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THE INVASIVE CARIBBEAN BIVALVE *MYTILOPSIS SALLEI* (DREISSENIDAE) INTRODUCED TO SINGAPORE AND JOHOR BAHRU, MALAYSIA

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ABSTRACT. – *Mytilopsis sallei* (Récluz) was present at densities of up to 830 individuals.100 cm^{-2} in nine of 20 tidal monsoon canals surveyed in Singapore. They formed a broad, extensive, densely populated band on vertical and sloping concrete walls as well as on the floor of monsoon drains, up to several kilometres inland from the sea. The bivalve was also present in high densities in a river (Sungei Sekudai) in Johor Bahru. Size-frequency plots showed continuous recruitment at two locations, whereas intermittent recruitment with single or multiple cohort peaks were seen at five other sites studied. The survey results suggest that *M. sallei* is thriving over a fairly wide salinity range in a man-made habitat, making it an excellent candidate for permanent residence, particularly as it is now widely distributed both here and in Johor Bahru.

KEY WORDS. – *Mytilopsis*, Dreissenidae, invasive alien species, Singapore, Johor Bahru, tidal monsoon canal.

INTRODUCTION

Non-indigenous, or alien, species invading marine and estuarine ecosystems have become a matter of great concern world-wide (Carlton, 1987; Ruiz et al., 1997; Ruiz, Fofonoff & Hines, 1999; Thresher & Kuris, 2004). The rapid spread of large numbers of introduced species, almost certainly as a result of increased trans-oceanic vessel traffic (Carlton, 1985; Williams et al., 1988; Chu et al., 1997; Ricciardi, 1998) and, to a lesser extent, the aquarium trade, has serious economic and health implications (Ruiz et al., 1997). Invasive exotic fouling species are typically highly tolerant of pollution and are able to grow and reproduce in a short period of time within a wide range of fluctuating environmental conditions. In Southeast Asia, one of the more spectacular but insidious invasive species is the dreissenid bivalve *Mytilopsis sallei* (Récluz, 1849). Whilst the Central Asian *Dreissena polymorpha* (Pallas) has notoriously invaded and caused havoc in freshwater habitats in the North American subcontinent from Europe (Hebert et al., 1991), its Central American counterpart has also now established a firm foothold in East Asia (Morton, 1987; Nuttall, 1990). *Mytilopsis* (not to be confused with the East Asian freshwater mytilid genus *Sinomytilus*) is now known from Fiji (Hertlein & Hanna, 1949; Morton, 1981, 1989; Marelli & Gray, 1983, 1985), Darwin, Australia (Willan et al., 2000), India (Ganapati, Lakshmana Rao & Varghese, 1971; Kalyanasundaram, 1975), Thailand (Swennen et al., 2001), Japan (Habe, 1980; Ishibashi & Kosaka, 1980; Morton, 1989; Otani, 2002; Kimura & Horii, 2004), Hong Kong (Morton, 1980, 1989; Huang & Morton, 1983) and Taiwan (Chang, 1985). Although *M. sallei* has been previously recorded from Singapore (Goh & Loo, 1990, as "Dreissenidae"; Sachidhanandam & Chou, 1996; Chan, 1997, as *M. adamsi*), their current widespread distribution and abundance of the species in man-made intertidal habitats have not been documented thus far. No records exist for Malaysia. The present study highlights the presence, abundance and distribution of this bivalve in Singapore and neighbouring Malaysia.

MATERIALS AND METHODS

A survey of 25 tidal monsoon drains and estuaries in Singapore and Johor Bahru was conducted during spring low tides on four consecutive days between 9 and 12 July 2001. These locations were chosen for their relative ease of accessibility. At each location, a thorough search was made for colonies of *Mytilopsis sallei* and the salinity of the water

Table 1. *Mytilopsis sallei* colonies in Singapore and Johor. The sampling locations are listed in ascending order of salinity. Density and mean size of live and dead individuals at each locality are also given (see also Fig. 2).

