Changes to fish assemblages visiting estuarine wetlands following the closure of commercial fishing in Botany Bay, Australia

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*A Before-After, Control-Impact sampling design was used to measure changes in fish assemblages in intertidal mangroves and saltmarsh prior to and following the closure of commercial fishing in the Botany Bay estuary, New South Wales, Australia. Of commercial species found as juveniles in the wetlands, there was a consistent pattern of decrease in numbers compared to the pre-closure surveys. Other small wetland fish (such as the Gobiidae) were also found to have decreased in numbers, with the exception of the Common Toadfish (*Tetractenos hamiltoni *Gray and Richardson, 1843) and the Glassfish (*Ambassis jacksoniensis Macleay, 1881). Results suggest that the immediate response of an estuarine fishery to commercial fishing closure may be a predator-mediated decline in juvenile fish of both prey and predator species.*

Keywords: mangrove, fyke net, saltmarsh, fishing-closure

Introduction

In an open estuary, stochastic variability in recruitment may dominate inter-annual variability in fish stocks. This model would present estuarine fish stocks as density-independent for those species with a pelagic nearshore larval phase. However, the strong relationships between habitat extent and commercial fishing catches in many estuaries in New South Wales (Saintilan, 2004) suggest a degree of density dependence. In these systems, predation and competition may be important controls on community structure (Power, 1987; Wilbur, 1988; Power, 1990).

The closure of an estuary to commercial fishing is an interesting case-study in predator-prey interactions. The immediate change to fish populations following a commercial closure would be a decrease in mortality amongst higher trophic level predators, with no immediate change in recruitment of juveniles. It could be expected that this would place increased predation pressure on prey species, which includes juveniles of commercially important species. Predation contributes significantly to high mortality rates for larval and juvenile fish (Calef, 1973; Morin, 1983; Fuiman, 1994). The contribution to recruitment made by the increased brood stock may not be felt immediately, or directly, for species with an oceanic larval stage.

Upon entering estuaries in south east Australia, juvenile fish congregate in shallow-water habitats on the fringes of estuaries (Mazumder et al., 2005). In the Botany Bay estuary, many juvenile and other small fish move into the mangrove and saltmarsh wetlands of Towra Point during spring high tides (Mazumder et al., 2005) and feed on brachyuran

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larvae and other products of the saltmarsh (Mazumder et al., 2006). A survey using buoyant pop nets demonstrated the importance of these wetlands to a number of commercially important species.

Approximately 60 commercial fishers were reported to be fishing in Botany Bay up until the commercial closure in mid-2002, using prawn trawling, net hauling, mesh netting and fish trapping. Commercial catches were dominated by (in order) *Pseudocaranx dentex, Mugil cephalus, Girella tricuspidata, Acanthopagrus australis, Sillago ciliata, Melicertus plebejus, Anguilla reinhardtii, Platycephalus fuscus and Metapenaeus macleayi.* The annual catch prior to closure was estimated at approximately 220 tonnes (Scribner and Kathuria, 1996). A study of the estuarine wetland fish assemblages therefore provides an insight into the response of juvenile and other prey fish stocks to increased predation pressure created by the closure of commercial fishing.

Methods

Study sites

The study compared temporal variation of nekton catch in mangrove and saltmarsh flats at Towra Point Nature Reserve, in Botany Bay with two reference sites in adjacent estuaries. The Towra Point Nature Reserve (1510 09′04″ E; 340 00′36″ S; Figure 1) is a relatively undisturbed sandy marine delta with mangrove forest dominated by *Avicennia marina* (Forsk.) Vierh. (Mazumder et al., 2005). The lower saltmarsh was dominated by a *Sarcocornia quinqueflora* (Bunge. ex Ung.-Sternb.) / *Sporobolus virginicus* (L.) Kunth, association, (Clarke and Hannon, 1967; Adam et al., 1988).

Allens Creek on the Hawkesbury River at Spencer (1510 06′ 47″ E; 330 27′50″ S) is an example of a tributary delta within the fluvial deltaic segment of the Hawkesbury River estuary. Intertidal soils consist predominantly of silts and clays, and salinities are periodically diluted by freshwater flows (Saintilan, 1997). The saltmarsh assemblage is similar to that of Towra Point, though *S. australis* is absent. *Avicennia marina and Aegiceras corniculatum* ((L.) Blanco) are abundant.

