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Chapter 16

Ostracods and sea level

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16.1 INTRODUCTION

Ostracods are small (~0.5–2 mm length) meiofaunal Crustacea whose low-magnesium calcite ($CaCO_3$) shells are preserved as microfossils in lacustrine, estuarine, and marine sediments. A total of approximately 65,000 ostracod species had been described as of 2005 (Ikeya et al., 2005) and, although estimates vary, there may be 20,000 species living today (Rodriguez-Lazaro and Ruiz-Muñoz, 2012). Ostracods inhabit virtually all types of non-marine and marine aquatic environments, including intertidal and subtidal zones in coastal marshes, mudflats, estuaries, bays, and coral reef complexes. A few species even live in moist supratidal terrestrial habitats (Horne et al., 2004). Many species have physiological limits on their survival and/or reproduction to specific temperature and salinity ranges, and most species are adapted to certain substrate types (i.e., mud, sand, submerged aquatic vegetation). Consequently, marginal marine ostracods have been used for reconstructing changes in relative sea level (Cronin, 1987; Penney, 1987; De Deckker and Yokoyama, 2009) and they have been used in numerous studies of coastal zones, mostly in northern Europe, the Mediterranean, parts of North America, and the Indo-Pacific region (Boomer and Eisenhauer, 2002; Frenzel and Boomer, 2005).

This chapter discusses biological and ecological attributes that make ostracods unique sea-level indicators, distinct from other biological proxies, and provides examples where they have been applied to sea-level reconstruction. This focus is on the practical application of species' ecology to paleo-sea-level reconstruction using assemblages (also called associations, biofacies) from coastal sediment records. Although lack of space prevents a discussion of ostracod shell chemistry, it is noteworthy that pioneering studies of magnesium/calcium and strontium/calcium ratios in marginal marine ostracods were first applied to document changes in regional sea level (De Deckker et al., 1988; see also Dettman and Dwyer, 2012; Holmes and De Deckker, 2012).

16.2 TAXONOMY

Correct taxonomic identification of marginal marine species is the foundation of any study of sea level using species' ecology and faunal assemblages. The most useful introduction to the taxonomy of major ostracod groups is that of Horne et al. (2002); Ikeya et al. (2005) also provide a useful review of taxonomic schemes for ostracods. Regarding higher taxonomic groups, ostracod biologists often use "soft-tissue" features (i.e., appendages, copulatory apparatus) to distinguish groups, but these are not typically preserved in sediments. In paleo-sea-level studies, ostracod specialists therefore identify genera and species from morphological features of their $CaCO_3$ shells, notably species-specific patterns of sieve and radial pores, muscle scars, the calcified inner lamella and vestibule, hinge morphology along the dorsal margin, and carapace surface ornamentation, among others (Fig. 16.1). This requires knowledge of the taxonomy and inter- and intra-population morphological variability, which in some species can vary with environmental conditions such as salinity, hydrochemistry, and temperature.

16.3 REPRODUCTION, GROWTH AND SHELL MORPHOLOGY

Ostracods reproduce through a variety of mechanisms (cloning, parthenogenesis, brood care of eggs and/or young) but most species used in

