

# **A preliminary study of methods for identifying archaeological sea urchin remains in the Pacific Northwest**

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# A Preliminary Study of Methods for Identifying Archaeological Sea Urchin Remains in the Pacific Northwest

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## ABSTRACT

The remains of sea urchins are common at archaeological sites in the Pacific Northwest, providing valuable data for marine biologists and for archaeologists interested in the use of marine resources by early inhabitants of this region. However, archaeological urchin remains are typically fragmentary, limiting the applicability of traditional identification techniques. Methods have been developed recently to identify northeast Atlantic urchin remains to genus, to quantify the numbers harvested, to examine the manner in which they were prepared and to reconstruct their population structure. These methods are tested on three species of Pacific Northwest *Strongylocentrotus* urchins (the sole shallow-water echinoid genus) and are shown to be useful for species discrimination. Features on auricles and jaw elements, as well as the geometry of the jaws, may be characteristic of a particular species. In addition to permitting the identification of archaeological urchin remains, these distinguishing features may also shed some light on specialization and adaptation among these sea urchin species.

## RÉSUMÉ

L'oursin est souvent présent dans les sites archéologiques du nord-est pacifique et représente donc une source importante de données sur les ressources maritimes et leur utilisation dans le passé. Malheureusement, les restes d'oursin sont typiquement mal conservés, ce qui restreint l'utilisation de techniques traditionnelles d'identification taxonomique pour cette classe. Des méthodes d'identification taxonomique pour les restes d'oursin ont été développées récemment dans le nord-est atlantique pour le calcul du nombre de restes, l'analyse des techniques de préparation et l'étude des structures de population. Dans cette étude, ces méthodes sont testées sur trois espèces du genre *Strongylocentrotus* de la côte du nord-est pacifique, démontrant leur utilité. Certains aspects des auricules et des éléments mandibulaires semblent caractériser les espèces et peuvent donc nous informer sur la spécialisation, l'adaptation et la spéciation des oursins.

*Aliter echino: solum mittes in aqua calida, coques, levas, in patella compones, addes folium, piper, mel, liquamen, olei modice, ova, et sic obligas in thermospodio coques, piper asparges et inferes.*

“another [thing to do with a] sea urchin: Drop one by one into boiling water, cook, lift out, and arrange on a platter; add [a sauce of] bay leaf, pepper, honey, fish sauce, a little oil, and eggs stirred together and cooked in a chafing dish; sprinkle with pepper and serve.”

- Apicius, *de re Coquinaria* IX, viii (compiled c. AD 500)

The consumption of sea urchins (marine invertebrates in the Class Echinoidea) is a common practice throughout the modern world (Lawrence 2001) which dates back to at least the Mesolithic (Menendez et al. 1986:286). Sea urchins are recovered regularly from coastal archaeological sites from around the world. In the Mediterranean, urchins have been found in Epipalaeolithic Cyprus (Reese 1999), Minoan Crete (Reese 1995) and Phoenician trading centres (Garcia and Moreno 1994, Reese 2003), and from Classical sites such as Pompeii (Ciaraldi 1997). Urchin remains have been found from sites all around the Pacific, including the Russian Pacific coast (e.g. Fitzhugh et al. 2007), Hawaii (Jones 2001), the Marshall Islands (Weisler 2001), Norfolk Island (Campbell and Schmidt 2001), and New Zealand (Best 1929), and in Chile (Jerardino et al. 1992) and Peru (LaVallee et al. 1999). Urchin remains are encountered regularly in archaeological excavations along the Pacific coast of North America, in Alaska (Dall 1877; Desautels et al. 1971), the Gulf of Georgia (Hanson 1995; Green 1999), the outer coast of Vancouver Island

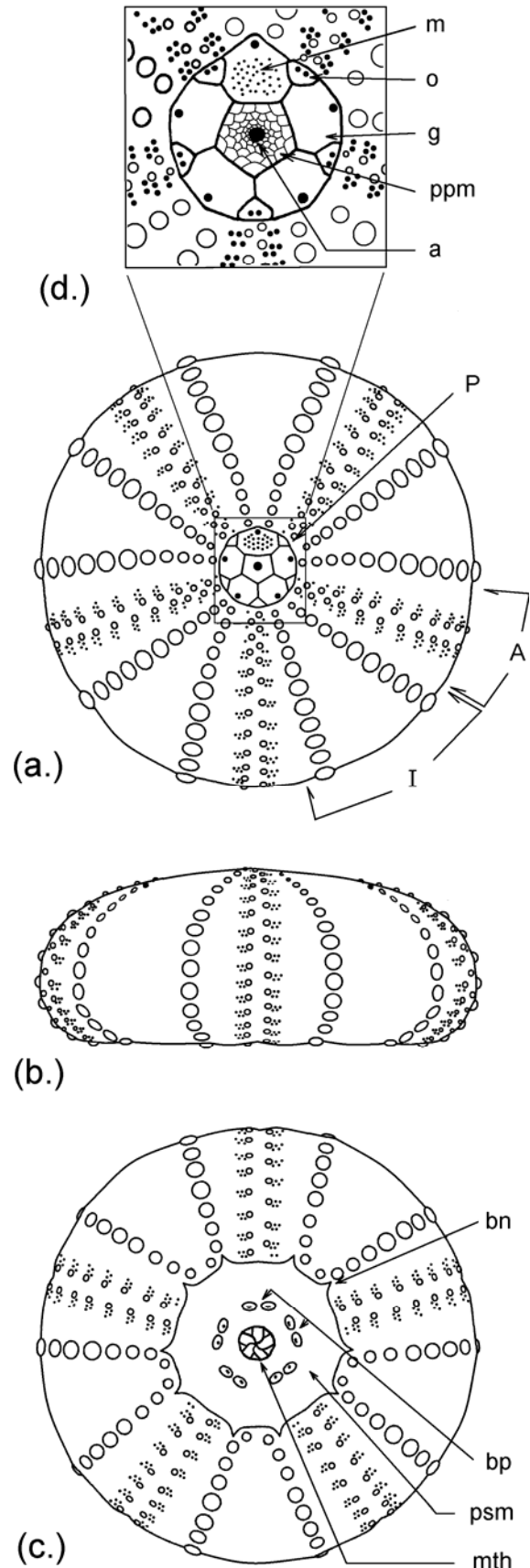
(Sumpter 1991, 2005) and the Channel Islands of California (Erlandson et al. 2005, Martz 2005).

