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Morphology and distribution of the acorn barnacle *Tetraclita reni* nom. nov. (Crustacea: Cirripedia) in Madagascar and adjacent waters

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Abstract

In Madagascan waters, both *Tetraclita rufotincta* Pilsbry 1916 and *T. africana* Ren 1989 have been reported. *Tetraclita rufotincta* is more widely distributed than *T. africana,* extending to the western Indian Ocean and east Africa. *Tetraclita africana* is reported from Madagascar and no further distribution record has been made apart from its type locality. Both species have pink parietes and are similar in size, which could lead to identification confusion. In this study, we revealed that *T. africana* differed from *T. rufotincta* in having multicuspidate setae on cirrus III, a feature that can be observed with both light microscopy and SEM. Additionally, the tergum of *T. africana* has a rounded spur and a larger basi-scutal angle than that of *T. rufotincta*. However, since the name *Tetraclita africana* has been pre-occupied under the name *Tesseropora (Tetraclita) wireni africana* Nilsson-Cantell, 1932, we, therefore, propose herein a replacement name, *Tetraclita reni* nom. nov. Based on museum specimens examined, *Tetraclita reni* nom. nov. is present in northeastern and southern Madagascar and Mauritius but absent from Yemen, Kenya, South Africa, Aldabra and northwestern Madagascar, suggesting the distribution of *T. reni* nom. nov. could be confined to the south and northeast of Madagascar and adjacent waters.

Key words: Barnacles, Cirripedia, the western Indian Ocean, *Tetraclita rufotincta, Tetraclita africana, Tetraclita reni* nom. nov.

Introduction

Barnacles of the genus *Tetraclita* are common intertidal inhabitants of tropical and sub-tropical waters (Newman & Ross 1976). They are often the major space occupiers on the shore, playing important roles in the filter-feeding food chain and as foundation species affecting the structure and dynamics of intertidal communities (Barnes 2000). In Madagascan waters, only two species of *Tetraclita* have been reported, *T. rufotincta* Pilsbry 1916 and *T. africana* Ren 1989. *Tetraclita rufotincta* is common in the mid shore (Taylor 1971), occurring from the western coast of India (Wagh 1969) to the eastern coast of Africa (Pilsbry 1916), Madagascar (Utinomi 1968, 1969) and the Red Sea (Ross 1999). *Tetraclita africana,* which has a narrower distribution record than *T. rufotincta,* has been reported only from Madagascar (Ren 1989), based on the collections in the Muséum national d'Histoire naturelle, Paris, France. In Madagascan waters, the identification of the species may be confusing since they are externally morphologically similar, both having pink parietes, and no detailed comparative morphological studies have been conducted. Scanning Electron Microscope (SEM) examination of arthropodal characters, such as setal types on cirri and mouth parts, in conjunction with light microscopy (Chan *et al.* 2007 a, b) can help resolve this problem. Arthropodal features have been proven to be useful and reliable for species identification and phylogenetic studies (Southward & Newman 2003; Chan *et al*. 2008a, b).

The name *Tetraclita africana* has been pre-occupied under *Tesseropora* (*Tetraclita*) *wireni africana* (Nilsson-Cantell 1932). Its geographical distribution is poorly known, except for its type locality in Sainte

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Luce, Madagascar (Ren 1989). The present study proposes a replacement name for *Tetraclita africana*, describes its morphology and compares it with the morphologically similar *T. rufotincta*, and records its geographical distribution in east African and Madagascan waters.

Materials and methods

Sampling sites. Specimens of *Tetraclita* were examined from the collections of the Natural History Museum, London, UK (NHM), Zoological Museum, Copenhagen, Denmark (ZMUC) and the Muséum national d'Histoire naturelle, Paris, France (MNHN). Sampling locations covered South Yemen, Kenya (Shimoni), South Africa (Kosi Bay), Aldabra (Dune Jean Louis), Mauritius (Connoniers Point) and Madagascar (Tanikely, Cape Diego, Sarodrano, Ambovombe and Fort Daulphin) (Fig. 1).