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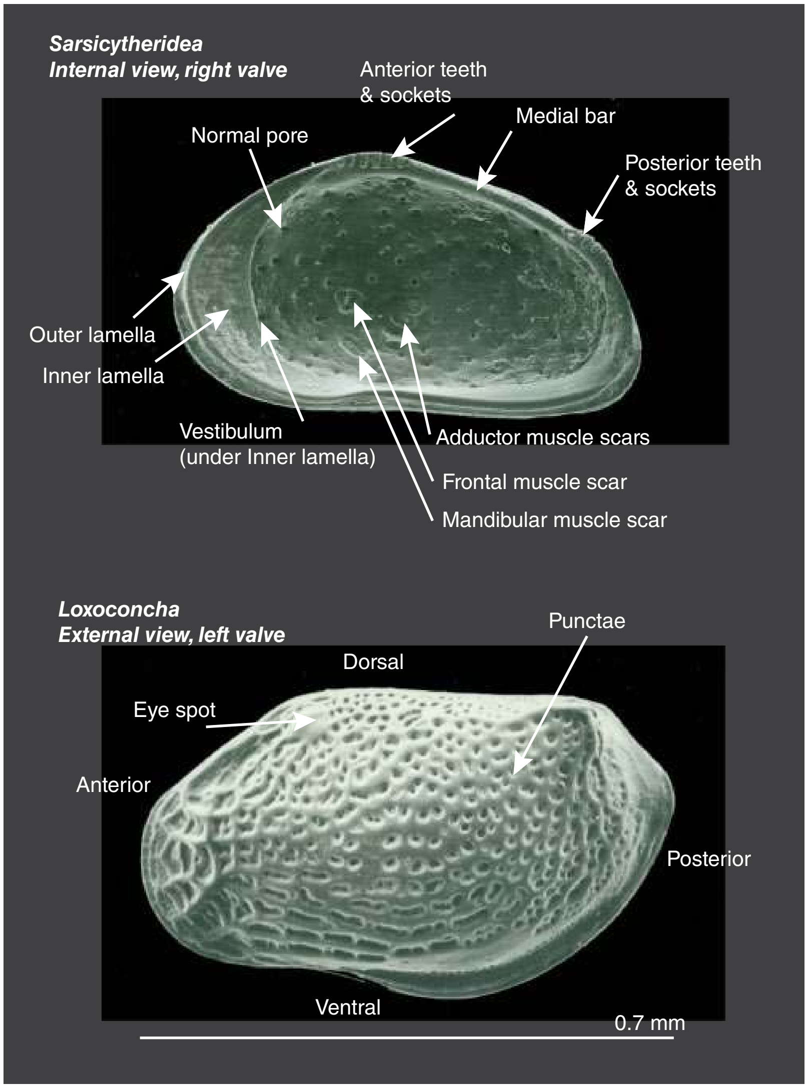

Fig. 16.1. Scanning electron photos of benthic ostracods *Sarsicytheridea* (top, internal view, right valve) from Late Pleistocene Champlain Sea, Quebec, Canada, and *Loxoconcha* (bottom, external view, left valve) from the continental shelf off North Carolina, US. Morphological features used in genus and species identification are shown. For discussion of basic ostracod morphology and taxonomy see Horne et al. (2002) and Rodriguez-Lazaro and Ruiz-Muñoz (2012).

sea-level studies are benthic in habitat, reproduce sexually, and either retain or deposit their eggs. With the exception of those taxa whose eggs are dispersed by birds (*Cyprideis*), or passively by floating marine algae, the lack of a mobile larval stage results in a high level of endemism for ostracods inhabiting coastal zones.

Intra-specific shell morphological variability comes from ostracod ontogeny, sexual dimorphism, and valve asymmetry (Rodriguez-Lazaro and Ruiz-Muñoz, 2012). Ostracods grow in discreet increments by molting (ecdysis) (Kesling, 1951), usually 7–9 molt stages, such that fossil assemblages consist of both adult and juvenile specimens. Shells of adults and 3–4 pre-adult molt stages are often represented in sediment from the >125 micron size fraction used in many microfaunal analyses. Furthermore, sexual dimorphism in carapace size and shape and valve overlap (either the right or left valve is larger and/or a different shape than the other) must be considered in taxonomic and ecological study of modern or fossil ostracods. Although shell morphology (e.g., sieve pore morphology, noding, carapace ornamentation, etc.) and chemistry (stable isotopes, minor element ratios) are used for paleosalinity reconstruction, faunal assemblage analysis (see the following section) is the most common approach for sea-level reconstruction. A useful online reference for further information on ostracode morphology is University College London's website (http://www.ucl.ac.uk/GeolSci/micropal/ostracod.html), and Cohen et al. (2007) provide a list of morphological terms for living ostracods.

