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An iconography of the Western Indian endemic abalone *Haliotis unilateralis* Lamarck, 1822 (Vetigastropoda: Haliotidae) with notes on its taxonomic history, distribution, ecology, and evolution

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ABSTRACT The rare West Indian Ocean endemic abalone *Haliotis unilateralis* is not well known and is often misidentified with the congeneric species *Haliotis rugosa pustulata* Reeve, 1846. Here we provide a photographic survey of the species from several populations throughout its distribution range to assist with identification.

KEY WORDS Abalone, *Haliotis*, Red Sea, reef, taxonomy.

INTRODUCTION

Haliotis unilateralis is a small-sized abalone species that is endemic to the Western Indian Ocean. Although the species is relatively rare, its distribution is widespread in the region, being found in the Red Sea, the northwestern Arabian Sea (Oman), the Gulf of Oman (United Arab Emirates), along portions of East Africa coastline (including Tanzania, Mozambique, and northernmost South Africa), southern Madagascar, the Seychelles, and the Mascarenes (Geiger & Owen, 2012; Owen, 2007; Owen *et al.,* 2016; Figure 1). This review is to provide addition information of the species including a comprehensive iconography of the taxon along with information about its ecology, fossil record, evolution, and taxonomic history. Additionally, plates are provided to highlight congeneric *Haliotis* taxa from the Western Indian Ocean and to provide visual assistance identifying and making determinations between *Haliotis unilateralis* and some specimens of *Haliotis rugosa pustulata*, which have been confused with the former species.

Abbreviation of collections: BOC: Buzz Owen Collection, Gualala, CA, USA; FFC: Franck Frydman Collection, Paris, France; RRC: Robert Kershaw Collection, Narooma, NSW, Australia; ARC: Arjay Raffety Collection, Marina del Rey, CA, USA; MHNG: Muséum d'Historie Naturalle, Geneva, Switzerland; NGC: Norbert Göbl Collection, Gerasdorf, Austria; MCZ: Museum of Comparative Zoology, Harvard University, Cambridge, MA, USA; WRC: Wilco Regter Collection, Gateshead, UK; BGC: Bavius Gras Collection, Leeuwarden, The Netherlands; KSC: Katherine Stewart Collection, (in Cal Adacemy of Sciences "CASIZ", San Francisco, CA, USA); TGC: Tom Grace Collection, USA. All shells in BOC unless otherwise indicated.

Materials and Methods: Shell specimens were cleaned and photographed with a Canon A650ES digital camera. Images were processed in Adobe Photoshop 6 and placed on black plates.

Shells examined: *Haliois unilateralis*, Red Sea area (Egypt and Israel), >50; northern Mozambique (Nacala), 28; southern

Mozambique (Ponta Techobanine; Inhaca Island) to S. Africa, 6; Mauritius, 24; Brandon Atoll, 22; Mirbut, Oman, 1; Fujairah, United Arab Emirates, 1; Bassas de India, 1. *Haliotis rugosa pustulata*, Northern Mozambique, 19. *Haliotis barbouri* (synonym of *H. unilateralis*). Holotype (unique).

Ecology: A subtidal to sublittoral (to at least 60 m depth) species, occurring in coral reef communities, particularly under coral rubble, coral heads, and reef ledges (Geiger, 1996; Zuschin *et al.*, 2009; Geiger & Owen, 2012).

Fossil Record, Evolution, and Biogeography: Pleistocene fossils purportedly representing *Haliotis unilateralis* are reported from coral reef deposits from Sudan and Zanzibar Island (Tanzania; Newton, 1900; Hall & Standen, 1907; Geiger & Groves, 1999; Geiger & Owen, 2012). While the paleoenvironment and geographic location of these fossils is congruent with the species, it is possible that this fossil material may actually represent *Haliotis rugosa pustulata* according to Geiger & Groves (1999).

Phylogenetic relationships between *Haliotis unilateralis* and other species in the family are not known (Geiger & Owen, 2012). No molecular phylogenetic studies have included samples of *Haliotis unilateralis* (Geiger & Owen, 2012). However, based on its location in the Western Indian Ocean, this species likely belongs to one of two clades within the family, the *Haliotis tuberculata* species group (*i.e. Haliotis rugosa, H. tuberculata*, *H. marmorata*) or the Indo-Pacific *Haliotis* species group (*i.e. Haliotis clathrata*, *H. ovina*, *H. varia*). In either case, future studies on the phylogenetic relationships within the Haliotidae should include the uncommon *H. unilateralis*.