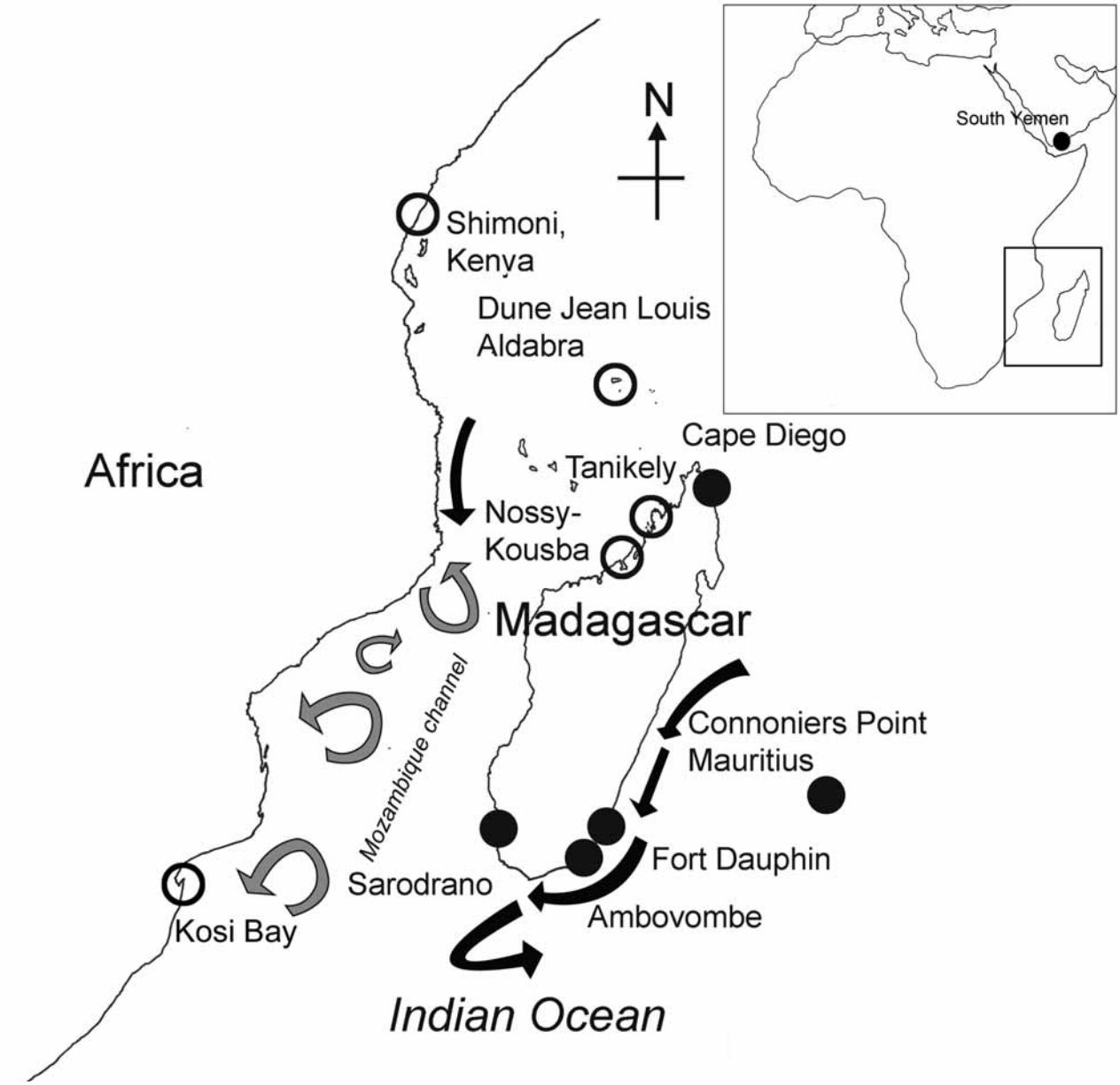

FIGURE 1. Collection sites of samples examined. Closed black circles indicate sites where *T. reni* nom. nov. were identified. Open circles indicate the sites where *T. rufotincta* were identified. Yemen is shown in the insert map due to its farther location. Arrows indicate the oceanographic currents in the region; black arrows indicate the East Madagascar Current, grey arrows the anti-cyclonic eddies. Patterns of oceanographic currents shown were modified from map in Gopal *et al*. (2006).

Morphological analysis. The posterior sides of the tergum and scutum were photographed under a stereomicroscope installed with a digital camera. The cirri and mouth parts were dissected out and observed by light microscopy. SEM investigations of the cirri and mouth parts of *Tetraclita africana* (Cape Diego, Madagascar) and *T. rufotincta* (South Yemen, Kenya and Aldabra) were also conducted. Cirri and mouth parts of the barnacles were dehydrated using graded ethanol (30%, 50%, 75%, 100%), critical-point dried, gold coated and observed using a SEM (FEI Quanta 200). Setal terminology follows that of Chan *et al*. (2008a).

Systematic description

Sub-family Tetraclitinae Gruvel, 1903

Tetraclita Schumacher, 1817

Tetraclita reni Chan, Hsu & Tsai nom. nov.

Figures 2A, 2D, 3A–C, 4, 5

Tetraclita squamosa rufotincta Utinomi, 1968: 180 (Cape Diego, Madagascar)
Tetraclita africana Ren, 1989: 452, 453, fig. 12 (Sainte Luce, Madagascar, type locality)

Material examined. Cape Diego, Madagascar (*Galathea* stn. 223), ZMUC CRU-9881, *Tetraclita squamosa rufotincta* (3 specimens), 03-March-1951, det. Utinomi 1967; Connoniers Point, Mauritius, ZMUC CRU-9882, *Tetraclita squamosa rufotincta* (2 specimens), 30-April-1929, coll. Th. Mortensen; Ambovombe, Madagascar, MNHN Entrée no. 7, *Tetraclita* (1 specimen), 1931, coll. D. de M. R. Decary; Sarodrano, Madagascar, MNHN C.l. 664, *Tetraclita porosa rufotincta* (2 specimens), 1906, coll. F. Geay; Fort Dauphin, Madagascar, MNHN, *Tetraclita porosa* (1 specimen), 1901, coll. Ferlus.

Description. Parietes pink, surfaces of some older specimens with white patches due to erosion. Posterior side of scutum and tergum varying from pink to white. Terga from majority of samples with wide base, rounded spur (Fig. 2A); mean basi-scutal angle 140 ± 8.6º (n = 6, pooled specimens from Cape Diego, Fort Dauphin and Amobvombe; Fig. 2A); scutal margin long, lateral depressor muscle crests 6–8. Scutum triangular, large teeth on occludent margin (Fig. 2A), tergal margin long; adductor muscle scar deep; depressor muscles crests well developed with 6–9 crests; adductor ridge short (Fig. 2A). Rami of cirrus I unequal (Fig. 3A, 4A); exopodite (18 segments, Mauritius sample) longer than endopodite (12 segments, Mauritius sample; Fig. 3A). Cirrus II shortest of cirri, rami approximately equal (exopodite 12 segments, endopodite 11 segments, Mauritius sample, Fig. 3B). Setae on rami of cirrus I and II serrulate with 3–4 rows of setules (Fig. 4A, B, D–F); coxa and base of protopod of cirrus I bearing long, thin, serrulate setae with 5 short setules (Fig. 3A, 4A, F), those of cirrus II bearing plumose setae with long feathery setules (Fig. 3B, 4B, G); cirrus II additionally bearing flattened, blade-shaped, serrulate setae, each with single row of setules (Fig. 4H). cirrus III with rami long,slender, somewhat antenniform (Fig. 3C, 4C); exopodite (15 segments) shorter than endopodite (24 segments; Mauritius sample, Fig. 3C). Setae on rami of cirrus III similar to those on cirrus II (Fig. 4C) plus additional dense, serrulate setae (Fig. 4E), bidentate, serrate setae (Fig. 2C, 4L), blade-shaped serrulate setae (Fig. 4H) and large multicuspidate setae (Fig. 2D, 4I); setules and inter-setule space of multicuspidate setae larger than those of bidentate serrate setae (Fig. 2C, D, 4I, L). Cirri IV, V and VI similar, all bearing serrulate setae with 1 row of setules (Fig. 4M, O); simple setae present on segment junctions of cirri IV–VI (Fig. 4N, O).