16.4 PRESERVATION IN SEDIMENTS

Oceanographic and sedimentological processes affect the preservation of microfossil assemblages in sediments and potentially introduce biases, such as selective transport of juveniles or smaller species, mixing (time-averaging) of populations from several years or longer, and shell dissolution. Burrowing and bioturbation can also mix formerly distinct assemblages up to several centimeters in the sediment. The taphonomy of fossil ostracod assemblages – that is, the degree to which fossil assemblages represent life assemblages – involves the assessment of these biases (Lord et al., 2012). In practice, stratigraphic intervals covering a freshwater to marine transition caused by sea-level rise often contain a sequence characterized by non-marine assemblages, "mixed" assemblages (including both non-marine and marine species), and brackish to marine assemblages with no non-marine species. Mixing of ecologically distinct assemblages in a freshwater to marine transition zone is influenced by the rate of sea-level rise, sources and rates of clastic sediment input, geomorphology of coastal habitats, tidal range, and other factors. In addition to understanding species' ecology, it is necessary to understand local coastal processes to interpret patterns and rates of sea-level change from sediment records.

Dissolution of ostracod calcitic shells can alter the original biocoenoses (life assemblages) either *in situ* (i.e., within the sediment), or after taking sediment cores but before laboratory processing of sediment. This problem applies especially to tidal marsh and estuarine environments. While *in situ* dissolution in sediments is difficult to assess, rapid refrigeration of sediment cores (usually at 2–4 °C) can inhibit dissolution; laboratory processing (washing/sieving) of marsh sediments as soon as possible after taking sediment cores is preferred and should eliminate or minimize dissolution artifacts.

Biological characteristics discussed above distinguish ostracods from other groups, such as diatoms and foraminifera, as valuable tools in paleo-sea-level studies (see De Deckker, 2002). For example, the preservation of a large number of carapaces (two valves still articulated) rather than disarticulated valves depends on morphological factors (dorsal hinge structure, ligament, adductor muscles), as well as environmental conditions (waves, currents, sedimentary processes). As a general rule, preservation of carapaces is more common in low-energy environments when little or no transport has occurred. Population structure – the relative proportions of adults and juveniles of a species – can be an important element in sea-level research, especially in the reconstruction of rapid sea-level rise over centuries or less. In the idealized case where an individual with 8 molt stages reached adulthood, the individual would contribute 14 juvenile valves (two valves, disarticulated during ecdysis, for each juvenile molt) and either 2 adult valves or 1 adult carapace to a sediment sample (assuming all size fractions were studied). In the case of high juvenile mortality, there will be fewer adults than juveniles and perhaps articulated juvenile carapaces that died before reaching adulthood. In any case, knowing the population structure of key species tells the researcher whether or not mixing of assemblages from different habitats occurred.

16.5 BIOGEOGRAPHY AND ECOLOGY

At large spatial scales such as shallow marine biogeographic provinces, ocean temperature required for species' reproduction and/or survival is a major factor controlling the distribution of genera and species on continental shelves (Hazel, 1970; Cronin and Dowsett, 1990; Ikeya and Cronin, 1993; Wood et al., 1993). Conversely, at regional and local spatial scales along coasts, ecological and habitat-related factors controlling the abundance and distribution of species are salinity (including daily, seasonal and interannual salinity variability), substrate, and other resources such as food. Most coastal regions exhibit a high degree of habitat heterogeneity and strong, often fluctuating, environmental gradients. Coastal ostracods from Europe, the Arctic, North America, and Asia shown in Figures 16.2 and 16.3 exemplify the wide range of species and morphological diversity. In addition, even when two or more species co-occur in the same salinity zone within a bay, lagoon, or other aquatic system, they can have distinct, seasonally varying life cycles (King and Kornicker, 1970; Horne, 1983), or habitat preferences, such as sand versus phytal dwelling (Kamiya, 1988).

The vertical resolution for paleo-sea-level estimates derived from microfossil assemblages is often based on species' preferred depth ranges or habitats in relationship to high or mean tide levels. Establishing an "error bar" for past sea levels is a critical aspect of paleoecological analyses of all fossil groups used in sea-level studies (benthic foraminifera, diatoms, corals, and ostracods; Barlow et al., 2013). Typically, preferred depth ranges of

