	
Macrophytes	38.2	29.1
Chrysophyta	4.9	29.1
<i>Cladophora</i> sp.	10.3	
Enteromorpha sp.	8.4	
Chaetomorpha sp.	0.6	
<i>Ulva</i> sp.	4.0	
Gracilaria verrucosa	1.3	
Polysiphonia subtillisima	7.2	
Polysiphonia cliftoniamum	0.7	
Ectocarpus silicosus	0.7	
Other material	16.2	64.6
Detritus	2.5	22.7
Sediment	13.7	41.9
Number of guts	665	195

4.3.2 Dietary compositions of Aldrichetta forsteri and Mugil cephalus in the Swan and Peel-Harvey estuaries

A series of one-way ANOSIMs, testing for overall differences between the two species of mugilid, fish size and season, was carried out on the overall similarity matrix. The Global R-statistic values were greatest for species (Global R=0.396, P=0.1%), followed by fish size (Global R=0.301) and season (Global R=0.041). A two-way nested ANOSIM, with site nested within estuary, was used to determine whether there were any overall dietary differences between either of the two estuaries and/or between the different sites in the two estuaries. The Global R-statistic value for estuary was very low (-0.086) while that for site was greater at 0.146.

Since species had by far the greatest influence (see above) on the diets of the two mugilids, the dietary data were therefore ordinated and the samples coded for the two species (Figure 4.1). On the resultant plot, the points for *Aldrichetta forsteri* lie in a widely-dispersed group on the top half of the plot, above those of all but one of the samples for *Mugil cephalus*, which lay in a tight group at the bottom midline of the plot. The MVDISP value for the dietary samples of *A. forsteri* (1.291) was far greater than for *M. cephalus* (0.583).



Figure 4.1: MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of *Aldrichetta forsteri* and *Mugil cephalus* in the Swan and Peel-Harvey estuaries.

SIMPER showed that the diet of *Mugil cephalus* was dominated by sediment, detritus and the alga *Chrysophyta*. Although *Aldrichetta forsteri* likewise ingested these food sources, it also ingested substantial quantities of algae such as *Cladophora* sp., *Enteromorpha* sp. and *Polysiphonia subtillisima*, the amphipod *Corophium minor* and the polychaete *Ceratonereis aequisetis*.

The dietary data was then separated by species in order to better explore the influence of fish size, estuary (and site within estuary) and season on the dietary compositions of *A. forsteri* and *M. cephalus*.

4.3.3 Dietary compositions of Aldrichetta forsteri in the Swan River and Peel-Harvey estuaries

One-way ANOSIM showed that season had a negligible effect on the dietary compositions of *A. forsteri* (R=0.053), while two-way nested ANOSIM demonstrated that site within estuary (P=0.1%, Global R=0.347) had a greater influence than estuary (Global R=-0.221). When the dietary data was coded for site (sites 1-9), it was apparent that the points for certain sites in the two estuaries, and in particular those for 2, 5, 8 and 9, tended to lie in discrete groups on different areas of the plot (Figure 4.2a). The points for each of these sites typically formed groups discrete from those of the other sites. In the case of site 3, the two points for autumn lay on the left of the plot and close together, while the two points for winter lay on the far right of the plot and also close together (cf Figures 4.2a, b). Within the other sites, such an extreme seasonal difference was not present.

Pairwise comparisons for site, using one-way ANOSIM, showed that the diets of *A. forsteri* differed between site 2 vs sites 3 and 5 in the Swan Estuary, and between site 7 vs sites 8 and 9 in the Peel-Harvey Estuary (Table 4.2). SIMPER indicated that the diets at site 2 contained mainly sediment, *Arthritica semen* and *Ceratonereis aequisetis* and *Corophium minor*, while *Enteromorpha* spp. and *Daphnia carinata*, which were not ingested at this site, were important in the diets of fish at sites 3 and 5. The diets at site 9 comprised mainly sediment, *C. aquisetis* and *Scoloplos simplex*, while the diets at the other sites had far greater contributions of *Cladophora* sp. and relatively larger amounts of *Marphysa sanguinea* at site 7 and of *C. minor* at site 8 (Tables 4.3 and 4.4).

The lack of an overall significant difference between the dietary compositions of *A. forsteri* in the Swan Estuary (sites 1-6) and the Peel-Harvey Estuary (sites 7–9), is supported by the distribution of points for those two estuaries on the ordination plot (Figure 4.2a). There were insufficient data to determine whether the dietary compositions of this species differed with body size, but the few points for small fish were intermingled with those for larger fish (data not shown).


- **Figure 4.2:** MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of *Aldrichetta forsteri* in the Swan and Peel-Harvey estuaries, with the dietary samples coded separately for (a) site and (b) season.
- **Table 4.2:**Results of pairwise ANOSIM comparisons, i.e. R-statistic values and associated P values (in
parentheses) between the dietary compositions of *Aldrichetta forsteri* at different sites in the
Swan (Sites 2, 3 and 5) and Peel-Harvey (Sites 7, 8 and 9) estuaries. (ns) denotes non-
significance.

Site	Site 1	Site 2	Site 3	Site 5	Site 7	Site 8
Site 2	0.585 (ns)					
Site 3	0.182 (ns)	0.422 (2.9%)				
Site 5	0.352 (ns)	0.556 (2.9%)	0.213 (ns)			
Site 7	0.294 (3.8%)	0.242 (ns)	0.399 (2.9%)	-0.031 (ns)		
Site 8	0.104 (ns)	0.198 (ns)	0.618 (ns)	0.444 (2.9%)	0.111 (ns)	
Site 9	0.729 (2.9%)	0.646 (2.9%)	0.510 (2.9%)	0.648 (ns)	0.333 (4.8%)	0.708 (2.9%)

Table 4.3:Dietary categories determined by SIMPER as those most responsible for typifying the
dietary compositions of *Aldrichetta forsteri* at sites 2, 3 and 5 in the Swan Estuary (non-
shaded boxes) and distinguishing between the diets of each pair of those sites. In this
and Tables 4.4-4.6, asterisks denote that the dietary category makes a greater
contribution to the diets recorded at the site at the top of the column.

Site	Site 2	Site 3	Site 5
Site 2	C. minor Sediment C. aequisetis A. semen		
Site 3	Enteromorpha spp. C. minor* D. carinata* G. imparipes	Enteromorpha spp. G. imparipes D. carinata Cladophora sp.	
Site 5	C. minor* D. carinata* A. semen Sediment	Ns	Sediment C. aequisetis G. verrucosa A. semen

Table 4.4:Dietary categories determined by SIMPER as those most responsible for typifying the
dietary compositions of *Aldrichetta forsteri* at sites 7, 8 and 9 in the Peel-Harvey
Estuary (non-shaded boxes) and distinguishing between the diets of each pair of those
sites.

Site	Site 7	Site 8	Site 9
Site 7	Sediment <i>Cladophora</i> sp. <i>M. sanguinea</i> <i>C. minor</i>		
Site 8	Cladophora sp. C. minor* M. sanguinea* P. subtillisima	C. minor Cladophora sp. P. subtillisima Sediment A. semen	
Site 9	Sediment M. sanguinea* S. simplex C. aequisetis Cladophora sp.*	Sediment C. minor* Cladophora sp.* S. simplex C. aequisetis P. subtillisima*	Sediment C. aequisetis S. simplex

4.3.4 Dietary compositions of Mugil cephalus in the Swan River and Peel-Harvey estuaries

One-way ANOSIM showed that fish size greatly influenced the dietary compositions of *M. cephalus* (Global R=0.924, P=0.1%), while season was relatively unimportant (Global R=-0.091). SIMPER showed that the smaller fish fed mainly on *Daphnia carinata* and Chrysophyta, while the larger fish did not ingest this small crustacean and ingested greater amounts of sediment and detritus. Two-way ANOSIM, with site nested within estuary, showed that estuary had a higher R-statistic value than site (0.108 and -0.079, respectively).

The dietary data was then subjected again to ANOSIM, this time excluding the dietary data for the smaller fish. One-way ANOSIM detected no significant differences according to season (Global R=-0.101), while two-way ANOSIM, with site nested within estuary, showed that there were significant differences between sites (P=0.3%, Global R=0.373) but not estuary (Global R =0.573).

When the dietary data were subjected to MDS ordination, it was evident that the points for the dietary samples from the different sites sometimes tended to lie in different parts of the plot (Figure 4.3). Pairwise ANOSIMS did not detect any significant differences between each pair of sites, which may be partly a result of the low sample sizes for certain sites.





The next step was to compare, for each species separately, whether the lack of dietary differences between the two estuaries for these two mugilids extended to an estuary on the south coast (Wilson Inlet). The data was re-organised into appropriate dietary categories, using fish of \geq 40 mm in size for *M. cephalus*, with data being kept separate for site and sampling occasion within each estuary.

4.3.5 Dietary compositions of Aldrichetta forsteri in two west coast and one south coast estuary

When the dietary data for fish caught at the different sites at different times of year in Wilson Inlet was initially subjected to one-way ANOSIMs, no significant differences were detected for either site (Global R=0.113) or season (Global R=0.110). When the dietary data for *A. forsteri* in Wilson Inlet was collated with those of this species in the Swan and Peel-Harvey estuaries and subjected to ANOSIM, diets were shown to significantly differ overall with estuary (P=0.1%,Global R=0.281). Pairwise comparisons revealed that the diets in Wilson Inlet differed from those in both the Swan River Estuary (P=0.1%, R=0.522) and Peel-Harvey Estuary (P=0.1%, R=0.573), while those of the Swan Estuary did not differ from those in the Peel-Harvey Estuary (P=58.7%).

On the ordination plot (Figure 4.4), most of the dietary samples for *A. forsteri* in Wilson Inlet lie to the right of the large group that contains intermingled samples from the Swan and Peel-Harvey estuaries. SIMPER demonstrated that diets in the Swan and Peel-Harvey estuaries contained relatively large amounts of algae, sediment, detritus and amphipods in comparison to Wilson Inlet, with far greater contributions being made by the polychaetes *Ceratonereis aequisetis* and *Capitella "capitata"* and the carid decapod *Palaemonetes australis* in the last system (Table 4.5)



Figure 4.4: MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of *Aldrichetta forsteri* in the Swan and Peel-Harvey estuaries and Wilson Inlet, with the dietary samples coded for estuary of capture.

Table 4.5:Dietary categories determined by SIMPER as those most responsible for typifying the
dietary compositions of *Aldrichetta forsteri* in the Swan and Peel-Harvey estuaries and
Wilson Inlet (non-shaded boxes) and distinguishing between the diets of each pair of those
estuaries.

