Chapter 9
Archeological and biological relative sea-level indicators

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9.1 INTRODUCTION

The great antiquity of human occupation in the Mediterranean has left rich archeological evidence along its coastlines, including harbors and fish tanks. Within this context, it has long been recognized that certain archeological structures can provide interesting insights into the direction and amplitude of relative sea-level changes since Antiquity. Over the past century, a number of authors have investigated the use of archeological markers to probe relative sea-level changes (e.g., Negris, 1903, 1904, 1921; Cayeux, 1907, 1914; Flemming 1969, 1979–80; Schmiedt, 1972; Pirazzoli, 1976a, b; Blackman, 1973, 1982a, b; Galili et al., 1988; Galili and Nir, 1993; Antonioli and Leoni, 1998; Stiros, 1998; Morhange et al., 2001; Sivan et al., 2001, 2004; Lambeck et al., 2004; Auriemma and Solinas, 2009; Faivre et al., 2010; Anzidei et al., 2011, 2013; Evelpidou et al., 2012; Mourtzas, 2012, among many others). Relative sea level (RSL) archeological evidence is particularly rich in the ancient worlds, including Atlantic Europe with the pioneering development of waterfront archeology (e.g., Milne and Hobley, 1981; Van de Noort and O'Sullivan, 2006), the Mediterranean and the Near East (e.g., Marriner, 2009; Carayon et al., 2011; Hein et al., 2011), India (e.g., Rao, 1988; Gaur, 2006) and China (references in Chinese). In a general context of RSL stability since 6000 cal. BP (van Andel, 1989; Lambeck and Bard, 2000), archeological heritage provides a unique opportunity to refine RSL variations in the highly diversified crustal context of the Mediterranean (Stewart and Morhange, 2009). In this chapter, we emphasize the use of fixed bioindicators in archeological contexts to further the precision of relative sea-level variations and trends during the mid–late Holocene. Archeological indicators on their own may be problematic in referencing RSL, but when combined with fixed bioindicators their value can be greatly increased.

One of the advantages of archeological structures relates to their great antiquity. For instance, the oldest harbor structures have been dated to the Old Kingdom c. 2600–2300 BC at Ayn Soukhna in the Red Sea (Tallet, 2009). By contrast, the oldest maritime installations in the Mediterranean seem to be more recent and have been attributed to the Iron Age. For example, radiometric dating has constrained the Phoenician mole at Athlit to the 9th century BC (Haggi and Artzy, 2007). A similar example is also known from the Syrian coast at Tabbat el-Hammam, where the archeological evidence supports a 9th/8th century BC age (Braidwood, 1940). For the Mediterranean, this restricts the use of archeological remains to the last c. 3000 years although drowned coastal sites dating from earlier periods can provide insights into broad sea-level tendencies during the early–mid Holocene (Galili et al., 1988; Sartoretto et al., 1995).

Analysis of harbor works and the fixed and boring marine organisms attached to waterfront structures has long been recognized as a potential source of sea-level data, for example the Roman columns of the market of Pozzuoli in southern Italy (Lyell, 1830; Fig. 9.1) or the Roman harbor of Marseille in France (Pirazzoli and Thommeret, 1973). Such data are fundamental to understanding the vertical distribution of coastal remains. Where precise vertical relationships can be established between archeological structures and past biological sea levels, it has been possible to

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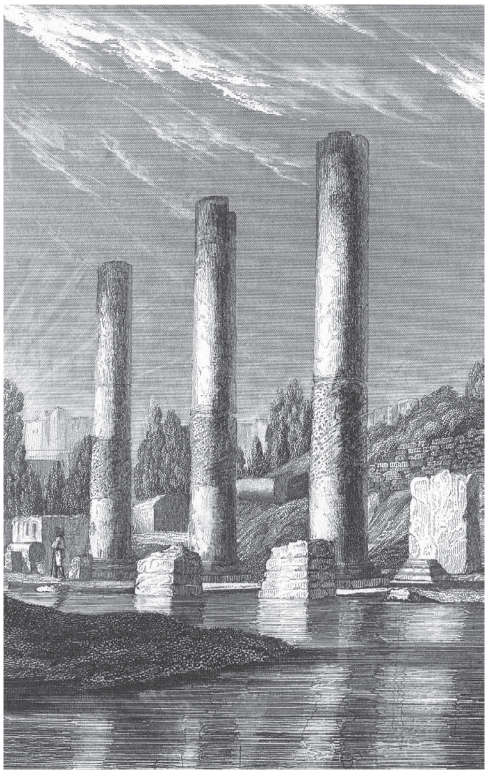

