

# Ecological framework of saltern system: possible biological indicators for salt production

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Salt content varies considerably in continental and coastal basins, which are classified according to salinity as follow: freshwater <0.5‰, oligohaline 0.5-5‰, mesohaline 5-18‰, polyhaline 18-30 ‰, euhaline 30-40 ‰ including marine waters, hyperhaline > 40‰ being the range of salinity well extending beyond 50 up to 350 ‰ (Venice System, 1959). Along the Mediterranean coast, hyperhaline habitats are largely distributed and include especially artificial solar salterns (saltworks), salt marshes, but also natural sabkhas (Mediterranean south coast), and the Jordan Dead Sea (salt lake).

Saltern ecosystems are extreme hypersaline habitats consisting in a series of shallow ponds connected in such a way that the gradual evaporation of seawater leads to a marked increase in salt concentration. The ponds are distinguished according to salinity, that is expressed in degrees Baumè. The first ponds contain sea water (3,5° Baumè = 35‰); in the subsequent ponds evaporation begins and dissolved salts precipitate in successive sequences depending on their solubility: i.e. iron oxide and calcium carbonate start to crystallize first, followed by calcium sulfate (gypsum); sodium chloride starts to crystallize in the saturated water (25° Baumè = 250‰) when the evaporation reaches 97% of the total water, followed, as last, by magnesium chloride (28-30° Baumè = 280-300‰) (Javor, 1989).

Although salterns are artificial, human-made systems to extract salt, their ecological dynamics are consistent with those of natural coastal brackish water ecosystems (Cefolli et al., 2013). So, the biological communities suffer similar selective drivers, resulting in peculiar zonation patterns that differ in terms of composition and species richness and diversity, especially along the salinity gradient. Indeed, many organisms are tolerant to different salt concentrations (halotolerant), but

hypersaline conditions are extreme for life, so only a very limited number of taxonomic groups of organisms are adapted to survive here. The characteristic components of the biota of saltern systems are some protists Archaeobacteria and phototrophic and non-phototrophic halotolerant Eubacteria; few tolerant to salinity Cyanobacteria (blue-green algae); some algae, among which the most halotolerant chlorophyte *Dunaliella salina*, and different species of Bacillariophyta (diatoms); certain invertebrate notably crustaceans as Anostraca as the brine shrimp *Artemia salina* and Ostracoda as *Cyprideis torosa*, some insect such as some Diptera, Hemiptera, Coleoptera; few aquatic vertebrates as the fish *Aphanius fasciatus*. In short, biotic community of hypersaline habitats varies along salinity gradients showing inverse relationship between salinity and species richness, resulting in a sharp decrease in species richness and diversity as the salinity levels increase. Therefore, in the salterns the biotic community appears progressively simplified and composed of very few dominant species along with the salinity gradient from evaporation to crystallisation ponds.

In ecological studies, halotolerant organisms closely adapted to very high salinity concentrations play the relevant role of bioindicators of hypersaline conditions at the sites where they live (Camara, 2020). This applies to both present and past investigations (palaeoecology). Besides the environment-specificity with respect to salt content, the presence in their body of some mineral/calcareous parties makes organisms, such as ostracods and brine shrimps (cysts), particularly suitable as bioindicators for detecting the different properties of subsoil layers traceable to ancient hypersaline habitats. The mineral content of shells, coatings, exoskeletons make these parts hard, non-putrescible unlike organic tissues and therefore long-lasting in time. For example, preserved *Artemia* cysts were recorded from sediment cores of Great Salt Lake (USA) and Lake Urmia (Iran) respectively 27,000 and 200,000 years old (Clegg and Jackson, 1997; Djamali et al., 2010).

Our contribution to the “Salt and Power. Early States Rome and Resource Control” is aimed at finding the mineral skeletal remains of the halotolerant organisms, i.e., especially ostracods and, possibly, brine shrimp cysts, extracted from sediment cores from the archaeological sites studied.

More in detail, *Cyprideis torosa* could represent an excellent proxy to depict the palaeoenvironmental evolution of the evaporation salt ponds, being adapted to a huge range of salinity (from 0.4 to 150‰) (Neale, 1988). In fact, changes in salinity induce changes in the osmoregulation that produce some modifications in the shell morphology (shape of the ventral

border – Grossi et al., 2017 -, ornamentation – Bodergat , 1983 -, and normal sieve-pore shape – Rosenfeld and Vesper, 1977) that will help to recognize the changes in the salinity gradient. In particular, the quantitative study of the percentage of rounded normal sieve pores will benefit of a transfer function elaborated by Frenzel et al. (2012), that will enable to reconstruct the salinity variations occurred. Such kind of analyses, together with the study of the ostracod palaeocommunities, has been already applied in geo-archaeology to depict the early anthropic impact on natural coastal ecosystems (inter alia: Vittori, 2015; Kalbe et al., 2016; Mazzini et al., 2021; Quante et al., 2022).

