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Research Article

Three-Year Closure of Fishing Seasons as a Management Tool for the Omani Abalone, *Haliotis mariae*, Fishery in the Sultanate of Oman

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Data from underwater surveys conducted between 2009 and 2021 were analyzed to determine the effect of closed fishing seasons on the density and size composition of Omani abalone, in the main fishing areas (Mirbat, Sadah, Hadbin, and Hasik). The average density of abalones, the abundance of mature and legal size abalone, and the average abalone size increased significantly after a 3-year closure (2008-2010). From 2012 to 2021, abalone density and size decreased despite four 1-2 years of closed fishing seasons. The density of mature abalone after 2011 was below the minimum spawning density of Haliotidae. Abalone densities were found to be relatively high in Sadah and Hadbin but very low in Mirbat and critical conditions in Hasik. Lack in regulations' enforcement, overlap between fishing and reproduction season, and the uncontrolled number of divers are probably the main reasons for the decline in abalone abundance and size. Future fishing closure must be extended for at least three years, and abalone harvest in Mirbat and Hasik should be banned for at least five years. The number of divers must be regulated, and changing the fishing season must be evaluated. It is necessary to identify if the population is sustainable, threatened, or recovering, by studying more biological aspects of the Omani abalone, including minimum spawning density, abalone aggregation, and recruitment levels at each fishing ground. These studies will help the authorities to decide when fishing must stop to avoid any further reduction in the abalone densities. It is important to understand the socioeconomic status of abalone diver's communities in Oman for better management and development.

1. Introduction

Abalone *Haliotis mariae* W. Wood, 1828, 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 [1]. The distribution of this species extends to the Al-Wusta region in Soqra and Lakbi but at very low densities [2].

Local skin divers in Oman collect abalone from shallow waters (up to 15 meters) along the subtidal rocky coasts. The mollusk is harvested mainly in four areas at Mirbat, Sadah, Hadbin, and Hasik in Dhofar Governorate, a coastline stretched for approximately 100 km [2, 3]. Previously, more abalone fishing areas, such as Sharbithat, Soqra, and Lakbi in the northeast of Dhofar, were used to harvest this species, but due to heavy fishing pressure, these fisheries had collapsed, with no signs of fishing activities any longer [3, 4].

Maintaining sustainable stocks has been a challenge for many abalone fisheries around the world. Many abalone stocks in different parts of the world have been overexploited [5]. The abalone fishery in Oman is managed by several regulations, including restricted fishing areas, minimum legal fishing size of 90 mm shell length, fishing gear restriction,

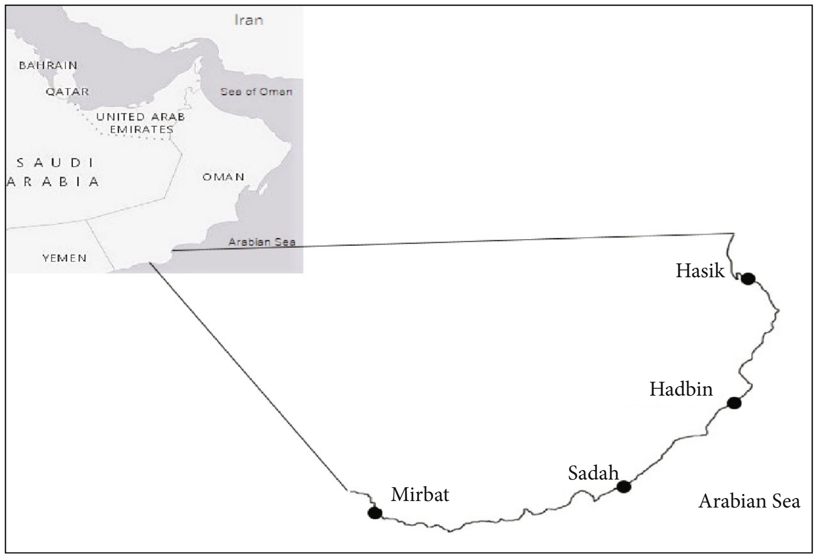

Figure 1: Location of study areas on the Dhofar coast in southern of Oman.

and closed fishing seasons. The closure of the abalone fishing season in Oman was introduced in 1987 for six months (April to September) from 1987 to 1990 by the Ministry of Agriculture and Fisheries (now the Ministry of Agriculture, Fisheries, and Water Resources (MAFWR)), followed by a two- to three-month fishing season (October, November, and December) from 1991 to 2007 [1, 6]. Since 2008, four complete closed abalone fishing seasons, 2008-2010, 2015, 2017-2018, and 2020-2021, have been used to regulate the abalone fishery in Oman, and the duration of the open fishing season (in 2011 to 2013, 2014, 2016, and 2019) was shortened to approximately 10-21 days per season [7]. It is important to mention that the divers ceased fishing for abalone in the open season of 2013 to allow recovery of the stock [6].

Abalone landings (foot wet weight) have been available since 1988. During the first 20 years (1988-2007), the abalone landings varied between 29 and 56 tons, with an average landing of 43 tons [6]. In the open fishing season in 2011, the abalone landings recorded the highest production of 149 tons (approximately 21.5 million US$), following a closure of fishing for three consecutive years from 2008 to 2010 [8]. However, during the period from 2012 to 2019, the average landing of abalone was approximately 46 tons, and a very low production of 24 tons was recorded in 2019 [7].

