RANGE EXTENSIONS FOR FOUR ESTUARINE GOBIES (PISCES: GOBIIDAE) IN SOUTHERN AUSTRALIA: HISTORICALLY OVERLOOKED NATIVE TAXA OR RECENT ARRIVALS?

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Summary

Targeted sampling for gobiid fishes in the Port River estuarine system adjacent to Adelaide, South Australia, identified four previously unrecorded species. Significant range extensions along the east-west coastline of southern Australia are reported for the Australian endemic flatback mangrove goby *Mugilogobius platynotus* (Günther, 1861), largemouth goby *Redigobius macrostoma* (Günther, 1861) and Krefft’s frill goby *Bathygobius kreffti* (Steindachner, 1866) plus the alien Trident goby *Tridentiger trigonocephalus* (Gill, 1859). Moreover, *M. platynotus, R. macrostoma* and *T. trigonocephalus* are new records to the fish fauna of the state of South Australia. While it is clear that *T. trigonocephalus* has invaded another southern Australian port, there is difficulty in determining the status of the three Australian endemics as being either native to the area or recent introductions (e.g. through ship mediated translocation) due to a previous paucity of sampling and the cryptic nature of goby behaviour that may have prevented historic detection. The long-term existence of suitable habitat on the one hand suggests that these populations are naturally occurring in the Port River. However, a drastically altered estuarine environment, the high incidence of other translocated marine organisms in the system and goby biological traits suiting transportation in ship ballasts or hull fouling conversely casts doubts over their origin. Contrasting management scenarios of conservation versus potential eradication for these newly discovered species highlights a dilemma for biodiversity conservation in an altered environment.

KEY WORDS: Aquatic biodiversity, environmental change, Gobiidae, marine bioinvasion

Introduction

Small cryptic fishes such as gobies (Family Gobiidae, >1,500 species occurring almost globally: Hoese 1998) are not infrequently encountered in ballast water and as exotics established in world ports (Wonham et al. 2000). Introductions of these fishes represent an increasing ecological problem in areas such as southern Australia where three oriental species, the yellowfin goby *Acanthogobius flavimanus*, striped sand goby *Acentrogobius pflaumii* and Trident goby *Tridentiger trigonocephalus* are established in ports within or nearby major cities (Pollard & Hutchings 1990; Hoese & Larson 1994; Lockett & Gomon 2001). There is also obvious potential for the transportation of local species over shorter distances (e.g. Middleton 1982; Willis et al. 1999; Francis et al. 2003), posing genetic risks such as introgression and swamping of distinct units (Avise 2004) in addition to ecological threats (e.g. Corkum et al. 2004).

Although several new gobiid arrivals have been documented for temperate southern Australia, the natural baseline of native species distributions remains poorly documented. The fauna comprises small species (generally <100mm) which typically exhibit cryptic behaviour, often occur in habitats rarely sampled for fishes (e.g. unappealing muddy areas, structurally complex habitat), and have no direct commercial value. Collectively these factors tend to inhibit the gathering of detailed information regarding the spatial occurrence of many gobies (i.e. range, distribution, abundance and habitat), particularly for species in the state of South Australia (Scott et al. 1974; Kuiter 1993; Hoese & Larson 1994). Nevertheless, such information is vital to our understanding of the overall biological diversity, ecology and biogeography of marine and estuarine systems (Irish & Norse 1996), especially as gobies are often reported as significant components of fish communities in shallow near-shore areas exposed to anthropogenic impacts (e.g. Bell et al. 1984; Hoese 1991; Gill & Potter 1993; Clynick & Chapman 2002).
The Port River estuary is a prominent system in southern Australia both in terms of its size and habitat, and due to its development as a shipping port servicing the major city of Adelaide (population over one million people). A host of exotic species have been translocated to the estuary, most likely due to shipping, including Sabellid fan worm *Sabella spallanzanii*, European shore crab *Carcinus maenas*, New Zealand screw shell *Maoricolpus roseus*, the bryozoan *Bugula flabellata* and the red alga *Polysiphonia brodiaei* (Furlani 1996). Previous studies have examined the fish fauna of the estuary (Connolly 1994; Jones et al. 1996; Connolly et al. 1997; Jackson & Jones 1999); however, these concentrated on species with commercial value and sampled only a few of the different macro and micro-habitats in the system. This study was designed to broaden the scope of sampling in the Port River estuary to help elucidate the true species richness of the local gobiid community.

