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Authors: Jufaili, Saud M. Al, Rashdi, Khalfan Al, and Elegbede, Isa O.

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THE OMANI ABALONE *HALIOTIS MARIAE* (WOOD, 1828) FISHERY: CHALLENGES OVER THREE DECADES

SAUD M. AL JUFAILI,^{1*} KHALFAN AL RASHDI² AND ISA O. ELEGBEDE^{3,4}

¹Department of Marine Science and Fisheries, Sultan Qaboos University, P.O. Box 34, Al-Khod 123, Sultanate of Oman; ²Directorate General of Fisheries Research, Ministry of Agriculture and Fisheries Wealth, P.O. Box 427, Muscat 100, Sultanate of Oman; ³Chair of Environmental Planning, Brandenburg, University of Technology, Cottbus-Senftenberg, 03046, Germany; ⁴Saeio Global (SGL), Lagos, Abesan Estate, Ipaja, 23401, Lagos, Nigeria

ABSTRACT The Omani abalone *Haliotis mariae* (Wood, 1828) supports one of the most valuable fisheries in Oman. It is specific to defined areas along the northern region of Dhofar in Oman. This study reviews the management of the Omani abalone fishery during the last 31 y, identifies the challenges encountered, and suggests solutions to overcome these difficulties. During the period 1988–2018, annual abalone landings ranged from 29 tonnes (mt) in 1999 to 149 mt in 2011, with an average of 53 mt. In 2019, landings 24 t (53 t whole weight) were reported to be the lowest in the last three decades and landed within 10 days of opening. The fishery generated 1.3 million Omani rials (3.38 million US\$) (OR, where 1 OR = 2.6 USD) in 1993 and 8.2 million OR in 2011, with an average of 2.5 million OR (6.5 million US\$). By contrast, the average annual price per kg was 50 OR (130 US\$). The fishery was mainly managed in accordance with seasonal closures, which ranged from 6 mo to less than 1 mo; in one case, there was a complete suspension of fishing for 3 y. The number of fishers engaged in this fishery was not stable, and fluctuated between 1,450 in 1993 and 8,539 in 2014. The seasonal closures between 1988 and 2003 resulted in a gradual decrease in average landings, reaching 2%–45% at the end of the season, with an average of 27%. The percentage of divers who participated at the end of the season ranged from 9% to 90%, with an average of 47%. It is suggested that the government should conduct comprehensive research to assess the Omani abalone stock, population dynamics, and habitat, as well as the behavior of the fishermen. Furthermore, better data collection and monitoring systems should be established. It is strongly recommended that a “pulse fishing” or spatial-based or temporary marine-protected area fishing (zonation) approach that serves the objectives of stock and habitat preservation be implemented. Thus, the restoration of the Omani abalone fishery is achievable but will require long-term research efforts.

KEY WORDS: *Haliotis mariae*, abalone, Oman, landings, catch, fishery management, fishing seasons

INTRODUCTION

Abalone fisheries have met with many challenges, especially concerning management and stock restoration globally (Cook 2014, Cook 2019). A worldwide decrease in abalone landings has been reported owing to various reasons, including overfishing, the collection of illegally sized abalone, and habitat degradation, as in the case of the abalone fisheries in Mexico (Morales-Bojórquez et al. 2008, Fulton et al. 2019), South Africa (Raemaekers et al. 2011, Crookes & Blignaut 2019), and Australia (Gorfine et al. 2001, Mayfield et al. 2012, Woolford 2019). Another reason for the decline is the outbreak of natural diseases in both the cultured and wild stocks (Mayfield et al. 2011).

Based on the biology and life cycle of the abalone, fisheries around the world are mainly managed with the help of seasonal closures. This circumstance applies, for example, to the Australian abalone (Mayfield et al. 2012), the Californian abalone (Karpov et al. 2000), and the South African abalone (Tarr 2000, Edwards & Plaganyi 2008). Although seasonal closure has always been considered to be a secure management method, there have always been problems associated with its implementation. There have been obstacles associated with abalone management. For instance, poaching and illegal catches of abalone accounted for 65% of the legal landings in 2008 worldwide (Tarr 2000, Gordon & Cook 2013). It was also reported that the

total allowable catch (TAC) has decreased regularly in several of the abalone fisheries globally (Shepherd & Rodda 2001, FAO 2008, Raemaekers & Britz 2009, Woolford 2019).

Between 1970 and 2013, abalone landings decreased from more than 20,000 tonnes (mt) to less than 8,000 mt worldwide (Gordon & Cook 2013, Cook 2014). Furthermore, as a result of external fertilization, abalones occur close together, thereby increasing the chances of breeding during fertilization periods (Coates et al. 2013). As a result, the ranges of population densities during the spawning seasons are crucial for a successful season (Levitin et al. 1992, Yund 2000, Nakamura & Archdale 2001). Another critical variable for a successful season is the availability of rocky areas, the required habitat for juvenile abalone. This is where they attach and protect themselves from predators as they grow (Visser-Roux 2011). They also, however, attach themselves to other aquatic animals such as sea urchins for shelter and protection (Kojima 1981, Fletcher 1987, Mayfield & Branch 2000). An abundance of sea urchins can compete with abalone for food (Tarr et al. 1996, Coates et al. 2013). Also, the South African abalones reach sexual maturity at about 20–25 mm shell width in almost 7 y (Wood & Buxton 1996). Under the right environmental conditions, most of the abalones grow up to 2–3 cm/year, and the adults live up to 30 y (FAO 1990, Steinberg 2005).

