



## Population ecology and shell chemistry of a phytal ostracode species (*Loxoconcha matagordensis*) in the Chesapeake Bay watershed

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Received 9 December 2003; received in revised form 16 June 2004; accepted 29 June 2004

### Abstract

Population ecology and shell chemistry were studied in the phytal ostracode *Loxoconcha matagordensis* (Swain 1955) collected from *Zostera marina* seagrass beds in the Chesapeake Bay to provide seasonal constraints on shell secretion time for paleothermometry. Population density and age structure were defined by two main breeding cycles that occurred between 01 to 15 June and 02 to 16 August 2001. The time interval between breeding cycles was ~2 months and total juvenile standing crop increased almost three-fold between the first and second breeding cycles. Dark brown over-wintered adults comprised the majority of the population between March and April 2001, while newly secreted translucent adults were predominant between June and September. Seasonal shell Mg/Ca and Sr/Ca ratios were positively correlated with water temperature at both sites, with the strongest correlations occurring between June and September from newly secreted shells at Dameron Marsh. Old, dark brown shells contained 10% to 23% and 1% to 6% less Mg/Ca and Sr/Ca, respectively, than new shells. Because a fossil assemblage of *L. matagordensis* will contain ~30% old shells (dark-brown), these results suggest that fossil Mg/Ca ratios yield an integrated late spring to summer temperature signal. Shell Mg/Ca and Sr/Ca ratios of specimens of *L. matagordensis* collected from living *Zostera* were positively correlated, suggesting that temperature may influence both elemental ratios. Mg/Ca and Sr/Ca ratios of fossil shells of the related species *Loxoconcha* sp. A obtained from four sediment cores were also studied and exhibited a weaker correlation between the two elemental ratios.

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**Keywords:** Ostracoda; Paleoclimatology; Ecology; Minor elements; Holocene; Seagrass

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## 1. Introduction

The chemical composition of ostracode shells has become an important tool in paleoenvironmental reconstruction of both lake (Chivas et al., 1986; Xia et al., 1997; Wansard et al., 1998; Ito et al. 2003) and marine systems (Dwyer et al., 1995; Corrège and De Deckker, 1997). Ostracodes are microcrustaceans that have bivalve shells comprised of the mineral calcite ( $\text{CaCO}_3$ ) and chitin. Unlike mollusks that exhibit accretionary growth, most ostracodes grow by molting their shells eight times during ontogeny. Following molting, calcification of the new shell occurs quickly, generally within a few hours (Turpen and Angell, 1971) to days (Chivas et al., 1983; Roca and Wansard, 1997), thus providing a chemical record representative of the environment in which it was formed.

Because ostracode shells are calcitic, magnesium and strontium can substitute for calcium in the calcite lattice. Several studies have shown that the rate at which Mg is incorporated into the shell depends primarily on water chemistry (Mg/Ca ratio of the host water) and temperature (Chivas et al., 1983; Engstrom and Nelson, 1991; De Deckker et al., 1999). It has also been proposed that the primary factor regulating Sr incorporation is water chemistry, specifically, the Sr/Ca ratio and salinity (Chivas et al., 1993). Several studies suggest, however, that the incorporation of Mg and Sr into the calcite lattice of some species is a function of more than just water chemistry and temperature (Xia et al., 1997; Wansard et al., 1998; Palacios-Fest and Dettman, 2001). For example, Sr/Ca ratios of the ostracode *Candona rawsoni*, living in a hyposaline lake, exhibited a positive covariance with shell Mg/Ca ratios indicating that Sr uptake increases with Mg content of the shell (Xia et al., 1997). In another study of lake ostracodes, *Candona neglecta*, *C. marchica* and *C. candida* exhibited high Mg shell contents even though they grew in water with low Mg/Ca values ( $\leq 2$ ) (Wansard et al., 1998). Recently, it has been suggested that the elemental composition of the *Cypridopsis vidua* shell is primarily a function of ostracode biology and water temperature, with water chemistry playing a minor role (Palacios-Fest and Dettman, 2001).

The extent to which shell chemistry can be accurately applied to environmental reconstruction

depends on an understanding of the chemical and biological mechanisms and ecological factors that govern shell secretion and chemical composition. Laboratory culturing studies have examined ostracode biology and ecology in relation to shell chemistry composition (Xia et al., 1997; De Deckker et al., 1999), but few studies have been conducted under natural field conditions. Frequent sampling in natural conditions is important for understanding the effects of seasonal climate variability on breeding cycle, molting, shell formation and general life history; effects that cannot be mimicked in artificially cultured environments.

This study expands the research of Cronin et al. (in press), which provides a discussion of *Loxococoncha* shell size, intra-shell Mg/Ca variability, and preliminary shell chemistry for a Mg/Ca: temperature calibration based on four Atlantic Ocean *Loxococoncha* species. In the current study, we investigated the population dynamics of the ostracode *Loxococoncha matagordensis*, with relation to shell chemistry composition over a 6-month period in the Chesapeake Bay. *Loxococoncha matagordensis* is a phytal species first described by Swain (1955) from San Antonio Bay, Texas. *L. matagordensis* tolerates a wide salinity range (~15–30 ppt) and lives mainly on leaf blades of the seagrass *Zostera marina* found growing along the North Atlantic and Gulf coasts of North America. Biological factors such as breeding cycle, ontogeny, and the relationship between *Z. marina* and *L. matagordensis* population density were analyzed. In addition, the chemical composition of *L. matagordensis* shells (Mg/Ca and Sr/Ca ratios) was compared with water temperature and salinity, and the relationship between Mg/Ca and Sr/Ca elemental ratios in a related species, *Loxococoncha* sp. A. occurring in sediment cores was evaluated.

## 2. Materials and methods

### 2.1. Dameron marsh

Dameron is a brackish marsh located between 37°46' 30" N and 37°47' 30" N and 76°17' W and 76°18' W that forms the southern peninsula shore of Ingram Bay, a tributary of the Chesapeake Bay (Fig. 1). The site has an abundance of both emergent and