Labrum notch slightly concave, with 4–5 teeth on each side (Fig. 5A, B); posterior surface densely clothed in serrulate setae (Fig. 5C). Mandible with four teeth, lower angle with ~ 10 small setae (Fig. 5D–F). Maxillule notched, two large setae on upper notch, 16 on lower notch (Fig. 5I). Mandibulatory palp oval, long serrulate setae distally (Fig. 5K, L). Maxilla bi-lobed, covered with dense, serrulate setae, notch between the lobes non-setose (Fig. 5G, H).

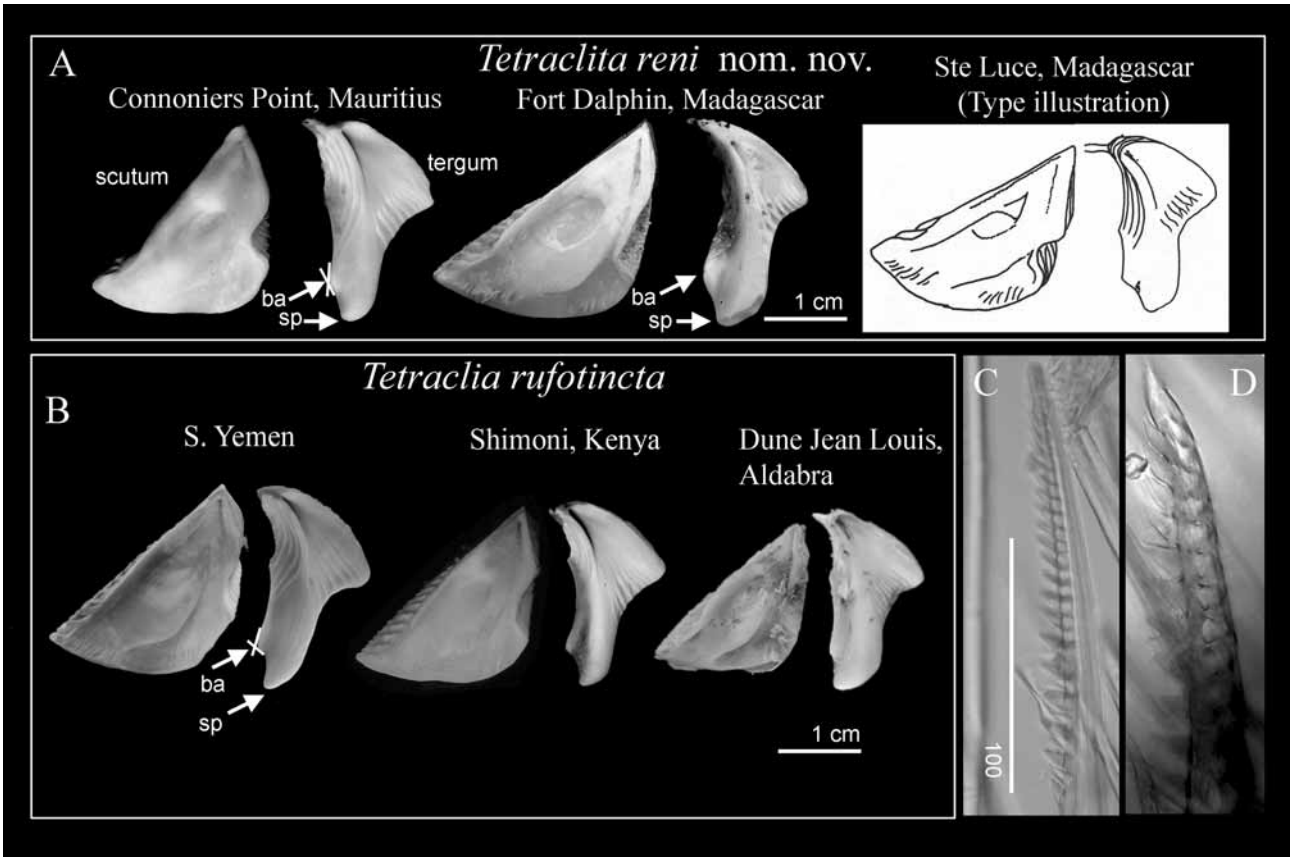

FIGURE 2. (A) Scutum and tergum of *Tetraclita reni* nom. nov. from Connoniers Point, Mauritius, and Fort Dalphin, Madagascar, and redrawing of type specimen of Ren (1989), collected from Sainte Luce, Madagascar. All opercular plates and type illustration in (A) share same scale bar; (B) scutum and tergum of *Tetraclita rufotincta* from South Yemen, Kenya and Aldabra. (A) and (B) white arrows indicate the morphological differences of the basi-scutual angle (ba) and the sharpness of the spur (sp) between *T. reni* nom. nov. and *T. rufotincta;* (C) bidentate serrate setae of *T. rufotincta* (from South Yemen) observed under light microscopy; (D) multicuspidate setae of *T. reni* nom. nov. (from Mauritius) observed under light microscopy. (C) and (D) shared the same scale bars in μm.

Diagnosis. *Tetraclita reni* nom. nov. is characterized by the multicuspidate setae on cirrus III, which are not seen in other species of *Tetraclita* except *T. japonica* Pilsbry 1916, a Pacific species (Ren 1989; Chan 2001).

Distribution. Northeastern and southern Madagascar and Mauritius.

Remarks. Ren (1989) described a new species of *Tetraclita* from Madagascar with the epithet *africana*, which was preoccupied by *Tetraclita wireni africana* (Nilsson-Cantell 1932). *Tetraclita wireni* was later assigned to *Tesseropora* (see Newman & Ross 1976). As *Tetraclita africana* Ren 1989 is a junior homonym of *Tetraclita wireni africana* Nilsson-Cantell 1932, *Tetraclita reni* nom. nov. is erected for the species described by Ren (1989). The present study provides new records of *T. reni* nom. nov. in southern and northeastern Madagascan waters and Mauritius.