The abalone fishery of Oman consists of one species, *Haliotis mariae*. For the last three decades, the government of Oman has been managing abalone fishing in an effort to restore stocks and sustain landings. The fishery management plan has experienced many changes and encountered many challenges. Published and

*Corresponding author. E-mail: sjufaily88@gmail.com
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unpublished reports have indicated a decline in the Omani abalone fishery (Al-Hafidh 2006, Balkhair et al. 2016). This article presents a comprehensive review of the Omani abalone fishery during the last three decades, with recommendations for future research and management. The findings of this review will help facilitate effective management by the Omani abalone fisheries managers and officials and aid the future development of the abalone fishery in Oman, mainly through stock assessment.

METHODOLOGY

During the period 1988–2019, various aspects related to abalone landings, values, the price/kg, number of divers involved in the industry, management measures, and other related statistics were analyzed. These data were obtained from the Omani Ministry of Agriculture and Fisheries (MAF) statistics yearbooks (MAF 1988–2019). The total landings reported were for the fresh flesh abalone without the shell. To convert the flesh weight to the whole abalone weight, the following equation (used by the MAF) was applied: whole weight = flesh weight/0.45. The equation assumes that abalone flesh contributes to 45% of the total body weight (MAF 1988). The total number of divers involved in each season was reported by the MAF. As divers can move from one diving site to another, it is assumed that there is a double or multiple count of the number of divers involved and presented per diving site for every given season (MAF 2019). During the study period, visits were made to a number of the abalone fishing villages in the Dhofar region, and personal interviews were conducted with several fishermen. The diving process, the postharvest handling, and the marketing of abalone were also analyzed, and the observations recorded. While reviewing the fishery, some officials of the MAF were approached for interviews, explanations, and the clarification of points that had arisen during the gathering of data. In addition to the aforementioned information,

the published literature, as well as unpublished articles and reports on the Omani abalone, including newspaper articles, were reviewed. The values are given in Omani rials, 1 OR = 2.6 US\$, based on the exchange rate in 2020.

RESULTS

The Omani Abalone Fishery

The distribution of the Omani abalone *Haliotis mariae* (Wood, 1828), also called “Sufailah” by locals, is limited to Dhofar Governorate, the southern region of Oman (Fig. 1). Dhofar experiences a southwest monsoon system, which results in the cooler temperatures preferred by the abalone (Shepherd et al. 1992). The ecosystem in the southern region of Oman is rich in nutrients which support the growth of seaweeds such as *Sargassopsis* sp., *Ecklonia radiata*, and *Sargassum* sp., which are food for abalones (Hamer et al. 2010). These algae were observed at depths up to 10 m in significant volumes, serving as a perfect feeding ground for small abalones (Shepherd et al. 1992). Feeding decreases after the monsoon period (Al-Hafidh 2006) as food becomes scarcer before and during this time (Jupp 2002). Along the coast of Dhofar, abalone is mainly found on the northern shores inhabiting rocky subtidal bays between Mirbat and Sharbithat, a stretch of coastline almost 360 km long. They are found at depths ranging from 0 and 30 m (Ogawa 1994) to 50 m (Hahn 1989) (Fig. 1). For years, it was believed that *H. mariae* is the only abalone species found in Oman; however, other abalone species have been recorded by Geiger and Owen (2012) in the Dhofar region. Both *Haliotis unilateralis* and *Haliotis arabiensis* have also been found in this region, but they are not widely distributed (Owen et al. 2016).

In the international market, Omani abalones are considered to be among the top 20 best abalones, owing to their nutritional

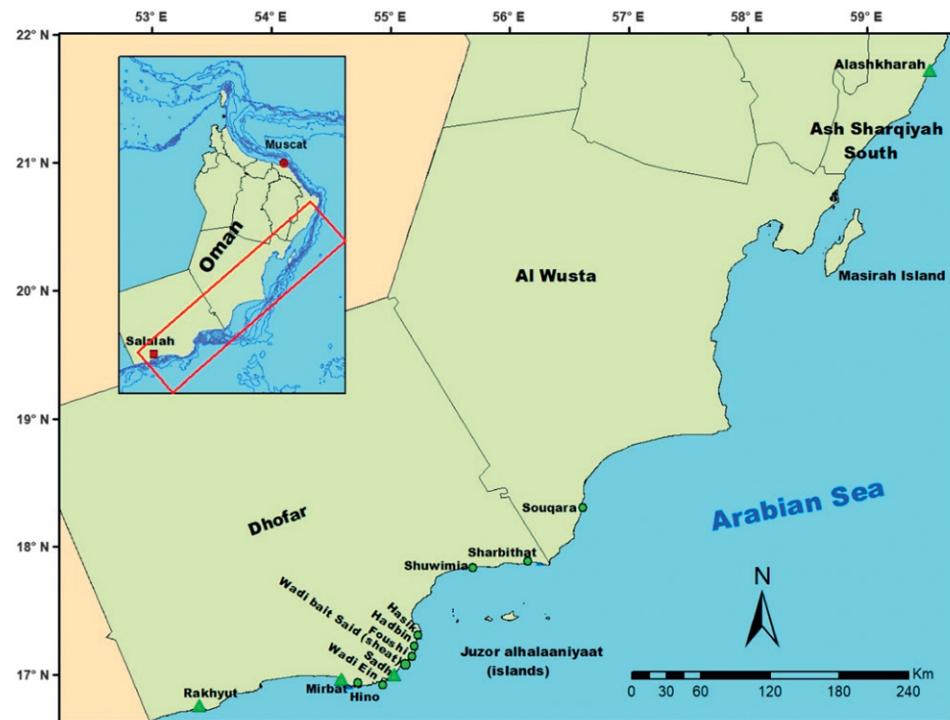


Figure 1. Oman map showing abalone fishing grounds covering three governorates from north to south, South Ash Sharqiyah, Al Wusta, and Dhofar.

value (Uki 1989). Despite the limited catch during the fishing seasons, abalone is as an excellent source of income for the local fishermen. They are harvested using traditional methods, as the size of the available catch is insufficient to support commercial exploitation.

