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Spatial and Ontogenetic Variation in the Diet of Wild and Stocked Mulloway (*Argyrosomus japonicus*, Sciaenidae) in Australian Estuaries

MATTHEW D. TAYLOR[1,]*, D. STEWART FIELDER[2], and IAIN M. SUTHERS[1]

[1] *School of Biological, Earth and Environmental Science, University of New South Wales, Sydney, 2052, Australia*
[2] *Port Stephens Fisheries Centre, New South Wales Department of Primary Industries, Taylors Beach, NSW, 2316, Australia*

ABSTRACT: Prey importance and ontogenetic transitions in the diet of stocked and wild mulloway (*Argyrosomus japonicus*) were compared between a southeast Australian riverine estuary and a coastal lagoon. Stomach content analysis of fish captured from these estuaries in 1977–1979, 1997–1998, and 2003–2005 revealed size-specific and estuary-specific diets. Mysid shrimp were most common in diets of fish < 250 mm total length (TL), and prawns were common in diets of fish measuring 301–450 mm. Forage fish were most abundant in diets of mulloway > 500 mm. Index of Relative Importance (IRI) of forage fish increased with TL, while IRI of mysids decreased with TL. Prawn IRI was greatest for fish 150–600 mm TL. Comparisons between benthic resources and dietary composition revealed that Georges River mulloway consumed prey categories in proportions similar to those in their environment. No mysid shrimp were detected in the coastal lagoon or in the diet of mulloway captured there; growth was comparable to the Georges River. Hatchery-reared fish fed < 16 d after stocking, indicating normal behavioural adaptation after release. Dietary information can be used to optimize stocking locations, times, and densities, as well as estimate potential effects of mulloway on potential prey and wild conspecifics.

Introduction

Estuarine habitats are important in the life cycle of many fish species as productive areas that both shelter and sustain juvenile fish (Beck et al. 2001; Costello et al. 2002). The dependence of juvenile and adult fish on estuaries is largely a response to the availability of food and shelter, as resources are often limited in offshore waters (e.g., Rochford 1979). Complex estuarine habitats, such as salt marsh, mangroves, and seagrass, also provide shelter from predation and adverse physical conditions for smaller fish (Morton et al. 1987; Blaber 1997).

The distribution or behavior of an estuarine fish is dependant on ontogenetic transitions (Labropoulou et al. 1998), major prey taxa (Werner and Gilliam 1984), and the associated change in foraging behavior and primary habitats used for foraging. Diet dependant transitions can occur in response to morphological changes (such as gape; Krebs and Turingan 2003) or decreased vulnerability of larger fish to predation, facilitating exploitation of new prey resources. Prey and habitat based size structuring of populations have important implications for stocking finfish, as stocking can be targeted outside areas where larger conspecifics forage.

Mulloway or jewfish, *Argyrosomus japonicus* (Sciaenidae), are a highly prized but elusive sportfish in estuarine and coastal areas of southern Australia, southern Africa, and China (Griffiths 1997). Australian recreational mulloway catches far exceeded commercial catches in 2000–2001, with Australian recreational fishers taking over 975 tonnes (Henry and Lyle 2003). Commercial catches of mulloway in New South Wales have halved in recent times (Taylor et al. 2005a), and this decline is commonly attributed to the susceptibility of mulloway to estuarine prawn trawling, of which juveniles form a significant nonretained bycatch (Broadhurst and Kennelly 1994). The decline of mulloway observed in New South Wales estuaries has led to an investigation into the feasibility, and environmental and predatory effects of mulloway stocking (Fielder et al. 1999; Taylor et al. 2005b).

Marine stocking may be justified by limitations to natural recruitment (Doherty 1999) and unexploited carrying capacity (Li 1999) to support additional recruits. In situations where a species is recruitment limited, stocking of fish can be optimized for the forage resources available in that area (Taylor et al. 2005a). The forage requirements of a predatory fish limits stocking density to resources available in the range of habitats used. These forage resources may

* Corresponding author; tele: +61 7 5523 3965; fax: +61 2 9385 1558; e-mail: mattytaylor@unsw.edu.au

TABLE 1. Origin of mulloway diet data analyzed in this study.