Etymology. *Tetraclita reni* nom. nov. is named in honour of Professor Xianqiu Ren, Institute of Oceanology, Chinese Academy of Science, in recognition of his discovery of this new species (= *T. africana*) and for his contributions in the field of Chinese barnacle taxonomy.

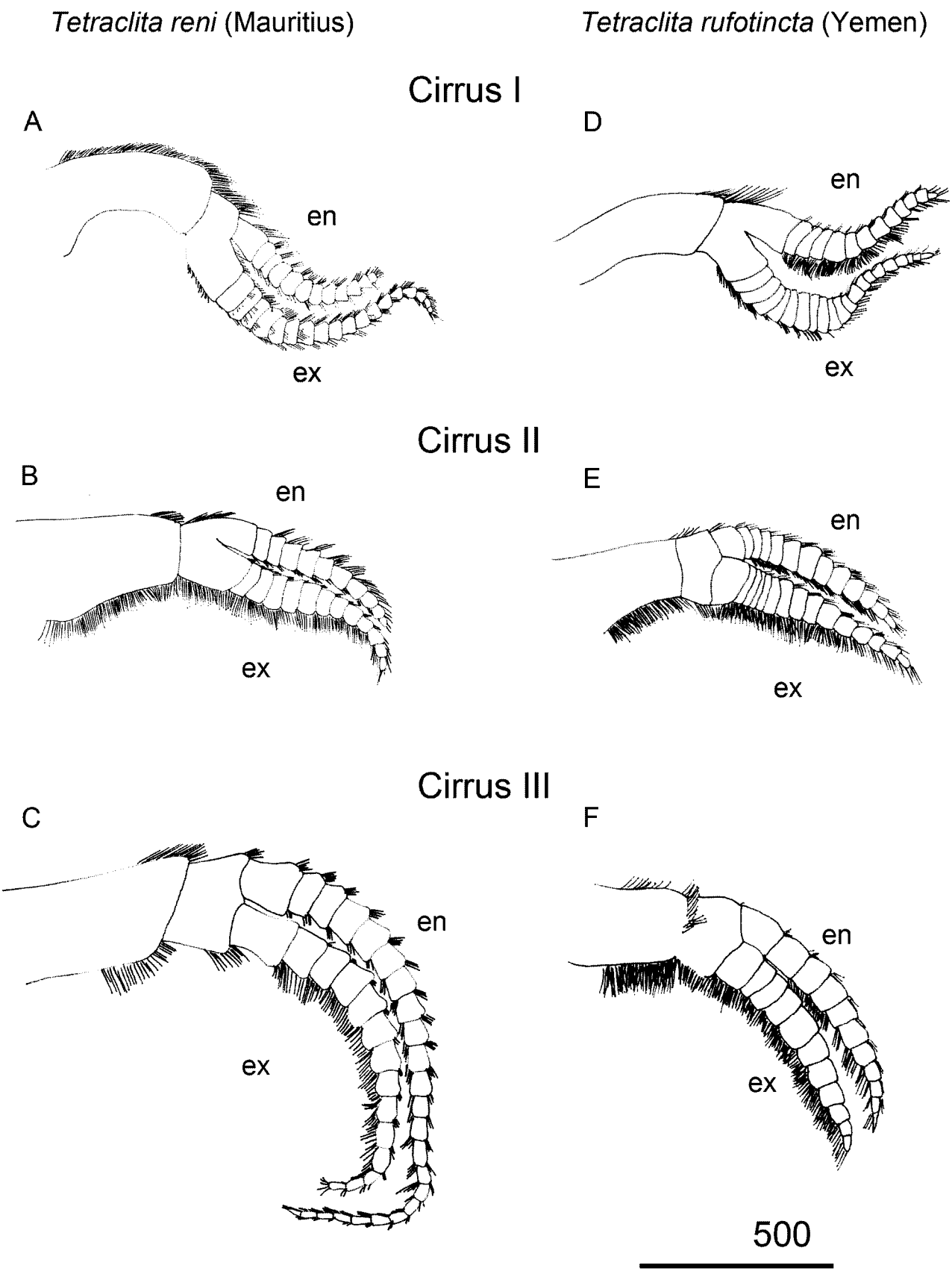

FIGURE 3. *Tetraclita reni* nom. nov. Stereomicroscope drawing of (A) cirrus I, (B) cirrus II, (C) cirrus III. *Tetraclita rufotincta*, (D) cirrus I, (E) cirrus II, (F) cirrus III. ex – exopodite. en – endopodite. Scale bars in μm.

