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Habitat Preferences of Juvenile Abalone *(Haliotis mariae* Wood, 1828) Along the Dhofar Coast of Oman and Implications for Conservation

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تفضيل البيئات بواسط صغار الصفيلح على طول الشواطئ في محافظة ظفار وأثر ذلك على حمايته

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الخلاصة: تم إجراء مسوحات على طول الساحل الشرقي لمحافظة ظفار في سلطنة عمان للوقوف على كثافة وطبيعة البيئات التي تفضلها صغار الصفيلح العماني (*Haliotis mariae*) (بطول صدفة أكثر من ٣ سم). بلغ متوسط كثافة الصفيلح ٠,٦٢ م-٢ (SD ٠,٥٦). فيما بلغ متوسط كثافة قنافذ البحر ٣,٤م-٢ قنفذ (SD ٣,٩) . أظهرت المسوحات وجود علاقة كبيرة ومؤثرة بين كثافة صغار الصفيلح وبين الصخور الصغيرة التي يبلغ قطرها أكثر من ٣٠سم (p=٠,٠٤٩), وكذلك وجود علاقة مماثلة بين كثافة صغار الصفيلح وكثافة قنافذ البحر (p = ٠,٠٣١), وتم في هذه الدراسة حساب قدرة صغار الصفيلح على انتقاء (w) مختلف الانماط والموارد المحيطة بها وذلك بتحويل القيم والمقاييس الى نسب ثابتة (B). حيث اظهرت القيم (B) دلالة احصائية معنوي (*p* =٠,٠٠٤) بين البيئة المحيطة وبين القنافذ والصخور الصغيرة التي يبلغ قطرها أكثر من ٣٠سم ,٣٠سم<>٥٠سم, أكبر من٥٠سم . وسجلت القيم (B) أعلى قيمة للقنافذ البحرية (٦ أضعاف أعلى من الصخور الصغيرة) وللصخور الصغيرة التي يبلغ قطرها <٣٠سم (ضعف القيم للصخور التي قطرها سم٣٠<>٥٠سم), وتتناقص قيم (B) كلما زاد حجم الصخور في بيئة وجود صغار الصفيلح. تستغل صغار الصفيلح القنافذ البحرية للحماية في الاماكن الجغرافية بنسبة من ١٥,٥٪-٤٧,٦٪ كحد أعلى. بالنسبة الى كل بيئة تواجد الصفيلح تم استنتاج ان ٩٧٪ من صغار الصفيلح تفضل التواجد في محيط بيئة بها قنافذ بحرية وصخور صغيرة قطرها أكثر من ٥٠ سم, شمل ذلك ٢٩٪ من أجمالي المنطقة المسوحة. اثبتت الدراسة أن دور القنافذ البحرية في بيئة صغار الصفيلح ليس حيويا ولكنه ذو دلالة مؤكدة. بالرغم ان كثافة صغار الصفيلح قليلة وليست محصورة حاليا بوجود البيئة المناسبة . فإنه من الأهمية التعرف والحفاظ على البيئة الداعمة لوجود واستقرار الصفيلح *H. mariae* ان تحديد المناطق التي توجد بها البيئة المفضلة لصغار الصفيلح سوف يسهم في وضع الآلية المثلى لإختيار المحميات الخاصة بالصفيلح مستقبلا.

كلمات مفتاحية: صفار الصفيلح ، تفضيل البيئات، تحاليل الإختيار ، حماية الموطن ، عمان.

ABSTRACT: Surveys were conducted along the eastern Dhofar coast of Oman to investigate densities and habitat preferences of juvenile *Haliotis mariae* (< 3 cm SL). Average density was 0.62 m^{-2} (SD 0.56); average urchin density was 3.4 urchins m^{-2} (SD 3.9). Relationships between juvenile abalone densities and small boulders (<30 cm in diameter (Ø)) tested significant (p = 0.049), as did those between juvenile abalone and urchin densities (p = 0.031). Selectivity (w) and standardized (B) ratios quantifying the relative probability of selection by juvenile abalone for different categories of resource available were calculated. For the studied area B values tested significantly different for (p = 0.004) the different habitats, urchins, boulders <30 cm, 30> <50 cm, and >50 cm Ø, respectively. B values were highest for urchins (6 times that for small boulders), and for boulders <30 cm Ø (double that for boulders 30> <50 cm Ø). B values for boulder habitats decreased as boulder size increased. Urchin utilisation by juvenile abalone as shelter ranged between geographic areas from a minimum of 15.5% to a maximum of 47.6%. The proportion of total habitat that is preferred by more than 97% of juvenile abalone found, including urchins and boulders < 50 cm Ø, comprises 29% of surveyed substratum. While the role urchins play on wild juvenile *H. mariae* has not proved vital, it is definitely significant. Although juvenile densities are low and are not currently limited by the availability of suitable habitat, it is crucial to identify and conserve those microhabitats that support recruitment of *H. mariae*. The abundance of these areas should be among the criteria used in selecting protected conservation areas.