Sea urchins are grazers of seaweed beds, sea-grass beds and stable surfaces such as rocky shores, from the low inter-tidal to depths of many metres. In well-lit levels of coastal waters, their grazing controls the balance between open space and seaweed cover and between different kinds of seaweed. They are the principal grazers of coastal kelp forests. The complex interaction between humans, sea otters and sea urchins seems to have controlled the rate and extent to which kelp forests were overgrazed into “urchin barrens” along this coast over the last few millennia (Erlandson et al. 2005:16). Reconstructing human impact on sea urchins in this and other coastal ecosystems may provide a useful line of evidence for interpreting human use of the coast over time.

Sea urchins are marine invertebrates in the phylum Echinodermata, along with the starfishes and sea-cucumbers. Those found outside tropical seas are usually in the Order Camarodonta. They are

typically a flattened spherical shape studded with spines (Figure 1) with the anus centrally positioned at the top, the mouth centered at the base, and the surface bearing numerous prominent maneuverable spines and less obvious tube-feet. The solid part of the urchin (the *test*) is a hollow flattened sphere made up of *test plates*, arranged into five ambulacral zones (in which the plates have rows of paired pores for the tube feet and tubercles which serve as articulations for the spines) alternating with five interambulacral zones (in which the plates have tubercles only).

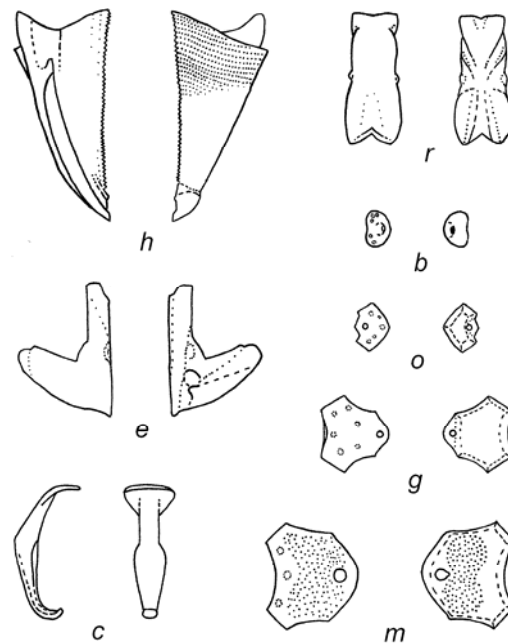
**Figure 1: Diagram of a sea urchin (regular echinoid) test, with patterns of tubercles (circles) and pairs of pores (dots) much simplified. (a.): top view, with anus central. *P*, periproct with apical disk; *A*, one of the five ambulacral zones; *I*, one of the five interambulacral zones. (b.): side view, directly facing an ambulacral zone. (c.): base view, with peristome central. *mth*: mouth; *psm*: peristomal membrane; *bp*: buccal plate; *bn*: buccal notch, formerly called the "gill-slit." (d.): magnified view of periproct, showing apical disk of specialised plates. *a*: anus; *ppm*: periproctal membrane with closely-packed plates; *g*: one of the genital plates; *o*: one of the five ocular plates; *m*: madreporite. From Campbell (in press). No scale is provided in this figure and some of the figures to follow, as sizes vary greatly among urchins.**



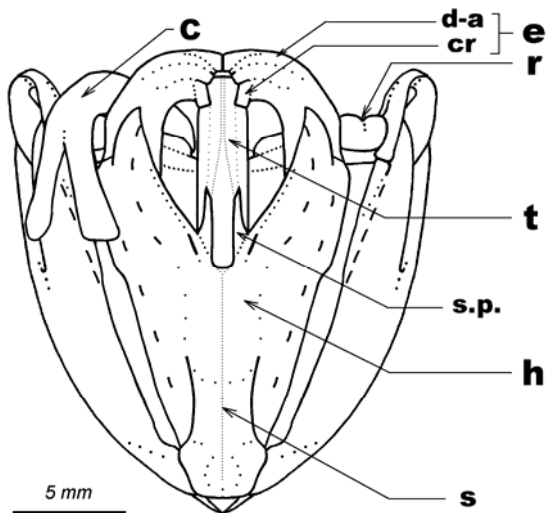
In the periproct on the top of the test are five *ocular plates* and five *genital plates*, one enlarged and perforate (the *madreporite*), arranged in rings around the periproctal membrane (Figures 1d and 2). This membrane bears numerous near-microscopic plates and surrounds the centrally placed anus. Around the mouth at the base of the animal is the tough peristomal membrane, sparsely packed with near-microscopic plates; in the camarodont urchins the only sizable ones are the five pairs of *buccal plates*. The test margin around the peristomal membrane is incised by five pairs of buccal notches, shallow in some urchin species and deep in others. Along the margin is an inward-pointing ridge, the perignathic girdle, which bears *auricles* (pairs of inward extensions for the muscles which align the jaws). Within the animal, just above the peristomal membrane, lies the urchin's jaw (known as "Aristotle's lantern"; Figures 2 and 3), a complex structure made up of five *teeth* (hard brittle structures of an open spiral shape), five pairs of *hemipyramids*, five pairs of *epiphyses*, five *rotuli* and five *compasses* ("T"-shaped in many urchins but "Y"-shaped in shallow-water *Strongylocentrotus* species on the Pacific coast of North America). A more detailed description of these parts and their relationships has been written with the archaeologist in mind (Campbell, in press). They are also described in many good biology and palaeontology texts (e.g., Melville and Durham 1966:244) and online (Smith 2005).

Urchins are useful in archaeology because they are found regularly in coastal excavations (sometimes in large

quantities), enough to show that they were consumed regularly in the past. They are also good indicators of seasonality (the roe masses within the test bodies are large enough to eat for a limited part of the year), climate (each species is associated with a different optimum sea temperature range), and shore type (each species has a different tolerance range for salinity and for exposure to wave action, and the size and age distribution of a given species differs for different habitats).