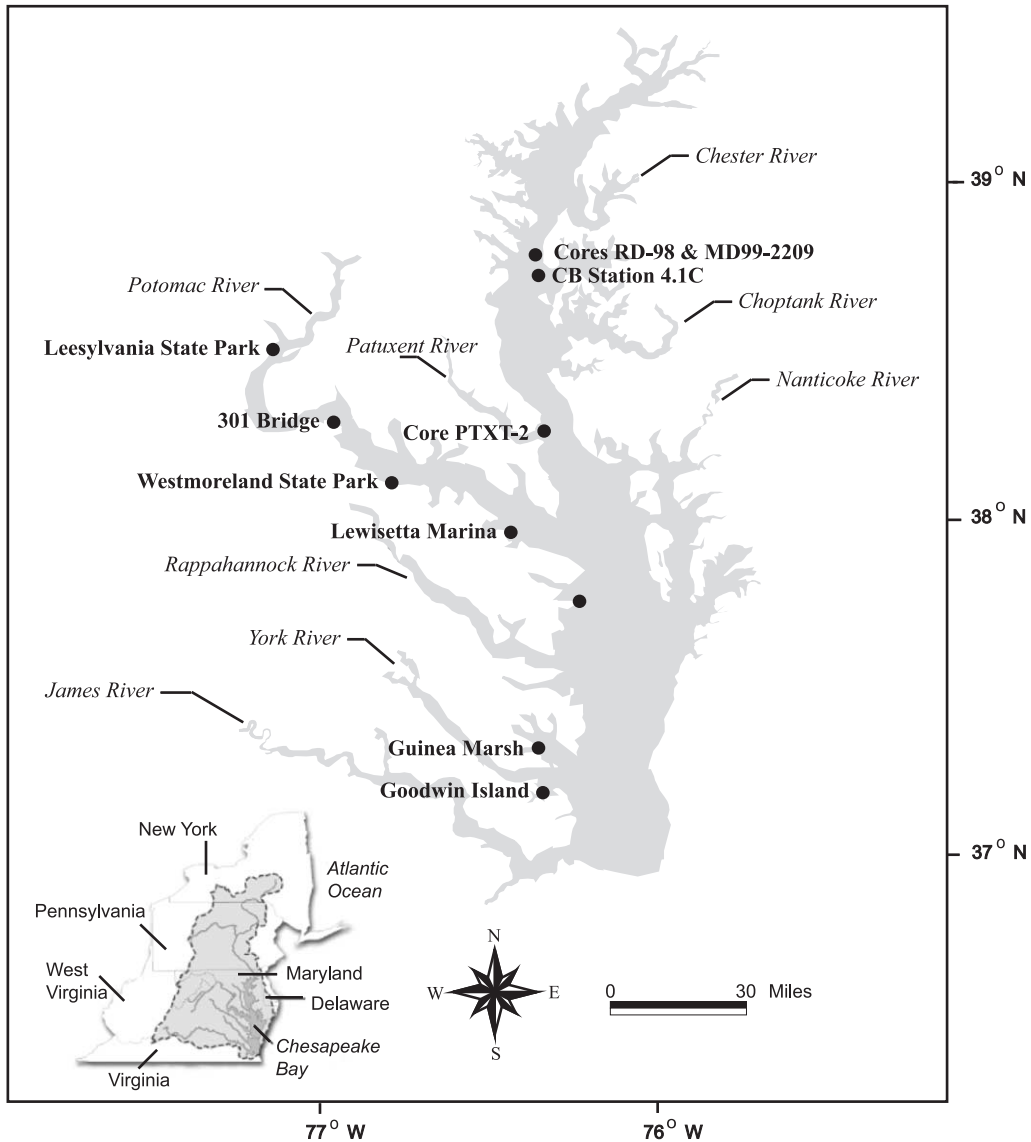


Fig. 1. Map of Chesapeake Bay showing the three study sites.

submerged aquatic vegetation that consists primarily of emergent *Juncus roemerianus*, *Spartina* sp., *Myrica* sp. and submerged *Z. marina* and *Ruppia* sp. Climatic conditions over the course of the 6-month experiment are presented in Table 1.

Two sub-sites were selected for this study. Site 1, (37°47' 4.3" N; 76° 17' 44.3" W) is characterized by three *Z. marina* beds, each <2.3 m<sup>2</sup>, located within 5.8 m of shore at a depth of ~0.5 m with no other seagrass beds in close proximity. During the study period,

water temperature was 7.8 to 30.3 °C and the salinity range was 13.5–17.9 ppt. A thin layer (<0.5 cm) of peat was consistently present on the sediment surface, indicating a greater input of organic matter from the adjacent *Spartina patens* at this site than at Site 2. Site 2, (37°47' 8.9" N; 76°17' 31.4" W) located ~0.5 km from Site 1, is characterized by larger *Z. marina* beds, each >3 m<sup>2</sup>, with many other beds in close proximity to our study beds. *Zostera marina* study beds were within 10 to 14 m of shore at a water depth of ~1 m.

Table 1

Mean air temperature (°C) and precipitation (cm) for Virginia between March and August 2001 (Website: <http://lwf.ncdc.noaa.gov>)

Date	Mean air temperature	Mean air temperature (°C)	Mean Precipitation	Mean Precipitation (cm)
March 2001	Below Normal	5.4	Above Normal	11.4
April 2001	Above Normal	13.7	Much Below Normal	4.1
May 2001	Normal	17.1	Above Normal	12.6
June 2001	Normal	21.9	Above Normal	11.9
July 2001	Much Below Normal	22.2	Above Normal	12.9
August 2001	Above Normal	23.8	Normal	9.6

Water temperature and salinity ranges were consistent with those of Site 1, except on 03 March 2001, when water temperature was 7.1 °C and salinity was 18.3 ppt yielding a difference between the two sites of 0.7 °C and 0.4 ppt, respectively.

Thousands of *Z. marina* leaves were collected from both sites by hand twice per month between March and September 2001, and placed into plastic bags and kept on ice until processing. Five *Z. marina* leaf blades per collection date were randomly selected for height and width measurements. All *Z. marina* leaves were dried at 45 °C for 5 days and weighed for biomass determination. Water temperature and salinity were measured at the time of collection using a portable conductivity, salinity and temperature meter (YSI 30) with an accuracy of  $\pm 0.1$  °C and  $\pm 1\%$ , respectively.

*Loxococoncha matagordensis* specimens were isolated from *Z. marina* leaf blades by washing the leaves through a 63- $\mu$ m sieve at the USGS ostracode lab, Reston, VA. The contents of the sieve were placed in a filter paper funnel and oven-dried at 45 °C. Ostracode carapaces that were alive at the time of collection and contained soft body parts, were picked from the dried sediment using a fine brush, placed on microfaunal slides and identified to the species level. Adult *L. matagordensis* specimens were categorized as translucent-clean or brown-dirty according to the terminology of Kamiya (1988), who showed that older adults accumulate organic debris on the exterior of their shells, leading to the brown-dirty appearance. This distinction allowed newly secreted shells to be differentiated from old, dark-brown shells.

Geochemical analyses (Section 2.4) were performed on individual *L. matagordensis* specimens from Dameron Marsh, Site 2 for each collection date between March and September 2001. Five adult

female carapaces, 0.27 to 0.30 mm in length, were selected from each collection date (Dameron Marsh) for analysis. In addition, 20 carapaces, 10 old and 10 new, from the 01 and 15 June 2001, collections were analyzed in order to compare the chemical composition of old versus new specimens.

## 2.2. York River

The York River is a major tributary of the Chesapeake Bay with a watershed covering approximately 1.7 million acres of the Virginia coastal plain. Two sites at the mouth of the York River, Guinea Marsh (latitude 37°16' N; 76°23' W) and Goodwin Island (latitude 37°13' N; 76°23' W), were selected for geochemical analysis of *L. matagordensis* because of healthy *Z. marina* beds and more than a decade of water quality monitoring by the Virginia Institute of Marine Science (VIMS) (Moore and Berry-Niekirk, personal communication, 2002). Seasonal variations in water temperature and salinity ranged from 13 to 27.2 °C and 12.2 to 20.5 ppt, respectively, at both sites.

*Zostera marina* samples were collected monthly between March and September 2000, by the US Geological Survey, in cooperation with the Virginia Institute of Marine Science. A post-hole device was used to collect a composite sample of sediment and *Z. marina* in ~1 m of water from both sites. After collection, *Z. marina* leaves were immediately separated from the sediment to minimize epiphytal and benthic ostracode species mixing, placed in separate sealed plastic bags in cooled containers, and shipped overnight to the USGS ostracode lab. Water temperature and salinity were measured at the time of collection.

*Loxococoncha matagordensis* specimens were isolated and picked from *Z. marina* samples following

procedures used for Dameron Marsh samples. Five adult female carapaces of *L. matagordensis*, 0.27 to 0.30 cm in length, were selected for each collection date for individual shell geochemical analysis.

### 2.3. Chesapeake Bay sediment cores

Four sediment cores, RD-K-98, MD99-2209, PTXT-2-P-5 and PTMC-3, were taken in the Chesapeake Bay at 38°53.20'N and 76°23.50'W; 38°19.58'N and 76°23.55'W; 38°01.61'N and 76°13.19'W, respectively (see Cronin et al., 2003 for core data and chronology). Cores RD-K-98 (~400 cm) and MD99-2209 (1720 cm) were from the same location and the uppermost 800 cm of MD99-2209 were spliced together with the RD-K-98 record to provide the longest record of fossil *Loxoconcha* shells that dated back to ~2200 years before present. PTXT-2-P-5 and PTMC-3 were shorter cores, total depths of 397 and 366 cm, and contained fossil *Loxoconcha* sp. shells that dated back to 475 and 734 years before present, respectively.

Sediment core samples were taken at 2-cm intervals and washed through a 63- $\mu$ m sieve at the USGS ostracode lab. The contents of the sieve were placed in a filter paper funnel and dried for 1 day at 45 °C. In contrast to the shallow water seagrass habitat of *L. matagordensis*, these cores were taken in the deeper (11 to >40 m) main channel of Chesapeake Bay, which is inhabited by a related species of *Loxoconcha*, referred to here as *Loxoconcha* sp. A. Adult shells of *Loxoconcha* sp. A were picked from the dried sediment and placed on microfaunal slides prior to geochemical analyses. From each 2-cm interval, one to five fossil adult carapaces or valves of *L. sp. A* were selected for geochemical analysis.