Many specimens of *Haliotis unilateralis* from the Red Sea appear to represent a distinctive morphotype. Mature shells of Red Sea specimens are typically larger, possess a more rounded shelf-like ridge between the columella and respiratory holes, and often have smoother texture compared to specimens found outside of this geographic area. In addition, specimens from localities outside of the Red Sea often have shell coloration patterns that include strong flammules, proscocline rays, and are brighter than Red Sea specimens, which are often more subdued in coloration. One possible explanation of this different phenotype may be Pleistocene isolation between populations in the Red Sea and those found in the Indian Ocean. During this period, water exchange between these two marine bodies was limited at the Strait of Bab al Mandab (DiBattista *et al.,* 2016). Fluctuations in sea level in the Red Sea, particularly near the Strait of Bab al Mandab may have hindered mixing between populations of gastropods in northern Red Sea and the rest of the Western Indian Ocean populations (DiBattista *et al.,* 2016).

Taxonomic History: Little was known about this species until two papers, Geiger 1991 and Geiger 1996 were published. Geiger (1991; 1996) noted that the original holotype specimen of *Haliotis unilateralis*, located in the Muséum d'Historie Naturalie de Geneva (MHNG), did not match the original description by Lamarck, and actually represented a specimen of *Haliotis varia* Linnaeus, 1758. Geiger (1996) corrected this error by assigning a neotype of *H. unilateralis.* Images of the former holotype and neotype are illustrated in Figure 1.

In addition, *Haliotis unilateralis* is likely the correct identity of the taxon *Haliotis barbouri* Foster, 1946 (Figure 7). A single specimen of what was considered to be an unknown species of *Haliotis* was found by J. Modesto dos Santos at Praia de Copacabana, Brazil in the early 1940s and was named in Foster (1946) as

Haliotis barbouri. However, no additional specimens of this taxon have been found in the Western Atlantic or Brazil. In 2005, the first author examined the holotype and was able to determine that the specimen was comparable to specimens of *Haliotis unilateralis* from Mozambique (Nacala). However, it is still not known how a *Haliotis unilateralis* shell from Mozambique arrived on a beach in Brazil, although a connection of both countries being former Portugese colonies and increased recreational and business travel during the early to mid-20th century at least provides some plausible explanations.

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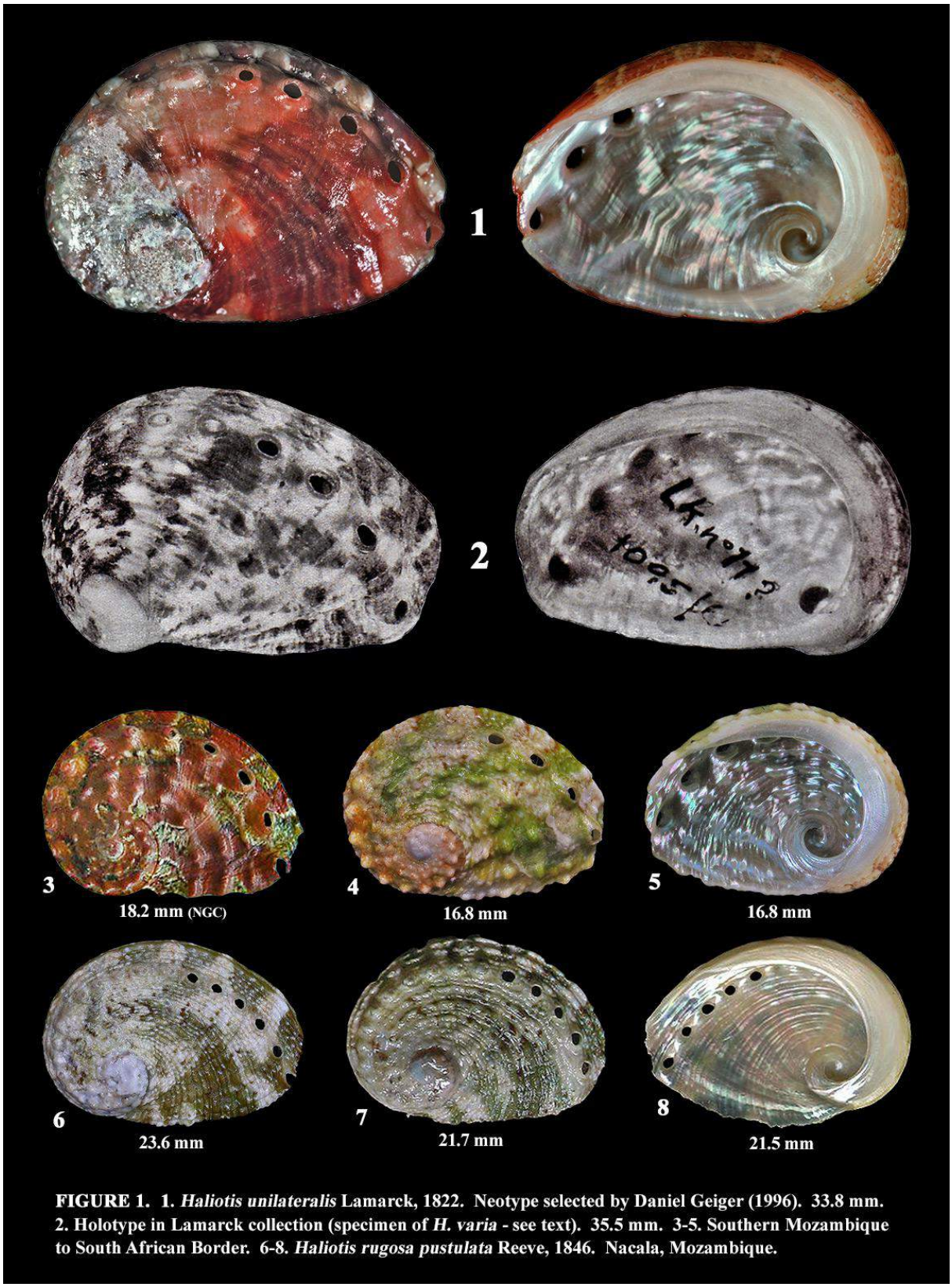