Site	Swan Estuary	Peel-Harvey Estuary	Wilson Inlet		
Swan Estuary	Algae Sediment Detritus Amphipods <i>C. aequisetis</i>				
Peel-Harvey Estuary	Other polychaetes <i>D. carinata</i> * Terrestrial insects	Algae Sediment Detritus Amphipods Other polychaetes			
Wilson Inlet	Algae* Sediment* Detritus* <i>C. aequisetis</i> <i>C. "capitata"</i> <i>P. australis</i>	Algae* Sediment* Detritus* <i>C. aequisetis</i> <i>C. "capitata"</i> <i>P. australis</i>	Detritus C. aequisetis C. "capitata" P. australis Sediment		

4.3.5 Dietary compositions of Mugil cephalus in two west coast and one south coast estuary

When the dietary data for fish caught at the different sites in the different seasons at Wilson Inlet were subjected to initial examination, the resultant low number of dietary samples was insufficient to explore whether there were any differences in the diets between either sites or times of the year. Furthermore, all of the fish captured in Wilson Inlet exceeded 40 mm in size. The dietary data for *M. cephalus* in Wilson Inlet was collated with those for this species in the two west coast estuaries and then subjected to ANOSIM to test for overall significant differences between the dietary compositions in these three estuaries. ANOSIM demonstrated that the diets differed overall with estuary (P=0.1%, Global R=0.427) and pairwise comparisons revealed that the diets in Wilson Inlet differed from those in the Swan Estuary (P=0.1%, R=0.805), but not the Peel-Harvey Estuary (P=9.1%) and those of the Swan Estuary did not differ from those in the Peel-Harvey Estuary (P=6.1%).

Following ordination, the large number of samples for *M. cephalus* from Swan and Peel-Harvey estuaries intermingled in a group on the left and upper part of the plot, while the five dietary samples for Wilson Inlet lay to the right and/or beneath those points (Figure 4.5). SIMPER showed that the diets of *M. cephalus* contained mainly sediment, Chrysophyta and detritus in the Swan and Peel-Harvey estuaries, with the

presence of the second food source distinguishing the diets of fish in the Swan Estuary from those of Wilson Inlet (Table 4.6). SIMPER also demonstrated that the diets of *M. cephalus* were distinguished from those of the Swan Estuary by the greater contributions of detritus and the small bivalve *Arthritica semen*.

Table 4.6:Dietary categories determined by SIMPER as those most responsible for typifying the
dietary compositions of *Mugil cephalus* in the Swan and Peel-Harvey estuaries and Wilson
Inlet (non-shaded boxes) and distinguishing between the diets of each pair of those
estuaries.

Estuary	Swan Estuary	Peel-Harvey Estuary	Wilson Inlet
Swan Estuary	Sediment Chrysophyta Detritus		
Peel-Harvey Estuary	ns	Sediment Chrysophyta Detritus	
Wilson Inlet	Detritus Chrysophyta* A. semen	Ns	Sediment Detritus <i>A. semen</i> Chrysophyta





4.4 Discussion

The use of sophisticated multivariate analyses on dietary data for two species of abundant mugilid (*Aldrichetta forsteri* and *Mugil cephalus*), recorded as summaries for the Swan and Peel-Harvey estuaries on the lower west coast of Australia, and as data for individual fish in a south coast estuary (Wilson Inlet), has clearly shown that the dietary compositions of these two fish species differ markedly. These analyses have also shown that there is little difference between the overall diets of each of these mugilids between the two estuaries on the west coast, while their diets differ considerably in the single estuary on the south coast of Western Australia.

4.4.1 Interspecific comparisons in the three estuaries

The diet of *A. forsteri* in each of three estuarine environments (Swan and Peel-Harvey estuaries and Wilson Inlet), was far more diverse than that of *M. cephalus* in the same environments. Thus, the diets of the latter species are dominated by Chrysophyta (diatoms), sediment and detritus, while that of the former species contain a wide variety of food sources, including different species of polychaete, a bivalve mollusc (*Arthritica semen*), a variety of crustaceans, particularly amphipods, and a range of different species of macrophytes.

The above dietary data for *M. cephalus* is consistent with the fact that this mugilid is described as being iliophagous, i.e. detritivorous, by many authors (e.g. Thomson 1954, Blaber 1977, Blay 1995) and ingests the bottom substrate in order to extract organic material, such as diatoms and detritus, as well as the biofilm that is present on sediment, which form the basis of their diet. This feeding behaviour, along with the relative proximity of the Swan and the Peel-Harvey estuaries, helps explain the fact that the diets of *M. cephalus* do not differ appreciably among those estuaries. When comparing the diets of *M. cephalus* in these two estuaries with that of the single estuary on the south coast (Wilson Inlet), the diets were shown to significantly differ with only the Swan Estuary, which lies to the north of the Peel-Harvey Estuary and thus at a greater distance from Wilson Inlet. The main food source that contributed to the above difference was the presence of greater amounts of diatoms in the Swan Estuary. It thus appears likely that diatoms are more abundant in estuaries on the west than south coast. However, independent studies are required to answer this question. Relatively high contributions of detritus and the small bivalve Arthritica semen also distinguished the diets of *M. cephalus* in Wilson Inlet. It is likely that both of these dietary categories are more prevalent in this south coast estuary than those on the west coast. This is

consistent with the profuse growths of large macrophytes in Wilson Inlet (Humphries et al. 1993), that would presumably contribute to the detrital load, and of the high abundances of *A. semen* which were recorded in an earlier study (Platell and Potter 1996).

When comparing the diets of A. forsteri, the compositions of those diets, with the presence of epibenthic and planktonic crustaceans, and of infaunal polychaetes such as "*Capitella capitata*", imply that this species is capable of feeding within the water column and both on and in the substrate, and is likely to employ particulate feeding to extract those prey. The above also suggests that this species is likely to show "opportunistic feeding behaviour" (sensu Gerking 1994), which simply means that, by virtue of feeding on a wide range of food, there is an increased possibility of this species utilising seasonal peaks in abundance of those food sources (see also Schafer et al. 2002). As expected, this "opportunistic" behaviour helps explain the fact that the diets of this mugilid differed significantly between the two west coast and one south coast estuary, with the largest difference occurring between the most geographically distant estuaries (Swan Estuary and Wilson Inlet). Thus, the diets of A. forsteri in the Swan and Peel-Harvey estuaries were distinguished by the presence of algae, sediment and detritus, while the presence in the diets of the polychaetes Ceratonereis aequisetis and Capitella "capitata" and of the carid decapod Palaemonetes australisi, which are all very abundant in Wilson Inlet (Platell and Potter 1996), does support the hypothesis of the opportunistic feeding nature of this mugilid.

4.4.2 Influence of site and season on dietary compositions in the Swan and Peel-Harvey estuaries

For the two west coast estuaries, the diets of *A. forsteri* varied among some of the sites within those estuaries. Thus, in the case of the Swan Estuary, the diets at site 2, which lay furthest downstream, contained greater amounts of the small crustaceans *Corophium minor* and *Daphnia carinata*. At the two more upstream sites (sites 3 and 5, greater contributions were made by the small crustaceans *Gladioferens imparipes* and macrophtye *Entermorpha* spp. (site 3) and the small bivalve *Arthritica semen* (site 5). The differences in the prevalence in the diets of the small crustacean species is likely to reflect differences in actual abundances, which is consistent with the trends observed for other small crustaceans in the Swan Estuary (Gaughan and Potter 1994). For the Peel-Harvey Estuary, the significant differences between site 9 and the other two sites are due largely to the greater contributions of the polychaetes *Ceratonereis aequisetis* and

Scoloplos simplex and of sediment at site 9, and greater contributions of *Cladophora* sp. at the other two sites. Site 9, which lies in a tributary river, thus appears more suited to the production of polychaete species than the other two sites, and the presence of sediment in the diets implies that *A. forsteri* is indeed foraging within the substrate for these polychaetes. Although the diet of *M. cephalus* did not demonstrate as marked a site difference as that of *A. forsteri*, this is not surprising, given its relatively restricted diet.

The lack of a strong seasonal difference in the diets of both mugilids in the two estuaries implies that the food abundance are not likely to change markedly throughout the year. Such a situation is unusual, since the majority of species in these local waters show seasonal variations in their diet (see e.g. Kanandjembo 1998, Sarre et al. 2000, Chapter 3).

4.4.3 Size-related changes in the diets of Aldrichetta forsteri and Mugil cephalus in the Swan and Peel-Harvey estuaries

The data summaries that were used as the basis for this chapter, included data for fish of only < 40 or \ge 40 mm in size, even though individuals of these two fish species can grow to at least 300 mm TL (Orr 2000). Moreover, the small amount of data that was available for fish of less than 40 mm in size restricted the type of analytical comparisons that could be made, and particularly for *A. forsteri*. However, the dietary data for *M. cephalus* showed that the very small individuals of this species fed mainly on the small crustacean *D. carinata* and Chrysophyta (diatoms), while the larger fish were far more iliophagous, i.e. fed predominantly on sediment and detritus.

4.4.4 How can this dietary data be used for ecosystem modelling?

The large dietary differences between these two species of mugilid serve to highlight the risks associated with assuming that confamilial species utilise similar food sources. Such an assumption is often made when grouping species into meaningful units for ecosystem modelling. This assumption can be misleading, since other workers have shown that confamilial species can very often feed in different ways and on different food sources (e.g. Prince et al. 1982, Hyndes et al. 1997, Platell et al. 1998ab). Although the dietary data provided in this chapter indicates that there is a size-related change in the diets of *M. cephalus*, this data is considered to be restricted in scope. Size-related differences for both mugilid species in Wilson Inlet will be further explored in the following chapter (Chapter 5). The diets of each species do vary within the Swan and

Peel-Harvey estuaries, presumably as a response to differences in the availability of food sources, but not overall between these two estuaries. This would suggest that it may be more important to include a range of sites (=habitat types) for fewer estuaries than relying on a single site to represent an estuary. In the choice of estuaries, the analyses in this chapter have shown that the diets in a south coast estuary differ considerably from those in two west coast estuaries, and thus more data contrast would have been achieved with the selection of **one, rather than two,** similar estuaries (Swan and Peel-Harvey estuaries).

Chapter 5

Diets of six commercially and recreationally important teleost species in Wilson Inlet

5.1 Introduction and aims

Wilson Inlet, which is a seasonally closed estuary on the south coast of Western Australia, supports one of the most lucrative fisheries for finfish in that state (Department of Fisheries, Western Australia). However, the land practices in the surrounding catchment in the last 30 years have meant that the waters in this estuary have become increasingly subject to the effects of eutrophication, which is manifested by large growths of the aquatic macrophyte *Ruppia megacarpa* (Potter et al. 1993). Although the characteristics of the fish and benthic macroinvertebrate communities and the dietary compositions of certain fish and bird species were studied in the late 1980s (Humphries et al. 1992, Humphries and Potter 1993, Potter et al. 1993, Platell and Potter 1996), when such eutrophication was already becoming evident, none of this data were collated with a view to their eventual use in ecosystem models. Furthermore, the dietary data for several of the large commercially and recreationally important fish species, which was not published at the time, would also be essential for the development of appropriate ecosystem models for Wilson Inlet.