Based on the landing reports from the Dhofar Governorate region, as reported annually by the MAF statistical report books, abalone fisheries are found in the areas (from south to north) of Mirbat, Hino, Wadi Ein, Soub, Wadi bait Said (sheat), Gangary, Sadh, Hat, Foushi, Hadbin, Haitoom, Hasik, Shuwimia, and Sharbithat. These areas are known for the large number of small rocky bays and the availability of the seaweed on which the abalone feed. In the past, there were reports that abalone existed as far west in the Dhofar Governorate region as the coast of Rakhyut, and also in areas of the Al Wusta Governorate, including the shores of Souqara, Masirah Island, Juzor al Hallaniyat (islands), and Al Ashkharah (Johnson 1990, Al Bahrani 1995) (Fig. 1). As a result of overfishing and a cyclone that hit in 1971, abalones are no longer found in these areas; however, it is possible that the habitat in these regions could still be suitable for abalone seeding and restocking. Based on landings catch data, it is worth noting that the Omani abalone is mainly concentrated in the more northerly areas of Hasik and Hadbin.

The species *Haliotis mariae* have been reported to spawn at different seasons, that is, October–November and January–March (Shepherd et al. 1995), November–January (Siddeek & Johnson 1993) and December–January (Al-Hafidh 2006). From this, it can be concluded that natural spawning is related to the post-monsoon season as seaweeds are present during this time, with an increase in temperature being another favorable factor. According to Al-Hafidh (2006), the abalone move toward shallower water from September to February for breeding and feeding (Al-Hafidh 2006). These spawning seasons are based on the sampling areas; that is, the data cannot be generalized to the whole coast covering all the abalone fisheries in Dhofar. Furthermore, the sizes at first maturation were reported to be different from one area to another. Abalone attained sexual maturity at approximately 60–65 mm shell length at Hat and 75–100 mm in Hadbin (Shepherd et al. 1993). These latter authors further suggested that the size at which abalone attained maturity at Hadbin could be 55 mm. In terms of years, the Omani abalone was reported to first mature at the age of 1 y (Stirn & Al-Hashmi 1994) and 2 y (Sanders 1982).

Abalone Management Rules and Regulations

The objective of abalone management is sustainability, that is, to restore and maintain commercial abalone populations and eventually to increase landings. During the open seasons, control has been limited to restricting the opening of the season, with little other guidance. For the last three decades, in addition to defining the diving season, the abalone management regulations from the Ministry Decrees included the following, among other measures, during the open season:

- (1) Banning of fishing, collecting, and trading abalone with a shell of less than 90 mm and also prohibiting the fishing and collection of abalone from a water depth of less than 8 m.
- (2) Use of SCUBA while diving for abalone is prohibited.
- (3) Collection of abalone is allowed only from sunset to sunrise.

- (4) Use of artificial lights of all kinds for locating abalone is prohibited.
- (5) Abalone extraction tools/screwdrivers must not be longer than 50 cm.
- (6) Flipping of rocks while removing abalone from its habitat is prohibited.
- (7) Fishers are not allowed to separate the meat from the shell before registering the catch at the landing site.
- (8) Prohibition of processing and handling of abalone during the off season. This includes transportation, purchase, sale, and export.
- (9) All abalone dealers must be registered.
- (10) Dealers are prohibited from buying abalone from unlicensed fishers. A special permit is required for purchasing after the end of the season.

The management of abalone is mainly based only on seasonal closures ranging from 6 mo to a full closure of 1–3 y.

Abalone Historical Landings

For 31 y (1988–2019), abalone landings contributed an average of only 1% of the total crustacean and molluscan sales in Oman, whereas the average value of abalone contributed 12% for the same period (Fig. 2). Also, the total abalone landings (during the season) ranged from 29 mt (64.4 mt whole weight) in 1999–149 mt (331 mt entire weight) in 2011 (fresh flesh) after a 3-y suspension of fishing, with the duration of fishing seasons ranging from 10 days to 6 mo (Fig. 3). All abalone fishing were

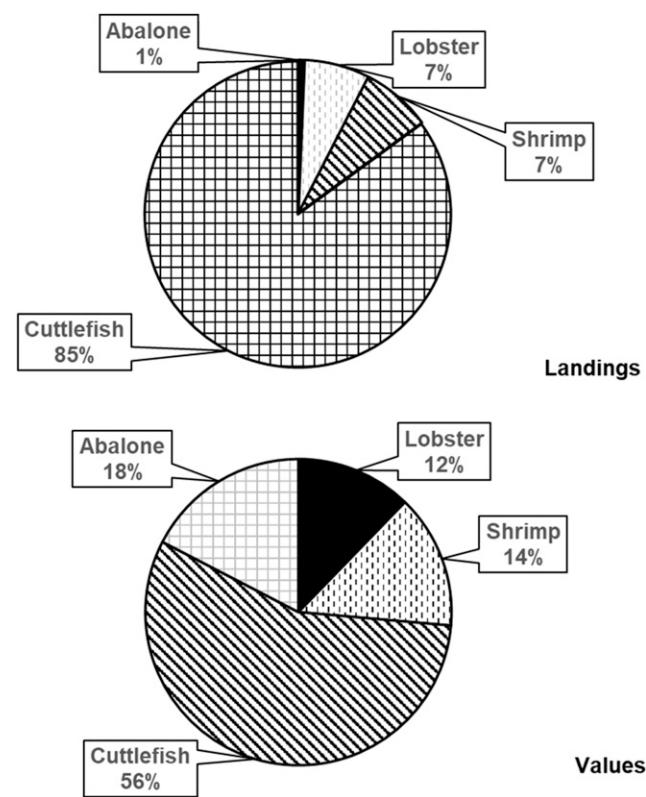


Figure 2. Percentage of average landings and values contributed by the Omani abalone with respect to the total Omani crustacean and mollusc landings (1988–2018).