FIGURE 1. 1. *Haliotis unilateralis* Lamarck, 1822. Neotype selected by Daniel Geiger (1996). 33.8 mm. 2. Holotype in Lamarck collection (specimen of *H. varia* - see text). 35.5 mm. 3-5. Southern Mozambique to South African Border. 6-8. *Haliotis rugosa pustulata* Reeve, 1846. Nacala, Mozambique.

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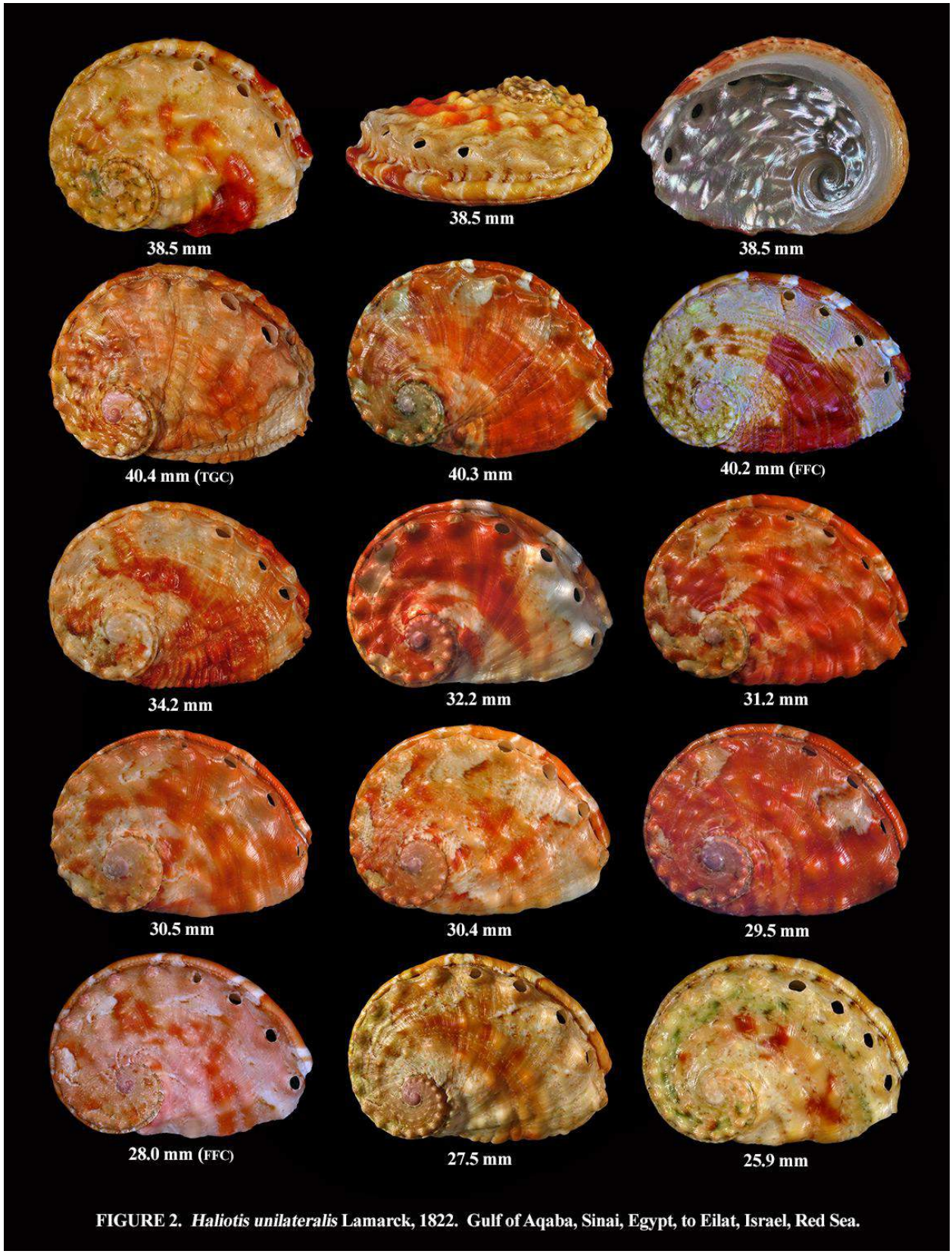