Keywords: Juvenile abalone, habitat preferences, selectivity analyses, habitat conservation, Oman.

Introduction

The wild abalone fishery along the eastern Dhofar coast of Oman has formed part of traditional fishing culture for decades, and as a valuable commercial species contributes substantially to the livelihoods of coastal dwelling fisher folk (Al Hafidh, 2006). The fishery takes place in the winter months, usually between October and December, when the seas are relatively calm and sea water temperatures are in excess of 20º C (Al Hafidh, 2006; Sanders, 1982).

Haliotis mariae is the only abalone species occurring in Oman. It is endemic in the Dhofar region of the Arabian Sea (Al Hafidh, 2006). Currently, it inhabits a rocky coastal

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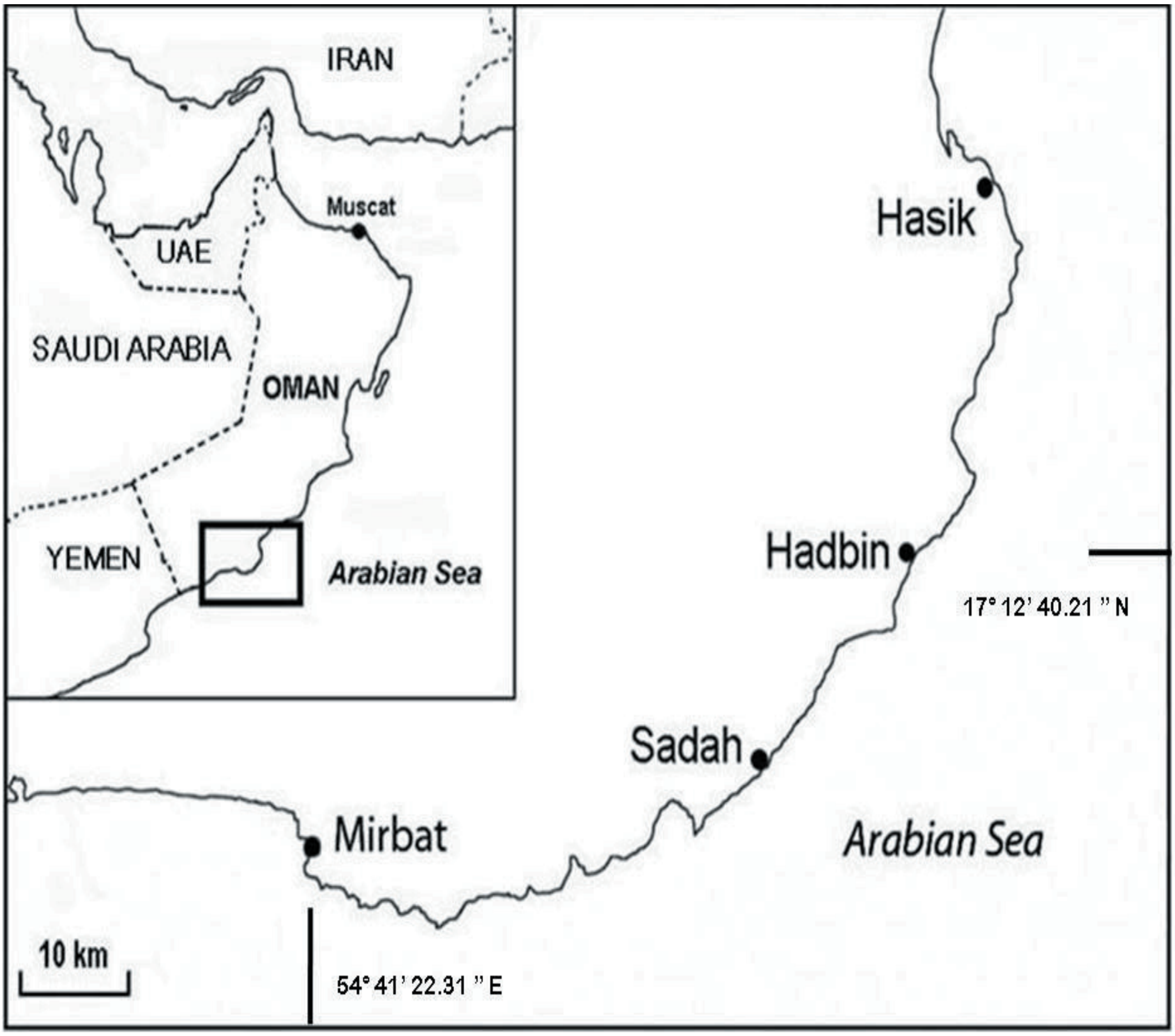

