



# Confirmed record of abalone *Haliotis arabiensis* near Muscat (Sea of Oman) and a description of abalone species from the Arabian Peninsula

Nadir Al-Abri<sup>1,\*</sup>, Mikhail Chesalin<sup>2</sup>, Yahya Al-Wahibi<sup>1</sup>, Mohammed Balkhair<sup>3</sup>

<sup>1</sup> Marine Science and Fisheries Centre, Ministry of Agriculture, Fisheries and Water Resources, Muscat 427, Sultanate of Oman

<sup>2</sup> Kovalevsky Institute of Biology of the Southern Seas of RAS, Sevastopol 290011, Russian Federation

<sup>3</sup> Fisheries Research Center-Dhofar, Ministry of Agriculture, Fisheries and Water Resources, Salalah 33, Sultanate of Oman

## Abstract

*Haliotis arabiensis* Owen, Regter & Van Laethem, 2016 was found near Muscat city of Oman in the Sea of Oman in September 2021. A total of 85 abalone specimens were collected under small boulders from a depth of 2–5 m during the scuba diving survey from seven stations located from Sidab to Bandar Khairan. The shell length (SL) of the abalone ranged between 10.0 and 30.0 mm, on average  $19.9 \pm 0.22$  mm SL. The sex was determined in 15 females and 21 males. The study presents photos and a comparative table with morphological descriptions of four abalone species (*H. arabiensis*, *H. mariae*, *H. rugosa multiperforata* and *H. unilateralis*) which are important for differentiating the small abalone species from juveniles of *H. mariae* during monitoring surveys of this important commercial species in Oman.

**Keywords:** *Haliotis arabiensis*, Abalone, Description, Muscat, Sea of Oman

## Introduction

Five abalone species are currently reported from the southern and eastern Arabian Peninsula: *Haliotis arabiensis*, *H. mariae*, *H. pustulata*, *H. rugosa multiperforata*, and *H. unilateralis* (Bosch et al., 2008; Geiger & Owen, 2012; Owen, 2013; Owen & Pan, 2016a, 2016b; Owen et al., 2016).

The largest and most abundant abalone is *Haliotis mariae* W. Wood, 1828, which is an endemic species restricted to Oman's coastal waters of the Arabian Sea, inhabiting a short

rocky coastal zone of approximately 250 km between Mirbat and Sharbithat in Dhofar, the southern region of the country (Al-Hafidh, 2006). The distribution of this species extends to the Al-Wusta region along the coastal rocky shores of the Arabian Sea as far north as Masirah Island and Al-Ashkharah, but at very low densities (Johnson et al., 1992). The Global Biodiversity Information Facility (GBIF), which is the most comprehensive database about occurrence of different species, contains information on specimens of *H. mariae* collected near Muscat in 1964, 1965, and 1978 (Chaney et al., 2024). In February 2023,

Received: Sep 26, 2023 Revised: Nov 28, 2023 Accepted: Dec 28, 2023

\*Corresponding author: Nadir Al-Abri

Marine Science and Fisheries Centre, Ministry of Agriculture, Fisheries and Water Resources, Muscat 427, Sultanate of Oman

Tel: +968-9920-6322, E-mail: n.alabri79@hotmail.com

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*H. mariae* was found in the more southwestern part of Oman between Mirbat and Salalah (Chaney et al., 2024). According to Siddeek & Johnson (1997), *H. mariae* can reach a maximum shell length (SL) of 152.8 mm. This abalone is actively harvested by divers during a restricted fishing season (from 10 days to 2 months) in the Dhofar region between Mirbat and Hasik, along a coast of about 100 km (Al Jufaili et al., 2020; Al-Ghassani et al., 2022). *H. mariae* is a premium seafood delicacy worldwide and a valuable export commodity of Oman to the East Asian market.