The abalone stock density in Oman was first estimated in 1982 by Sanders [9] to be 0.205 abalone.m^{-2} during a preliminary field study of the abalone resources on the southeast coast of the country [1]. In 2005, Al-Hafidh [1] conducted a comprehensive survey to assess the status of the natural stock of *H. mariae*, including estimating abundance and size structure. The results of the 2005 survey revealed a very low abalone density of 0.07 abalone.m^{-2} and considered the stock to be in severe decline. Since 2009, the abalone stock in Oman has been monitored annually by specialists from the Dhofar Fisheries Research Center, assessing the density and size structure in the main fishing areas between Mirbat and Hasik [10]. The present paper is aimed at evaluating the effect of closing the fishing seasons in the last decade as a management tool to regulate the abalone fishery in Oman. We analyzed temporal and spatial variation in the average abalone density, the density of immature and mature abalone, the density of legal size abalone, and size structure of abalone in the fishing areas during the past 12 years.

2. Materials and Methods

2.1. Study Area. Underwater surveys were conducted along the southern coast of Oman in the main abalone fishing areas of Mirbat, Sadah, Hadbin, and Hasik every year from March to May during 2009-2021 (Figure 1). Data from 2016 and 2018 were not available since the survey was not conducted at that time. It should be emphasized that the abalone open fishing season has always occurred later, from October to December.

2.2. Survey Method. During the surveys, 6-8 experienced scuba divers collected data using transect and quadrat methods. In 2009-2012, following Al-Hafidh [1], 6 sites were surveyed in each of the 4 areas using a 160 m transect (320 m^2) and a 10×10 m quadrat used as a secondary sampling unit placed at the end of each transect, at least 1 m away, to avoid the sampling area overlapping. Data from transects and quadrats from surveys in 2009-2012 were pooled [1]. From 2013 to 2021, 8 sites in each area were surveyed using 100 m transects (200 m^2). The total number of transects and squares studied during a survey ranged from 32 to 48. The line transects that run perpendicular to the shore were placed at preselected sites that are considered prime fishing areas. Two divers searched for abalones within 1 m on each side of the transect. Emergent abalones were measured in shell length (SL, mm), while abalone that were impossible to remove from the shelter were only counted. All collected abalone were then placed back to their original position. The average, the immature, the mature, and the legal size abalone densities were calculated as the total number of abalone individuals (ind.) divided by the total surveyed area (ind.m^{-2}).

Table 1: Average density (ind.m^{-2}) of *H. mariae* in the studied areas during underwater surveys from 2009 to 2021.

Area	Year										
	2009	2010	2011	2012	2013	2014	2015	2017	2019	2020	2021
Mirbat	0.12 (0.04)	0.35 (0.12)	0.45 (0.20)	0.17 (0.05)	0.17 (0.05)	0.19 (0.05)	0.25 (0.05)	0.11 (0.02)	0.10 (0.02)	0.06 (0.01)	0.12 (0.03)
Sadah	0.16 (0.06)	0.42 (0.16)	0.65 (0.13)	0.50 (0.13)	0.30 (0.03)	0.36 (0.04)	0.34 (0.05)	0.16 (0.03)	0.27 (0.07)	0.19 (0.04)	0.28 (0.06)
Hadbin	0.22 (0.07)	0.41 (0.11)	0.55 (0.13)	0.47 (0.10)	0.21 (0.04)	0.22 (0.05)	0.18 (0.04)	0.13 (0.04)	0.24 (0.04)	0.10 (0.02)	0.21 (0.04)
Hasik	0.05 (0.02)	0.12 (0.04)	0.31 (0.10)	0.18 (0.08)	0.04 (0.01)	0.09 (0.02)	0.04 (0.01)	0.03 (0.01)	0.07 (0.02)	0.04 (0.01)	0.05 (0.01)
Average	0.14 (0.02)	0.33 (0.05)	0.49 (0.07)	0.33 (0.04)	0.18 (0.02)	0.21 (0.02)	0.20 (0.02)	0.10 (0.01)	0.17 (0.02)	0.10 (0.01)	0.17 (0.02)

*Above line is the average value; the standard error in brackets.

2.3. Statistical Analysis. Analysis of variance was used to determine whether the density of Omani abalone changed significantly between years (time) and between areas (location). The data was log-transformed (log (density + 1)), following Rogers-Bennett et al. [11], to meet assumptions of normality before being analyzed by a two-factor ANOVA (year: fixed factor; area: random factor). The size at first maturity of *H. mariae* was accepted as 60 mm, following Al-Hafidh [1], and individuals above that were considered mature. The density of immature abalone (<60 mm) and mature abalone (≥60 mm) was estimated and compared over time. The minimum legal fishing size for *H. mariae* is 90 mm. The density of the legal fishing size (≥90 mm) was determined and compared over time (years). The average size of abalone for each year was compared using the analysis of variance (one-way ANOVA) after data was log-transformed. The size distribution of each survey was grouped into 5 mm size classes and compared using the Kruskal–Wallis tests. The data was analyzed using the Microsoft Excel StatistiXL V.2 analysis tool.

