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BRACHIDONTES STRIATULUS (BIVALVIA: MYTILIDAE) INTRODUCED INTO SINGAPORE

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***ABSTRACT.* –** *Brachidontes striatulus* (Hanley) is reported for the first time from Singapore. This highly variable species from India was found either in monospecific byssus aggregates or nestled amongst the byssal mats of another invasive species, *Mytilopsis sallei*, in tidal monsoon drains. Densities of up to 75 individuals.100cm^{-2} were recorded in salinities ranging between 12 and 20‰. Size-frequency relationships of live and dead shells suggested that the mussel has established itself recently and is likely to spread.

***KEY WORDS.* –** Singapore, India, mussel, fouling, *Brachidontes*, Mytilidae.

INTRODUCTION

Brachidontes striatulus (Hanley, 1843) was first identified as an important fouling organism in 1969 (Krishnamoorthi & Rajagopalan, 1969) when it extensively fouled the Paltra and Baranagar–Kamarhati Waterworks in West Bengal, India. The species was studied in detail in 1975 (Morton, 1979), both in terms of its anatomy and basic physiology. It was shown, for example, to have a filtration rate that was maximal at salinities of between 7-11‰ and near zero in freshwater and at 18‰. *B. striatulus* is thus an estuarine species that is widespread in the docks of Calcutta (Morton, 1979), and Cochin Harbour (Cheriyan, 1969). The collections of the Zoological Survey of India also contain specimens from the Irawadi, Rangoon, Burma, and from Lake Chilka, Orissa State, India (Morton, 1979). The species has been studied in Lake Chilka (Annandale & Kemp, 1916) where six other "species" of "*Modiola*" have been similarly identified, but all of which were considered to represent but ecomorphs of *M. striatulus*, including *M. emarginata* (Benson MS.), Reeve, 1858, and placed into junior synonymy (Annandale & Kemp, 1916). These authors were also responsible for suggesting that *B. striatulus* has been recorded from Singapore but this claim has not been substantiated.

In July 2001, a survey was made of canals and hard shorelines in Singapore for the presence of *Mytilopsis sallei* (Récluz, 1849) (Dreissenoidea) (Tan & Morton, 2006). At one site (Rochor Canal), several specimens of a mytilid bivalve hitherto unrecorded from Singapore (Chai, 1966; Morris & Purchon, 1981; Tan & Chou, 2000), were collected together with *M. sallei*. In April 2002, a more substantial population of the same bivalve was found in Siglap Canal some 10 km east of the first site. The bivalve was subsequently identified as the Indian mytilid *Brachidontes striatulus* (Hanley). This study provides a brief account of the populations established in Singapore and some taxonomic remarks concerning its identity.