Other abalone species are small, with a maximum size of less than 60 mm SL, are quite rare and are often misidentified by divers as juvenile *H. mariae*. Bosch et al. (2008) reported the occurrence of *Haliotis pustulata* Reeve, 1846 with a maximum size of ~35 mm SL near the coast of Oman in the Sea of Oman (Gulf of Oman), but the authors did not provide detailed information about the collection sites of the specimens. The GBIF database recorded specimens of *H. pustulata* collected from Muscat (Al Bustan) in 1999, and in Masirah Island from 1995 to 1999. *H. pustulata* is known to occur along the coast of Madagascar and from South Africa to the Red Sea and east to Yemen (Owen, 2013). However, Owen et al. (2016) did not report the presence of *H. pustulata* in the waters of the southern and eastern Arabian Peninsula. For a long time, *H. pustulata* was confused with *H. rugosa* (Owen, 2013). Specimens found in Yemen were formerly considered to be *H. pustulata* (Ali et al., 2009), then *H. rugosa pustulata* (Owen, 2013), but later Owen & Pan (2016a) reviewed the *H. rugosa* complex of the Western Indian Ocean and described four new subspecies, with specimens collected from Yemen (Mukalla) being designated as a new subspecies *Haliotis rugosa multiperforata* Reeve, 1846. The GBIF database applied the name *Haliotis multiperforata* Reeve, 1846, and reported the occurrence of this abalone in Yemen, Reunion Island and South Africa.

*Haliotis unilateralis* Lamarck, 1822 is an uncommon species with widespread distribution in the Western Indian Ocean, being found in the Red Sea, the northwestern Arabian Sea (Mirbat, Oman), the Gulf of Oman (Dibba, United Arab Emirates), along the coast of East Africa, southern Madagascar, Seychelles and Mascarene Islands (Geiger & Owen, 2012; Owen, 2007; Owen & Pan, 2016b). The GBIF database does not contain information on occurrence of *H. unilateralis* in Oman. T. Chesalina (pers. comm.) found several shells of *H. unilateralis* on the Bandar Rawdah beach in Muscat in 2013.

Recently, a new abalone species was discovered and de-

scribed by Owen et al. (2016) as *H. arabiensis* Owen, Regter & Van Laethem, 2016. The authors collected specimens of *H. arabiensis* in the southern part of Oman (north of Salalah city) in the Arabian Sea and along the coast of Fujairah (near Dibba) of the United Arab Emirates in the Sea of Oman. In January 2020, several specimens of *H. arabiensis* were found by Paulay and Claereboudt with colleagues near Muscat (cove at Haramel village, Bandar Al Jissah, cove in Bandar Khairan, Qantab) (Florida Museum of Natural History, 2024). In November 2022, Paulay with colleagues collected three specimens of *H. arabiensis* from Masirah Island (Florida Museum of Natural History, 2024). The specimens from Muscat and Masirah is. were deposited in the Florida Museum of Natural History and recorded in the GBIF database.