Thus, although dietary information is available for five important fish species, i.e. *Mugil cephalus, Aldrichetta forsteri, Sillaginodes punctata* and *Arripis georgiana* (Orr 2000) and *Cnidoglanis macrocephalus* (Laurenson 1992), this dietary data has not yet been subjected to the type of multivariate analyses that would enable the most important influences on the diets of those species to be determined (see e.g. Platell and Potter 2001, Hourston et al. 2004). Since the raw data for the diets of the above six species could be located, with the exception of the site of capture information for both *Cnidoglanis macrocephalus* and *Platycephalus speculator*, this data was entered into "Guts" and re-analysed with a view to determining

- the relative importance of method of capture, site and season on the diets of the six species,
- (2) the extent of size-related changes in the diets of each species,
- (3) the extent of dietary partitioning among those six species, taking into account size composition and any important factors as determined above,
- (4) the usefulness of the above dietary data in terms of ecosystem modelling.

5.2 Materials and methods

5.2.1 Sampling regime and laboratory processing

Individuals of *Mugil cephalus, Aldrichetta forsteri, Sillaginodes punctata* and *Arripis georgiana* were obtained using seine and gillnetting at sampling locations throughout Wilson Inlet on a monthly basis between April 1988 and January 1990 (Table 5.1). N.B. The site numbers and accompanying names are recorded in "Guts" and form part of the standardised data set for diets of fish in Wilson Inlet.

Individuals of both *Cnidoglanis macrocephalus* and *Platycephalus speculator* were collected using seine and gill netting at sites in Wilson Inlet (precise location not specified) during each month between December 1987 and October/November 1988.

The seine net, which was 40.5 m long and 2 m in depth, comprised 25 mm mesh in the body of the net and 9 mm mesh in the bunt. Using a dinghy, the net was rowed out from the shoreline and hauled into shore during the day. The composite sunken gill net, which contained 30 m panels that each comprised 38, 51, 63, 79, 89 or 102 mm mesh, was deployed soon after sunset and retrieved 3 h later.

Up to 25 individuals of each species, covering a wide size range, were removed from the seine and gill net samples collected from each site in each month. Each fish was measured to the nearest 1 mm (total length) and its entire gut removed and preserved in 70% ethanol.

Site No.	Site Name	Mugil cephalus	Aldrichetta forsteri	Sillaginodes punctata	Arripis georgiana
110	Bar		Seine	Seine	
120	Nullaki Point	Seine			
210	Poddy Point				???
230	Honeymoon Island	Gillnet	Seine		Gillnet
250	Basin				Professional
260	Landing		Seine	Seine Gillnet	Gillnet
330	Pelican Island 4 m				Gillnet
335	Pelican Island 2 m		Seine	Seine	
340	McCombs		Seine	Seine	
370	Rudgyard Beach	Seine Gillnet	Seine	Seine	
400	Denmark River				Gillnet
510	Bird Rocks				Gillnet
530	Youngs Rocks		Gillnet	Gillnet	
600	Hay River	Gillnet	Gillnet	Gillnet	

Table 5.1: Details of site number (as recorded in "Guts"), site name and main sampling methods of
capture for *Mugil cephalus, Aldrichetta forsteri, Sillaginodes punctata* and *Arripis georgiana*,
outlined in Orr (2000).

The number of individuals of each species with empty foreguts, hereafter referred to as guts, was recorded and, in the case of all but *C. macrocephalus* and *P. speculator*, the fullness of each gut with food was scored on a scale of 1 (ca 10% full) to 10 (100% full). The contents of each gut were examined under a dissecting microscope using reflected light and its items identified to the lowest possible taxon. Each prey item was allocated to one of a number of taxonomic groups, subsequently referred to as dietary categories (see Table 5.2). In this section, the dietary categories were also designated as either intra-specific, i.e. those dietary categories that were used for comparisons within species, or interspecific, i.e. those dietary categories that were used for comparisons among species. The frequency of occurrence of each dietary category in the gut of each fish (%F) was recorded and the percentage contribution made by the volume of each dietary category to the total dietary volume of the gut of each fish (%V) was determined. N.B. In the case of *M. cephalus*, the volumetric contributions of gill rakers, which occurred in 42.9% of the guts and were presumed to have been consumed by individuals when gill netted, are excluded from subsequent analyses.

5.2.2 Dietary analyses

For each fish species, the first series of analyses focussed on ascertaining the influence of method of capture (also corresponding to water depth), site and season, on the mean percentage volumetric contributions of the intraspecific dietary categories. Thus the dietary data were square-root transformed and subjected to the Bray-Curtis similarity measure using PRIMER v5.2 software (Clarke and Gorley 2001). These six matrices were then subjected to ANOSIM (Analyses of Similarities) in order to determine the extent to which the various factors influenced the diets of each species (Clarke 1993). The magnitude of the global R-statistic value was used to ascertain the extent to which dietary composition differed among those factors and the significance level recorded. Thus, R-statistic values range from 1, if the composition of all samples within each group are more similar to each other than to any of the samples from any other group, down to ca 0 if the average similarities between and within groups are the same (Clarke 1993). The null hypothesis for ANOSIM tests that the dietary compositions were not significantly different was rejected if the significance level (P) exceeded 5%.

Since the above analyses demonstrated that method of capture which, in this case, corresponds to water depth, was the only one of the three factors to have a measurable influence on the dietary compositions of each species, this factor was therefore taken into account for the next series of analyses, i.e. when determining the

influence of increasing body size on the diets of those species. Thus, for each species, the mean percentage volumetric contributions of the intraspecific dietary categories in the guts of each species in the different water depths, i.e. shallow or deeper waters, and belonging to sequential length classes of 25-74, 75-124 mm etc, and thereafter referred to as a dietary sample for multivariate analyses, were determined. These data were then plotted as stacked histograms (Figures 5.1a-5.6a).

The above dietary samples were square root transformed and the Bray-Curtis measure applied to those data to produce similarity matrices. The six resultant matrices were then subjected to non-metric multidimensional scaling (MDS) ordination (Clarke and Gorley 2001) in order to examine the influence of water depth and body size on the diets of the six fish species.

The next set of analyses determined the extent of interspecific differences in the diets of the six species, when taking into account body size (see above), but using a simplified series of dietary categories, i.e. interspecific dietary categories. The mean volumetric contributions of those interspecific dietary categories to the diets of individuals in sequential length classes of 25-74, 75-124 mm etc, and for each of shallow and deeper waters were subjected to MDS ordination as described above (Clarke and Gorley 2001). The resultant Bray-Curtis similarity matrices were subjected to Analyses of Similarities (ANOSIM) to determine whether there were any differences between the dietary compositions of the six species and, if so, the extent of such differences (Clarke 1993). Similarity of Percentages (SIMPER) were used to determine which dietary categories either typify and/or distinguish between *a priori* groups that are shown to be significantly different (Clarke 1993). Multivariate dispersion (MVDISP) was used to ascertain the variability in the dietary samples of the different species (Somerfield and Clarke 1997).

5.3 Results

5.3.1 Overall species patterns

A total of 46, 262, 166, 197, 238 and 413 guts were examined in the case of *Mugil cephalus, Aldrichetta forsteri, Cnidoglanis macrocephalus, Sillaginodes punctata, Arripis georgiana* and *Platycephalus speculator*, respectively (Table 5.2). The percentage of guts that contained identifiable food ranged between 41.6 and 49.2% for the first, second and fifth species and between 85 and 90% of the guts of the fourth and sixth species. Note that, in the case of *C. macrocephalus*, a record was not made of the empty guts.

Table 5.2:The frequency of occurrence (%F) and mean percentage volumetric contribution (%V) of major taxa and intra- and inter-specific (boldface) dietary
categories to the overall diets of *Mugil cephalus, Aldrichetta forsteri, Cnidoglanis macrocephalus, Sillaginodes punctata, Arripis georgiana* and
Platycephalus speculator in Wilson Inlet. N.B. The shaded boxes show those dietary categories that were not used in intraspecific comparisons.

Major taxa and dietary categories	M. cepi	halus	A. fors	steri	C. macroc	rephalus	S. pun	ctata	A. georg	giana	P.specı	ulator
	%F	%V	%F	%V	%F	%V	%F	%V	%F	%V	%F	%V
Chrysophyta	8.3	1.1	2.8	2.8								
Macrophyta			5.5	2.8			1.7	<0.1	0.9	0.7		
Nemertini spp.			0.9	0.1			9.2	8.7				
Polychaeta			27.5	21.1	23.5	2.8	64.2	56.5	22.2	9.5	5.7	1.1
Capitella "capitata"									0.9	< 0.1		
Unidentifiable capitellids			11.9	9.2			3.3	1.5				
Scoloplos simplex							6.7	4.9	0.9	0.1		
Nereid spp.			17.4	10.4			52.5	43.4	21.4	9.4	5.7	1.1
Unidentifiable polychaetes			1.8	1.4	23.5	2.8	6.7	6.8				
Mollusca	8.3	1.8	11.9	6.6	81.9	48.0	25.0	17.3	0.9	< 0.1	3.4	1.0
Polyplacophora					6.0	<0.1						
Mytilidae					34.3	8.2	1.7	0.1				
Xenostrobus spp.					21.1	5.2	0.8	<0.1				
Mytilus edulis planulatus					18.1	3.0	0.8	<0.1				
Other Bivalvia			2.8	<0.1	59.0	34.1	16.7	10.3	0.9	<0.1	0.3	<0.1
Pinna bicolour					0.6	< 0.1						
Arthritica semen	8.3	1.8	2.8	< 0.1								
Tellina deltoidalis					47.0	24.8			0.9	< 0.1	0.3	< 0.1
Donax columbella					1.2	< 0.1						
Gomphina undulosa					5.4	1.0						
Sanguinolaria biradiata					4.8	1.2						
Irus crenata					22.9	7.1						
Bivalve siphons							15.0	8.6				
Unidentifiable bivalves							1.7	1.7				

