TWO PREVIOUSLY UNREPORTED BARNACLES COMMENSAL WITH THE GREEN SEA TURTLE, *CHELONIA MYDAS* (LINNAEUS, 1758), IN HAWAII AND A COMPARISON OF THEIR ATTACHMENT MODES

BY

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ABSTRACT

Two species of barnacles found living in the skin of green sea turtles, *Chelonia mydas*, and not previously recorded in Hawaii are reported and their attachment mechanisms compared. These findings bring to five the total number of barnacles commensal with Hawaiian sea turtles and to 50 the number of shallow-water cirripedes known in Hawaii. Identified as *Stomatolepas elegans* and *Platylepas decorata*, both species live embedded in the soft skin of the limbs, neck, and tail of their host. *Stomatolepas elegans* is perhaps a recent arrival in Hawaii with this being the first report of it, or any member of the genus, occurring with hawksbill turtles, *Eretmochelys imbricata*. We found the barnacle embeds by penetrating the epidermis of sea turtles and then anchors in connective tissue of the dermis by way of small spikes extending from the shell. Conversely, *P. decorata* invades host tissue less deeply, lacks anchoring devices, and becomes encapsulated only by epidermis. Species diagnoses were made by light and scanning electron microscopy and by comparison with other members in each genus.

RÉSUMÉ

Deux espèces de cirripèdes vivant dans la peau des tortues vertes marines *Chelonia mydas* et inconnues jusqu'à ce jour d'Hawaii sont étudiées et leur mécanismes de fixation comparés. Ces trouvailles portent à cinq le nombre total de cirripèdes commensaux des tortues marines d'Hawaii et à 50 le nombre d'espèces de cirripèdes d'eaux peu profondes connues à Hawaii. Identifiées comme *Stomatolepas elegans* et *Platylepas decorata*, les deux espèces vivent enfoncées dans la peau molle des membres, du cou et de la queue de leur hôte. *Stomatolepas elegans* est peut-être d'arrivée récente à Hawaii, ceci étant la première mention de sa présence, comme la première mention de ce genre, vivant avec les tortues imbriquées, *Eretmochelys imbricata*. Nous avons trouvé que le cirripède s'enfonce en pénétrant dans l'épiderme des tortues de mer et s'ancre ainsi dans le tissu conjonctif du derme au moyen de petites pointes venant de la coquille. Inversement, *P. decorata* envahit le tissu-hôte moins profondément, n'a pas de système d'ancrage et s'encapsule seulement dans l'épiderme.

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Crustaceana 80 (11): 1303-1315
Also available online: www.brill.nl/cr

Les diagnoses des espèces ont été effectuées à l'aide de la microscopie optique et de la microscopie électronique à balayage et par comparaison avec les autres membres de chaque genre.

INTRODUCTION

Forty-eight species comprise the shallow-water barnacle fauna of the Hawaiian Islands (Pilsbry, 1927; Matsuda, 1973; Eldredge & Evenhuis, 2003), including several introduced (Newman, 1986; Southward et al., 1998; Zardus & Hadfield, 2005) and epibiotic representatives (Edmondson, 1946; Gordon, 1970). Of the latter group, three are commensal with sea turtles (Balazs, 1980). These so-called "turtle barnacles" associate strictly with sea turtles and are specialized either for glueing to the shell and epidermal scales of their host or for invading the skin. Generally considered commensals rather than parasites, these barnacles filter-feed on plankton and do not take any nutrition from their hosts apart from capturing stray food released by turtles during feeding (GHB, pers. obs.). The most conspicuous turtle barnacle in Hawaii is *Chelonibia testudinaria* (Linnaeus, 1758), which cements to the carapace, plastron, and large scales of the turtle body. Perhaps more common but less obvious is *Platylepas hexastylos* (O. Fabricius, 1798), which embeds in the surface of the skin on the flippers, around the neck, and at the base of appendages. *Stephanolepas muricata* Fischer, 1886, a less commonly encountered barnacle, burrows into the flippers, penetrating to a depth of nearly 1 cm (Balazs, 1978, 1980).

