Vol. 8: 61–69, 2009
doi: 10.3354/ab00206

AQUATIC BIOLOGY
Aquat Biol

Published online December 29

OPEN ACCESS

Population structure and breeding pattern of the mangrove horseshoe crab *Carcinoscorpius rotundicauda* in Singapore

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ABSTRACT: The first year-long survey of the mangrove horseshoe crab *Carcinoscorpius rotundicauda* was conducted at the Mandai mudflats at Kranji in Singapore to determine if breeding is year round or seasonal and to provide qualitative and quantitative baseline data to monitor the health of the population. At spring tide from September 2007 to July 2008, volunteers collected horseshoe crabs along the exposed mudflats as the tide receded. The carapace width was measured, and the sex and breeding status of each individual were determined. The proportion of juveniles in different size groups varied in each month. In November and January, 25 and 30%, respectively, were 2 to 3 cm in width, while in June and July, 8 and 4%, respectively, were in this size group. The size cohorts showed recruitment to the smallest size classes from November to March and recruitment to the larger size classes from March to July. Juveniles less than 2 cm were not found in June, suggesting that there may be a rest period of low or no breeding activity from May to July resulting in none of the smallest sizes mid-year. Ratios of males to females varied from 0.85 to 1.78 throughout the year, and although pairs in amplexus were found year round, no spawning activity was seen. Males mature at about 8 cm while females may mature later at 10 cm. A mean of 33% growth during ecdysis in juveniles was observed, suggesting that juveniles of approximately 2 cm may moult about 5 more times before maturity.

KEY WORDS: Mangrove horseshoe crabs · *Carcinoscorpius rotundicauda* · Breeding patterns · Population structure · Growth · Sex ratio

INTRODUCTION

Horseshoe crabs have changed very little over 500 million years and have survived 2 mass extinctions (Stormer 1952), but now, according to the IUCN Red Data Book, one species is near threatened (*Limulus polyphemus*), and data on the other three are deficient (IUCN 2008).

One of the 4 species of horseshoe crab, the mangrove horseshoe crab *Carcinoscorpius rotundicauda* (Latreille, 1802), occurs only in Asia: around India, Indonesia, Malaysia, Philippines, Singapore, Thailand and Hong Kong (Lee & Morton 2005, IUCN 2008). The Singapore Red Data book released in November 2008 classifies this species as vulnerable (Davidson et al. 2008). The global distribution of all species of horseshoe crab has been well described by Mikkelsen (1988), but his book was based on work carried out before the late 1980s. Since then, land reclamation and coastal development or degradation have destroyed much of the habitat of horseshoe crabs (Savage 2001, Ng & Sivasothi 2002, Mishra 2009). Moreover, the biology, ecology and breeding patterns of *C. rotundicauda* have not been as well documented as those of the North American species *Limulus polyphemus* (Linnaeus, 1758). According to Mikkelsen (1988), the breeding cycle of *C. rotundicauda* in Thailand is thought to be continuous, whereas in Borneo it is thought to occur from March to July, but there are no quantitative data to support this. For other parts of Southeast Asia, including Singapore and Malaysia, there is a paucity of information, and it is still not clear if this tropical species has a seasonal breed-

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ing pattern, as occurs with *L. polyphemus,* along the temperate shores of USA, or if breeding occurs year round. Abundance, population structure and spawning patterns of the Atlantic horseshoe crab off the east coast of the USA have been well studied (Botton et al. 2003, Carmichael et al. 2003, James-Pirri et al. 2005, Leschen et al. 2006), but very little has been published on the spawning activity of *C. rotundicauda*. The massive seasonal migration up the beach for spawning that is a well known part of the breeding pattern of *L. polyphemus* in the USA has never been described for *C. rotundicauda*.

There is little recent information on abundance, sex ratios, population structure or densities of *Carcinoscorpius rotundicauda*, or whether numbers are stable or decreasing. A 2008 report in Marine News (www.merinews.com/article/horseshoe-crabs-galloping-towards-extinction/136265.shtml) indicated that 2 species, *C. rotundicauda* and *Tachypleus gigas* (Müller, 1785), are being poached in their thousands by children engaged by local fishermen to collect the crabs, which are then sold to pharmaceutical companies. In addition, harvesting for commercial purposes is considered a serious threat to the survival of these species in Malaysia (Christianus & Saad 2007). With the increasing interest in *C. rotundicauda* for medical research (Ding et al. 2005, Ng et al. 2007) and the additional threats of habitat loss due to coastal development in Southeast Asia, such information is urgently needed to assess the ecological requirements and conservation status of this species and to manage and conserve it. Loss of habitat is listed as one of the 2 main threats to horseshoe crabs in Singapore (Davidson et al. 2008); the other is pollution.