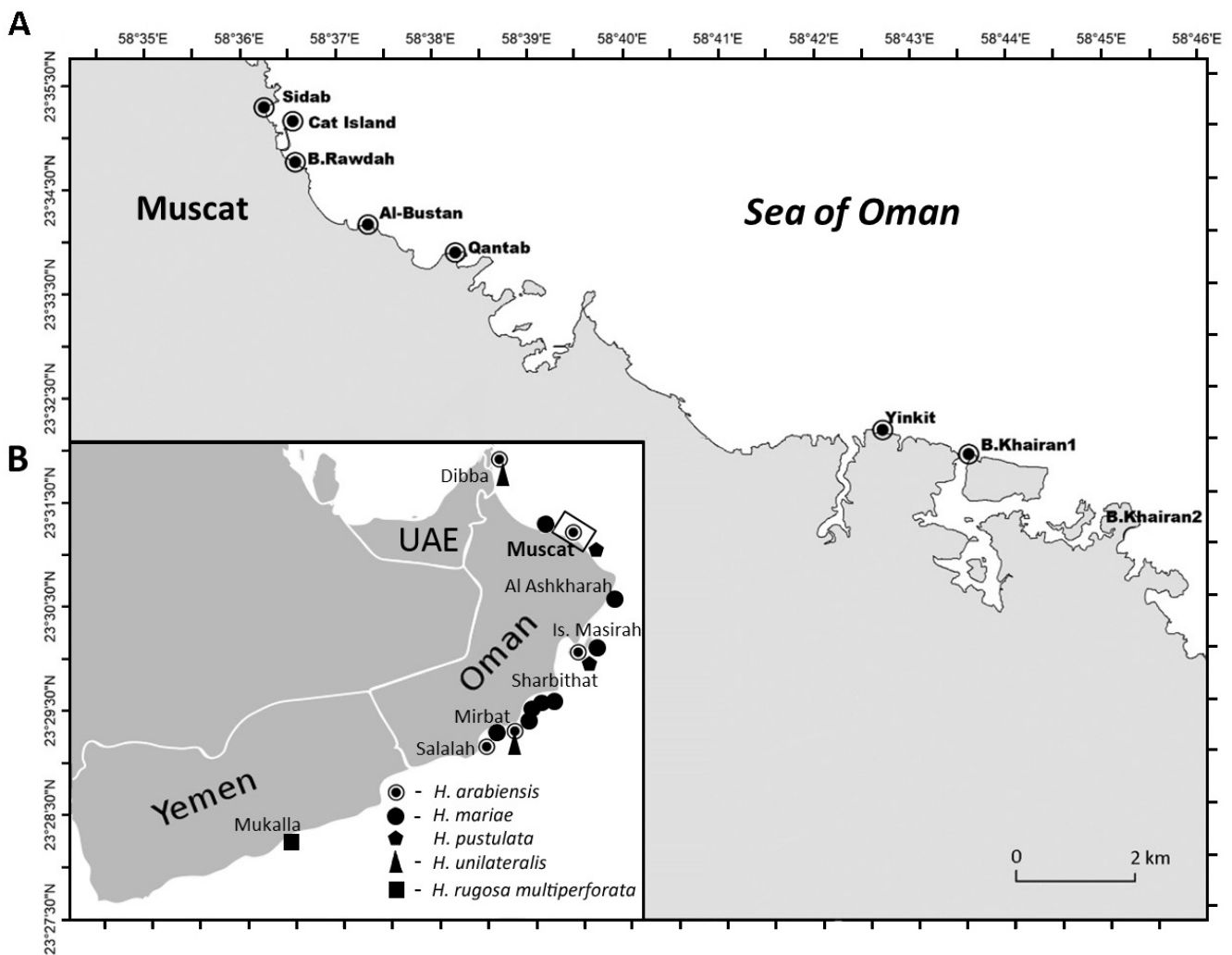
We found dozens of small live abalones under boulders near Muscat during an underwater survey in September 2021. The collected specimens from Muscat were identified according to Owen et al. (2016) as *H. arabiensis*. The purpose of this work is to present a confirmed record of *H. arabiensis* in the waters of Oman and describe the morphology of various abalone species to help distinguish juveniles of a very important commercial *H. mariae* from small abalone species.

## Material and Methods

The abalone was collected during SCUBA diving near Muscat city (Sea of Oman) in September 2021. The study was conducted at eight underwater stations located in rocky areas with hard bottom substrate (boulders and rocks). The location of the stations is shown in Fig. 1A and the coordinates of the stations were: Sidab (23°35' 17"N, 58°36' 15"E), Cat Island (23°35' 08"N, 58°36' 33"E), Bandar Rawdah (23°34' 45"N, 58°36' 34"E), Al-Bustan (23°34' 08"N, 58°37' 19"E), Qantab (23°33' 52"N, 58°38' 14"E), Yinkit (23°32' 07"N, 58°42' 40"E), Bandar Khairan 1 (23°31' 52"N, 58°43' 34"E), and Bandar Khairan 2 (23°31' 03"N, 58°45' 16"E). In Fig. 1B, the rectangle shows the location of the study area near Muscat and the sites where, according to the literature, various species of abalone were found.