Estuary	Date	Origin of Fish	Size Range (mm TL)	n	
Georges River	1977–1979	Wild only	15–636	162	Pease et al. (1981)
Smiths Lake	1997–1998	Stocked and wild	169–304	39	Fielder et al. (1999)
Georges River	2003–2005	Stocked and wild	68–1,300	212	

not be present in all estuarine environments, and stocking of fish in locations where major prey sources are not present may lead to high mortality. Hatchery-reared fish are often naive toward prey and lack necessary foraging behavior due to a potential lack of experience with wild prey in the hatchery (Suboski and Templeton 1989). If this is the case, stocking strategies should also include offering hatchery-reared fish experience with wild prey prior to release (Tsukamoto et al. 1999).

There have been several studies of the diet of African *A. japonicus* (Whitfield and Blaber 1978; Marais 1984; Griffiths 1997), but the ontogenetic changes in the diet of Australian mulloway remain unknown. This study aimed to determine ontogenetic variation in the diet of Australian subadult mulloway, compare dietary differences of mulloway in a shallow intermittently closed opening landlocked lagoon with those found in a riverine estuary, evaluate foraging of hatchery-reared mulloway soon after release, and compare the diet with the benthic resources available to mulloway in typical southeast Australian estuaries.

Materials and Methods

Study Areas

The Georges River (33.998°S, 151.155°E) has a waterway area of 12 km^2 and is located in the southern Sydney metropolitan area. The river discharges into a large open embayment (Botany Bay, 33.983°S, 151.200°E) before flowing into the Tasman Sea. Both the Georges River and Botany Bay have been affected by urban and industrial development (Gibbs 2001; Haworth 2002) and receive urban pollution inputs. The river extends 50 km upstream where the upper tidal limit is bounded by a weir; the freshwater section extends for an additional 40 km. Smiths Lake (32.395°S, 152.520°E) is a shallow ($<$ 5 m) intermittently closed opening landlocked lagoon of 11 km^2 area. The 32 km^2 catchment is largely agricultural land and a national park, with mild nutrient input from septic tanks in surrounding communities (Anon. 2001).

Mulloway Diet

Mulloway sampled in three different projects were investigated in this study (Table 1). Wild mulloway were sampled in the Georges River between 1977 and 1979 using an otter trawl (18.3 m mouth, 3.8 cm cod-end mesh), multipanel gill nets (five 60-m panels of 38, 63, 76, 89 and 102 mesh butted together randomly), or a commercial beach seine (400 × 3 m, with 3.8. cm cod-end mesh; Pease et al. 1981). Mulloway were mainly captured off a mud bottom in the southwestern corner of Botany Bay at the mouth of Georges River (Pease et al. 1981). Trawls were towed for 5 min and covered an area of 5,400 m^2, and gill nets were set for 2–5 h. Captured mulloway were weighed and total length (TL) was measured, stomach contents were identified, and composition was estimated volumetrically (Hyslop 1980).

Hatchery-reared juvenile mulloway were marked and stocked into Smiths Lake in 1997 (Fielder et al. 1999), and the Georges River in 2003 and 2004 (Table 2; Taylor et al. 2005b). All mulloway captured in the 1997–1998 Smiths Lake and 2003–2005 Georges River studies were measured for TL and weight. These fish were also analyzed for the presence of a chemical mark on the otolith using methods described previously (Taylor et al. 2005b) to indicate whether they were of hatchery origin.

In Smiths Lake, released and wild mulloway were sampled from 1997 to 1998 (Table 1) through a commercial beach seine and gill net operation. Samples were preserved on ice, and stomach contents of captured fish were extracted, identified, and counted. Stomach contents were not weighed in this study.

In Georges River, released and wild mulloway were sampled between 2003 and 2005 (Table 1) using an otter trawl (6 m mouth, 12 m length, 0.6 mm cod-end mesh size), multipanel gill nets (ten 5-m panels of 13, 19, 25, 32, 38, 45, 50, 55, 60, and 70 mm mesh butted together randomly), and the recreational fishery. Captured mulloway were euthanized in ice slurry upon landing. Intestinal tracts from the oesophagus to the anus and gonads were removed and fixed in 5% formalin for 7 d

TABLE 2. Releases of hatchery-reared mulloway into Smiths Lake and the Georges River between 1997 and 2004.