In Singapore, the Mandai mudflats at Kranji on the north coast of the main island are the largest mudflats remaining in the country and are the habitat of a population of *Carcinoscorpius rotundicauda.* The Nature Society of Singapore (NSS) has been organising volunteers to visit this site every 3 to 4 mo to rescue horseshoe crabs that have become entangled in deployed or abandoned fishing nets. In 2007, the volunteers also started collecting demographic information on the horseshoe crabs found during this operation. These unpublished data showed a large proportion of small juveniles in March with very few seen in June, suggesting some seasonal pattern to spawning, contrary to opinion in Singapore and Malaysia (R. Tan, A. Christianus pers. comm.; www.wildsingapore.com/wildfacts/arthropoda/limulidae/limulidae.htm). Beginning in September 2007, more regular visits were made to the site at the spring tide each month for 1 yr, and data on *C. rotundicauda* were collected more systematically to determine breeding patterns and provide information on population structure. This is the first systematic, quantitative survey over a period of 1 yr on a population of this species anywhere in Asia.

The aim of this project was to provide qualitative and quantitative baseline data over a period of 1 yr to determine if breeding is year round or seasonal. From these data, the structure and stability of the population can be monitored over time.

MATERIALS AND METHODS

Study site. The study site is on the north coast of the main island of Singapore at 1° 26′ N and 103° 45′ E, at Kranji. About 2 km to the east is the stone causeway across the Strait to Johor Baru in Malaysia. There is flow of the sea through the strait, but flushing is restricted to some extent by the causeway. The Strait of Johor is an estuary, and salinities vary depending upon the state of tide, weather and terrestrial runoff. The salinity in the strait typically exhibits 2 high levels, in March/April and October/November, and 2 low levels, in January and June/July (Ng & Sivasothi 2002), depending upon the state of tide, weather and terrestrial runoff.

The tidal amplitude varies from about 3 m during the spring tides at the full moon to about 1 m at the neap tides. The distance, as measured for the study, from the high tide to the lowest tide mark is about 200 m. The intertidal zone is almost flat, has no mangroves, and the mud is very sticky, at least ankle deep in most parts. Part of the area is bounded by a sea wall. The search area was approximately 26 680 m^2, 115 m from the high to low tide area by 232 m along the shore line, with a firm man-made earth bund or quay midway along the shore stretching out to sea. This bund is almost level with the mudflats, so it is exposed at low tide but covered as the tide comes in. The site, particularly near the high tide area, is strewn with various types of debris at low tide, including large lumps of concrete, driftwood, logs and sticks, and pieces of metal or plastic, and it is here in the intertidal zone that the mangrove horseshoe crab *Carcinoscorpius rotundicauda* can be found.

Search times and dates. The tide heights were the overriding factor in selecting search times and dates. The searches required uncovered mudflats, so the spring tides were chosen for the search days, which all occurred within 3 d of full moon. To determine population structure over time, searches were made over the whole of the study area from September 2007 through to July 2008, except for December 2007 and February 2008, when the optimal search times fell on public holidays, and August 2008, when the optimal tide time was after dark. As trained volunteers were recruited to provide sufficient manpower, searches were all done at weekends, which meant that the searches were not always conducted on exactly the

same day of the lunar cycle. Visits to the site were timed to start when the receding tide height was about 1 m. At this time, enough of the mudflats were exposed to provide access to the site while maximising search time. A programme was designed to ensure that all volunteers were trained in search techniques and biographical data collection. Supervision and instruction was provided by the team leaders at all times.

Visual search methods. Search methods were dictated by the fact that mangrove horseshoe crabs of all sizes are readily found on the mud surface when the tides recede. Individuals can be seen moving slowly over the surface of the mud or resting on the mud. Some but not all settle into the surface so that they are partly covered by the mud, particularly the anterior part of the carapace. They can then be picked out of the mud by hand. Care was taken not to tread on the crabs.

For the searches, volunteers spread out over the mudflats, taking with them containers with a little seawater. They searched the mud for horseshoe crabs of all sizes from the high tide level towards the low tide level following the receding tide. Searches were made for approximately 2.5 h, and the same area was searched each month. It is a very labour intensive search method, and walking in the deep mud is difficult.