The site at Homebush Bay (1510 09′ 50″ E; 330 50′27″ S) is also a tributary fluvial delta, occurring in the central reaches of the Parramatta River. The mangrove forest is extensive and dominated by A. marina, while the saltmarsh is patchy, and is dominated by *S. quinqueflora, S. virginicus* and the introduced *Juncus acutus* L. (Clarke and Bensen, 1988).

Fish sample collection

Fyke nets (Morton et al., 1987; Williams et al., 1996) were used in the saltmarsh and mangrove wetlands to collect fish. The 4-metre long funnel-shaped fyke nets consisted of one central and two lateral wings and a 40 cm wide and 25 cm high entrance. The fyke nets were placed systematically at 50 metre intervals, facing land to sample nekton during the draining of the ebb-tide. Net location was fixed throughout the pre- and post-closure surveys.

In the pre-closure surveys, four replicate fyke nets were deployed in the saltmarsh and two replicate fyke nets were deployed in the adjacent mangrove flat. In the post-closure surveys, the number of nets deployed in the mangrove was increased to three. Fish were retrieved from the fyke nets following spring tide inundations when the tide water fully receded from the saltmarsh and mangrove. At Towra Point, fish samples were collected every month during the winter months of June, July and August, and the summer months of December, January and February, during both sampling periods (2001/2002 and 2004/2005). Fish samples from the control sites were collected during December, January and August during the same spring tidal cycles sampled at Towra Point, with the exception of December 2004 at Allen's Creek.

Statistical methods

Differences in assemblages of fish between pre and post- fishing closure were examined from the Bray-Curtis measures of dissimilarity (Bray and Curtis, 1957) using square root transformed data. Nonmetric multidimensional scaling (nMDS) plots were also used to demonstrate the patterns of fish assemblages pre and post fishing closure (Clarke and Warwick, 2001). Multivariate techniques such as ANOSIM (Clarke and Warwick, 2001) were used to test the statistical significance of differences between the fish assemblages, pre and post fishing closure. The contribution made by particular species to differences in species assemblages was determined
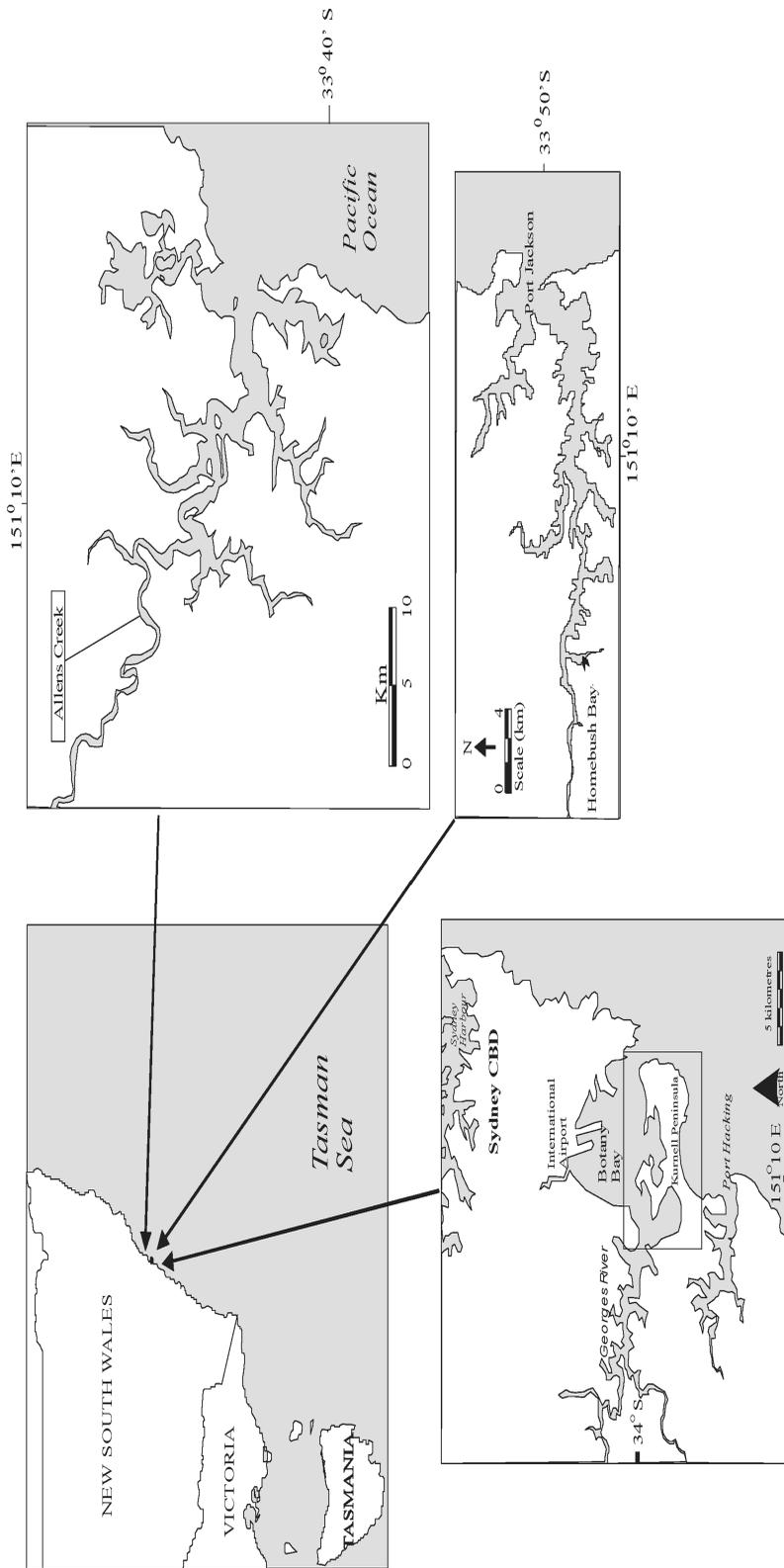
Figure 1. Location of Towra Point and the two reference sites, Allens Creek and Homebush Bay.