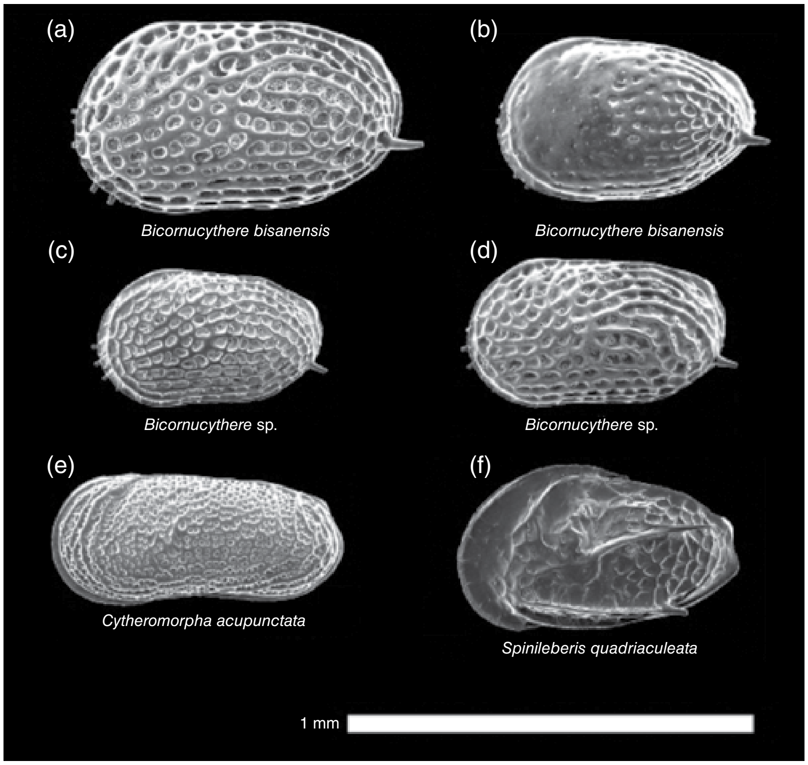

Fig. 16.2. Scanning electron micrographs of ostracode fossils from core HIR94-3 (Japan). Scale bar: 1 mm. All specimens are lateral views of left valves. (a) *Bicornucythere bisanensis*, adult, female, sample no. H36. (b) *Bicurnucythere bisanensis*, A-1 instar, sample no. H36. (c) *Bicurnucythere* sp., A-1 instar, sample no. H52. (d) *Bicornucythere* sp., adult, female, sample no. H52. (e) Cytheromorpha acupunctata, adult, male, sample no. H49. (f) *Spinileberis quadriaculeata* adult, male, sample no. H52. *Source*: Photograph by M. Yasuhara. Reproduced with permission.

coastal ostracod species are less than 10 m water depth (e.g., Yasuhara and Seto, 2006), but many tidal marsh species are dominant in water less than a few meters deep, in some cases due to substrate preferences. For example the depth limits of phytal species, such as those in the genus *Loxoconcha*, are limited by light penetration (usually a few meters in estuaries) which controls seasonal growth of the host vegetation (the sea grass *Zostera*; Kamiya, 1988; Vann et al., 2004). Macrobenthic algae also host ostracod species living within a few meters of sea level, especially in subtropical and tropical regions (e.g., Triantaphyllou et al., 2005).

In sum, understanding the complex ecology of coastal ostracods requires field studies of the distribution and abundance of living populations across salinity gradients and in relation to substrate, submerged aquatic vegetation, and tidal patterns (Boomer, 1998).

16.6 QUANTITATIVE FAUNAL ANALYSES

Due to high endemism and habitat heterogeneity discussed above, species diversity of non-marine, brackish, and marine species can be quite high for any coastal region. A few examples illustrate this point: 105 species in lagoon and carbonate platform environments off Belize (Teeter, 1975); 129 species in the Baltic Sea (Frenzel et al., 2010); 35 species along the mangrove coast of southwest Florida (Keyser, 1975a, 1975b); 35–39 species in Texas bays and lagoons (King and Kornicker, 1970; Garbett and Maddocks, 1979); 81 species in Osaka Bay, Japan (Yasuhara et al., 2004); and about 30 species in Chesapeake Bay (Tressler and Smith, 1948; Cronin and Vann, 2003).