No	Location	Co-ordinates	Salinity (‰)	Density (live/dead individuals.100 cm^{-2})	Mean size (mm) of live/dead individuals
1	Sungei Mandai	1°26.2'N, 103°45.7'E	0	–	–
2	West Coast Drain 1	1°17.8'N, 103°45.9'E	1	–	–
3	Sungei Danga, Johor	1°28.6'N, 103°40.9'E	2	–	–
4	Kim Seng Canal	1°17.5'N, 103°50.2'E	2	8/141	12.3/19.0
5	Sungei Sekudai, Johor	1°29.4'N, 103°42.2'E	5	830/54	11.3/14.0
6	Sungei Serangoon	1°23.0'N, 103°54.2'E	9	335/19	13.2/14.5
7	Siglap Canal	1°19.0'N, 103°55.7'E	10	–	–
8	Kallang River (upper)	1°20.4'N, 103°51.7'E	11	67/19	14.1/18.0
9	Rochor Canal A	1°18.2'N, 103°51.5'E	12	117/23	16.8/21.7
10	Kallang River (lower)	1°18.8'N, 103°52.3'E	13	34/5	14.9/22.8
11	Rochor Canal B	1°18.3'N, 103°51.8'E	16	46/42	15.8/22.7
12	Sungei Senibong Puteh, Johor	1°28.8'N, 103°51.1'E	17	–	–
13	Whampoa/Kallang River junction	1°19.2'N, 103°52.1'E	19	–	–
14	Rochor Canal mouth	1°18.4'N, 103°51.9'E	19	118/36	16.5/22.9
15	Sungei Sembawang	1°27.0'N, 103°48.7'E	20	8/82	12.3/21.4
16	Sungei Pandan	1°18.4'N, 103°45.1'E	22	318/26	15.0/16.1
17	Sungei Plentong, Johor	1°29.7'N, 103°48.1'E	22	–	–
18	Lim Chu Kang Rd end	1°26.8'N, 103°42.4'E	24	–	–
19	Sungei Simpang	1°27.0'N, 103°51.1'E	24	–	–
20	Sembawang Park	1°27.7'N, 103°50.3'E	25	–	–
21	Causeway	1°26.9'N, 103°46.3'E	25	–	–
22	Kranji bund	1°26.3'N, 103°45.3'E	25	–	–
23	Stulang Laut, Johor	1°28.2'N, 103°47.0'E	26	–	–
24	West Coast Drain 2	1°18.0'N, 103°45.6'E	27	–	–
25	Singapore River	1°17.4'N, 103°50.9'E	27	–	–

in the immediate vicinity was measured on-site with a refractometer. The salinity readings were taken to be representative of the location although tides and rain will obviously cause deviations from the values obtained at low tide. Where the bivalves were present, an area 10x10cm was haphazardly chosen and cleared of all live and dead specimens and the shell lengths of either intact or right valves (RV) of disarticulated individuals were measured to the nearest millimetre using dial callipers. An RV length–frequency histogram was constructed for each of the locations where *Mytilopsis* was present.

RESULTS

Twenty locations were sampled in Singapore and a further five examined in Johor Bahru (Fig. 1). Of these, *Mytilopsis sallei* was collected from nine locations in Singapore and one in Johor Bahru. Clearly, *Mytilopsis* is well established in Singapore and in at least one estuary in Johor. Colonies were byssally attached to the concrete drains as well as to each other, trapping much silt. The bivalves formed a broad, extensive, densely populated band on vertical and sloping concrete walls as well as on the floor of monsoon drains, up to several kilometres inland from the sea. Nearer the sea, *M. sallei* was generally replaced by the byssate mangrove bivalve *Isognomon ephippium* (L.) and the oyster *Saccostrea cucullata* (Born), which also formed significant colonies on the vertical walls of the drains. In general, *M. sallei* appeared to be restricted to salinities ranging between 2 and 22‰ (Table 1), although at locations 7, 12 and 13 with salinities of 10, 17 and 19‰, respectively, no colonies were seen. The densities of living animals varied between 8 and 830 individuals.100 cm^{-2}. The highest density of living individuals was at Sungei Sekudai (Location 5) in the West Johor Straits, where the salinity was 5‰. A maximum density of 141 dead individuals.100cm^{-2} was obtained from Location 4 (Kim Seng Canal) where the salinity was 2‰.

