Archaeofauna 29 (2020): 7-22

Echinoids: An atlas for the identification of parts, determination of morphology, definitions of terminology and their relevance to archaeology

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(Received *4 June 2018*; Revised *29 August 2018*; Accepted *24 September 2018*)

ABSTRACT: Although not as common as vertebrates or molluscs, echinoids (sea urchins) do occur in coastal archaeological sites; they were probably a source of food and the spines of some species were potentially tools. However, the necessary expertise to identify even complete specimens, let alone their disarticulated ossicles, is not generally available. Herein, we provide a suite of tools that will enable preliminary determination of echinoid remains in an archaeological context, including photographs of complete tests and disarticulated elements, discussions of them and definitions of the main terms. More or less complete specimens will be obvious and should be identifiable to genus, at least. Although disarticulated elements may be difficult to identify even to genus, the nature of all ossicles should be determinable.

KEYWORDS: SEA URCHINS, ECHINODERMS, OSSICLES, SPINES, ARISTOTLE'S LANTERN, PRESERVATION

RESUMEN: Aunque no son tan comunes como los vertebrados o los moluscos, los equinoideos (erizos de mar) sí aparecen en sitios arqueológicos costeros. Probablemente eran una fuente de alimento y las espinas de algunas especies podrían potencialmente usarse como herramientas. Sin embargo, la experiencia necesaria para identificar, incluso especímenes completos, y mucho menos sus osículos desarticulados, no está generalmente disponible. Aquí proporcionamos un conjunto de herramientas que permitirán el reconocimiento preliminar de restos de equinoideos en un contexto arqueológico, incluidas fotografías de pruebas completas y elementos desarticulados, discusiones sobre ellos y definiciones de los términos principales. Los especímenes más o menos completos serán obvios y deberían ser identificables por género, al menos. Aunque los elementos desarticulados pueden ser difíciles de identificar incluso para el género, la naturaleza de todos los osículos debería ser determinable.

PALABRAS CLAVE: ERIZOS DE MAR, EQUINODERMOS, OSÍCULOS, ESPINAS, LINTERNA DE ARISTÓTELES, PRESERVACIÓN

http://doi.org/10.15366/archaeofauna2020.29.001

INTRODUCTION

The animal remains most commonly identified from archaeological sites, particularly those in coastal situations, belong to two major groups, namely the vertebrates, such as mammals, birds and fishes, and the molluscs, principally snails, clams and oysters (examples include Purdy, 1996; Allsworth-Jones *et al*., 2006; Gouldwell *et al*., 2006; Gutiérrez-Zugasti *et al*., 2011; Szabó & Amesbury, 2011; amongst many others). These remains are associated with evidence of human activities because they are all important as food, although skeletal remains also may be adapted as a range of tools or personal decorations. Molluscs are easy to identify to species because their simple skeleton is commonly preserved more or less complete (the univalve snails or gastropods) or only simply disarticulated (bivalves such as clams and oysters). Vertebrates pose more of a conundrum because they ordinarily occur as separate and diverse, disarticulated elements such as bones or teeth, although there are many experts able to identify such fragmentary remains, at least to the generic level.

Yet, in their hearths and middens, prehistoric humans demonstrably interacted with members of other edible invertebrate groups, most notably decapod crustaceans (crabs) and echinoids (sea urchins) (Dupont *et al*., 2010; Gutiérrez-Zugasti, 2011; Bejega García *et al*., 2014). These groups share with the vertebrates a high probability of being preserved as disarticulated elements, but the necessary expertise for identifying them is not so widely available. It is the latter group that is the subject of the present paper. We aim to provide an illustrated guide for identification of echinoid remains and guidelines for their more detailed identification. Fragments of echinoids include at least some components that are fairly easily identifiable (for example, test plates and spines, otherwise known as radioles), but others are quite confusing (for example, jaw components, apical and oral plates; but see Bejega García *et al*., 2014). Campbell (2008b) has already published a preliminary guide for identifying these tantalizing fragments; we aim to take this approach further and have compiled a short photographic atlas to the echinoid test of broad applicability in archaeology (Figures 1-5). We do not try to figure every species that has been or might be found in an archaeological context *sensu lato* which would be a near-impossible task; rather, we aim to illustrate the range of disarticulated components that are to be found in a typical echinoid test [For illustration of many more different extant species, see Mortensen (1928-1951) and Smith & Kroh (2011), amongst others]. That is, this paper discusses the various basic components of sea urchin tests as an aid to the process of identifying them, guided by the combined experience of over 70 years studying echinoids by two of the authors, D.N.L. and S.K.D. Our discussion mainly focuses on the regular echinoids (radially symmetrical; Figure 1) which are the group most commonly used as a food group at the present day (Table 1) and, presumably, also in the prehistoric past. But sea urchins do not, and have not, merely represented a food source although this is undoubtedly important. Echinoid spines were a potential basis for tools, perhaps drills, but certainly as writing implements. Echinoids have also been identified as grave goods and are known to be symbolic artefacts (see below). In short, their significance in archaeology is undoubtedly many-sided.

Eucidaris tribuloides	Caribbean
Heterocentrotus mamillatus	Indo-Pacific
Echinus esculentus	Atlantic temperate coasts of northern Europe, North Sea coasts
Paracentrotus lividus	Mediterranean and North Atlantic
Strongylocentrotus droebachiensis	North Atlantic
Strongylocentrotus franciscanus	Pacific coast of North America
Strongylocentrotus purpuratus	Pacific coast of North America
Evechinus chloroticus	New Zealand
Loxechinus albus	Chile

TABLA 1

Some examples of sea urchins eaten at the present day (sources include Wikipedia; Lawrence, 2007; and others).

