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Relationship between human exploitation and condition of mussel populations in Aoufist, (SW Morocco, Atlantic Ocean)

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Abstract

In Morocco, human exploitation of mussels caused overfishing and drastic reductions of local stocks. For comparative purposes, we studied patterns of abundance and distribution of the mussels before and after the fishing season (May 2014 - February 2015), at locations subject to subsistence exploitation and at unexploited reference locations. The fished shores experienced significant decrease in mussel cover ($p < 0.01$) while no significant increase occurred at the unexploited shores ($p > 0.05$). Human exploitation brought a decrease in abundance of individuals of commercially valuable size (5-7 cm) while the unexploited shores experienced a marked increase in abundance of large mussels. Significant reduction in biomass of 44 - 93% occurred at the fished locations while the reference shores experienced an increase of 11 - 34% in biomass. The findings are discussed in relation to various biological attributes which may determine the susceptibility of the local stocks to depletion. The present study emphasize the high level of exploitation in the fishery of Aoufist and emphasize the urgent need to apply appropriate management strategies.

Keywords: Mussels, overfishing, biomass, size, density, management

1. Introduction

Rocky intertidal habitats are often used by humans for recreational, educational, and subsistence-harvesting purposes, with intertidal populations sometimes damaged by such activities as extraction, trampling, and handling [1, 2]. Coastal managers are concerned with the status of these intertidal communities and are often charged with implementing procedures that protect and enhance species composition, diversity, and ecological services [3]. They seek to determine the current condition or "health" of a site and trends in this condition over time, and to communicate this condition to the public and decision-makers [4]. However, the development of simple metrics that reflect the condition of rocky intertidal communities has remained elusive due to the complex, dynamic, and heterogeneous nature of rocky shore ecosystems [5]. A key need is the ability to distinguish anthropogenic-driven changes in a coastal community from changes due to natural or non - anthropogenic agents. Impacts of human activities in coastal areas are of increasing concern for ecologists and policy makers [6, 7]. Flora and fauna populations on wave-exposed rocky shores are subjected to perturbations when large numbers of people visit intertidal zones for recreational or education purposes or to collect intertidal species for food [8, 9]. Human impacts include collecting, trampling, turning, and handling of intertidal species, causing alterations of community processes [10]. Excessive collection may lead to major changes in population structure and functioning [11] and can seriously deplete stocks of intertidal organisms [12, 13]. Disturbance can have direct effects, such as loss of individuals through collecting [14, 15] and the dislodging or crushing of individuals by trampling [16, 17]. Human activities also may result in morphological damage that can affect other physiological or reproductive processes, thus reducing overall fitness [10, 18, 19].

Mussels are an important ecological component of rocky shore communities throughout the world, and occupy a central trophic position in intertidal food webs worldwide [20]. Thus, more information on mussel biology and habitat is crucial for their conservation [21, 22]. The harvesting intensity of *Mytilus galloprovincialis* was related to accessibility, type of day (weekday, weekend or holiday), period of the day, weather and tidal amplitude [23]. Similarly, there are gradients of human disturbance, depending on the distance from the access point [24], and a negative correlation between accessibility to sites and abundance of mussels [23].

In Morocco, there has been an increase in intensity of subsistence exploitation due to population growth and poverty. The mussel fisheries expanding from already overexploited areas on the north Atlantic coast to less-exploited ones on the south Atlantic coast. Both species, *Perna perna* and *Mytilus galloprovincialis*, are subject to human exploitation at the shallow rocky shores of Aoufist (SW Morocco, Atlantic Ocean). This activity seems to be not selective, both in terms of species and size of individual removal. The condition of mussel populations at the fished locations has never studied and the lack of information on their ecology hinders their conservation. The present study, therefore, was undertaken to provide information on the condition of mussel populations, before and after the fishing season, in Aoufist area where it constitutes an important resource for subsistence collectors. We compared density, size, and biomass of the target species at the shallow rocky shores in Aoufist strongly affected by fishing and at the unexploited shores in Lakraa. This paper also provides an overview of the harvesting activity in Aoufist including descriptions of the demography of the fishermen, and the fishing and handling practices.

2. Materials and Methods

2.1 Study area

The present study was conducted during two periods: May 2014 (i.e., just before the fishing season) and February 2015 (i.e., immediately after the fishing season) at four different shallow rocky shores along the South Atlantic Coast of Morocco (Fig. 1). This coast is north-south oriented, exposed to prevailing northwest oceanic swells and characterized by a semi-diurnal tidal regime.