Life histories of turtle barnacles are known only for *C. testudinaria* (see Zardus & Hadfield, 2004). However, they have also been documented for *C. patula* (Ranzani, 1820), a species commensal with crabs and gastropods (Crisp, 1983), and *Coronula diadema* (Linnaeus, 1767), a confamilial species commensal with whales (Nogata & Matsumura, 2006). Each of these species follows the typical barnacle developmental pattern of seven larval stages that swim freely in the plankton with the terminal stage, the cyprid, attaching to a host and undergoing metamorphosis. Despite the complexity of their life cycle, the commensal life-mode has evolved several times in thoracican barnacles (Anderson, 1994), probably as a response to predation (Foster, 1987).

Being one of the most remote archipelagos on earth, the Hawaiian Islands have a highly endemic biota, both on land and in near-shore waters (Wagner & Funk, 1995). Several barnacle species are endemic (Newman, 1986) and resident populations of the green sea turtle, *Chelonia mydas* (Linnaeus, 1758), and the less numerous hawksbill turtle, *Eretmochelys imbricata* (Linnaeus, 1766), are considered insular to some degree, because following their pelagic phase as post-hatchlings, they nest and forage only in Hawaii (Balazs, 1980). Whether these

Hawaiian turtles constitute subspecies is a matter of debate (Bowen et al., 1992; Norman et al., 1994; Parham & Zug, 1996), but the epibionts they host have not been examined in like regard. Shorter lived than their hosts, barnacles and other epibionts of turtles may experience restricted gene flow in Hawaii and perhaps form a distinct Hawaiian assemblage that reflects population isolation in their hosts.

In 1999, a previously undocumented species of barnacle living embedded in the skin of Hawaiian green sea turtles was brought to our attention by local naturalists. This and a second unfamiliar species have subsequently been collected by one of us (GHB) over the last several years from green turtles in Hawaii. Using light and electron microscopy we describe these additions to Hawaii's inventory of barnacles and list of sea turtle commensals, identifying them as *Stomatolepas elegans* (Costa, 1838) and *Platylepas decorata* Darwin, 1854. Despite their similarity in life mode and choice of host, they display distinct morphologies and attachment mechanisms that readily distinguish them from each other and from other species.

MATERIAL AND METHODS

All samples of barnacles were collected by or under direct supervision of one of us (GHB) following established and safe protocols. Individuals of *Platylepas decorata* disengage more easily from host skin than do those of *Stomatolepas elegans* and were carefully and harmlessly collected with thumb and forefinger from live turtles in the field and placed immediately in 95% ethanol for preservation. Specimens of the latter species were also preserved in 95% ethanol after being excised along with patches of skin from stranded and debilitated green turtles that were either found dead or that were humanely euthanized by a certified veterinarian (Work et al., 2004).

Barnacle hard parts were prepared for microscopy by immersing shells in a 50% Clorox™ solution until adherent tissue was removed. The shells were examined and photographed under a stereoscopic light microscope (LM), and the length and width of five individuals from each turtle were measured using an ocular micrometer. Shell samples prepared for scanning electron microscopy (SEM) were sputter-coated with gold for 90 sec. and imaged on a JEOL JXA-840 SEM at 25 kV.

Type specimens of *P. decorata* and *S. elegans* were not obtainable for comparison from museums or collections, but comparisons were made at the light microscope level with other species of *Stomatolepas* and *Platylepas* obtained from a variety of localities and referable by description and host turtle to the species indicated (table I).