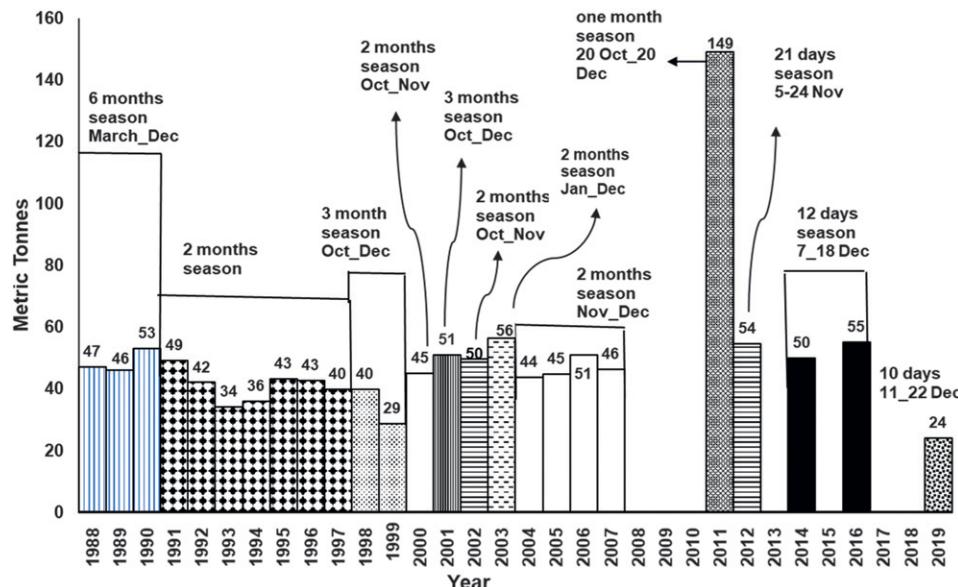


Figure 3. The Omani abalone *Haliotis mariae* (Wood, 1828), flesh landings (*t*) with information on the duration of the fishing season. In 2013, the fishing season was opened for 10 days, that is, December 22–31, but the fishermen willingly chose not to activate the season.

banned for four complete seasons, 2008–2010, 2015, and 2017–2018. In 2013, the government opened the season for only 10 days (December 22–31). At that time, however, the fishermen themselves undertook no fishing activities in an effort to save abalone stocks and give them time to recover (Fig. 2).

Likewise, the average abalone landings for the last 31 y were 49 mt of flesh weight (109 mt whole weight), whereas the average landing for the previous 10 y, excluding 2011, was 47 t of flesh weight (104 mt overall weight). The fishing season was reduced from 6 mo in 1988–1990 to 2 mo in 1991–1997. This reduction helped to limit abalone landings, with the average landing during this period being 41 mt (91 mt whole weight). Despite the low average landing, the season was extended for 3 mo during 1998–1999. Regardless of the basis for shifting, the fishing season from 3 to 2 mo, or *vice versa*, the fishing season was changed six times (from 2 to 3 mo or *vice versa*) during the period 1991–2007. These changes successfully maintained the average abalone landings at around 44 mt (whole weight of 98 mt). The government then decided to take an extreme measure and banned fishing for 3 y, from 2008 to 2010. In 2011, fishing was carefully resumed for 1 mo only, and the landings were 149 t (whole weight of 331 mt), the highest ever since the 1980 figures of 200 mt (full weight of 444 mt) (Shepherd et al. 1995). In 2012, the season was opened for 21 days, and the landings dropped to 54 mt (full weight of 120 mt). The season was then decreased to 10 days in 2013. At this point, the fishermen refused to go fishing and preferred a total closure. Then, the season was reopened in 2014 and 2016 for 12 days with another closure in 2015. Finally, the government decided to suspend fishing completely for the years 2017 and 2018.

In 2019, the landings were reported to be the lowest for last three decades, at 24 mt (whole weight of 53 mt) within 10 days of opening. In addition, landings from the two major fishing villages, Sadah and Hadbin, showed a very sharp decrease, and this strongly indicated that there had been excessive fishing between 2003 and 2019. The landings in Sadah decreased from

33 mt (whole weight) in 2003 to 15 mt (whole weight) in 2014, falling to only 6 t (whole weight) in 2019. At the same time, the landings in Hadbin decreased from 57 mt (whole weight) in 2003 to 23 mt (whole weight) in 2014, and only 12 mt (whole weight) in 2019 (Fig. 4). Annual surveys indicated a decrease in the density of the abalone/m², and the results from the 2020 survey indicated a decrease in the density of abalone in Sadeh by 31% to only 0.19 abalone/m². The density also decreased in Mirbat, Hadbin, and Hasik by 38% (0.06/m²), 58% (0.1), and 38% (0.04/m²), respectively (MAF 2020a). Overall, the abalone densities decreased from 0.39 in 2011 to 0.1 in 2020 (Fig. 5). At the same time, the abalone aggregations decreased from 0.05 in 2011 to 0.01 in 2020, and those figures are considerably lower than 0.15–0.2, which are the values needed for successful reproduction (Riffell et al. 2004) (Fig. 5).