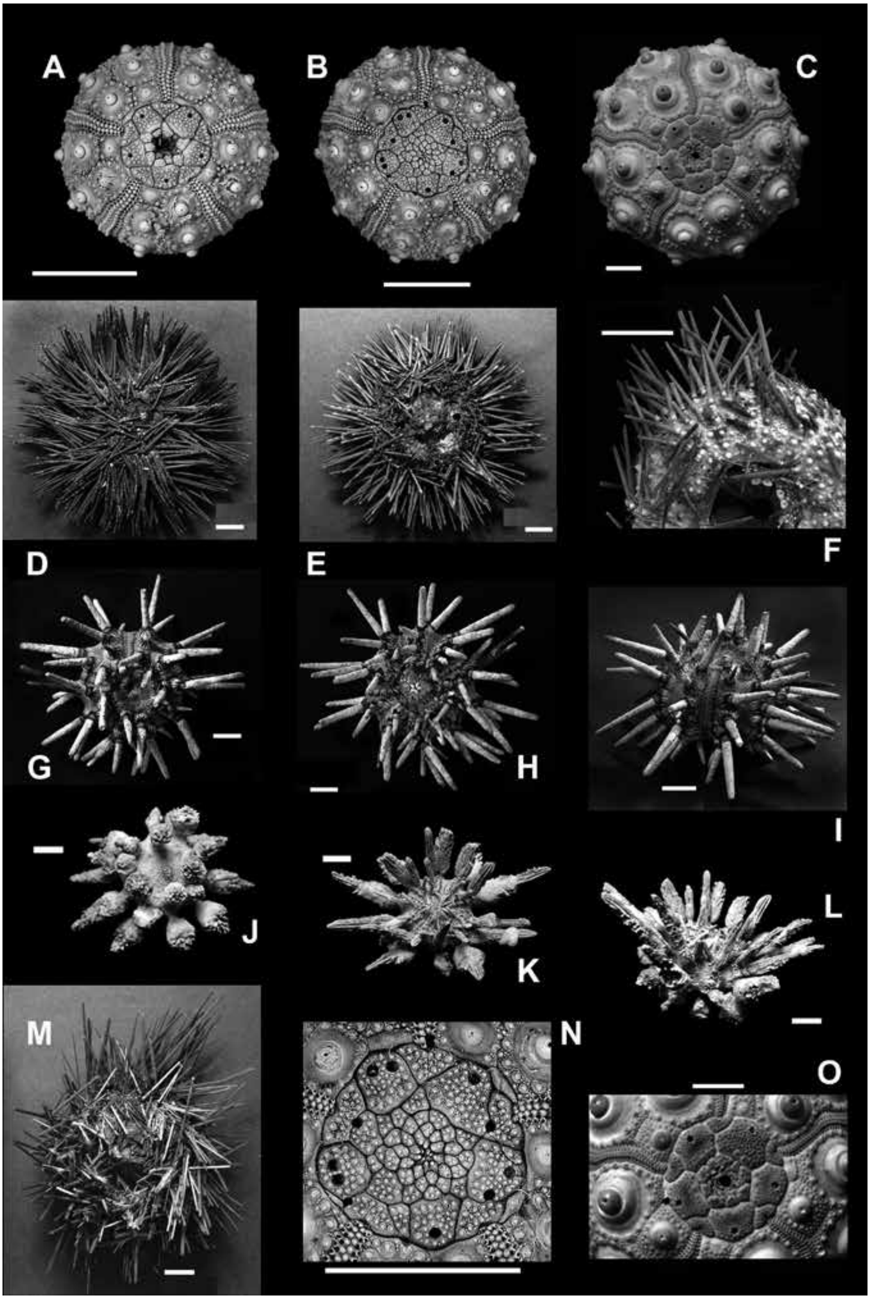

FIGURE 1

Regular (= epifaunal) echinoid tests, both with and without spines, and details of apical systems (N, O). A, B, G-I, N Cidaroid *Eucidaris tribuloides* (Lamarck), tropical western Atlantic. A RGM 554 911, apical view (after Donovan & Lewis, 2009: fig. 1C). B, N RGM 554 912, specimen with abnormal apical disc (after Donovan & Lewis, 2009: fig. 1A, B, respectively). B Apical view. N Apical disc showing component plates and abnormal genital plates with two genital pores on four of them (compare with O). G-I BMNH, test retaining spines. G Apical view (compare with A, B). H Oral view. I Three-quarters lateral view. C, O BMNH, cidaroid *Cidaris* sp. C Apical view. O Apical disc and adjacent test plates. D, E BMNH, arbacioid *Arbacia lixula* (Linné), Mediterranean, eastern Atlantic and Brazil. D Apical view. E Oral view. F BMNH, parechinid *Paracentrotus lividus* (Lamarck), Atlantic and Mediterranean, oral view showing variations of spines on test and plates of the buccal membrane (lower centre). J-L BMNH, cidaroid *Psychocidaris oshimai* Ikeda, Philippines. J Apical view. K Oral view. L Lateral view, showing the variations of the spines. M BMNH, diadematoid *Diadema antillarum* Philippi, tropical western Atlantic, oral view. All scale bars represent 10 mm.

The terminology of the echinoid endoskeleton used herein follows Durham & Wagner (1966), Melville & Durham (1966), Smith (1984), Lewis & Donovan (2007) and Smith & Kroh (2011). Specimens discussed and figured herein are in the collections of the Natural History Museum, London (BMNH), the Naturalis Biodiversity Center, Leiden (RGM) and the National Museum of Natural History, Smithsonian Institution, Washington, D.C. (USNM). The terminology of the echinoid test is summarized in Appendices 1 and 2. Figures marked simply as BMNH illustrate unregistered and unlocalised specimens of Recent taxa in the Department of Earth Sciences. They are from a small comparative collection which also includes ex-display material, used to demonstrate test components.

THE COMPONENTS OF THE TEST

The Class Echinoidea is part of the Phylum Echinodermata, the spiny-skinned animals, which also includes the crinoids (sea lilies and feather stars), asteroids (starfishes or sea stars), ophiuroids (brittle stars) and holothurians (sea cucumbers). Holothurians are the only other class of echinoderm that are also an important food group, particularly in the tropics (Bradbury *et al*., 1998; Conrad, 1998; Khotimchenko, 2015), but their calcareous hard parts (= ossicles) are minute and unlikely to be apparent except in particular circumstances. For example, holothurian ossicles (Frizzell *et al*., 1966) might be recognizable in a microscopic study of inclusions of human coprolites from selected sites (compare with Appelt *et al*., 2016). Asteroids and ophiuroids are not important food groups for humans, are likely to disarticulate soon after death and, if anything, are most probably found as artefacts in burials due to their distinctive pentaradial symmetry (Hammond, 2017). Stalked crinoids are denizens of deep water and most commonly encountered as fossils; in particular, their columnals (= ossicles of the stem) may have been used as beads. Thus, according to legend, St Cuthbert used Mississippian columnals from Lindisfarne as part of his rosary, although the veracity of this tale is in doubt (Lane & Ausich, 2001). Only sea urchins are likely to have been a locally common and easily recognizable echinodermal food source in archaeological sites.

Sea urchins are divided into two morphological groups: the 'regular' echinoids, which are commonly bun-like and radially symmetrical (Figure 1); and the 'irregular' echinoids, which have a bilateral symmetry which 'overprints' an ancestral five-fold symmetry (Figure 5). Regular urchins may have tests held together by soft tissues, which allow the test to fall apart after death and decay, or in certain clades by interlocking microstructures which make the test more likely to survive at least partly intact post-mortem. Tests of irregular urchins have a better chance of remaining intact post-mortem because of their interlocking test microstructures and their life habit, which is commonly infaunal (Kier, 1977). Components of the tests of both kinds, which detach soon after the death of the urchin, include the various types of spines and pedicellariae. Sea urchin spines vary in shape and size according to their function. Pedicellaria are very small components, and in life serve the functions of defence or cleaning and removal of foreign bodies such as larvae trying to attach to the test. Defensive kinds are equipped with poison glands. The urchin uses specialized appendages, called spheridia, for orientation. These are tiny, spherical, specialized spines located in pits (spheridial pits) on the adoral surface of all urchins except cidaroids. The Aristotle's Lantern (Figure 4) is an internal structure concerned with feeding, and comprises the jaws, teeth and components which hold the structure together and in place. Some of these are fused or very tightly joined, while others are held together solely by soft tissues (Smith & Kroh, 2011).

Sea urchins, in common with other echinoderms, are constructed from many individual components of calcite (calcium carbonate) forming the test (= body) (Figures 1, 2, 5), spines (Figure 3), jaws (Figure 4) and other components, and which are attached to one another by interlocking calcite microstructure, ligaments and muscles. In some sea-urchins, the plates comprising the test are only held together by soft tissues. These tests, such as those of the cidaroids (Figures 1A-C, G-L, N, O, 2A, B, D-H, J, 2A-D, F, 4A-E, H-K), do not remain whole for long after death because tissue decomposition allows the plates to separate and fall apart. Unless rapid burial occurs, they are less likely to be found complete than those whose plates rely on a mechanical calcite linkage. In other species, particularly among the bilaterally symmetrical irregulars (Figure 5), the mechanical connections in life between plates are sufficiently robust to allow considerable reduction in the thickness of some tests where they are almost paper-thin. A familiar example from around the North Sea and British Isles are the 'sea potatoes', the heart urchin *Echinocardium cordatum* (Pennant). The test of *E. cordatum* is thin, but robust, and at certain times of the year may be washed up as nekroplankton in large numbers on the shore.