### 2.4. Geochemical analysis

Geochemical analyses were performed on individual *L. matagordensis* specimens from either Guinea Marsh or Goodwin Island and Dameron Marsh, Site 2 for each collection date between March and September 2000 and 2001, respectively. Five replicate adult carapaces per collection date from both Dameron Marsh and York River sites and between one and five fossil adult carapaces or valves per 2-cm interval

(Chesapeake Bay sediment cores) were soaked in 100% Clorox (5% by volume sodium hypochlorite) for 24 h to remove organic matter. An additional 20 carapaces, 10 old and 10 new, from the June 1 and 15 Dameron Marsh collections were soaked for the old versus new trace element comparison. Carapaces were then rinsed four times with deionized water, with the final two rinses under gentle sonication. One valve per carapace was dissolved for 24 h in 3 ml of 0.05 N nitric acid and analyzed for magnesium, calcium, strontium and sodium (not addressed in this paper) using a Spectrascan 7 direct current plasma (DCP) emission spectrometer at Duke University (Dwyer et al. 1995). Replicate analyses of samples and standards yielded an analytical precision of  $\pm 3\%$  and a limestone standard (Duke PE3) yielded a Mg/Ca reading of 8.40 mmol/mol and a Sr/Ca reading of 7.82 mmol/mol. The data presented in this paper are available at the following URL: <http://geology.er.usgs.gov/eespteam/Atlantic/>.

## 3. Statistical analyses

Linear regression analyses were performed to establish the relationship between water temperature and shell Mg/Ca and Sr/Ca ratios and *Z. marina* height. A paired *t*-test, confidence level 99%, was used to compare Mg/Ca and Sr/Ca ratios of old and new shells.

## 4. Results

### 4.1. *Zostera marina* growth cycle—Dameron Marsh

*Zostera marina* leaf blades began emerging from underground rhizomes between February and March 2001, with average heights of 11.4 and 9.5 cm at Sites 1 and 2, respectively (Fig. 2). *Zostera marina* leaf blade height was positively correlated with water temperature at both sites (Fig. 3). As the growing season progressed and water temperatures increased, leaf blade height increased. The correlations between *L. matagordensis* populations and *Z. marina* height were not significant at either Site 1 or Site 2. *Zostera marina* decreased in density between 02 July 2001 and 04 September 2001.

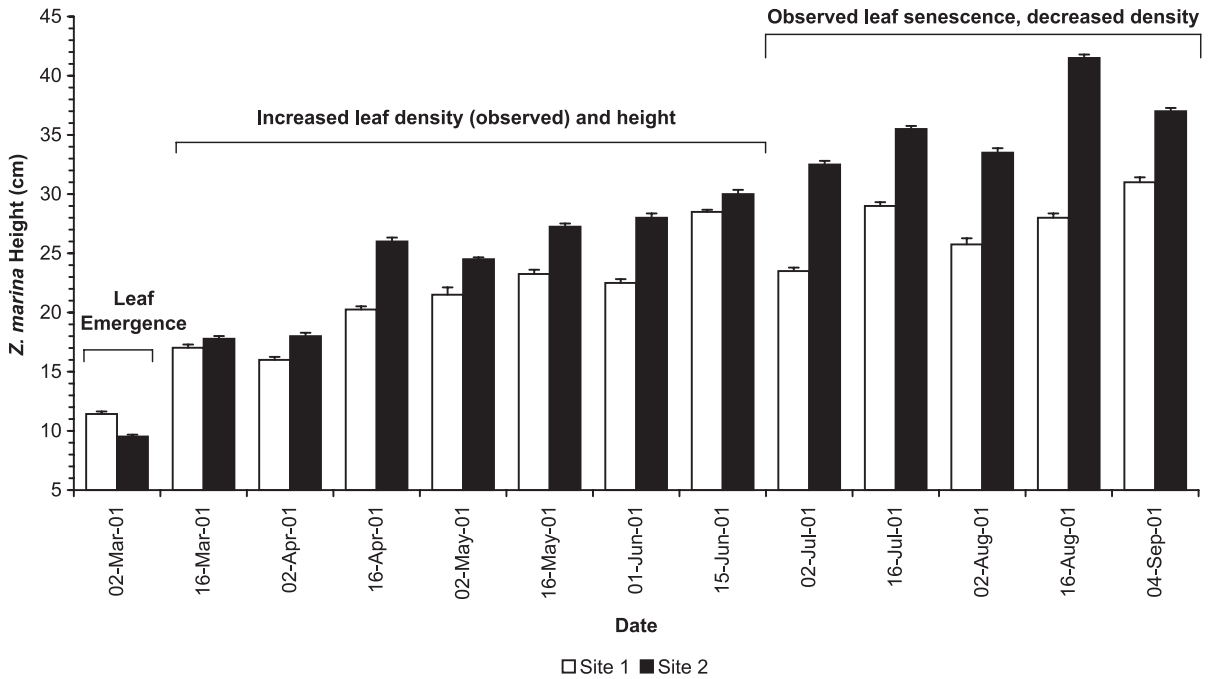


Fig. 2. Seasonal changes in *Z. marina* height for each collection date at Dameron Marsh Sites 1 and 2.

4.2. *Loxoconcha matagordensis* breeding cycle—*Dameron Marsh*

*Loxoconcha matagordensis* had two main breeding cycles between March to September 2001, which

preceded juvenile population peaks by ~15 to 30 days; the first breeding cycle was from 01 to 15 June 2001 and the second cycle was from 02 to 16 August 2001 (Fig. 4). The length of time between the breeding cycles was approximately 2 months. The number of

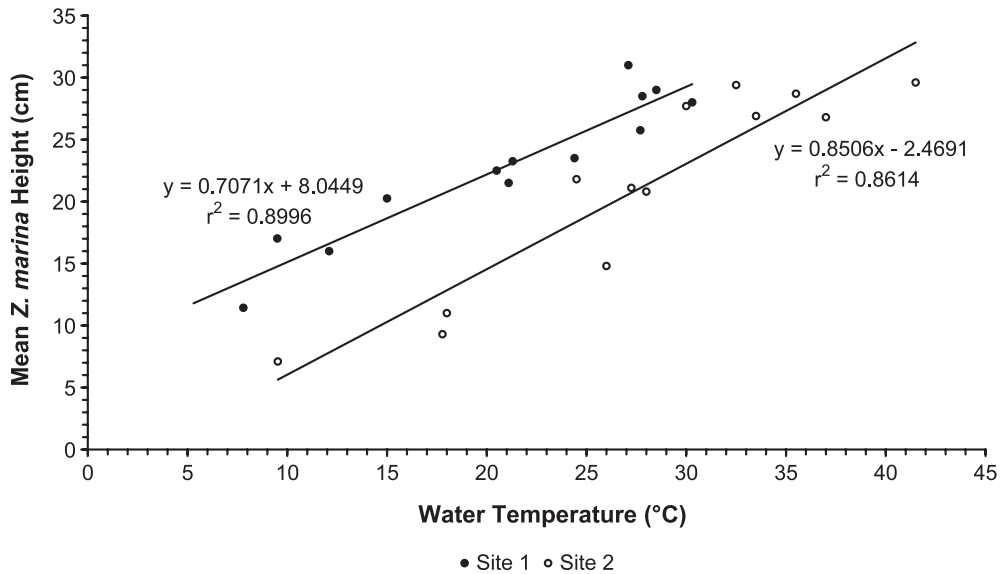


Fig. 3. Linear regression analyses of mean *Z. marina* height versus water temperature for each collection date at Dameron Marsh Sites 1 and 2.