Fig. 9.1. Frontispiece of the three pillars of the Roman market at Pozzuoli (southern Italy) which have become an icon of uniformitarianism since their publication in Lyell's Principles of Geology (1830). Lyell argued that the rise and fall of these coastal archeological remains showed that the land had undergone significant vertical movements since Antiquity.

accurately reconstruct relative sea-level trends since Antiquity at a number of Mediterranean sites (Marriner and Morhange, 2007). Paradoxically, this simple methodology is rarely used.

9.2 HISTORICAL RESEARCH CONTEXT IN THE MEDITERRANEAN

Since the early 20th century, a number of scholars have undertaken systematic surveys of submerged port structures (e.g., in Egypt, Jondet 1916; in Greece, Paris 1915, 1916; and in Dalmatia, Degrassi 1955). At the beginning of the 20th century – in a scientific context dominated by the dogma of a stable sea level during historical times as advocated by Suess (1885–1908) – a debate opposed the Greek Negris (1903, 1904, 1921) and the influential French geologist Cayeux (1907, 1914) regarding the position of submerged archeological remains around the coasts of the Mediterranean (e.g., Delos, Lefkada, and Aegina). For Negris, the observed meter-scale submergence was not to be linked with localized phenomena but was rather a ubiquitous basin-wide rise in sea level. By contrast, Cayeux, who was very close to Suess, suggested that the general level of the Mediterranean had not varied significantly since Antiquity. At Delos, Cayeux identified archeological examples of sea-level changes that he interpreted as being the result of sediment compaction. He ignored the well-documented example of Phalasarna's uplifted harbor (western Crete), refusing to concede the possibility of regional sea-level changes since Antiquity. Around the same time, the seminal archeological synthesis of Lehmann-Hartleben (1923) furnished one of the most comprehensive and authoritative early studies on Mediterranean port infrastructures, but with the noticeable absence of any discussion of relative sea-level changes.

Much of this RSL debate ended from the 1950s onwards, when high-resolution archeological excavations and the advent of radiometric dating techniques ushered in much greater temporal control. During the 1970s and 1980s, scholars such as Flemming (1969), Pirazzoli (1976b), Blackman (1982a, b), and Raban (1985) resuscitated sea-level geoarcheological research as an aid to understanding ancient sites. In a similar vein, Schmiedt (1972) used Roman fish tanks to precisely reconstruct sea-level changes during the past 2000 years along the western coast of Italy.

9.3 ARCHEOLOGICAL ZONATION AND FUNCTIONAL HEIGHTS

Auriemma and Solinas (2009) recently presented a very complete synthesis of archeological sea-level proxies. Many different archeological structures that were originally emerged, or in contact with seawater, today lie below mean sea level and therefore attest to a relative change in the position of the sea surface and the structure. Following the work of Flemming (1969, 1979–80) and Flemming and Webb (1986), the methodology consists of finding the original and functional position of the analyzed remains and their relationship to sea level. *Sensu stricto*, in the absence of fixed biological fauna archeological structures can rarely be used as precise index points; rather, they are employed to generate an indicative meaning.

The "functional height" of an archeological benchmark corresponds to the elevation of