This study details significant range extensions for four gobies, and provides an initial assessment of their spatial occurrence, ecology and conservation status.

**Methods**

**Study region**

The Port River/Barker Inlet system is a c.100 km² temperate zone estuary in St Vincent Gulf adjacent to the Adelaide Plains, South Australia (34°48´S, 138°32´E), and central to the Flindersian Biogeographical Province (Bennett & Pope 1953). As is typical with many estuaries of the world, significant physical and chemical alterations have occurred (Kraehenbuehl 1996; Edyvane 1999; Wade 2002), with particular hydrological changes including the diversion of the major natural freshwater input (River Torrens) and warm-water discharge from the Torrens Island power station (Thomas et al. 1986). Remaining habitat is highly modified, especially in the upper reaches of the system which comprises shipping docks, rock levees, cement embankments (e.g. West Lakes) and small patches of mudflats supporting grey mangrove *Avicennia marina*.

**Sampling**

Targeted non-destructive sampling using dip-nets (400 mm² frame, 3mm stretch mesh) investigated areas of high structural integrity, such as artificial vertical surfaces (e.g. cement walls), crevices and rock banks. Sampling was from shore and by wading at sites accessible by road, with a site covering a 30m stretch of bank. Two supplementary techniques were also employed: at night specimens could be observed under torchlight and coerced into one of two dip nets used in unison, and at low tide the turning of rocks in some cases revealed specimens for hand capture or with small aquarium nets. Sampling was designed to cover a range of daily and seasonal conditions such as tide height and diurnal phase (day or night) and to record specific characteristics of captured species habitat and ecology. Some laboratory observations using aquaria were also undertaken. Equipment was sterilised (dilute bleach solution and sun-drying) between use in different parts of the Port River system. Representative vouchers were euthanased, then fixed in 10% formalin, and subsequently transferred to 70% ethanol and lodged at the South Australian Museum, Adelaide (SAMA). Identification followed the keys of Hoese & Larson (1994) and incorporates subsequent updates in nomenclature (Larson 2001; Larson & Murdy 2001). Fish lengths are given in Total Length (TL) for live specimens to be consistent with Hoese & Larson (1994) and in Standard Length (SL) taken from preserved material.
Table 1 Relative abundance of goby species sampled at 17 sites in the upper Port River estuary between March 2001 and February 2004. [Conditions: night (N) or day (D), tide height low (L), med. (M) or high (H) - note water levels are relatively constant in West Lakes. Habitat: rock pile (RP), vertical wall (VW)] * Introduced to Australia