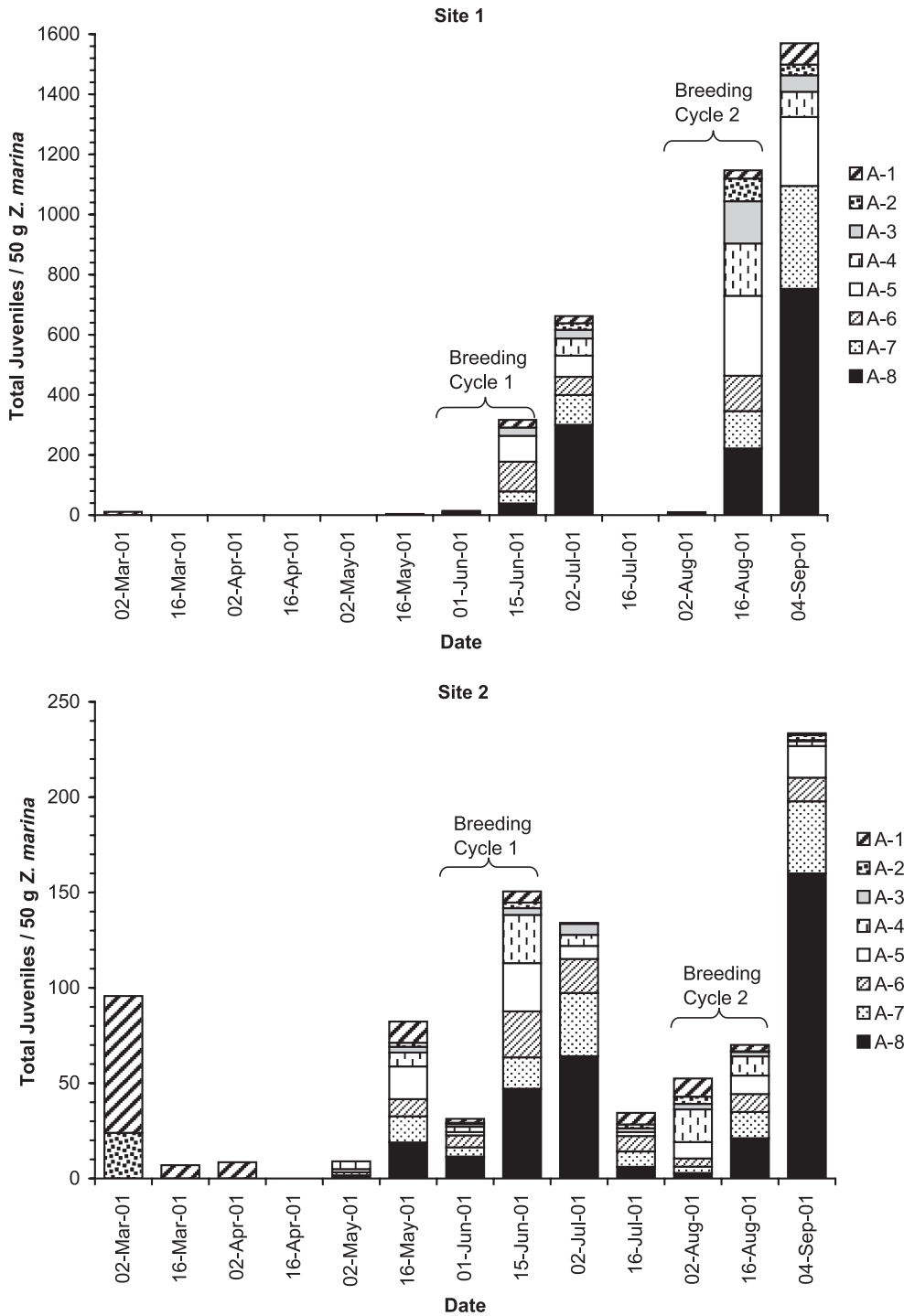


Fig. 4. Seasonal changes in juvenile population structure at Dameron Marsh, Sites 1 and 2. A-1 through A-8 stand for pre-adult molt stages (instars); A-1 is the pre-adult stage. Breeding cycles immediately precede peak total juvenile populations and A-8 instar production.

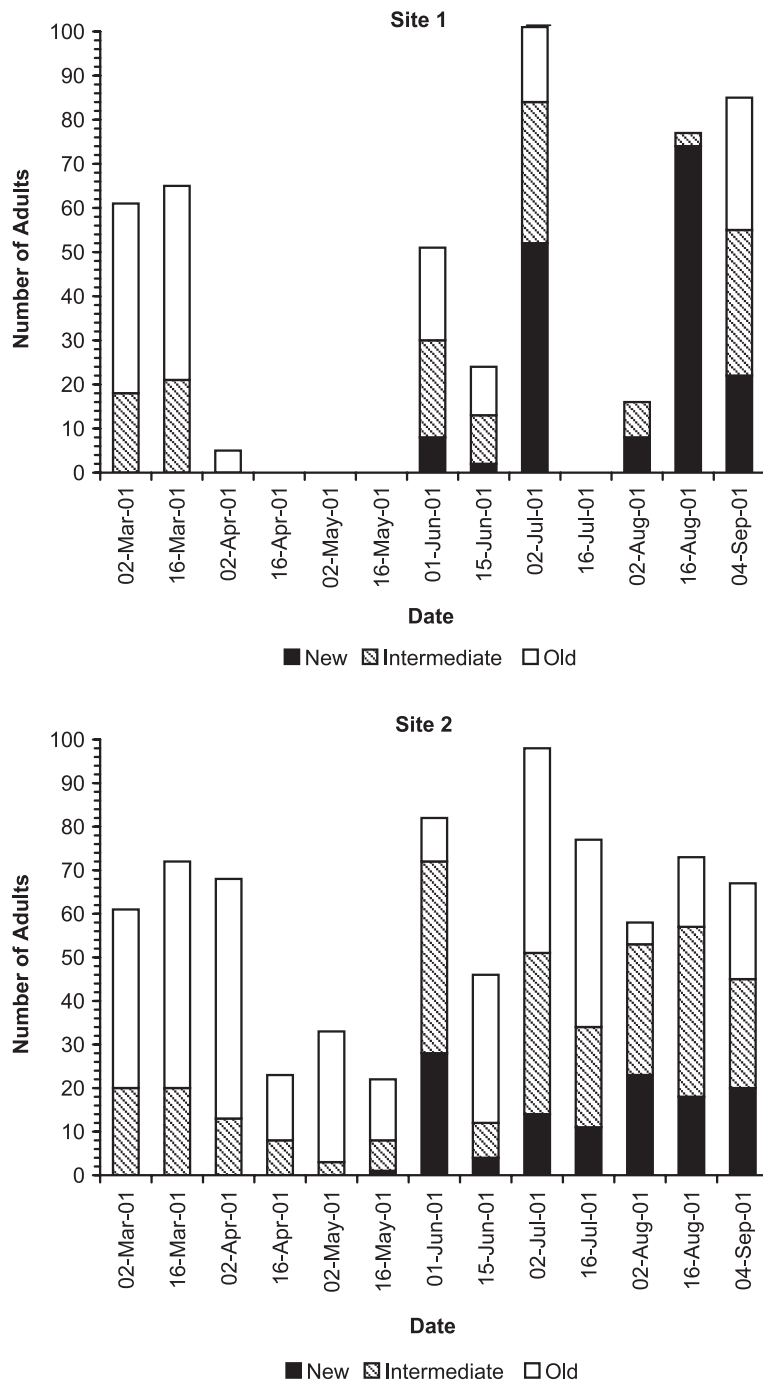


Fig. 5. Seasonal age distribution of adult (male and female) *L. matagordensis* at Dameron Marsh sites 1 and 2. New=clear translucent shell, Intermediate=transparent brown shell and Old=opaque dark brown shell.



juveniles produced increased from June to September with the second cycle producing the largest number of total juvenile (2679) individuals per unit volume of seagrass. In addition, juvenile production closely paralleled increases in water temperature.

Old, dark-brown shelled adults were present between March to April 2001, and most likely represented individuals that over-wintered from the fall of 2000. New, clear-shelled adults did not appear until 16 May to 01 June 2001 (Fig. 5).

Peak populations of new, clear-shelled adults occurred on 01 June, 02 July and 16 August 2001 (Site 1), and 02 August 2001 (Site 2). Female adults accounted for 59% to 100% of the total adult population, except for the period between 01 June and 02 July 2001, when females accounted for only 41% to 58% of the adult population. The number of males exceeded the number of females by 9% to 17% on 01 and 15 June 2001, at Site 1 (Fig. 6).