High diversity and complex niche-partitioning among species has led ostracod workers to apply multivariate faunal analyses such as transfer functions, modern analog technique (MAT), cluster analyses, detrended correspondence analysis (DCA) (Viehberg and Mesquita-Joanes, 2012) to characterize modern and fossil ostracode assemblages. These methods involve analysis of species' relative frequencies (RF, percent abundance of each species out of the total ostracod assemblage) in relation to environmental parameters. Modern assemblages are then applied to analysis of fossil assemblage composition from sediments. A total of 300 individuals per sample is a standard used in quantitative microfaunal analysis, but identifying statistically significant temporal assemblage

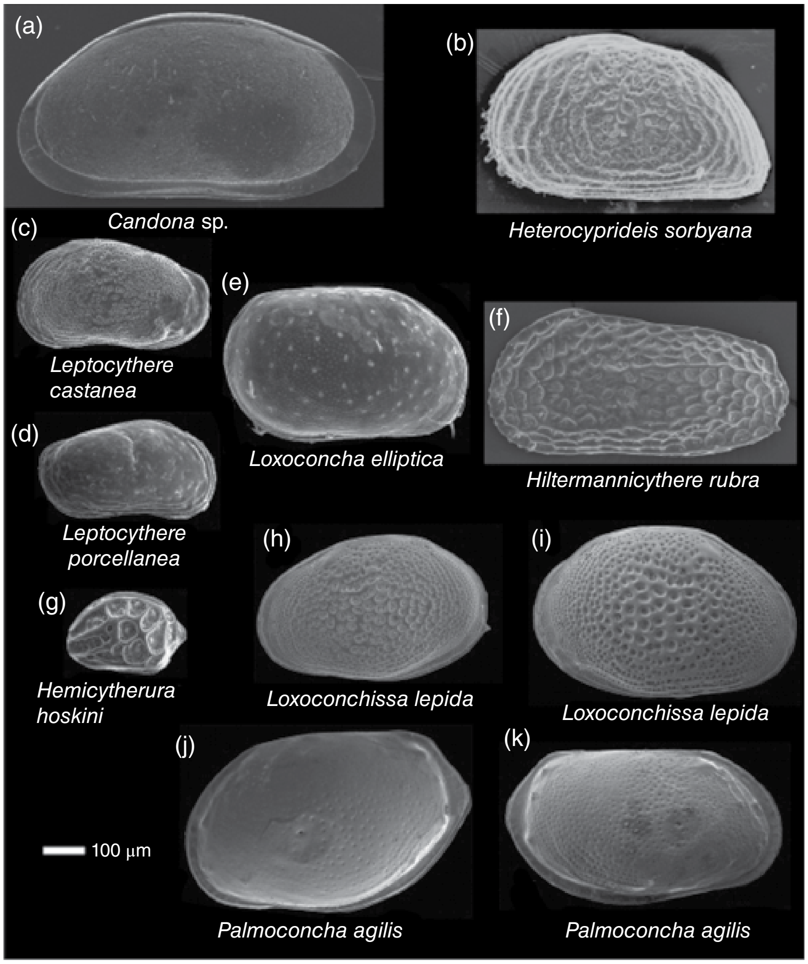

Fig. 16.3. Scanning electron micrographs of ostracode fossils. All external view except (a). Scale bar: 100 μm. (a) *Candona* sp internal view, right valve. *Source*: Rayburn et al., 2011. Reproduced with permission of Elsevier; (b) *H. sorbyana*, external view, right valve; (c) *Leptocythere castanea* external view, left valve; (d) *Leptocythere porcellanea* external view, right valve; (e) *Loxoconcha elliptica* external view, right valve; (f) *Hiltermannicythere rubra* external view, left valve, male; (g) *Hemicytherura hoskini* external view, left valve; (h) *Loxoconchissa (Loxocaspia) lepida*, external view, left valve, male; (i) *Loxoconchissa (Loxocaspia) lepida*, external view, right valve, female; (j) *Palmoconcha agilis* external view, left valve, male; (k) *Palmoconcha agilis* external view, right valve, female. (a) from post-glacial Lake Vermont, New York (Rayburn et al., 2011); (b) from Laptev Sea (Stepanova et al., 2007), courtesy A. Stepanova; (c–e, g) from Tina Menor Estuary, Northern Spain, (Martínez García et al., 2013), courtesy J. Rodriguez-Lazaro; (f, h–k) from Black Sea Holocene (Ivanova et al., 2007), courtesy M. Zenina.

changes can be accomplished with smaller sample sizes if there are large temporal changes in RFs of dominant, ecologically sensitive species (Buzas, 1990). In some cases, temporal patterns in a few dominant species can provide convincing evidence for sea-level change.