3. Results

3.1. Abalone Density. The average density of *H. mariae* in the studied areas from 2009 to 2021 is presented in Table 1. A high abalone density was observed in all areas in 2010–2012, with the highest value of (mean ± SE) 0.65 ± 0.13 ind.m^{-2} in Sadah in 2011. The average density for all areas during 2009-2021 was calculated at 0.22 ± 0.03 ind.m^{-2}. The post hoc ANOVA test showed a significant difference in the average abalone density between years and between study areas (Table 2). However, the temporal trends were approximately the same in all areas ($P = 0.966$).

Generally, a high overall abalone average density was recorded in Sadah (0.33 ± 0.07 ind.m^{-2}) and Hadbin (0.27 ± 0.06 ind.m^{-2}), where there were no significant differences ($P = 0.093$) in density over the years, but both areas were significantly higher ($P < 0.05$) in this parameter than in Mirbat (0.19 ± 0.06 ind.m^{-2}) and Hasik (0.09 ± 0.03 ind.m^{-2}), with the latter being significantly the lowest ($P < 0.001$) in density among all areas throughout time. It is worth mentioning that the Mirbat and Hasik areas are at the edges of the abalone fishing zone in Oman, whereas the Sadah and Hadbin areas are in the middle of this zone.

Table 2: Results of ANOVA test differences in the abalone density during the study period (year: fixed factor) and in different locations (area: random factor).

Source	df	F	P	Post hoc test
Year	10	9.330	<0.001*	2010 > 2009, 2017, 2020 2011 > all years 2012 > 2009, 2017, 2020
Area	3	22.973	<0.001*	Mirbat > Hasik Sadah > Mirbat, Hasik Hadbin > Mirbat, Hasik
Year * area	30	0.576	0.966	—

* indicates significance at the 95% confidence limit.

The average density in 2011 was estimated at 0.49 ± 0.07 ind.m^{-2} and was significantly higher than that in all other years, whereas the densities in 2010 and 2012 were equal to 0.33 ind.m^{-2} and significantly higher than those in 2009, 2017, and 2021. The analysis did not show significant differences between the abalone densities from 2013 to 2021.

The average abalone density increased by 71%, from 0.14 ± 0.18 ind.m^{-2} in 2009 to 0.49 ± 0.07 ind.m^{-2} in 2011 after a 3-year closed fishing season. In the past ten years, during which two closed seasons in 2013 and 2015 and four closed seasons in the periods 2017-2018 and 2020-2021 took place, the density of abalone gradually decreased significantly to 65% by 2021 compared to that in 2011. The density during the investigated period reached the lowest value in 2017 and 2020 after the open fishing seasons in 2016 and 2019.

3.2. Density of Immature and Mature Abalone. The density of immature (<60 mm SL) and mature (≥60 mm SL) abalone in each study area is presented in Figure 2. The maximum densities of immature abalone were found in all areas in 2012 (Figure 2(a). The maximum densities of mature individuals were observed in all areas in 2011 (Figure 2(b)).