This method does not assess activity of the horseshoe crabs under water or include individuals in deeper water. To study *Limulus polyphemus*, a sand-dwelling species of horseshoe crab, Carmichael et al. (2003) used visual searches with snorkels or view boxes for surface crabs in the water and a modified 50 cm clam rake towed behind a boat to collect and count buried crabs in a given area. At Kranji, however, the sticky mud and the debris at the study site made it difficult to use rakes, particularly near the high tide zone. In addition, the suspended silt made it impossible to see through the water, so searches could not be done by looking through the sea water. Thus a visual search on the surface with probing the substrate for buried crabs when the mud was exposed was the only way horseshoe crabs could be found.

All horseshoe crabs found were brought to a recording station set up on the firm bund at the study site. Here the carapace width at the widest point of the individual horseshoe crabs was measured to the nearest mm, and the gender and age class (juvenile or adult) were determined and recorded.

The sex of the adults was determined based on the shape of the first 2 pairs of claws and the presence of pedipalps in males. The sex of juveniles and sub-adults was not recorded, as it was too difficult in the field with limited time for volunteers to distinguish the sex of juveniles reliably from the shape of the genital pores. Therefore, sex determination was only confirmed on adult horseshoe crabs, and the females were distinguished from juveniles by their size alone. Since all males found were 8 cm or above, all individuals less than 8 cm were classified as juveniles and those 8 cm and above were considered adults. Thus 8 cm was considered the size at which this species matures. As far as possible, mating pairs were left in amplexus, but some became uncoupled during the collection and measuring process. After their details had been recorded, the individuals were kept in a holding trough until the search was completed, and then returned to the mudflats. This was to avoid recapturing individuals that had already been measured.

Population structure over time; size and sex. The population structure of juveniles and adult males and females was analysed to determine if there was any change over the months that would indicate a seasonal pattern to breeding. If the size distribution of juveniles remained consistent throughout the year, this would constitute evidence that breeding was year round and not seasonal. In addition, if very small juveniles were found in equal measure in every month, then year-round breeding was more likely. If very young juveniles were found only at restricted times or if the size distribution of juveniles showed a change over time, then seasonal breeding could be inferred.

Box plots were constructed from the carapace width data for juveniles, males and females in each month. These provide 5 key statistical measures (median, upper and lower quartiles and 95% CI) and allowed ready visual comparisons across months. A 1-way ANOVA model that width was affected by sampling time was applied to determine whether monthly differences in carapace width were statistically significant.

In addition, individuals collected each month were classified into size classes of 1 cm from 0 up to 16 cm. Histograms of the percentage frequency distributions of the carapace width for each month in size classes of 1 cm were used to display age structure and change in population structure over time.

Sex ratios and seasonal breeding patterns. The adult sex ratios and the numbers of pairs in amplexus (coupled) as well as any gravid females and spawning activity were recorded. The presence of coupled pairs and a steady sex ratio in each month would suggest year-round breeding, while substantial changes in sex ratios over the year or in the percentage of adults in amplexus or females with eggs would suggest seasonal breeding. Every attempt was made to keep the pairs together during data collection, but if they became separated they were returned to the sea together. The searches were timed on or within 3 d of full moon to optimise the chances of seeing spawning activity. Sex ratios were calculated for each collection, and the chi-

squared test was applied to determine if the ratios deviated from 1 throughout the study period of 11 mo.

Data entry and analysis. All data were recorded on data collection sheets at the site and later entered onto computer spreadsheets. Full checking of data and information entries was done on all manually entered data to ensure accuracy. Before any tests were conducted, normality of data and homogeneity of variances were checked, and tests selected were appropriate for the type of data and hypotheses being tested. Statistical analysis was performed using Excel and The R Project for Statistical Computing (v. 2.7.2). In addition, all outliers were re-checked and corrected if necessary.

RESULTS

Population structure over time

Size

In total, 4756 captures were recorded over the study period: 1298 adults and 3458 juveniles. The width of the females showed consistency over the months (ANOVA, $F = 3.7514$, $p = 0.05562$, $n = 592$; Fig. 1).

Similarly, there was no difference from month to month in the width of adult males (ANOVA, $F = 1.5441$, $p = 0.1384$, $n = 706$; Fig. 2), Males were smaller than females (Mann-Whitney *U*-test, $p < 0.05$) for all months except October, which showed no significant difference in size. In addition, among pairs in amplexus, the males were smaller than the females (Mann-Whitney *U*-test, $W = 519$, $p < 0.0001$, $n = 141$). This indicates that although the size ranges of males and females overlap, there is sexual dimorphism with respect to size, confirming other studies on *Carcinoscorpius rotundicauda* (Hong 2004, Hajeb et al. 2005).