The transect method was used for the study. The 10 meter long rope was placed to a depth of 1–5 m and two divers searched for abalone within 1 m on both sides of the rope. This method was repeated three times at every station on the same day.

A total of 85 abalones were collected and measured in the SL using a digital vernier caliper with an accuracy of 0.1 mm. The abalone sex was determined visually using the color of the



**Fig. 1. Distribution maps.** (A) Map of our sampling stations of *Haliotis arabiensis* near Muscat (Oman). (B) Map with the rectangle showing location of this sampling area near Muscat and finding sites of various abalone species along the Arabian Peninsula on literature data.

gonads as an indicator: males have milky gonads, while females were recognized by dark green gonads. Some abalones have not been sexed due to their small size and lack of clarity of the gonad color. In addition, for comparison with abalone from Muscat, several juveniles of *H. mariae* were collected in the southern Dhofar region of Oman from the sea near Mirbat Aquaculture Station (MAS) and also taken from rearing tanks.

## Results

Small alive abalones were found off Muscat at a depth of 2–5 m in seven stations, except the most remote from the city station Bandar Khairan 2. The specimens were collected under boul-

ders, covered with brown algae *Padina boergsenii* Allender & Kraft, 1983. The largest number (45 specimens) was in Sidab, more than ten individuals were sampled in Qantab and Al-Bustan, and only one specimen was found in Yinkit and another one in Bandar Khairan 1 (Table 1).

The size of the abalone ranged between 10.0 mm and 30.0 mm SL, on average of  $19.9 \pm 0.22$  mm SL. Larger specimens were registered in Qantab (on average  $22.7 \pm 0.38$  mm SL) and smaller ones (on average  $17.9 \pm 0.32$  mm SL) in Sidab. One specimen from Bandar Khairan 1 has a size 17.6 mm SL.

A total of 36 out of the 85 specimens were sexed, with 15 females and 21 males. Overall, the sex ratio was not significantly different from equal (Chi-square test value,  $\chi^2$ : 9.17; df: 4; *p*-val-

**Table 1. Shell length (SL, mm) and sex of *Haliotis arabiensis* in the stations**

Station name	Number of specimens	Average SL (mm) ± SD	Range SL (mm)	Sex
Sidab	45	17.9 ± 0.32	10.0–25.0	10 M; 6 F; 29 UN
Cat Island	5	19.8 ± 0.31	15.0–22.0	5 M
Bandar Rawdah	4	19.5 ± 0.20	18.0–21.0	UN
AINABustan	13	20.1 ± 0.27	16.0–25.0	4 M; 9 F
Qantab	16	22.7 ± 0.38	15.0–30.0	1 M; 15 UN
Yinkit	1	18.4	NA	1 M
Bandar Khairan 1	1	17.6	NA	UN
Bandar Khairan 2	0	NA	NA	NA
Total	85	19.9 ± 0.22	10.0–30.0	21 M; 15 F; 49 UN

M, male; F, female; UN, unidentified; NA, not applicable.