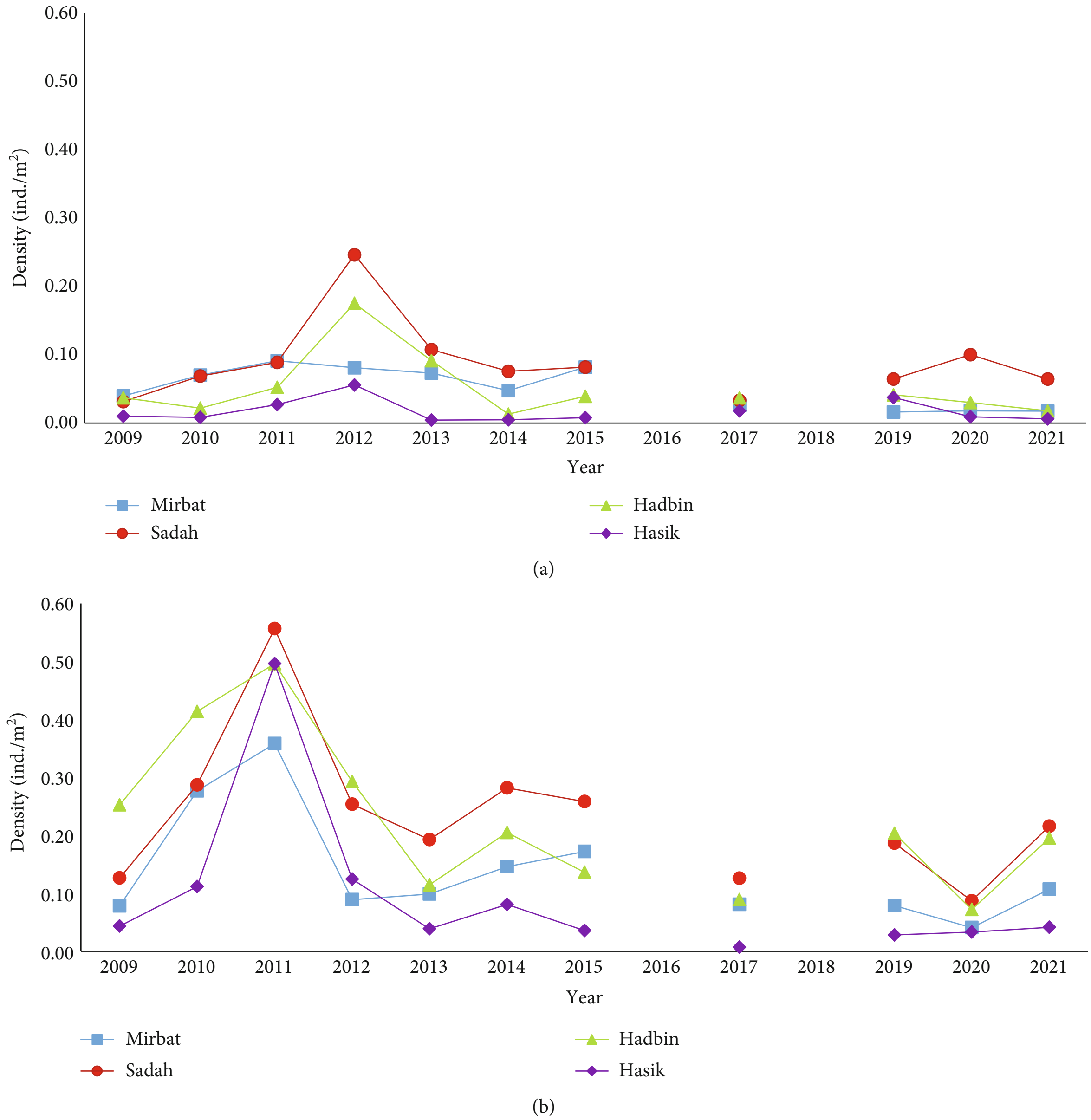

Figure 2: Density of immature (a) and mature (b) *H. mariae* in the studied areas from 2009 to 2021.

Sadah was significantly higher ($P < 0.001$) in mature and immature abalone density than in other areas. A relatively high density of mature abalone was registered in Sadah and Hadbin in 2014, 2019, and 2021. Overall, the mature abalone density in Sadah and Hadbin was not significantly different ($P = 0.868$) but was significantly higher ($P < 0.001$) than that in Mirbat and Hasik, which did not differ significantly from each other ($P = 0.730$). Very low densities of mature abalone were observed in all areas in 2017 and 2020. In general, a trend of decreasing immature and mature abalone density was observed in the past decade from 2012 to 2021. Changes in the density of immature and mature abalone in each study area differed significantly over time ($P < 0.001$) (Table 3).

The relative density of mature abalone (in % to all) averaged over each area was very close, ranging from 71.4% in Mirbat to 79.2% in Hadbin. Therefore, the number of immature abalone (<60 mm) in a population is typically 20-30%. The relative density of mature individuals varied greatly by year and area, reaching over 90% in Hadbin and Hasik in 2010-2011 and decreasing to less than 50% in Hasik in 2017, 2019, and Mirbat in 2020.

3.3. Density of Legal Size Abalone. Temporal changes in density were analyzed separately for legal size (≥90 mm SL) abalone. The density showed significant differences during the study period ($P < 0.001$) (Table 4). The highest density was observed in 2011, reaching 0.19 ± 0.03 ind.m^{-2} (Figure 3). The density of the large abalone decreased significantly after 2011 and fluctuated in the following years at low values of 0.01-0.05 ind.m^{-2}.

In general, the density of legal abalone averaged 0.05 ind.m^{-2}, which is 25% of the total abundance. A large

Table 3: Results of ANOVA test differences in immature and mature abalone density throughout the study period (year: fixed factor) and at different locations (area: random factor).

Source	df	F	P	Post hoc test
Immature density				
Year	10	8.402	<0.001*	2012 > all years
Area	3	17.481	<0.001*	Mirbat > Hasik Sadah > Mirbat, Hadbin, Hasik Hadbin > Hasik
Year * area	30	1.552	0.035*	
Mature density				
Year	10	13.687	<0.001*	2010 > 2013 2011 > all years
Area	3	11.863	<0.001*	Sadah > Mirbat, Hasik Hadbin > Mirbat, Hasik
Year * area	30	1.174	0.246	

* indicates significance at 95% confidence limits.

Table 4: Results of the ANOVA test differences in legal size abalone density during the study period (year: fixed factor) and at different locations (area: random factor).

Source	df	F	P	Post hoc tests
Year	10	13.238	<0.001*	2011 > all years
Area	3	8.356	<0.001*	Sadah > Mirbat, Hadbin, Hasik Hadbin > Hasik
Year * area	30	1.021	0.439	

* indicates significance at 95% confidence limits.

portion of the large abalone (approximately 39-42%) was recorded from 2009 to 2011. The smallest percentage (only 7%) of legal abalone in our observations was in 2013 and 2020.

3.4. Abalone Size. The shell length of *H. mariae* in different areas during the study varied between 10 mm and 140 mm. The abalone size averaged for all areas and years was 71.6 ± 1.17 mm. Overall, larger animals were recorded in Hadbin (mean 75.6 ± 0.89 mm, $n = 5534$) and Hasik (71.4 ± 1.86 mm, $n = 1707$). Noticeably, smaller abalone occurred in Sadah (70.0 ± 0.82 mm, $n = 6944$) and Mirbat (69.3 ± 1.11 mm, $n = 3997$).