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using SIMPER (similarity percentages-species contribution, Clarke and Warwick, 2001).

Results

Towra point

Table 1 shows the total fish catches within the saltmarsh and mangrove for each site, pre and post fishing closure at Botany Bay. At Towra Point, species richness within the wetlands increased from 29 species pre-closure to 33 species post-closure of commercial fishing.

Fish assemblages within the saltmarsh and mangrove forest at Towra Point showed a significant difference pre- and post-closure (ANOSIM P = 0.001 and P = 0.025 respectively). The species contributing most to this difference are listed in Table 2. Within the saltmarsh, a decrease in *Macrobrachium intermedium, Pseudomugil signifier* and *Mugilogobius stigmaticus* and an increase in *A. jacksoniensis* explained 47% of the difference. Within the mangroves, an increase in the abundance of A. jacksoniensis and a decrease in abundance of *M. intermedium, Gobiopterus semivestitus* and *G. subfasciatus* explained 52.5% of the difference.

Average fyke net abundances for selected individual species pre- and post-closure are shown in Figure 2. Overall, within the mangroves and saltmarsh, all species decreased in abundance post-closure, except for *A. jacksoniensis* and *T. hamiltoni.*

Reference sites

Within the saltmarsh and mangrove at Homebush Bay, species richness increased from 22 species pre-closure of commercial fishing, to 24 species post-closure (Table 1). Differences in fish assemblages between pre-closure and post-closure sampling times were detected in the saltmarsh (P = 0.012) and the mangrove (P = 0.002). Within the saltmarsh, an increase in *P. signifer, M. paludis* and *Gambusia holbrooki* accounted for 52% of the difference. Within the mangrove, the species most contributing to this difference was a decrease in *Pseudogobius olorum*, and an increase in *A. jacksoniensis, G. semivestitus and P. signifer*. Together, these changes accounted for over 43% of differences between pre and post-closure assemblages at Homebush Bay.

There was no difference between fish assemblages at Allen's Creek pre- and post-closure in either the saltmarsh (P = 0.23) or the mangrove (P = 0.12). However, samples were limited to three pre and two post-closure sampling occasions.

Discussion

Juveniles of commercially important (predator) species may compete with non-commercial species at the lower-trophic level phase (Werner and Gilliam, 1984; Stein et al., 1988; Polis et al., 1989). In these circumstances, where small non-commercial species co-exist in mangrove wetlands with juvenile predators, small predators may be competitively inferior due to constraints imposed by more dramatic ontogenic shifts in diet over time (Werner and Gilliam, 1984; Persson, 1988). Juveniles may experience high mortality in these life phases, to a degree inversely related to size and ontogeny (Miller et al., 1988; Neill, 1988). One of the major causes of mortality at this stage may be predation (Werner et al., 1983; Wilbur, 1988; Fuiman, 1994).