The highest ratio of live to dead individuals (~18 live:1 dead) was at Location 6 (Sungei Serangoon) with a salinity of 9‰, whilst the lowest ratio (1 live: 10 dead) was obtained from

Kim Seng Canal (Location 4; salinity 2‰) and Sungei Sembawang (Location 15; salinity 20‰). The sample from Location 6 revealed a high live versus dead shell length ratio of 0.91, whereas samples from locations 4 and 15 showed lower ratios of 0.65 and 0.57, respectively. These values suggest salinities in the region of 9‰ promote recruitment, growth and survival in *M. sallei*, although adults are known to tolerate salinities ranging from freshwater to 50‰ (Ramachandra Raju et al., 1975). Osmotic conditions which are either more saline or less saline than 9‰ might be sub-optimal, but it is also likely that factors other than salinity can determine the survivability of *Mytilopsis*. For example, high ratios of live versus dead individuals were recorded from Locations 14 (Rochor Canal mouth) and 16 (Sungei Pandan), where salinity readings were 19 and 22‰, respectively. Similarly, *M. sallei* was absent from some monsoon drains where salinity values were within the optimal range of 2 and 22‰.

Size-frequency plots for each location sampled (Fig. 2) showed continuous recruitment at Sungei Sekudai (5‰) and in the Rochor Canal (all three locations), while intermittent recruitments with single or multiple cohort peaks were seen at Kim Seng Canal, Sungei Serangoon, Kallang River, Sungei Sembawang and Sungei Pandan.

DISCUSSION

The results suggest that *M. sallei* is thriving over a fairly wide salinity range in the tropical monsoon drains of Singapore, making it an excellent candidate for permanent residence, particularly as it is now widely distributed both in Singapore and in Johor Bahru. A recent checklist of subtidal Singapore bivalves (Sachidhanandam & Chou, 1996, p. 527) listed *M. sallei* as "the most commonly occurring bivalve in Singapore". A subsequent report (Chan, 1997) of *M. sallei* from Punggol identified it as *Mytilopsis adamsi* Morrison. There is some evidence (J. B. Sigurdsson, pers. comm.) that large numbers were present as early as 1983 in Sungei Pandan (Fig. 1), and two individuals were collected from Mandai mangroves (immediately west of the Causeway linking Singapore to Johor Bahru) in May 1984 by D.H. Murphy. In an early study of mangrove fauna at Sungei Pandan in 1957