Estuary	Cohort	Mark	Number Released	Release TL
Smiths Lake	February 1997	OTC[a]	7,600	58.0 mm
	March 1997	OTC	10,000	65.0 mm
	March 1997	OTC	4,000	106.0 mm
Georges River	April 2003	OTC	54,000	79.8 mm
	March 2004	ALC[b]	5,200	77.2 mm
	April 2004	OTC	19,000	47.5 mm

[a] indicates Oxytetracylcline hydrochloride (Taylor et al. 2005b).
[b] indicates Alizarin complexone (Taylor et al. 2005b).

before preservation in 95% ethanol. The intestinal tract was separated from other organs and weighed. Stomach fullness was subjectively estimated as empty (0) to completely full (5). The intestine was then separated from the stomach and weighed separately, and the stomach contents extracted and empty stomach weighed. Contents were sorted, identified, and enumerated. Sorted prey items were then freeze dried for 48 h, and the dry weight of each prey type was determined.

Prey Assemblages

A trawl net (6 m mouth, 12 m length, 0.6 mm cod-end mesh size) was towed at dusk for 5 min in deep holes surrounding the release site in the Georges River during winter (n = 26) and spring (n = 14) 2003, and all organisms captured were preserved in ice slurry. Trawls were also conducted in the deepest basin in Smiths Lake (5 m) on 16 May 2003 (n = 7) and 23 May 2003 (n = 4). Frozen organisms were identified, counted, and weighed in the laboratory. Biomass of prey species in all trawls were expressed as a proportion (%) of total biomass. Biomass proportions were arcsin transformed for statistical analyses.

Data Analysis

All length measurements are TL. Diet data from the 2003–2005 Georges River samples were expressed as percent composition in each stomach by number (%N), percent composition in each stomach by dry weight (%W), and frequency of occurrence in the diet for each size class analyzed (%F). The Index of Relative Importance (IRI; Pinkas 1971) measures the importance of each prey item relative to other prey items by taking into account both the weight and number of each prey item, and the frequency at which it occurs in the diet. IRI was calculated for prey items from the 2003–2005 Georges River samples using the following equations (Pinkas 1971):

$$IRI = (\%N + \%W).\%F$$

Jacobs electivity index (D) measures the relationship between diet content and prey assemblages in the environment, and whether selective feeding is occurring (Jacobs 1974). D was calculated for mulloway samples for which prey assemblages were determined using the following equation (Jacobs 1974):

$$D = (p - q)(p + q - 2pq)^{-1}$$

where p is the proportion of food item in the diet and q is the proportion of food item in the environment. D values range between −1 and +1. Values of D close to zero (−0.1 to +0.1) show prey are taken in a similar proportion to their occurrence in the environment; positive values indicate the prey is actively selected over prey that have negative values, indicating avoidance of an item (Llanso et al. 1998).

Dietary composition of the 1977–1979 and 2003–2005 mulloway were compared across eight size classes using two-way analysis of variance (ANOVA; Quinn and Keough 2002). Linear regressions of prawns and forage fish size versus predator size were calculated for mulloway caught in the Georges River in 2003–2005. As 1997–1998 Smiths Lake diet samples were only evaluated as proportion by number, these data were compared only with proportion by number estimates for equivalent sized fish in the 2003–2005 Georges River samples using two-way ANOVA. Prey abundance in the Georges River and Smiths Lake in May 2003 were compared using two-way ANOVA, and trends in prey biomass over time were evaluated for Georges River 2003 trawl samples using a Kruskal Wallis test. All statistical calculations were carried out using Systat v. 10 (Systat Software Inc., Richmond, California).

Results

Diet and Ontogeny

Of 374 stomachs analyzed from the Georges River, 30% (113) were empty. The number of nonempty stomachs (70.7 ± 4.7%, mean ± SE) was greater than the number of empty stomachs (29.3 ± 4.8%) in all seasons, but the proportion of empty stomachs appeared higher in winter than other seasons. There were more nonempty stomachs than empty stomachs sampled across the entire size range, with the exception of the 51–100 and 501–550 mm size classes. Smaller size classes were not evenly represented across summer and winter, as mulloway typically spawn through early summer (West 1992) so it is unlikely to see these smaller size classes in winter.