| Location          | Site/habitat      | Date/conditions | Acentrogobius bifrenatus (Kner, 1865) | Afrogobius tamarensis (Johnston, 1883) | Bathygobius krefftii (Steindachner, 1866) | Callogobius mucosus (Günther, 1872) | Favonigobius lateralis (Macleay, 1881) | Gobiopterus semivestita (Munro, 1949) | Magnogobius platymunos (Günther, 1881) | Pseudogobius olorum (Sauvage, 1880) | Redigobius macrostoma (Günther, 1881) | Tridentiger trigonocephalus (Gill, 1859) |
|-------------------|-------------------|-----------------|--------------------------------------|----------------------------------------|----------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| North Arm         | 1 RP, mangroves   | 20/09/03 N, M   | 3                                    | 20                                    | 25                                    | 100                                  | 3                                    | 100                                  | 5                                    | 35                                  | 15                                    |                                      |
|                   |                   | 30/10/03 N, H   |                                      |                                        |                                        |                                      |                                      |                                      |                                      |                                      |                                      |                                      |
|                   |                   | 06/11/03 D, L   |                                      |                                        |                                        |                                      |                                      |                                      |                                      |                                        |                                      |
|                   | 2 RP, mangroves   | 05/08/03 N, H   |                                      |                                        |                                        |                                      |                                      |                                      |                                      |                                        |                                      |
|                   |                   | 08/08/03 N, L   | 3                                    | 5                                      | 15                                    | 30                                   | 5                                    | 3                                    |                                      |                                      |                                      |
|                   | 3 Rocks           | 06/11/03 D, L   |                                      |                                        |                                        |                                      |                                      |                                      |                                      |                                      |                                      |
| Angas Inlet       | 4 RP              | 05/08/03 N, H   |                                      |                                        |                                        |                                      |                                      |                                      |                                      |                                        |                                      |
|                   |                   | 08/08/03 N, L   | 3                                    | 5                                      | 15                                    | 30                                   | 5                                    | 3                                    |                                      |                                      |                                      |
|                   |                   | 06/11/03 D, L   |                                      |                                        |                                        |                                      |                                      |                                      |                                      |                                        |                                      |
|                   | 5 VW, rocks       | 06/11/03 D, L   |                                      |                                        |                                        |                                      |                                      |                                      |                                      |                                        |                                      |
| Port River        | 6 Rock pools      | 06/11/03 D, L   |                                      |                                        |                                        |                                      |                                      |                                      |                                      |                                        |                                      |
| Old Port Reach    | 7 RP              | 06/11/03 D, L   | 15                                   | 1                                      | 3                                    | 28                                   |                                      |                                      |                                      |                                        |                                      |
|                   | 8 Mangroves       | 21/10/01 N, M   | 3                                    | 7                                      | 100                                   | 5                                    |                                      |                                      |                                      |                                        |                                      |
|                   |                   | 30/07/03 N, H   |                                      |                                        |                                        |                                      |                                      |                                      |                                      |                                        |                                      |
| West Lakes        | 9 RP and VW       | 21/10/01 N      | 10                                   | 2                                      |                                      | 50                                   |                                      |                                      |                                      |                                        |                                      |
|                   | 10 VW, rocks at base | 01/03/01 D    | 15                                   |                                        |                                       | 8                                    | 12                                   | 1                                    |                                      |                                        |                                      |
|                   |                   | 21/10/01 N      |                                      |                                        |                                       | 10                                   | 4                                    |                                      |                                      |                                        |                                      |
|                   |                   | 10/01/04 D      | 100                                   | 3                                      | 13                                    | 10                                   | 1                                    |                                      |                                      |                                        |                                      |
|                   | 11 RP and VW      | 30/07/03 N      |                                      |                                        |                                        | 5                                    | 1                                    |                                      |                                      |                                        |                                      |
|                   | 12 VW             | 10/02/03 D      | 3                                    |                                        |                                        | 3                                    | 12                                   |                                      |                                      |                                        |                                      |
|                   |                   | 30/07/03 N      |                                      |                                        |                                        | 10                                   | 3                                    |                                      |                                      |                                        |                                      |
|                   | 13 VW, seagrass bed | 28/02/04 D      | 8                                    | 1                                      | 35                                   | 40                                   |                                      |                                      |                                      |                                        |                                      |
|                   | 14 RP             | 10/02/03 N      | 1                                    | 4                                      | 12                                   | 2                                    |                                      |                                      |                                      |                                        |                                      |
|                   | 15 VW             | 10/02/03 N      |                                      |                                        |                                       | 1                                    | 5                                    |                                      |                                      |                                        |                                      |
|                   | 16 VW             | 21/10/01 N      | 5                                    | 1                                      | 5                                    | 2                                    |                                      |                                      |                                      |                                        |                                      |
|                   |                   | 29/07/03 N      | 2                                    | 2                                      | 10                                   | 4                                    |                                      |                                      |                                      |                                        |                                      |
|                   |                   | 05/08/03 N      |                                      |                                        |                                       | 7                                    | 4                                    |                                      |                                      |                                        |                                      |
|                   |                   | 01/02/04 D      | 10                                   |                                      | 32                                   | 1                                    |                                      |                                      |                                      |                                        |                                      |
|                   | 17 VW             | 29/07/03 N      |                                      |                                        |                                        | 14                                   |                                      |                                      |                                      |                                        |                                      |
|                   |                   | 03/08/03 D      | 1                                    |                                        |                                       | 5                                    | 4                                    |                                      |                                      |                                        |                                      |
|                   |                   | 05/08/03 N      |                                      |                                        |                                       | 14                                   |                                      |                                      |                                      |                                        |                                      |
|                   |                   | 24/12/03 N      | 2                                    | 1                                      | 25                                   |                                      |                                      |                                      |                                      |                                        |                                      |
|                   |                   | 01/02/04 D      | 5                                    | 2                                      | 28                                   |                                      |                                      |                                      |                                      |                                        |                                      |
Results