Much greater variation among months was seen in the sizes of juveniles than in the adults (ANOVA, $F = 72.351$, $p < 0.0001$, $n = 3458$; Fig. 3), suggesting periods of low and high reproductive activity rather than equal year-round breeding activity.

The smallest male recorded showing pedipalps was 8.0 cm, and the smallest male in amplexus was just over 8 cm. Males of 8.1 and 8.2 cm were often recorded, so if mature males were genuinely smaller than 8 cm, more of them would be found. Therefore 8 cm was taken as the cut-off for sexual maturity.

Frequency distributions

Crab width data were arranged into 1 cm size classes (0 to <1, 1 to <2, … cm). The numbers of crabs collected varied each month, depending on the number of volunteers searching, so for comparison, the percentage of the total catch was used rather than raw numbers.

The sizes of horseshoe crabs are presented as frequency histograms using the percentage of the total catch. The peak categories varied month by month, as indicated in Fig. 4. This change in size may indicate cohort growth.

Recruitment into the smallest size classes (<2 cm) increased steadily from 0% in September, peaking at 11.1% in March and then declining to 0% in June and 0.25% in July, suggesting that reproductive activity is not steady throughout the year, but that there may be periods of low and high reproductive activity. At the same time, there was a higher percentage of the larger size classes as numbers in the smallest size classes decreased, suggesting that while there was more recruitment of the smallest individuals into the population from November to March, the large juveniles were maturing into small adults between September and November.

The percent of adults dropped between October and April, corresponding with the increase in numbers of small juveniles, again suggesting a change in reproductive activity through the year.

These findings support unpublished NSS data collected in the previous year. Numbers collected in March 2007 also showed a high proportion of small juveniles, while June 2007 showed a high proportion of adults, suggesting that this is a real annual phenomenon and not just an isolated pattern.

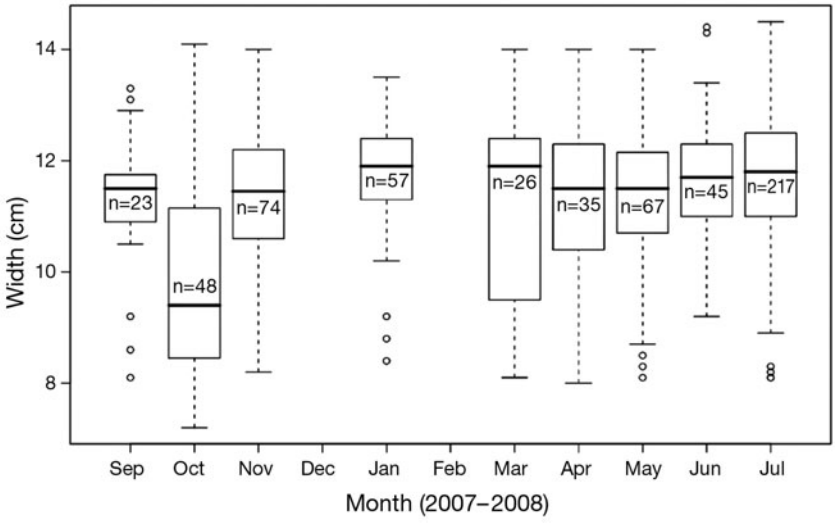

Fig. 1. *Carcinoscorpius rotundicauda.* Variation in sizes of females among months, 2007 to 2008. Box shows median and quartiles, whiskers are 95% confidence interval, circles are outliers

Sex ratios

An even balance between males and females was observed in most months. The sex ratios were not significantly different from 1 except in May and June 2008, when there were more males than females ($p < 0.05$, Table 1). The null hypothesis that the sex ratio is equivalent to 1 in any month cannot be rejected, except for 2 months, May and June 2008. The male: female sex ratio in March 2007 was similar to that of March 2008, while in June 2007, it was slightly lower than in June 2008.