TABLE I

Barnacles in the genera *Stomatolepas* and *Platylepas* used for morphological comparison, including species, collecting region, and host turtle species

Barnacle species	Region	Host turtle species
S. dermochelys Monroe & Limpus	South Africa	Leatherback, *Dermochelys coriacea* (Vandelli)
S. elegans (Costa)	Panama	Hawksbill, *Eretmochelys imbricata* (Linnaeus)
S. praegustator Pilsbry	South Carolina	Loggerhead, *Caretta caretta* (Linnaeus)
S. transversa Nilsson-Cantell	Japan	Green turtle, *Chelonia mydas* (Linnaeus)
P. decorata Darwin	Panama	Hawksbill, *E. imbricata* (Linnaeus)
P. hexastylos (O. Fabricius)	Hawaii	Green turtle, *C. mydas* (Linnaeus)
P. coriacea Monroe & Limpus	West Indies	Leatherback, *D. coriacea* (Vandelli)

TABLE II

Occurrence of the barnacle, *Stomatolepas elegans* (Costa) from green sea turtles found stranded in Hawaii, including location, date, and average size ($n = 5$)

Stranding location	Date	Barnacle size in mm	
		Length ($\pm$ sd)	Width ($\pm$ sd)
Paia, Maui	18 Nov. 2001	4.9 (0.4)	4.2 (0.4)
Kanaha Beach, Kahului, Maui	14 Sep. 2004	6.6 (1.6)	5.3 (1.2)
Wailea, Maui	24 May 2004	6.9 (0.3)	6.3 (0.6)
Maalaea, Maui	6 Jan. 2005	6.4 (0.7)	5.9 (1.0)
Mahinui, Kaneohe Bay, Oahu	4 Feb. 2005	7.1 (0.5)	6.0 (0.4)
Heeia, Kaneohe Bay, Oahu	19 July 2006	7.9 (1.0)	7.0 (0.8)
Palaau, Molokai	14 July 2006	9.1 (1.2)	7.5 (1.2)

RESULTS

Over a seven year period (1999-2006) the barnacle *Stomatolepas elegans* was collected from seven green sea turtles (table II). Occurring in the soft skin at the base of limbs, neck, and tail, this barnacle penetrates the epidermal and dermal layers of turtle skin, residing with its wide aperture positioned nearly flush with the surface of its host and its test fully embedded. The host responds histologically by surrounding the barnacle with fibrous connective tissue as described for other *Stomatolepas* species (see Monroe & Limpus, 1979; Monroe, 1981). Large numbers of individuals live packed together on a host giving the skin a characteristic peppered appearance (fig. 1). This barnacle has a moderately oval, bowl-shaped test (fig. 2) and closely matches other descriptions of *Stomatolepas elegans* (cf. Hiro, 1936; Zullo & Bleakney, 1966; McCann, 1969; Smaldon & Lyster, 1976; Young, 1991; Carriol & Vader, 2002). Unlike more typical barnacles, the widest region of the test is the aperture rather than the base and McCann (1969)

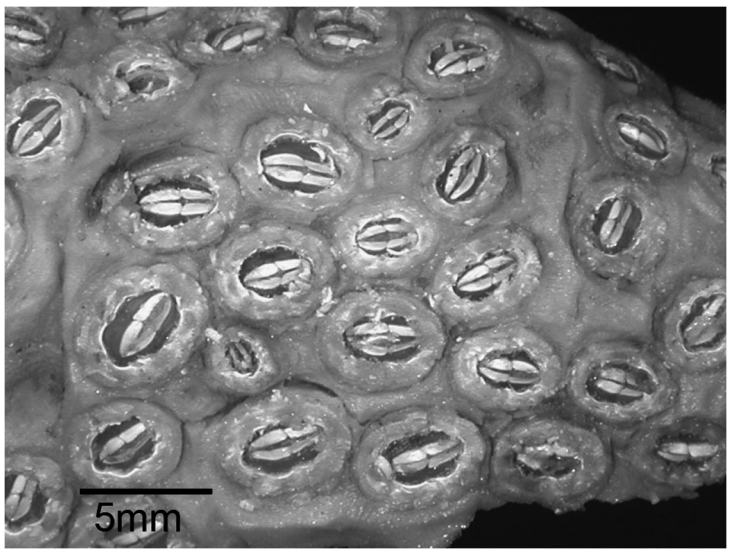

Fig. 1. Multiple individuals of the barnacle, *Stomatolepas elegans* (Costa, 1838) embedded in situ in the skin of a green sea turtle, residing with aperture flush with the host surface; light microscope (LM).