Data on the average size of the abalone in the studied areas and years are shown in Table 5. Changes in the abalone size had similar temporal trends in all areas. The abalone size was significantly higher ($P < 0.05$) in 2010 and 2011 than in other years, reaching more than 80 mm in Sadah, Hadbin, and Hasik. After an intensive fishing season in 2011, the abalone size decreased significantly ($P < 0.001$) in 2012 and 2013 to approximately 60 mm in Mirbat, Sadah, and Hadbin. In 2014, after the closure of fishing in 2013, the abalone size increased in all areas, especially in Hadbin and Hasik, exceeding 80 mm. However, in the following years, the size of the abalone generally decreased but slightly increased in 2021, exceeding 80 mm in Hadbin and Hasik. In general, there has been a downward trend in the size of the Omani abalone population in the past ten years (Figure 4).

3.5. Relation of Abalone Density and Size with Fishing Season. Because the trends in the variability of the density and size of the Omani abalone in different areas were similar, the data for different areas were averaged, and their dependence on the fishery was considered (Figure 5). The maximum average abalone density and size were registered in 2011 after a 3-year closed fishing season (2008-2010). The most noticeable drop in both parameters occurred in 2012 after a very intensive fishing in 2011 (149 tons). The abundance and size of abalone continued to decrease in 2013, recording the largest decrease occurred in the number of legal size abalone (≥90 mm) and mean size (60.5 mm) during the study (see Figure 5). This is why divers themselves stopped fishing in 2013 [6]. The next year, 2014, our survey showed that the density and size of the abalone had recovered to approximately the average level; the fishing season was opened, and the catch was high, amounting to 50 tons. After this fishery, the size and density of abalone decreased slightly in 2015; however, the MAFWR decided not to open the fishery this year. In 2016, the fishery was opened, and 55 tons of abalone was collected. Such a high catch led to overfishing because according to the data from our survey of 2017, the average size of abalone has decreased, and its density has halved compared to 2015, so the fishing season was again closed. The abalone fishery was also closed in 2018. Despite two years of closure of the abalone fishery, the population has not recovered, as our 2019 survey revealed that the average size and density were well below average levels. However, the MAFWR opened the fishing season in 2019, but the catch was only 24 tons. The density and size of abalone in 2020 turned out to be among the lowest and only increased slightly in the next 2021, not reaching average levels, although the fishery was closed in these years.

4. Discussion

Analysis of the results in this study demonstrates how abalone is vulnerable to fishing pressure. Over the past decade, despite two 1-year closure seasons (2013 and 2015) and two 2-year closure seasons (2017-2018 and 2020-2021), the abalone density and size have gradually declined in all fishing areas. During the first closure of the abalone fishing season in Oman (2008-2010), a substantial increase in the abalone density and size was observed. The stock recovered and even significantly exceeded the calculated average density, as well as any historical abalone density recorded for the fishery. Therefore, it can be assumed that the fishery management goal was successfully achieved after the first 3-year closed fishing season. However, fishing during the open seasons from 2011 to 2016, when harvesting more than 50 tons, resulted in significant overfishing and a decline in the abalone stock. Over the next five years, the abundance and size of abalone were at very low levels, and the fishing season was opened only once in 2019, but the abalone

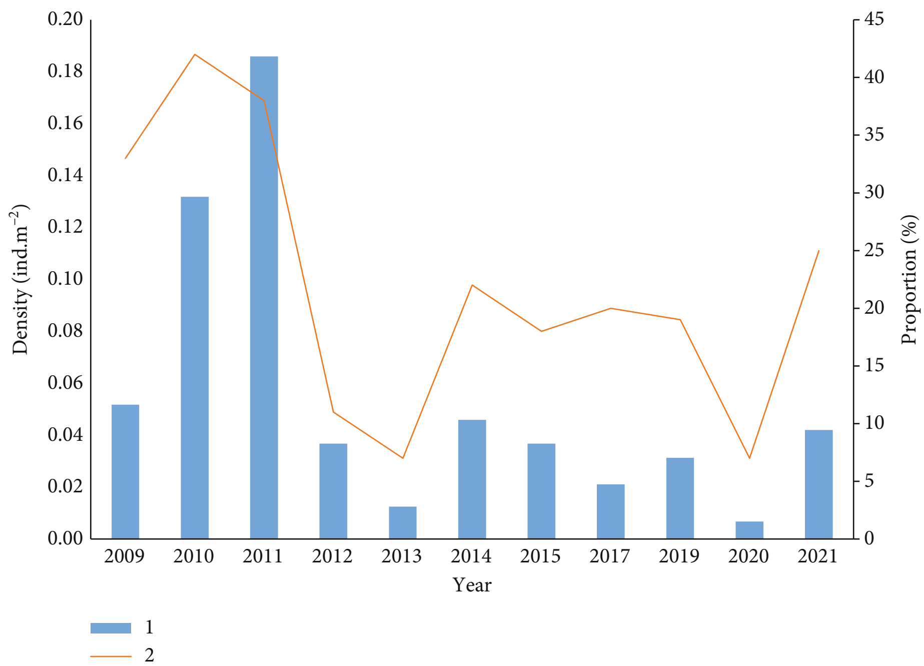

Figure 3: Density (1) and proportion (2) of legal size (≥90 mm SL) abalone during the study.

Table 5: Sample number and average shell length (mm) with standard error of *H. mariae* in the studied areas from 2009 to 2021.