16.7 CASE STUDIES

Micropaleontological studies have used ostracods preserved in marine and brackish water sediments to infer changes in sea-level changes during the Phanerozoic over timescales ranging from 10^3 to 10^7 years. Cyclostratigraphy of orbital-scale sea-level oscillations, for example, uses marginal marine ostracods as proxies for sea-level positions in Cretaceous (Cenomanian–Turonian) sediments of the Colorado Plateau (Tibert et al., 2003), Messinian (5.4–5.3 Ma) sediments of the Adriatic (Cosentino et al., 2006, 2011), and Quaternary deposits in the eastern US (Cronin et al., 1981).

In the majority of cases, however, ostracods have been applied to late Quaternary (including

Table 16.1. Application of ostracodes to sea-level reconstruction

Region	Ostracode taxa	Sea level event	References
Chesapeake Bay	*Cytheromorpha*	8.2 ka Holocene climate anomaly	Cronin et al. (2007a, b)
British Isles	Various	Various	Athersuch et al. (1989)
Bahamas	*Candona*, *Limnocythere*, *Cypridopsis*, *Perissocytheridea*, *Cyprideis*, *Bairdia*, *Aurila*, *Loxoconcha*, *Xestoleberis*	Late Holocene	Teeter (1995)
Lake Champlain, New York	*Candona*, *Cytheropteron*	Post-glacial Champlain Sea, Younger Dryas	Rayburn et al. (2011); Cronin et al. (2011)
Black Sea	Candonidae, Leptocytheridae and Loxoconchidae	Early Holocene	Boomer et al. (2010)
Osaka Bay	*Loxoconcha*, *Bicornucythere*, *Cytheromorpha*, *Spinileberis* others	Early Holocene	Irizuki et al. (2001); Yasuhara et al. (2004)
Baltic Sea	Candonids, *Metacypris*, *Ilyocypris*, *Cyprideis*, *Cytheromorpha*	*Littorina* Sea, early Holocene	Wastegård et al. (1995); Viehberg et al. (2008)
Mediterranean	*Cyprideis*, *Ilyocypris*, *Loxoconcha*	Holocene	Primavera et al. (2011)
Bonaparte Gulf, Australia	*Tanella*, *Neocytheretta*, *Leptocythere*	Early deglacial (19.4 ka)	De Deckker and Yokoyama (2009)
East Anglia, UK	Various	Early Holocene	Boomer and Godwin (1993)

Holocene) sea-level reconstruction, including the following examples (Table 16.1):

- Rapid sea-level rise during early deglaciation (post-19.4 ka cal BP) in Bonaparte Gulf, Australia (De Deckker and Yokoyama, 2009).
- Holocene and Pleistocene sea-level changes in the British Isles (Athersuch et al., 1989; Boomer and Godwin, 1993).
- The Younger Dryas-age (~13 ka cal BP) Champlain Sea marine transgression (Rayburn et al., 2011).
- Rapid early Holocene sea-level rise at the end of the last deglaciation (Irizuki et al., 2001; Yasuhara et al., 2004; Yasuhara and Seto, 2006; Cronin et al., 2007a; Viehberg et al., 2008; Yasuhara, 2008).
- Abrupt Holocene flooding of the Black Sea (Boomer et al., 2010) and Tampa Bay (Cronin et al., 2007b).
- Mid- to late Holocene sea-level changes in the Mediterranean (Primavera et al., 2011).
- Small but significant late Holocene sea-level oscillations (Boomer, 1993; Teeter, 1995; Boomer et al., 2009; Mazzini et al., 2011).

One common feature in these studies is that ostracod microfaunal analyses were part of broader, multidisciplinary assessments of sea level that used other proxy methods (foraminifera, diatoms, palynology, geochemistry), lithostratigraphy, geochronology, and/or geophysical analyses of isostatic, tectonic, or other processes. It is therefore fair to say that, given their suitability for paleo-sea-level reconstruction based on their ecology and preservation in coastal sediments, ostracods hold great promise in future studies of past sea-level changes.

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