Predation is therefore an important control on the structure of aquatic communities (Carpenter et al., 1987; Kerfoot and Sih, 1987; Wilbur, 1987; Power, 1990), and this might particularly be the case in estuarine wetlands where small fish congregate. Predators can have direct effects by imposing higher mortality rates, or indirect effects by altering the availability of alternate food sources (Kerfoot and Sih, 1987; Wootton, 1993, 1994). Behavioural effects may also be significant, with a possible increased use of shallow wetlands as predator avoidance.

One model would suggest that the effect of the closure might be to increase the numbers of juveniles of commercially important fish, particularly in the habitats where they congregate; the seagrass, mangrove and saltmarsh wetlands on the southern side of the bay. Fortuitously, we measured these populations between 2001 and 2002, and it was this assumption that prompted the repeat of the surveys in 2004–2005.

Only three species of commercial importance were observed to have increased in numbers in the 2004–2005 survey, and all were found as adults: pike eel (a single specimen of 7 kg), squid, and school prawns. Of commercial species found as juveniles in the wetlands, there was a consistent pattern of decease in numbers compared to the pre-closure surveys. Other small wetland fish (such as the Gobiidae) were also found to have decreased in numbers, with the exception of *T. hamiltoni* and *A. jacksoniensis.*

Table 1. Number of individuals caught from mangrove and saltmarsh using fyke nets at Towra Point, Homebush Bay and Allen's Creek, pre and post fishing closure at Botany Bay. The asterisk (*) designates species of commercial and/or recreational significance.

Family	Genus/ Species/ Authority	Common name	Towra Point Saltmarsh Pre	Post	Mangrove Pre	Post	Allens Creek Saltmarsh Pre	Post	Mangrove Pre	Post	Homebush Bay Saltmarsh Pre	Post	Mangrove Pre	Post
Fish														
Anguillidae	*Anguilla reinhardtii* Steindachner, 1867	Long-finned eel	0	0	0	1	0	0	0	2	0	0	0	0
Atherinidae	*Pseudomugil signifier* Kner, 1866	Blue eye	357	193	32	9	53	14	2	49	46	68	32	65
Chandidae	*Ambassis jacksoniensis* Macleay, 1881	Glassfish	108	1097	398	412	14	5	4	10	0	5	10	91
Eleotridae	*Gobimorphus australis* Krefft, 1864	Striped gudgeon	0	0	0	0	0	0	11	0	0	0	0	0
Gerreidae	*Gerres subfasciatus* Curvier, 1830	Silver biddy *	109	12	124	15	0	0	0	0	0	0	10	0
Gobiidae	*Arenigobius bifrenatus* Kner 1865	Bridled goby	0	0	1	0	0	0	0	0	0	0	4	0
	Butis amboinensis Bleeker, 1853	Flathead gudgeon	0	0	0	0	0	0	0	0	0	0	6	0
	Gobiopterus semivestitus Munro, 1949	Glass goby	49	4	57	2	453	10	17	2	9	5	13	71
	Mugilogobius paludis Whitely, 1930	Mangrove goby	12	33	7	11	2	2	8	3	20	37	30	15
	Mugilogobius stigmaticus De Vis, 1884	Checkered mangrove goby	78	24	9	10	22	2	7	1	0	37	14	9
	Pseudogobius olorum Sauvage, 1880	Blue spot goby	78	2	24	6	6	0	0	2	17	25	191	7
	Redigobius macrostoma Günther, 1861	Largemouth goby	0	0	0	0	0	0	3	0	0	0	0	0
	Taenioides mordax De Vis, 1883	Snake head goby	0	0	0	0	0	0	0	2	0	0	0	0

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Table 1. Number of individuals caught from mangrove and saltmarsh using fyke nets at Towra Point, Homebush Bay and Allen's Creek, pre and post fishing closure at Botany Bay. The asterisk (*) designates species of commercial and/or recreational significance. *(Continued)*