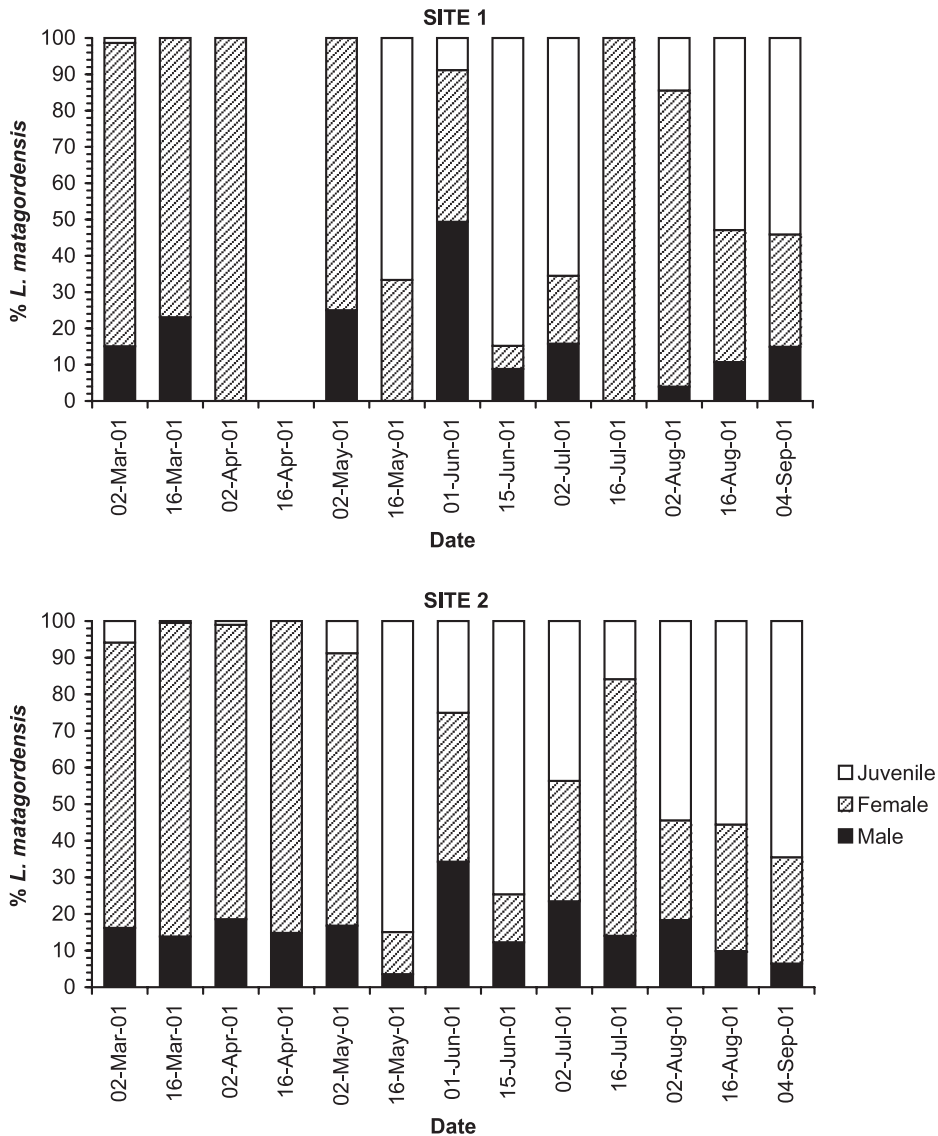


Fig. 6. Seasonal population structure of adults and juveniles for each collection date at Dameron Marsh Sites 1 and 2.

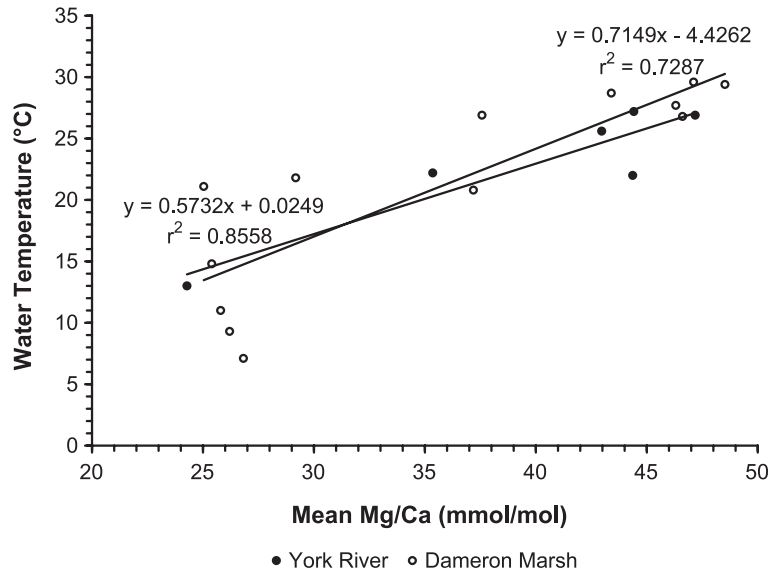


Fig. 7. Linear regression analyses of mean Mg/Ca ratios of adult shells versus water temperature at Dameron Marsh, Site 2 and York River.

#### 4.3. Geochemical Analyses

Mg/Ca and Sr/Ca ratios of adult *L. matagordensis* shells were positively correlated with water temperature at the Dameron Marsh and York River sites (Figs. 7 and 8). At Dameron Marsh, this correlation was strongest between 01 June and 04 September

2001, the time period in which there was a predominance of new to intermediate aged *L. matagordensis* (Figs. 9 and 10). Mg/Ca ratios of old shells collected from 03 March and 01 June 2001, were not correlated with water temperature and Sr/Ca correlations were lower. Old *L. matagordensis* shells collected from Dameron Marsh on 01 and 16 June

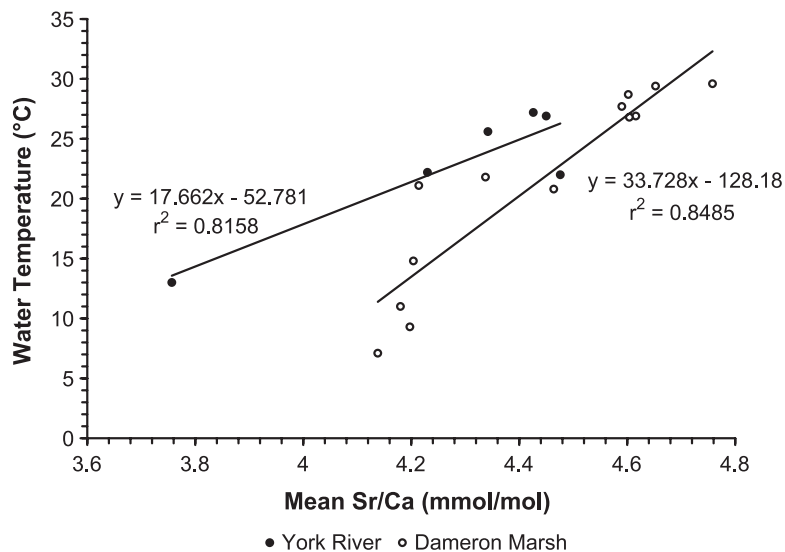


Fig. 8. Linear regression analyses of mean Sr/Ca ratios of adult shells versus water temperature at Dameron Marsh, Site 2 and York River.