All sea urchin tests have some components which are only attached by soft tissue, such as muscles or membranes. When the animal dies and the tissues decompose, it is these skeletal parts are the first to fall from the test. Such structures include the tiny plates present in the membranes around the anus and the mouth, the microscopic pedicellariae, and the spines and similar structures held attached by muscles. Internal parts of the test which can fall apart on death are those of the feeding apparatus known as the 'Aristotle's Lantern' (Figure 4), a complex structure comprised of 40 components,

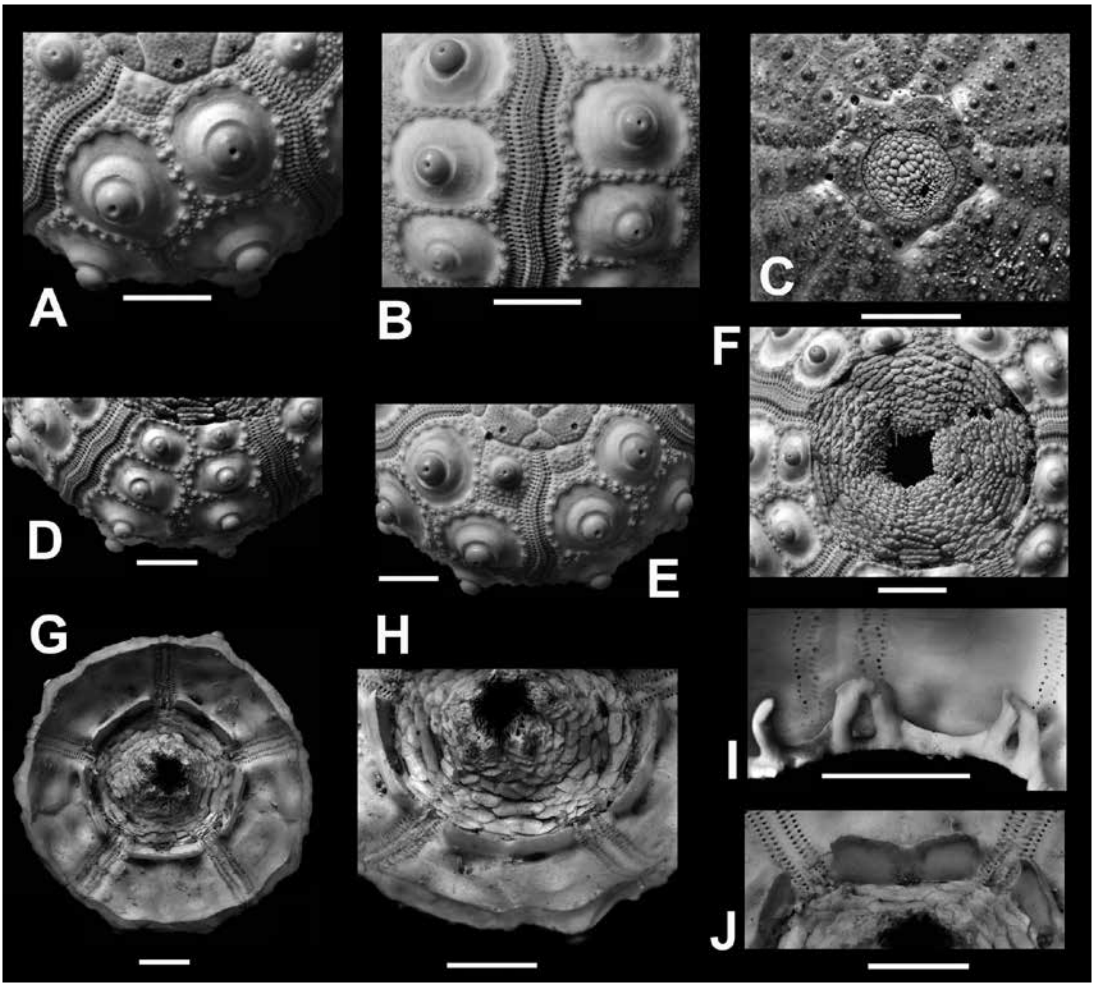

FIGURE 2

Details of tests and their components. A, B, D, E BMNH, cidaroid *Cidaris* sp. A Adapical interambulacral plates showing large perforate primary tubercles and surrounding rings of secondary tubercles. B Sinuous column of ambulacral plates (centre) showing the pore pairs and tiny primary tubercles, with two adjacent (left and right) adradial columns of interambulacral plates. D Adoral ambulacral and interambulacral plates. E Adapical interabulacral plates, showing variations in size towards the disc, and parts of three sinuous columns of ambulacral plates (4, 6 and 8 o'clock). The junctions with the ocular plates with the ambulacral column and the genital plates with the interambulacral columns are shown. C, I BMNH, echinid *Sterechinus* sp., Antarctica. C Apical disc with periproctal plates on the periproctal membrane. Note the periproctal aperture at the five-o-clock position. I Auricles. F BMNH, cidaroid *Cidaris* sp., buccal plates with peristome in the centre. G, H, J BMNH, cidaroid *Phyllacanthus* sp., internal views. G Layout of the perignathic girdle of apophyses and the buccal plates. The lantern is not present. H Close-up view of apophyses and buccal plates. Note the tiny oral spines just visible within the peristomal opening. J Apophysis. All scale bars represent 10 mm.

some held together by soft tissue and some by mechanical linkage (see below). Some of these components are robust and can preserve well, whilst others are delicate and are easily broken down. Other skeletal parts involved in feeding are parts of the test itself, called the auricles (Campbell, 2008b: figure 4; Figure 2I herein), and the apophyses (Figure 2J), serving for the attachment of the muscles which control the jaw apparatus. These, too, are fairly robust.

Thus, the disarticulated components of a sea urchin test which are likely to be found during sieving may be divided into three broad groups: fragments of the test; spines and appendages (but not the microscopic pedicellaria); and plates of the lantern. Each group of remains is considered in turn.

FRAGMENTS OF THE TEST

Apart from the primary spines, the interambulacral plates are likely to be the largest components of the regular sea urchin. They can be approximately hexagonal (though the margin adjacent to the ambulacral plates will appear 'scalloped' rather than angular), elongated along one axis and may have a large tubercle centrally placed, with or without a circle of much smaller tubercles around it. Tubercles support the spines during life.

Plates from irregular urchins have numerous small tubercles scattered over the surface and do not generally have such a large tubercle present, although there are some exceptions, such as the anterior apical plates of heart urchins (spatangoids) and plates from the oral surface. The outline of the plates is similar to the regular urchins, but they may be much thinner and more fragile.

Ambulacral plates of both regular and irregular sea urchins are much smaller than interambulacral plates. They can be simple, composed of a single plate, or compound, whereby two or more plates have fused together. The outline varies from elongated, roughly hexagonal (with one edge more curved rather than angular) for a simple plate, to irregularly polygonal for compound plates. Both simple and compound plates have paired pores which perforate the surfaces, the holes passing from the inner surface to the outer. The pores enable the tube-feet (soft tissue) to pass through the plates. Simple plates only have one pore pair per plate; compound