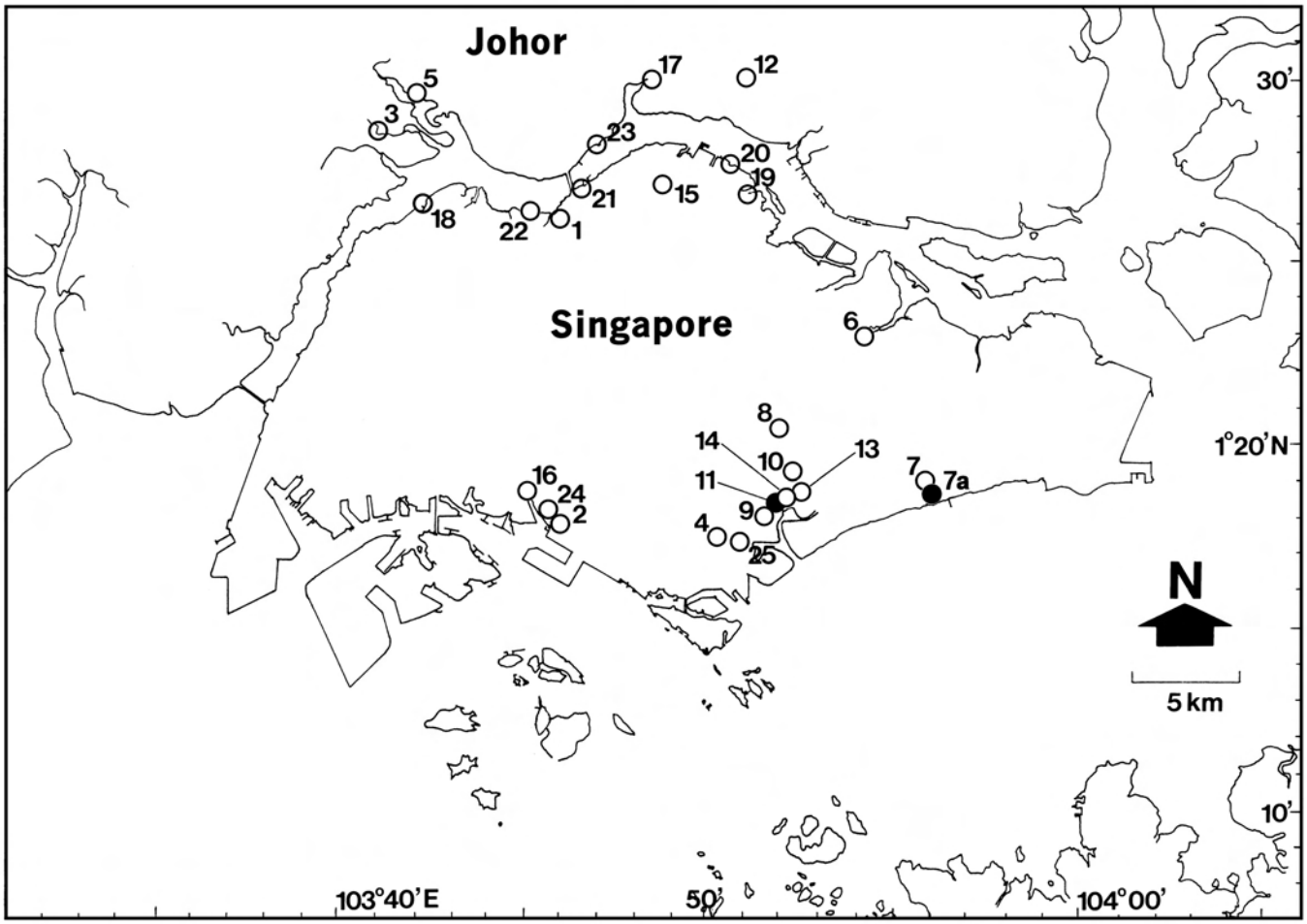
MATERIALS AND METHODS

A total of 25 tidal monsoon drains and estuaries in Singapore and Johor Bahru was sampled during low tides in July 2001 (Fig. 1). Supplementary observations were also made in April 2002 and again in July 2002 at localities where *Brachidontes striatulus* (Fig. 2) was present. Samples were collected using a 10x10 cm quadrat placed haphazardly on the sloping walls of the drains. All live (intact) specimens of the bivalve were counted and measured to the nearest millimetre using dial callipers. The right valves (RV) of dead specimens were also counted and measured. An RV length-frequency histogram was then constructed for each population. The identity of *Brachidontes striatulus* was confirmed by comparing specimens obtained in Singapore with the holotype and other pertinent material lodged in the Leeds Museum and the Natural History Museum in the UK, respectively.

RESULTS

Characteristics of the Singapore population.—*Brachidontes striatulus* was found intertidally among a muddy mat of *Mytilopsis sallei*, a species now known to be introduced recently into Singapore (Tan & Morton, 2006) along the walls of the tidally influenced Rochor Canal some 4 km from the sea (Fig. 1). A total of 11 living *B. striatulus* individuals was collected nestling within byssal mats of *M. sallei* in a 10x10 cm^2 sample. Shell lengths ranged between 11 and 22 mm (Fig. 3A). One year later, in July 2002, a similar sample yielded four living *B. striatulus* individuals that were between 16 and 24 mm in shell length. No dead individuals were found. Additionally, in April 2002, a more substantial and extensive sample of *B. striatulus* was collected from the Siglap Canal (salinity = 20‰) (Fig. 3B), about 600 m from the sea. These individuals were nestled in byssus mats built by themselves and were not associated with *Mytilopsis sallei*, which was absent from this canal. Two 10x10 cm^2 samples taken from the wall and floor of the similarly tidally-influenced canal contained live individuals ranging in shell length from 4 mm to 30 mm and comprised a single distinct cohort, although a few individuals of 4 mm shell length may represent new recruits of the year. Of the 148 intact individuals measured, five were dead (shell lengths 10–16 mm and 24 mm). The species was present in densities ranging from 69 to 75 individuals.$100cm^{-2}$ in byssal mats on the muddy concrete floor of the canal and attached to shells and the byssal threads of *Isognomon ephippium* (L.), which itself forms dense, extensive colonies in canals subjected to the tides.