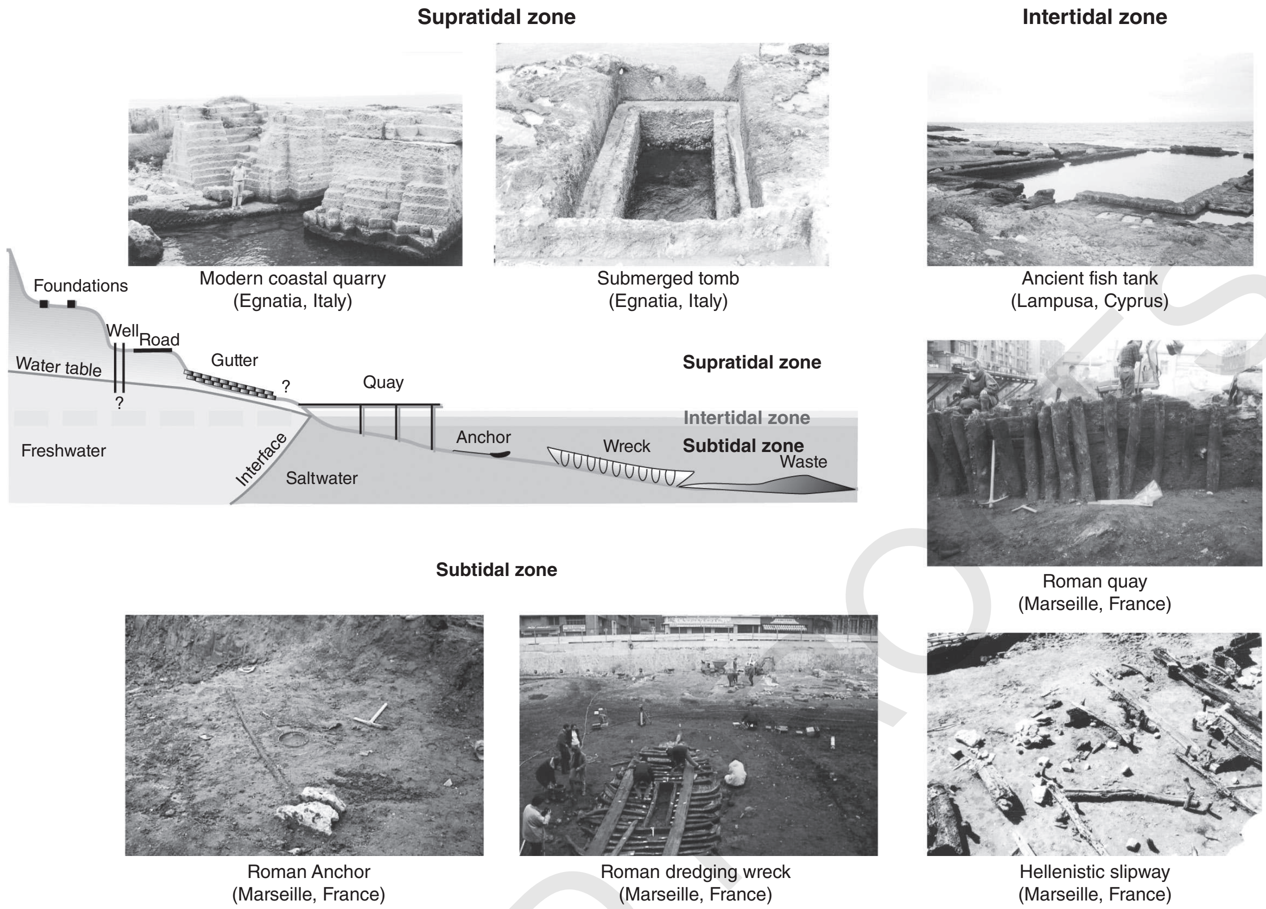

Fig. 9.2. Archeological RSL indicators adapted from Flemming and Webb (1986) (photographs by the authors) organized into three categories from base to top: (1) submerged archeological zone including wrecks and harbor foundations (subtidal); (2) interface structures zone comprising harbor installations (quays, piers, breakwaters, slipways, etc.) and fish tanks (intertidal); and (3) emerged structures zone including buildings, tombs, and quarries (supratidal).

specific architectural parts with respect to an averaged sea-level position at the time of their construction. Functional elevations define the minimum elevation of the structure above the highest local tides (Lambeck et al., 2004; Antonioli et al., 2007). In practical terms this is very difficult to achieve because the functional heights and the error bars are estimated on the basis of present analogs, which are not always related to past archeological structures. A good example of this approach is provided by recent work on Lechaion harbor in the Corinthian Gulf (Mourtzas et al., 2014) and Delos harbor in the Aegean Sea (Mourtzas, 2012).