Area	Year										
	2009	2010	2011	2012	2013	2014	2015	2017	2019	2020	2021
Mirbat	217 72.9 (1.55)	611 76.2 (0.82)	695 74.2 (0.84)	364 61.1 (1.03)	656 59.5 (0.67)	337 69.5 (1.08)	406 67.8 (0.96)	171 67.3 (1.55)	152 71.1 (1.22)	189 67.8 (1.26)	199 75.2 (1.24)
Sadah	286 77.0 (1.02)	662 78.4 (0.84)	1136 81.2 (0.60)	916 60.3 (0.70)	1339 60.0 (0.41)	659 73.0 (0.70)	544 70.2 (0.77)	254 71.7 (1.14)	401 69.0 (0.98)	299 59.5 (0.97)	448 70.3 (0.86)
Hadbin	463 80.6 (0.77)	718 89.5 (0.61)	920 87.2 (0.64)	934 65.6 (0.68)	784 60.3 (0.64)	339 82.3 (0.75)	280 73.8 (1.08)	201 70.5 (1.49)	391 75.0 (1.01)	163 66.2 (1.21)	341 80.7 (0.94)
Hasik	83 78.4 (2.14)	185 81.8 (1.17)	435 81.6 (0.89)	276 71.1 (1.28)	232 66.6 (1.30)	137 84.7 (1.46)	70 74.1 (2.63)	40 44.7 (3.18)	105 52.8 (2.14)	68 68.3 (2.08)	76 81.6 (2.18)
Average	1049 77.2 (1.37)	2176 81.5 (0.86)	3186 81.1 (0.74)	2490 64.5 (0.92)	3011 61.6 (0.76)	1472 77.4 (1.00)	1300 71.4 (1.36)	666 63.5 (1.84)	1049 67.0 (1.34)	719 65.4 (1.38)	1064 77.0 (1.31)

*Above line is the sample number; middle line is the average value; the standard error in brackets.

landing was the lowest (24 tons) in the history of statistical records for the species. In general, the closing of the fishing season has a positive effect, leading to an increase in the size and number of abalone, but overfishing during open seasons undermines the stock.

The highest abalone density in this study was observed in Sadah and Hadbin, whereas a lower abundance occurred in Mirbat and Hasik. This result is in agreement with the findings of Al-Hafidh [1], which showed a similar abalone distribution in the same region. It is important to mention that Sadah and Hadbin are located in the middle of the abalone fishing zone, whereas Mirbat and Hasik are located at the edges of this zone (Figure 1). This result is important to define areas with a lower abundance of abalone for future management and protection programs.

Studies on some abalone species suggested that fertilization success might be reduced as a result of a reduction in the density of adult spawners below a certain threshold [12–14], also known as the Allee effect [15]. These studies estimated a minimum threshold of mature abalone densities between 0.15 and 0.33 ind.m^{-2}, in which abalone populations are subjected to a significant Allee effect [16]. The concept of minimum threshold has been used for different abalone species [13, 17]. According to Rothaus et al. [16], overexploitation