Sampling for gobies was undertaken at 17 sites in the upper sections of the Port River between March 2001 and February 2004 (Fig. 1). Ten goby species were located in or near the targeted habitat (Table 1). There was considerable variation in the detection of goby species interrelating between habitat, environmental conditions (e.g. tidal height) and time of day, and broader temporal replication at sites often revealed contrasting catches (Table 1).

Figure 1 Map showing the location of goby sampling sites in the upper Port River estuary within urban Adelaide, South Australia. PS = Torrens Island Power Station; stars indicate Tridentiger trigonocephalus capture locations.
Range extensions

Four species previously unknown from the Port River were collected. These included three additions to the known fish fauna of the state of South Australia: (a) flatback mangrove goby *Mugilogobius platynotus* collected at three sites in the upper Port River (Table 1; SAMA F10130, 10132, 10133), representing a range extension of some 1000km westward along Australia’s southern coastline (Larson 2001); (b) largemouth goby *Redigobius macrostoma* collected from nine of ten sites in West Lakes (Table 1; SAMA F10137, 10138, 10312), representing a westerly range extension from the Glenelg River of approximately 550 km (Kuiter 1993; Hoese & Larson 1994), and (c) *T. trigonocephalus* collected from two sites in West Lakes (Table 1; SAMA F10134, F10141), a species otherwise native to the north-west Pacific and now known from the immediate vicinity of all capital cities (major shipping ports) on the coastline of mainland southern Australia (Hoese 1973; Chubb *et al.* 1979; Gill & Potter 1993; Lockett & Gomon 2001). The fourth new Port River record, Krefft’s frill goby *Bathygobius krefftii*, collected from one site in West Lakes (Table 1; SAMA F10142) extends the range of this species by 440 km to the east (by sea) to include St Vincent Gulf as a second distinct western population within a broader disjunct distribution – the species is also known from upper Spencer Gulf, South Australia (recent presence confirmed by the author at Whyalla Marina: SAMA F10453) and the east coast of Australia (Kuiter 1993; Hoese & Larson 1994).

Habitat

Field data suggest that the occupied habitat of the four newly recorded gobies is quite specific. Between and within site observations indicate that the distribution of *M. platynotus* is patchy and related to select microhabitat of sheltered intertidal rock piles over silty mud (as opposed to coarse sand) within or near mangrove stands. Here they were sympatric with western bluespot goby *Pseudogobius olorum* at low tide located in moist depressions under rocks, and with additional species when habitats were immersed, mainly the pelagic smallmouth hardyhead *Atherinosoma microstoma* and glass goby *Gobioperus seminvesitita*, and the benthic southern longfin goby *Favonigobius lateralis* and bridled goby *Acentrogobius bifrenatus*.

*Redigobius macrostoma* was located almost exclusively at vertical algal and mussel covered surfaces (particularly at night), occasionally being caught at weedy and rocky areas nearby (more so during the day). Removal and vigorous shaking of groups of mussels from vertical surfaces often released fish from within cavities or dead shells. At the southern end of West Lakes (Site 13b) specimens (mostly juveniles) were netted from a *Zostera* seagrass bed. *Redigobius macrostoma* and oyster blenny *Omobranchus anolius* were generally the exclusive inhabitants of vertical surface microhabitats with other sympatric species such as *P. olorum*, *A. bifrenatus*, and Tamar River goby *Afurcagobius tamarensis* captured from nearer to the benthos. *Bathygobius krefftii* and *T. trigonocephalus* occupied structurally complex habitat such as rocks and clumps of dead mussels.