A variety of archeological remains can be used to reconstruct sea-level changes with varying degrees of precision. An archeological zoning exists that can be organized into three categories from base to top (Fig. 9.2):

(1) Submerged structures including harbor foundations and wrecks. These remains give an indication of the direction of sea-level change but are generally low-precision indicators for the amplitude of movement.
(2) Interface structures constitute harbor installations proper (quays, piers, breakwaters, equipped banks, slipways, etc.) and fish tanks (Higginbotham, 1997; Evelpidou et al., 2012). For instance, excavations of the Roman and Medieval harbors of London unearthed a wide variety of this type of proxy in a meso-tidal context (Milne, 1985, 2003). This type of remain tends to yield quite precise RSL data because their function is directly related to sea level. The vertical error is usually speculated from present-day analogs.
(3) Emerged structures comprise residential units: villae maritimae (Lafon, 2001), buildings, or

town quarters (flooring, roads, and pavements, etc.), tombs, and quarries. Again, this type of indicator can provide information on the direction of sea-level changes. For instance, Late Roman tectonic movements in south Lebanon have led to the drowning of town quarters on the southern portion of the paleo-island of Tyre (Marriner et al., 2008).

Some research has also used more indirect proxies such as well bottoms (e.g., Sivan et al., 2004 in Caesarea, Israel), sewage outlets (e.g., Toker et al., 2012 in Akko, Israel) and flooring in churches (e.g., St Nicholas Basilica, Bari, Italy; Pagliarulo et al., 2013) to reconstruct water table changes in coastal areas. The RSL measurements are always indirect and imprecise because they are linked to the mobility of the coastal aquifer, which is affected by climate variability, groundwater extraction, and sea-level changes.

In order to use these indicators, the archeological interpretation must ensure the "maritime" function of the interface structure, and clarify the typology. Further considerations include the building techniques, which are important markers of height or depth at the time of construction (foundation versus elevation, e.g., Papageorgiou et al., 1993 for the elevated harbor of Aigeira on the uplifted coast of fault-controlled North Peloponnesia), as well as the "functional" elements, namely the relationship between the emerged part of the archeological remains compared to past and present mean sea level (Auriemma and Solinas, 2009). It is therefore important to determine the time of construction, its period of use, and the dynamics of its abandonment or destruction (Marriner and Morhange, 2006). These can be established using archeological excavation of the study area and high-resolution geoarcheological investigations. The emphasis is on multidisciplinary work to establish the precise functional depth in relation to present mean sea level and strong chronological brackets using dates based on both the typology of pottery and archeological structures (Fig. 9.2).

9.4 METHODOLOGICAL CONSIDERATIONS

The use of RSL archeological indicators is at the origin of two main uncertainties that can bias the precision of sea-level index points.

9.4.1 Difficulties in establishing the former functional height

Establishing the functional heights of archeological indicators is key to estimating local sea-level change. This parameter is defined as the elevation of specific architectural parts of an archeological structure with respect to an estimated mean sea level at the time of its construction by comparison to present contexts. The assumed functional height is dependent on the type of structure, its use, and the geomorphological and coastal hydrodynamic contexts (exposure, tidal amplitude, river discharge, etc.). As outlined in the previous section, functional heights define the minimum elevation of the structure above the mean high water mark (Fig. 9.2). Nonetheless, there is a great diversity of ancient coastal remains and many of these have undergone significant erosion due to wave dynamics in the intertidal zone. It is often the estimation of the functional height that can pose a problem of precision. The error bar in tens of centimeters is often greater than the absolute measurement.

9.4.2 Difficulties in estimating the amount of submersion

Many archeological structures are poorly preserved due to tidal wave action and subtidal bioerosion. Some examples of archeological features include (Fig. 9.2) fish tanks and harbor structures, as described in the following sections.

9.4.2.1 Fish tanks

Fish tanks are assumed to be the most reliable types of archeological indicators because they have a relatively precise relationship with sea level at the time of construction between the 1st century BC and the 1st century AD (Higginbotham, 1997). For instance, fish tanks have been widely used to reconstruct sea-level variations on the Tyrrhenian coast of Italy by Schmiedt (1972), Pirazzoli (1976a, b), Lambeck et al. (2004), and Evelpidou et al. (2012).