Figure 1. The main centres for the existing abalone fishery along the Dhofar coast of Oman.

zone between Mirbat and Hassik, approximately 100 km in length (Fig. 1). Prior to 2008 the species range extended approximately 80 km further east from Hassik to Ras Sharbithat (Al-Hafidh, 2006). However, an extreme episode of harmful toxic algal blooming by the species *Cochlodinium polykrikoides* during 2008 and 2009 (Al Gheilani, 2009) wiped out virtually all the abalone in the Ras Sharbithat region. As a result of the commercial importance of the species, worth approximately OR 8.2 million in 2012 (Fishery Statistics, 2012), extra consideration is being given to the management of the fishery.

The annual abalone survey now includes juvenile specific surveys to broaden the investigation into the dynamics of the species. The lifecycle of abalone in general can be considered complex. Juvenile abalone are sensitive to bright light (Heasman *et al.*, 2007) and as a result cryptic by nature. They generally inhabit under-boulder habitats, cracks and crevices (Roberts *et al.*, 2007; Dixon *et al.*, 2006), becoming emergent as they mature. Abalone, specifically juveniles have a wide range of predators from which they need to seek refuge. These include sea stars, moray eels, lobsters, crabs, some species of fish, and octopus. Many of these predators inhabit the same general habitat, under-boulder, cracks and crevices, as the abalone themselves, making it crucial for juvenile abalone to find suitable shelter. In this study, we have investigated juvenile abalone up to 30 mm in SL (shell length), i.e. the cryptic juvenile phase. These animals differ in diet and behavior from adult animals. *H. mariae* is considered generally to become emergent at approximately 60-mm SL moving onto exposed sites on reefs or boulders. Adult *H. mariae* are grazers as well as trappers of a range of drift seaweed species, with the choice of species depending on the area and the abundance and diversity of seaweeds present (Al-Hafidh, 2006). Juveniles, on the other hand, have been shown to be grazers, the epithelial layer of the encrusting corallines on which the recruits are found, together with benthic diatoms, are a source of nutrition for recruits and small juveniles (Al-Rashdi and Iwao, 2008). The association between urchins and abalone is well documented for various abalone species worldwide. However, this association is not always simple, in some cases urchin and abalone numbers are inversely related due to their competition for food (Tarr *et al*., 1996; Andrew and Underwood, 1992). Recruits from some species that grow to the juvenile stage have been found predominantly under sea urchins (Goodsell *et al.,* 2006, de Waal, 2005, Day and Branch, 2002, 2000). Although urchins are considered a source of shelter for juvenile abalone the relationship between *H. mariae* recruits and urchins has not yet been investigated (Al-Hafidh, 2006). Adult abalone generally occupy habitats less hidden than that of juveniles. It is crucial however that the habitat requirements of juvenile abalone are met if recruitment is to be successful. Part of understanding the ecology of the species includes an understanding of the habitat requirements of wild juvenile *H. mariae*. This understanding will also play a crucial part in providing information that can be used to select suitable conservation areas for the species.