Analysis of diet information from the 1977–1979 and 2003–2005 Georges River studies revealed several prey species (Table 3). There was no significant difference in dietary composition of mulloway captured in 1977–1979 and 2003–2005 for mysid shrimp, prawns, and forage fish (Table 4). Data from the 1977–1979 and 2003–2005 Georges River studies were pooled for subsequent analyses. Forage fish in the stomachs of smaller mulloway were dominated by the goby *Pseudogobius olorum*, while forage fish in the stomachs of larger mulloway were mainly sprat *Hyperlophus vittatus* (Table 3). Other fish species found in smaller numbers in stomachs of larger mulloway included glassfish

TABLE 3. Major prey species of *Argyrosomus japonicus* in a riverine estuary.

Species	Classification	Prey Group
Hyperlophus vittatus	Family Clupeidae	Forage fish
Pseudogobius olorum	Family Gobiidae	Forage fish
Acanthopagrus australis	Family Sparidae	Forage fish
Mugil cephalus	Family Muglidae	Forage fish
Ambassis jacksoniensis	Family Ambassidae	Forage fish
Metapenaeus macleayi	Family Penaeidae	Prawns
Alpheus strennus	Family Alpheidae	Prawns
Rhopalophthalmus sp.	Order Mysidacea	Mysids
Birubius sp.	Suborder Gammaridea	Miscellaneous invertebrates
Gonodactylus smithii	Family Gonodactylidae	Miscellaneous invertebrates
Sepioteuthis australis	Family Loliginidae	Cephalopods
Sepia apama (juv.)	Family Sepiidae	Cephalopods

Ambassis jacksoniensis, bream *Acanthopagrus australis*, and mullet *Mugil cephalus.* The proportion by biomass of each prey group in the mulloway diet clearly varied with mulloway size (Fig. 1). Mysid shrimp *Rhopalophthalmus* sp. were most numerous in fish < 250 mm, while prawns *Metapenaeus macleayi* and *Alpheus strennus* were most common in 200–600 mm fish, and forage fish became most abundant in mulloway > 501 mm. Miscellaneous invertebrates were mostly amphipods *Birubius* sp. in smaller mulloway (Fig. 1, Table 3) and stomatopods *Gonodactylus smithii* in mulloway > 700 mm. Cephalopods (Table 3) appeared in the stomachs of mulloway > 601 mm. Prawn ($F = 30.53$, $df = 52$, $p < 0.01$) and forage fish ($F = 139.19$, $df = 79$, $p < 0.01$) size increased exponentially with mulloway size.

The IRI calculated for Georges River mulloway captured in 2003–2005 showed similar trends to the percent composition (Fig. 1). Importance of forage fish in the diet increases with size, while the importance of mysids decreases with size. Prawns appear most important for mulloway 301–450 mm, with lower importance when either mysids or forage fish are of greater importance. Miscellaneous invertebrates have minor importance for small fish, while cephalopods have minor, but increasing importance for larger fish.

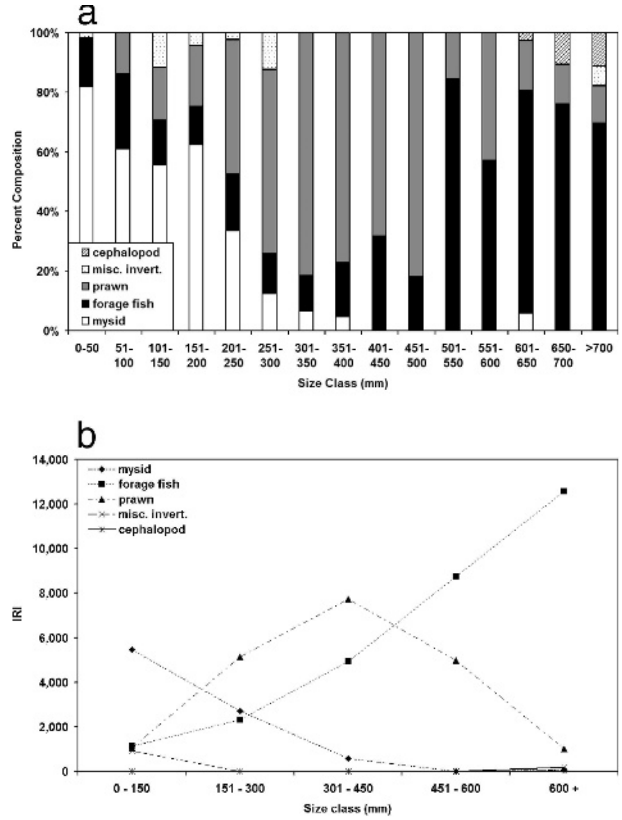

Fig. 1. Diet of mulloway captured in the Georges River between 1977–1979 and 2003–2005. Percent diet composition by biomass and index of relative importance (IRI) for major prey detected in the mulloway stomachs.