**Figure 2: Sea urchin non-test elements often recovered from archaeological deposits. Elements from the jaw (Aristotle's lantern) include the hemipyramid (h), the epiphysis (e), the compass (c), and the rotula (r); buccal plates (b) from the membrane around the mouth, ocular plates (o), genital plates (g) and madreporites (m) from the periproct at the top of the test. After Campbell (in press).**



**Figure 3: Abaxial (side view) of the jaw or lantern of a camarodont sea urchin (*S. fransiscanus*), orientated as in life. *c*: compass (removed from the right side of the figure); *e*: epiphysis; *d-a*: demi-arc; *cr*: crest; *r*: rotule; *t*: tooth, visible through the foramen magnum; *h*: hemipyramid; *s.p.*: styloid process; *s*: suture along which mirror-image pairs of hemipyramids are joined, surrounding lower part of tooth.**

However, interpretations of urchin remains from archaeological deposits have been limited. A general problem for urchin remains is one of preservation: sea urchins are seldom found whole after death. Soft-tissue rot means that the spines, periproct and jaw come free of the test and the jaw falls apart, while the urchin test weakens and slowly falls apart along the joints between plates (Smith 1984:15-16). Dead or fossil animals are usually identified by the pattern of tubercles and especially by the number of pore-pairs on ambulacral plates (e.g., Smith 2005). However, surface sculpture and pore-pair counts vary within an animal. The count is low on plates near the mouth and high on plates near the top, and the

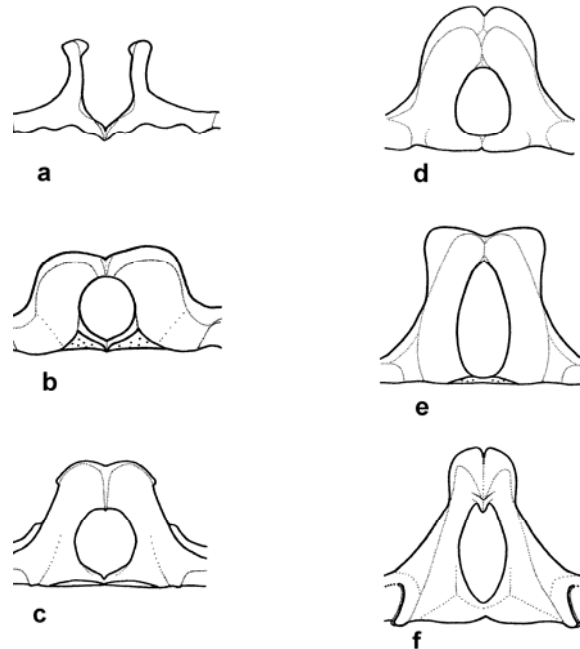
difference in count due to position is greater than the difference in typical pore pair count between species. Therefore, it is not possible to tell from pore-pair counts on loose plates whether those plates came from different species of urchin or from different parts of the test in the same species of urchin. In some regions, some genera are indistinguishable on the basis of test sculpture and pore-pair count. The usual methods of identifying urchins to species or genus will not work on sea urchin remains in their typical state of preservation in archaeological deposits.

This typically poor preservation presents other problems for interpretation. As with other kinds of animal used for food, the numbers of urchins and their average sizes are required for estimation of intensity of exploitation and of their importance in the diet. A measure of the distribution of sizes, such as range or standard deviation, is required to compare urchin exploitation and use over time, both between deposits within a site and between sites or cultures. In addition, the size and age distribution for a particular species of urchin will vary with habitat; reconstructing these distributions therefore offers the potential to determine the past habitats that were being exploited. However, the typically poor preservation means that individual urchins can almost never be recognized, and the sizes of individual urchins can almost never be measured directly. Therefore, data on urchin numbers, their average size, and their size distribution (from which age distributions are derived) are usually not available.

Recent work on a European Atlantic sea urchin assemblage has drawn on previous work and pioneered some methods to begin to overcome some of these problems (Campbell 2007). The applicability of the methods devised to archaeological sea urchins in general is discussed elsewhere (Campbell, in press). Numbers of individuals can be reconstructed from counts of elements of the periproct, the auricles and the jaws, since each urchin has a known number of these elements. Differences between the numbers of elements from the top of the urchin (in the periproct) and from the base (the auricles and jaws) may represent evidence for processing prior to consumption. Such inferences can be examined by looking at differences in test fragmentation, since breaks in tests while fresh can be recognised because they propagate across test plates (Smith 1984:19). Because jaw size is roughly proportional to test size (although this may vary within a species depending on the availability and type of food [Ebert 2001]), the average size of an individual can be estimated from hemipyramid length. The distribution of sizes can be estimated from the distribution of hemipyramid lengths by using this proportional relationship. The age distribution can be estimated from the size distribution by a method applied commonly elsewhere in marine biology (Sparre and Venema 1998:63-94) for organisms including shelled marine invertebrates (Cerrato 1980:427).

The method devised to identify European Atlantic sea urchins was based on the observation by Mortensen (1943:167) that the most reliable way of

discriminating between two genera with indistinguishable surface sculpture and pore-pair counts (*Paracentrotus* and *Strongylocentrotus*) is by the shape of the auricles. Differences in auricle form between genera had been recognized previously and a simple classificatory scheme had been devised (Hawkins 1934:621-2).



**Figure 4: Diagram of auricles from North Atlantic shallow-water sea urchins. a: *Arbacia*; b: *Psammechinus*; c: *Echinus*; d: *Paracentrotus*; e: *Strongylocentrotus*; f: *Sphaerechinus*. From Campbell (2007).**

A survey of the auricles for the North Atlantic genera showed that auricle shapes are different for different genera (Figure 4), ranging from simple upright shafts with enlarged heads, which are occasionally fused in larger animals, to increasingly complex and forms that are usually fused. The simplest auricle form occurs in that genus with the most basic anatomy (*Arbacia*), with auricle

complexity increasing with anatomical complexity within the North Atlantic camarodont urchins. Therefore, there seems to be some adaptive advantage to changing the arrangement of how the auricle muscles work the jaws, which is preserved in auricle form.

A particular problem for the Pacific coast of North America is that the shallow-water urchins (those in water less than 200 m deep) are all in the same genus, *Strongylocentrotus* (Lambert 2007:1-2). While there are some features which distinguish between species (Jensen 1974), many are associated with elements that are typically lost through decay (Biermann et al. 2003:360). Usually, archaeological remains are reported as "*Strongylocentrotus* sp." In cases in which species designations are made, it is usually assumed that the species represented by the archaeological material is the same as the extant local species. In the few instances where more than one species of urchin has been recognized at a single site (Sumpter 2005), identification to species was based on test colour where preserved (Sumpter, pers. comm.). Changes in the ranges of the various urchin species over time along this coast are likely to be a topic of interest in its own right to marine biologists. Reconstructing the types of shore exploited by humans in the past as implied by the ecological requirements of the different urchin species is a topic of great interest to archaeologists. Reconstructing the direct and indirect effects of this human exploitation on coastal habitats (especially coastal kelp forest) is a topic of interest to both marine biologists and archaeologists.

Therefore, developing a means of discriminating urchin species within a genus (in this case, *Strongylocentrotus*) would be useful to both marine biologists and archaeologists in the Pacific Northwest.