Population status

The relative abundance of *M. platynotus* was typically low with up to 13 individuals located in a 30m stretch of bank (usually five or less). The total length of 32 fish sampled ranged from a 21 mm juvenile to a 74 mm TL adult male (16-59 mm SL) and a number were larger than the reported 60 mm TL maximum size for the species (Hoese & Larson 1994). The fore-mentioned adult male displayed nuptial colours and was located under an exposed rock at Site 4 beside a 59 mm TL (48 mm SL) female with distended abdomen on 6/xi/03, suggesting that breeding was imminent (SAMA F10131).

*Redigobius macrostoma* was more common within its restricted range (total of 215 captured) with up to 40 fish (often >10) captured at a site and higher catches in greater water depths (i.e. increased vertical surface). Population size-structure was evident with fish ranging between 22-50 mm TL (17-41 mm SL) and this indication of recruitment was matched with observations of local reproduction. Ripe fish were captured in early August 2003 through to February 2004 (some
transferred to an aquarium spawned in a rock cave, within four days at approximately 22°C whereby the male guarded the eggs). In December 2003 two natural spawning sites were discovered (Site 16). Adult male fish displaying distinct enlarged mouths (~40-50 mm TL) were found inside dead mussel shells guarding patches of eggs. One patch preserved and examined (SAMA F10136) covered an area of ~13 cm² (in the order of 3000-3500 eggs) in two roughly symmetrical patches on either shell half. The semi-transparent eggs were cylindrical, adhesive at one end and just over 1mm in length. Observations on the behaviour of *R. macrostoma* larvae were made following the transerral of an egg patch to the laboratory (maintained at room temperature; 18-22°C, and with artificial aeration): 2-3 mm larvae hatched after six days and swam with difficulty throughout the water column, often resting against surfaces.

Both *T. trigonocephalus* and *B. krefftii* were apparently rare in the habitats sampled (i.e. 3 and 2 captured respectively). Records for *T. trigonocephalus* spanning the three year sampling program suggest it is persistent in its small area of occupancy with adult and sub-adult specimens caught: 37 mm TL (29 mm SL), 52 mm TL (43 mm SL) and 80 mm TL (voucher not retained for SL). The two *B. krefftii* were adults (56 and 50 mm TL; 46 and 39 mm SL) with the smaller specimen a ripe female.

**Discussion**

The discovery of three species new to South Australia at a location adjacent to the state capital city shows that the ichthyofauna of near-shore environments in the region is poorly understood. It is clear that targeted, temporally replicated and intensive sampling of different microhabitats is necessary for confidence in regional species lists, especially for diminutive and cryptic species such as gobies.

The gobiid community of the Port River estuary is species-rich by southern Australian standards (cf. Potter & Hyndes 1999). Evidence of both the reproduction and recruitment of *M. platynotus* and *R. macrostoma* indicates that these species are well established in suitable habitats of the upper Port River. Conversely *B. krefftii* and *T. trigonocephalus* do not appear to be widespread or in high abundance. It is clear that *T. trigonocephalus* is an introduced species which almost certainly arrived via international and/or domestic ships. However, determining whether *M. platynotus*, *R. macrostoma* and *B. krefftii* were present prior to the arrival of Europeans is less certain and more complex, with a resolution on their native or introduced status currently unknown due to evidence consistent with both scenarios (explored below).

The restricted distribution, cryptic behaviour and micro-habitat noted for the three species may have prevented their previous detection as collections from littoral areas of high structural integrity do not appear in the literature (Connolly 1994; Jones *et al.* 1996; Connolly *et al.* 1997; Jackson & Jones 1999) or in institutions that maintain historical voucher specimens such as SAMA (note however, that a single *M. platynotus* was captured during a concurrent research program that targeted varied microhabitats in the Port River system: Bloomfield & Gillanders 2005). Hence the available survey coverage is inadequate for determining historic presence or absence.