Hatchery-reared mulloway were released during the day around the trawling sites in Georges River on April 9, 2003 (20,000) and in the same location on April 12, 2003 (7,000; Table 2). The first trawling event was conducted during the evening of April 12, 2003, 3 d after the first stocking, and the day of the second stocking. Fish were not marked to allow differentiation between the two stocking events, but 24% of stocked fish ($n = 36$) had nonempty stomachs, indicating that feeding was occurring between 1 and 3 d after release. All stocked mulloway captured on the sampling events 16 d later

TABLE 4. Analysis of variance in dietary composition between mulloway captured in the Georges River at different times (1977–1979 and 2003–2005) for different size classes.* Indicates a significant difference.

Source of Variation	df	Mysid MS	Mysid F	Mysid P	Fish MS	Fish F	Fish P	Prawn MS	Prawn F	Prawn P
Time	1	2,365	1.39	0.24	2,345	2.66	0.11	29	0.02	0.89
Size class	7	10,280	6.03	<0.01*	456	0.52	0.82	11,023	7.87	<0.01*
Time × size class	7	1,091	0.64	0.72	467	0.53	0.81	1,986	1.42	0.20
Error	155	1,705			881			1,400		

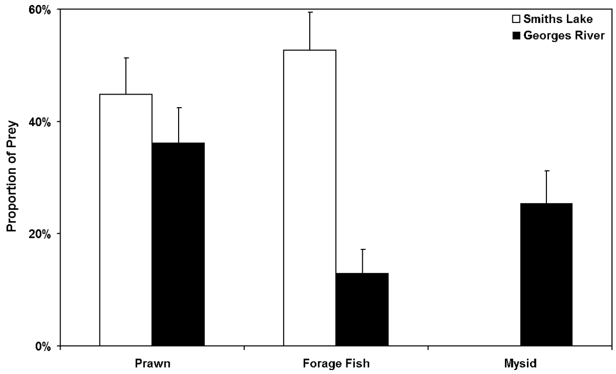

Fig. 2. Proportion of prey items by number in stomachs from Smiths Lake mulloway and similar sized fish captured in the Georges River.

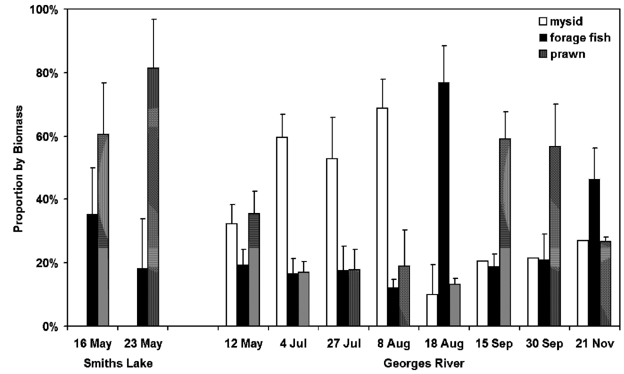

Fig. 3. Proportion by biomass of major prey organisms captured in Smiths Lake trawls in May 2003 and Georges River trawls from 12 May to 21 November 2003 (mean ± SE).

(April 28, 2003) had nonempty stomachs. The proportions of mysids (*t*-test, df = 6, $t = 0.08$, p = 0.94) and forage fish (*t*-test, df = 11, $t = 0.15$, p = 0.89) in the diet were not significantly different between stocked fish captured on 12 April 2003, and wild fish of the same size class sampled in 1977–1979. There were no wild fish of comparable size captured in the Georges River in 2003–2005.