There are five *Strongylocentrotus* species common in the Pacific coast of North America, south of Alaska (Lambert 2007:2). The pink urchin, *S. fragilis* Jackson, 1912, is found in waters deep enough (below 50 m) to be a challenge to harvesting and therefore is unlikely to be found in archaeological assemblages. The white urchin, *S. pallidus* (Sars, 1871), is found only below 5 m in depth and would be expected to have been encountered by humans only occasionally in the past. The remaining three species, all found in shallow waters, have overlapping ranges. The red urchin, *S. fransiscanus* (Agassiz, 1863), the species which produces the world's largest urchins, is found throughout the northern Pacific; the purple urchin, *S. purpuratus* (Stimpson, 1857), occurs from southern Alaska to Baja California; and the green urchin, *S. droebachiensis* (Müller, 1776), found from Puget Sound northwards, has a circum-Arctic distribution (Jensen 1974). Jensen (1974:142) observed that green urchins have tubercles with undercut necks while red and purple urchins both have tubercles with squat plug-like tops. Jensen (1974:140) also observed that there were species differences in the features on the epiphyses.

### Material

Material was kindly supplied from four areas along the west coast of North America:

- In September 2005, seven purple urchins and eight red urchins from 7 m depth, from Coal Oil Point, California (34°24'N, 119° 52.5'W).
- In April 2006, 24 purple urchins from Cape Blanco, Oregon (42°50'N, 124°34'W): six from pits and six from bare rock at 0.15 m above mean low water (MLT), and six from pits and six from bare rock at 0.3 m below MLT.
- In winter 2005, green urchins from subtidal waters and white urchins from below 50 m in the San Juan Channel, Washington (48°31'N, 122°57'W), and purple urchins originally from Slip Point, Clallam Bay, Washington (48°16'N, 124°18'W), held in subtidal cages in the San Juan Channel.
- In June 2006, 11 red urchins from 7 m depth, and eight red urchins and eight green urchins from 5 m depth, from the vicinity of Nanaimo, British Columbia (49°N, 123°W).

The urchins provided from each location ranged in size from small (22-25 mm diameter) to large (45-60 mm for most species, and 95-145 mm for red urchins). From around the San Juan Channel, only larger urchins (over 35 mm) without lanterns were provided.

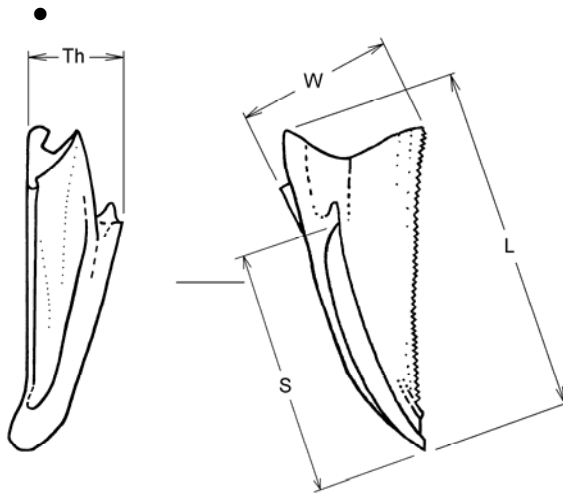
### Methods

The smaller tests had their spines removed and the jaws (lanterns) extracted and disarticulated by overnight suspension in a dilute sodium hypochlorite solution (domestic bleach). They were rinsed and air-dried, either by the author or by the contributors prior to shipping. The larger urchins (the more mature red urchins), shipped dry, had their jaws dissected out and disarticulated by overnight soaking in dilute hypochlorite, and were rinsed and air-dried. The maximum diameter (D) and height (H) of each air-dried test was measured to the nearest millimetre. The auricles and lantern elements were examined visually, in some cases under low-power magnification, to see if there were any attributes of these elements which might distinguish between species.

Differences in jaw element attributes raised the possibility that there might be differences in lantern shape between species. Any difference in lantern shape will be reflected in differing shapes of the hemipyramid, so, to test this possibility, the following dimensions were taken of a hemipyramid or two from each urchin, to the nearest 0.1 mm (Figure 5):

*Length (L)*: Maximum overall dimension, from the oral tip of the broad flat plate to the dorsal tip of the projecting process. This measure was used in preference to the usual measurement for hemipyramid length, the maximum dimension of the broad flat plate (Lawrence et al. 1995: 244), since the corners of the

plate are fragile and are frequently broken off on small fresh hemipyramids and in archaeological material.



**Figure 5: Sea urchin hemipyramid, showing measurements employed.**

- *Thickness (Th)*: Dimension from the broad flat surface of the plate to the articular suture with that hemipyramid's pair, at the base of the foramen magnum.
- *Width (W)*: Maximum dimension across the plate. This is a bit tricky to measure consistently even in fresh material, and it is not well preserved in archaeological contexts, due to the breakage of plate corners.
- *Suture length (S)*: Distance from the oral tip of the broad flat plate to the aboral end of the articular suture with the hemipyramid's pair, at the base of the foramen magnum.

A simple way to remove size as a factor when comparing shapes is to calculate ratios, expressing one dimension as a proportion of another. Comparing shapes via the means and standard

deviations of these ratios is a traditional method in interpreting shape in archaeological invertebrates (e.g., Kent 1992:25-27). Ratios of width/length, thickness/length, thickness/width and suture/length were calculated for each hemipyramid.

Archaeologists face different sampling challenges from ecologists and palaeontologists: archaeological samples are small, biased due to selection during harvesting (size ranges are often restricted, and distributions are often positively skewed because young small prey were ignored) and likely to have come from a range of habitats. Harvesters probably exploited more than one habitat for a single consumption event, and single deposits can consist of waste from several consumption events.

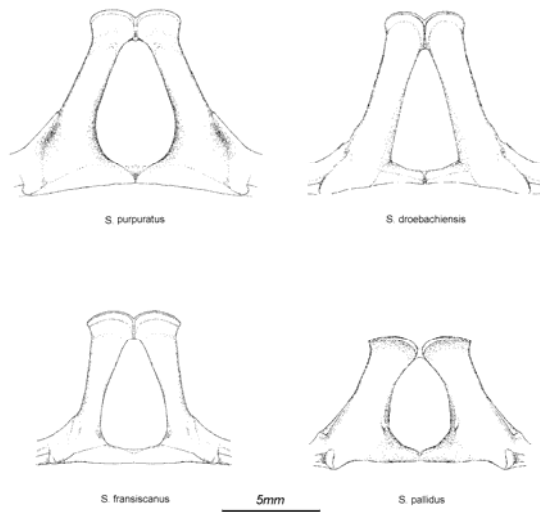
## Results

### *Auricles*

About 20% of the smaller urchins (<30 mm) had unfused auricles, normally one (rarely two) in a particular urchin. There were some subtle differences in auricle shape between larger animals of the three *Strongylocentrotus* species (Figure 6).