FIGURE 2. ***Haliotis unilateralis*** **Lamarck, 1822. Gulf of Aqaba, Sinai, Egypt, to Eilat, Israel, Red Sea.**

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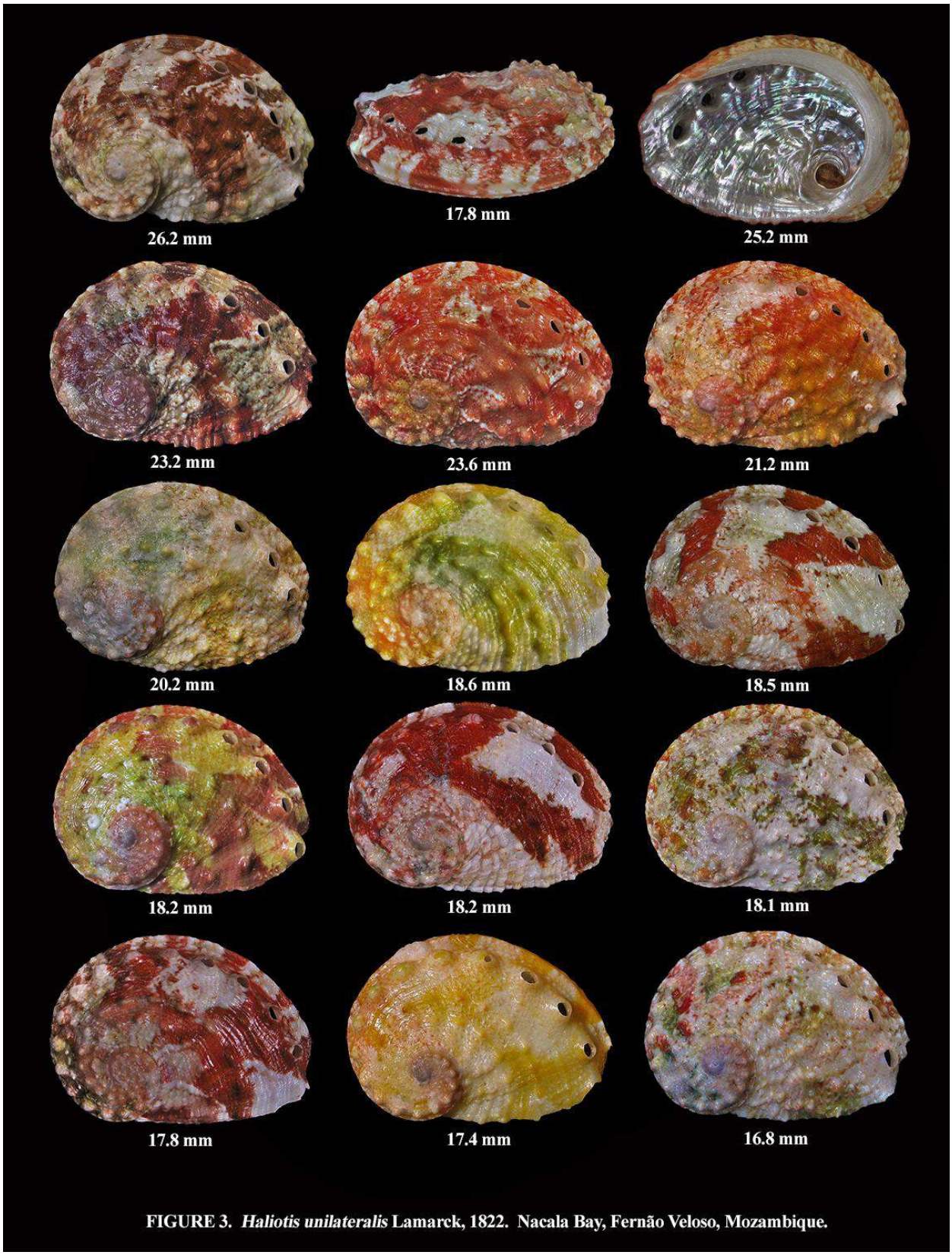

FIGURE 3. ***Haliotis unilateralis*** **Lamarck, 1822. Nacala Bay, Fernão Veloso, Mozambique.**