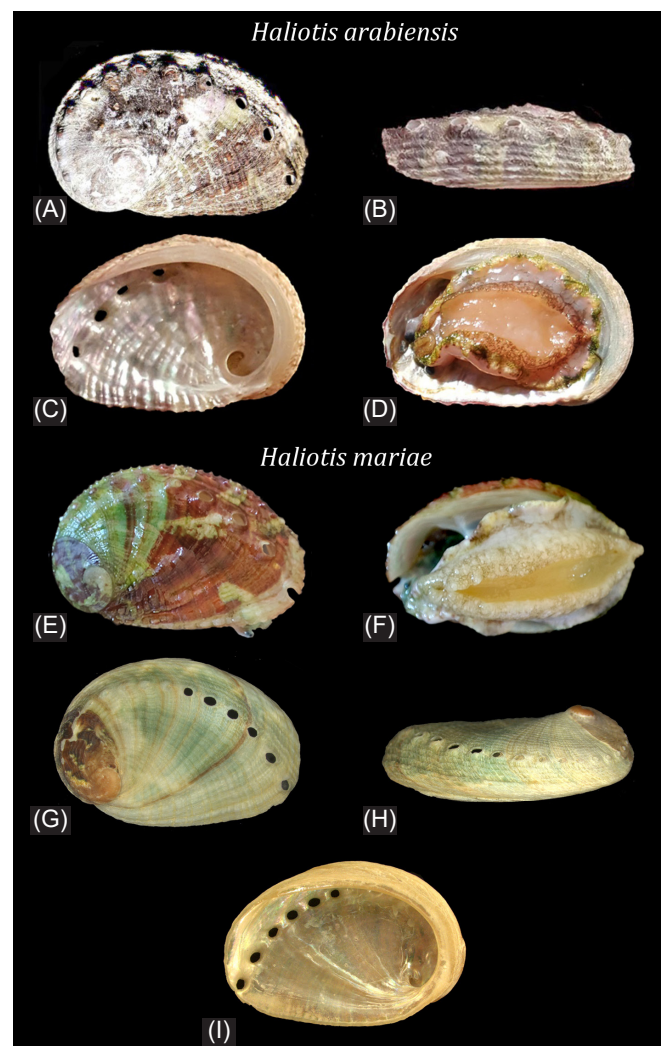
ue: 0.0568).

Based on the description of Owen et al. (2016), the abalones were identified as *H. arabiensis* Owen, Regter & Van Laethem, 2016. These specimens were compared with similar-sized juveniles of *H. mariae* that we collected from the Arabian Sea in the south of Oman near MAS and from the station's culture tanks. *H. arabiensis* can be distinguished from *H. mariae* by several features: more widely spaced and fewer number of open holes (4–5 vs. 5–6); the spire is positioned closer to the anterior part of the shell; the dorsal surface of the shell has a stronger spiral ribbing; fewer ribs (4–6 vs. 10–12) between the holes and columella; the ventral edge of the shell is more serrated; the ventral surface of the shell with strong furrows (Fig. 2). It should be noted that the number of open holes usually increases as abalone grows and getting older, then it becomes a fixed number. Cultured *H. mariae* from MAS tanks have a greenish shell color, possibly due to feeding on diatoms on culture plates and their shell sculpture was characterized by a finer ribbing in comparison with wild specimens (Fig. 2, G–I).

In order to facilitate the identification of abalone species occurring off the Arabian Peninsula, especially in Oman's waters, we combined in Table 2 data of our own examinations of *H. arabiensis* and *H. mariae* with descriptions of *H. unilateralis* and *H. rugosa multiperforata* given B. Owen with colleagues (Geiger & Owen, 2012; Owen, 2007, 2013; Owen & Pan, 2016a, 2016b; Owen et al., 2016).

## Discussion

Our finding of many live specimens of *H. arabiensis* in the area of Muscat city confirmed previous records of this species in the waters of Oman and expands knowledge about biology of



**Fig. 2. Abalone shells.** (A–D) *Haliotis arabiensis*. 17 mm SL. Found near Muscat city of Oman; (E, F) *Haliotis mariae*. 18 mm SL. Live-taken in Mirbat (Dhofar region, South Oman). (G–I) *Haliotis mariae*. 16 mm SL. Cultured in Mirbat aquaculture station. SL, shell length.