This study investigates habitat preferences of wild juveniles along the Dhofar coast with the aim of quantifying the relationship between substratum structure, urchins and wild juveniles. It was conducted with a number of questions in mind: (1) Are there specific physical substratum limitations in effect in the distribution of wild juvenile abalone? (2) Is the availability of habitat a limiting factor with respect to recruitment, how much habitat is being utilized by juvenile abalone? (3) What is the relationship between wild juvenile abalone and the sea urchin? (4) Are there findings that impact on potential conservation of this species?

Materials and Methods

Quantitative Wild Juvenile Surveys

Between March and early April 2012, juvenile specific surveys were conducted in four abalone fishery areas: Mirbat, Sadah, Hadbin and Hassik (Fig.1). Abalone smaller than ≈ 3 cm (SL) were classified as juvenile. The survey comprised 35 separate 10X1 m transects, totalling 350m^2, placed randomly in areas considered to be prime abalone fishing areas. Transects were placed both parallel and perpendicular to the beach and did not exceed an average depth of 6 m. In each transect a destructive invasive search was conducted; all boulders, stones and urchins were lifted and searched, cracks and crevices were searched where possible (Rogers-Bennet *et al.*, 2002). In addition to an abalone and urchin count, average depth was recorded in each transect. An estimate was made of the physical substratum in the following categories (de Waal, 2002): (1) Percent area exposed. This is defined as open reef, bedrock or sand, area that does not provide any shelter for juvenile abalone. Exposed reef does not necessarily have to be flat and open; many exposed areas have a high degree of rugosity (Southwest Region Protected Resources Division, 2011; McCormick, 1994) and may be complex in features including outcrops, pockets, and ridges. While not providing under-boulder habitat these areas may provide anchor opportunities for sea urchin species which in turn offer shelter to juvenile abalone. (2) Boulders with diameter (Ø) greater than (>)50 cm. (3) Boulders with Ø between (><)30 and 50 cm. (4) Boulders with Ø less than (<)30 cm.

All juvenile abalone and urchins in each transect were counted. For each juvenile the exact position was recorded in the categories described above, in addition to being found under an urchin.

Data Analyses

Abalone densities and urchin densities were calculated for each transect. Proportional distribution of each habitat category and the proportional utilization of each category, including urchins, by juvenile abalone were calculated (Table 1). The following statistical analyses (using StatistiXL Software) were conducted: (1) Non parametric Kruskal-Wallis Tests were conducted to test for differences in habitat composition between the four areas. (2) Linear regression analyses to test for relationships between number of juveniles found and habitat composition in the categories listed above including depth and number of urchins per transect. (3) Selectivity analyses of juvenile abalone for substratum habitat categories including urchins for shelter:

The selectivity analyses were done using Manley's formula that calculates a resource selection function w_i (the relative probability of selection for the category i, Formula I) for the different categories of resource available. The selection function attempts to estimate the probability that the next resource used will be of a specific type. It allows a biological interpretation of used and available resource ratios by animals, and has been used to test habitat selectivity by abalone (de Waal, 2002; Manly *et al*., 2002; Day and Branch, 2002, 2000).

$$w_i = u_i / m_i \qquad (1)$$

w_i is the selectivity ratio; m_i is the number of available units in category i in a sample of available resource units; and u_i is the number of units in category i in a sample of used units.

A useful way of presenting selection ratios is to standardize them so that they add up to a total of 1. This leads to Manly's standardized selection ratio B_{i1} (with used resource units replenished or in this case constant, Formula II).

$$B_{i1} = (u_i/m_i) / \Sigma(u_i /m_i) \qquad (2)$$

Table 1. General data describing biological and substratum characteristics from each transect. Proportional distribution of habitat categories and proportional distribution of utilization of different habitat categories by juvenile abalone from each fishing area are shown.