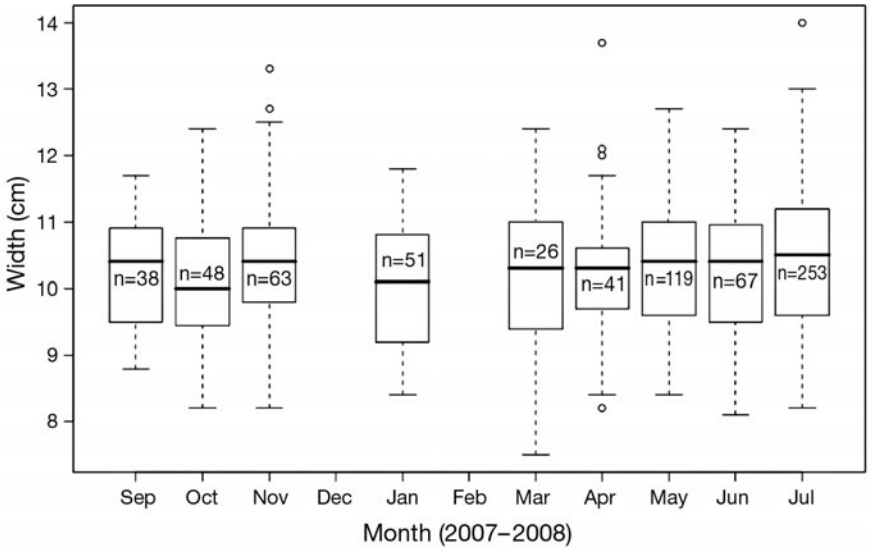

Fig. 2. *Carcinoscorpius rotundicauda.* Variation in sizes of males among months, 2007 to 2008. See Fig. 1 for definitions

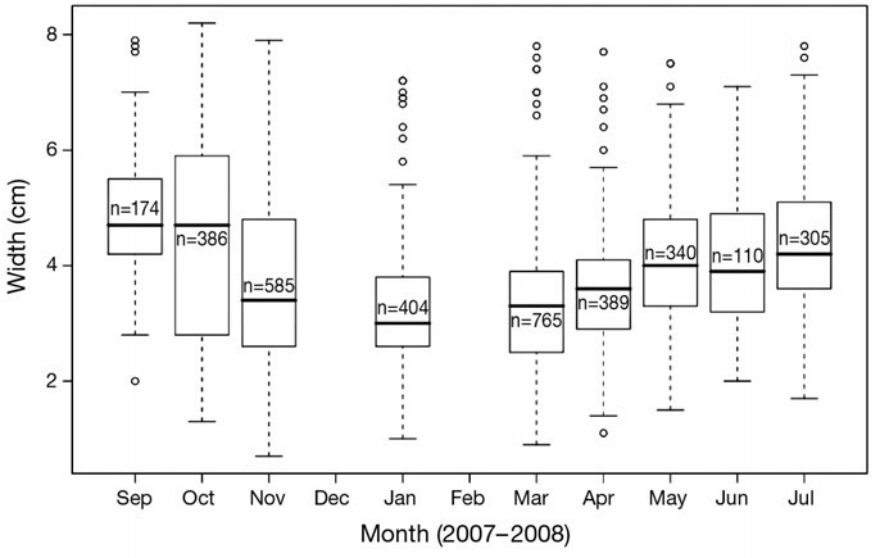

Fig. 3. *Carcinoscorpius rotundicauda.* Variation in sizes of juveniles among months, 2007 to 2008. See Fig. 1 for definitions

Breeding behaviour

Pairs in amplexus were seen in each month, although the percentage of adults in amplexus varied. The mean (± SD) percentage of individuals in amplexus out of all adults caught was 15 ± 14.3%. However, the numbers are an underestimate because some pairs or groups came apart before they could be recorded. In some cases, groups were observed with a second male attached to the first male attached to the female. Three such groups were recorded, 2 with 2 males and 1 with 3 males attached. This is the first time attached groups have been recorded for this species of horseshoe crab.

Pairs were found all along the mudflats, from the high water mark to the low water mark. They were immobile when the tide was out and mostly buried very shallowly in the mud surface. There were no sightings of pairs spawning. Unlike the phenomenon of the mass spawning migration up the beach in the USA, at no time was a migration or indeed any movement of pairs or even single adults seen that might indicate mass spawning activity.