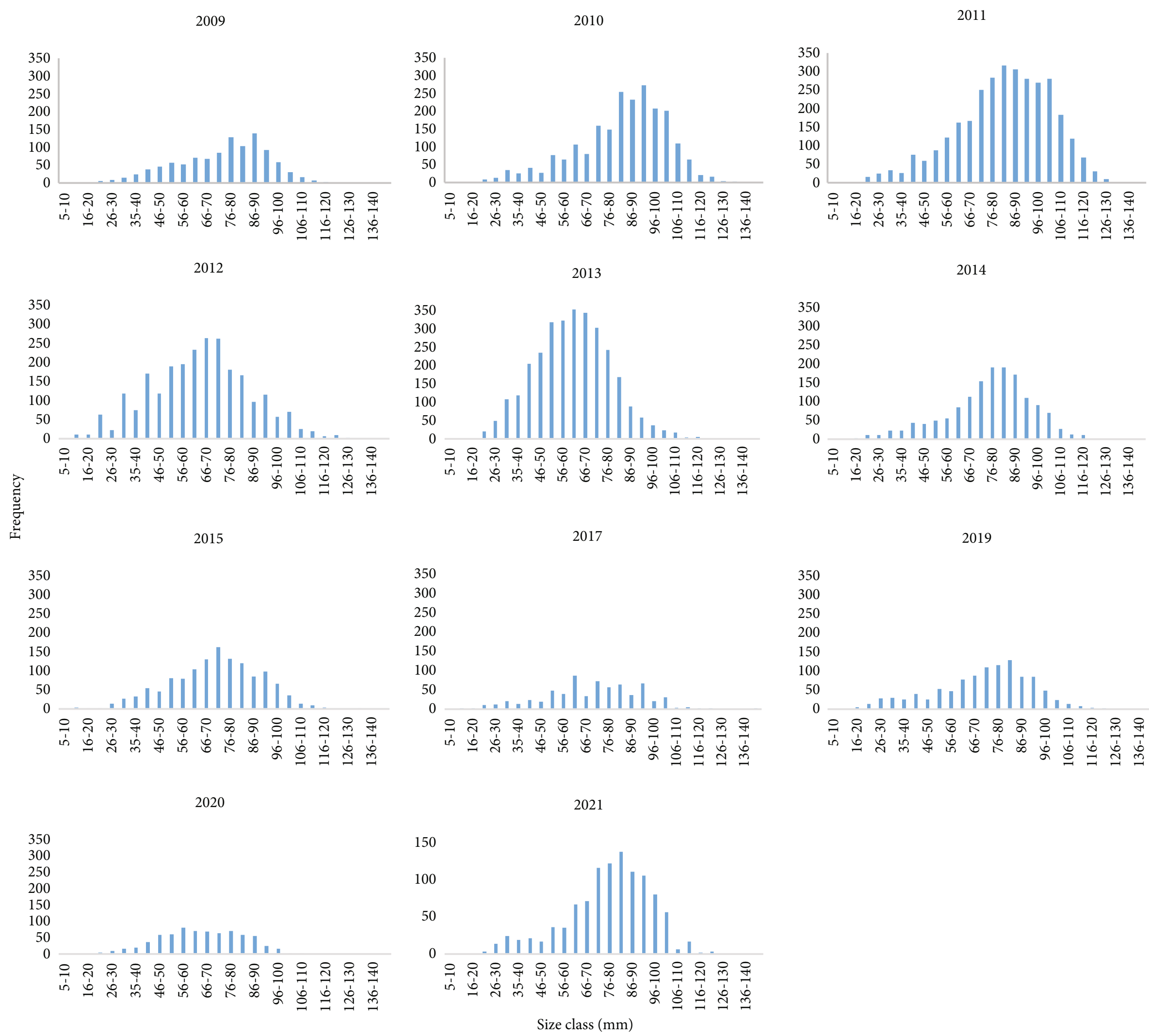

Figure 4: Size frequency distribution (5 mm) of the Omani abalone during the surveys (2009-2021).

may have been responsible for low densities of northern abalone on San Juan Island in northwestern Washington State in the United States in the 1990s, but the Allee effect was thought to be responsible for further reduction in fertilization success. The overall density of mature abalone in Oman in all years, with the exception of 2011, was below this critical range, suggesting that this may lower the ability of this species to reproduce successfully. Similarly, the mature abalone density in all investigated areas during the study period was less than this minimum threshold (except in Hadbin in 2010 and all areas in 2011). Additionally, the abalone densities in Mirbat and Hasik were well below this range compared for several years, indicating a severe effect on the abalone stock in their fisheries. The average abalone density in Hasik has been at very low levels since 2013 (0.03-0.07 ind.m^{-2}), which strongly suggests that the fishery in this area is collapsing. Although there were differences in the abalone densities between Mirbat and Hasik, the statistical analysis in this study revealed no significant difference between both areas; therefore, it can be assumed that the abalone fishery in Mirbat is also on the verge of collapse.

The fluctuation in the density of the large size class during this study is clear evidence of a noncompliance of divers with size limit regulation, indicating size-selective fishing (poaching) mortality by the divers in Oman. This may be attributed to the harvest of undersized abalone, which resulted in the decrease in abalone that can reach a large size available for legal harvest. In addition, the percentage of undersized abalone harvested by divers during the open fishing seasons was probably higher than that officially registered. According to Al-Ghassani [18], between 49 and 76% of the abalone catch during the open fishing season in the past ten years has been below the legal fishing size (90 mm). Al Jufaili et al. [6] reported that abalone dealers purchase undersized abalone from children and women divers. Additionally, Al Jufaili et al. [6] suggested that the free movement of all divers between different fishing areas and the absence of individual fishing quota per season or area led to an uncontrolled harvest of the abalone and consequently possible short-term overfishing of small abalone populations. Therefore, targeting undersized abalone probably hindered the accumulation of legal large abalone (90 mm) available for harvest during the open fishing season.