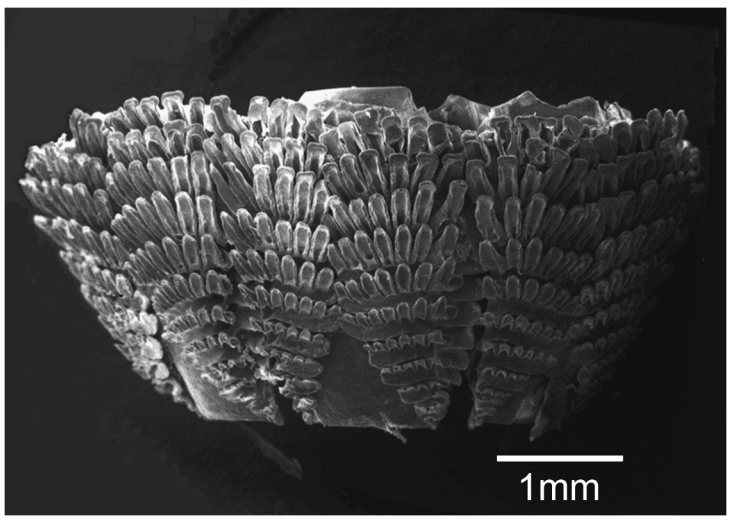

Fig. 2. Side view of the barnacle, *Stomatolepas elegans* (Costa, 1838) in upright orientation and removed from host tissue. Visible are imbricating ranks of parietal spikes, those near the aperture displaying T-shaped heads, and extensions from the inner lamina rising slightly beyond the rim of the aperture; SEM.

figured it upside-down, either confusing the aperture with the base or perhaps erroneously concluding that the barnacle feeds on host tissue.

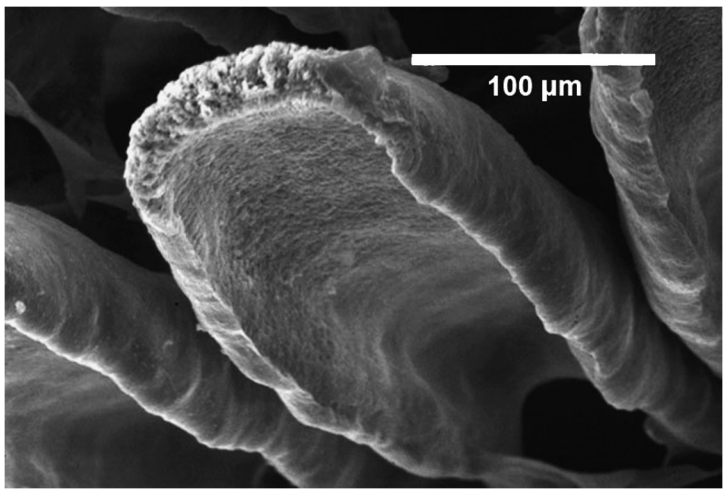

Fig. 3. Detail of half-barrel shaped parietal spike of the barnacle, *Stomatolepas elegans* (Costa, 1838); SEM.

The test of *S. elegans* is composed of six compartments or parietal plates, each plate bearing horizontal imbricating ranks of short spikes on the outer lamina and a delicate crescentic extension of the inner lamina or sheath that rises above the rim of the aperture like a fingernail (fig. 2). The spikes are half-barrel shaped and those most recently formed near the rim of the aperture terminate with a T-shaped head in profile; whereas older, eroded spikes located towards the base are square- or round-headed (fig. 3). The upper ranks of spikes completely traverse the width of each parietal plate and fully line the rim of the aperture. However, as they descend towards the base, each rank becomes successively shorter in length and lines up along the margins of the plate, resulting in chevron-shaped patches of spikes and triangular areas devoid of spikes at the compartment base (fig. 4). How penetration of the host epidermis is effected is uncertain, but the shell spikes, if not assisting in the process, at least serve to hold the barnacle in place by becoming enmeshed in host connective tissue. The inner lamina of the parietal plate is smooth, with presumptive growth lines marking the surface (fig. 5).