Moults and moulting

At each visit many moults were seen, but not all were collected and measured. The largest moult seen was 13.5 cm and female, while the smallest moult was 1 cm. Each month, many individuals of all sizes appeared to be about to moult or had just moulted. Female moults were commonly seen, and females of sizes from 9 to 13.5 cm had been seen either in the process of ecdysis or had recently moulted. No male moults were seen during any searches, but males varying from 8 to 12 cm were seen in the early stages of ecdysis or recently moulted. Moreover, the largest male caught was 14 cm, so ecdysis is likely to have occurred at some point after sexual maturity (8 cm) for it to reach this size. Very many smaller moults from 2 to 8 cm were found. Six juveniles between 2.1 and 7.5 cm were seen shedding their old carapace, and both moult and the emergent horseshoe crab were measured. The mean growth of these

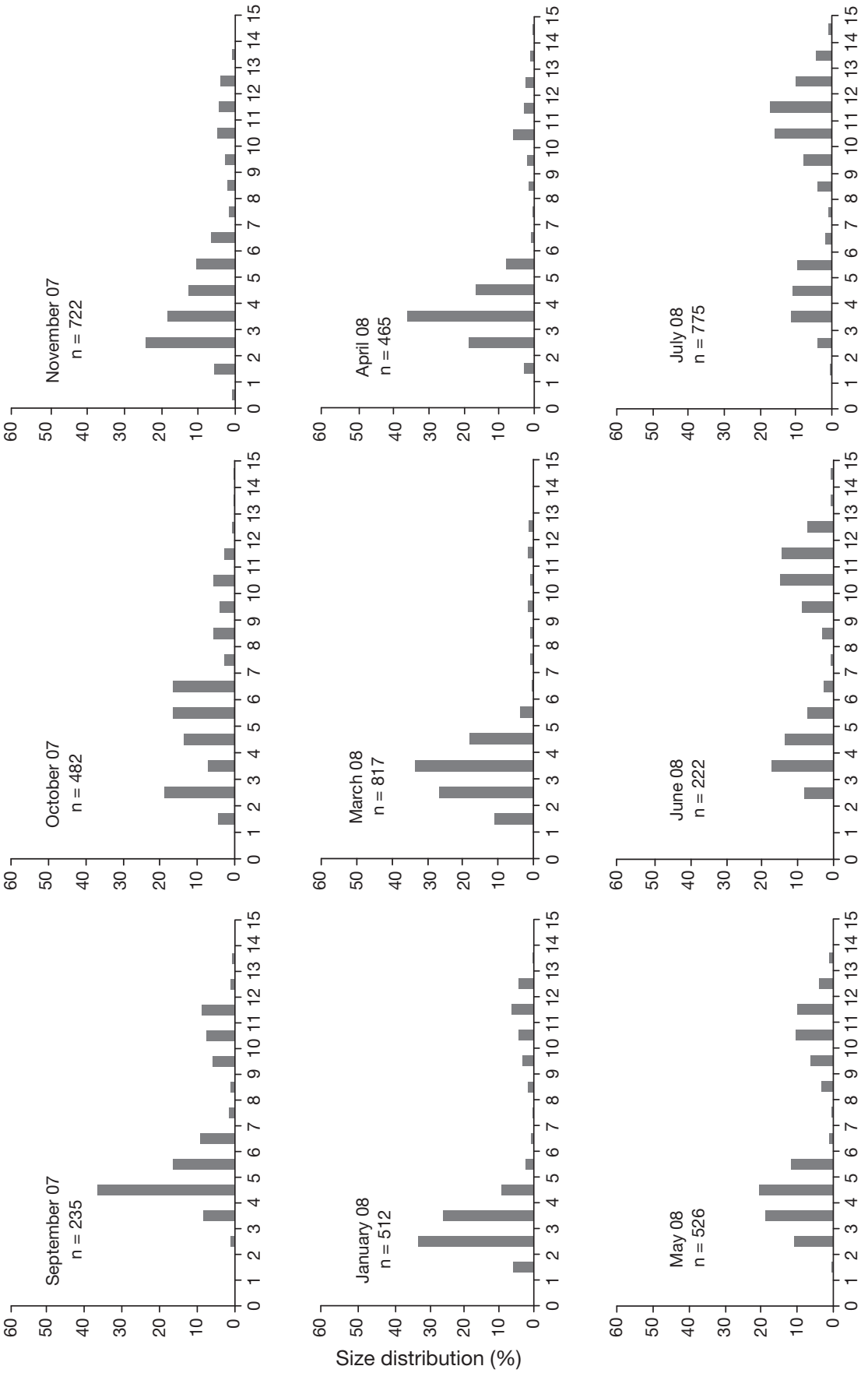

Fig. 4. *Carcinoscorpius rotundicauda*. Frequency of size classes from September 2007 to July 2008. Size distribution is % of total n