In purple urchins (*S. purpuratus*) the auricles were thin shafts, angled away from the lantern; only the upper third of the shaft was flattened. In green urchins (*S. droebachiensis*) the shafts were thicker, with the upper half flattened. Red urchins (*S. fransiscanus*) had even thicker shafts, wider towards the top with the upper half flattened. White urchins (*S. pallidus*) had short, thick shafts; the top edge of the auricle was rolled forward and curved to form a

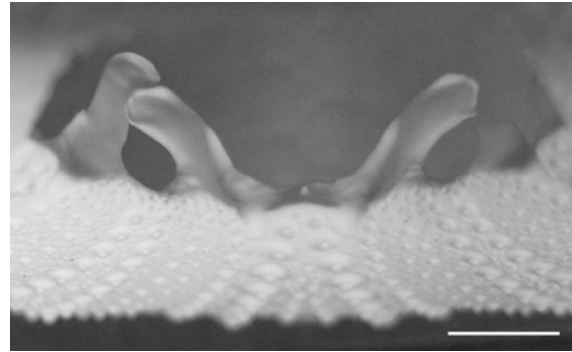
gutter. In the other three types, the top of the auricle bears a small flange which meets the flat face at a sharp angle. This deeper-water near-shore species has auricles similar to the deeper-water near-shore North Atlantic species *Echinus esculentus* (Figure 4c), so auricles facing similar forces due to similar living conditions may take similar forms.



**Figure 6:** Diagram of the abaxial (inner) face of the auricles in mature specimens of the shallow-water Pacific North American sea urchins (*Strongylocentrotus* sp.). Clockwise from top left: *S. purpuratus*, *S. droebachiensis*, *S. pallidus* and *S. fransiscanus*.

Auricles may have some other uses. Three of the purple urchins from Cape Blanco had misshaped auricles, bent over and fused oddly (Figure 7). This form of auricle was restricted to pit-dwelling urchins. It may therefore result from these urchins being struck with enough force to break the auricles against the jaws, but surviving and repairing the damage because they were safe in their pits. As a result, these

structures may have the potential to discern the life history of individuals, as well as the shore type of their habitat.



**Figure 7:** View of the abaxial (inner) face of the perignathic girdle of a pit-dwelling purple urchin (*S. purpuratus*) from Cape Blanco, Oregon (test diameter of 44 mm), showing two anomalous auricles. On the left, the upper part of right shaft has been displaced downwards toward centre of auricle and has fused with the inner face of the left shaft. On the right, the upper part of the left shaft has been displaced centrally, and the upper part of the right shaft has been resorbed. Other auricles were of typical form (cf: Figure 6). Scale bar = 5mm.

However, differences in auricle shape between species are small, and auricles vary with test size within a species. In a blind test on identified *Strongylocentrotus* specimens from the collection at the Natural History Museum, London, *S. pallidus* was usually recognized by its auricles, but the other species could not be distinguished.

#### *Jaw features*

Each epiphysis bears a long thin arm, which articulates with the top of the broad flat plate of the hemipyramid, and a shorter stouter curved arm, the demiarc. In camarodont urchins, the demi-

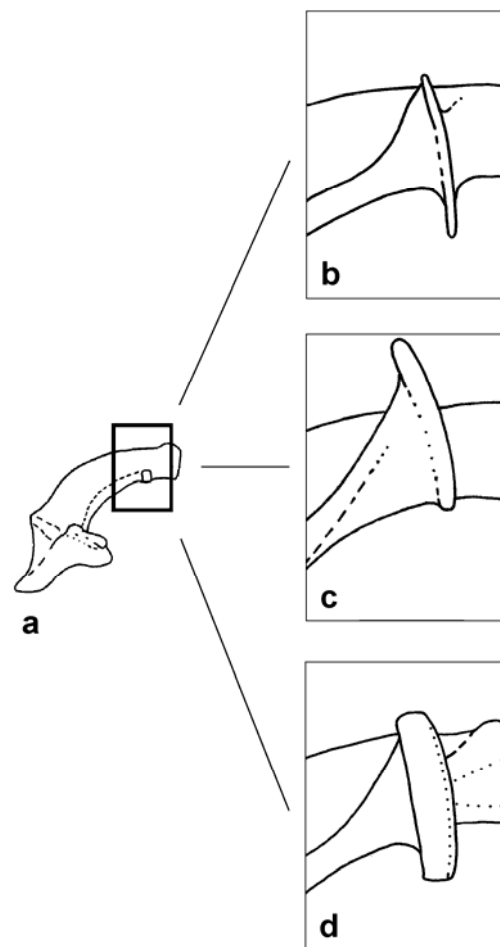
arcs span the space between the tops of the joined pairs of hemipyramids (Figure 3). The abaxial (inside) face of the demi-arc bears a crest, a small extension which supports the upper part of the tooth (Figures 3 and 8). The material studied here was consistent with the observation of Jensen (1974:140) that these crests were small buds in small individuals across all *Strongylocentrotus* species (Figure 8a), but were different in larger individuals (Figure 8b-d). In purple urchins (*S. purpuratus*) the crests are thin and project both upwards and down from the demi-arc (Figure 8b). In green urchins (*S. droebachiensis*) the crests are broader and project only upwards from the demi-arc (Figure 8c). In red urchins (*S. fransiscanus*) the crests are broad and stocky, and project only slightly (Figure 8d).

Each hemipyramid has a styloid process (Figure 3), a spur-like upward extension which supports the middle part of the tooth. In the material studied, the styloid processes were all quite small and stubby in small animals (Figure 9a), but in mature purple urchins (*S. purpuratus*) they were short and blunt (Figure 9b), in green urchins (*S. droebachiensis*) they were longer and pointed (Figure 9c), and in red urchins (*S. fransiscanus*) they were very long and thin (Figure 9d), fragile, and often broken even in fresh material.