From 1992 to 2019, the diving seasons were limited and occurred from October to January. Based on the literature review, the spawning season for the Omani abalone was also reported to occur within these periods (Shepherd et al. 1992, Siddeek & Johnson 1993, Al-Hafidh 2006).

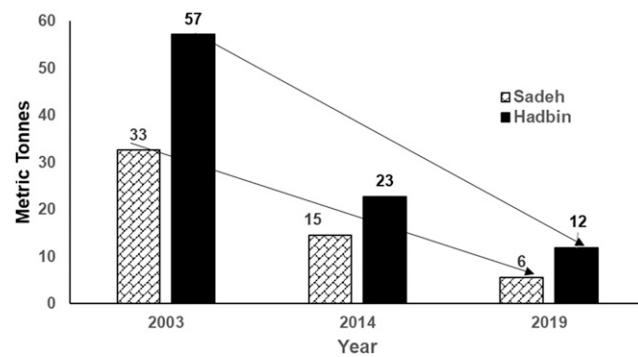


Figure 4. Abalone landings from two major fishing villages for 3 y indicating a sharp decrease.

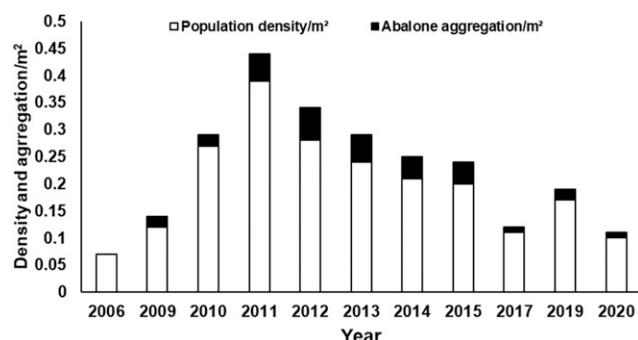


Figure 5. (A) Overall abalone density/m² and (B) aggregation/m² in Omani fishing areas during the period 2006–2020. Reproduced from an abalone survey report by the Ministry of Agriculture and Fisheries (2020).

Behavior of Fishermen

As the season commences, abalone dealers set up camps along the coastline, particularly in front of abalone-rich fishing areas. These dealers move their tents to the various areas during the fishing seasons, with the numbers of camps depending on the catch. These camps are usually set up on the beach, and they become landing sites for divers and a market for their products. The location of the camps is changed from one area to another, depending on the availability of the abalone. During the open season, as there is no defined TAC or individual transferable quotas, in addition to the continuous market demand and its high values, the fishermen tend to rush for abalone fishing. The landings gradually decrease toward the end of the season, as do the number of fishers and divers.

Based on the data available for the seasons 1988–2003, the average number of divers decreased to 47% by the end of the season. They were thus compared with divers at the beginning of the season from 9% in 1999 to 90% in 1991, respectively. Contrary to the existing trend, landings increased by 1,074 kg in 1991, with a decrease in the number of fishermen (84 divers) (Table 1).

During the 1-mo season in 2011, the daily number of active divers ranged from 14 to 2,726, with an average of 941. Thus, the daily catches ranged from 43 to 36,586 kg, with an average of 4,805.5 kg. The number of divers, however, decreased by two, by the last day of the season, which is only 19% of the total number of divers compared with the first day (Table 2).

In 2012, the season lasted for 21 days, and the number of divers/day ranged from 698 to 2,357, with an average of 1,659. So, the catch per day ranged from 1,141 kg to 9,783 kg, with an average of 2,723 kg (Table 2). The number of divers decreased by 1,659 by the last day of the season, this being only 30% of the total number of divers who were present on the first day. In 2014, the season was opened only for 12 days, and the number of divers ranged from 334 to 1,299, with an average of 712 divers daily. Nevertheless, the number of divers decreased by 965 by the last day of the season, and, that is, only 26% of the total number of divers were present on the first day. The catch per day ranged from 1,344 kg to 16,450 kg, with an average of 4,126 kg (Table 2).

The latest data from the 10-day season in 2019 show that the number of divers ranged from 354 to 1,489, with an average of 853. The number of divers decreased by 1,135 by the last day of the season, leaving only 24% of the total number of divers who were present on the first day. The daily catches ranged from 503 kg to 7,563 kg, with an average of 2,440 kg (MAF 2019).

TABLE 1.
Number of divers and associated abalone catch (in kg) per season from 1988 to 2003.