Prosobranchia	0.6	< 0.1	27.1	2.3	2.5	2.3			3.4	0.6
Trochidae		1012		210						0.0
Phasionotrochus irisodontes			9.0	0.8						
Other trochids			7.8	0.5						
Turbiniid spp.			6.6	0.5						
Tatea preisii	0.6	< 0.1							3.4	0.6
Hydrobia buccinoiodes			0.6	< 0.1						
Salinator fragilis			8.4	0.4						
Nassarius burchardi			2.4	0.1	2.5	1.8				
Unidentifiable prosobranchs					0.8	0.5				
Neogastropoda	9.2	6.6	13.3	1.8	5.8	4.9			0.6	0.4
Liloa brevis	2.8	1.9	4.8	0.3	0.8	0.4				
Philine angasi	6.4	4.7	10.2	1.5	5.0	4.3			0.6	0.4
Akera bicincta			0.6	< 0.1						
Akera solute			0.6	< 0.1						
Crustacea	40.4	28.0	21.7	5.0	18.3	12.9	64.1	53.2	88.1	65.3
Cladoceran spp.	0.9	0.9								
Copepod spp.	6.4	2.8							0.3	<0.1
Gastrosaccus sp.							10.3	7.6	2.3	1.0
Gammaridea	0.9	0.9	1.2	<0.1			<0.1	<0.1	0.6	0.1
Melita spp.									0.3	< 0.1
Corophium minor			1.2	< 0.1					0.3	0.1
Unidentifiable gammarids	0.9	0.9					< 0.1	< 0.1		
Isopod spp.			0.6	<0.1					4.0	0.1
Caridea	32.1	23.4	20.5	4.4	16.5	12.9	57.4	46.1	84.7	60.5
Macrobrachium sp.									2.0	0.6
Palaemonetes australis	32.1	23.4	20.5	4.4	15.8	10.8	57.3	46.1	83.5	59.9
Unidentifiable carids					2.5	2.1	0.9	< 0.1		
Halicarcinus ovatus									8.0	3.3
Ovalipes australiensis			<0.1	0.6						

Insecta			11.9	10.6			0.8	<0.1	6.8	3.3		
Collembolan spp.			4.6	4.0								
Hymenopteran spp.			7.3	6.5			0.8	< 0.1	6.8	3.3		
Chironomid spp.									< 0.1	<0.1		
Chordata			0.9	0.6	3.0	0.8			35.9	32.9	50.3	32.5
Geotria australis									0.9	< 0.1		
Teleostei												
Engraulis australis									18.8	18.8	4.0	2.5
Cnidoglanis macrocephalus											0.6	0.2
Iso rhothophlius											0.3	< 0.1
Urocampus carinirostris												
Atherinidae									0.9	0.8	15.3	7.6
Leptatherina wallacei											2.0	1.4
Leptatherina presbyteroides											1.7	0.9
Atherinosoma elongata											0.6	0.3
Unidentifiable atherinids									0.9	0.8	11.9	5.1
Gobiidae					3.0	0.8			6.9	5.4	28.4	17.3
Pseudogobius olorum					1.8	0.6					12.2	5.5
Favonigobius lateralis											5.7	2.9
Afurcagobius suppositus					1.2	0.2					13.4	8.1
Unidentifiable gobiids									6.9	5.4	2.0	0.9
Unidentifiable fish			0.9	0.6					9.4	7.8	10.2	4.8
Sediment	83.3	74.1	9.2	4.9			1.7	0.5	<0.1	<0.1		
Detritus	16.7	15.4	23.9	16.6	69.3	45.5	2.5	2.0	0.9	<0.1	0.3	<0.1
Unidentifiable material	50.0	7.4	8.3	6.0			1.7	1.7	<0.1	< 0.1		
Number of guts (with food)	46	(21)	262	(109)	166	(166)	220	(197)	238	(117)	413	(352)

Sediment was found in 83% of the guts of *M. cephalus* and contributed 74.1% to the overall dietary volume of this species (Table 5.2). While detritus made moderate contributions, i.e. ca 15-17%, to the dietary volumes of this mugilid and also A. forsteri, it made a far greater volumetric contribution to the diets of C. macrocephalus (45.5%). For the other three species, the contribution of detritus to the overall dietary volumes was negligible, i.e. < 2%. Polychaetes were found in ca 25% of the guts of A. forsteri, C. macrocephalus and A. georgiana and in 64.2% of the guts of S. punctata (Table 5.2). The volumetric contributions of polychaetes ranged from 2.8% for C. macrocephalus to 9.5% for A. georgiana, upwards to 21.1% for A. forsteri and were very high for S. punctata (56.5%). Insects were important only in the diets of A. forsteri, where they contributed 10.5% to the overall dietary volumes. Molluscs were found in the vast majority of the guts of C. macrocephalus (81.9%) and contributed nearly 50% to the overall dietary volumes. Molluscs also made moderate contributions to the dietary volumes of S. punctata, i.e. 17.3%. Crustaceans were recorded in the diets of five of the six species, with their contributions to the overall dietary volumes varying widely, i.e. 5.0% for C. macrocephalus, 12.9% for S. punctata, 28.0% for A. forsteri and 53.2 and 65.3% in the case of the diets of A. georgiana and P. speculator, respectively. The contributions of chordates (fish) were also particularly high in the diets of the last two species, i.e. ca 32-33% (Table 5.2).

For the polychaetes ingested by the above species, these were mainly represented by nereids, orbiniids and capitellids, with a very high contribution of nereids (43.4%) to the overall dietary volume of *S. punctata* (Table 5.2). The most important insects in the diets of *A. forsteri* and *A. georgiana* were collembolans and hymenopterans, respectively. For the diets of *C. macrocephalus*, molluscs were represented mainly by *Tellina deltoidalis, Irus crenata* and *Xenostrobus* spp., which collectively contributed 37.1% to the dietary volumes of this plotosid. In contrast, *S. punctata* ingested mainly bivalve siphons (8.6%). Prosobranch gastropods contributed <4% to the diets of all species while neogastropods, and particularly *Philine angasi*, were the most important gastropods in the diets of *A. forsteri, C. macrocephalus, S. punctata* and *P. speculator* (Table 5.2).

Of the crustaceans, the mysid *Gastrosaccus* sp. was important in the diets of only *A. georgiana* (Table 5.2). However, carid decapods, and particularly *Palaemonetes australis*, were by far the most important crustacean in the diets of *A. forsteri*, *C. macrocephalus*, *S. punctata*, *A. georgiana* and *P. speculator*, contributing as much as 46.1 and 59.9% to the dietary volumes of the last two species, respectively. In the case of the volumetric contributions of different fish species to the diets of *A. georgiana*, the main prey comprised *Engraulis australis* (18.8%) and gobiids (5.4%), while *P. speculator* fed on a large number of fish species, including *E. australis* (2.5%), *C. macrocephalus* (0.2%) and different species of atherinids and gobiids (0.3 to 8.1%) (Table 5.2).

5.3.2 Intraspecific comparisons of dietary compositions

The mean percentage volumetric contributions of each intraspecific dietary category (as shown in Table 5.2) to the diets of each species and, where possible, being kept separate for method of capture (corresponding to water depth), site and month, were initially subjected to the Bray-Curtis similarity measure and the resultant six matrices tested for those factors using ANOSIM. Since the influences of site and month on the diets of each species were far less important than that for method of capture, the dietary data for each species was separated into either shallow water (seine net samples) or deeper water (gill net samples) and then examined, at a fine taxonomic level, for the presence of size-related differences.

For *Mugil cephalus*, the smallest individuals, i.e. 75-124 mm, from shallow waters consumed mainly sediment and detritus (Figure 5.1a). The diets of the largest fish in shallow waters (125-174 mm) and the smallest fish in deeper waters (275-324 mm) comprised mainly sediment, while those of the largest individuals in deep waters contained sediment and small amounts of the small bivalve *Arthritica semen* (Figure 5.1a). When the dietary data was ordinated, the points for the three smaller size classes, which included fish from shallow and deeper waters, lay together on the left of the plot and well separated from the single point for the largest size class on the right of the plot (Figure 5.1b).



Figure 5.1: The mean percentage volumetric contributions of the different dietary categories to the diets of *Mugil cephalus* in shallow and deeper waters of Wilson Inlet, presented as (a) stacked histograms and (b) an MDS ordination. *N.B. In this Figure and Figures 5.2 - 5.6, some of the dietary categories used to construct (b) have been combined in (a) to increase the perspicuity of the histograms.

In the case of *Aldrichetta forsteri*, which was also represented in both shallow and deeper waters, the smallest fish (25-74 mm) in shallow waters consumed mainly hymenopterans and copepods, collectively contributing over 80% of the total dietary volume (Figure 5.2a). The diets of the next larger size class in shallow waters consumed large amounts of collembolans and gammarid amphipods. None of the previous four dietary categories were consumed by any other size class of fish and the diets of different size classes in both shallow and deep waters contained varying amounts of detritus and polychaetes. In deeper waters, the carid *Palaemonetes australis* was important in the diets of the larger fish (Figure 5.2a). After ordination, the point for the smallest fish lay on the far left of the plot, and those for the other size classes in both water depths formed a relatively tight cluster on the right side of the plot (Figure 5.2b).



Figure 5.2: The mean percentage volumetric contributions of the different dietary categories to the diets of *Aldrichetta forsteri* in shallow and deeper waters of Wilson Inlet, presented as (a) stacked histograms and (b) an MDS ordination.

Polychaetes, presumably nereids, and the prosobranch gastropod *Phasianotrochus irisidontes* made substantial contributions to the diets of only the smallest Cnidoglanis macrocephalus, i.e. 125-174 mm. (Figure 5.3a). In the smallest fish, detritus was the most important dietary category, i.e. 33%, with its importance increasing to ca 68% in the diets of fish of 275-374 mm and thereafter decreasing to ca 6% in the largest fish, i.e. 625-674 mm. The mytilids Xenostrobus securis and *Xenostrobus pulex* were ingested by most size classes of fish, with their contribution being greatest in the smallest fish, i.e. ca 17%, and least in the largest fish, i.e. < 1%(Figure 5.3a). While the large bivalve *Tellina deltoidalis* contributed 15-20% to the diets of fish between 225 and 474 mm in size, its contribution to the overall dietary volume increased markedly thereafter, reaching a maximum of nearly 60% in the largest fish. Another large and more robust bivalve(Irus crenata) did not appear in the diets until fish exceeded 325 mm in size, and its contribution tended to progressively increase with increasing fish size (Figure 5.3a). When the dietary data was subjected to ordination, the point for the smallest fish lay well to the left of the points for the larger fish and, with increasing fish size, the points progressed to the right on that plot (Figure 5.3b).



Figure 5.3: The mean percentage volumetric contributions of the different dietary categories to the diets of *Cnidoglanis macrocephalus* in deeper waters of Wilson Inlet, presented as (a) stacked histograms and (b) an MDS ordination.

In shallow waters, the diets of the smallest individuals of *Sillaginodes punctata*, i.e. 75-124 mm, were exclusively comprised of polychaetes, including nereids (Figure 5.4a). In that same water depth, the contribution of polychaetes decreased with increasing fish size, while the reverse was true for the carid decapod *P. australis* and nemertine worms, such that they collectively contributed over 98% to the diets of the largest fish, i.e. 175-224 mm. In deeper waters, while fish of that same size ingested large amounts of *P. australis*, they also ingested nereid polychaetes and the orbiniid polychaete *Scoloplos simplex* (Figure 5.4a). With further increases in fish size, the contributions of *P. australis* declined, while bivalve siphons made moderate contributions to the diets of fish of 225-374 mm and the large neogastropod *Philine angasi* appeared in the diets of the two largest size classes of fish. Following ordination of the dietary data, the points for fish of 75-224 mm lay on the top of the plot, while those of larger fish lay beneath those points, with no apparent separation by water depth (Figure 5.4b).