Fish tank remains can yield information on past sea-level positions. The external perimeter of fishpond walls cannot provide precise data on the ancient sea level because: (1) its summit is not directly linked to mean sea level; and (2) there is a great plethora of architectural types (Carre et al., 2011). By contrast, analysis is usually more precise when confined to the reference heights gathered from walkways, canals, and intertidal closing gates.

(1) Walkways are narrow paths running along the inner basins. Originally they were used for maintenance purposes and are therefore often considered to lie above mean sea level. Unfortunately, these structures are not very common and only indicate the direction of RSL movement. In some cases, such as the Lucullus fish tank (Circeo National Park, Italy), lower foot-walks were built below the openings for water arrival (Chiappella, 1965; Pirazzoli, 1976a).
(2) Canals were used to refill and empty the basins with water. They can correspond to mean sea level when they function as sluice gates, but can also be immersed fixed gates such as at Fréjus (Morhange et al., 2013a) and should therefore be studied with great care.
(3) *In situ* intertidal closing gates, which are precise indicators of RSL change, are exceptionally rare due to their original location in the wave-breaking zone.

In conclusion, archeological RSL proxies must be used with great care in fish tank contexts. Most publications are overconfident with regards to the precision of these structures, often quoted as being ±5 cm (Lambeck et al., 2004). Corrections for present tides and pressure do not overcome these uncertainties.

9.4.2.2 Harbor structures

Harbor contexts are interesting due to the diversity of their waterfront interface structures. In most cases however, they present an important margin of vertical error due to the poor state of preservation of most remains (intertidal dismantlement by natural and human processes over several millennia) and uncertainties with regards to functional heights in relation to former sea level. These sea-level markers are pier and quay surfaces with three important elements to determine: (1) the draught of ancient ships, which was smaller than present-day vessels (Boetto, 2010); (2) the tidal range, which varies depending on the study area; and (3) harbor function and their hierarchy (Auriemma and Solinas, 2009). In most circumstances, the original work surfaces are not preserved due to long-term wave action. By chance, in silted areas excavations can unearth well-preserved interface structures such as at Portus (Rome's harbor), Marseille, or Naples. As we demonstrate in the following section, archeological approximations can only be resolved using a multidisciplinary approach that integrates the use of biological indicators (Morhange et al., 2013b, c; also see Chapter 18).

9.5 PRINCIPLES OF BIOLOGICAL ZONATION OF BENTHOS ON ARCHEOLOGICAL REMAINS

The archeological indicators described in the previous section are by no means independent. For example, ancient harbors are important stratigraphical archives (e.g., Marriner and Morhange, 2007) and many Mediterranean sea-level studies typically combine sedimentological, geomorphological, and archeological indicators. However, few of these indicators are valuable without associated biological proxies. Traditionally, biological proxies provide dateable radiocarbon material from which to establish sea-level histories, but it is notably their precision as reference markers for former sea levels that are of particular interest. Over the last two decades or so, the use of biological sea-level indicators in the study of Mediterranean sea-level changes has gradually evolved from a descriptive to a multidisciplinary approach integrating many of the proxies outlined above (Laborel and Laborel-Deguen 1994). It is an approach based on the recognition that the vertical distribution of the fauna and flora of rocky shores shows a pattern of juxtaposed ecological belts, known as biological zonation (Stephenson and Stephenson, 1972; Péres 1982; Kelletat, 1988; and Chapter 18).

RSL biological proxies are mediated by physical factors. According to biological zonation, marine benthic animals and plants are finely adapted to very precise ecological conditions such as light intensity, turbidity, water salinity, temperature, tidal, and surf exposure. However, biological interactions can be important. Littoral flora and fauna are organized in three subhorizontal belts (Péres and Picard, 1964; Stephenson and Stephenson, 1972; Laborel and Laborel-Deguen, 1994; Stewart and Morhange, 2009). Marine biological studies have shown that on archeological structures (including harbor quays) there exists a precise biological zonation. Consequently, changes in local ecological conditions such as