	Site	Depth (m)	Abalone m^{-2}	Urchins m^{-2}	Proportional Distribution (% area) Habitat Categories					Proportional Distribution (%) Abalone Utilizing Habitat Categories			
					Urchins	<30 cm ø	30> <50 cm ø	>50 cm ø	Exposed	Urchins	<30 cm ø	30> <50 cm ø	>50 cm ø
Mirbat	1	7	0.2	1.8	1.24	10	20	50	18.76	0.00	50.00	50.00	0.00
	2	6	0.2	5.1	3.50	20	40	20	16.50	0.00	50.00	50.00	0.00
	3	5	0.3	4.3	2.95	10	20	30	37.05	0.00	100.00	0.00	0.00
	4	8	0.2	0.3	0.21	10	10	20.	59.79	0.00	0.00	100.00	0.00
	5	6	0.4	0.6	0.41	10	10	10	69.59	50.00	50.00	0.00	0.00
	6	9	0.3	1.2	0.82	10	20	10	59.18	0.00	0.00	100.00	0.00
	7	1	0	7.2	4.95	10	10	20	55.05	0.00	0.00	0.00	0.00
	8	7	0.3	0.8	0.55	0	0	40	59.45	100.00	0.00	0.00	0.00
	9	5	1.2	0.2	0.14	50	50	0	0.00	25.00	58.33	16.67	0.00
	10	3.5	1.3	20	13.74	0	0	10	76.26	69.23	0.00	0.00	30.77
	11	6	1	2	1.37	10	20	60	8.63	10.00	50.00	40.00	0.00
	12	5	0.3	1	0.69	0	0	60	39.31	33.33	66.67	0.00	0.00
	13	3.5	1.4	5	3.43	10	10	55	21.57	21.43	42.86	35.71	0.00
Sadh	1	3	0.7	4.8	3.30	10	10	60	16.70	0.00	57.14	28.57	14.29
	2	0.5	0.5	6	4.12	10	10	70	5.88	60.00	40.00	0.00	0.00
	3	3	0.9	6.8	4.67	10	20	60	5.33	11.11	11.11	22.22	55.56
	4	3	0.9	2.4	1.65	20	40	40	0.00	0.00	77.78	22.22	0.00
	5	3	0.7	4.8	3.30	10	10	80	0.00	0.00	42.86	57.14	0.00
	6	4.5	0.2	3.8	2.61	10	10	10	67.39	100.00	0.00	0.00	0.00
	7	6	1	0	0.00	40	10	50	0.00	0.00	90.00	10.00	0.00
	8	4	1	3.6	2.47	10	10	20	57.53	20.00	70.00	10.00	0.00
	9	2	1.1	3.8	2.61	10	20	20	47.39	54.55	27.27	18.18	0.00
	10	2.5	1.8	13.3	9.14	0	0	0	90.86	100.00	0.00	0.00	0.00
	11	1.5	0.1	1.8	1.24	10	10	50	28.76	100.00	0.00	0.00	0.00
	12	5	0.3	1.8	1.24	0	0	60	38.76	33.33	66.67	0.00	0.00
	13	3.5	1.4	1.5	3.43	10	10	55	21.57	21.43	42.86	35.71	0.00
Hadbin	1	4	2.2	1.9	1.31	30	30	40	0.00	9.09	54.55	36.36	0.00
	2	4	0.8	1.2	0.82	20	30	20	29.18	37.50	62.50	0.00	0.00
	3	2	0	0.4	0.27	10	10	50	29.73	0.00	0.00	0.00	0.00
Hassik	1	6	0	0	0.00	0	0	0	100.00	0.00	0.00	0.00	0.00
	2	3	0	0	0.00	0	0	0	100.00	0.00	0.00	0.00	0.00
	3	6	0.1	3	2.06	0	0	50	47.94	100.00	0.00	0.00	0.00
	4	3	0	0.5	0.34	10	10	20	59.66	0.00.	0.00	0.00	0.00
	5	3	0.1	3.6	2.47	20	35	35	7.53	100.00	0.00	0.00	0.00
	6	3	0.7	3	2.06	25	30	40	2.94	85.71	14.29	0.00	0.00
		Average	0.62	3.36	2.37	11.87	14.71	34.71	36.52	32.62	32.14	18.08	2.87
		SD	0.56	3.97	2.72	11.12	13.11	22.62	30.12	38.29	31.40	27.07	10.78

Table 2. Kruskal-Wallace tests on all categories of habitat description including number of urchins per transect.