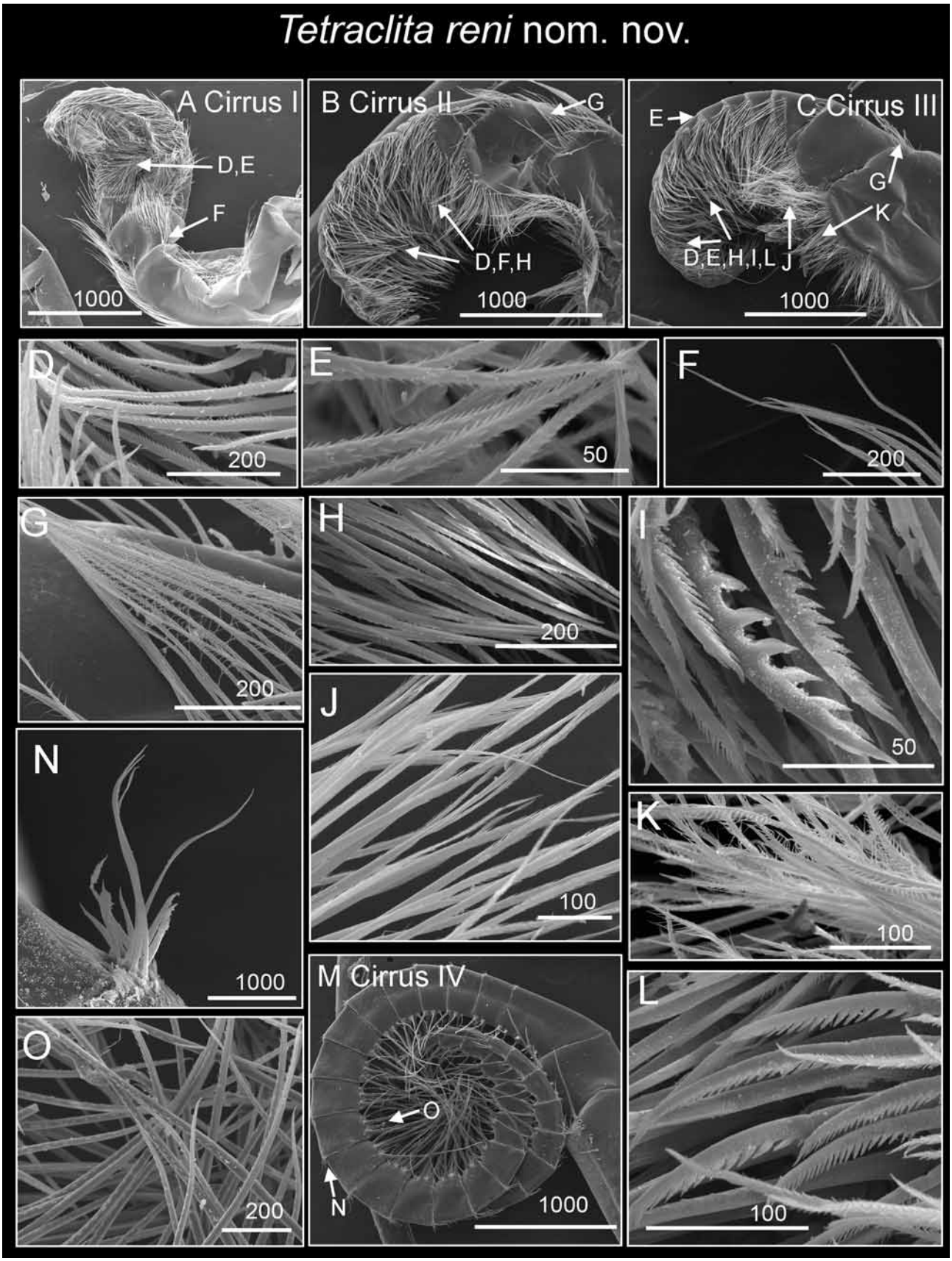

FIGURE 4. *Tetraclita reni*. nom. nov. (from Cape Diego, Madagascar) Scanning Electron Micrographs showing (A) cirrus I; (B) cirrus II; (C) cirrus III; (D–F) serrulate setae; (G) plumose setae; (H) blade shaped serrulate setae; (I) multi-cuspidate setae; (J, K) serrulate setae; (L) bidentate serrate setae; (M) cirrus IV; (N) simple setae; (O) serrulate setae found on cirri I–IV. Scale bars in μm.