Two locations (Aoufist Sud and Aoufist Nord, hereafter H1 and H2, respectively) were haphazardly selected as fished shores. Both locations (H1: lat. 25° 42' 35" N, long.14° 38' 52" W and H2: lat. 25° 44' 16" N, long.14° 38' 43" W) are located within Aoufist area at 45 km from Boujdour city (Fig. 1). Two locations (Lakraa Nord and Lakraa Sud, hereafter U1 and U2, respectively) were randomly selected as controls (*i.e.*, unexploited) among those available on 10 km of coastline (Fig. 1). Reference locations (U1: lat. 24° 42’ 29” N, long. 14° 52’ 57” W; U2: lat. 24° 41’ 6” N, long. 14° 54’ 4” W) were selected as being analogous to the fished shores in terms of physical traits, including spatial extent, type of substrate (*i.e.*, granite), slope (*i.e.*, almost flat), exposure (*i.e.*, at all shores, the coastline was oriented from north to south), and accessibility. Both groups have similar environmental features (i.e., substrate type, slope, algal coverage) and were 0.5-1 km long and 2 km apart. These locations are typically dominated by the mussels *Perna perna* and *Mytilus galloprovincialis* at mid-intertidal level and by diverse algal and invertebrate assemblages lower on the shore. The allocation of shores to each condition was based on our investigation and on the available data provided by the Department of Marine Fisheries (DPM).

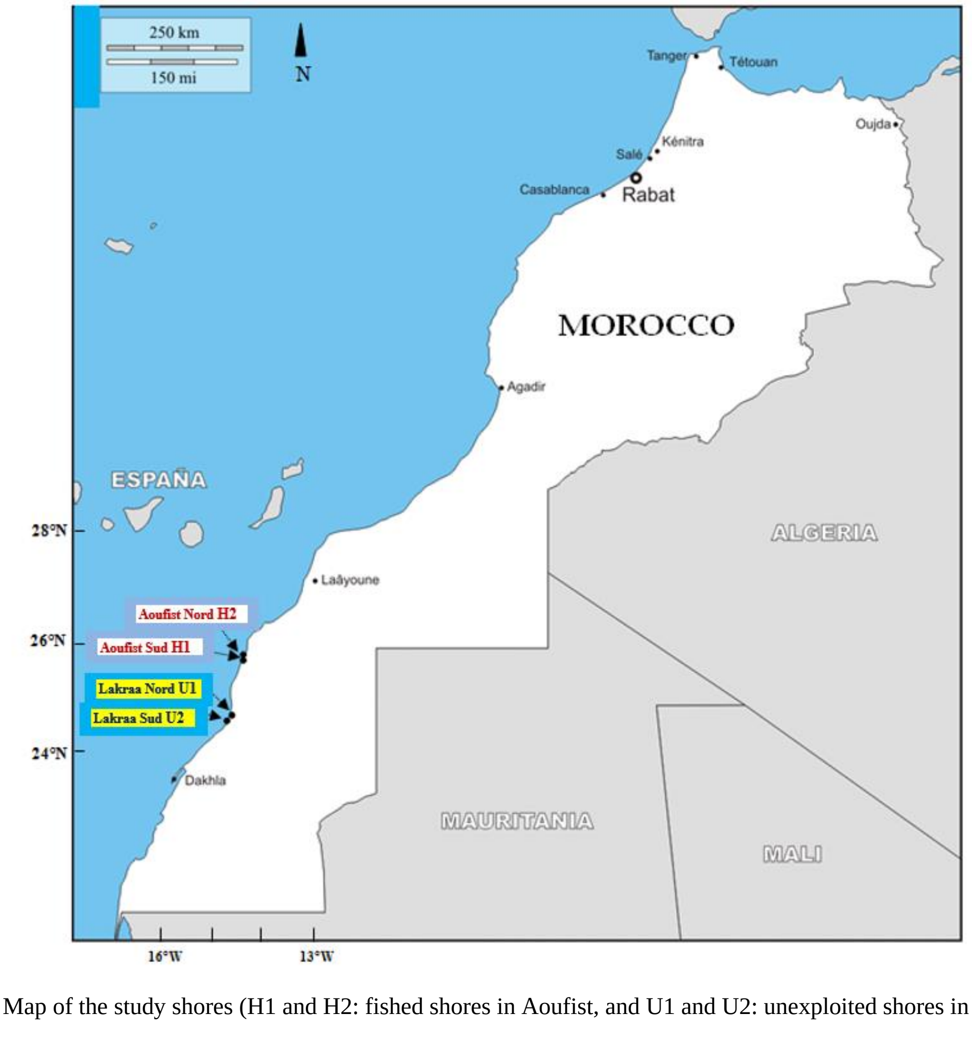


Fig 1: Map of the study shores (H1 and H2: fished shores in Aoufist, and U1 and U2: unexploited shores in Lakraa)

2.2 Biology of *P. perna* and *M. galloprovincialis*

The general pattern of gametogenic activity of *P. perna* was comparable with that of *Mytilus galloprovincialis*. The reproductive cycle of both species spans over the whole year with three spawning periods: two optional (in winter and summer) and one principal in spring [25]. These sexual events were synchronized for the two species and the gonads were ripe in January and February. Recruitment occurred generally between May and September [26] while [25] reported continuous recruitment throughout the year of *P. perna* in Agadir Bay (Morocco). The reproductive effort increases with size independently of the season [25]. The max life span was 24 months in *P. perna* and 28 months in *M. galloprovincialis* [27].