Transect characteristics (SD)	Df	F	P
Average depth (m)	3	4.41	0.017*
Average density (abalone m^{-2})	3.8	3.00	0.019*
Average density (urchins m^{-2})	1.80	3.00	0.41
Physical substratum			
Boulders <30 cm ø	1.10	3.00	0.35
Boulders 30 > < 50 cm ø	0.80	3.00	0.51
Boulders >50 cm ø	1.50	3.00	0.23
Exposed area	0.90	3.00	0.41

*Significant at 95% confidence limits.

Non-parametric Friedman tests were conducted on the w (Selectivity ratio) and B values (Standardized ratio) for each area grouped to test for differences between the four fishery areas, and on B values from all the sites for each of the different habitat categories, including urchins, grouped to test for differences in strength of preference for different habitats.

Results

Depth for all sites combined ranged from 1m to a maximum of 9 m (average 4m, SD 1.1). The average abalone density was 0.63 abalone m^{-2} (SD 0.37), and the average urchin density 2.8 urchins m^{-2} (SD 1.6). The averaged data sets calculated for each separate geographic area were too small to allow constructive testing for significance, however, general differences can be seen in Table 1. There are a number of species of urchin found in the area, including *Diadema setosum* (Leske, 1778), *Echinostrephus molaris* (Blainville, 1825), *Echinometra mathaei* (Blainville, 1825), *Toxopneustes pileolus* (Lamarck, 1816), and *Stomopneustres variolaris* (Lamarck, 1816). Juvenile abalone are generally associated with the shorter spine dark urchins like *S. variolaris* and *E. mathaei.* Abalone densities were lowest in Hassik, the most easterly of the areas, and highest in Hadbin, the area just west of Hassik. In both areas the number of transects surveyed were limited, 3 in Hadbin and 6 in Hassik (Table 1).

Analyses showed that transects were generally similar in physical substratum structure and appearance, and no significant differences were found between the four areas with respect to the physical attributes described in the categories listed in the methods section above. Depth differences between transects, however, tested significant (p = 0.017, Table 2). Abalone densities also tested significantly different (p = 0.019, Table 2), while urchin densities did not. The utilization of urchins by juvenile abalone ranged between geographic areas from a minimum of 15.5% to a maximum of 47.6%. The area under urchins (using an average urchin Ø of 9.3 cm SD 1.3) is by far the lowest compared to the area under all other categories of substratum (boulders with varying average Ø, Table 1).

In all four fishery areas the area comprising small boulders (<30 cm Ø) made up the smallest proportion of boulder habitat (Table 1). In Mirbat and Hassik the proportion of exposed area was higher than the proportion of area under boulders, and in Sadah and Hadbin exposed area was less than that under boulders. It is important here to note how small the proportion of total area comprises small boulders. In this study this category of substratum is shown to be significantly important to juvenile *H. mariae*. Seventy-six percent of wild juvenile abalone utilise 14% of the total substrate available, that is the area comprising urchins and area under boulders <30 cm Ø. Ninety-seven percent utilize boulders <50 cm Ø, which is 29% of the available substratum. In other words, less than 30% of the total available surveyed habitat comprises substratum that can support juvenile abalone, including the area under urchins which will be variable over time.

Analyses (Pearson Correlations and Anova, Table 3, Fig. 2) showed significant positive relationships exist between juvenile abalone densities and small boulders (< 30 cm Ø, p = 0.049), and juvenile abalone densities and urchin densities (p = 0.031). The relationships between juvenile abalone densities and all categories of larger boulder tested insignificant. A negative significant correlation was shown to exist between urchin densities and depth (p = 0.037).

Non-parametric Friedman tests showed no significant differences (p = 0.416) between the four fishery areas when using either w or B as a measure. However, the same tests showed the highly significant (p = 0.004) difference values of B for all categories of habitat when

Table 3. Linear regression analyses (Pearson correlation and Anova) for relationships between abalone and urchin densities and substratum categories.