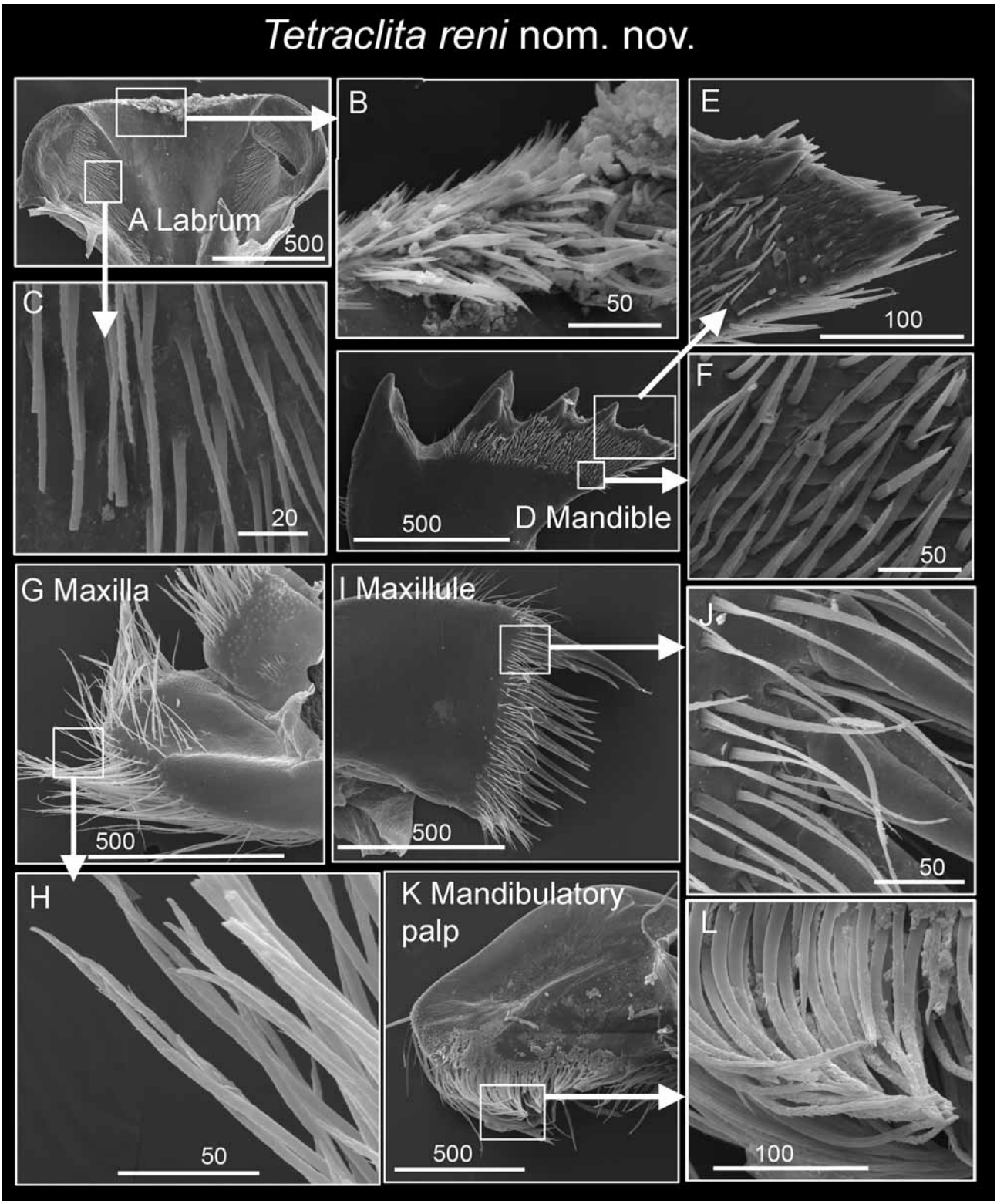

FIGURE 5. *Tetraclita reni* nom. nov. (from Cape Diego, Madagascar). Scanning Electron Micrographs showing (A) labrum; (B) teeth on labrum; (C) serrulate setae found on posterior surface of labrum; (D) mandible; (E) lower angle of mandible; (F) serrulate setae on mandible surface; (G) maxilla; (H) serrulate setae on maxilla; (I) maxillule; (J) serrulate setae on maxillule; (K) mandibulatory palp; (L) serrulate setae on mandibulatory palp. Scale bars in μm.

***Tetraclita rufotincta* Pilsbry, 1916**
Figures 2B, 2C, 3D–F, 6, 7

Tetraclita squamosa rufotincta Pilsbry, 1916: 253–254, pl. 58, figs. 5–6a (Gulf of Aden-type locality).
Tetraclita porosa rufotincta—Nilsson-Cantell, 1928:35, fig. 16 (Muscat, Gulf of Oman).
Tetraclita squamosa rufotincta—Utinomi, 1969: 92 (Nabiyu Tunb, Strait of Hormuz). *Tetraclita rufotincta*. - Ross, 1999 (Red Sea).

Material examined. South Yemen, MNHN, Paris, *Tetraclita rufotincta* (3 specimens), det Diana Jones; Islet east of Shimoni, Kenya, NHM, London, Tl978. 370-379, *Tetraclita rufotincta* (2 specimens), 20-November-1971, coll, J.D. Taylor, det A.J. Southward; Aldabra, Indian Ocean, NHM, London, 1978.47, *Tetraclita* sp. (3 specimens), Dune Jean Louis, 16-August-1973, coll. J.D. Taylor; Lontide Muscat (Gulf of Oman), NHM, London, 1902.12.8.3–8, *Tetraclita porosa var rufotincta* (4 specimens); Kosi Bay, Mozambique, NHM, London, 1967.3.14.31, *Tetraclita rufotincta* (1 specimen), coll. 13.7.49, University of Cape Town, Ecological Survey; Madagascar (Nossy-Kousba), MNHN, Paris, *Tetraclita squamosa rufotincta* (1 specimen), 1991, coll. Joly; Tanikely, Madagascar, MNHN, Paris, CI674, CI675, *Tetraclita rufotincta* (3 specimens), 1- April-1960.

Description. Parietes pink, surfaces of some older specimens with white patches due to erosion. Posterior side of scutum and tergum varying from pink to white. Tergum spur sharp (Fig. 2B); mean basi-scutal angle 110 ± 13° (n = 6, pooled specimens from Aldabra, Kenya and South Yemen); lateral depressor muscle crests 7–10. Scutum triangular, large teeth on occludent margin (Fig. 2B); adductor muscle scar deep; depressor muscle crests 10–11. Cirrus I with rami unequal, exopodite (20 segments, Yemen sample) longer than endopodite (12 segments, Yemen sample; Fig. 3D); rami (Fig. 6A) bearing serrulate setae with 3 rows of setules (Fig. 6D), feathery serrulate setae (Fig. 6E) and blade-shaped serrulate setae with very short and sparse setules (Fig. 6J); coxa and base of protopod with feathery serrulate setae (Fig. 6F). Cirrus II shorter than cirrus I; exopodite (15 segments, Yemen sample) and endopodite (13 segments, Yemen sample) similar length (Fig. 3E, 6B). Setal types of cirrus II similar to cirrus I (Fig. 6A, B), except blade-shaped setae with short, sparse setules absent (Fig. 6J); coxa with plumose setae (Fig. 6G). Cirrus III with exopodite (11 segments, Yemen sample) and endopodite (11 segments, Yemen sample) similar length (Fig. 3F, 6C); cirrus III exhibiting highest diversity of setal types (Fig. 6C); setae on base and coxa of protopod plumose (Fig. 6G) and serrulate (Fig. 6F); rami with serrulate setae (Fig. 6D, E, H), bidentata, serrate setae (Fig. 2C, Fig. 6I) and thick, blade-shaped, serrulate setae with short setules (Fig. 6J). Rami of cirri IV, V, VI with serrulate setae, each with 1 row of setules (Fig. 6K, L); segmental junctions with short, simple setae (Fig. 6M).

Labrum concave, 4–5 large teeth on each side of notch (Fig. 7A, B); posterior side of labrum with serrulate setae (Fig. 7C). Mandible with 4 teeth, 2nd and 3rd bidentate, 4th tridentate (Fig. 7D, E, F); lower angle with 5–6 small setae (Fig. 7E). Maxillule notched, 2 large setae at upper notch, 8 setae on lower notch (Fig. 7I, J). Mandibulatory palp oval (Fig. 7G, H). Maxilla bilobed with long setae, notch between lobes non-setose (Fig. 7K, L). Maxillule, mandibulatory palp and maxilla with serrulate setae(Fig. 7J, K, L).

Diagnosis. *Tetraclita rufotincta* can be distinguished from *T. reni* nom. nov. by the lack of multicuspidate setae on cirrus III, and the tergum with a sharper spur and a smaller basi-scutal angle when compared to *T. reni* nom. nov.

Distribution. West coast of India (Mumbai), Gulf of Aden, Red Sea, East coast of Africa, NW Madagascar.