Family	Genus/ Species/ Authority	Common name	Towra Point Saltmarsh Pre	Post	Mangrove Pre	Post	Allens Creek Saltmarsh Pre	Post	Mangrove Pre	Post	Homebush Bay Saltmarsh Pre	Post	Mangrove Pre	Post
Mugilidae	*Liza argenta* Quoy and Gaimard, 1825	Flat tail mullet *	12	38	2	4	19	0	2	21	0	0	11	19
	Mugil cephalus Linnaeus, 1758	Sea mullet *	0	61	0	0	0	0	0	8	0	0	0	0
	Myxus elongates Günther, 1861	Sand mullet *	37	3	28	1	4	0	0	0	0	0	0	3
Platycephalidae	*Platycephalus fuscus* Cuvier, 1829	Dusky flathead *	35	4	0	0	15	0	1	0	0	3	10	0
Poeciliidae	*Gambusia holbrooki* Girard, 1859	Mosquito fish	14	0	0	0	0	0	0	0	0	37	56	10
Sillaginidae	*Sillago cliiata* Curvier, 1829	Sand whiting *	6	2	13	7	0	0	0	0	0	0	0	1
Sparidae	*Acanthopagrus australis* Günther, 1859	Yellow fin bream *	60	28	25	21	7	0	0	0	0	0	5	0
	Rhabdosargus sarba Forsskål, 1775	Tarwhine *	0	0	0	0	0	0	0	0	0	0	5	0
Tetraodontidae	*Tetractenos hamiltoni* Gray and Richardson, 1843	Common toad	17	73	0	7	0	1	0	14	0	0	0	26
Crustacean Atyidae	*Macrobrachium intermedium* Stimpson, 1860	Grass shrimp	218	178	133	27	68	22	24	86	3	4	20	33
Penaeidae	*Metapenaeus macleayi* Haswell, 1879	School prawn *	18	33	0	6	10	2	0	64	0	0	0	8
Portunidae	*Scylla serrata* Forsskal, 1775	Mud Crab	0	0	0	0	0	0	0	0	0	0	0	2
	16	17 Total no. of species	13	16	12	8	10	13	6	9	16	15	0	2

Table 2. SIMPER output showing the contribution of species to the differences in fish assemblages pre and post-closure in the Towra Point saltmarsh and mangrove. Fish are listed in order of their contribution to the differences in fish assemblages.

Species	Av. abundance pre-closure	Av. abundance post-closure	Cumulative % contribution to dissimilarity
Saltmarsh			
Macrobrachium intermedium	11.70	15.82	14.45
Pseudomugil signifer	6.73	17.21	27.36
Ambassis jacksoniensis	38.20	8.64	40.09
Mugilogobius stigmaticus	0.93	4.46	46.94
Gerres subfasciatus	0.40	4.64	53.37
Gobiopterus semivestitus	0.33	3.14	59.66
Acanthopagrus australis	1.03	2.89	65.46
Platycephalus fuscus	0.13	2.21	70.64
Metapenaeus macleayi	1.20	1.21	75.61
Myxus elongatus	2.20	1.79	80.47
Tetractenos hamiltoni	2.57	0.54	85.26
Liza argenta	1.53	0.61	89.69
Mugilogobius paludis	1.33	0.14	93.43
Mangrove			
Ambassis jacksoniensis	31.35	26.87	22.72
Macrobrachium intermedium	1.59	18.27	36.02
Gobiopterus semivestitus	0.12	5.27	44.33
Gerres subfasciatus	0.88	8.87	52.53
Mugilogobius stigmaticus	0.88	2.20	59.50
Pseudomugil signifer	1.00	3.33	66.26
Acanthopagrus australis	1.41	2.00	72.61
Mugilogobius paludis	0.76	1.07	77.23
Myxus elongatus	0.06	1.80	80.24
Tetractenos hamiltoni	0.41	0.33	83.22
Pseudogobius olorum	0.59	1.13	86.06
Liza argenta	0.29	0.33	91.32

There are two possible interpretations of this result. One is that the change reflects inter-annual variability relating to patterns of recruitment into the bay. The vast majority of estuarine nekton have a nearshore oceanic larval stage, and it is this life-history stage that is key to determining year class strength. This hypothesis is supported by the results from the Homebush Bay reference site, where increases in glassfish and toadfish were also observed, along with a decrease in yellowfin bream. However, replication at this site was lower than at Towra Point. Further monitoring would be required to determine whether the marked and consistent change detected is within the range of normal variability over this timescale.

A second explanation considers the expected consequences of closing the commercial fishery. The immediate change on demographic structure of commercially harvested fish would be an increase in the adult population before any change in the juvenile cohorts. A larger adult population would place significant predation pressure on smaller fish, both commercial and non-commercially important. Connell (1998) found low rates of mortality on a species of reef fish where large predatory fish were excluded, with the magnitude of difference between caged and uncaged sites reflecting differences between locations of low and high predator density respectively.