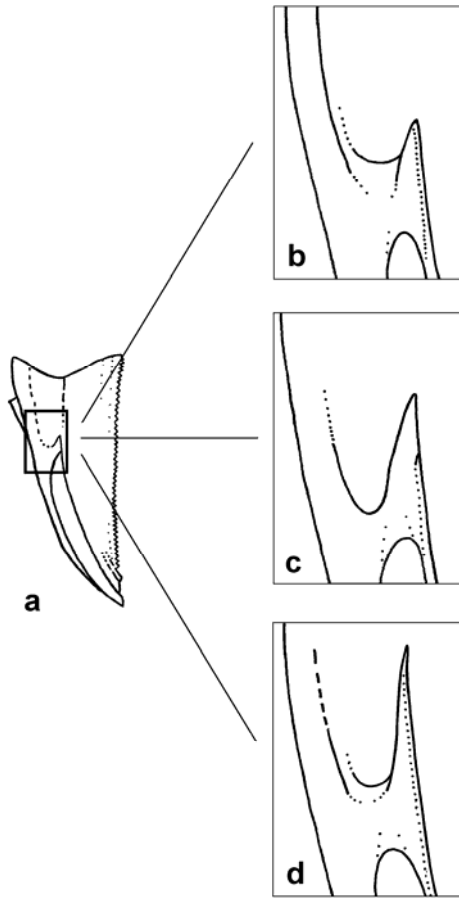
#### *Jaw morphology*

The three different species of urchin appeared to have a different arrangement of crests and styloid processes to support the tooth. This raised the possibility that each species

had a characteristic lantern shape. Any such lantern shape differences would be reflected in the relative shape of the hemipyramids: short broad lanterns would be made up of comparatively short broad hemipyramids. Therefore, if the lantern shape is really different between species, the ratios of the hemipyramid dimensions should be significantly different between species.



**Figure 8:** (a): Adaxial (outer) view of epiphysis showing the crest typical of smaller *Strongylocentrotus*. Crests of larger individuals: (b) *S. purpuratus*, (c) *S. droebachiensis*, (d) *S. fransiscanus*.



**Figure 9:** (a): View of the internal face of a hemipyramid, showing the location of the styloid process typical of smaller *Strongylocentrotus*. Processes of larger individuals: (b) *S. purpuratus*, (c) *S. droebachiensis*, (d) *S. fransiscanus*.

The relationship of test diameter to jaw length (the jaw-test allometry) and of thickness to jaw length (the jaw length-thickness allometry) for the three species is shown in Figure 10. There were clear differences in test size distribution within species from different locations.

The jaw-test allometry was only roughly linear and was clearly different within species from different locations. The jaw-test allometry and jaw length-thickness allometry formulae for the various samples are presented in Table 1, although it may not be justifiable to compare jaw-test allometry on such small samples.

However, there seems to be no difference within species in the relation of hemipyramid thickness to jaw length from different locations (Figure 10). The relationship appeared reasonably linear (the slopes,  $\beta$ , of the jaw length-thickness allometry formulae in Table 1 are all near to 1.0), and the jaw length-thickness allometry seemed quite different between species.

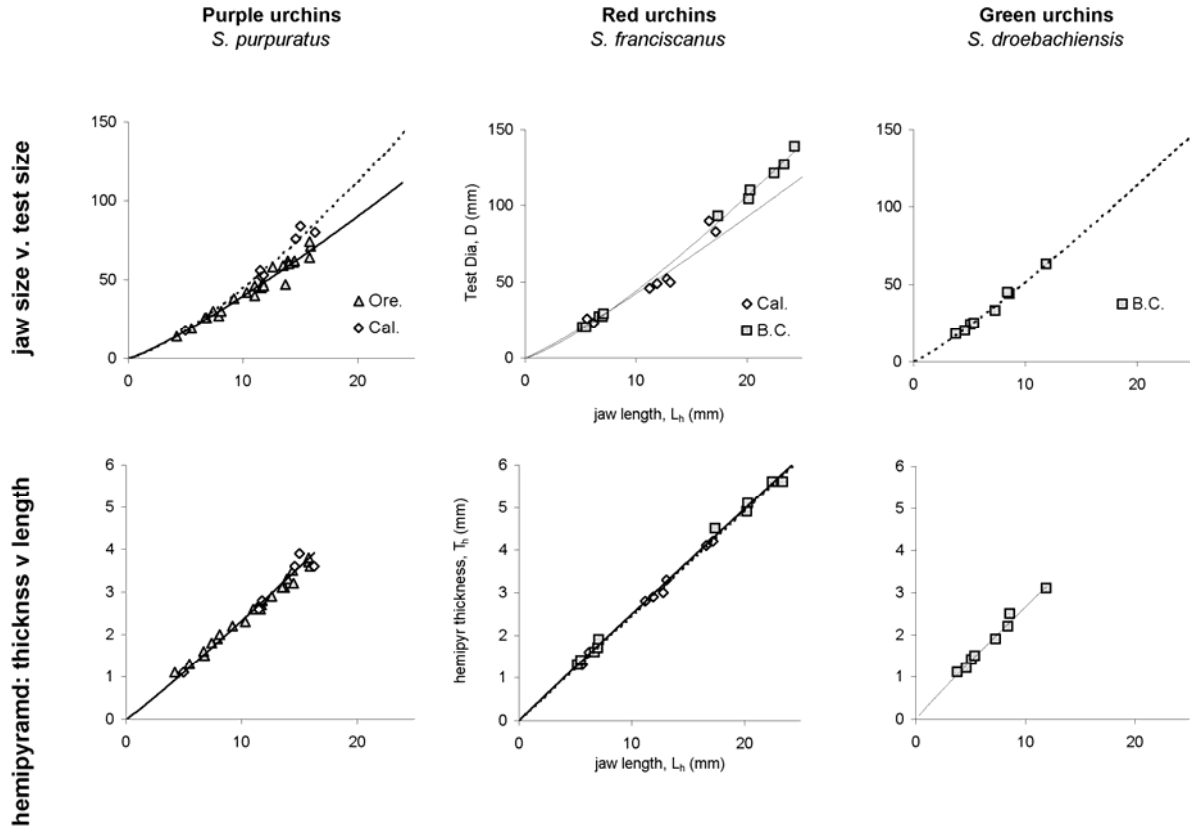


Figure 10: Test diameter (D) and hemipyramid thickness (Th) as a function of jaw size (L) for three species of *Strongylocentrotus*.