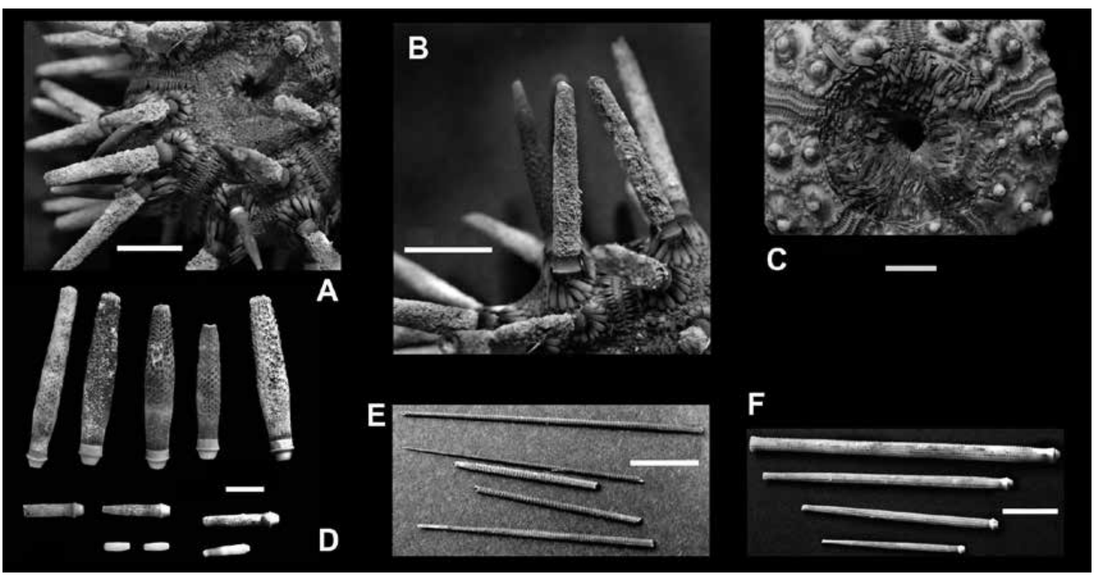

FIGURE 3

Spines (= radioles). A, B, D BMNH, cidaroid *Eucidaris tribuloides* (Lamarck), tropical western Atlantic. A) View of adoral test showing primary interambulacral spines surrounded by secondary spines. B) Close up view of primary and, around the bases, secondary interambulacral spines. D) An array of primary spines (upper row) and secondary spines (lower two rows). C) BMNH, cidaroid *Phyllacanthus* sp., oral spines. E) BMNH, diadematoid *Diadema antillarum* Philippi, tropical western Atlantic, long, needle-like primary spines. These can give painful wounds to those who step on them. F) BMNH, cidaroid *Cidaris cidaris* (Linné), North Atlantic, primary spines showing the spinules along the shaft and the splayed tips. All scale bars represent 10 mm.

plates have more than one pore pair, depending on the number of component plates. Tubercles may be large or small, though not generally as large as those of the interambulacral plates.

The plates of the apical disc include circlets of both genital and ocular plates (Figure 1N, O). Genital plates are small polygonal plates, interradial in position, and each has a pore more or less in the centre for the passage of genital products (sperm or eggs). One of the genital plates has many pores over the surface – this is the madreporite or madreporic plate, which serves for pressure equalization, connecting the internal water vascular system to the external environment.

Ocular plates are small and kidney-shaped, and have a single pore centrally on the concave edge. They may have a granular appearance. Ocular plates are radial in position and occur at the apical end of the ambulacral plates.

The periproctal plates are tiny (best seen in Figure 1N, O). They surround the anus and protect the anal membranes, and are found centrally within the apical disc of a regular urchin or around the periproct of an irregular urchin. One or more of these plates may be tessellated into the apical disc itself and are then called suranal plates, characterising one particular group of sea urchins, the salenioids. Buccal plates are also tiny (Figure 1H), but which surround the mouth and protect the oral membranes.

SPINES AND APPENDAGES

In regular urchins, primary spines are the largest of their kind (Figure 3A, B, D-F). They may be hollow or solid, and some can even be 'spongy'. Their size, sculpture and shape vary according to their location on the test and their function. They may be long, slender and finely pointed (Figure 3F); short, robust and blunted (Figure 3D); or have club-shaped ends (Figure 1J, K). Some may even take the form of plates in a sort of 'armour plating'. They may be smooth or have small spinules along the shaft. Spines of *Diadema* (Figure 1M) have a 'verticilate' structure which gives a rough feel to the shaft when rubbed (gently!) from tip to acetabulum. The structure appears as a series of tiny crowns sitting inside one another, with the points of the crown directed outwards, starting wide and gradually decreasing in diameter towards the pointed end. It is this sort of construction which makes treading on such sea-urchins so very painful; the spines are not only fine and pointed, but also very brittle, so they snap easily in your foot.

More robust spines are those of the 'pencil urchins' such as *Heterocentrotus* and which are used to write with on slates. They are commonly used today in decorative wind-chimes.

Primary spines of varying geometry are used in different ways by the echinoid, such as for protection (diadematids can angle their spines towards a perceived threat), for locomotion or for digging into rock surfaces to create protective hollows. Irregular urchins generally have much smaller and more slender spines, slightly curved, and can give a 'hairy' appearance to the test. These are most commonly used to excavate sediment. However, there are some irregular urchins which do have larger and often noticeably curved spines at the anterior end of the test; these belong to the spatangoids or heart urchins. The test has large tubercles for their attachment, on the upper (apical) surface and on the lower (oral) surface, and they may be deeply inset in the test.

Secondary spines are usually much smaller than the primaries and simpler in form (Figure 3A, B, D). They may serve to protect the more vulnerable soft parts of the test, especially the musculature of the primary spines. There are also considerably more of them than primary spines. For example, a cidaroid primary tubercle has a circle of many secondary (or scrobicular) tubercles, and between these scrobicular circles there are commonly many even smaller spines, the tertiary or 'milliary' spines (Figure 3B).

Pedicellariae keep the surface of the test clean and safe. They have a shaft which has tiny jaws at the tip, which act as pincers. Some of the defensive pedicellariae can also be poisonous, with poison sacs within their structure. The toxin of some urchin pedicellariae can affect humans who mishandle the urchins. Other pedicellariae remove debris from the surface of the test.

Clavulae are present only on spatangoids irregular urchins (= heart urchins; Figure 5A, B, E, F). These are tiny spines present on fascioles, which are narrow, specialized bands on areas of the surface of the irregular spatangoid (heart) urchins. Their purpose is to create water currents for respiration along the fascioles.

PLATES OF THE LANTERN

The lantern is the jaw mechanism of the regular sea urchin. It is a complex structure with forty components – ten demipyramids, five teeth, ten epiphyses, five rotulae and five compasses made of two parts each (Figure 4). Not all sea urchins have this structure, but it is invariably present in regular echinoids. Irregular urchins may or may not have jaws. For example, *Clypeaster* (Figure 5C, D), a large irregular urchin, has a robust jaw apparatus, but it is not identical to that of regular urchins.

There are five robust pyramids in the lantern (Figure 4A-C), each made of two demipyramids which are held together by soft tissue and may become separated on death. The shape of a single pyramid resembles a small rodent skull, broad at the top and tapering almost to a point. Each demipyramid has an epiphysis at the broader end (Figure 4D, E), shaped rather like a clavicle. The epiphysis is held in position by soft tissue, but is also articulated by a pitted surface, so may be found along with its demipyramid, even in fossils.

The teeth are long, slender, pointed at the distal end and fit inside the pyramids along a 'slide'. They are curved along their length, are concave on the inner surface of the curve and also may be keeled. Although they are composed of calcite, their structure is such that they are tough enough for some of the urchins to chew through mollusc shells (Märkel, 1979). Attached to the proximal end is soft tissue, the 'plumula', which controls the vertical movement of the tooth.