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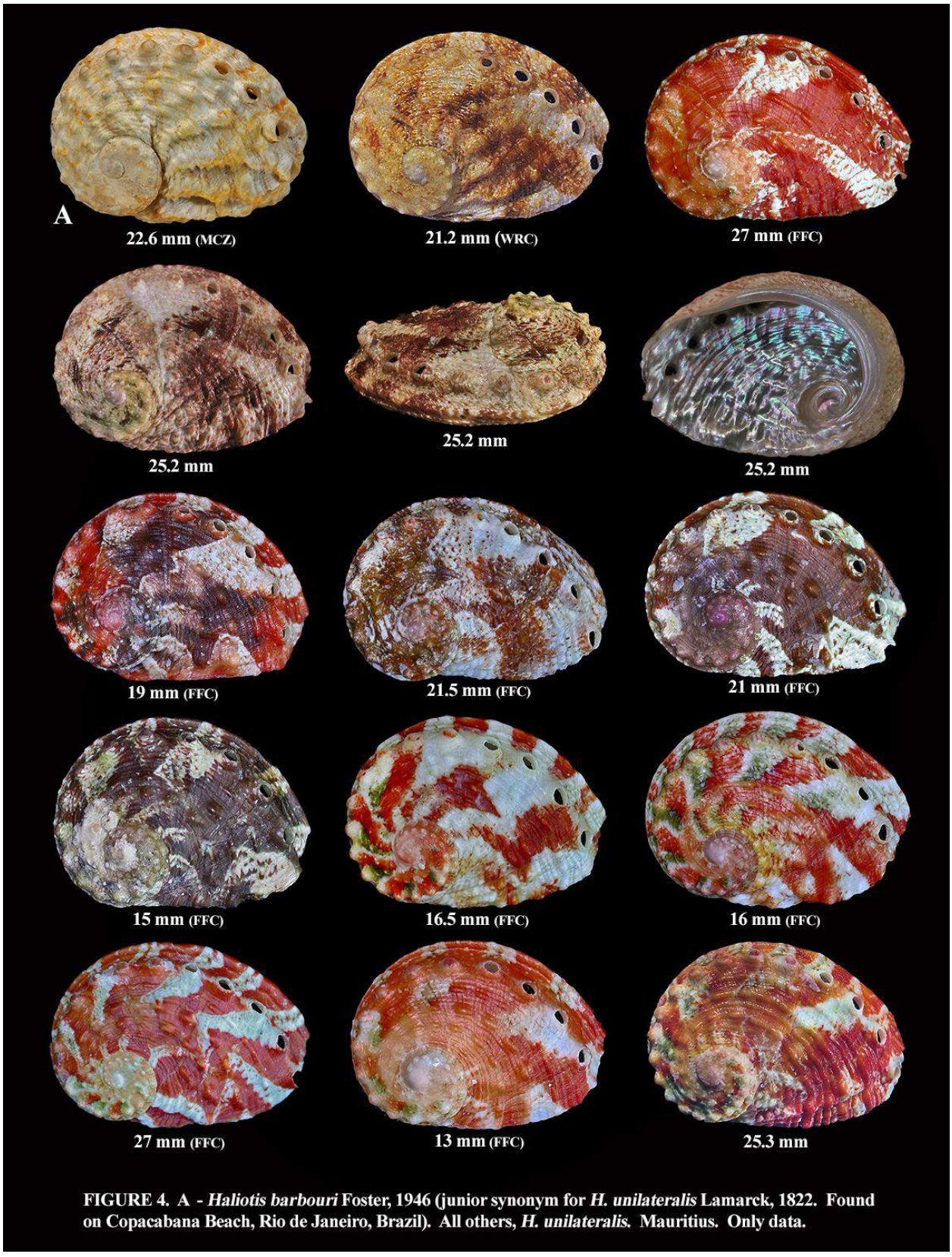

FIGURE 4. A - *Haliotis barbouri* Foster, 1946 (junior synonym for *H. unilateralis* Lamarck, 1822. Found on Copacabana Beach, Rio de Janeiro, Brazil). All others, *H. unilateralis*. Mauritius. Only data.