Table 1. *Carcinoscorpius rotundicauda*. Number, percent and sex ratios of adult males to females from March 2007 to July 2008. p-value:sex ratio ≡ 1, df = 1

Date	n	Sex ratio (m:f)	χ^2	p-value
March 07[a]	48	1.09	0.0833	0.7728
June 07[a,b]	59	0.74	1.3729	0.2413
Sept 07	83	1.24	0.9759	0.3232
Oct 07[c]	94	1.09	0.0426	0.8366
Nov 07	137	0.85	0.8832	0.3473
Jan 08	108	0.89	0.3333	0.5637
Mar 08	52	1.0	0	1
April 08	76	1.17	0.4737	0.4913
May 08	186	1.78	14.5376	0.0001374
June 08	112	1.49	4.3214	0.03764
July 08	471	1.17	2.9066	0.08822

[a]Searches were done by Nature Society of Singapore volunteers before the project started
[b]Sex of 2 individuals was not recorded
[c]Sex of 1 individual was not recorded

6 juveniles was 33% (SD = 8.42%). No fully emerged adults with their moults were observed, so no figures for adult growth are available.

DISCUSSION

This study is the first to examine the population structure and breeding pattern of *Carcinoscorpius rotundicauda* over a period of nearly 1 yr. The primary aim of the study was to determine if breeding of *C. rotundicauda* was seasonal or year round. Three aspects of the study suggest that although breeding may occur year round, there are periods of low and high breeding activity.

First, the recruitment into the population of the very smallest juveniles increased steadily from September to reach a peak in March and then fell to almost zero in June and July. If breeding were steady year round, we would expect recruitment into the smallest sizes to be consistent all year, while seasonal breeding would show more marked periods of no recruitment at all. Very small juveniles were found in all months except June. Unpublished NSS data from 2007 also showed a high frequency of small juveniles in March, with a much lower frequency of small ones in June, so the results from this study are likely to represent a regular pattern. Although the American horseshoe crab *Limulus polyphemus* shows marked seasonal breeding patterns in the temperate latitudes where tidal amplitudes are high, this species shows no such seasonal breeding pattern farther south off Florida, in estuaries and microtidal lagoons with low tidal amplitudes and warmer waters (Ehlinger & Tankersley 2009). In these southern waters, as at Kranji, which is also an estuary with low tidal amplitudes and warm waters, no large spawning aggregations were seen, and spawning is not triggered by environmental cues (Ehlinger & Tankersley 2007); instead spawning in Florida was protracted and occurred year round but was either aperiodic (Ehlinger & Tankersley 2009) or showed episodes of increased mating activity in early spring (Ehlinger et al. 2003). *Carcinoscorpius rotundicauda* in the tropics seems to display a similar pattern.

If breeding of the mangrove horseshoe crab were markedly seasonal, we would expect to find a steady and marked shift towards more larger juveniles as the months progressed and the smaller juveniles moulted and grew with a loss of the very tiny ones until after the breeding season, as shown by studies from the USA with *Limulus polyphemus* (Botton et al. 2003, Carmichael et al. 2003). In our study, there was a higher frequency of larger individuals in some months, but there were still some small individuals most of the year suggesting a short rest period with low or no breeding activity rather than continuous breeding or clear seasonal breeding.

Secondly, the sex ratios did not vary much from 1 except in May and June when males out-numbered females by a small margin, less than 2 to 1, suggesting a period of more active breeding. There was never a time when sex ratios were heavily male-dominated, as has been described during the spawning season of *Limulus polyphemus* in the eastern USA, which show marked seasonal breeding when males substantially outnumber females (Carmichael et al. 2003, James-Pirri et al. 2005). Indeed, in November and January at Kranji, females slightly outnumbered males.

Finally, attached pairs could be found year round, although the percent in amplexus varied between sampling periods. In a microtidal lagoon of Florida, mating pairs were also recorded in most months during the observation period (Ehlinger et al. 2003), but the frequency of mating pairs peaked in late winter to early spring. However, at that site, mating was associated with spawning, although the environmental cues for spawning were not clear. In contrast, spawning activity was never seen at Kranji. Individuals pair up but spawning may be delayed until conditions are favourable. Attempts at breeding this species in captivity at the Singapore Zoo (Julienne Lee pers. comm.) suggest that adults remain coupled for some months. Also, local fishermen believe that male and female *Carcinoscorpius rotundicauda* stay together for a long time, so for this species, unlike *Limulus polyphemus*, coupling may not necessarily equate to mating or spawning.