The expected results of the core sediments analysis we propose from the archaeological sites of interest are the discovery of faunal remains indicative of specific biotic community. The possible presence of remains of species associated with hypersaline conditions may lead to the palaeoenvironmental reconstruction of the site, thus testifying the presence of hypersaline habitats as salterns for salt production.

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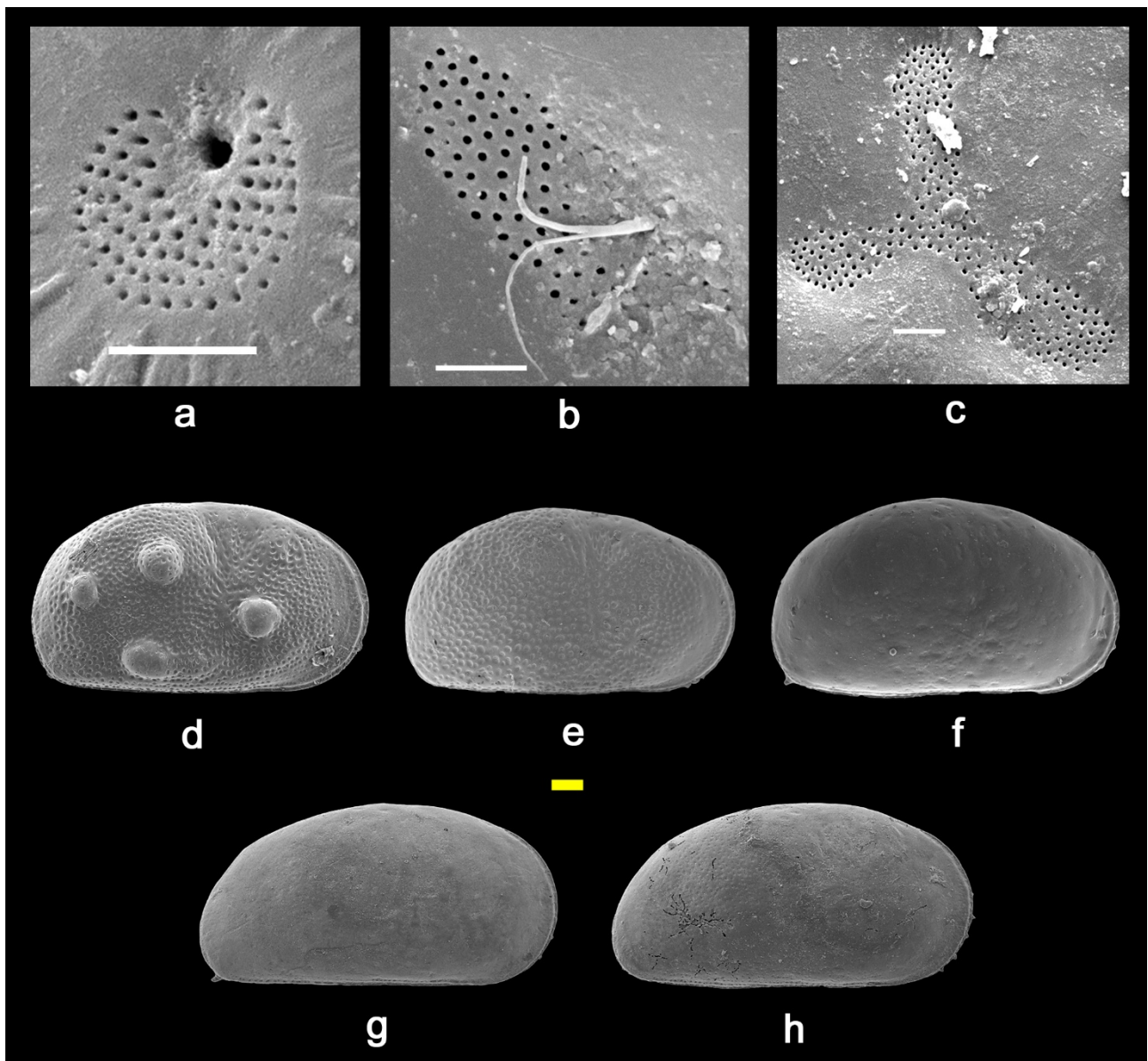


Fig. 1. Ecophenotypical characters depending on salinity recognized on *Cyprideis torosa* shells. a-c: normal sieve-pore shapes (a. rounded; b. elongated; c. irregular); d-f: female right valves with different ornamentations (d. pitted and tuberculated from Lake Trasimeno, salinity 0.9‰; e. pitted, S. Faustino section, Umbria, inferred salinity 2.6‰; f. smooth, Salina Bella, Trapani, salinity 99‰); g-h: male right valves with different shapes of the ventral border (g. rectilinear, Salina Maria Stella, Trapani, salinity 119‰; h. sigmoidal, Salina Maria Stella, Trapani, salinity 99‰). White bars correspond to 0.005 mm; yellow bar corresponds to 0.1 mm.