In side-by-side comparisons with other *Stomatolepas* species, the Hawaii specimens differ from *S. transversa*, which has a much narrower, elongate test (Nilsson-Cantell, 1930; Young, 1991) and longer parietal spikes. They also differ from *S. dermochelys* Monroe & Limpus, 1979 and *S. praegustator* Pilsbry, 1910 which are very circular in outline and larger in size. *Stomatolepas dermochelys* is also known only from *Dermochelys coriacea* (Vandelli, 1761), the leatherback turtle, and *S. praegustator* only from the gullet of *Caretta caretta* (Linnaeus, 1758), the loggerhead turtle (Pilsbry, 1910; Monroe & Limpus, 1979). There were no observable differences between the Hawaii specimens and *S. elegans* from hawksbill turtles

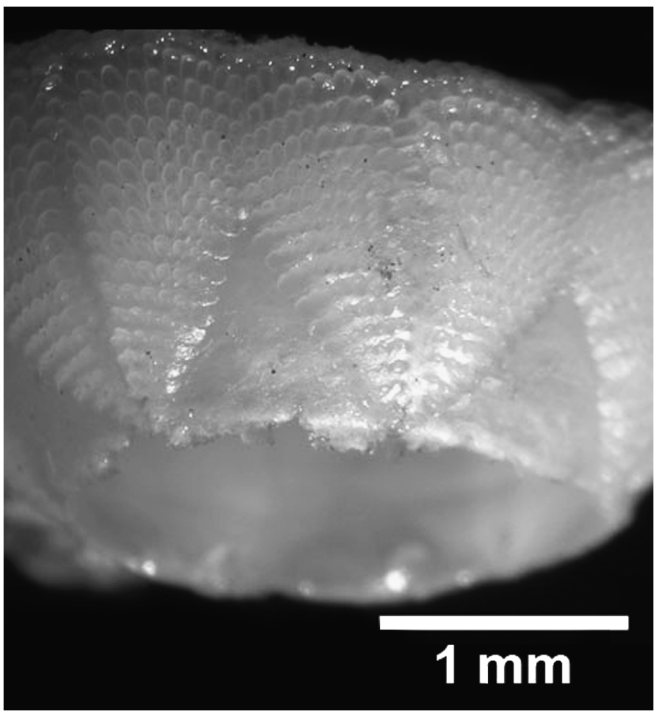

Fig. 4. Basal view of the barnacle *Stomatolepas elegans* (Costa, 1838) removed from host tissue and showing open base, chevron-shaped patches of parietal spikes, and triangular bare areas; LM.

in Panama. It is not known if type specimens for *S. elegans* are extant. Because of this and the fact that previous descriptions are vague, Monroe & Limpus (1979) considered it a nomen dubium. They described a new species, *S. dermochelys*, morphologically similar but associated with leatherback turtles; however, they did not clearly designate it as a replacement for *S. elegans* and the latter name has remained in use for barnacles from hosts other than leatherbacks (see Carriol & Vader, 2002).

From 2001 to 2004, the barnacle *Platylepas decorata* was collected from the skin of two green turtles (fig. 6 and table III). This species penetrates the superficial epidermis and embeds by depressing the host tissue with blunt-tipped prongs that extend downward; it then becomes encapsulated in layers of keratinized host epidermis (fig. 7). The barnacle can be removed intact within a capsule of non-living host epidermal tissue relatively easily, using forcipulate pressure. The test is approximately hexagonal in outline and columnar rather than oval and bowl-shaped (fig. 8).