Periods of low reproductive activity are not unknown in tropical species where some environmental factors like temperature and day length are constant throughout the year. Two species of tropical hermit crab,

Clibanarius chapini and *C. senegalensis*, in Africa (Ameyaw-Akumfi 1975) and several species of decapod crustaceans in the Caribbean (Heck 1977) show year-round breeding but with periods of low breeding activity during some months of the year. Recruitment into the population of sicyoniid and caridean shrimp species off the coast of Puerto Rico is described as episodic rather than truly continuous or seasonal (Bauer 1992).

This study has provided interesting data on growth after moulting. Most work on growth and development has been done on the larger species *Limulus polyphemus* and *Tachypleus tridentatus* (Leach 1819) from temperate waters and grown in captivity (Sekiguchi et al. 1988, Carmichael et al. 2003) with very little comparable published work on breeding and growth rates of *Carcinoscorpius rotundicauda* in warm waters. In our study, the mean growth at ecdysis was consistent with that of two *C. rotundicauda* individuals recorded in Hong Kong with mean growth of 24% (Lee & Morton 2005), and with the growth of earlier larval stages from hatching up to 2.3 cm reared in captivity in Malaysia (Zadeh et al. 2009). These larvae showed incremental growth in width of between 34 and 40% in the 1st to 7th instars. If this growth is maintained in the juveniles and sub-adults until maturity, it would require about 5 or 6 moults to grow from 2 cm to 8 cm.

Although males of 8 cm were seen in amplexus, the smallest female seen in amplexus was just over 10 cm. This may indicate the true size at which females reach sexual maturity, in which case females may require an extra moult before reaching sexual maturity.

The period from egg laying to the 5th instar (about 1.5 cm) takes approximately 7 to 8 mo (Zadeh et al. 2009, A. Christianus pers. comm.). Although the growth figures from Kranji were based on a small sample, these were wild individuals and support the findings from those that were captive bred.

At Kranji, the highest proportions of the smallest class sizes of 1 to 2 cm were collected in January and March. If this was 7 to 8 mo from egg laying, it would suggest that the period from May to July when males outnumbered females may be the period of high reproductive activity accounting for the high numbers of small juveniles in January and March, while November to January represents a period of low reproductive activity resulting in few of the smallest sizes from June to September of the following year. This has not been described before for *Carcinoscorpius rotundicauda*.

During the study, we observed large, sexually mature females in the process of moulting, and the largest female moult found was 13.5 cm. Thus, rather than undergoing a terminal moult at maturity, female *Carcinoscorpius rotundicauda* may moult at least once after reaching sexual maturity. Although male moults have not yet been found, the largest male caught was 14 cm, supporting the suggestion that male horseshoe crabs moult more than once after reaching adulthood (Carmichael et al. 2003). These authors calculated that *Limulus polyphemus* moults 6 times in the first year, but studies on captive *Tachypleus tridentatus* indicate that growth is more rapid in warmer waters (Lee & Morton 2005). In Malaysia, Zadeh et al. (2009) demonstrated that *C. rotundicauda* reared in the laboratory at 28°C went through 6 moults in about 8 to 9 mo, and that the larger *T. gigas* took longer to moult than the smaller species. Thus at Kranji, where water temperature is usually about 30°C, growth is likely to be optimal with more moults per year in the smaller *C. rotundicauda* than in colder waters or in larger species.

This is the first comprehensive study to collect census data and determine population structure and breeding patterns of *Carcinoscorpius rotundicauda* over a 1 yr period at the same site. The findings suggest that there is a healthy and balanced population of *C. rotundicauda* at the site, and that breeding is not continuous or stable year round, but shows periods of low reproductive activity. To conserve this species, it will be important to monitor the balance of males, females and juveniles as an indicator of the health of this population.

Acknowledgements. The Nature Society Singapore (NSS) thanks the Caterpillar Foundation for their generous funding to conduct the study. We also thank the many individual NSS members who gave of their time and effort to help with the horseshoe crab searches. In addition, thanks go to volunteers from the following schools and institutions who helped with the searches: the National Institute of Education (NIE), the International School of Singapore (ISS) Bukit View Secondary School and Nanyang Junior College. In addition, Dr. P. Todd (National University of Singapore, NUS) helped with the design of the project, and S.T. Lee (NUS) helped with some of the statistics.

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Editorial responsibility: Hans Heinrich Janssen, Oldendorf/Luhe, Germany

Submitted: May 20, 2009; Accepted: November 2, 2009
Proofs received from author(s): December 19, 2009