Season 1988			Season 1989			Season 1990		
Month	Divers	Catch (kg)	Month	Divers	Catch (kg)	Month	Divers	Catch (kg)
October	236	99,330	October	376	10,536	October	325	14,889
November	246	11,338	November	321	9,164	November	299	12,354
December	281	8,976	December	345	6,218	December	284	9,551
January	329	7,234	January	240	7,271	January	488	4,254
February	266	10,087	February	220	4,805	February	208	2,919
March	109 (46%)	3,000 (3%)	March	186 (49%)	3,870 (36%)	March	57 (18%)	266 (2%)
Season 1991			Season 1992			Season 1993		
November	882	20,990	November	1,000	28,676	November	991	26,896
December	798 (90%)	22,064 (105%)	December	692 (69%)	12,968 (45%)	December	459 (46%)	7,158 (26%)
Season 1994			Season 1995			Season 1996		
November	1,014	25,109	November	1,267	32,625	November	991	32,638
December	705 (69%)	11,029 (44%)	December	710 (36%)	9,880 (23%)	December	590 (37%)	10,040 (24%)
Season 1997			Season 1998			Season 1999		
November	1,069	29,721	October	1,050	18,849	October	876	20,566
December	626 (58%)	10,018 (34%)	November	761	11,192	November	569	7,731
—	—	—	December	377 (36%)	1,654 (9%)	December	80 (9%)	385 (2%)
Season 2000			Season 2001			Season 2002		
October	1,439	31,461	October	1,376	40,175	October	1,624	47,103
November	899 (62%)	13,019 (41%)	November	936 (68%)	10,675 (27%)	November	424 (26%)	2,400 (5%)
Season 2003			—	—	—	—	—	—
January	1,467	52,546	—	—	—	—	—	—
December	436 (30%)	3,833 (7%)	—	—	—	—	—	—

Figures in brackets show the percentage of divers and catch at the end and beginning of the season. In 1999, the catch increased by 1,074 kg.

TABLE 2.
Number of divers and abalone catch (in kg) for the seasons 2011–2014.

Season 2011			Season 2012			Season 2014		
October 20–November 20 (1 mo)			November 5–24 (21 days)			December 7–18 (12 days)		
Date	Catch (kg)	No. of divers	Date	Catch (kg)	No. of divers	Date	Catch (kg)	No. of divers
October 20	36,586	2,726	November 5	9,783	2,357	December 7	16,449	1,299
October 21	21,195	2,542	November 6	5,600	1,675	December 8	5,258	828
October 22	16,009	2,408	November 7	4,911	1,709	December 9	3,397	714
October 23	11,700	2,120	November 8	3,912	1,704	December 10	3,621	733
October 24	8,606	1,942	November 9	2,591	1,336	December 11	4,481	802
October 25	7,526	1,855	November 10	3,403	1,442	December 12	3,912	769
October 26	6,048	1,680	November 11	2,689	1,252	December 13	2,749	721
October 27	4,863	1,534	November 12	2,328	1,189	December 14	2,106	573
October 28	2,785	1,212	November 13	2,298	1,271	December 15	1,768	542
October 29	3,182	1,237	November 14	2,071	1,186	December 16	2,559	670
October 30	1,973	801	November 15	1,935	1,101	December 17	1,860	554
October 31	970	285	November 16	1,372	902	December 18	1,343	334
November 1	413	124	November 17	1,171	842	—	—	—
November 2	242	59	November 18	1,140	739	—	—	—
November 3	239	43	November 19	1,306	816	—	—	—
November 4	210	55	November 20	1,221	795	—	—	—
November 6	43	14	November 21	1,370	844	—	—	—
November 7	251	55	November 22	1,425	844	—	—	—
November 8	966	216	November 23	1,227	732	—	—	—
November 9	682	171	November 24	2,704	698	—	—	—
November 10	1,356	331	—	—	—	—	—	—
November 11	2,315	594	—	—	—	—	—	—
November 12	4,261	905	—	—	—	—	—	—
November 13	4,201	1,153	—	—	—	—	—	—
November 14	2,908	1,085	—	—	—	—	—	—
November 15	2,428	1,024	—	—	—	—	—	—
November 16	1,448	723	—	—	—	—	—	—
November 17	1,688	765	—	—	—	—	—	—
November 18	730	423	—	—	—	—	—	—
November 19	1,337	551	—	—	—	—	—	—
November 20	1,814	522	—	—	—	—	—	—

The average fishing days changed from 1 mo to another within the same season and from one season to another. Owing to the rush for fishing, the average number of fishing days may become less per given season. The average fishing days per month during the period from 1988 to 2011 ranged from 9 to 17 days. In the 2012 and 2014 seasons, the average fishing days per month were 20 and 12, respectively (Table 3).

Abalone Marketing and Processing

Divers sell their catch only to licensed buyers, dealers, and processors, and dealers must preserve all their records and transactions and are obliged to give them to the MAF. The average price of abalone per kg increased from 21 OR (54.6 US\$) in 1988 to 60 OR (156 US\$) in 1997 (Table 3). During the 2011 season, after the moratorium, the price per kg ranged from 42 to 59 OR, with an average of 55 OR. In the following season, the cost per kg ranged from 42 to 47 OR, with an average of 44 OR. This variation is equal to the average price observed between 1988 and 2018. Furthermore, the price per kg increased by 1.89 OR from 1991 to 2007, before a sudden decrease after the moratorium (Fig. 5). In 2019, the price per kg dropped again

and was recorded at only 42 OR per kg. The average revenue of a diver per season during the period between 1988 and 2012 ranged from 94 OR (244.4 US\$) in 2012 to 1,314 OR (3,416.4 US\$) in 1996 and 1997 (Table 3). Historically, the revenue for each fisherman reached its lowest level after the suspension. The total abalone values from 1991 to 2019 ranged from 1,025,000 OR (2,665,000 US\$) in 2019 to 8,248,000 OR (21,444,800 US\$) in 2011, with an average of 2,476,000 OR (6,437,600 US\$). It is worth noting that during the suspension, the government provided compensation to the divers and traders, amounting to sums between 600 OR (1560 US\$) and 1200 OR (3120 US\$).

A linear regression analysis was conducted on the abalone landings and price per kg for the seasons before suspension (1988–2007). The abalone price/kg increased to 2.4 OR/y ($r^2 = 0.8$) (6.24 US\$), whereas the total values increased to 122 OR (317.2 US\$)/year ($r^2 = 0.8$) (Fig. 6). Both total values and the price per kg started to decrease sharply afterward.