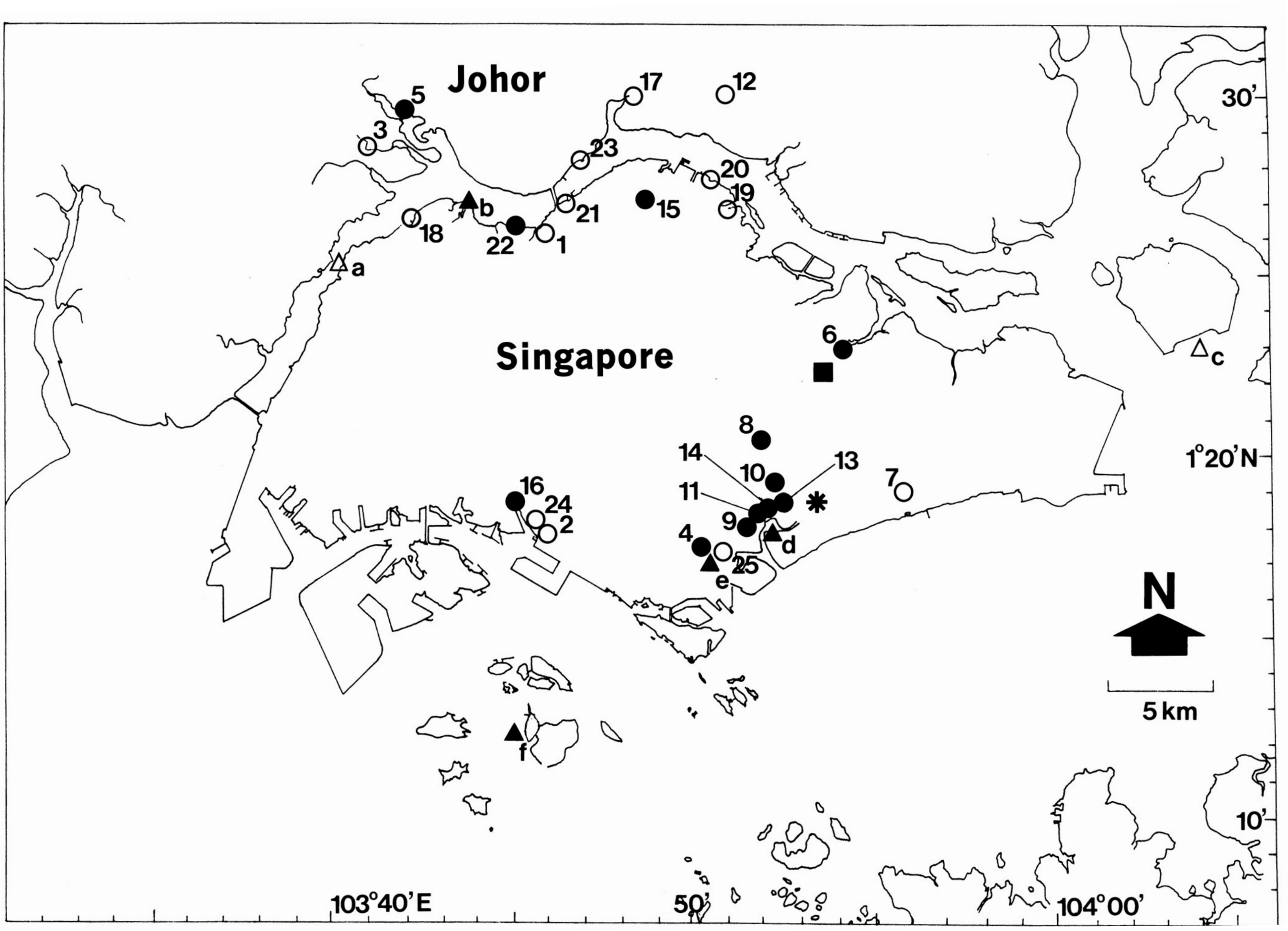

Fig. 1. Occurrence of *Mytilopsis sallei* in Singapore and Johor Bahru. Open and closed dots represent localities where *Mytilopsis* was either absent or present, respectively. Location numbers correspond to those provided in Table 1, which are arranged in order of increasing salinity. Open and closed triangles denote locations as reported upon earlier (Sachidhanandam & Chou, 1996) and where *Mytilopsis* was also either absent or present, respectively. Two other localities where *Mytilopsis* occurs are represented by a closed square (Punggol Park; see Chan, 1997) and an asterisk (Geylang Canal; pers. obs.). Abbreviations: a–West Johor Straits; b–Sungei Buloh; c–Pulau Tekong; d–Kallang Basin; e–Singapore River; f–Pulau Semakau.