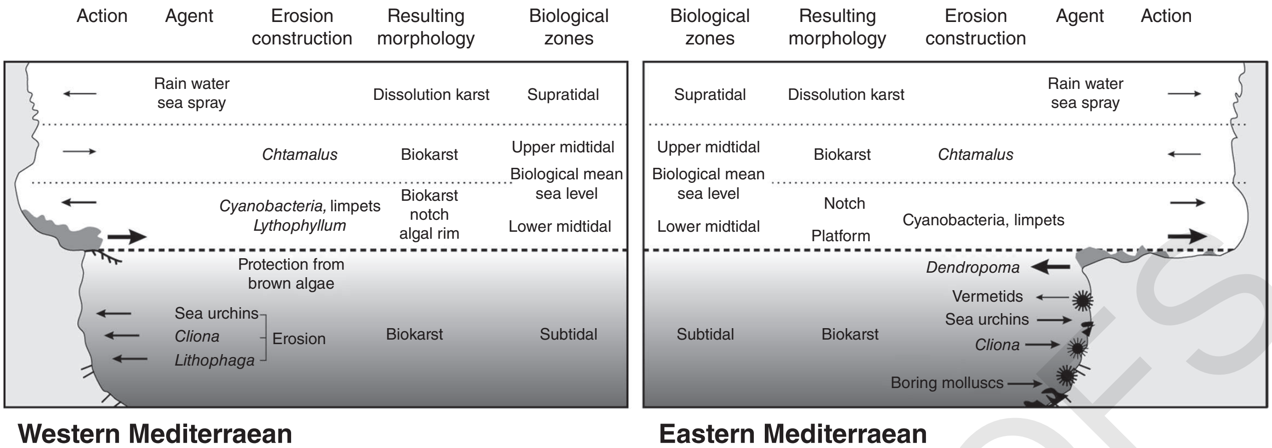

Fig. 9.3. Coastal profile showing the main characteristics of bioconstruction and biodestruction on limestone coasts in (a) the western Mediterranean; and (b) the eastern Mediterranean (adapted from Laborel and Laborel-Deguen, 1994).

relative sea-level change are followed by a concomitant quantitative and qualitative modification of the organisms with replacement by more tolerant forms. Laborel (1986, 1987) has discussed this biological zonation in detail, and demonstrated its scope in measuring past sea levels. Several parallel zones can be recognized (Fig. 9.3) and these are outlined as follows.

(1) A supratidal zone, wetted by surf but never or rarely submerged, in which the biomass is very low and mainly represented by boring endolithic cyanobacteria and grazing gastropods.
(2) An intertidal zone submerged by tides and waves on a regular basis, which displays a pattern of parallel algal and faunal belts, with biomass and species diversity increasing downwards. Cyanobacteria, limpets (*Patella* spp.), and Chitons are the main bio-eroders in this zone. Constructional elements such as the rim-building coralline rhodophyte *Lithophyllum byssoides* may develop in the northwest Mediterranean. A submerged intertidal notch can be carved into archeological structures such as in the ancient harbor of Aegina in the Saronic Gulf (N.D. Mourtzas, pers. comm., 2013). This erosional form is very useful in accurately determining a past sea level but very difficult to date.
(3) A subtidal zone whose upper limit is marked by a sudden increase in biodiversity, thus defining a biological sea level that ranges down to the lower limit of marine phanerogams (*Posidonia oceanica*) and photophilous algae, that is, to a mean depth of about 35 m. The upper part of this subtidal zone is densely populated by brown algae (*Cystoseira*), Coralline Rhodophytes, fixed vermetid gastropod molluscs (such as *Dendropoma* sp.), and cirrhipeds, for example *Balanus* spp. Active erosive agents, such as clionid boring sponges, sea-urchins, and rock-boring mussels (*Lithophaga*, *Hyatella*, *Coralliophaga* spp.), are responsible for rapid underwater erosion of the limestone outcrop such as the Roman columns of the market of Pozzuoli (Morhange et al., 2006).

The limit between the intertidal and the subtidal zones corresponds to the "biological sea level" or mean sea level (Laborel, 1986). Biological MSL corresponds to the base of the tidal zone. The influence of local variations in coastal morphology upon surf exposure explains why this biological limit undulates locally, reflecting the level of energy. Aperiodic sea-level oscillations linked to atmospheric pressure or wind variations are included in the "average" biological signal, translated by a precise marine zoning of living organisms with a lifespan of more than one year. Biological zonation is the cumulative expression of all these parameters at different timescales. In a harbor context, it is particularly interesting to note that the environment is artificially protected and that, as a result, the biological zonation is very precise and not significantly affected by high-energy events such as storms. Although species corresponding to such zones may differ between the western and eastern Mediterranean, biological zonation has the potential to yield very precise RSL index points.