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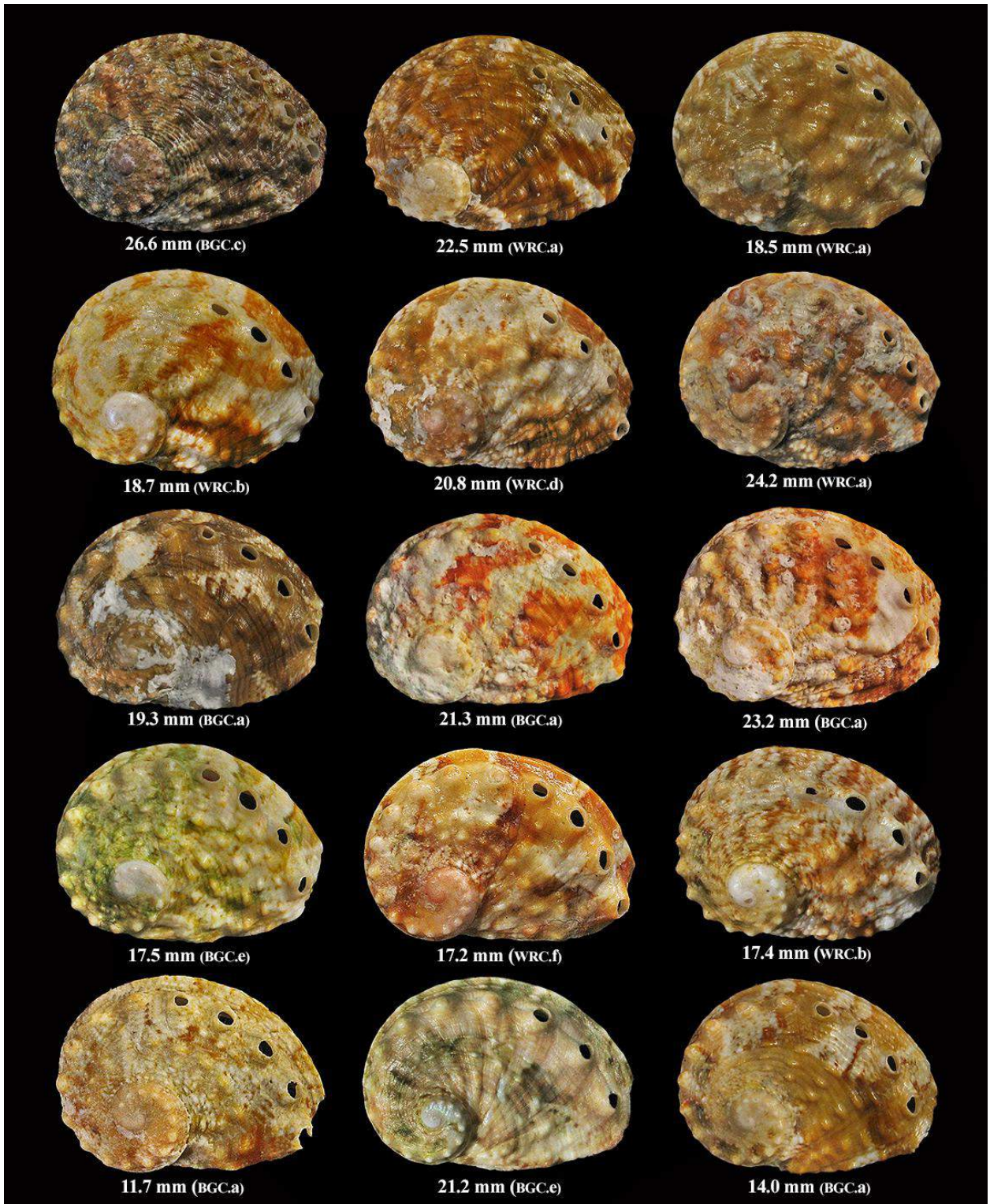

FIGURE 5. ***Haliotis unilateralis*** **Lamarck, 1822. Mauritius. (a= Flacq district, Plage de Palmar; b= Flacq district, Ile Marianne; c= Riviere Rempart district, Péreybere; d= Savanne district, St-Felix). Red Sea. (e= Eilat, Israel; f= Egypt, Gulf of Aqaba, Dahab Bay). All collected by WRC & BGC as noted.**