The dealers detach the abalone meat from the shells, clean it very thoroughly, and boil it for more than an hour in seawater. The fresh meat typically equals 45% of the total weight (MAF 1988). The boiled abalones are then dried carefully in the sun for several days and finally packed according to size (small,

TABLE 3.

Omani abalone fishing seasons showing the average number of fishing days per month and the average number of divers per month or season.

Year	Fishing season	Divers Avg. Revenue (R.O)	Avg. Fishing days/mo	Avg. Divers/mo	Avg. Price per kg (R.O)	Avg. Season Revenue (R.O)	Avg. Catch (kg) per month
1988	March–October (6 mo)	727	17	245	21	1,77,000	23,328
1989	March–October (6 mo)	577	15	281	24	1,60,500	6,977
1990	March–October (6 mo)	672	14	277	28	2,00,167	7,372
1991	November–December (2 mo)	926	14	840	36	7,75,000	21,527
1992	November–December (2 mo)	1,185	15	846	50	1,04,10,00	20,822
1993	November–December (2 mo)	854	12	725	40	6,81,000	17,027
1994	November–December (2 mo)	847	10	860	43	7,50,000	18,069
1995	November–December (2 mo)	873	13	989	44	9,35,112	21,253
1996	November–December (2 mo)	1,124	15	791	45	9,60,267	21,339
1997	November–December (2 mo)	1,314	13	848	60	1,19,21,65	19,869
1998	October–December (3 mo)	666	9	729	55	5,67,928	10,565
1999	October–December (3 mo)	705	8	508	51	4,78,039	9,561
2000	October–November (2 mo)	918	9	1,169	50	1,12,46,37	22,240
2001	October–December (3 mo)	678	6	772	49	8,25,830	16,951
2002	October–November (2 mo)	910	9	1,024	53	1,29,85,21	24,752
2003	January–December (2 mo)	1,218	10	952	55	1,53,82,16	28,190
2004	November–December	—	—	—	—	—	—
2005	November–December	—	—	—	—	—	—
2006	November–December	—	—	—	—	—	—
2007	November–December	—	—	—	—	—	—
2008				Fishing season suspended			
2009							
2010							
2011	October 20–November 20 (a month)	215	16	940	52	2,66,063	—
2012	November 5–24 (21 days)	94	20	1,172	44	1,18,759	—
2013	December 22–31 (10 days)	—	—	—	—	—	—
2014	December 7–18 (12 days)	—	12	1,299	—	—	—
2015				Fishing season suspended			
2016	December 7–18 (12 days)	—	—	—	—	—	—
2017				Fishing season suspended			
2018							
2019	December 11–22 (10 days)	—	—	—	—	—	—

medium, and large) for export (Figs. 7 and 8). Not all abalones are shipped right away, some are exported during the off season in accordance with the price and demand in the international market.

The government has conducted several experiments reseeding some of the selected areas along the Dhofar coast. From

2013 to 2015, the abalone culture center in Mirbat was thriving. It produced 120,000 juvenile abalones, and the seeds were hand-launched in Mirbat, Sadeh, Hadbin, and Hasik (MAF 2020b). Sharbithat had been previously seeded. Experimental seeding projects gave promising results, but these juveniles were heavily targeted by the fishermen. If they are not protected, then the seeding project will fail (De Waal et al. 2013, MAF 2020b).

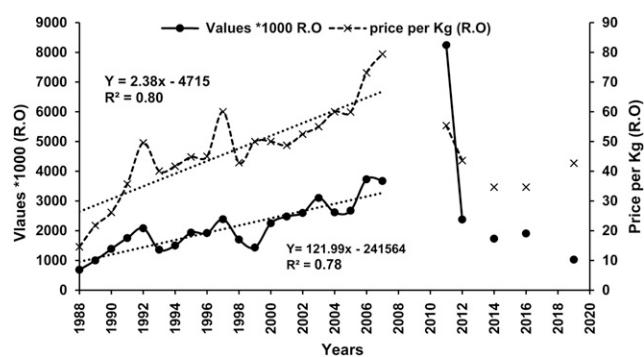


Figure 6. Abalone values (*1,000 OR) and price per kg. The linear regression was fit between 1991 and 2007.



Figure 7. Abalone of various sizes processed by the dealers. Both legal and illegal sizes are included in the catch.



Figure 8. Abalone processing steps: (A) buying, (B) cleaning, (C) boiling, (D) drying, and (E) packing.

DISCUSSION

It is an indisputable fact that abalone fishing is an essential source of income for the Omani divers and their families. Hence, it is crucial to understand all the factors related to this traditional industry for its better management and development. At present, the fishing season commences toward the end of the year, between November and January, which also appears to be the period when the abalones spawn. There is, however, no recent detailed scientific research to prove or disprove that assumption. The available information with regard to the spawning period goes back to 1993 (Shepherd et al. 1993, Siddeek & Johnson 1993, Al-Hafidh 2006).

The behavior of the fishermen is difficult to categorize as the number of abalone divers fluctuates significantly and in an unpredictable fashion. Lack of firm data on this issue, however, could be the result of the collection process. During the fishing season, the dealers set up camps near the different fishing villages, with more camps usually being established in front of the most productive fishing bays. This free movement of divers and dealers along the fishing villages could easily lead to short-term overfishing of small-sized abalone populations. The camps also provide a market for abalones caught by unlicensed women and children, who mostly catch undersized abalone from shallow waters.