Biological markers can be grouped on the basis of their bathymetric relationship to mean sea level.

(1) Sea-level indicators proper: The most appropriate organisms for RSL studies are those with a very narrow vertical life range, near sea surface. For example, in the Mediterranean Sea, biological sea level is best characterized by the development of a few marine species with a very narrow depth range, located immediately above (e.g., *Lithophyllum* rim) or below (e.g., *Dendropoma*) the mean waterline.
(2) Biological indicators of submersion: (a) Boring species: boring mussels include *Lithophaga lithophaga* and several species of *Petricola* and *Coralliophaga*. (b) Subtidal builders; these building species have a wide ecological range.

Although they do not show a precise relationship with sea level, they can yield interesting information about paleobathymetry. The upper limit of biological perforations by *Cliona* and *Lithophaga* (Laborel and Laborel-Deguen, 1994) are excellent proxies with a centimeter-scale indicative range in the case of artificially protected coastal environments such as ancient harbors. Consequently, bioconstructions and the upper limits of bioerosive elements (marine burrows and perforations), and fixed invertebrates (oysters, barnacles, solitary vermetids) are commonly used as biological sea-level indicators on archeological structures (Fig. 9.4).

The long-term stability of biological belts results from the fact that the zones are defined by species living at least a few years; they therefore tend to be confined to horizontal belts permitting their long-term survival. Consequently, if no significant changes in the relative sea level occur (as well as in the currents, temperature, and other characteristics of seawater), the biological zoning remains stable.

There are some further important methodological points to note. (1) Generally, sampling should be avoided at sites of strong exposure to surf because of the upward displacement of species zones. This is not usually the case in archeological contexts, which are well sheltered. (2) Measurement should occur between relic and current species (e.g., the upper limit of fossil and living balanids). (3) The precision of the height measurements depends on whether there is a clearly distinguishable upper limit (Baker and Haworth, 2000). The excavation of silted harbors allows this type of preservation. Laborel and Laborel-Deguen (1994) believed that, in sheltered environments, it is possible to accurately determine paleo-sea level to within ±5–10 cm.

If sea-level changes due to crustal effects, such as coseismic movements, biological zoning will be concomitantly modified (Stiros and Pirazzoli, 2008). Coastal species adapt to the new mean sea level, abandoning bands of rocks or archeological structures on which they were previously living. In many instances, such as uplifted or silted harburs, these bands are fossilized and can be used as precise sea-level indicators (Pirazzoli, 1991; Morhange et al., 1998).

Depending on the type of species, comparison of active and fossil biological zoning permits accurate identification of former sea levels (Morhange et al., 2001). In some instances, estimates for the velocity of the movement can even be obtained (episodic or slow movement, e.g., Laborel and Laborel-Deguen, 1994; Pirazzoli et al., 1996). Marrying archeological and biological proxies gives the most precise insights into the real marine conditions and RSL changes.

9.6 CONCLUSION

Tectonic uplift (e.g., the port of Phalasarna in western Crete probably around 365 AD) and silting up of sedimentary basins such as ancient harbors is particularly conducive to the preservation of fixed or boring marine organisms on archeological remains and their subsequent use as precise sea-level index points. The precision of the measurements depends upon the definition of a reliable benchmark (e.g., present biological sea level). Recent geoarcheological work embracing bioindicators and archeological remains has allowed progress to be made in the measurement of relative sea-level changes at archeological sites such as Marseille (Morhange et al., 2001) and Fréjus in France (Devillers et al., 2007; Morhange et al., 2013a), Pozzuoli (Morhange et al., 2006) and Portus of Rome in Italy (Goiran et al., 2009), Vis in Croatia (Faivre et al., 2010), Seleucia Pieria in Turkey (Erol et Pirazzoli, 1992), and Alexandria in Egypt (Goiran, 2001), among others.