2.3 Sampling Design and Procedures

Density, size and biomass of both species were assessed, before and after the fishing season, at two locations (H1 and H2) where intense fishing occurred and at two controls (U1 and U2) not subjected to human exploitation (Lakraa Nord and Lakraa Sud). During each sampling times (i.e., before and after the fishing season), mussel biomass (fresh weight) and density of both species were estimated within 30 random quadrates of 0.25 m^2 at each location. We took digital photographs of each quadrate. The photographs were analyzed using the computer SigmaScan Pro 5 (developed by Jandel Scientific Software in the late 1980s which was later acquired by SPSS Inc.) to estimate the mean percentage of cover. Random samples of individuals (500 of each species) within quadrates from each location were measured in situ for shell length to the nearest 0.1 mm using a Vernier calliper. Finally, shell length data were used to assign individuals to each of seven size classes (Class 1, < 10 mm; 10 ≤ Class 2 < 20; 20 ≤ Class 3 < 30; 30 ≤ Class 4 < 40; 40 ≤ Class 5 < 50; 50 ≤ Class 6 < 60 and Class 7, ≥ 60 mm).

2.4 Survey methods

The survey was conducted at the fished shores in Aoufist area by making observations and interviewing the fishermen and further documenting the observations with photographs. The interviewees were asked several questions relating to the use of mussels. The photographs were taken in the intertidal zone where exploitation pressure was greatest. The purpose of the survey was to obtain a broad overview of subsistence and informal fishers. A period of one week was allocated for this purpose. Collectors were distinguished from people on the shore because they were observed to be harvesting or searching on rocky platforms, frequently also carrying bags for storing collected animals. It was assumed that any collector within a 1 km radius of a study site could potentially affect that site.

2.5 Data analysis

The data on percentage mussel cover were tested using the non-parametric Kruskal-Wallis tests. Two-way ANOVA was performed to test for differences in density, size, and biomass between locations (harvested vs. unharvested) and sampling time (before vs. after fishing season). Prior to the analysis, Cochran’s C test was used to check the assumption of the homogeneity of variances [28] and, whenever necessary, data were appropriately transformed. Post-hoc multiple comparisons were performed using the Student-Newman-Keuls (SNK) test [29].

3. Results

3.1 Mussel fishery

During the fishing period (June-December 2014), seasonal fishermen came daily from Boujdour city (SW Morocco, Atlantic coast) to collect mussels on the shallow rocky shores of Aoufist. We counted an average of 5 permanent harvesters/day at the fished shores (H1 and H2), whereas no harvesters were ever recorded at the reference shores (U1 and U2). This fishery has been their main input of income; some have other part-time jobs. The mussel fishermen ranged in age from 20 to 40 years. The fishermen had been harvesting for 5 to 10 years for subsistence. Moreover, fishermen did not receive sufficient education by completing only the lower grades because they had been forced to work so young to help their families. In absence of restrictive harvest regulations, mussels were intensively collected on the rocky shores of Aoufist to supply the domestic market (Fig. 2). The fishermen handled themselves the sales of the mussels collected. Until now, there are almost no regulations for the mussel fisheries, except that juvenile mussels should not be taken.

Fig 2: A fisherman moving towards the low intertidal zone after having scraped the mussel bed in the medium intertidal zone

Mussel harvests occurred at low tide, mostly from late spring to autumn. The fishermen used hand tools (i.e., iron bars, spades and shovels) to collect mussels only during daytime, while scuba diving equipment was forbidden. After about 5-6 hours of harvesting, the fishermen collected 400-500 kg (8-10 bags) of mussels. Earlier observations indicated that harvesters did not selected a particular species when collecting. The Aoufist fishery showed recently several signs of overexploitation with any respect to the marketable size (Fig. 3 and Fig. 4). In fact, exploited areas are already characterized by a scattered distribution of mussel patches, so that fisherman has to move continuously from one patch to another.