Figure 5.4: The mean percentage volumetric contributions of the different dietary categories to the diets of *Sillaginodes punctata* in shallow and deeper waters of Wilson Inlet, presented as (a) stacked histograms and (b) an MDS ordination.

For *Arripis georgiana* of between 175 and 374 mm in size in deeper waters, all ingested moderate to large amounts of the carid *P. australis*, while the diets of the two smaller size classes also contained small amounts of the smaller crustacean *Gastrosaccus* sp. (Figure 5.5a). Terrestrial hymenopterans contributed 12% to the diets of the smallest fish and less to the diets of the 275-324 mm fish. With increasing body size, the contributions of various fish species, which included *Engraulis australis* and species of gobiids, progressively increased. Ordination of the dietary data showed that the dietary samples progressed from left to right on the plot with increasing body size (Figure 5.5b).



Figure 5.5: The mean percentage volumetric contributions of the different dietary categories to the diets of *Arripis georgiana* in deeper waters of Wilson Inlet, presented as (a) stacked histograms and (b) an MDS ordination

While the carid *P. australis* contributed nearly 90% to the overall dietary volume of small *Platycephalus speculator* (25-74 mm) in shallow waters, its contribution ranged between 55 and 68% to the overall dietary volumes of the other size classes of *P. speculator* (Figure 5.6a). In deeper waters, the diets of larger fish also comprised small amounts of taxa such as the crab *Halocarcinus ovatus* and gastropods, while fish such as *E. australis*, gobiids (including *Pseudogobius olorum* and *Afurcagobius suppositus*), atherinids and others, collectively comprised the remainder of the dietary volume. After ordination of the dietary data, there was a marked tendency for the points to progress from left to right on the plot with increasing fish size (Figure 5.6b).



Figure 5.6: The mean percentage volumetric contributions of the different dietary categories to the diets of *Platycephalus speculator* in shallow and deeper waters of the Wilson Inlet, presented as (a) stacked histograms and (b) an MDS ordination

5.3.3 Interspecific comparisons of the dietary compositions of the six species

When the dietary data for fish species in the shallow and deeper waters of the Wilson Inlet, calculated using the interspecific dietary categories, were ordinated and the dietary samples coded for species, the points for each species showed a strong tendency to lie in different parts of the plot (Figure 5.7). Thus, the points for *M. cephalus* formed a discrete group on the left hand side of the plot, while the points for each of *P. speculator* and *A. georgiana* formed tight and discrete groups in the midline of the plot and above those for the discrete group of the dietary samples for *C. macrocephalus*. The large group of points for *S. punctata* lay to the right or above those for all other species, with the exception of a single point for *A. forsteri*. In the case of *A. forsteri*, the dietary samples were scattered on the right side of the plot (Figure 5.7).



Figure 5.7: MDS ordination of the mean percentage volumetric contributions of the different dietary categories to the diets of individuals in 50 mm length intervals of *Mugil cephalus*, *Aldrichetta forsteri*, *Cnidoglanis macrocephalus*, *Sillaginodes punctata*, *Arripis georgiana* and *Platycephalus speculator* in Wilson Inlet. The dashed lines highlight the species groupings on the plot.

ANOSIM demonstrated that dietary compositions were influenced markedly by species (Global R-statistic value=0.904, P=0.1%), with pairwise comparisons showing that the diets of all species, where there were sufficient permutations, differed significantly from each other (Table 5.3). The R-statistic values were 0.463 for *A. forsteri* vs *S. punctata*, 0.769 for *A. georgiana* vs *P. speculator* and, in the case of all other comparisons, ranged from 0.9 to 1.0 (Table 5.3) The relative dispersion was least for *P. speculator* (MVDISP=0.383) and ranged between 0.667 and 0.830 for *M. cephalus* and *C. macrocephalus*. The relative dispersion was similar and highest for *S. punctata* (MVDISP=1.373) and *A. forsteri* (MVDISP=1.456).

Table 5.3: Results of ANOSIM pairwise comparisons, i.e. R-statistic values and associated P values in
parentheses, between the dietary compositions of the six species in Wilson Inlet. Note that P
values are only shown when the number of permutations in the ANOSIM test exceeds 35

Species	Mugil cephalus	Aldrichetta forsteri	Cnidoglanis macrocephalus	Sillaginodes punctata	Arripis georgiana
A. forsteri	1.000				
C. macrocephalus	1.000 (1.5%)	0.906			
S. punctata	1.000	0.463	0.949 (0.1%)		
A. georgiana	1.000	0.917	0.990 (0.1%)	0.888 (0.8%)	
P. speculator	1.000	0.956	0.988 (0.1%)	0.988 (0.8%)	0.769 (0.8%)

In terms of dietary categories that typify and can also distinguish the diets of the different species, that were determined using SIMPER, this was sediment for *M. cephalus*, other bivalves and mytilid bivalves for *C. macrocephalus*, nemerteans for *S. punctata* and the crab *H. ovatus* for *P. speculator* (Table 5.4). Relatively large volumes of detritus distinguished the diets of *A. forsteri* and *C. macrocephalus* from most other species, but this dietary category was more important in the diets of the latter species. The presence of polychaetes distinguished the diets of *A. forsteri*, *S. punctata* and *A. georgiana* from the diets of *S. punctata* from the other two species, with the contribution of polychaetes being least in *A. forsteri*. Fish were important only in the diets of *A. georgiana* and *P. speculator* and distinguished the diets of these fish species from the other four species (Table 5.4). Insects were also responsible for distinguishing the diets of *A. georgiana* from two other species (*S. punctata* and *P. speculator*).

Species	Mugil cephalus	Aldrichetta forsteri	Cnidoglanis macrocephalus	Sillaginodes punctata	Arripis georgiana	Platycephalus speculator
M. cephalus	Sediment					
A. forsteri	Sediment* Polychaetes Detritus	Polychaetes Detritus Carid decapods				
C. macrocephalus	Sediment* Detritus Other bivalves Mytilid bivalves	Other bivalves Polychaetes* Detritus Mytilid bivalves Carid decapods*	Detritus Other bivalves Mytilid bivalves			
S. punctata	Sediment* Polychaetes Carid decapods Nemertines	Detritus* Carid decapods Nemertines	Detritus* Polychaetes Other bivalves* Mytilid bivalves* <i>M. e. planulatus</i> *	Polychaetes Carid decapods Nemertines		
A. georgiana	Sediment* Carid decapods Fish Polychaetes*	Carid decapods Fish Detritus* Polychaetes*	Detritus* Other bivalves* Carid decapods Fish Mytilid bivalves*	Fish Polychaetes* Carid decapods Nemertines * Insects	Carid decapods Fish Polychaetes	
P. speculator	Carid decapods Sediment* Fish H. ovatus	Carid decapods Fish Polychaetes* Detritus* <i>H. ovatus</i>	Carid decapods Detritus* Other bivalves Fish Mytilid bivalves*	Polychaetes* Fish Carid decapods Nemertines *	Polychaetes* <i>H. ovatus</i> * Insects Mysid crustaceans*	Carid decapods Fish <i>H. ovatus</i>

Table 5.4:Dietary categories determined by SIMPER as those most responsible for typifying the dietary compositions of the six species (non-shaded boxes) and
distinguishing between the diets of each pair of those species in the waters of Wilson Inlet. Asterisks denote that the dietary category makes a greater
contribution to the diets recorded for the species at the top of the column.

5.4 Discussion

5.4.1 Intraspecific comparisons

The first main focus of this aspect of the overall project was to examine, at as low a taxonomic level as possible, i.e. using intraspecific dietary categories, the extent of size-related changes in the dietary compositions of the six commercially and recreationally important fish species in Wilson Inlet. Since individuals of each fish species were collected from comparatively small total lengths, i.e. < 100 mm, and ranged upwards from 260 mm in the case of Arripis georgiana to over 600 mm for Cnidoglanis *macrocephalus*, the relatively great size range present suggests that, if such changes were present, they would be likely to be detected for those fish species. Such size-related changes were limited in the case of Mugil cephalus, which consumed sediment throughout its size range, with the very smallest fish also consuming detritus, while the larger individuals also ingested small amounts of the small bivalve Arthritica semen, which can reach high abundances in Wilson Inlet (Platell and Potter 1996). In contrast, while the small individuals of Aldrichetta forsteri consumed insects (hymenopterans and collembolans) and small crustaceans (copepods and gammarid amphipods), once the individuals of this species had attained a certain size, their diet differed markedly in consisting mainly of detritus and polychaetes and, for the largest fish, also small amounts of the carid decapod Palaemonetes australis.

The diets of each of C. macrocephalus and Sillaginodes punctata also showed size-related changes. In the case of the first species, these changes were highly progressive in nature, mainly reflecting the consumption of the relatively thin-shelled mytilid bivalves when small to larger and more robust bivalves such as Tellina deltoidalis and Irus crenata. Such a size-related change could be explained by an increased prey-handling ability as C. macrocephalus increases in size, accompanied by increasing mouth gape and jaw strength. Although S. punctata fed on a variety of food sources, those food sources differed slightly with water depth as well as with size of fish. Thus, in shallow waters, the diets of the smaller fish comprised polychaetes, which then declined with increasing body size while that of the relatively large P. australis and nemertine worms increased. However, in deeper waters, while the corresponding size class of S. punctata did ingest P. australis, it also ingested orbiniid and nereid polychaetes. This focus on the larger and deeper-burrowing orbiniid polychaetes in deeper waters could imply an increased abundance of this type of polychaete in those waters, which could be associated in foraging within the rhizomes of the dominant microphyte Ruppia megacarpa (see Platell and Potter 1996). With further increases in

size of *S. punctata*, the increasingly important food sources of the neogastropod *Philine angasi* and bivalve siphons, presumably from the large bivalve *T. deltoidalis*, strongly suggest that this sillaginid can feed in both *Ruppia* meadows and on the rapidly retracting siphons of infaunal bivalves that can also colonise bare sand substrata, respectively.

The diets of *A. georgiana* and *Platycephalus speculator* were both dominated by the carid *P. australis*, which is considered to be highly abundant in this estuary as a result of its association with the massive growths of the aquatic macrophyte *R. megacarpa* (Humphries and Potter 1993). Likewise, with increasing body size, both species also ingested larger volumes of fish and mainly the engraulid *Engraulis australis* and various species of gobiids. However, *P. speculator* ingested a greater variety of fish, including atherinids, than did *A. georgiana*, and it also ingested the crab *Halocarcinus australis* and gastropods when of relatively large size. Such changes in the dietary compositions of the above two species with increasing body size of fish.