***Identity of* Brachidontes striatulus.—**The holotype of *Modiolus striatulus* is located in the collections of the Leeds Museum, U.K. (Hanley Collection). The label reads: "*striatulus* Lin." Schrot. Conl. certo 36". The number 36 corresponds to that in the Hanley Catalogue for *M. striatula*. A figured syntype of *M. striatula* Hanley, 1843 (plate 24, fig.29; Hanley, 1842–1856) is in the type collection of the Natural History Museum, London (B.M.(N.H.)) Reg. No.1907.10.28.54. The species is also illustrated as "Species 59", plate X (*Modiola*), fig.72 in Reeve (1858), from the "Philippine Islands". In the type collection of the Natural History Museum, London, is also the holotype of *M. emarginatus* Reeve, 1858 "Species 60" plate X (*Modiola*),



Fig, 1. A map of Singapore and southern Johor showing the sites examined (O) and the locations where *Brachidontes striatulus* was collected (●) (locations 7a and 11). The locations are numbered in order of ascending salinity, except location 7a; 1: Sungei Mandai, 0‰; 2: West Coast, 1‰; 3, Sungei Danga, 2‰; 4, Kim Seng Canal, 2‰; 5, Sungei Sekudai, 5‰; 6, Sungei Serangoon, 9‰; 7, Siglap Canal, 10‰; 7a, Siglap Canal, 20‰; 8, Kallang River, 11‰; 9, Upper Rochor Canal, 12‰; 10, Kallang River, 13‰; 11, Lower Rochor Canal, 16‰; 12, Sungei Senibong, 17‰; 13, Whampoa/Kallang River junction, 19‰; 14, Rochor Canal mouth, 19‰; 15, Sungei Sembawang, 20‰; 16, Sungei Pandan, 22‰; 17, Sungei Plentong, 22‰; 18, Lim Chu Kang Road end, 24‰; 19, Sungei Simpang, 24‰; 20, Sembawang Park, 25‰; 21, Causeway, 25‰; 22, Kranji bund, 25‰; 23, Stulang Laut, 26‰; 24, West Coast Drain 2, 27‰; 25, Singapore River, 27‰.

Fig.73 (Reg. No. B.M.(N.H.).1965115), locality unknown. In the general collections of the Natural History Museum, the above two species are placed together but the former is distinguishable from the uniformly-coloured latter by its distinctive radial bands of brown, one wider than the others. Specimens in the collection of what we consider to be *M. striatulus* are all from the east coast of India, as follows with their corresponding label details:

(i) *Brachydontes emarginata*. Port Canning, Bengal. Three specimens (largest shell length 35.5 mm)
(ii) *Brachidontes emarginatus* (Rv.) 1953. Madras. Seventeen specimens (largest shell length 23.5 mm)
(iii) *Brachiodontes striatula* (Acc. No.1829). Calcutta. Three specimens (largest shell length 28.4 mm)
(iv) *Modiola strialata* [sic] Calcutta. Two specimens (largest shell length 25.2 mm)
(v) *M. emarginata* 3296. Calcutta. Eleven specimens (largest shell length 27.1 mm)
(vi) *M. striatula* (Accession No. 20010211). Calcutta Docks 1975. B. Morton. Twelve specimens (largest shell length 28.1 mm)

Brachidontes striatulus and *B. emarginata* have thus been either consistently misidentified or are synonymous (Annandale & Kemp, 1916) but, regardless, the specimens here under consideration are identical to Reeve's (better) illustration of *M. striatula* Hanley, 1843 and since this name has priority over *M. emarginata* Reeve, 1858 are identified as such. Furthermore, the species is described by Hanley (1842–1856, p. 241) as "covered with an olive epidermis which is usually rayed anteriorly with narrow black streaks", a description matching that of the species in Calcutta (Krishnamoorthy & Rajagopalan, 1969; Morton, 1979) and Singapore (Fig. 2). Because of the wide range of intertidal and subtidal habitats which can be colonized, moreover, shell size and form are highly variable in *B. striatulus* (see Nandi et al., 2000). The species is highly variable in terms of not only shell form, but also the degree of radial ray development and striping, the latter also often different for the left and right valves of an individual. In addition, the degree of development of the antero-ventral valve projection beyond the umbones is variable but, nevertheless, anterior shell rays and stripes can still be detected. The radial sculpture, present on the dorsal half of the posterior region of the shell, is also characteristic.