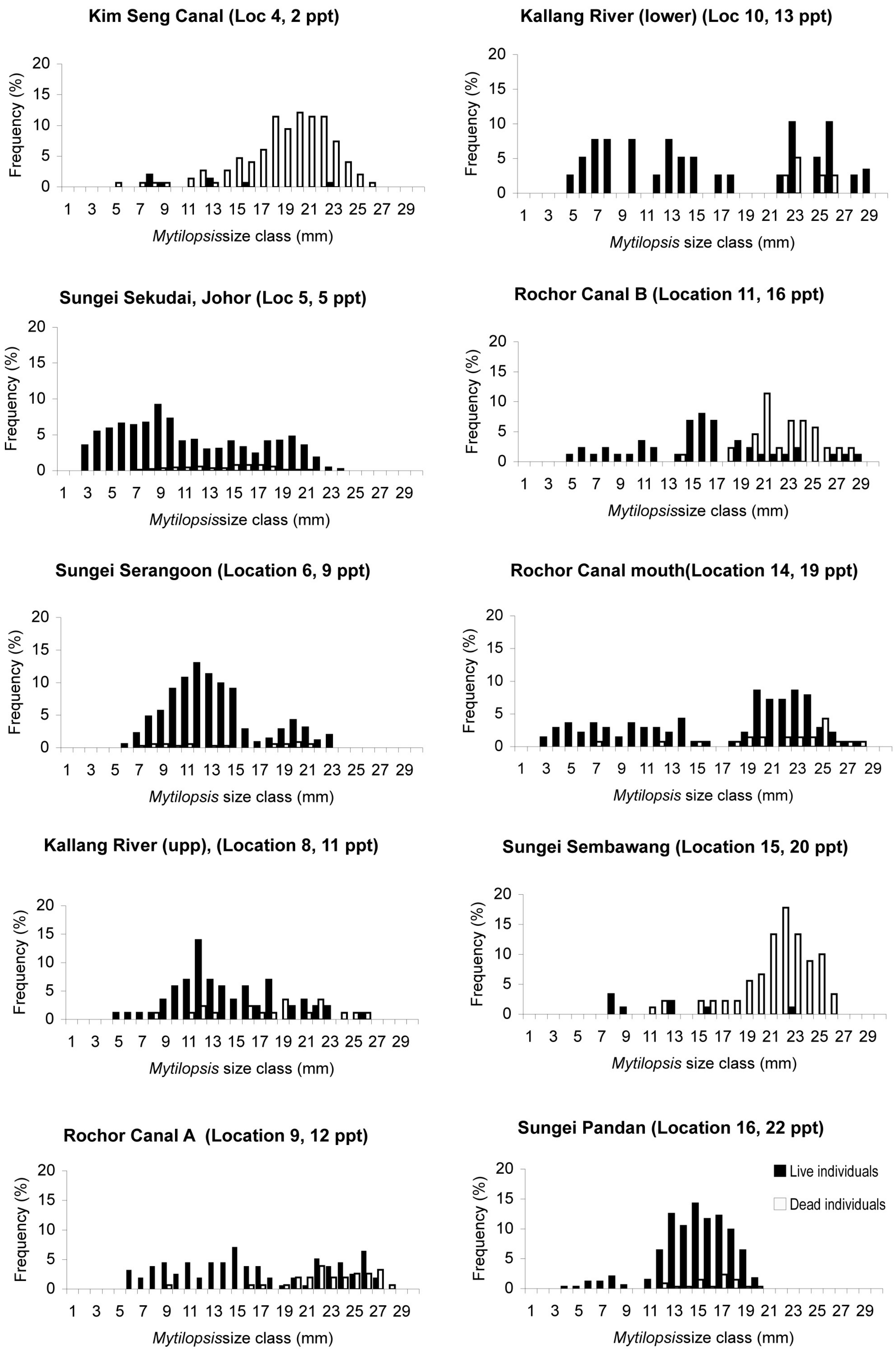

Fig. 2. Percentage frequency histograms of live (filled bars) and dead (white bars) *Mytilopsis* size classes at ten localities in Singapore and Johor Bahru and arranged in order of increasing salinity. Size was measured as either shell length (living individuals) or right valves only (dead individuals). The largest individual recorded was 29 mm long. See Table 1 for sample sizes.

and 1958, no mention was made of *M. sallei* (Berry, 1963). An unpublished checklist of Singapore bivalves by C.F. Lim in 1970 (Lim, 1970) also did not include *M. sallei*, but Sachidhanandam & Chou (1996) recorded it from Pulau Semakau, Sungei Buloh, Kallang Basin and the Singapore River (Fig. 1). While we are unable to ascertain the time and likely route of invasion, the earlier reported upon first occurrences of *M. sallei* in India (introduced in ~1967; Ganapati, Lakshmana Rao & Varghese, 1971; Morton, 1981), Hong Kong (introduced in ~1980; Morton, 1981, 1987, 1989; Huang & Morton, 1983), Taiwan (introduced in ~1977; Chang, 1985) and Japan (introduced in ~1974; Habe, 1980; Ishibashi & Kosaka, 1980; Furuse & Hasegawa, 1984; Morton, 1989; Otani, 2002; Kimura & Horii, 2004) suggest that *M. sallei* was probably introduced into Singapore during the last twenty to thirty years, possibly via larvae in ballast water (Chu et al., 1997) and/or via adults attached to ships' hulls (Carlton, 1987), as may have been the case for the abovementioned localities.

Although it is suggested that ecosystems with a high species diversity are more resistant to invasions by non-indigenous species (Hutchings et al., 2002), since species-rich communities make intensive use of available space (Stachowicz, Whitlatch & Osman, 1999), this may not be the case for artificial tropical estuarine systems. Indigenous mangrove flora and fauna form an impressive component of life in tidal monsoon drains in Singapore, but *M. sallei* is now by far the dominant fouling species of the upper reaches of such man-made habitats, together with the cosmopolitan barnacle *Balanus amphitrite* (Darwin). It is conceivable that such large populations of filter-feeders might be serving to keep the drain waters clean, but they are also an important source of larvae which may eventually be taken up in the ballast water of ocean-going vessels and thus exported elsewhere. The fact that Singapore is now one of the busiest ports in the world makes this very likely. The role of *M. sallei* in consolidating and redistributing sediment in the water column has also not been investigated, but the implications of such activities certainly deserve further study, particularly since *Dreissena polymorpha* introduced into the great lakes of North America has changed Saginaw Bay, Lake Huron, from a pelagic-dominated system to a benthic/pelagic system which will have long term effects on food web structure and productivity at higher trophic levels (Fahnensteil et al., 1995).

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