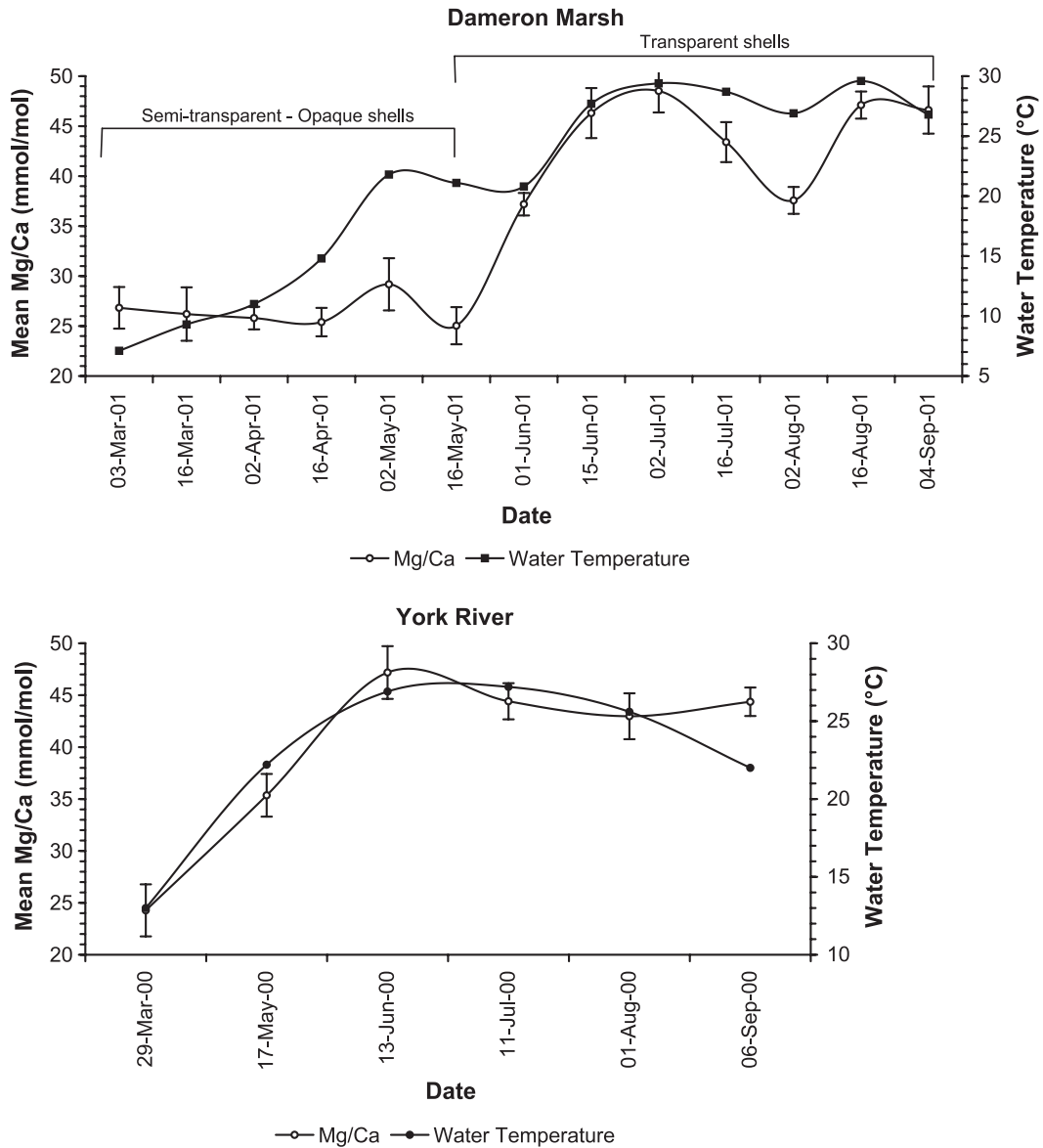


Fig. 9. Relationship between mean Mg/Ca ratios of adult shells and water temperature for each collection date at Dameron Marsh, Site 2 and York River. Semi-transparent–opaque shells that wintered-over from the previous season are less correlated with water temperature than newly secreted transparent shells at Dameron Marsh, Site 2.

2001, contained 10% to 23% and 1% to 6% less Mg/Ca and Sr/Ca, respectively, than newly secreted shells.

Shell Mg/Ca ratios were positively correlated with Sr/Ca ratios at both Dameron Marsh and York River (Fig. 11), however, water salinity showed no apparent correlation with Mg/Ca or Sr/Ca ratios at either site.

In contrast to the living *L. matagordensis*, fossil shells of *Loxoconcha* sp. A from three Chesapeake Bay sediment cores showed weak correlations between Mg/Ca and Sr/Ca ratios from the same shells (Fig. 12a). Moreover, both Mg/Ca and Sr/Ca ratios are generally lower for *Loxoconcha* sp. A than those for *L. matagordensis*. However, there are

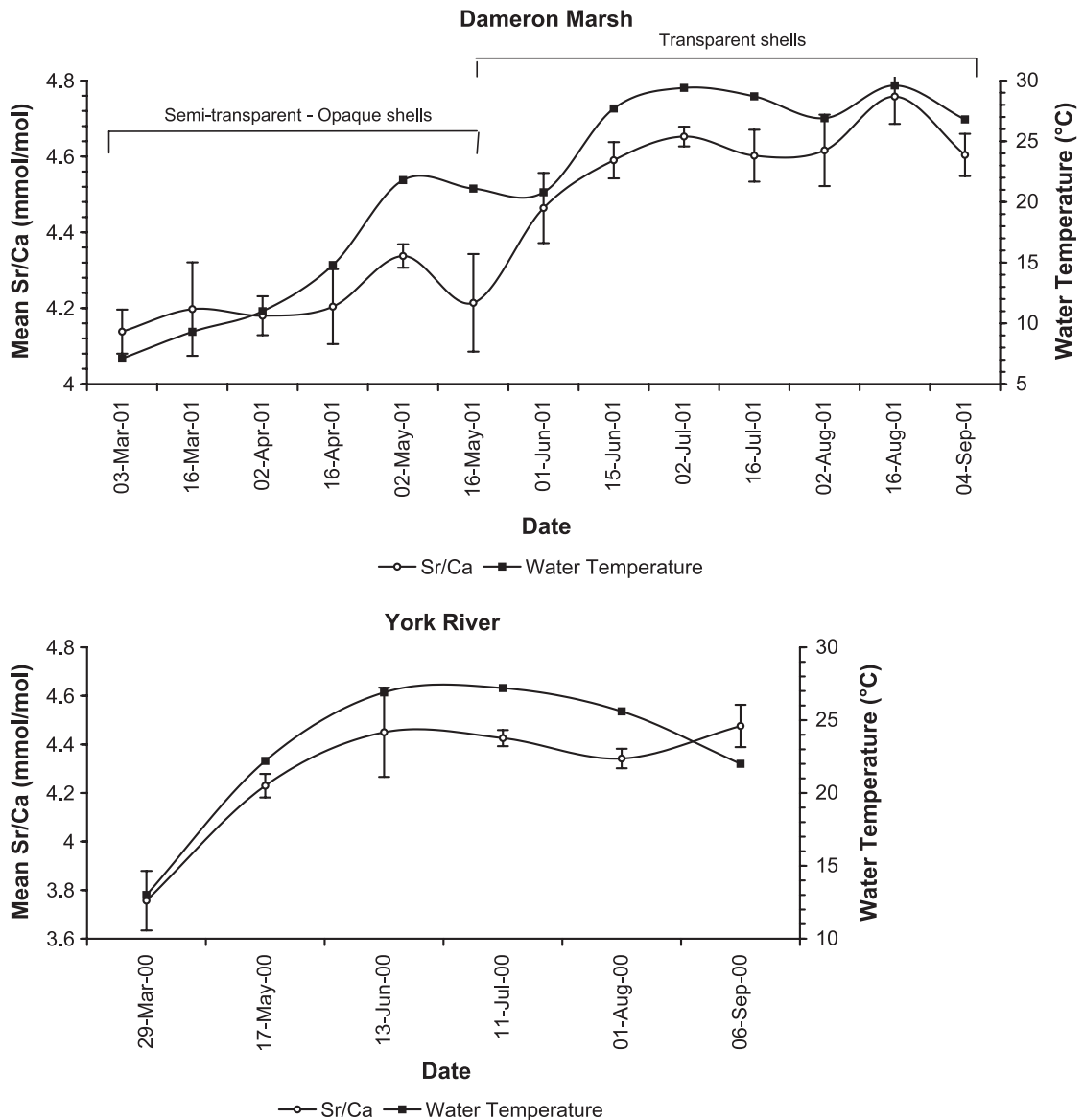


Fig. 10. Relationship between mean Sr/Ca ratios of adult shells and water temperature for each collection date at Dameron Marsh, Site 2 and York River. Semi-transparent–opaque shells that wintered-over from the previous season are less correlated with water temperature than newly secreted transparent shells at Dameron Marsh, Site 2.

notable periods of low Mg/Ca and Sr/Ca ratios in core PTXT-2-P-5 (~1530–1550, 1680, 1780–1810, 1840 AD) and core RD-K-98 (~1750, 1790, 1840–1850 AD) (Fig. 12b), which seem to signify cool regional conditions during parts of the Little Ice Age (Cronin et al., 2003).