5.4.2 Interspecific differences

The tabulation of the frequency of occurrence and volumetric contributions of the different intra- and interspecific dietary categories, as well as that of the major taxa, highlighted some marked differences between the diets of the entire size range of the six species in Wilson Inlet. Thus, in terms of volume, sediment dominated, i.e. > 80%, the overall dietary compositions of Mugil cephalus and detritus was found in moderate amounts in the diets of this mugilid and also A. forsteri. Detritus and molluscs, particularly mytilid (mainly Xenostrobus pulex and Xenostrobus securis), tellinid (Tellina *deltoidalis*) and venerid bivalves (*Irus crenata*), also constituted the main food sources, i.e. 40-45%, of the dietary volume of *C. macrocephalus* and made only low contributions to the diets of the five other species. Polychaetes, mainly nereids (including Ceratonereis aequisetis), orbiniids (Scoloplos simplex) and capitellids (including Capitella "capitata"), collectively contributed nearly two thirds to the overall dietary volume of S. punctata. The diets of both A. georgiana and P. speculator, which contained much greater volumes of the carid *P. australis* and fish species (including *E. australis* and gobiids), than the other four species, only differed slightly from each other, reflecting the consumption of a greater number of individuals of fish species by *P. speculator*.

Using the interspecific dietary categories, which optimally accounted for differences in data recording by the three dieticians and following ordination and ANOSIM, the above differences were strongly supported. Thus, the points for the different species, except *A. forsteri*, were confined to relatively tight groups that were discrete from each other, with the ANOSIM test producing very high R-statistic values, i.e. > 0.750 for all species comparisons, excluding that for *A. forsteri* vs *S. punctata*, for which the R-statistic value was 0.463. Such extreme differences were significant in all cases except when the number of permutations were too low, i.e. < 35. The above provides overwhelming evidence that the food resources of Wilson Inlet are partitioned amongst the majority of main commercially and recreationally important fish species, irrespective of water depth. For *A. forsteri*, the lack of a significant difference between the dietary compositions of this mugilid and the five other species is outweighed by the typically high R-statistic values and the presence of the points for the dietary samples in a relatively restricted region of the ordination plot.

5.4.3 Intra- and interspecific differences in relation to intrinsic and extrinsic factors

The marked intra- and inter-specific differences in the dietary compositions of the six species are obviously facilitated by differences in body and feeding morphology and behaviour and/or location of feeding. However, although all species except *P. speculator* can be considered as having a fusiform body (Hutchins and Swainston 1986) and are presumably often found in the water column, the compositions of their diet imply that they are feeding in very different ways. Thus, *M. cephalus* feeds exclusively on the substrate and ingests only low amounts of very small fauna (the bivalve *A. semen*), which is reflected in its low dispersion values. The diet of this mugilid is in marked contrast to the confamilial *A. forsteri*, the diet of which has a relatively high dispersion value. This latter species is clearly capable of feeding on and in the substrate (detritus and polychaetes) and the water surface (collembolans) and also over and/or within *Ruppia* meadows (*P. australis*).

Another important benthic feeder, *C. macrocephalus*, is relatively slowswimming throughout life and has a soft fleshy mouth with large crushing plates (Laurenson 1992). This plotosid also possesses terminal and well-developed barbels that can be used to detect food within or on the substrate (Hutchins and Swainston 1986). However, the prey handling ability of this species obviously changes with increasing body size, with the smaller individuals of this species ingesting thin-shelled and epibenthic mytilid bivalves and the larger individuals consuming more robust bivalves that lie burrowed beneath the substrate, which is related, as least partly, to an increase in mouth size.

Sillaginodes punctata feeds to a large extent in the benthic environment by using its highly protrusible jaws to quickly "suckup" slender taxa, such as different types of polychaetes, from the substrata (Hyndes et al. 1997). With increasing body size, this sillaginid is more able to ingest larger worms, such as nemertines, which can be abundant in south coast estuaries (Hodgkin and Clark 1988). However, once this species reaches a certain size, i.e. > 225 mm. and thus has a larger mouth gape, it can then ingest bivalve siphons, which can retract quickly into the substrate and the relatively large neogastropod *Philine angasi*.

Both *A. georgiana* and *P. speculator* feed to a greater extent on crustaceans when small and ingest increasingly large volumes of fish with increasing body size. Despite this broad similarity, their body morphology differs greatly, with that of *A. georgiana* being laterally compressed and fusiform, with a large eye and mouth and of silver colouration, implying that this fish is well-adapted to swimming in open water. In contrast, *P. speculator* is dorso-ventrally compressed, with small eyes set in the top of its head, a wide mouth and sandy pattern on its dorsal surface, suggesting that this species is well-equipped to lie in wait on the substrate to "ambush" its crustacean and fish prey. The above morphological differences help accounts for the fact that *A. georgiana* also ingests insects, presumably from the water surface, and for the typically higher contribution of fish in the diet of *P. speculator*.

5.4.3 Influence of site, season and method of capture on dietary compositions

Although data for site of capture was not available for two of the six species (*C. macrocephalus* and *P. speculator*), the multivariate analyses of the diets of the four other species demonstrated that neither site of capture nor season had an overwhelming effect on the dietary compositions of those species. Although a site difference might have been expected, given the large spatial and depth differences between those sites and associated data on the benthic macroinvertebrate and fish food sources (Potter et al. 1993, Platell and Potter 1996), it would thus seem that the main sampling sites did not differ largely in their habitat characteristics and thus food sources. Since an earlier examination of temporal changes in faunal communities showed that benthic macroinvertebrate and fish species were strongly seasonal, it is surprising that such differences are not reflected in the diets of the six species, which suggests that these food sources may remain sufficiently abundant throughout the year, unlike the situation in the Swan Estuary (Chapter 4).

5.4.4 How can this data be used for ecosystem modelling?

The scientific skill of two of the three dieticians in this study, with most prey being identified to the lowest possible taxonomic level (species) means that, if this study were to be repeated in the near future, any differences in the diets of five of these important commercial six species could be quickly detected. The only main exception was that of the diets of *C. macrocephalus* where polychaetes, which were of moderate importance in the diet, were not further separated to a lower taxonomic level. Since the six species that were the subject of this study collectively feed on a wide variety of prey, yet show strong partitioning of the food resources in this estuary, such dietary comparisons may prove extremely useful when assessing long-term ecosystem changes. The main deficit in this data set is the lack of site of capture information for *C. macrocephalus* and *P. speculator*. However, it is possible that such data may be located at a later date.

The relatively unimportant influence of site, within the basin of Wilson Inlet, and season on the diets of the six species, does suggest that scientifically rigorous determination of the diets of these species may not have to include all of those sites and could also restrict sampling to within certain seasons. However, caution should be exercised since the previous sampling regimes were not aimed at the detection of such spatial or temporal differences. In the case of season, the strong seasonality in the fish and benthic macroinvertebrate communities in the Swan Estuary (Potter et al. 1993, Platell and Potter 1996) and of the diets of certain atherinids and gobiids (Humphries unpublished data) does indicate a need for a re-assessment of seasonal differences in the diets of these six species.

The above dietary data can be used to provide very good input to ecosystem models, and, in conjunction with dietary data on the atherinids, gobiids and main avian piscivores (cormorants) (Humphries et al. 1992), such an ecosystem model should be strong. However, the lack of population data for the abundant carid *P. australis*, and for certain other fish species which have recently become abundant within the system (O. McIntosh, personal communication), suggests that this model may be weakened by such an exclusion. Furthermore, the increasing eutrophication of Wilson Inlet may also mean that the above dietary data, which was collected over 15 years ago, may not accurately reflect the current feeding relationships within that system. There is a clear need for a re-examination of the diets of those fish species and of *P. australis*, to be used as a standardised input to ecosystem models of the type being developed by Norm Hall at Murdoch University.

Chapter 6 A novel approach to dietary analysis

6.1 Introduction

Chapters 3 to 5 have outlined the types of analyses of raw dietary data or detailed data summaries that can be undertaken in order to determine the extent of intra- and inter-specific differences in the diets of fish species. Those analyses, which have relied upon the multivariate software package of PRIMER v5.2, have highlighted the difference in diets between fish species and also the extent of size-related, spatial and temporal changes in the diets of fish species. Such analyses provide the type of data that can be used to develop approaches to categorise fish into functional groups, which form solid bases for ecosystem analyses (e.g. Livingston 1985, Mangel et al. 2000, Pauly et al. 2000).

Although the foregoing chapters provided essential information for those fish species, and other published works provide comparable data for further fish species in south-western Australia (see Chapter 1), such categorisation of fish into feeding groups is hampered by the fact that only simple summaries of dietary data are available for some species while, for others, there is an almost complete lack of dietary data. This means that, for the majority of fish in marine and estuarine waters of Western Australia, and especially for many of commercial and recreational importance, a different type of approach to provide sound feeding categorisations is required.

In the case of data summaries for fish species, these can range from breakdowns of the contributions of different dietary groups to fish of different sizes, different locations and/or different times of the year (e.g. Geijsel 1983), to those for a fish species overall (e.g. Chalmer and Scott 1984), which may also be combined with that species in different waters or for closely related species in the same environment (e.g. Thomson 1957). In extreme cases, the only available information is anecdotal evidence from commercial and recreational fishers. Although it is evident such data are limited at best, there is no doubt that, in some of these cases, this data could increase our understanding of trophic structure within systems. This obviously implies that the usefulness of the data need to be evaluated and interpreted against a background of solid dietary data for other fish species in that system (or compared with same species in different systems).

One of the major hindrances to using data summaries in a meaningful and consistent way is that fact that, in a taxonomic or functional sense, such data are not always directly comparable. The first step must then be to develop a list of dietary categories that are based on

taxonomic and functional criteria that (a) can overcome difficulties in the identification and quantification of different food types and (b) ideally optimise "real" patterns in dietary data.

In this chapter, such an approach is described, using dietary summaries that have been computed from the raw data for twelve fish species in Wilson Inlet. The use of data for this environment has the advantage of using detailed dietary data that has been recorded from sites throughout the estuary for a wide size range of individuals of those fish species. Furthermore, the data for the 12 species has been extensively analysed (Humphries et al. 1992, Chapter 5) and the main influences on dietary compositions well understood. The approach is further tested by incorporating dietary data for *Acanthopagrus butcheri*, which has been recorded in Wilson Inlet (Potter et al. 1993) and has also been demonstrated to be an opportunistic feeder in other west and south coast estuaries by Sarre et al. (2000).