Table 1: Allometry of test diameter (D) and hemipyramid thickness (Th) with jaw size (L) for the three species of *Strongylocentrotus*

species	site	No.	$D = \alpha (L)^\beta$			$Th = \alpha (L)^\beta$		
			slope ( $\alpha$ )	exp ( $\beta$ )	$r^2$	slope ( $\alpha$ )	exp ( $\beta$ )	$r^2$
<i>S. purpuratus</i>	Cape Blanco, OR	24	2.59	1.185	0.974	0.265	0.949	0.990
	Coal Oil Pt., CA	7	2.12	1.325	0.988	0.195	1.076	0.985
<i>S. franciscanus</i>	Vancouver Isl., BC	11	2.39	1.267	0.999	0.255	0.991	0.997
	Coal Oil Pt., CA	8	3.22	1.120	0.939	0.242	1.005	0.993
<i>S. droebachiensis</i>	Nanaimo, BC	8	3.66	1.148	0.987	0.296	0.954	0.986

The statistics for the various hemipyramid ratios are presented in Table 2. While the Cape Blanco, Oregon, purple urchins came from four

different habitats, these four samples were not significantly different in terms of their ratio of hemipyramid Th/W (anova:  $F_{[3,20]} = 1.146, P = 0.355$ ), W/L

( $F_{[3,20]}=0.114$ ,  $P=0.950$ ), S/L ( $F_{[3,20]}=0.317$ ,  $P=0.813$ ), or Th/L ( $F_{[3,20]}=0.679$ ,  $P=0.575$ ). When the purple urchins from Coal Oil Point, California, were included, there was still no significant difference in the ratios (anova: Th/W:  $F_{[4,26]}=0.699$ ,  $P=0.60$ ; W/L:  $F_{[4,26]}=0.119$ ,  $P=0.97$ ; S/L:  $F_{[4,26]}=0.220$ ,  $P=0.93$ ; Th/L:  $F_{[4,26]}=0.364$ ,  $P=0.83$ ). While the red sea urchins came from three different locations, the three samples were also not significantly different in terms of their hemipyramid ratios (Th/W:  $F_{[2,24]}=0.339$ ,  $P=0.72$ ; W/L:  $F_{[2,24]}=1.020$ ,  $P=0.38$ ; S/L:  $F_{[2,24]}=0.256$ ,  $P=0.78$ ; Th/L:  $F_{[2,24]}=0.672$ ,  $P=0.52$ ). The hemipyramid ratios appear to be similar within a given species, whether collected in different parts of the same locality or from different localities.

The Nanaimo red urchins came in two size ranges, one small (20-33 mm diameter), the other very big (93-148 mm). The two size ranges had different hemipyramid ratios (Table 2). The difference was not significant for Th/L ( $t_{[17]}=1.46$ ,  $P=0.16$ ), but in large red urchins, Th/W was significantly larger ( $t_{[17]}=2.58$ ,  $P=0.019$ ), S/L was significantly smaller ( $t_{[17]}=3.31$ ,  $P=0.0041$ ), and W/L was significantly smaller ( $t_{[17]}=3.70$ ,  $P=0.0018$ ). The Coal Oil Point red urchins seemed to exhibit the same trends between big and small, with the larger urchins (>35 mm across) being similar to big red urchins from Nanaimo (Table 2). The smaller purple urchins from Cape Blanco also seemed to have different ratios from those over 35 mm across (Table 2): this difference

was not significant for Th/W ( $t_{[22]}=0.277$ ,  $P=0.78$ ) or for S/L ( $t_{[22]}=0.480$ ,  $P=0.64$ ), but Th/L was significantly smaller in big purple urchins ( $t_{[22]}=2.27$ ,  $P=0.033$ ) and W/L was significantly smaller in big purple urchins ( $t_{[22]}=2.82$ ,  $P=0.010$ ). The purple urchins from Coal Oil Point seemed to exhibit the same trends between big and small, with the larger purple urchins similar to the big purple urchins at Cape Blanco (Table 2). The three larger green urchins from Nanaimo (>35 mm) had hemipyramid ratios virtually identical to those of the smaller ones. There may be some alterations of jaw morphology with age and size under certain conditions.

When the three hemipyramid ratios were pooled by species, there was a significant difference between species for each ratio except S/L (Table 3). When the species pooling was restricted to larger urchins (>35 mm) to minimize the effects of size, there was still a significant difference between species in two of the ratios, but not in Th/W or S/L. The middle of the three average values of Th/L ratio was for the larger red urchins; this was significantly different from that for both the larger purple urchins ( $t_{[38]}=4.45$ ,  $P<0.001$ ) and the larger green urchins ( $t_{[18]}=4.49$ ,  $P<0.001$ ). The middle of the three W/L ratio averages, also from the larger red urchins, was also significantly different from the average W/L ratio of larger purple urchins ( $t_{[38]}=2.06$ ,  $P=0.046$ ) and that for the larger green urchins ( $t_{[18]}=5.80$ ,  $P<0.001$ ).

**Table 2: Hemipyramid ratios for the three species of urchin**

species	locality	category	No	Th / W		W / L		Th / L		S / L		
				avg	s.d.	avg	s.d.	avg	s.d.	avg	s.d.	
<i>S. purpuratus</i>	Cape Blanco, OR	low, bare	6	0.535	0.017	0.435	0.020	0.233	0.009	0.595	0.040	
		low, pits	6	0.556	0.028	0.431	0.018	0.240	0.012	0.594	0.038	
		v low, bare	6	0.536	0.019	0.437	0.031	0.234	0.008	0.579	0.040	
		v low, pits	6	0.534	0.030	0.439	0.021	0.234	0.007	0.579	0.036	
		all	24	0.540	0.025	0.436	0.022	0.235	0.009	0.587	0.037	
		large	17	0.543	0.022	0.429	0.018	0.232	0.007	0.577	0.035	
		small	7	0.533	0.031	0.453	0.021	0.241	0.012	0.611	0.032	
	Coal Oil Pt, CA	all	7	0.544	0.036	0.432	0.019	0.235	0.015	0.585	0.045	
		large	6	0.551		0.431		0.237		0.579		
		small	1	0.500		0.440		0.220		0.620		
	<i>S. fransiscanus</i>	Nanaimo, BC	5 m	8	0.553	0.028	0.453	0.033	0.250	0.010	0.584	0.026
			7 m	11	0.544	0.032	0.460	0.027	0.250	0.009	0.592	0.033
			all	19	0.548	0.030	0.457	0.029	0.250	0.009	0.589	0.030
large			11	0.561	0.019	0.441	0.013	0.247	0.008	0.573	0.016	
small			8	0.530	0.033	0.479	0.031	0.253	0.010	0.610	0.032	
Coal Oil Pt, CA		all	8	0.554	0.024	0.443	0.012	0.245	0.009	0.584	0.021	
		large	6	0.561		0.437		0.245		0.584		
		small	2	0.536		0.458		0.245		0.583		
<i>S. droebachiensis</i>		all	8	0.570	0.032	0.478	0.014	0.272	0.013	0.608	0.040	
Nanaimo, BC	large	3	0.568		0.477		0.271		0.609			
	small	5	0.571		0.478		0.273		0.607			