## 5. Discussion and conclusions

This is the first study to investigate breeding cycles, population structure and shell chemistry of *Loxococoncha* in a natural estuarine environment. In this study, we determined that two breeding cycles

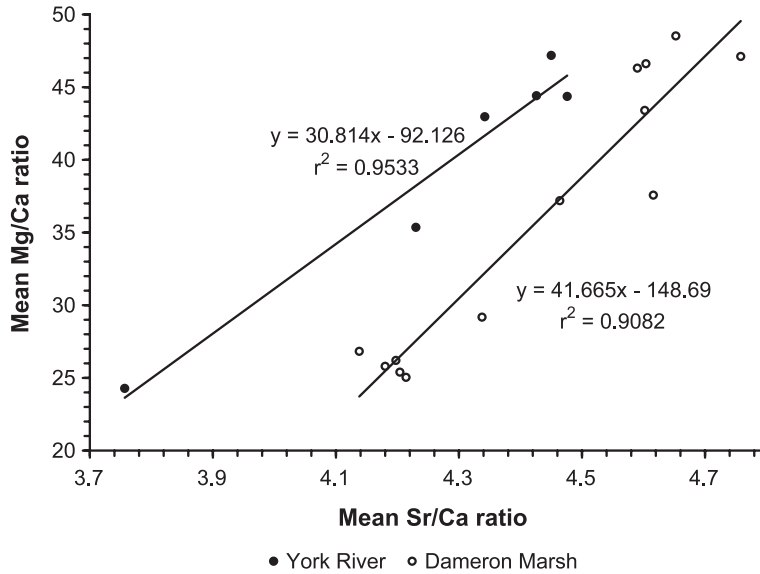


Fig. 11. Linear regression analyses of mean Sr/Ca versus mean Mg/Ca ratios at Dameron Marsh, Site 2 and York River.

occurred between March and September 2001 at Dameron Marsh. Each breeding cycle produced a progressively greater number of juveniles, with the largest numbers produced from the second breeding

cycle in August 2001. This late season increase in production is most likely a survival strategy that ensures continued existence from one season to another and from year to year.

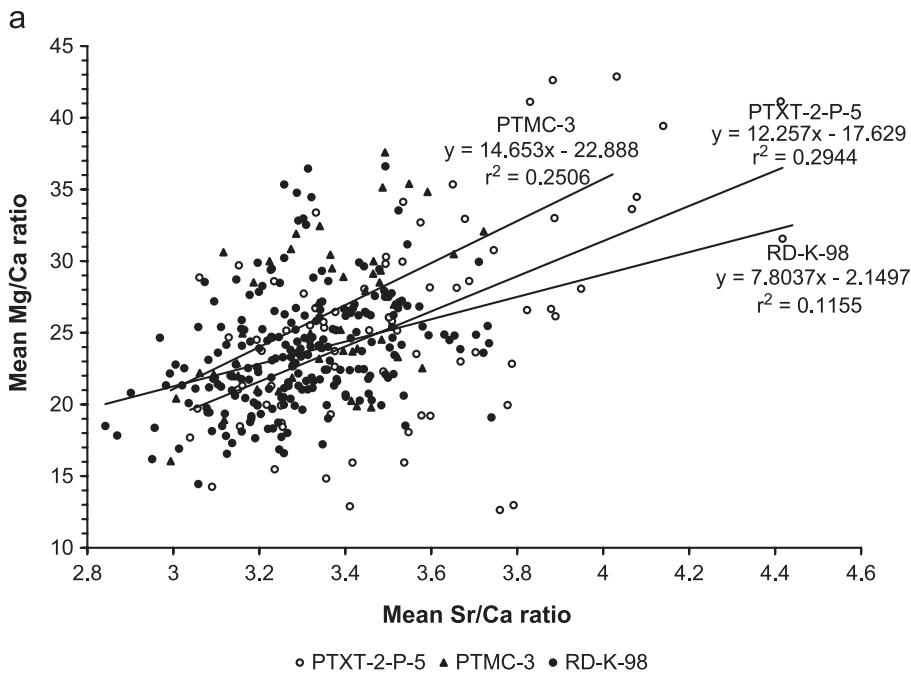


Fig. 12. (a) Regressions of Sr/Ca and Mg/Ca ratios of fossil shells of *Loxoconcha* sp. A from sediment cores RD-K-98/MD99-2209, PTXT-2-P-5 and PTMC-3, from the Chesapeake Bay. (b) Same downcore Sr/Ca and Mg/Ca data plotted against age (see Cronin et al. 2003 for age data).

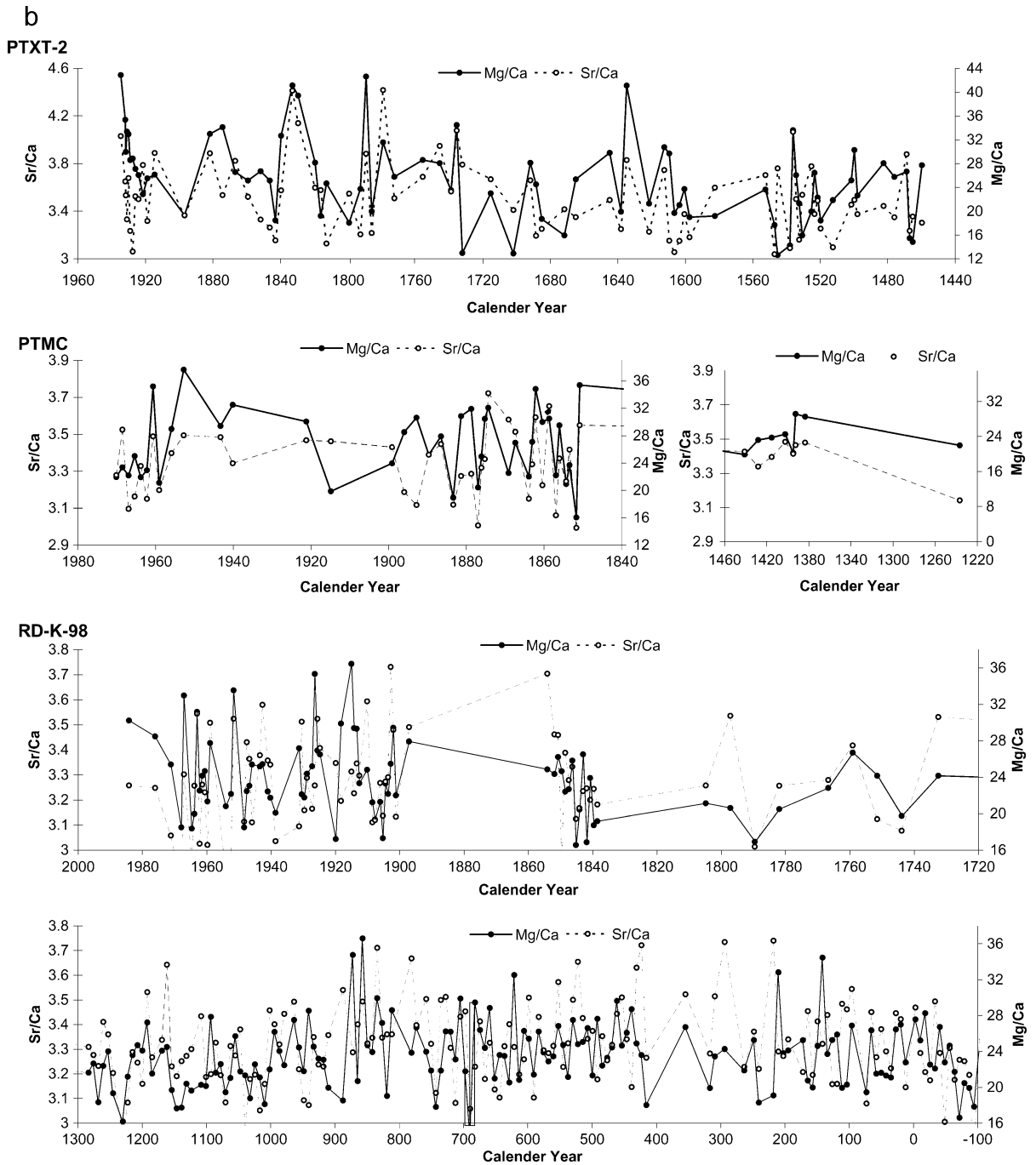


Fig. 12 (continued).

Because water temperature affects several physiological processes in ostracodes, it is most likely a major factor that influences the time of breeding.