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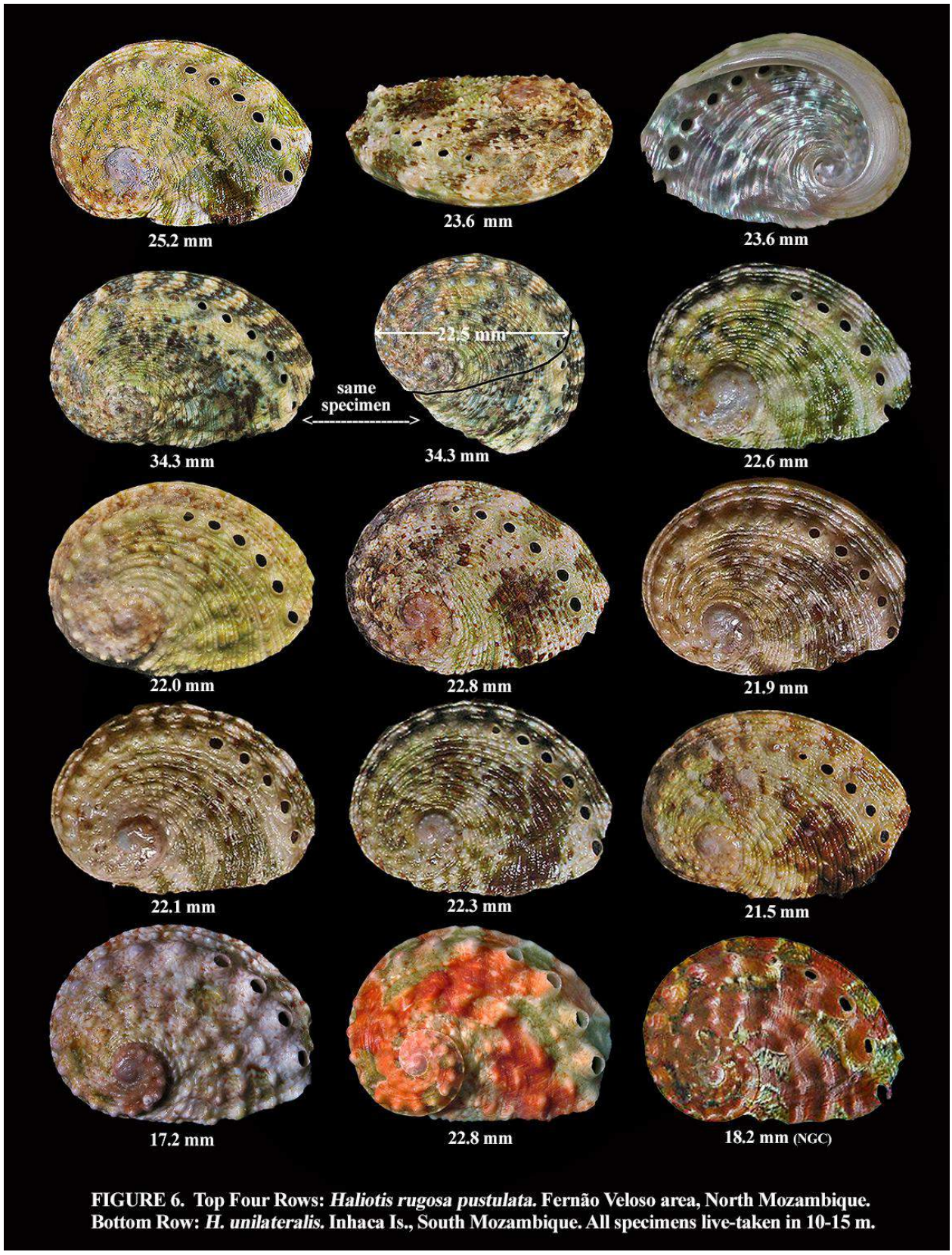

FIGURE 6. Top Four Rows: *Haliotis rugosa pustulata.* Fernão Veloso area, North Mozambique. Bottom Row: *H. unilateralis.* Inhaca Is., South Mozambique. All specimens live-taken in 10-15 m.

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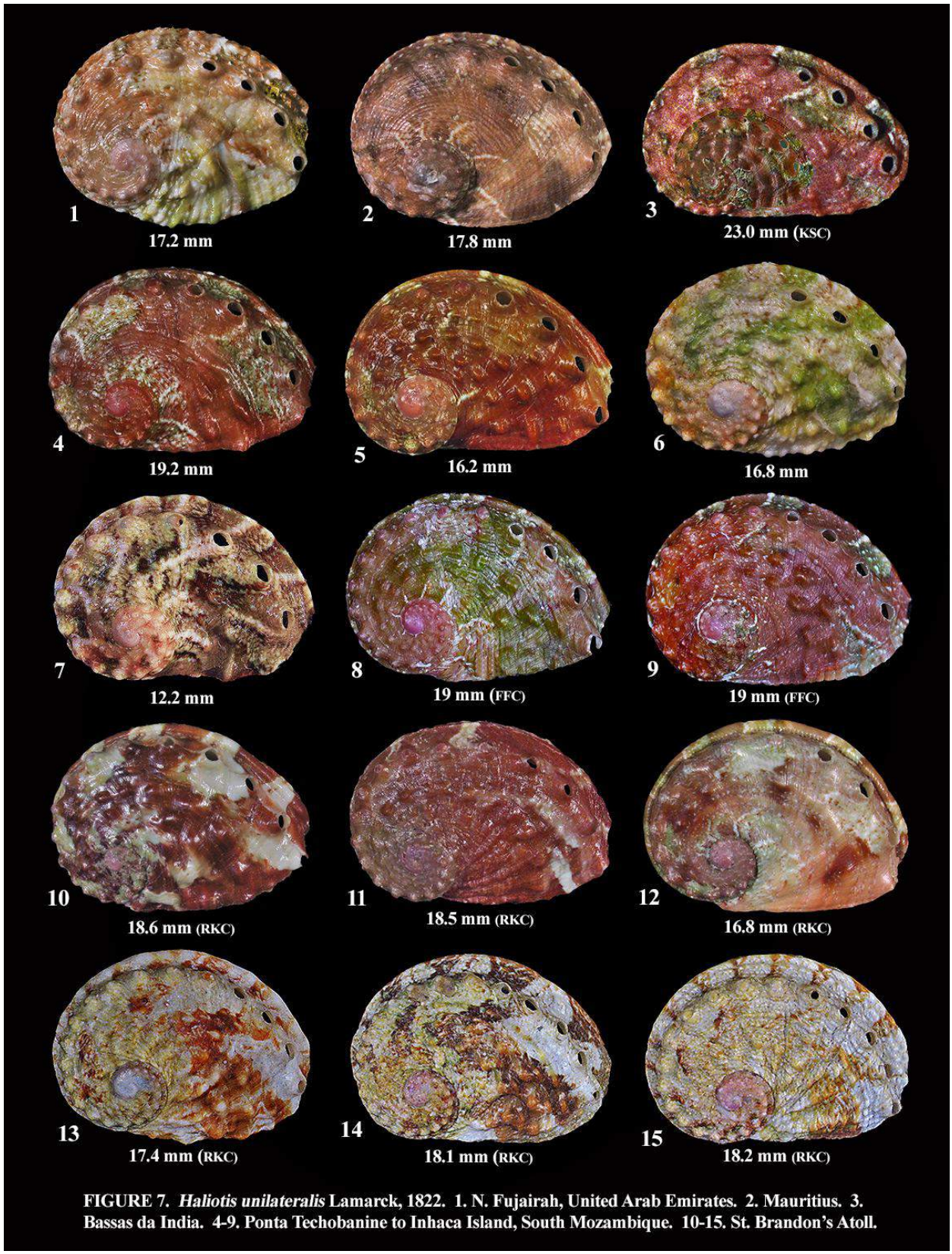