Estuary-specific Diets

Fish stocked and captured in Smiths Lake between 1997 and 1998 showed differences in dietary composition (Fig. 2) compared to the Georges River. Prawns in Smiths Lake mulloway stomachs were either *Penaeus plebejus* or *Metapenaeus macleayi*, and forage fish were dominated by the estuarine hardyhead *Craterocephalus honoriae*. Other organisms detected in mulloway stomachs included isopods and polychaetes. The two sampling events analyzed for stomach contents in Smiths Lake occurred when mulloway were 249.5 ± 12.5 mm (n = 24) and 278.1 ± 17.5 mm (n = 15). These data were pooled and compared with dietary composition by number in 201–300 mm Georges River mulloway (Fig. 2). There was a significant difference in the dietary composition of mulloway between the two estuaries (F = 14.10, df = 261, $p < 0.01$). Tukeys post-hoc comparisons revealed no significant difference in the proportion of prawns in the diet between the two estuaries (p = 0.98); there was a significantly higher proportion of forage fish in the Smiths Lake diet ($p < 0.01$), which compensated for the absence of mysid shrimp.

Prey Assemblages and Prey Selectivity

Trawl samples from 2003 (n = 2–9 per sampling event) were standardized for trawl area. Biomass of major prey groups captured in the Georges River and Smiths Lake (mysid shrimp, forage fish, and school prawn (*Metapenaeus macleayi*); Table 3) are expressed as proportion of forage species biomass per trawl for each sampling date (Fig. 3). Mysid shrimp were detected in the Georges River at densities up to 121 organisms or 9 g m^{-2}. The majority of forage fish in the Georges River trawl samples were goby, while sprat were found in lower numbers as they are not a benthic species. No cephalopods were captured in Georges River trawl samples. In Smiths Lake, prawns *M. macleayi* and *M. bennettae* dominated the forage resources, while forage fish comprised mainly the estuarine hardyhead *Craterocephalus honoriae* (Fig. 3). Other forage resources included squid *Sepioteuthis australis* (2.5 ± 1.8%) and *Alpheus strennus* (0.3 ± 0.2%). Two-way ANOVA revealed no significant differences in overall forage resources between estuaries (F = 1.66, df = 54, p = 0.20), while there was a significant difference between the proportion of forage species (F = 9.57, df = 54, $p < 0.01$) and a significant estuary-forage species interaction term (F = 7.54, df = 54, $p < 0.01$). Tukeys post-hoc comparisons revealed a significantly greater proportion of prawn biomass for May 2003 trawl samples than the Georges River (p = 0.02), while the proportion of forage fish biomass was not significantly different (p = 0.91) between the two estuaries. There were no mysids captured in Smiths Lake trawl samples (Fig. 3).

The proportion of prawn biomass (Fig. 3) increased significantly (Kruskal-Wallis test, $p < 0.01$) in September, which coincides with the emergence of adolescent and maturing *M. macleayi* spawned in the previous summer and autumn from the bottom sediment (Kailola et al. 1992). This increase also corresponds with a marked increase of prawn IRI (Fig. 1) for mulloway spawned the previous summer (Fig. 3), which are c. 200 mm by September–October. A significant drop in the proportion of mysid biomass (Kruskal-Wallis test, $p < 0.01$) was observed when there was an apparent, but non-significant (Kruskal-Wallis test, $p = 0.17$) peak in the proportion of forage fish biomass in August.

Jacobs electivity index (D) was calculated for those trawls in which mulloway with full stomachs were captured (12 May, 8 August, 18 August, and 15 September in the Georges River). D values were −0.01 for mysid shrimp, −0.01 for forage fish, −0.02 for prawns, and 0.06 for miscellaneous invertebrates. All values were close to zero (−0.1 to +0.1), indicating all species appear in the mulloway stomachs in similar proportions as they appear in the environment (Llanso et al. 1998).

Discussion

Diet and Ontogeny

Ontogenetic changes in the predatory diet of Australian mulloway has great economic and ecological importance, as mulloway are the main species targeted for restocking in southeast Australia. The diet shifts from mysid dominated to prawn dominated at ca. 200 mm TL, and then to a forage fish dominated diet > 500 mm. Teleost prey in the diet is dominated by benthic gobies in smaller mulloway (< 500 mm) and schooling pelagic sprat in larger mulloway (> 400 mm). Larger mulloway exploit both larger prey in the case of prawns, and more active prey in the transition from benthic forage fish to pelagic species. The increase in prawn and forage fish size being targeted is facilitated by increased gape size (Krebs and Turingan 2003), a greater level of foraging experience (Croy and Hughes 1991), lower reliance on refugia (Walters and Martell 2004), and in the case of prawns, the availability of larger prawns emerging from the sediments (Kailola et al. 1992) as the mulloway approach age 1+. Cephalopods are of increasing importance in the diet of larger fish, but they were absent from trawl samples taken in the river. This may be due to either gear avoidance or evidence of these larger fish travelling out into Botany Bay seagrass beds.