Theisen (1966) showed that a minimum water temperature of 8 to 12 °C was required for egg development in the brackish-water species, *Loxocon-*

*cha elliptica* (Brady). In addition, water temperature acts as a secondary regulator in the molt cycle of all crustaceans (Aiken and Waddy, 1992; Skinner, 1985). A culture study of the ostracode *Krithe praetexta praetexta* showed that warmer temperatures (14 °C) resulted in more rapid ontogenetic development than cooler temperatures (5 and 10 °C) (Majoran et al., 2000).

Breeding time may also be influenced by the seasonal growth characteristics of the seagrass *Z. marina*. Our results show that *Z. marina* height is strongly correlated with water temperature at both

study sites, and that leaf senescence begins in mid-June resulting in a progressive decrease in habitat density through 04 September 2001. When the habitat decreases to a certain point, the second breeding cycle is likely initiated. Thus, water temperature may indirectly regulate *L. matagordensis* breeding time by affecting the habitat on which it lives.

Water salinity did not affect breeding time in this experiment. Salinity levels declined between 03 March 2001 and 02 July 2001 at both Dameron Marsh sites due to above normal precipitation during this period (Fig. 13). This salinity decline and the

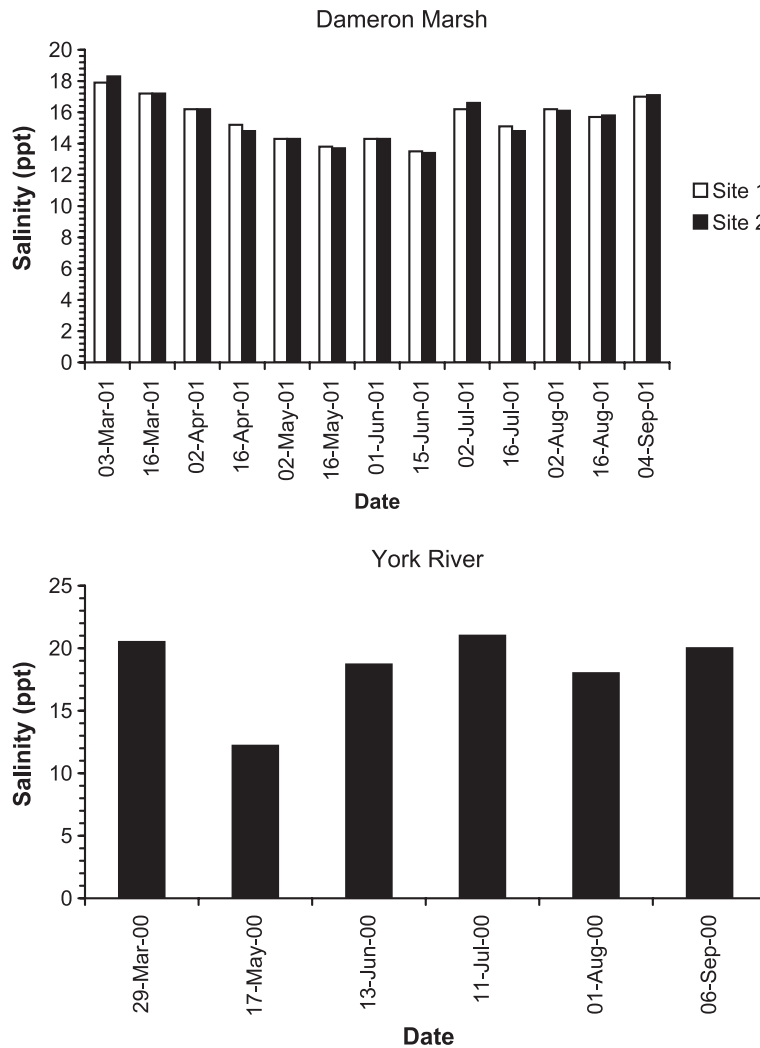


Fig. 13. Water salinity levels at Dameron Marsh and York River.

small amount of variance in salinity levels, 4.3 ppt, over the course of the experiment showed no relationship with the time of breeding.

Although two breeding cycles were apparent, there was continuous juvenile production from May to September 2001, especially at Dameron Marsh Site 2. Juvenile production was 53% to 100% lower at intermittent times than directly after peak breeding cycles. This continued production after peak breeding most likely occurred as a result of instars being discharged over a period of time, instead of all at once. In a culturing study of *Xestoleberis hanaii* Ishizaki, Ikeya and Kato (2000) found that the order in which the eggs were laid determined the time of hatching; eggs laid first, hatched first. *Xestoleberis hanaii* Ishizaki instars were subsequently released at a rate of two to three per day from the adult carapace and total discharge of all instars took ten to fifteen days (Ikeya and Kato, 2000).

Continuous calcification of new adult shells throughout the breeding season introduces variability when using minor element analyses of adult shells for paleoenvironmental reconstruction. Although Sr/Ca and Mg/Ca ratios can vary by as much as 6% to 23%, respectively, between new and old shells, our results indicate that water temperature is strongly correlated with both Sr/Ca and Mg/Ca ratios between March and September. These results are consistent with several previous studies that have suggested water temperature as a dominant factor controlling Mg/Ca ratios in ostracode shells (Chivas et al., 1983; Engstrom and Nelson, 1991; De Deckker et al., 1999).

The incorporation of Sr into the shell, however, is more complex and poorly understood. Some studies have suggested that Sr uptake is regulated by water chemistry, specifically the Sr/Ca ratio and salinity of the host water, and is independent of temperature (Chivas et al., 1993). In contrast, Xia et al. (1997) reports a strong positive covariance between Mg/Ca and Sr/Ca ratios of the lacustrine ostracode *C. rawsoni*, suggesting that the Mg content of the shell directly affects Sr uptake by either crystallography (as the shell Mg content increases, the calcite structure becomes more distorted thereby allowing for greater Sr uptake) or, possibly, because of the large amount of physio-

logical energy required to exclude Mg and/or Sr during calcification. If the shell Mg/Ca ratio is primarily regulated by water temperature as suggested, this Mg/Ca–Sr/Ca correlation would indicate that seasonal variability in shell Sr/Ca ratios is an indirect result of fluctuating water temperatures (Xia et al., 1997). In this study, water salinity varied within a range of only 4.9 and 8.3 ppt between March and September at Dameron Marsh and York River, respectively (Fig. 13), and salinity was not correlated with shell Sr/Ca ratios. In addition, shell Sr/Ca ratios were strongly correlated with water temperature for Dameron Marsh and York River and with shell Mg/Ca ratios for Dameron Marsh and York River. These results suggest that the seasonal variability in shell Sr/Ca ratios may be indirectly regulated by changes in water temperature.

In contrast to this study, a strong positive correlation between shell Sr/Ca and Mg/Ca was absent (Dwyer et al., 2002) in laboratory culturing experiments on *L. matagordensis*, perhaps due to weak calcification or other unnatural environmental factors in the cultures. A positive correlation between Mg/Ca and Sr/Ca was also absent in sub-tropical Florida Bay populations of *Loxococoncha* (Dwyer and Cronin, 2001) and in the deep-sea ostracode genus *Krithe* (Cronin et al., 1996). Because Sr/Ca ratios increase with precipitation rate in inorganic calcite (Morse and Mackenzie, 1990), our study suggests that *L. matagordensis* populations from temperate regions like Chesapeake Bay may behave in a similar fashion and precipitate their shells more rapidly in warmer water than in colder water, leading to the apparent temperature–Sr/Ca relationship. In other words, temperature variation in the Chesapeake Bay may be sufficiently large to affect calcification rates, and thereby lead to the observed Mg/Ca:Sr/Ca covariation. The lack of an obvious correlation between Mg/Ca and Sr/Ca ratios in the fossil *Loxococoncha* sp. A may indicate ‘vital’ effects between the two species in terms of Sr substitution during calcification, different seasonal ecology, or unknown hydrological factors.

#### Acknowledgements

We thank Drs. K. Moore, R. Orth and B. Berry-Niekirk and their staff at the Virginia Institute of



Marine Science for the collection of York River seagrass samples. We are grateful to J. Damon, C. Nytch, A. Lavenburg and D. Korejwo for their assistance in the collection of seagrass at Dameron Marsh. Drs. B. Wardlaw and J. Self-Trail kindly provided useful reviews of the manuscript.

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