**Table 2. Description of the morphology of *Haliotis* species inhabiting the waters of the Arabian Peninsula**

Characteristics	Description	<i>H. arabiensis</i> (our data)	<i>H. mariae</i> (our data)	<i>H. rugosa multiperforata</i> (from Owen & Pan, 2016a)	<i>H. unilaterialis</i> (from Owen & Pan, 2016b)
Shell size		To ~ 35–40 mm SL	To ~ 145 mm SL	To 63 mm SL	To 60 mm SL
Number of open holes		4–5	5–6	6–9	3–5
Shape & structure of holes		Quite large, oval, elevated, widely spaced	Small, oval or round, slightly elevated, closely spaced	Small, round, slightly elevated, closely spaced	Large, round, elevated, widely spaced
Shell shape		Oblong, slightly convex, flattened	Oval and convex, flattened	Oblong, slightly convex	More circular, flattened
Dorsal shell sculpture		Strong spiral ribbing with finer ribs to the edge	Narrow spiral ribbing with finer ribs to the edge	Smooth, rarely weak and narrow spiral ribbing	Smooth, rarely weak spiral ribbing
Shell apex		Apex located 20%–25% from anterior margin of the shell	Apex located 10%–20% from anterior margin of the shell	Apex located 17%–19% from anterior margin of the shell	Apex located 23%–29% from anterior margin of the shell
Shell margin		4–6 strong ribs between columella and row of holes; ventral margin thin and serrated	10–12 narrow ribs between columella and row of holes; ventral margin smooth or slightly serrated	4–5 very weak narrow ribs between columella and row of holes; ventrally smooth	One wide rib in the center and 1–3 weaker ribs above and below it between columella and row of holes; ventrally smooth
Columella		Narrow	Narrow	Medium width	Wide
Color of shell exterior		Greenish tan or brown; medium to dark red, sometimes with scattered whitish or yellowish patches	ReddishNDbrown with large whitish markings, occasionally greenish	Dark brown with irregular markings of greenishNDwhite	From orange, red and brown to yellow or green with scattered grey patches
Ventral shell surface		Regular furrows reflected dorsal sculpture; highly iridescence silver and reflections of green, pink, and steel blue	Smooth or weak furrows; silvery, with red, blue and green reflections	ND	ND
Color of body		Foot sole pale cream; lobed epipodium brown and greenish mottled	Depends on the type of food and varies between cream, brown and green	ND	ND
Epipodium		Ventral margin bears numerous thin tentacles with dark transverse stripes, length of tentacles can reach a third of the width of the shell, the cephalic tentacles are yellowish with a longitudinal dark stripe	Ventral margin has numerous thicker and shorter tentacles, transverse stripes less noticeable, the cephalic tentacles are light	ND	ND

SL, shell length; ND, not detected.

this abalone species. As was mentioned above, *H. arabiensis* was discovered and described relatively recently by Owen et al. (2016) based on the study of 32 specimens from southern Omani waters of the Arabian Sea north of Salalah and 6 specimens from Dibba Al-Fujairah (UAE) in the Sea of Oman. The authors noted that this small-sized abalone, reaching only ~35–40 mm SL, occurs extremely rare under rocks and corals at a relatively great depth of 12–18 m. van Gemert (2016) noted the discovery of three shells of *H. arabiensis* (23–30 mm SL) on the beach at Mirbat in 2012, along with many shells of *H. mariae* of approximately the same size and larger. The author suggested that *H. arabiensis* may also occur at shallower depths than those mentioned by Owen et al. (2016). Our samples of *H. arabiensis* were collected at 2–5 m depth, so the speculation of van Gemert (2016) about the vertical distribution of this species was confirmed. Recently, several specimens of *H. arabiensis* were collected from Muscat in 2020 and from Masirah Is. in 2022 (Florida Museum of Natural History, 2024). The discovery of *H. arabiensis* forced specialists to revise existing identification guides and collections of abalone in different countries, as it was previously identified as juvenile *H. mariae*. So, Bosch et al. (2008) illustrated *H. mariae* (the smallest shell on the plate) with *H. arabiensis*. Geiger & Owen (2012: plate, figure) also identified a specimen of *H. arabiensis* as *H. mariae*. Several abalones deposited in the Naturalis Biodiversity Center (Leiden, Netherlands) that were collected in Masirah Is. in 1995 and 1997, and in Mirbat (Dhofar region) in 2003 were re-identified as *H. arabiensis* (Goud et al., 2024).