The dietary data for this species from the Swan Estuary on the west coast was selected for comparison, since the main potential prey in that system is the most similar to that of Wilson Inlet (Platell and Potter 1996, Kanandjembo et al. 2001b). Furthermore, since two separate studies have been carried out on the diets of *A. butcheri* (Kanandjembo 1998, Sarre et al. 2000), this provided an extra dimension to these analyses.

6.2 Materials and methods

6.2.1 Data treatment

The percentage volumetric dietary data for each of three species of atherinids (*Atherinosoma elongata, Leptatherina presbyteroides* and *Leptatherina wallacei*) and gobiids (*Afurcagobius suppositus, Favonigobius lateralis* and *Pseudogobius olorum*), and of six species of recreational and commercial importance (*Mugil cephalus, Aldrichetta forsteri, Cnidoglanis macrocephalus, Sillaginodes punctata, Arripis georgiana* and *Platycephalus speculator*), were re-calculated into a series of food sources, that can contain one or more of the dietary categories that were recognised in previous analyses of the volumetric dietary data (Humphries et al. 1992, Chapter 5). These food sources, which are shown in Table 6.1, were developed using the known dietary compositions of fish species in marine and estuarine waters of south-western Australia. The data was then pooled for all individuals of each species, irrespective of fish size, site or season of capture and shown in Table 6.2.

6.2.2 Dietary analyses for known data in Wilson Inlet and incorporating those for Acanthopagrus butcheri in the Swan Estuary

For each fish species in Wilson Inlet, the dietary data that were shown in Table 6.2 were square-root transformed and subjected to the Bray-Curtis similarity measure using PRIMER v5.2 software (Clarke and Gorley 2001). This matrix was then subjected to nonmetric multidimensional scaling (MDS) ordination (Clarke and Gorley 2001), which was used to demonstrate the extent of similarities (or differences) in the compositions of the food sources in the diets for each of the twelve fish species (Figure 6.1).

The next step was to recode the quantitative volumetric contributions of the different food sources that are presented in Table 6.2 into a series of quantitative values, i.e. 1=0.1-9.9%, 2=10-19.9%, 3=20-49.9% and 4=50-100%. This "stepwise" data were then subjected to the Bray-Curtis similarity measure and MDS ordination (Figure 6.2). The RELATE procedure in PRIMER was used to assess the degree of correspondence between similarity measures, and the Weighted Spearman rank coefficient and its significance level recorded.

The final analyses incorporated dietary data for *Acanthopagrus butcheri*, which was first re-computed into the appropriate food sources and then assigned a quantitative value of 0-4 as described above. The combined stepwise dietary data formed the basis of comparison, in order to lessen any subjective error from the different dieticians undertaking these studies. The dietary data was then subjected to MDS ordination as described above (Figure 6.3).

6.3 Results

6.3.1 Initial comparisons

The dietary data for each of the different fish species was allocated into the appropriate food source, a list of which is shown in Table 6.1, and the mean percentage volumetric contribution of that food source to the overall diet of each species shown in Table 6.2. The diets of *Mugil cephalus* were almost totally dominated by sediment, with this food source also making high contributions to the diet of *Cnidoglanis macrocephalus* (ca 45%) and moderate contributions to the diets of *Aldrichetta forsteri* and *Leptatherina presbyteroides* (17-19%). Worms contributed to between 13 and 30% of the diets of *A. forsteri*, *Leptatherina wallacei*, *Atherinosoma elongata*, *Pseudogobius olorum* and *Arripis georgiana* and approximately 55% to the diets of *Favonigobius lateralis* and *Sillaginodes punctata*. Epifaunal gastropods and chitons comprised between 8 and 18% of the diets of three species (*A. forsteri*, *A. elongata* and *S. punctata*). Infaunal bivalves were consumed by all but two fish species, with their contribution being high in *C. macrocephalus*, which also consumed eipfaunal bivalves, i.e. 34.2 and 8.2%, respectively, and greatest in *P. olorum* (Table 6.2). Small planktonic crustaceans were most important in the diets of the three species of atherinid, ranging from

25.1% for *A. elongata* to 59.7% for *L. wallacei*. In contrast, small benthic crustaceans were most important in the diets of the three gobiid species, ranging between 14 and 17% for *P. olorum, Afurcagobius suppositus* and *F. lateralis*. Small benthopelagic crustaceans comprised around 40% of the diets of both *A. forsteri* and *A. suppositus*, and 11-13% of the diets of *A. elongata* and *S. punctata*. The diets of both *A. georgiana* and *Platycephalus speculator* were dominated by large epibenthic crustaceans, i.e. 46.1 and 63.3%, respectively, and were also the only fish species to treat fish as a food source. Of those fish, the contribution of small pelagic fish was relatively greatest in the diets of *P. speculator*. Terrestrial and aquatic insects contributed by far the most, i.e. 13.6%, to the diets of *L. presbyteroides* and were either absent or present in small amounts in the diets of all other species (Table 6.2).

Table 6.1:List of food sources for fish species in marine and estuarine waters of south-western
Australia, that were compiled and developed using dietary references (see references in
Chapter 1) and Wells and Bryce (1984), Hutchins and Swainston (1986), Jones and Morgan
(1994), Edgar (1997) and Huisman (2000).

Number	Food source	Constituents	Examples in local waters
1	Sediment	Sediment Detritus Foraminiferans Diatoms Fish scales	
2	Suspended material	Microalga	
3	Plant material	Macrophtya	Ruppia megacarpa
4	Worms	Class Polychaeta Class Oligochaeta Phylum Nematoda Phylum Nemertini Phylum Echiura Class Scaphopoda	Ceratonereis aequisetis
4a	Epiphytic fauna	Phylum Bryozoa	
5	Epifaunal gastropods and chitons	Class Aplacophora Class Gastropoda	Stenochiton longipes Nassarius burchardi Philine angasi
6	Infaunal bivalves	Class Bivalvia	Family Tellinidae Family Galeommatidae Family Veneridae Family Donacidae Bivalve siphons
7	Epifaunal Bivalves	Class Bivalvia	Family Haliotidae Family Mytilidae Family Pectiniidae
8	Benthopelagic cephalopods	Class Cephalopoda	Order Teuthoidea Order Octopoda
9	Small planktonic crustaceans	Class Cladocera Class Conchostraca Class Copepoda Class Notostraca Class Ostracoda	Oithona simplex
		Class Malocostraca Class Ascidiacea Class Tunicata	Lucifer sp.
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9a	Meroplankton	Class Polychaeta Class Mollusca Class Insecta Order Teleostei	Eggs and larvae
10	Small benthic crustaceans	Order Amphipoda Order Cumacea Order Isopoda Order Tanaidacea Order Leptostraca	Allorchestes compressa Nebalia sp.
11	Small benthopelagic crustaceans	Class Mysidacea Class Caridea	Gastrosaccus sp. Palaemonetes australis
12	Large epibenthic crustaceans	Class Palinuridae Class Portunidae Class Penaidae Order Stomatopoda	Panulirus cygnus Portunus pelagicus Melicertus latisulcatus Metapenopsis dallii Squilla sp.
12	Eniformal ashina dama	Sub-Order Paguroidea	
13 14	Terrestrial and aquatic insects	Class Insecta	Order Chironomidae Order Hymenoptera
15	Small pelagic fish	Family Clupeidae Family Engraulididae Family Notocheiridae	Hyperlophus vittatus Engraulis australis Iso rhothophilus
16	Small benthopelagic fish	Family Apogonidae Family Atherinidae Family Pempheridae	Apogon rueppellii Atherinosoma elongata Pempheris klunzingeri
17	Small benthic fish	Family Gerreidae Family Gobiidae Family Leptoscopidae Family Triglidae	Parequula melbournensis Favonigobius lateralis Lesueurina platycephala Lepidotrigla papilio
18	Medium benthic fish	Family Plotosidae Family Sillaginidae Family Platycephalidae Family Mugilidae Family Mullidae Family Sparidae Family Teraponidae Family Tetraodontidae Family Monacanthidae Family Bothidae Family Pleuronectidae	Cnidoglanis macrocephalus Sillaginodes punctata Platycephalus speculator Mugil cephalus Upeneichthys lineatus Acanthopagrus butcheri Amniataba caudavittata Torquigener pleurogramma Meuschenia freycineti Pseudorhombus jenynsii Ammotretis elongatus
19	Medium benthopelagic fish	Family Arripidae Family Carangidae Family Clupeidae Family Hyporhamphidae Family Pomatomidae	Arripis georgiana Pseudocaranx wrighti Nematalosa vlaminghi Hyporhamphus melanochir Pomatomus saltratrix
20	Large benthic fish	Family Cheilodactylidae Family Glaucosomidae Family Kyphosidae Family Labridae Family Sciaenidae Family Sparidae Class Elasmobranchii	Nemadactylus valenciennesi Glaucosoma hebraicum Kyphosus cornelii Choerodon rubsecens Argyrosomus japonicus Pagrus auratus Aptychotremata vincentiana

Fish species	Food source												Gut fullness ± S.E.		
	1	3	4	5	6	7	9	10	11	12	14	15	16	17	(no. of guts)
Mugilidae															
M. cephalus (3)	99.1	-	-	-	0.1	-	-	0.9	-			-	-	1.7 ± 0.2 (20)	
A. forsteri (3)	16.9	8.0	21.6	8.4	8.4 0.2		44.2	-	0.5	< 0.1	< 0.1	< 0.1	$2.1 \pm 0.1 (116)$		
Plotosidae															
C. macrocephalus (3)	45.4	-	2.8	4.2	34.2	8.2	-	< 0.1	4.4	< 0.1	-	-	-	0.8	(167)
Atherinidae															
L. presbyteroides (1)	19.3	0.2	2.6	0.2	23.4	-	37.9	0.6	1.6	-	13.6	-	-	-	6.3 ± 0.2 (207)
L. wallacei (1)	3.2	0.9	13.7	3.6	12.0	-	59.7	4.1	1.4	-	1.3	-	-	0.1	7.3 ± 0.1 (285)
A. elongata (1)	4.3	0.9	19.7	14.0	14.0	-	25.1	6.5	13.9	-	1.7	-	-	-	6.0 ± 0.2 (234)
Gobiiidae															
P. olorum (1)	5.1	0.5	13.4	5.5	50.3	-	10.4	14.1	0.1	-	0.1	-	-	0.1	6.5 ± 0.2 (170)
A. suppositus (1)	-	0.4	30.6	0.1	11.5	-	0.7	17.3	38.1	-	-	-	0.3	1.0	4.9 ± 0.2 (204)
F. lateralis (1)	-	1.1	55.2	2.3	21.4	-	2.9	13.8	2.8	-	-	-	-	0.6	$7.3 \pm 0.2 (130)$
Sillaginidae															
S. punctata (3)	1.0	0.1	55.2	18.4	13.2	0.1	-	-	11.0	-	-	0.4	0.4	0.4	$1.7 \pm 0.1 (142)$
Arripididae															
A. georgiana (3)	< 0.1	1.3	13.4	0.9	< 0.1	-	-	0.1	1.3	46.1	0.8	26.0	2.5	9.1	$2.3 \pm 0.1 (150)$
Platycephalidae															
P. speculator (2)	-	-	1.2	1.9	-	-	< 0.1	0.3	1.7	63.3	-	3.9	8.8	19.8	(354)

Table 6.2: Mean percentage volumetric contributions of the different food sources to the overall diet, and the mean gut fullness ± 1 S.E. of those guts thatcontained food, of fish species that are abundant in Wilson Inlet, on the south coast of Western Australia. Data extracted from Humphries and
Potter (1993) (1), Humphries et al. (1992a) (2) and Chapter 5 (3).