	Pearson R^2	Anova Prob.
Juvenile abalone no vs.		
Boulders <30 cm ø	0.112	0.049*
Boulders 30> <50 cm ø	0.044	0.227
Boulders >50 cm ø	0.003	0.275
Exposed area	0.081	0.098
Urchin density	0.134	0.031*
Depth	0.027	0.348
Urchin no vs.		
Boulders <30 cm ø	0.072	0.119
Boulders 30> <50 cm ø	0.030	0.316
Boulders >50 cm ø	0.011	0.556
Exposed area	0.027	0.348
Depth	-0.125	0.037*

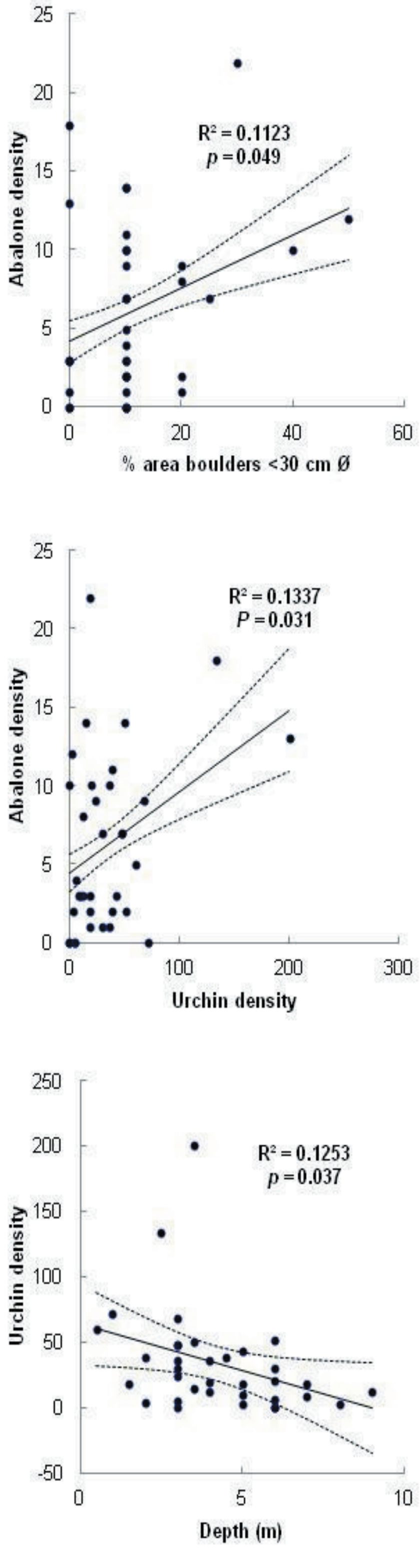

Figure 2. Significant Pearson correlation analyses between abalone and urchin densities, the abundance of small boulders and depth of transects.

Table 4. Standardized B values showing habitat preferences by juvenile abalone (All data is pooled).

Pooled	π	0	W	B
Urchin area 0.02	0.02	0.38	19.03	0.80
<30 cm ø	0.12	0.37	3.12	0.13
30 > <50 cm ø	0.15	0.21	1.41	0.06
>50 cm ø	0.35	0.03	0.10	0.00
Exposed	0.36	0.00	0.00	0.00
			23.66	1.00

the same categories are grouped from each transect. The standardized B value for urchins selected as shelter by juvenile abalone is almost 6 times higher than for small boulders (<30 cm Ø). The B values for the other categories decrease as boulder size increases with a minimum for exposed areas. For boulders <30 cm in diameter B is double that for boulders 30> <50 cm diameter (Table 4).

Discussion

The survey data reflect abalone and urchin densities at a specific time of the year, and therefore must be seen in the context of growth and dispersal, since recruitment, food availability and general environmental conditions vary depending on the season. Analyses were conducted on a specific size range of juveniles. Observations made during other months suggest that juvenile abalone inhabit the same type of habitat throughout this lifecycle phase. Densities, however, will change during the year, and this too has been observed. In this context the abalone densities observed here are relatively low when compared to those from other species, *Haliotis rubra* (Leach, 1814) juveniles for example average between 1 and 3 m^{-2} (Roberts *et al*., 2007; Goodsell *et al*., 2006). However, this is variable and must be seen in the context of the recent and current status of the abalone stocks in general together with site-specific ecological regimes and habitat characteristics (Roberts *et al*., 2007). It is not enough to attempt to manage only emergent or adult stocks; in California for example juvenile red abalone abundance was not correlated with local adult red abalone abundance (Rogers-Bennett and Pearse, 2001). In that study it was concluded that fishing for red urchins potentially decreased the microhabitat available for juvenile abalone.