The distribution of other abalone species along the coast of Oman has not yet been sufficiently studied. Many specimens of *H. pustulata* were collected in Masirah Is. in 1995–1999 and one specimen was found in Muscat in 1999. However, these findings were not confirmed by later studies. *H. unilateralis* was collected only in Mirbat (Owen & Pan, 2016b) and from unconfirmed reports in Muscat. Even the current occurrence of the most common and large abalone species, *H. mariae*, along the Muscat coast is questionable because museum specimens were sampled in 1964, 1965, and 1978, but has not been found here in numerous subsequent dives or on shore.

The Omani abalone *H. mariae* is very important commercial species and export commodity in Oman. Its fishery has been active since the 1950s and reached a maximum annual production of 149 tonnes of fresh meat in 2011 (MOAFW, 2020). However, during last years (2015–2022) the abalone landings, density and mean sizes in the population declined

drastically, indicating an urgent need for additional measures to prevent its collapse (Al Jufaili et al., 2020; Al-Ghassani et al., 2022). Specialists from the Fisheries Research Center-Dhofar (Salalah) have been monitoring the size and density distribution of the *H. mariae* population annually using underwater surveys for nearly 20 years (Al-Ghassani et al., 2022). During these underwater surveys it is very important to distinguish juvenile *H. mariae* from small and non-commercial abalone species, namely *H. arabiensis* and *H. unilateralis*, therefore comparative Table 2 may be of practical value, especially for divers. In addition, the occurrence of *H. arabiensis* in rocky areas near Muscat and previous findings of *H. mariae* in this location may stimulate translocation and seeding trials with *H. mariae* from the south of the country to the northern regions. However, there are differences between these habitats. Abalone are known as selective feeders, showing a preference for a certain type of algae (Shepherd & Steinberg, 1992). *H. mariae* is herbivorous, its postlarvae and early juveniles feed on benthic diatoms, advanced juveniles and adults feed on seaweeds *Nizamuddinina zanardinii* and *Ulva fasciata* (Al-Rashdi & Fermin, 2012). In the present survey, *H. arabiensis* was associated with rocky areas covered by the brown algae *Padina boergsenii*.

Undoubtedly, the study of the spatial distribution and biology of different abalone species in Omani waters and around the Arabian Peninsula should be continued. It is necessary to conduct a genetic analysis of the abalone species in order to clarify the history of their origin, distribution and phylogeographic relationships.

### Competing interests

No potential conflict of interest relevant to this article was reported.

### Funding sources

Not applicable.

### Acknowledgements

We appreciate the Ministry of Agriculture, Fisheries and Water Resources and the General Directorate of Fisheries Research for financial support of our investigations. We would like to thank our diver team from the Marine Science and Fisheries Centre Ahmed Al-Humaidi and Salem Kahoom from Fisheries Research Center-Dhofar in Salalah for help in collection of the abalone samples. We are grateful to Asila Al-Maawali for abalone photos.

**Availability of data and materials**

Upon reasonable request, the datasets of this study can be available from the corresponding author.

**Ethics approval and consent to participate**

This article does not require IRB/IACUC approval because there are no human and animal participants.

**ORCID**

Nader Al-Abri <https://orcid.org/0000-0002-8564-3798>  
Mikhail Chesalin <https://orcid.org/0000-0003-0254-5939>  
Mohammed Balkhair <https://orcid.org/0000-0001-8382-1856>

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