Similar prey items were detected in mulloway from the Great Fish River estuary in South Africa (Griffiths 1997). South African mulloway prey on mysids *Mesopodopsis slabberi* and *Rhopalophthalmus terranatalis*, prawns *Palaemon pacificus* and *Penaeus japonicus*, and the clupeid fish *Gilchristella aestuaria*. There were some similarities between the relative importance of the above prey items with those of Australian mulloway (Fig. 1), but forage fish were the most important prey across the entire size spectrum of African mulloway analyzed (< 50 to 805 mm TL). Mysids were the second most important prey of fish sized < 50 to 150 mm, when prawns became more important (Griffiths 1997). Both prawns and mysids had negligible importance for mulloway by the time they reach 805 mm, similar to Australian mulloway.

Red drum *Sciaenops ocellatus* is a similar sciaenid that is stocked in the Gulf of Mexico and southern USA (McEachron et al. 1995; Taylor et al. 2005a). The autumn diet of red drum in Galveston Bay, Texas, was comprised of primarily decapod crustaceans (*Callinectes sapidus* and *Penaeus setiferus*), while the diet of the same cohort in the next spring was dominated by the clupeid *Brevoortia patronus* (Scharf and Schlicht 2000). The importance of prey was not evaluated for predator size in this study, but the greater abundance of forage fish in the spring diet the following year may be a reflection of the shift in size of the red drum and consequent ontogenetic shift in prey preference as the cohort has grown. This is supported by our data, and a higher IRI for fish in red drum > 200 mm length in Upper Tampa Bay, Florida, compared with red drum < 200 mm (Llanso et al. 1998). The popping alpheid shrimp *Alpheus estuariensis* was also present in the stomach of red drum in low numbers (Scharf and Schlicht 2000), as was the case for Australian mulloway (Table 3). While no mysids were detected in the diet of Galveston Bay red drum, amphipods and mysids were common in red drum < 200 mm sampled in Upper Tampa Bay where there was a lower salinity (Llanso et al. 1998). Tampa Bay red drum showed a similar transition as mulloway (Fig. 1), with consumption of non-mysid decapod crustaceans increasing in fish > 200 mm (Llanso et al. 1998).

Estuary-specific Predation

Mulloway of 150–460 mm captured in the Coorong Lagoon, South Australia, had a predominantly piscivorous diet of Ogilby's hardyhead *Atherinomorus ogilbyi* (44%) and bony bream *Nematalosa erebi* (22%), with shrimps and mysids less frequent (13%), even in fish 150–250 mm (Hall 1986). Similar forage fish species were consumed in the Coorong Lagoon and Smiths Lake with hardyheads the most abundant prey. Gobies were the most common forage fish prey for Georges River mulloway, but hardyheads were consumed in greater numbers than gobies in both the Coorong Lagoon and Smiths Lake. Gobies are abundant in both the Coorong Lagoon and Smiths Lake (Robinson et al. 1982; Eckert and Robinson 1990), which indicate they are not being preferentially targeted in these systems. Mysids were completely absent from the diet of Smiths Lake mulloway as they do not occur in the estuary (Robinson et al. 1982) and were absent from trawl samples undertaken in Smiths Lake in 2003 (Fig. 3). Similarities in the diet of mulloway in the Coorong Lagoon and Smiths Lake are to be expected, as both estuaries are higher salinity (> 30) environments (Robinson et al. 1982; Geddes 1987); Georges River salinity ranges from 5 to 30. Smiths Lake does not support a natural population of juvenile mulloway (Robinson et al. 1982), possibly due to the lack of deep water habitat, brackish water, and the absence of preferred mysid prey.