The parietal plates of *P. decorata* lack ornamentation exteriorly, except for fine longitudinal grooves that run the length of each compartment and a few supporting prongs that extend from their basal margins (fig. 9). One major prong and three or

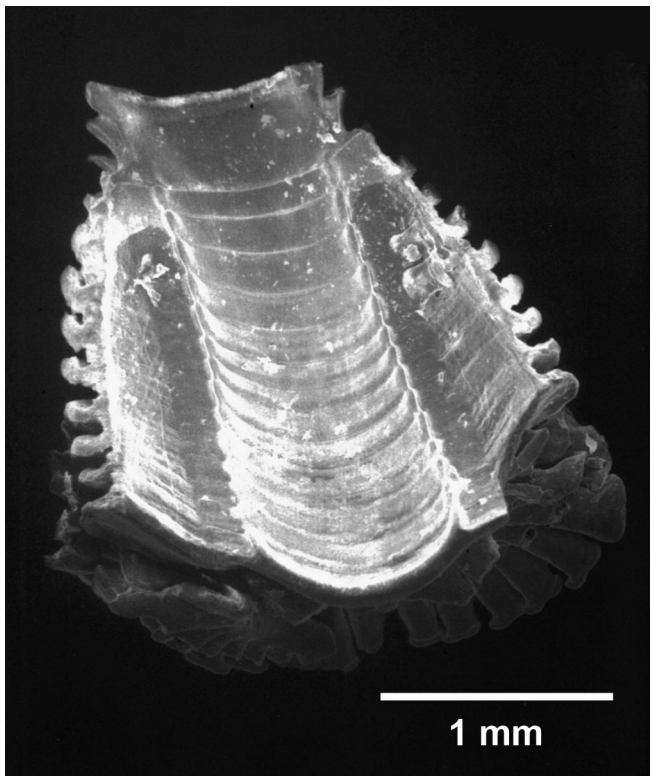

Fig. 5. Inner lamina view of rostrum of the barnacle, *Stomatolepas elegans* (Costa, 1838); SEM.

Fig. 6. Multiple individuals of the barnacle *Platylepas decorata* Darwin, 1854 embedded in situ in the skin of a green sea turtle, residing with aperture flush with the host surface (photo courtesy of Peter Bennett and Ursula Keuper-Bennett of www.turtles.org).

TABLE III
Occurrence of the barnacle, *Platylepas decorata* Darwin from green sea turtles in Hawaii, including location, date, and average size ($n = 5$)

Location	Date	Barnacle size in mm	
		Length (± sd)	Width (± sd)
Kaneohe Bay, Oahu	31 Aug. 2004	4.0 (0.3)	3.3 (0.4)
Kanaha Beach, Kahului, Maui	14 Sep. 2004	3.9 (0.5)	3.0 (0.4)

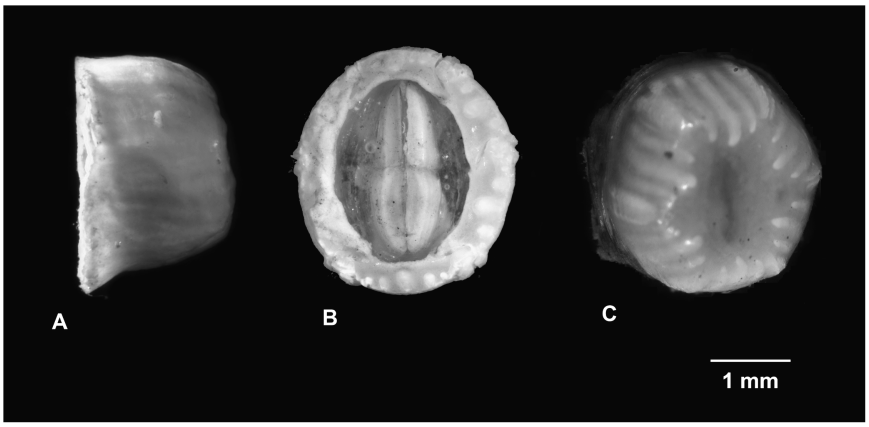

Fig. 7. The barnacle, *Platylepas decorata* Darwin, 1854 encapsulated in host epidermis: A, side view of capsule with the top oriented to the left and the base oriented to the right; B, top view; C, bottom view of capsule showing arrangement of parietal prongs behind the host tissue; LM.