Remarks. *Tetraclita rufotincta* is a widely distributed species in the West Indian Ocean. Pilsbry (1916) identified this species from Aden (type locality) and concluded specimens from Zanzibar, East Africa, were also *T. rufotincta*. Pilsbry (1916), however, noted there were intra-specific morphological variations between a Zanzibar specimen and the Aden specimens. The Zanzibar specimen had a tergum with a spur which was 'less deeply entered' (i.e. larger basi-scutal angle) and a straighter scutal margin, and a scutum with deeper articular furrows when compared to the Aden specimens. In the present study, *Tetraclita rufotincta* specimens from Aldabra appeared to have a larger basi-scutal angle (spur less deeply entered) than those from Kenya and

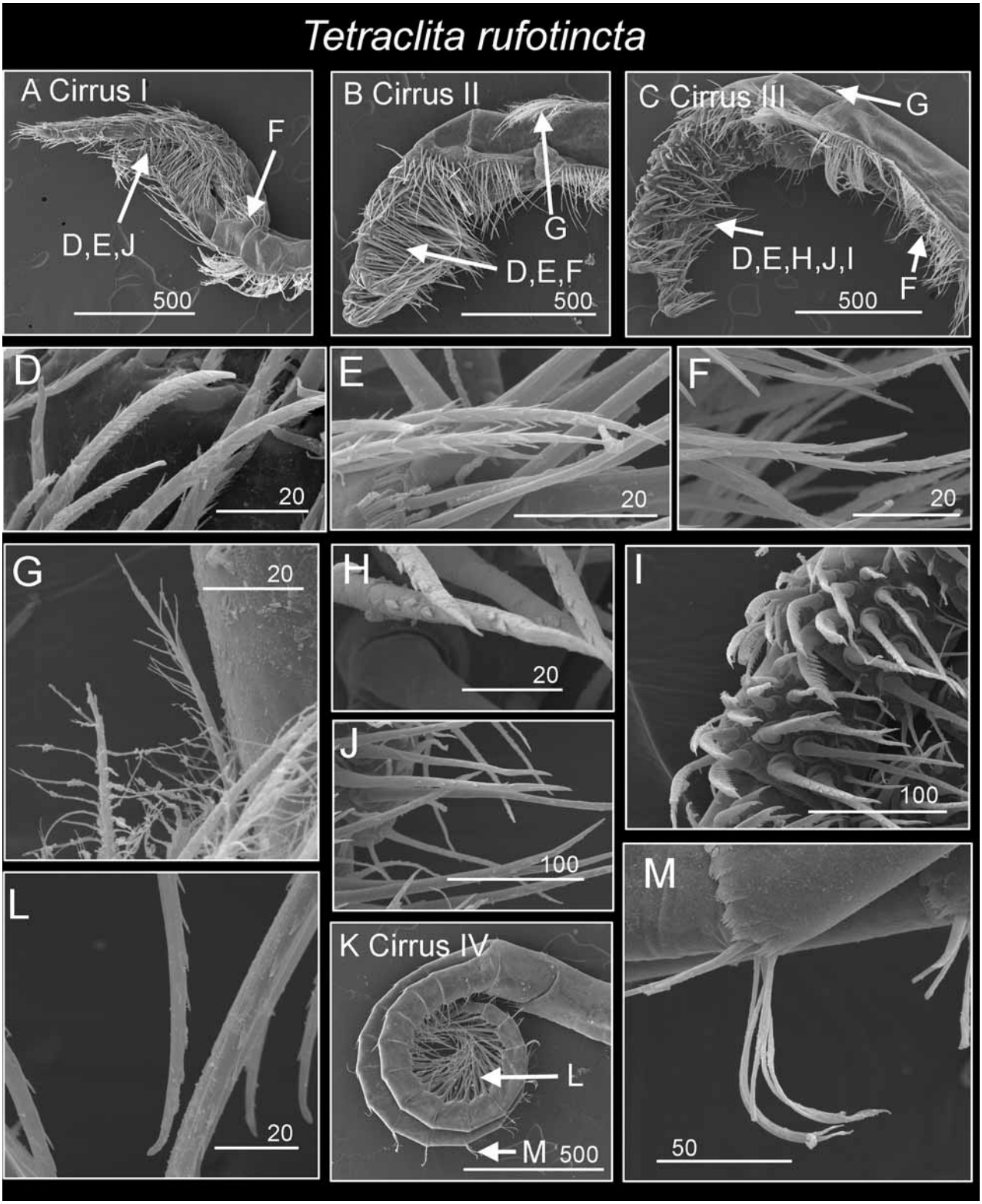

FIGURE 6. *Tetraclita rufotincta.* (from South Yemen). Scanning electron micrographs showing (A) cirrus I; (B) cirrus II; (C) cirrus III; (D–F) serrulate setae; (G) plumose setae; (H) blade shaped serrulate setae; (I) bidentate serrate setae; (J) serrulate setae; (K) cirrus IV; (L) serrulate setae of cirrus IV; (M) simple setae found on cirri I–IV. Scale bars in μm.

Aden (Fig. 2B). The setal types of cirri and mouth parts of these populations were similar. As there are no obvious diagnostic morphological variations between these populations, they are considered as *T. rufotincta* in the present study. However, since there are intra-specific morphological variations among geographical