Prey Assemblages and Prey Selectivity

The differences in the diet of mulloway and red drum discussed above may be explained in part by the prey selectivity values calculated for the Georges River samples. Values of Jacobs electivity index (D) close to zero infer flexibility in the diet and a tendency to consume prey in similar proportions to that of the environment, so the diet and relative importance of different prey to mulloway is likely to be different between estuarine environments, as observed for red drum. Diet flexibility is further supported by the distribution of mulloway across a wide range of salinities and estuarine environments including rivers (Gray and McDonall 1993), coastal embayments (Hall 1986), and nearshore reefs (Loneragan et al. 1987). Although prey preference may not restrict distribution of juvenile mulloway, the lack of suitable refugia could result in higher mortality (Walters and Martell 2004; Taylor unpublished data). While exhibiting fast growth at 1 mm d^{-1} (Fielder et al. 1999) without using mysid shrimp as a forage resource, fish stocked in Smiths Lake experienced low survival (Taylor et al. 2006). Good growth indicates forage demands were being met, so low survival must be a result of other limitations, most probably the absence of suitable refugia from predation. The absence of mysid shrimp in Smiths Lake may be related to a significantly greater proportion of prawn biomass in the system (Fig. 3), but the lack of mysids in the diet was compensated by a significantly higher proportion of forage fish (Fig. 2). Dietary flexibility is advantageous, as distribution is not completely limited by the presence of certain prey, and other areas providing suitable habitat may be exploited. Dietary flexibility in red drum facilitated the exploitation of additional forage resources available in a restored mangrove impoundment (Llanso et al. 1998).

The changes in prey importance for Georges River mulloway may also be linked with seasonal changes in prey availability. Prawns become more abundant in September and October (Fig. 3; Kailola et al. 1992), which coincides with the peak in prawn IRI for age 0+ fish spawned the previous summer (Fig. 1). This cannot be tested in the field as small size classes of mulloway do not occur year-round, but laboratory prey selection experiments may be useful in resolving whether prawns are being selected due to ontogenetic change or because there is a greater biomass. Morphological changes may also facilitate this change in prey preference, as a bigger gape size of larger mulloway may allow them to target a prey larger than mysids more effectively.

Implications for Stocking

The size-specific shifts in target prey demonstrated here have important implications for stocking. These results will allow the selection of suitable stocking sites and times based on presence of preferred prey for mulloway. This would be riverine systems that support populations of mysid shrimp and penaeid prawns, and have deep holes with structure for refugia (Taylor unpublished data). Given the flexibility in the diet of mulloway, the absence of important prey items like mysid shrimp should not preclude future stocking of mulloway in estuarine lagoons. Provided there is a suitable area of key habitat refugia, good growth and survival of stocked fish may still be achieved. Flexibility in the diet of other species targeted for stocking may allow areas of suitable habitat to be exploited for stock recovery through restocking.

All hatchery-reared mulloway in this study were feeding within 16 d after release. Adaptation to the natural environment by hatchery-reared fish includes learning to recognize, capture, and handle prey. These behavioral traits often develop within 14 d of release, as observed in released cod *Gadus marhua* (Kristiansen and Svåsand 1992). If these are learned traits in mulloway, training of hatchery-reared fish to recognize prey prior to release may encourage feeding sooner after release (e.g., Suboski and Templeton 1989). Potential gape limitations of stocked fish should also be considered when developing stocking strategies. Where there is a lack of small prey like mysids, stocking should coincide with peaks in abundance of early juvenile prawns or similar sized organisms, to ensure stocked fish have access to suitably sized prey. Potential gape limitations and body-size-prey-size relationships need to be investigated further for mulloway.

Information on diet composition and importance form a basis for further assessment of estuarine finfish stocking. The predatory effect of stocked fish on prey species in an ecosystem may be modelled to assist in the estimation of appropriate stocking density. These modelled estimates of consumption would be further supported by in situ daily ration estimates obtained from diet, feeding periodicity, and stomach throughput information (Boisclair and Marchand 1993). Given the success of red drum stocking in Texas (McEachron et al. 1998), similarities in the diet and life history of red drum and mulloway make mulloway a plausible candidate for a similar enhancement program in Australia. While the success of the red drum stocking program in Texas is potentially enhanced by diet flexibility in the species, evaluation of red drum stocking density in terms of dietary requirements may further improve survival of stocked fish and allow identification of predatory effects. Postrelease production of hatchery-reared fish can be estimated by coupling production of mysids, prawns, and forage fish in the ecosystem with mortality, emigration, and consumption rates of stocked fish (Taylor unpublished data). This information will in turn allow the assessment of cost-effectiveness of the stocking endeavor, and associated optimal size-at-release (Leber et al. 2005). This study represents a practical application of ecological experiments in the evaluation and refinement of pilot stocking strategies, as proposed by Blankenship and Leber (1995).

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