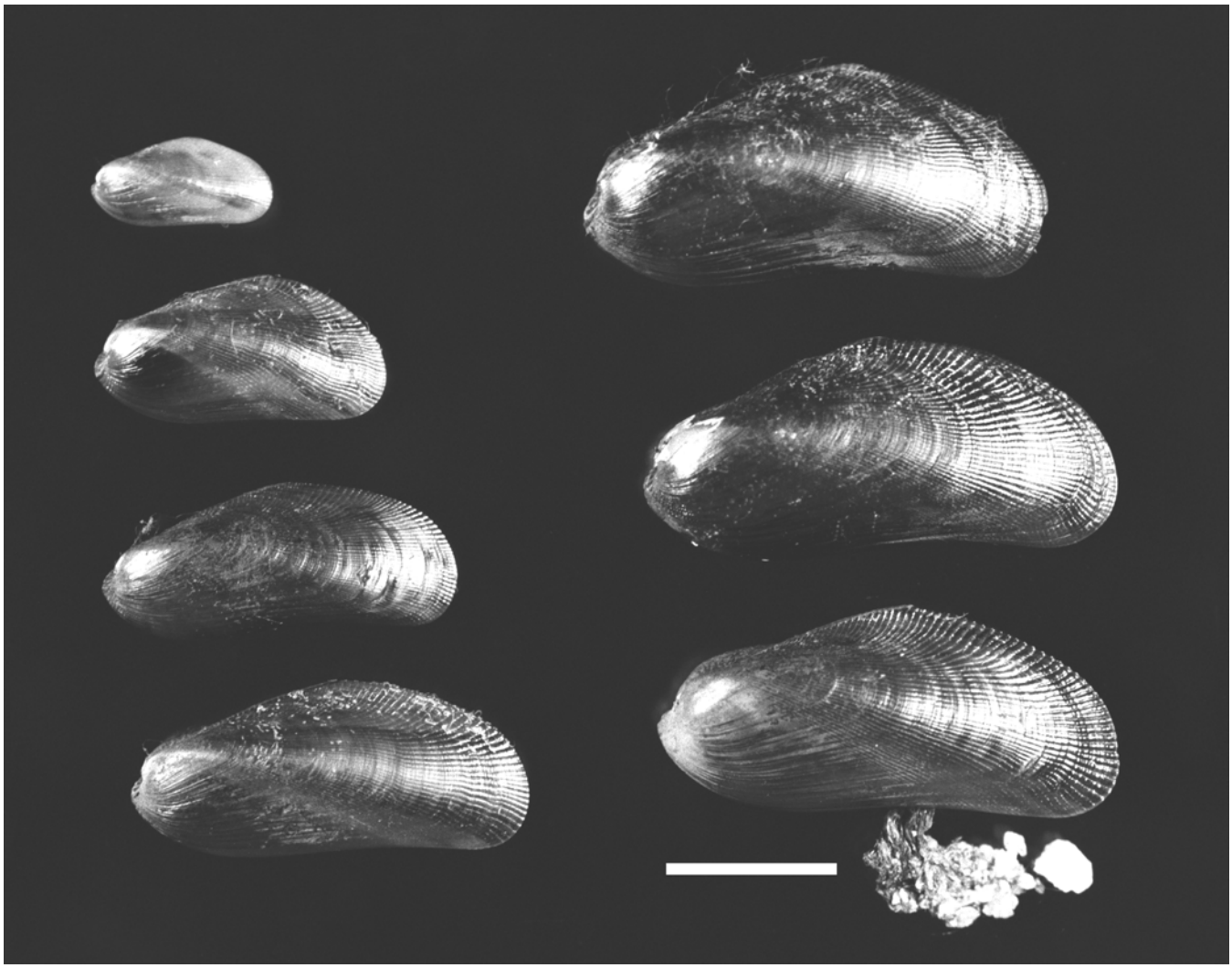


Fig. 2. *Brachidontes striatulus*. External view of specimens from Singapore. Scale bar = 10 mm.

DISCUSSION

Brachidontes striatulus is widely distributed in estuaries in the Bay of Bengal and in harbours along the coast and where it is an important fouler of power station cooling systems but can be controlled by chlorination (Rajagopal et al., 1997). At 1 mg·L^{-1} residual chlorine, 100% mortality was obtained in between 20–24 days (Rajagopal et al., 1997). *Brachidontes striatulus* appears to reproduce but once a year, in winter (Cheriyan, 1969; Krishnamoorthi & Rajagopalan, 1969; Morton, 1979), with new recruits appearing with the adult population in spring, i.e. February–April. *Brachidontes striatulus* thus seems to live for but two years at most and so, in the presence of so few empty shells among the samples collected in Singapore, it seems possible that the larger adults settled in the winter months of 2000 and, thus, represent the founding population [this would also be suggested by the recorded occurrence of the species at only two sites in Singapore]: smaller individuals in this sample therefore represent recruits of 2001, and this further significantly suggests that the founding population is capable of reproduction in Singapore. This was further borne out by the fact that all the collected Rochor Canal individuals in July 2001 and again in July 2002, were mature. The sample from the Siglap Canal collected in April 2002 also seems to represent a founding population recruited in 2001, but also with possibly new early 2002 recruits (shell length of ~4 mm).