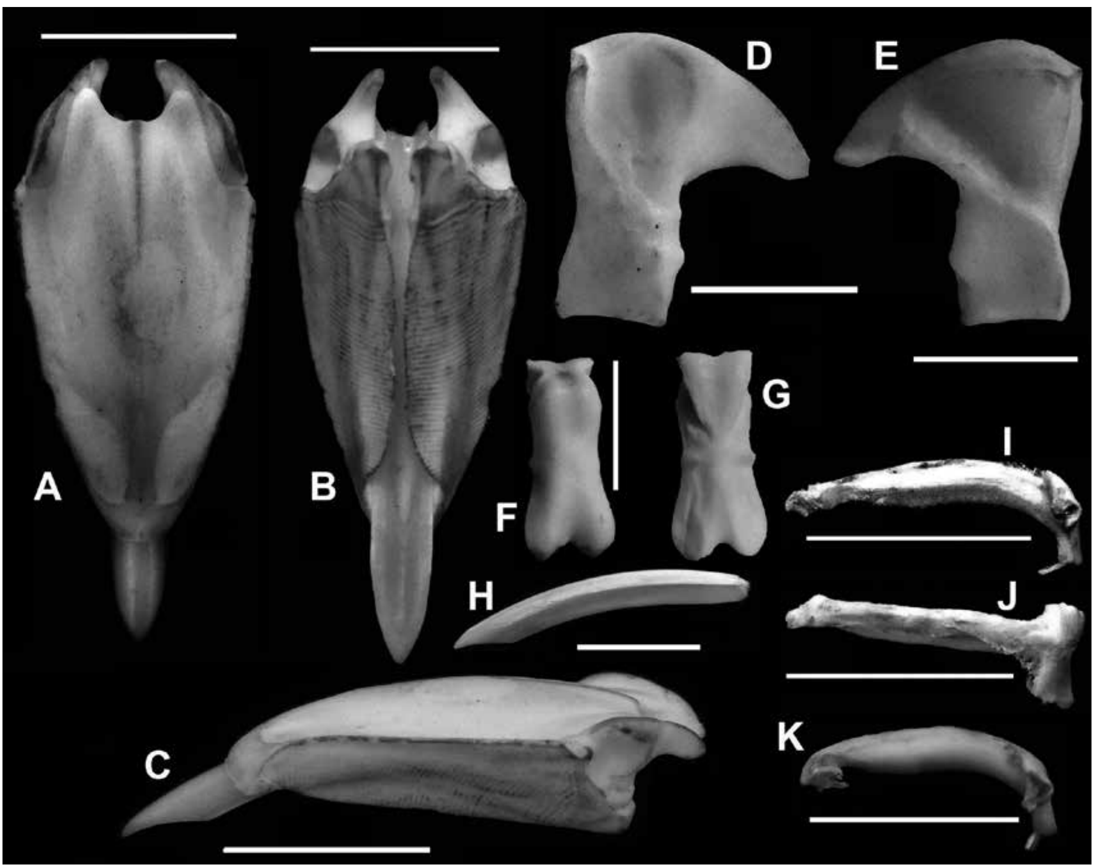

FIGURE 4

Disarticulated parts of the Aristotle's lantern. A-C) BMNH, cidaroid *Phyllacanthus* sp., pyramid. A) Outer surface. B) Inner surface. C) Lateral view. D, E) BMNH, cidaroid *Phyllacanthus* sp., epiphyses. Scale bars represent 5 mm. D) Outer surface. E) Inner surface. F, G) BMNH, diadematoid *Diadema antillarum* Philippi, tropical western Atlantic, rotula. Scale bar represents 5 mm. F) Outer surface. G) Inner surface. H) BMNH, cidaroid *Phyllacanthus* sp., side view of tooth. I-K) BMNH, cidaroid *Phyllacanthus* sp., compass. I) Side view. J) Outer surface. K) Oblique view. All scale bars represent 10 mm unless stated otherwise.

The rotulae (or 'braces') are shaped rather like small, robust limb bones (Figure 4F, G). They articulate with the epiphyses of adjacent demipyramids to serve as a brace for the structure.

Compasses (Figure 4I-K) lie over the rotulae and serve to raise and lower the jaws. They are delicate and fine, composed of two parts, one of which is bilobed and can be shaped like a catapult or stirrup. Radial compass muscles are attached to the two lobes or prongs.

Appendix 2 lists all the components and descriptive parts of the echinoid test. They are used as a checklist when describing an echinoid, but it is unlikely that archaeologists will need to use it as such, and is included mainly for interest and completeness. That being said, some of the characteristic parts can assist, either singularly or in association, with the identification of the echinoid to the level of family or, perhaps, to genus.

DISCUSSION

Echinoids are not a common subject of investigation to archaeologists, probably due to several reasons, including the constraints of taphonomy, excavation methodologies and, part of the reason for the importance of the present contribution, a lack of specialists. Yet they may be relevant in several ways. Herein, we recognize three important areas in which sea urchins may provide archaeological data: echinoids as food; robust echinoid spines as tools; and echinoids as burial artefacts.

Edible echinoids

In different parts of the world, echinoids are part of the food supply for coastal dwellers, from Barbados to Japan, and have been in the past (e.g., Campbell & Harbo, 1991; Keegan *et al*., 2003). Although not an important part of the modern larder in, say, North America and northern Europe, perhaps they have been in the past (e.g., Gutiérrez Zugasti, 2011; Gutiérrez Zugasti *et al*., 2016). Echinoid debris may thus be an important source of data in ancient shell middens (see Campbell, 2008a, b), although perhaps not as easy to determine to species as the remains of vertebrates, molluscs and crabs.

The gonads of both male and female urchins are eaten raw, the test nowadays being opened with tools specially designed for this purpose. They are considered a delicacy and may be eaten together with other special foods, with regional variations as to what is added (Table 1).

In such a situation, any and all parts of a regular echinoid test might be expected to be preserved, although individual plates may be broken. Echinoids would most likely be conveyed to an eating place and only cracked open on arrival; premature breakage would most likely lead to some of the (sparse) nutritious contents to be shed. Striking the test with, say, a rock would cause breakage through the larger plates of the test. This would be different for a specimen that had not been eaten and disarticulated without mechanical damage, in which case none of the plates of the test would show actual breakage; that is, plates would be disarticulated, but each would be whole. All preservational states between these extremes might be envisaged.

Echinoid spines as tools

The large and robust spines of some extant echinoids may have been adapted as tools. Howard (2008), responding to previous speculation, explored the possibility that such spines may have been used as drills for making shell beads on San Nicolas Island, offshore California, but found them inadequate for such a task. Even nowadays, urchin spines are used as writing implements and slate pencil urchins (e.g., *Heterocentrotus*, *Eucidaris*) are so-called because the spines are used to scribe words on sheets of slate, especially in schools. The scratched letters can be erased easily by using a damp cloth. They can also be ornamental, such as their use as wind chimes, with different lengths of spine producing different musical notes. The ornamental applications of sea urchins continue at the present day (for example, see www.etsy.com/market/sea_urchin_ornament).

Echinoids as burial artefacts

McNamara (2007, 2011) has been evangelical in demonstrating how fossil echinoids may occur as part of the archaeological record of grave goods and 'lucky stones' in folklore. What made fossil echinoids so important to at least some of our ancestors, including Neanderthal Man and Heidelberg Man, that they collected them, sometimes in huge quantities? McNamara has argued, convincingly, that it is the five-fold star made by the echinoid ambulacra, and seen to best effect on flint steinkerns (internal casts and moulds) of Chalk irregular echinoids such as the heart urchin *Micraster* (Figure 5E, F). These are locally common, robust fossils that survive exhumation and might turn up as a flint in a field. McNamara recognised that superstition, and pagan and religious convictions, have been intertwined in making such fossil echinoids a centre of belief to different cultures over many thousands of years and kilometres.

It is worth emphasizing that similar superstitions persist. In 1989, S.K.D. was part of a team that went looking for the Eocene type locality of the primitive amphibious dugong *Prorastomus sirenoides* Owen in the Quashies River in western Jamaica. The Quashies River and its impressive sinkhole were easily located, but Owen's fossil skull must have come from a float boulder of Eocene limestone rather than the older red beds exposed *in situ* on either side of the stream (adapted from Donovan, 2011: 661). We excited local interest and S.K.D. was invited to inspect the 'lucky stones' in the garden of one lady, and found a limestone exposure with abundant tests of the common Eocene cassiduloid echinoid *Eurhodia matleyi* (Hawkins). McNamara reported 'lucky stones' as a term in European folklore for, mainly, flint steinkerns of Chalk *Echinocorys*.