Regardless of the efforts put in by the government to control abalone fishing in the last three decades, catches have decreased sharply and reached a historic low in 2019 (only 24 mt). This decrease has been exacerbated by the uncontrolled number of divers involved in the industry and the inadequate monitoring system during the fishing season. From data collected for this study, it can be confidently asserted that a considerable number of undersized abalone are still being caught and added to the total catch. Abalones of different sizes have been observed at different landing camps. Landings included several different sizes, both legal and illegal, as was observed by Shepherd et al. (1995). They indicated that 90% of the samples collected from the fishermen in Hat were less than 90 mm in size. Shepherd added that abalone as small as 50 mm were also found. Abalones of various sizes, including small ones, are observed during

all seasons. Although the government prohibits the sale or purchase of undersized abalone, enforcement of the ban is limited because dealers demand abalone of all sizes while purchasing the catch.

The abalone fishery is mainly regulated by seasonal closure, but without TAC or individual transferable quotas being established. This restriction has resulted in competition for diving among fishermen and created a rush to start diving in almost all seasons. The rush to fish was particularly intense in significant areas such as Hadbin and Hasik. The landings in these areas then decreased dramatically over the years as a result of overfishing.

Challenges and Recommendations

There are some challenges and knowledge gaps that jeopardize the appropriate review of the fishery for the restoration and management of the abalone stock in the Dhofar region.

The following are some of these gaps and challenges along with suggested solutions to overcome the obstacles. Please note that these recommendations are the opinions of the authors and may not reflect contrary opinions.

Research Needed and Data Availability:

The following information is necessary to aid in the management and development of the Omani abalone fishery.

- (1) A stock assessment must be conducted, along with dynamic population studies of the Omani abalone. This must include stock distribution along with the different fishing villages and bays.
- (2) The life cycle of the Omani abalone must be studied, including spawning, recruitment seasons, and areas of different size distribution within the abalone fishing areas.
- (3) Continuous collection of socioeconomic data on fishermen is required. This should include their household and family data throughout the year.
- (4) Studies must be conducted referencing the diver behavior and the bases on which they choose their diving grounds. There are two aspects to be investigated: (1) How do divers

- distribute their catch among themselves? (2) What is the age distribution of the divers within each fishing village?
- (5) Oceanography, habitat, and topography of the fishing grounds should be studied. This information should be associated with the abalone spawning, recruitment, and larval distribution.
- (6) The government should establish a sound data collection system to follow up on the total abalone catches, the actual number of divers, and fishing days involved in the industry.

Management Technique

For the last three decades, only seasonal closures and size limitation techniques have been applied. These measures are difficult to implement and monitor when the fishing areas are distributed on a long coast. Abalone fishermen move in groups from one fishing area to another, and they conduct their activities in very remote areas. This behavior is difficult to monitor and control. Therefore, abalone fishing areas must be identified in zones according to the results of official research. After that, the fishing zones should be opened or closed according to the spawning and recruitment season, size distribution, and stock size. In this way, the government will be able to open or close the season in some of the fishing areas (zonation) at certain periods to provide more time for spawning and restocking.

At the same time, fishing in other areas could be opened. This zonation or “pulse fishing” is a common management technique for abalones around the world. It helps in the preservation of stock and habitat, and helps in monitoring and compliance. Zonation means separating the fishing areas into zones and alternating the fishing seasons among these zones. Also, the government should issue guidelines on how to estimate the TAC and the associated performance indicators. Moreover, a licensing system (limited entry) should be used to limit access to the fishing grounds.

Compliance and Monitoring

Abalone divers and families need to be educated on the importance of the abalone industry and its management for the sake of long-term sustainability. The extension of fisheries extension and collaboration with the divers are both crucial at this stage. Without these things, the administration will be costly and unproductive. For monitoring, abalone landing sites and timings during diving seasons must be identified. At the landing site, there should be a trained data collector to tally the total weight, the abalone sizes, and other biological parameters after the catch is sold to the dealers.

Abalone Handling and Marketing

The total abalone catch is very small (on an average 45 mt), and it could easily be handled by a company which is specialized in abalone processing. The company should be allowed to buy all the catches from the fishermen (within an acceptable price range), process the abalone, add value, and use abalone shells for building art and craft products, which contributes to valuable side business. In 2008, the Mexican abalone fishery gained USD 1 million from abalone art and craft (Ricardo Searcy-Bernal et al. 2010). An Abalone divers association or cooperative should also be created, and the company should be registered under it.

Aquaculture and Stock Enhancement

Release of hatchery-reared juveniles into natural habitats has been considered to be a possible measure to restore collapsed abalone stocks (Hamasaki & Kitada 2008). Abalone culture in Oman started in 1994 at Mirbat in the Dhofar region. The objective of the cultural center is to produce hatchery-reared seeds for wild stock enhancement (Al Rashdi 2008). The culture process includes the production and release of juveniles (30 mm) to shallow rocky bays and shores. Hundreds of seed were released in different abalone fishing areas between 2010 and 2017 (Al Amri 2018); however, regardless of the number of seeds that were released, the juveniles are likely to be caught as soon as they are released into the fishery unless they are protected. It is therefore suggested that the shores and bays where the seed are released should be defined as “temporary protected areas,” and diving for abalone should be banned there for 3–5 y, depending on the growth rates. The abalone from these bays could then be sold to the abalone diver cooperative, which, as suggested earlier, should be established. Across the world, wild abalone fisheries have been replaced mainly by aquaculture, and today, more than 95% of abalone come from farms (Cook 2014). Commercial aquaculture in Oman has now been initiated to support the collapsed national production and to reduce the pressure on wild populations.

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