N.B. For food sources, 1=Sediment, 3=Plant material, 4=Worms, 5=Epifaunal gastropods and chitons, 6=Infaunal bivalves, 7=Epifaunal bivalves, 9=Small planktonic crustaceans, 10=Small benthic crustaceans, 11=Small benthopelagic crustaceans, 12=Large epibenthic crustaceans, 14=Terrestrial and aquatic insects, 15=Small pelagic fish, 16=Small benthopelagic fish and 17=Small benthic fish (see Table 6.1

6.3.2 Multivariate comparisons

When the dietary samples for each of the twelve fish species from Wilson Inlet were subjected to ordination, the point for *M. cephalus* lay on the left lower part of the plot, while that for *C. macrocephalus* lay to the right of that point (Figure 6.1). On the upper part of the plot, the points for the three atherinid and three gobiid species lay in a relatively tight group on the central midline of the plot, close to that of *S. punctata*. The points for *A. georgiana* and *P. speculator* lay on the right of the plot and relatively close together, while that of *A. forsteri* lay between the latter two points and that of *S. punctata* (Figure 6.1a).

After ordination of the "stepwise" data for the dietary compositions of the fish species, the patterns on the resultant plot did not differ greatly from that of the plot produced by ordination of the raw dietary data (cf Figures 6.1a,b). Indeed, RELATE showed that the degree of correlation between the underlying similarity matrices was very high and significant (Rho=0.918, P=0.1%).

Upon combination of the "stepwise" values for the dietary compositions of *Acanthopagrus butcheri* with those of the other twelve fish species, followed by ordination, the points for those twelve species lay in a similar pattern on the plot to when they were ordinated without the points for *A. butcheri* (cf Figures 6.1b,c). The two points for *A. butcheri* lay on the bottom of the plot, to the right of that for *C. macrocephalus* and beneath the points for all other species (Figure 6.1c).

Tabulation of the dietary data into the appropriate food sources (Table 6.2) demonstrated that epifaunal bivalves were of the greatest importance in the diets of *A. butcheri* (3 or 4) and that medium benthopelagic fish were also present in its diet (Table 6.3)



Figure 6.1: MDS ordination of (a) the mean percentage volumetric contributions and (b) the stepwise contributions of the different food sources to the diets of *Mugil cephalus*, *Aldrichetta forsteri*, *Cnidoglanis macrocephalus*, *Atherinosoma elongata*, *Leptatherina presbyteroides*, *Leptatherina wallacei*, *Afurcagobius suppositus*, *Favonigobius lateralis*, *Pseudogobius olorum*, *Sillaginodes punctata*, *Arripis georgiana* and *Platycephalus speculator*, and (c) the stepwise contributions of the above 12 species and those of *Acanthopagrus butcheri*, recorded by (1) Kanandjembo (1998) and (2) Sarre et al. (2000).

Fish species	Food source														
	1	3	4	5	6	7	9	10	11	12	14	15	16	17	19
M. cephalus	4	0	0	0	1	0	0	1	0	0	0	0	0	0	0
A. forsteri	2	2	3	2	0	0	0	1	3	0	1	1	1	1	0
C. macrocephalus	3	0	1	1	3	2	0	1	1	1	0	0	0	1	0
L. presbyteroides	2	1	1	1	3	0	3	1	1	0	2	0	0	0	0
L. wallacei	1	1	2	1	2	0	4	1	1	0	1	0	0	1	0
A. elongata	1	1	2	2	2	0	3	2	2	0	1	0	0	0	0
P. olorum	2	1	2	2	4	0	2	2	1	0	1	0	0	1	0
A. suppositus	0	1	3	1	2	0	1	2	3	0	0	0	1	1	0
F. lateralis	0	1	4	1	2	0	1	2	1	0	0	0	0	1	0
S. punctata	1	1	4	2	2	1	0	0	2	0	0	1	1	1	0
A. georgiana	1	1	2	1	1	0	0	1	3	0	1	3	1	2	0
P. speculator	0	0	1	1	0	0	1	1	4	1	0	1	2	2	0
Sparidae															
A, butcheri (1)	1	2	2	1	1	3	1	1	1	1	1	0	1	1	1
A. butcheri (2)	1	1	1	1	1	4	0	1	0	1	1	0	0	1	1

Table 6.3:Mean percentage volumetric contributions of the different food sources to the overall diet, recoded into values of 0-4 (see Materials and
methods), and the mean gut fullness ± 1 S.E. of those guts that contained food, of fish species that are abundant in Wilson Inlet, on the south
coast of Western Australia. Data extracted from Table 6.2, Kanandjembo (1998) (1) and Sarre et al. (1999) (2).

N.B. For food sources, see Table 6.1, and 19 = medium benthopelagic fish

6.4 Discussion

The patterns of differences in the dietary compositions of the twelve main fish species in Wilson Inlet are highlighted and simplified using MDS ordination on the raw data for the different food sources utilised by those species. Importantly, the pattern of differences using those mean dietary compositions of the food sources for the fish species is strikingly similar to those shown when the dietary data is taken to a finer level, including the identification to dietary categories, rather than food sources, and when the data was separated according to size of fish (results in Chapter 5). This demonstrates that this broad approach using food sources, rather than dietary categories, does provide a realistic picture of the overall patterns in a fish community in an estuary such as Wilson Inlet. Furthermore, it has the advantage of "smoothing out" any differences in recording techniques that may occur between different dieticians. However, in the case of *Aldrichetta forsteri* (yellow-eye mullet) the single mean point did not fully encapsulate the variation which was revealed when the dietary data were ordinated at a finer level, which implies that such a generalisation may not apply equally well to all species, and particularly those which are relatively opportunistic in their dietary compositions.

The fact that the overall patterns in the ordination of food sources based on mean values still held true when those mean values were recoded into values ranging from 0 - 4 also has exciting implications. Furthermore, when the simplified dietary data for the black bream *Acanthopagrus butcheri* were included in a subsequent ordination, the resultant patterns strongly implied that this recreationally important sparid would be mainly feeding on a food source (epifaunal bivalves, such as mytilids) that, of the twelve species, is only ever ingested by *C. macrocephalus* and to a relatively small extent. This implies, in turn, that there would be a limited potential for direct competition for food sources among those species.

It is evident that the above approach to dietary analyses has a number of important attributes. Firstly, it can greatly simplify the identification of dietary components and can thus be quickly and easily applied to complex systems. Secondly, it can be used to assess whether fish species are likely to be competing with other fish species for the same food sources or feeding on different food sources. And thirdly, it is a potentially valuable tool for identifying which species warrant further scientific attention. Thus, this approach has an obvious advantage in that it can provide data that can be applied with some confidence to ecosystem models. However, despite the promise of this approach, it should be emphasised that a solid and quantitative dietary data set, which allows the exploration of any spatial, temporal or size-related differences (see West et al. 2003), is essential for a complete understanding of the complex feeding interrelationships amongst fish in aquatic systems.

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Conclusions

- There is a paucity of high-quality dietary data for many commercially and recreationally important fish species in the marine and estuarine waters of southwestern Australia.
- **2.** Species for which dietary data has been required have been ranked in order of importance, which will enable a suitable direction of future scientific effort.
- 3. There is little or no dietary data for fish species in two west coast estuaries (Peel-Harvey and Leschenault estuaries).
- **4.** In combination, MS Excel TM and MS Access TM provide excellent data storage facilities for dietary data and associated metadata.
- 5. Marked interspecific differences in dietary compositions are apparent when the diets of a number of species are examined in at least three environments in south-western Australia, i.e. nearshore and offshore marine environments and Wilson Inlet.
- **6.** A wide array of feeding types is known to be represented in marine and estuarine waters, ranging from detritivores to lower and higher order invertivores and then piscivores.
- 7. The majority of species for which detailed dietary data are available in southwestern Australia are lower order invertebrate predators.
- **8.** Size-related differences in dietary compositions, which can vary in their extent, are shown for all species in which the size at capture was recorded.
- **9.** The diets of different fish species can vary either very little (e.g. Chapter 3) or to a great extent (e.g. Hourston et al. 2004) between locations.
- 10. Seasonal differences in the diets of certain species are most probably related to fluctuations in their food resources. When seasonal differences are not recorded, this is due either to the fact that densities of certain prey do not become too low, or that predators do not apparently respond to increases in densities of certain prey items.
- **11.** The choice of dietary category can affect outcomes of dietary analyses.
- 12. A multivariate approach to dietary analyses, which relies upon allocation of dietary categories into broad "food sources", holds firm promise for the analysis of complex dietary data sets.

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Appendix 1

Intellectual Property

The value of the intellectual property will be 66.3%, based on Part C of the FRDC project proposal.

List of Staff

Dr Margaret Platell Assoc. Prof. Norm Hall Prof. Ian Potter Mr Mat Hourston Ms Thea Linke

Appendix II

Maintenance and use of "Guts"

1. Housing and maintenance

The original version of the database "Guts" is permanently housed at Murdoch University, at which Norm Hall is the data custodian. A backup database is held by the Research Office at this University and by Margaret Platell, who is presently located at the University of Newcastle, Ourimbah. A third backup is to be held at FRDC.

"Guts" is regularly accessed by Margaret Platell, as part of its ongoing development. Any new developments are immediately communicated to Norm Hall and new backups created, which are then lodged at Murdoch University.

2. Use of the database by others

No data is to be added, modified or deleted from "Guts" without the written permission of Margaret Platell and Norm Hall.

At present, use of the database by others is to be restricted to viewing the data through queries, which are part of the MS Access software. Certain queries have been developed for data interrogation:

- How Many Fish? Determines number of individuals of each fish species per dietician per environment, for which dietary data have been recorded.
- (b) Prey Type simplified. Provides a simplified prey table, with genus, species, common and endname.

The analysis of any dietary data is only possible after written consent has been obtained from Margaret Platell and Norm Hall. The query "Analyses" has been developed and can be used for extraction of raw dietary data and its relevant details. The data can then be saved as MS Excel and imported into statistical packages for further analysis.