In this study a prime abalone fishing habitat was selected. However, along the entire Dhofar coast suitable habitats for juvenile abalone will be relatively less abundant than in this area. Due to the complex ecological requirements for successful recruitment to take place, habitats suitable for recruitment may in fact be more limited than that available for juveniles to live in. The fact that a significant correlation is found between juvenile abalone and small boulders corresponds with findings for abalone species internationally. Juvenile abalone are generally sheltered in the shallows in under-boulder habitats. In New Zealand *Haliotis iris* (Gmelin, 1791) juveniles are found almost exclusively under boulders from the low water mark to several meters (Roberts *et al*., 2007). In Canada it was found that juvenile *Haliotis Kamtschatkana (*Jonas, 1845) require cryptic habitats with some boulders (Lessard and Campbell, 2007). In California *Haliotis cracherodii* (Leach, 1814) (black abalone) juveniles up to a size of about 20 mm, black abalone are highly cryptic, occurring primarily in under-boulder habitats or in deep narrow crevices (Southwest Region Protected Resources Division, 2011).

It is important to note that these surveys were conducted in areas considered prime adult abalone habitats and does not therefore reflect the entire Dhofar coastline. This limited portion of intertidal and sub tidal habitats is not a safe or stable area when human and natural effects are taken into account. In this habitat juveniles are vulnerable to the movement of boulders, either by natural forces or by humans during abalone fishing or collecting of other marine organisms and the clogging of under-boulder habitats by sand and shale during storms (Roberts *et al*., 2007; Maliao *et al*., 2004). It is also this area that is most accessible to people and pollution. For example, trash discarded by fishermen and day visitors in abalone fishery areas along the Dhofar coast is a clear hazard

The positive correlation between juvenile densities and urchin densities combined with the strong selectivity index B found in this study correspond with a number of international findings. In North America, field studies have shown a strong correlation between juvenile abalone and sea urchins (Rogers-Bennett and Pearse, 2001). In South Africa the same has been found with the species *Haliotis midae* (Linnaeus, 1758) [Day and Branch, 2002, 2000; Tarr *et al*., 1996 with similar results in Japanese species (Kojima, 1981)]. It is thought that small abalone are protected by the extended spines of the urchin (Goodsell *et al*., 2006). In 1997 along the Californian coast between 30 and 45% of the juvenile *Haliotis rufescens* (Swainson, 1822) found in specific study sites in marine protected areas were located under the spine canopy of red urchins with the remainder in other microhabitats (Rogers-Bennett and Pearse, 2001). In Canada survey sites showed 7% of *H. Kamtschatkana* <45 mm SL were found under urchins and a positive correlation was found between abalone numbers and sea urchins (Tomasckik and Holmes, 2003). The same authors found a negative correlation between urchin densities and abalone size, indicating that urchins may have a beneficial role in survival of smaller abalone. Urchins play a significant role in supporting a large proportion (≈ 31%) of the wild juvenile abalone population in the fishery areas of the Dhofar coast. While this role is significant it is not vital to juveniles because a larger proportion of juvenile abalone occupy under-boulder habitats.

Conclusions

It is important to note that the proportion of total habitat that is preferred by more than 97% of juvenile abalone found, including urchins and boulders <50 cm Ø, comprises 29% of the substratum surveyed. The proportion of total habitat that will support recruitment requires ecological factors not measured in this study, one being the presence of crustose coralline algae. In effect this additional requirement might make total habitat available for recruitment even less than this. While the role that urchins play on wild juvenile *H. mariae* has not proved vital it is highly significant. However, inferences cannot be made from this data about the relationship between urchins and the recruitment of *H. mariae.* This must be investigated in future studies.

Studies in California and the Philippines have shown that marine protected areas result in an increase in juvenile abalone densities (Maliao *et al*., 2004; Rogers-Bennett and Pearse, 2001). This study shows that while juvenile densities are low they are not currently limited by the availability of suitable habitat. However, conservation of this species requires managing the entire lifecycle of the species which includes the physical substratum required. It is crucial to identify and conserve those microhabitats that support recruitment of *H. mariae*; shallow inter-tidal areas easily accessible and most prone to human activities. The distribution and abundance of these areas should be among the criteria used in selecting protected conservation areas.

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