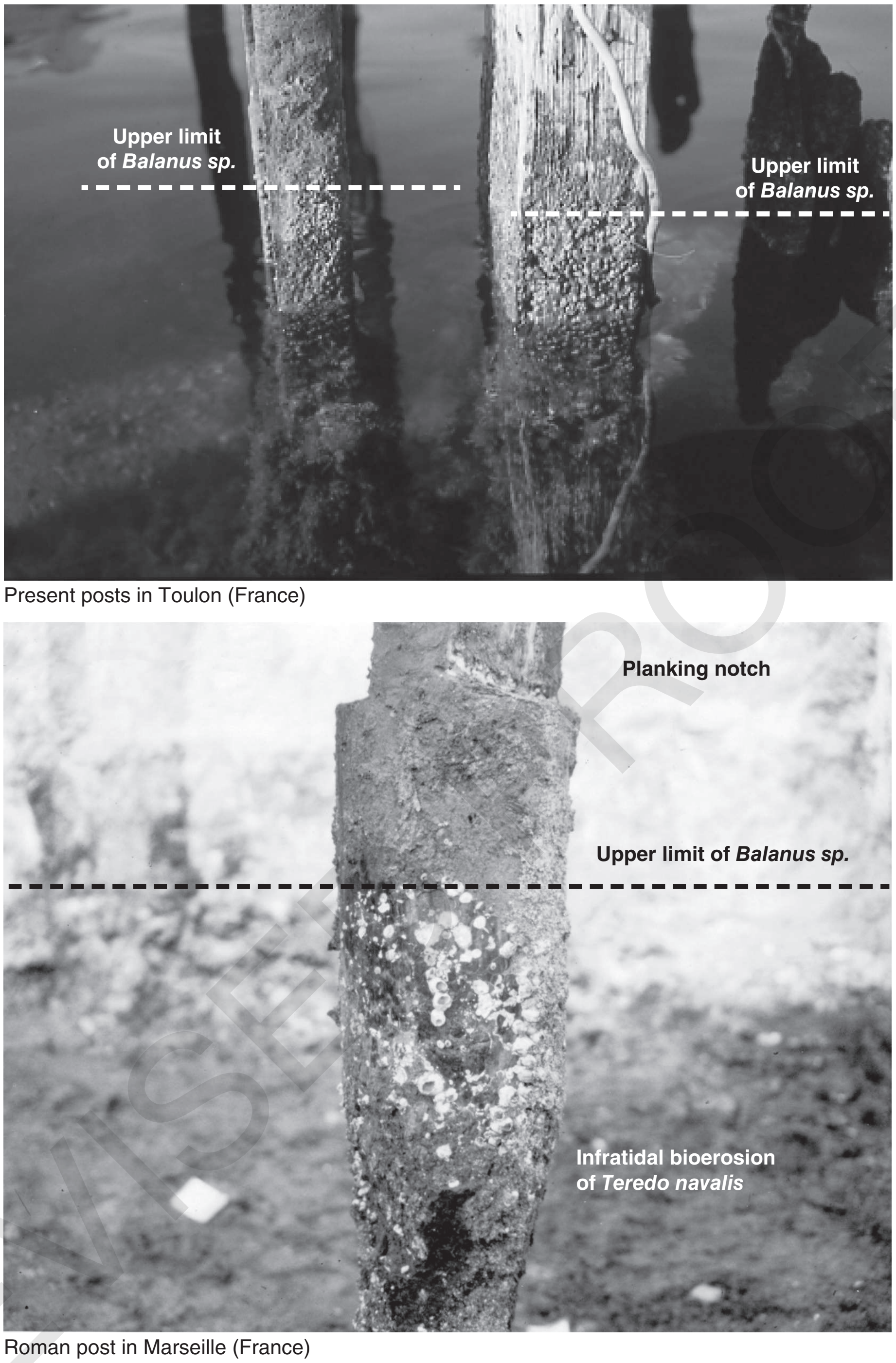

Fig. 9.4. Biological zones on stakes from the ancient harbor of Marseille and present-day Toulon.

In terms of understanding mid–late Holocene coastal environments and archeological contexts in the Mediterranean, RSL modifications are generally a minor agent of change when compared with the important role of sedimentary budgets at base level, especially at sites on or close to deltaic systems. Today, it is widely recognized that close interaction between archeologists, geomorphologists, and biologists is needed to obtain the most robust RSL results.

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