**Table 3: Hemipyramid ratios from sea urchins pooled by species, and *anova* results**

common name	purple urchin		red urchin		green urchin			
species	<i>S. purpuratus</i>		<i>S. fransiscanus</i>		<i>S. droebachiensis</i> .		<i>anova</i>	
Urchins of all sizes								
No.	31		27		8		$F_{[2,63]}$	<i>P</i> of <i>F</i>
	avg	s.d.	avg	s.d.	avg	s.d.		
Th / W	0.541	0.027	0.550	0.028	0.570	0.032	3.45	0.038
W / L	0.435	0.021	0.453	0.026	0.478	0.014	12.8	0.000022
Th / L	0.235	0.010	0.248	0.009	0.272	0.013	44.2	$1.0 \times 10^{-12}$
S / L	0.586	0.038	0.587	0.027	0.608	0.040	1.39	0.258
large urchins (D > 35mm)								
No.	23		17		3		$F_{[2,40]}$	<i>P</i> of <i>F</i>
	avg	s.d.	avg	s.d.	avg	s.d.		
Th / W	0.547	0.025	0.561	0.016	0.568	0.036	2.51	0.094
W / L	0.429	0.018	0.440	0.011	0.477	0.001	13.6	0.000031
Th / L	0.234	0.009	0.246	0.007	0.271	0.017	26.3	$5.2 \times 10^{-8}$
S / L	0.577	0.035	0.577	0.017	0.609	0.017	1.66	0.203
small urchins (D < 35mm)								
No.	8		10		5			
	avg		avg		avg			
Th / W	0.529		0.531		0.571			
W / L	0.451		0.475		0.478			
Th / L	0.239		0.252		0.273			

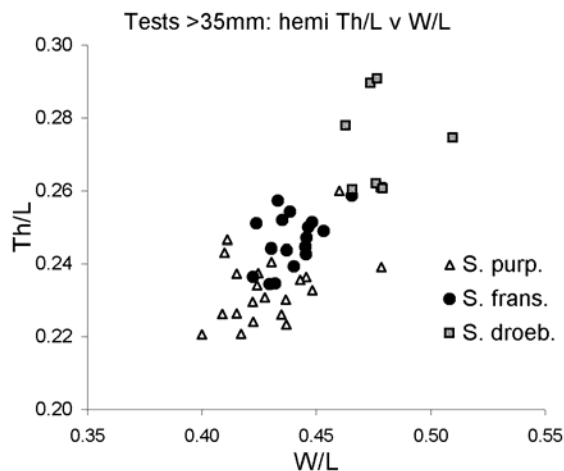
There were significant differences between species in hemipyramid thickness as a proportion of length and width as a proportion of length. Comparing Th/L ratios with W/L ratios (Figure 11) showed quite clear clusters for each species, although there is some overlap. It appears there are significant

differences in jaw geometry between species of *Strongylocentrotus*.

### Discussion

This is a preliminary study, based on a small number of samples, with small numbers of individuals within a sample. This is especially notable for green urchins, which were represented by a

sample of eight individuals from only one location. However, it can no longer be assumed that there are no differences in the solid anatomy within the test of the shallow-water *Strongylocentrotus* species of the central Pacific coast of North America. There do seem to be significant differences in the development of several features with age or size: the crests on the epiphyses, the styloid processes on the hemipyramids, and the shape of the lantern (as measured by hemipyramid thickness/length and width/length ratios) and, to a lesser extent, the shape of the auricles.



**Figure 11: Distribution of hemipyramid thickness-length ratios vs width-length ratios for all of the green urchins (*S. droebachiensis*) and the larger tests (>35 mm) of red urchins (*S. fransiscanus*) and purple urchins (*S. purpuratus*).**

What are the causes of these differences? In the material studied here, the differences in these structures are best explained as differences between species, rather than differences within a species at different locations. The hemipyramids of red urchins tend to be relatively wider and thicker than purple urchins, with those of green urchins the

widest and thickest of the three. Since the point of maximum thickness occurs at about the same distance up the hemipyramid in all three species (S/L ratios not being significantly different), purple urchins tend to have the most sharply pointed lantern of the three, with those of green urchins being the most broad and blunt.

If the features noted are different between species, they can therefore be used to identify urchin species. Identifying the urchin species present at archaeological sites will help both biologists and archaeologists to reconstruct near-shore conditions such as sea temperature or sea-weed cover, and to look for potential succession of dominant forms along this coastline over time. Population structures are different for different shores, and the relationship between jaw size and test size for these different populations has been researched for other purposes (e.g., Ebert et al. 1999:203). As a result, reconstructing population structures from hemipyramid length distributions (in the manner of Campbell 2007:34-38) would allow the reconstruction of former shore conditions with some accuracy. For archaeological material this has the potential to reconstruct exploitation strategies (types of shores and populations of urchins exploited), and compare such strategies over time and between sites and cultures. It may also help elucidate the phylogenetic relationships within each genus.

If there are no real differences in these anatomical structures between species, the differences observed in this study may be the result of adaptation to

environmental conditions such as food type, food availability or substrate (Ebert et al. 1999:194). As a result, we can still use the structures directly to reconstruct type of shore and its change over time, even if we do not know the species of *Strongylocentrotus* urchin present.

It is also possible that these structures are neither species-specific nor closely adaptive, but simply reflect the genetic makeup of a population. Since changes in these structures would therefore reflect changes in this genetic makeup, tracing changes in these structures still provides an opportunity to follow genotype proportions over time. This provides the potential to estimate rates of change in urchin populations and whether change in the nature of the coast was abrupt or gradual.

For the variation of the features of the auricles and lantern to be fully understood and its potential fully employed, it needs to be studied within a given species, on different shore types (given variables such as wave exposure, tidal cover and seaweed cover) at a given latitude, and with a particular shore type across a range of latitudes. Only then can any variation be seen to be due to species, habitat or genetics. The urchin *S. polyacanthus* should be included to see if variation in auricles and lantern can discriminate species along the Alaskan coast. Such a study may seem dauntingly large in scope, but a small army of researchers is already deployed in collecting archaeological urchin remains from across this coast and in assessing modern populations of *Strongylocentrotus* urchins as part of

fish stock assessments, ecological surveys, and experiments in embryology and aquaculture. All that is required is continued cooperation between archaeologists and marine biologists.

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