more minor prongs extend from the base of each compartment, their tips curving inward terminally to provide support against the host tissue. A related species, *P. hexastylos*, also occurs with Hawaiian green turtles but is distinctly different in having compartments that flare outward at a wide angle against the turtle skin. When embedded, *P. decorata* resides flush with the surface and the rim of its aperture appears as a fine raised ring; whereas *P. hexastylos* has a low volcano shape with a smooth rim that is partially or entirely covered by turtle skin. There were no discernible differences between samples of *P. decorata* from Hawaii and Panama.

DISCUSSION

Two new records of barnacles associated with green sea turtles in Hawaii, *Platylepas decorata* and *Stomatolepas elegans*, bring to five the number of species of turtle barnacle known in Hawaii and to 50 the number of barnacles occurring

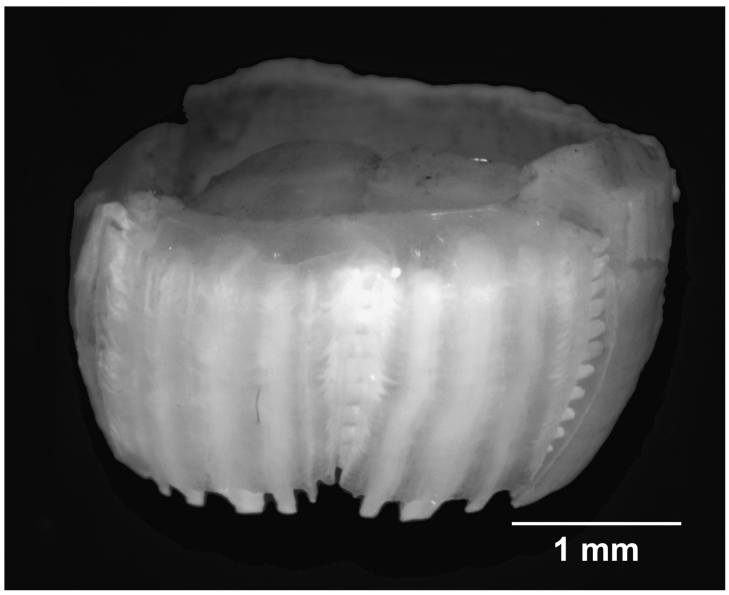

Fig. 8. Side view of the barnacle, *Platylepas decorata* Darwin, 1854 removed from encapsulating host tissue; LM.

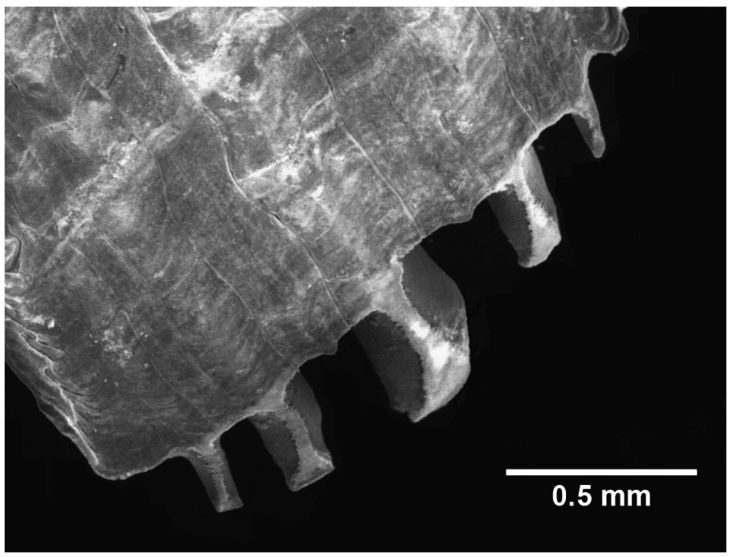

Fig. 9. Detail of a lateral parietes in the barnacle, *Platylepas decorata* Darwin, 1854 showing longitudinal grooves as well as one major and four minor prongs along basal margin; SEM.