FIGURE 7. ***Haliotis unilateralis*** **Lamarck, 1822. 1. N. Fujairah, United Arab Emirates. 2. Mauritius. 3. Bassas da India. 4-9. Ponta Techobanine to Inhaca Island, South Mozambique. 10-15. St. Brandon's Atoll.**

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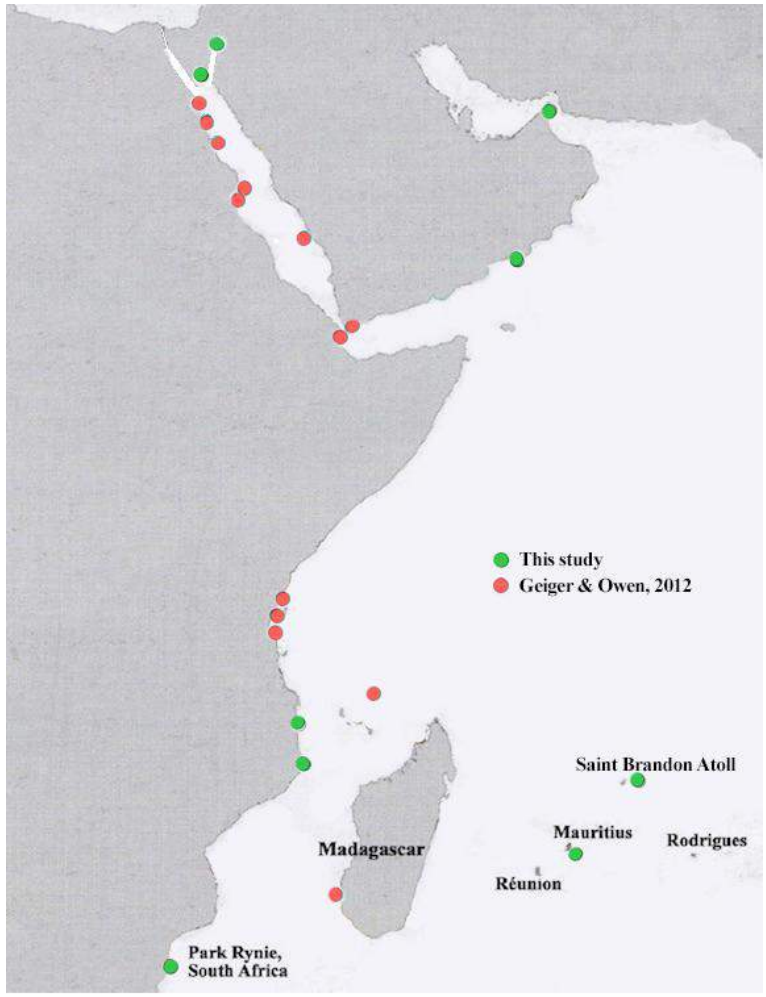

Figure 8. Map illustrating distribution of *H. unilateralis* this study and additional sites listed in Geiger & Owen, 2012

Collection Management System is a museum style database program, which enables a collector to keep, organize, and maintain the individual records and data from their shell collection in a readily accessible form. The program is easy to use, and is menu driven by self-explanatory pull tabs. Reports and labels are easy to print. This latest version is readily adaptable to work with any systematic collection, including malacologists and entomologists, and runs in a Windows operating environment. See www.shellcollections.com or our Facebook page for more information.