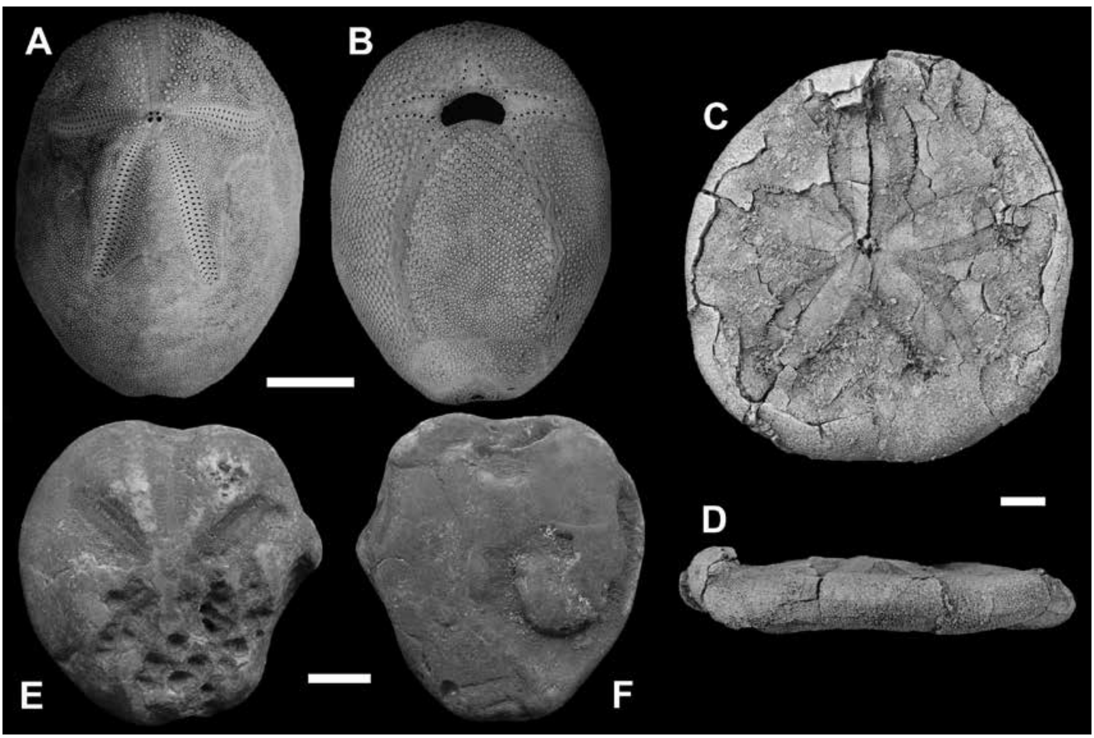

FIGURE 5

Recent (A, B) and fossil irregular echinoids. A, B) USNM 44054 (two specimens), spatangoids *Brissus unicolor* (Leske), tropical western Atlantic (after Donovan & Veale, 1996: figs 4.1, 4.2). A) Apical surface. Note the four petaloid ambulacra (3, 5, 7 and 9 o'clock) and one non-petaloid ambulacrum (12 o'clock). Four prominent genital pores apically. B) Oral surface; kidney-shaped peristome (mouth) anterior. C, D) BMNH EE5690, clypeasteroid (sand dollar) *Clypeaster oxybaphon* Jackson (after Donovan, 2004: figs 4, 3, respectively). Members of this genus, which is still extant and widespread, have particularly robust tests. C) Apical surface; note there are five ambulacral petals. D) Lateral view. E, F) RGM 792 290, spatangoids (heart urchin) *Micraster* sp. cf. M. *cortestudinarum* (Goldfuss), Upper Cretaceous Chalk of northern Europe (after Donovan & Lewis, 2017: fig. 1E, F). This is a flint *Steinkern* (= infill), a particularly durable mode of preservation. E) Apical surface. F) Oral surface. All scale bars represent 10 mm.

FINDING THE EVIDENCE: (VH-L) A PERSONAL PERSPECTIVE

The following is a brief account of how echinoids can be discovered in archaeological material and of my experience in working with material from excavations during 1995-1998 at Gorham and Vanguard Caves, Gibraltar. Earlier excavations and finds in the region had revealed Neanderthal occupation and the aim was to obtain more in-depth information about these humans, their environment, their diet and tools in this part of Europe, and shed further light on this area of research (see Barton R N E, Stringer C B *et al*, 2012 for a full report of the excavations). I worked on and off site in Gibraltar, and at the Natural History Museum in London, as finds assistant, sorter, curatorial assistant and occasional co-ordinator.

This section will demonstrate finding evidence for echinoids in sieved samples, a large number of which were collected during the excavations.

The samples were sieved on-site, spread out on trays to dry and then put in appropriately labelled, large, white cloth bags for transport back to the Natural History Museum where they would be stored and the contents meticulously sorted into category of find, using macro-inspection (= the naked eye, with the occasional help of a x10 or x12 magnifying glass).

To my knowledge, no larger remains of echinoids were recorded during these excavations. Even a fully grown echinoid is not normally a large animal, (although they are hard to miss if you have accidentally trodden on one). Remains from, potentially thousands of years back, are likely to be small, worn by taphonomic processes and may not even be recognised. Larger echinoid fragments would, hopefully, be isolated during excavation as "small finds" and suitably recorded. Obviously, this will depend on the general skills of the excavator(s) in identifying something of interest. Such skills build through repeated exposure, and this is no less true with echinoids. Unless the excavator is already a specialist worker in the field, it is probably realistic to conclude that, sadly, many echinoid remains will have gone undetected.

It is helpful for a sorter faced with a potentially very rich mixture of remains from an area where early occupation has already been established to be made aware of this fact, unless they are already familiar with the site. This ensures that a broad spectrum is maintained while going through the material. Thus, there may be evidence for artefactual behaviour such as the making of stone or bone tools, butchery or the making of decorative items, and also remains of living things, e.g. bone, shells, assorted land and/or marine fauna (whereunder echinoids), charcoal and seeds. It may seem daunting to go through, bag after muddy bag, items, none of which will be larger than the mesh of the finest sieve used, and most of which will be considerably smaller. I decided to adopt an attitude of treasure hunt, which was amply rewarded.

This is how I prepared for my task:

Step 1: Fetch sediment bags from repository - a long walk from my desk, and the bags were heavy.

Step 2: Select one bag (opening more than one bag at a time can lead to confusion about the original provenance of the contents).

Step 3: Locate a reasonably sized "tray" for pouring small quantities of sediment into. This step proved relatively easy for someone working at a museum with a good collection of white, medium calibre specimen boxes of different sizes. A lid of a box of about 25cm x 13cm proved ideal, since it was small enough to prevent having to chase tiny objects across the surface, yet provide adequate space for segregating the material sorted from that still to be done. The pale background was uniform, and provided a good contrast for the material, most of which was of a dark colour. It was also small enough to be positioned at a slight tilt, which stopped processed fragments from re-mixing with those already sorted.

Step 4: Find small containers for receiving different categories of finds. I used a mixture of small, lidded, plastic vials and small zip-topped plastic bags, preferably with writing panels on them (40mm x 75mm, or 60mm x 75mm). Obtain the containers before beginning sorting or a re-sort may well be necessary.

Step 5: Choose a good tool to work with. Small fragments, echinoids or other things, will require picking up. A long-nosed, lightly sprung pair of tweezers/forceps proved ideal. They did not squash the fragments, and I could separate the amount of sediment I was looking through and select precisely any item of interest I wanted to collect.