The exception would be those fish not known to be prey of adult fish, such as *Tetractenos hamiltoni,* which produces a powerful neurotoxin. Such a model fits the data presented in this survey. *T. hamiltoni* were also observed to feed on *A. jacksoniensis*, which showed greater abundance in the post-closure survey. These two species were found also to increase at the Homebush Bay control site,
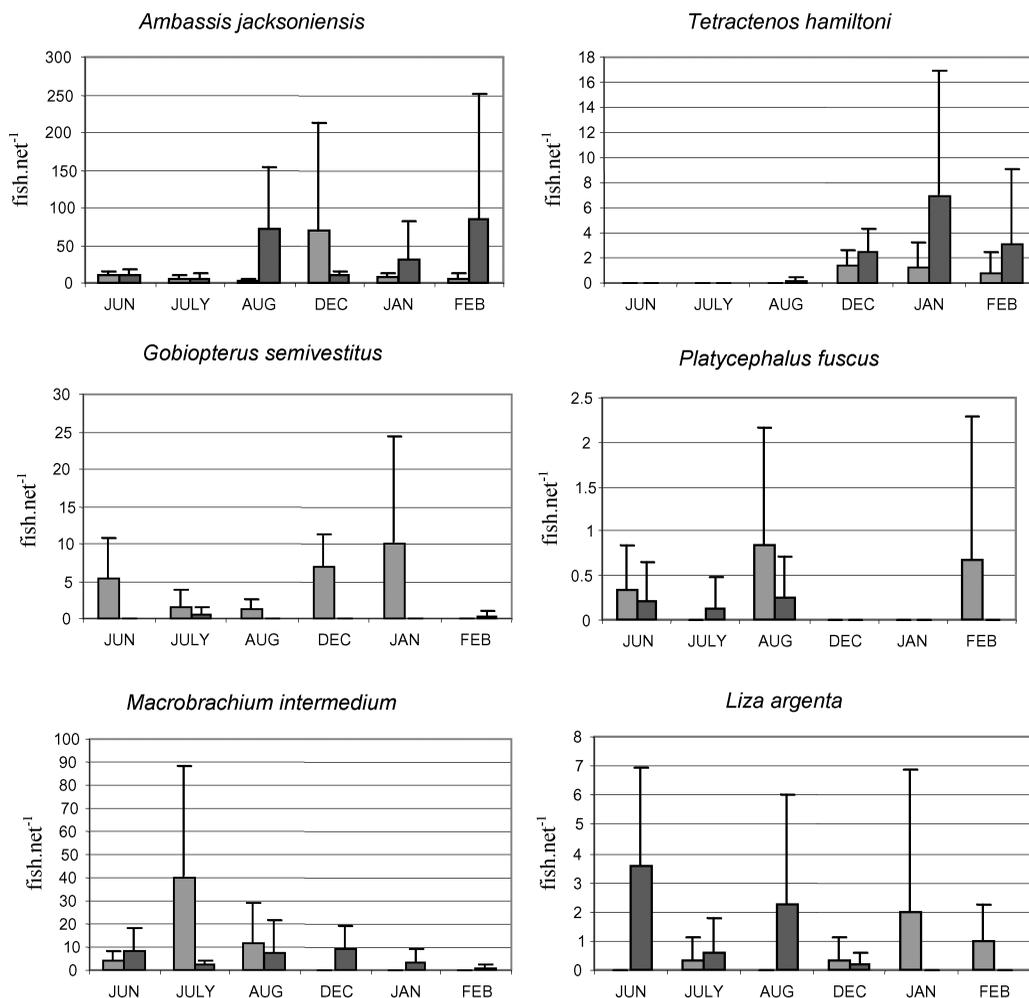
Figure 2. Pre and post-closure catches of the various fish and crustacean species at Towra Point wetlands (mean and standard deviation). Light shade = Pre-closure, dark shade = Post-closure.

which may suggest regionally favourable conditions for recruitment and growth over the period.

This does not mean that adult stocks would be expected to decline, because recruitment into the adult population is likely to be enhanced in the absence of commercial fishing pressure, and the proportional declines observed were not large for any species. Though there may be a lower number of juveniles, they may be more likely to become large adult fish once they cease to be effective prey, now that commercial fishing has ceased.

Conclusions

The closure of selected estuaries to commercial fishing in New South Wales over recent years has been implemented to relieve pressure on wild fish stocks and improve the prospects of recreational fishers. The assumption is that the closure of a fishery will lead to a greater abundance of commercially-targeted fish species. This research has provided a cautionary note. The relationships between fish abundance within an estuary, recruitment of juveniles from the nearshore environment, and competitive and predatory interactions between fish within an estuary are complex. Initial survey results have suggested an initial decline in the availability of juveniles of commercially important fish in the "nursery" shallow-water habitats of one estuary closed to commercial fishing, possibly due to an increase in predation by larger fish.

Acknowledgements

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