The current study supports observations that two of the species are habitat specialists, with *M. platynotus* occurring in areas with mangroves and *R. macrostoma* preferring vertical structure and rocky areas in estuaries (Kuiter 1993; Hoese & Larson 1994; Larson 2001). These habitats are limited in southern Australia. Mangrove habitat east of the Port River is absent coastal until southern New South Wales, with the exception of one small patch in Western Port, Victoria (Butler *et al.* 1977; Busby & Bridgewater 1986), and the few estuaries are widely separated by exposed, high-energy coastlines, particularly west of the Glenelg River. For *B. krefftii* its broader distribution matches relictual subtropical distribution patterns for other marine fauna such as the tiger pipefish *Filigampus tigris* (Kuiter & Debelius 2000), blue swimmer crab *Portunus pelagicus* (Bryars & Adams 1999) and numerous molluscs (K. Gowlett-Holmes, CSIRO Marine Research, pers. comm. 2004), as well as a highly divergent northern lineage of the sea-star *Coscinasterias muricate*.
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(Waters & Roy 2003). Hence, outlying natural goby populations in the Port River could be explained by the long-term existence of suitable habitat.

A natural presence in the region may also be explained by occasional or episodic marine dispersal of larval or adult gobies to the Port River/St Vincent Gulf. This is documented along the east coast of Australia and northern New Zealand where ephemeral populations of tropical and subtropical fish species have been reported to range southward to temperate areas (Kuiter 1993; Francis et al. 1999).

An alternate explanation for recent detection could be the result of human mediated translocation from shipping (i.e. *M. platynotus* and *R. macrostoma* as recent arrivals from the east and *B. krefftii* from the east and/or Spencer Gulf). A precedent exists for such introductions given the array of exotic biota in the Port River system (Furlani 1996), which notably is also now known to include an introduced goby, *T. trigonocephalus*. The species in question also have biological traits suited to transportation via ship ballasts or hull fouling. Wonham et al. (2000) matched the crevicolous nature of gobies with entry through ballast-intake holes on ships, and judging from the occupied habitat of *R. macrostoma* and *M. platynotus* in South Australia, both actively seek refuge and spawning sites in confined spaces. Observations on the small size and behaviour of *R. macrostoma* larvae are consistent with them being pelagic (Hoese 1998) and thus entrapment with ballast intake could easily occur (Carlton & Geller 1993). Moreover, *R. macrostoma* is known to occur in close proximity to ships (i.e. pylons in harbours: Kuiter 1993) and appears to have an affinity for hull fouling organisms such as mussels.

The physically altered Port River environs appear suitable for colonisation of newly arrived gobies. For example warm water discharge from the Torrens Island Power Station may provide conditions to sustain subtropical species though winter (a warm water plume can extend from Angas Inlet, through the North Arm and on to the Port River: Thomas et al. 1986). Similarly, artificial structure such as rock piles and debris common to the area provides structural habitat for colonisation. Nonetheless, *R. macrostoma* and *B. krefftii* populations in West Lakes may be relics from former seagrass/mangrove habitat prior to development (Kraehenbuehl 1996), and imported man-made rock piles may provide alternate habitat for *M. platynotus* offsetting habitat loss (e.g. mangrove clearance, channel deepening, swamp reclamation). Other altered and artificially maintained habitat nearby in the lower River Murray is known to provide refuge for rare or threatened native fishes (Wedderburn & Hammer 2003).

The dilemma over the status of gobies in the Port River highlights a problem concerning species origin that is going to be increasingly difficult to answer in areas where faunas are poorly catalogued, loss of habitat continues and where increasing number of species introductions occur. Further assessment of the status of Port River gobies would be assisted by examination of genetic and morphological variation (Hickley et al. 2004) and potentially by sampling other regional estuaries not frequented by ships. The examination of preserved material after extirpation will however, do little to protect unique lineages or even discrete species adapted to local conditions, and hence the three Australian endemic gobies should best be treated as species native to the Port River until evidence to the contrary is provided.

In principle, management decisions will differ significantly depending upon whether these gobies are indigenous or recently-translocated, since the former would involve measures for species conservation whereas the latter would address eradication. This notion has practical significance given populations in the Port River appear to be restricted, leaving them vulnerable to extirpation (e.g. fish kills, further habitat loss, treatment methods to control introduced organisms). Vigilance is required with respect to the population dynamics and ecological impact of *T. trigonocephalus* and other potential piscine invaders, especially *A. flavimanus* and *A. pflaumi* that are already established elsewhere in southern Australia.
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