Reference has been made to the slight tilt of the sorting tray. One does not often talk about "fragment behaviour" in a sorting context, but this was exactly what made echinoids relatively easy to spot: spine fragments roll. They are cylindrical (see Plate 3), and when freed from their context of other material, head for the bottom of the tray without prompting. This turned out to be true however much the ridges along the length of the fragment had been eroded. A variant on this would be spine fragments with remains of the acetabulum, which would roll a little way and then swing in an arc, stopped from further downwards progress by the acetabulum , but still easily detectable. Spotting these little "active" items taught me about echinoids in samples.

One cannot, of course, say anything about the origin of the echinoids in question, or about their role in a settlement. Samples from our particular context had spent time both in and out of water and might have been washed out by waves and re-deposited later, or might be the result of fragmented dead animals being washed up on the beach. Accurate dating might be difficult. This is where much more detailed research investigation is needed.

CONCLUSIONS

The question that we have aimed to answer in this paper is not do echinoids occur in archaeological sites, but how do we identify them from their disarticulated skeletal elements? More or less complete specimens will be obvious and should be identifiable to genus at least, and more probably species, using published guides (for example, Smith & Kroh, 2011, is available free on-line and is comprehensive). It may be difficult to determine disarticulated elements to even genus, but we have provided a photographic atlas (Figures 1-5), with accompanying descriptive text and supported by comprehensive appendices, which will facilitate identification of all the major plates of the echinoid test.

ACKNOWLEDGEMENTS

We thank Dr Igor Gutiérrez-Zugasti (IIIPC-Universidad de Cantabria, Spain) and a second, anonymous referee for reviewing an earlier version of this contribution, and providing many suggestions for improvement, which we have been happy to act upon.

REFERENCES

Allsworth-Jones, P.; Lalor, G.; Lechler, G.; Mitchell, S.F.; Rodriques, E.Z. & Vutchkov, M. 2006: The Taíno settlement of the Kingston area. In: Atkinson, L.G. (ed.): *The Earliest Inhabitants: The Dynamics of the Jamaican Taíno*: 34-46. University of the West Indies Press, Mona.

Appelt, S.; Drancourt, M. & Le Bailly, M. 2016: Human coprolites as a source for paleomicrobiology. *Microbiology Spectrum* 4, PoH-0002-2014. Doi: 10/1128/microbiolspec.PoH-002-2014.

Bejega García, V.; González Gómez de Agüero, E. & Fernández Rodríguez, C. 2014: Un nuevo método para la estimación de la abundancia de *Paracentrotus lividus* en yacimientos arqueológicos. *Archaeofauna* 23: 39-49.

Bradbury, A.; Palsson, W.A. & Pacunski, R.E. 1998: Stock assessment of the sea cucumber *Parastichopus californicus* in Washington. In: Mooi, R. & Telford, M. (eds.): *Echinoderms: San Francisco*: 441-446. A.A. Balkema, Rotterdam.

Campbell, A. & Harbo, R.M. 1991: The sea urchin fisheries in British Columbia, Canada. In: Yanagisawa, T.; Yasumasu, I.; Oguro, C.; Suzuki, N. & Motokawa, T. (eds.): *Biology of Echinodermata*: 191-199. A.A. Balkema, Rotterdam.

Campbell, G. 2008a: A preliminary study of methods for identifying archaeological sea urchin remains in the Pacific northwest. *Canadian Zooarchaeology* 25: 15-35.

.— 2008b: Sorry, wrong phylum: a neophyte archaeomalacologist's experiences in analyzing a European Atlantic sea urchin assemblage. *Archaeofauna* 17: 77-90.

Conrad, C. 1998: Overexploitation in the present world sea cucumber fisheries and perspectives on mariculture. In: Mooi, R. & Telford, M. (eds.): *Echinoderms: San Francisco*: 449-454. A.A. Balkema, Rotterdam.

Donovan, S.K. 2004: Echinoderms of the mid-Cainozoic White Limestone Group of Jamaica. *Cainozoic Research* 3 (for 2003): 143-156.

.— 2011: "The Star-Crossed Stone" by Kenneth J. McNamara. *Geological Journal* 46: 661. [Book review.]

Donovan, S.K. & Lewis, D.N. 2009: Paleontological implications of multiple genital pores in the apical system of *Eucidaris tribuloides* (Lamarck), Recent of Jamaica. *Caribbean Journal of Science* 45: 20-24.

.— 2017: On the use of deep concave-dished containers in fossil invertebrate macrophotography. *Bulletin of the Mizunami Fossil Museum* 43: 31-33.

DONOVAN, S.K. & VEALE, C. 1996: The irregular echinoids *Echinoneus* Leske and *Brissus* Gray in the Cenozoic of the Antillean region. *Journal of Paleontology* 70: 632-640.

DUPONT, C.; MARCHAND, G.; CARRIÓN MARCO, Y.; DESSE-BERSET, N.; GAUDIN, L.; GRUET, Y.; MARGUERIE, D. & OBERLIN, C. 2010: Beg-an-Dorchenn (Plomeur, Finistère): une fenêtre ouverte sur l'exploitation du littoral par les peuples mésolithiques du VI[e] millénaire dans l'Ouest de la France. *Bulletin de la Société préhistorique française* 107: 227-290.

DURHAM, J.W. & WAGNER, C.D. 1966: Glossary of morphological terms applied to echinoids. In: Moore, R.C. (ed.): *Treatise on Invertebrate Paleontology, Part U, Echinodermata* 3(1): U251, U253-U256. Geological Society of America and University of Kansas, New York and Lawrence.

FRIZZELL, D.L.; EXLINE, H. & PAWSON, D.L. 1966: Holothurians. In: Moore, R.C. (ed.): *Treatise on Invertebrate Paleontology, Part U, Echinodermata* 3(1): U641-U672. Geological Society of America and University of Kansas, New York and Lawrence.

GOULDWELL, A.; ALLSWORTH-JONES, P.; LECHLER, G.; MITCHELL, S.F.; WALTERS, S.; WEBSTER, J. & YOUNG, R. 2006: The pre-Columbian site of Chancery Hall, St Andrew. In: Atkinson, L.G. (ed.): *The Earliest Inhabitants: The Dynamics of the Jamaican Taíno*: 47-68. University of the West Indies Press, Mona.

GUTIÉRREZ ZUGASTI, I. 2011: The use of echinoids and crustaceans as food during the Pleistocene-Holocene transition in northern Spain: methodological contribution and dietary assessment. *Journal of Island and Coastal Archaeology* 6: 115-133.

GUTIÉRREZ ZUGASTI, I.; ANDERSEN, S.H.; ARAÚJO, A.C.; DUPONT, C.; MILNER, N. & MONGE-SOARES, A.M. 2011: Shell midden research in Atlantic Europe: State of the art, research problems and perspectives for the future. *Quaternary International* 239: 70-85.

GUTIÉRREZ ZUGASTI, I.; TONG, E.; GARCÍA-ESCÁRZAGA, A.; CUENCA-SOLANA, D.; BAILEY, G.N. & GONZÁLEZ-MORALES, M.R. 2016: Collection and consumption of echinoderms and crustaceans at the Mesolithic shell midden site of El Mazo (northern Iberia): Opportunistic behaviour or social strategy? *Quaternary International* 407B: 118-130.

HAMMOND, N. 2017: Aztec gods were starfish lovers. *The Times* November 4: 1 p.

HOWARD, J.M. 2008: *No drills, no problem? The possible use of sea urchin spines as drills on San Nicolas Island: an experimental archaeological project*. Unpublished MS thesis, Department of Anthropology, Northern Illinois University, Dekalb.

KEEGAN, W.F.; PORTELL, R.W. & SLAPCINSKY, J. 2003: Changes in invertebrate taxa at two pre-Columbian sites in southwestern Jamaica, AD 800-1500. *Journal of Archaeological Science* 30: 1607-1617.