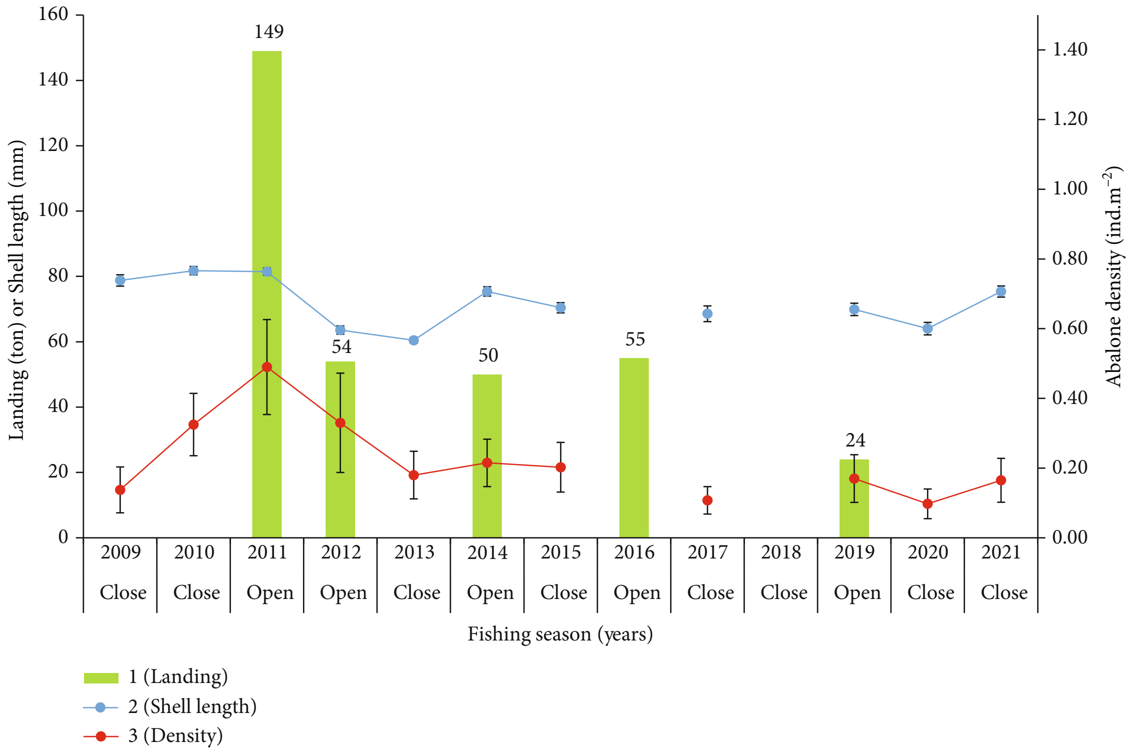

Figure 5: Abalone landing (1), average size with ±SE (2), and average density (3) of *H. mariae* from 2009 to 2021.

Abalone are broadcast benthic spawners that require high densities for successful fertilization [19]. The sedentary behavior and tendency for most abalone species to aggregate during the spawning season offer an easy target for divers [20]. Removal of aggregations could reduce rates of gametes' fertilization during spawning [21, 22]. Since 1991, the abalone fishing season in Oman (November and December) has coincided with the *H. mariae* peak of the spawning season [6]. Ogawa [23] reported fully mature stages of most adult Omani abalone during the same period, and Al-Hafidh [1] suggested that the reproduction rate of this species was negatively affected by a dramatic decrease in the number of mature abalone harvested during the spawning seasons in Oman. One goal of closing the fishing season is allowing breeding to take place to increase the success rates of reproduction [24]. Therefore, the occurrence of an abalone fishing season and a spawning season at the same time in Oman contradicts one of the goals of the closed season, and low recruitment over a prolonged period may have further contributed to the decline of the Omani abalone population.

Although different factors may affect the density of the abalone population, the number of divers and fishing efforts can be considered the main factor that led to the decrease in the abalone stock in Oman. The number of divers catching abalone during the fishing season increased from 244 in 1988 to 951 in 2003 [1] and then increased dramatically to 5281 in 2011 before decreasing to 1740 in 2019 [7, 8]. Al Jufaili et al. [6] reported that uncontrolled numbers of divers, along with insufficient monitoring of the fishery, have intensively reduced abalone catches in Oman. Additionally, other sources of mortality, including diseases, were not reported or observed for this species, and predation is expected to be minimal in the absence of large predators feeding on adult abalone [1, 25]. However, despite the absence of these factors (disease and predation) and the frequent closures in this fishery, the abalone density has continued to decrease in the past decade.

The harvest of abalone is an important source of income for the Omani divers and their families [1, 2]. Therefore, understanding the socioeconomic status of abalone diver's communities in Oman is crucial for better management and development. More involvement of the divers in the management and marketing of this fishery can be considered by the authorities, including forming associations, encouraging to establish community interest companies, and engaging in alternative fishing activities and participation in aquaculture and sea ranching projects. Al Jufaili et al. [6] suggested creating abalone diver association that can be registered under a specialized company to purchase and process the abalone production. Sea ranching experiments aimed for the diver's communities, could be established jointly with the authorities as an alternative activity to reduce the pressure on the natural abalone fishing grounds. Discarded abalone shells could also be used for handicraft production, as a side business [6].

5. Conclusion

The system of alternating the open or closed fishing season over the next year or two turned out to be ineffective for the abalone fishery in Oman. This alternation did not solve the problem of achieving a sustainable stock. Short-term closures may not provide sufficient time for the build-up of size class densities and for reaching a sustainable proportion of legal size abalone available for fishing. Therefore, it is recommended that any future closure should not be less than three years. In addition, the current densities in the Hasik and Mirbat areas can be considered very low and critical, so any abalone fishing activities should be stopped for at least five years while monitoring the stock physical recovery indicators.

There is an agreement and recognition of more efficient enforcement of the existing abalone management regulations in Oman, including harvesting legal size abalone, fishing gear restriction, and closing the fishing season. However, such regulations may not be effective unless the number of divers is regulated.

The current information regarding the abalone spawning season needs to be updated. However, the cooccurrence of the fishing season (November-December) with the previously estimated peak of the spawning season can significantly reduce the chances of mature abalone reproduction. Therefore, the harvest of abalone should not be allowed during the spawning period to avoid any other possible effect on the reproduction efficiency of this species. However, any shift or change in the fishing season must be evaluated.

More studies are required on the biological aspects of the Omani abalone fishery. This may include estimating the minimum threshold of mature abalone density (minimum spawning density (MSD)) in each fishing area. Estimating these threshold densities will help decide when fishing must stop to avoid any further reduction in the densities. Abalone aggregation aspects also need to be considered. Currently, critical levels of abalone aggregation in Oman have not been identified due to the lack of adequate data. In addition, recruitment levels in each fishing ground should be assessed. Therefore, clear measurable criteria could be established to identify whether the abalone population in Oman is sustainable, threatened, or recovering.

It is important to understand the socioeconomic status of abalone diver's communities in Oman for better management and development. Providing alternative sources of income for these communities would help reduce their dependency on the abalone fishery and subsequently on the natural stock.

Data Availability

The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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