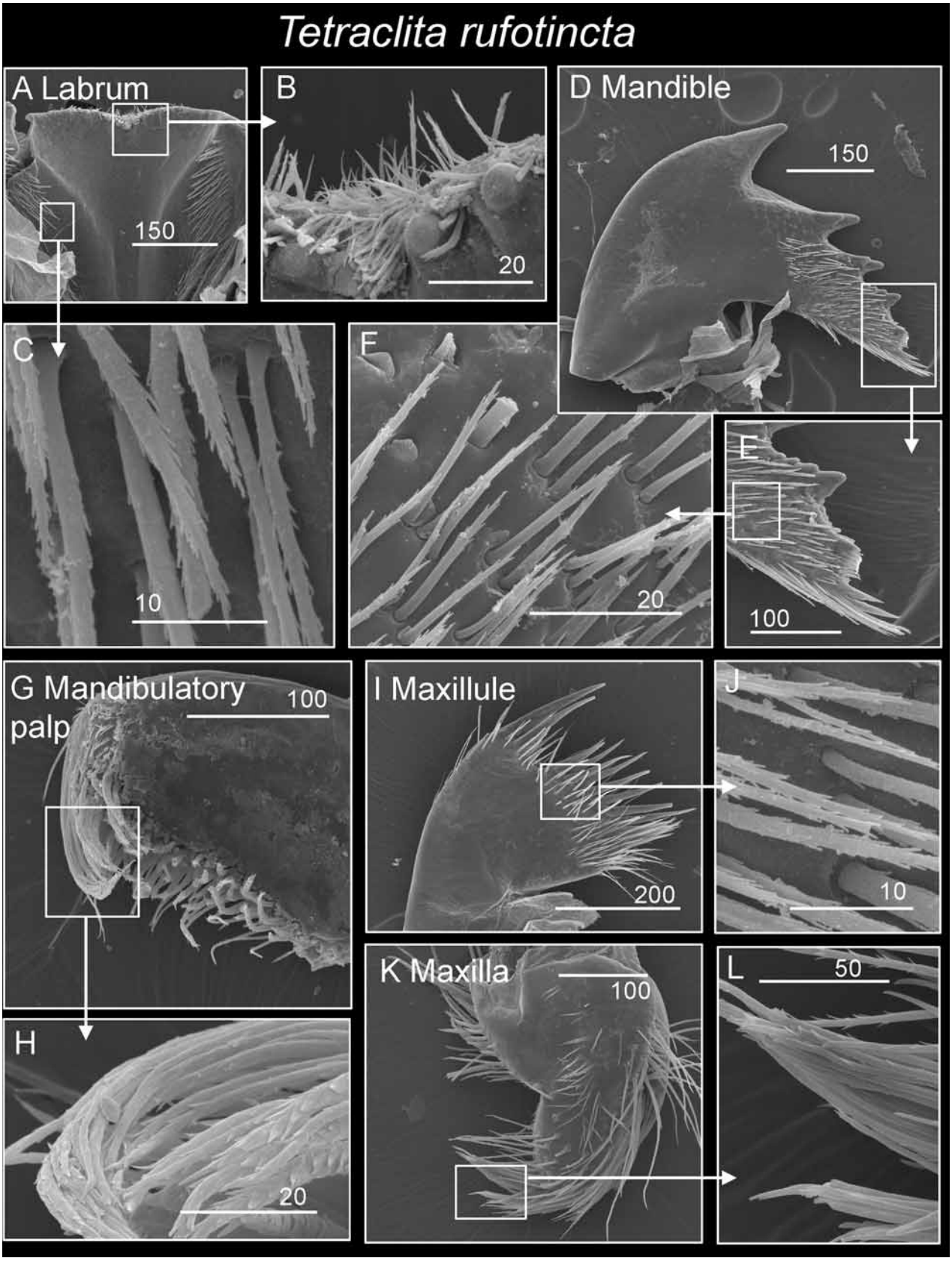

FIGURE 7. *Tetraclita rufotincta.* (from South Yemen). (A) labrum; (B) teeth on labrum; (C) serrulate setae found on posterior surface of labrum; (D) mandible; (E) lower angle of mandible; (F) serrulate setae on mandible surface; (G) mandibulatory palp; (H) serrulate setae on mandibulatory palp; (I) maxillule; (J) serrulate setae on maxillule; (K) maxilla; (L) serrulate setae on maxilla. Scale bars in μm.

populations, it is likely that *T. rufotincta* contains a cryptic species complex in the West Indian Ocean. Further studies should be conducted on molecular analysis to compare the genetic differentiation of *T. rufotincta* in different geographical populations of the West Indian Ocean to further ascertain the taxonomic status of the barnacle from different geographical locations.

Discussion

Tetraclita rufotincta and *T. reni* nom. nov. are similar in external morphology, both having pink parietes, and are hard to distinguish from each other externally. Both *T. reni* nom. nov. and *T. rufotincta* have bidentate and blade-shaped, serrulate setae (Fig. 2C, D, 4I). However, *T. reni* nom. nov. has a larger basi-scutal angle and a rounded tergal spur when compared to *T. rufotincta* (one way ANOVA on basi-scutal angle between *T. rufotincta* and *T. reni* nom. nov.: $F_{1,10} = 1463$, $P < 0.05$) (Fig. 2A, B; Table 1). In addition, cirrus III of *T. reni* nom. nov. has large, multicuspidate setae, which are absent from *Tetraclita rufotincta*. Examination of the *T. rufotincta* specimen identified by Utinomi (1968) in the Danish Zoological Museum revealed this type of multicuspidate setae on cirrus III (Fig. 4I), suggesting the species recorded by Utinomi (1968) to be *T. reni* nom. nov. and not *T. rufotincta*.

The only previous record of *T. reni* nom. nov. is its type locality, Sainte Luce in southern Madagascar (Ren 1989). In the present study, examination of specimens from northeastern (Cape Diego), southern Madagascar (Sarodrano, Fort Dauphin and Ambovombe) and Mauritius revealed the presence of *Tetraclita reni* nom. nov. Specimens collected from northwestern Madagascar (Tanikely, Nossy-Kousba), Kenya, South Africa, Aldabra atolls and Yemen were *T. rufotincta*. This suggests that larvae of *Tetraclita reni* nom. nov. may not disperse across the Mozambique Channel to the African coast and may be confined to the waters of northeastern to southern Madagascar and Mauritius. Anti-cyclonic eddies of the Agulhas Current in the Mozambique Channel could retain the larvae of marine species between Madagascar and the East African coast (Fig. 1; Lutjeharrns 1988 ; Ridderinkhof & De Ruijter 2003). For example the lobster, *Palinurus delagoa*, exhibits distinct genetic divergence between Madagascan and east African populations (Gopal *et al*. 2006), suggesting that gene flow across the Mozambique Channel is limited. On the South African coastline, *Tetraclita serrata* becomes dominant (Barnard 1924). *Tetraclita reni* nom. nov. could be a closely related species to *T. rufotincta* and may have diverged when Madagascar was separated from the east African mainland (see geological history of Madagascar in Benstead & Goodman 2006). Further studies should focus on molecular analysis to study the phylogeography of *T. reni* nom. nov. and *T. rufotincta* in Madagascar and its adjacent waters.

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