KHOTIMCHENKO, Yu.S. 2015: The nutritional value of holothurians. *Russian Journal of Marine Biology* 41: 409-423.

KIER, P.M. 1977: The poor fossil record of the regular echinoid. *Paleobiology* 3: 168-174.

LANE, N.G. & AUSICH, W.I. 2001: The legend of St Cuthbert's beds: a palaeontological and geological perspective. *Folklore* 112: 65-73.

LAWRENCE, J.M. (ed.) (2007): *Edible sea urchins: biology and ecology*. Second revised edition. Developments in Aquaculture and Fisheries Science 37: 529 pp.

LEWIS, D.N. & DONOVAN, S.K. 2007: A standardized method of describing fossils, using Echinoidea as an example. *Scripta Geologica* 134: 109-118.

MÄRKEL, K. 1979: Structure and growth of the cidaroid socket-joint lantern of Aristotle compared to the hinge-joint lanterns of non-cidaroid regular echinoids (Echinodermata, Echinoidea). *Zoomorphologie* 94: 1-32.

MCMAMARA, K.J. 2007: Shepherds'crown, fairy loaves and thunderstones: the mythology of fossil echinoids in England. In: Piccardi, L. & Masse, W.B. (eds.): *Myth and Geology*. Geological Society Special Publication 273: 279-294.

.— 2011: *The Star-Crossed Stone: the secret life, myths, and history of a fascinating fossil*. University of Chicago Press, Chicago.

MELVILLE, R.V. & DURHAM, J.W. 1966: Skeletal morphology. In: Moore, R.C. (ed.): *Treatise on Invertebrate Paleontology, Part U, Echinodermata* 3(1): U220-U251. Geological Society of America and University of Kansas, New York and Lawrence.

MORTENSEN, T. 1928-1951: *A Monograph of the Echinoidea*. In five volumes, C.A. Reitzel, Copenhagen.

.— 1977 [first published 1927]: *Handbook of the Echinoderms of the British Isles*. Reprint. W. Backhuys, Rotterdam.

PURDY, B.A. 1996: *How to do Archaeology the Right Way*. University Press of Florida, Gainesville.

SMITH, A.B. 1984: *Echinoid Palaeobiology*. George Allen and Unwin, London.

SMITH, A.B. & KROH, A. (eds.) 2011: *The Echinoid Directory*. World Wide Web electronic publication.

http://www.nhm.ac.uk/research-curation/projects/echinoid-directory [accessed 30 April 2018].

Szabó, K. & Amesbury, J.R. 2011: Molluscs in a world of islands: The use of shellfish as a food resource in the tropical island Asia-Pacific region. *Quaternary International* 239: 8-18.

APPENDIX 1

Glossary of principal terms applied to components (= ossicles) of the echinoid test

ambulacra	the five thinner rays radiating form the ocular plates, and composed of two columns of individual component plates.
apical disc	the group of plates on the upper surface of the test which includes the genital plates, madreporite, ocular plates and sometime suranal plates.
clavula	a specialised appendage found on the fasciole.
fasciole	band of specialised tubercles on some irregular urchins.
genital plate	one of the component plates of the apical disc, interradial (or interambulacral) in position. There are normally five of these and each has a single pore (but see also madreporite).
interambulacra	the five (commonly) broader rays radiating from the genital plates, and composed of two columns of plates.
irregular	test having a bilateral symmetry
madreporite	an enlarged genital plate which is perforated by many other small pores (see also genital plate).
milliary tubercles	tiny tubercles which may occur over the test.
ocular plate	one of the component plates of the apical disc, radial (or ambulacral) in position. There are normally five of these.
pedicellaria	tiny specialised appendages which have various functions, including protection and cleaning.
periproct	the aperture in the test through which the anus opened.
peristome	the aperture in the test which contained the mouth.
radioles	the spines of sea urchins.
regular	test having an apparent radial symmetry, with periproct and peristome in polar positions.
spheridium	a spherical appendage used for orientation of the urchin.
spines	see radioles. Not to be confused with the spines (or vertebral columns) of vertebrates.
suranal plate	a small plate sometimes present in certain urchins and which may be tessellated into the apical disc.
test	the ‘shell’ or skeleton of the urchin.
tubercle	a raised protuberance which bears the radiole.

APPENDIX 2

Components and descriptive parts of echinoid tests (after Lewis & Donovan 2007: table 1)

1. Test Regular
Periproct within disc
central
offset

2. Test Irregular
Periproct not within disc
apical
marginal
supramarginal
inframarginal
oral
posterior end

3. Shape
oblate spherical (sub-spherical)
globular
plano-convex
conical
flattened oro-apically
oral surface depressed
oral surface inflated
oral surface plane
tall
low
elongated (axis III-5)
quadrate
outline
circular
angular
heart-shaped
rostrate
truncate

4. Size
large
medium
small

5. Apical Disc
circular
elongated
disjunct
central
ad-anterior
ad-posterior
monocyclic
dicyclic
hemiolicyclic

6. Ocular plates (I-V)
insert
exsert

7. Genital plates (1-5)
five present
one plate/gonopore present
tetrabasal (1-4)
monobasal (1-5)
madreporite (2)
large
small
ethmolytic
ethmophract
5 genital pores
4 genital pores (1-4)

8. Suranal plate
present and tesselated into disc
not tesselated into disc

9. Peristome
shape
circular
oval
D-shaped
asymmetric
position
central
anterior
perignathic girdle
auricles/apophyses/mixed
buccal clefts ("gill slits" or buccal notches)
no buccal clefts

10. Lantern
absent in adults
present in adults
demipyramids
tops pitted
tops unpitted
cidaroid
aulodont
stirodont
camarodont
epiphyses
rotulae
teeth
grooved
keeled
compasses

11. Coronal sculpturing
sculptured
unsculptured

12. Coronal plate imbrication
imbricated
tesselated
simple butt-joint
sutural pegging
flexible
rigid

13. Ambulacra
non-petaloid
sub-petaloid
petaloid
open
closed
depressed/sunken
raised/convex
flush
wide cf. interambualcra
narrow cf. interambualcra
2 columns
more than 2 columns (pluri-serial)

14. Ambulacral plates
simple
pseudo-compound
compound
diadematoid
arbacioid
acrosalenioid
echinoid
echinothurioid
reduced plates
demi-plates
occluded plates
included plates
pore pairs

straight
oblique
conjugate
non-conjugate
pore columns
simple (uniserial)
bigeminate (biserial)
trigeminate (triserial)
polyporous
phyllodes
(phyllodes + bourrelets = floscelles)
spheridial pits
oral
aboral
perradial
adradial
one pair
2-4 pairs
Multiple

15. Interambulacra
wide
narrow
2 columns
more than 2 columns (pluriserial)
labral plate
sternum
protosternous
meridosternous
amphisternous
bourrelets
(bourrelets + phyllodes = floscelles)

16. Primary Tubercles
large
small
tubercles sunken
tubercles flush
regular series
alternating series
perforate
non-perforate
parapet crenulate
parapet non-crenulate
neck straight
neck undercut
platform
flush
impressed (with parapet)
scrobicule
basal terrace

17. Secondary tubercles
perforate
non-perforate
large
small
scrobicular ring
contiguous
confluent
complete
non-confluent tangential
non-confluent separated

18. Other tubercles etc.
aboral naked zone
miliaries
fascioles
internal
peripetalous
lateral
latero-anal
subanal
anal
granules

19. Appendages
Radioles
long
short
slender
fat
straight
curved
clavate (clubbed)
spinules
smooth
ornamented
solid
hollow
verticillate
non-verticillate
cortex
no cortex
Pedicellariae
globiferous
tridentate
ophicephalous
triphyllous
Clavulae
Spheridia