there. In the turtles examined in our study, *P. decorata* and *S. elegans* were found inhabiting the soft skin around the base of the limbs, tail, and neck of their host, and numbering in the hundreds or thousands in each case. *Stomatolepas elegans* imparts a distinctive peppered appearance to the skin and has been found in only a handful of 255 necropsied turtles over a ten year period (Work et al., 2004). Very likely a recent arrival to Hawaii, it has also been observed in several animals in the field. *Platylepas decorata* could also be newly arrived but may possibly have been overlooked in previous barnacle inventories due to its inconspicuous appearance, low occurrence, and superficial resemblance to *P. hexastylos*.

Green sea turtles are the most abundant chelonian in Hawaiian waters, but whether *P. decorata* and *S. elegans* also occur with hawksbill turtles resident in the islands or with other turtles that migrate past the archipelago is not known. Elsewhere in the Pacific, *P. decorata* has been reported on green, hawksbill, and loggerhead sea turtles (Monroe & Limpus, 1979; Ren, 1980; Green, 1998). On the other hand, *S. elegans*, while occurring with green turtles in the Atlantic (Young, 1991), has only been reported in the Pacific on olive ridley, *Lepidochelys olivacea* (Eschscholtz, 1829), and leatherback sea turtles (Hiro, 1936; McCann, 1969). Therefore, its absence on hawksbill turtles in Hawaii would not be unusual. Apart from specimens we obtained from hawksbill turtles in Panama, *S. elegans* and its congeners have not been reported on hawksbill, Kemp's ridley, *L. kempii* (Garman, 1880), or flatback, *Natator depressus* (Garman, 1880), sea turtles (see Carriol & Vader, 2002). Other species in the genus that occur with green sea turtles in the Pacific include *S. pulchra* Ren, 1980 and *S. transversa* Nilsson-Cantell, 1930 (see Nilsson-Cantell, 1930; Monroe & Limpus, 1979; Ren, 1980). Whether green turtles in Hawaii are unique among Pacific populations in hosting *S. elegans* remains unknown.

For turtle barnacles, global geographic and host species boundaries are generally poorly known, complicated by their association with elusive, migratory hosts, and in some cases by uncertainty in their identification. Connectivity among barnacle populations presumably mirrors linkages in host populations and subdivisions in one may be reflected in the other, or may be indicative of particular phylogeographic phenomena (Rawson et al., 2003). In particular, the epibiota of Hawaii's turtles may provide an indirect measure of the functional insularity of their host populations. Indeed, elucidation of species and population boundaries in this group of crustaceans merits further clarification and could provide insight into the biogeography of sea turtles generally.

ACKNOWLEDGMENTS

We are indebted to Ursula Keuper-Bennett and Peter Bennett of *www.turtles.org*, who, through their keen observations, first brought *S. elegans* to our attention. We

thank Shawn K. K. Murakawa, Shandell Brunson, Bridget McBride, and Cody Hooven for assistance both in the field and the lab in obtaining samples. For turtle necropsies we thank Dr. Thierry Work and Robert Morris, D.V.M. Specimens for comparative purposes were generously made available by Ryota Hayashi, Kelly Thorvalson, George Hughes, and Peter Meylan. Sarah Deptula and Alan Benda helped in preparing samples for microscopy, and Dr. Kevin Crawford assisted with SEM imaging. Funding for this study was provided by The Citadel Foundation (to JDZ).

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First received 22 December 2006.
Final version accepted 18 June 2007.