It can be summarised, therefore, that *Brachidontes striatulus* was introduced into Singapore (perhaps the Rochor Canal) sometime in early 2000, possibly as larvae released in discharged ballast water from a commercial vessel probably originating from a harbour in the Bay of Bengal, India in view of the extensive trade between that country and Singapore. The species appears to be established – there being evidence of reproductive maturity and recruitment. There also seems to be evidence of local spread, the species next being identified from the Siglap Canal in 2002 but possibly recruited into it in 2001. The habitat occupied by *B. striatulus* in Singapore and in Visakhapatnam Harbour, India (Morton, 1981), is dominated by the dreissenid 'mussel' *Mytilopsis sallei* (see Tan & Morton, 2006) which appears to outcompete the mytilid. In Singapore too, therefore, *B. striatulus* is likely to be kept in check by *M. sallei* which has been introduced widely throughout Asia from the Gulf of Mexico (Morton, 1989). However, the present study also shows that *B. striatulus* in Singapore has managed to establish itself in the lower, more saline regions of tidal canals where *M. sallei* is absent.

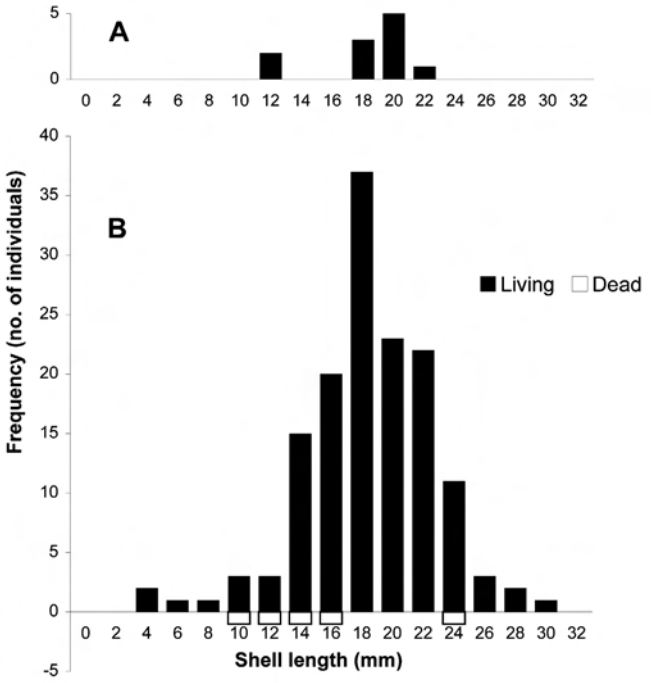


Fig. 3. Size-class distribution of *Brachidontes striatulus* in (A), the Rochor Canal (n=11, July 2001; 10x10 cm^2 sample from wall) and (B), Siglap Canal (n=144, April 2002; individuals were pooled from one 10x10 cm^2 sample each from the floor and wall of canal). Solid and unfilled bars represent live and dead individuals, respectively.

There are a number of freshwater, i.e. *Limnoperna fortunei* (Dunker), and estuarine mytilids, e.g. *Musculista senhausia* (Benson in Cantor) and *Xenostrobus securis* Wilson, that have been introduced from their home ranges to other parts of the world, with ship ballast water usually being considered the source of infection (Carlton, 1985). *Limnoperna fortunei* has been introduced from China (Morton, 1975) into South America, i.e. Argentina (Darrigan & Pastorino, 1995). *Musculista senhausia* has been introduced into Australia (Slack-Smith & Brearley, 1987; Willan, 1987) and California (Reusch, 1998) also from Asia (Morton, 1974). Conversely, *Xenostrobus securis* has been introduced into Japan (Kimura, et al., 1999) from Australia (Wilson, 1968). Based on an Index of Invasion Potential, *Brachidontes striatulus* was given the highest ranking for introduction elsewhere (Morton, 1996) because of its life-history characteristics and the growing economy of India's east coast ports. It has now been introduced into Singapore, arguably the world's largest port with, unlike Australia, no controls on the discharge of ballast water. Now established in Singapore, it is just a matter of time before *B. striatulus* is introduced elsewhere. As with *Mytilopsis sallei* (see Willan et al., 2000), only programmed chlorination measures will be able to control it in water supply systems (Rajagopal et al., 1997).

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