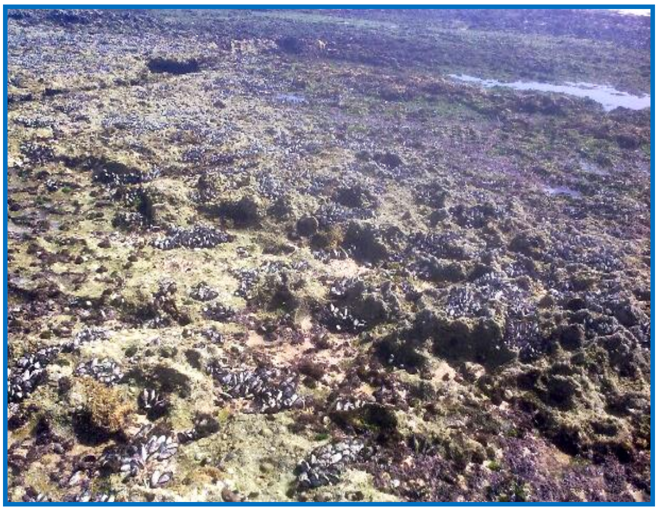


Fig 3: Aggregates of mussels remaining at mid intertidal zone after harvesting Unharvested

Fig 4: Non-selective collection of mussels in plastic bags

Processing of mussels was done close to the site in the same afternoon. The fishermen separated the seed mussels from the clumps and rejected them on the sand, without putting them back into the sea. Therefore, it is urgent to limit this practice by applying a stocking technique for further growth. The mussels to be processed were put in large barrels (50 l) with some seawater (Fig. 5). The mussels were boiled for about 30 min with a fire fueled by the gas cylinder. While being cooked, the mussel meats became loose from their shells. Afterward, the shells were tossed onto a pile next to the cooking area (Fig. 6). The meats were poured after cooling into plastic bags and weighted. The meat product was sold to permanent customers who came daily from Boujdour city.

Fig 5: Area of mussel cooking in Aoufist

Fig 6: Empty shells deposited close to the cooking area

4.2 Mussel cover

Mussel cover decreased significantly at the fished shores (H1 and H2) ($p < 0.01$) while no significant increase occurred at the controls ($p = 0.08$ and $p = 0.22$ in U1 and U2 respectively) (Fig. 7). Kruskal-Wallis tests revealed strong site effects for mussel cover, before and after the fishing season ($p < 0.0001$ for both periods).

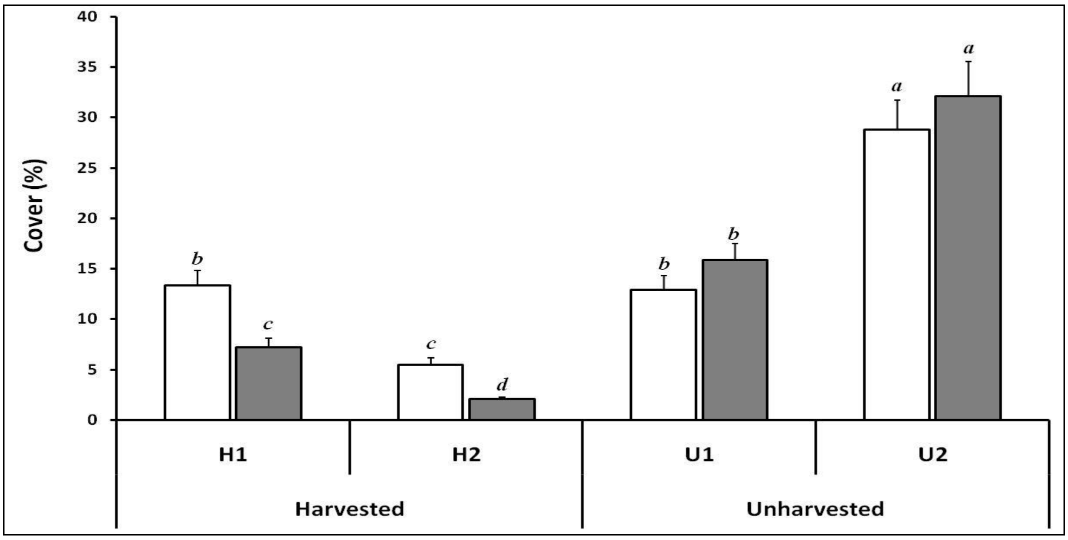


Fig 7: Mussel cover (Mean + SD) at the fished (H1 and H2) and unexploited shores (U1 and U2) before (white) and after (dark) the fishing season. Letters indicate homogeneous groups as determined by multiple comparison Kruskal-wallis tests

4.3 Density

Before the fishing season, mean densities of *P. perna* were 182, 46, 18 and 262 mussels. m^{-2} at H1, H2, U1 and U2 respectively (Fig. 8). After the fishing season, densities of *P. perna* shifted to 110, 39, 28 and 333 mussels m^{-2} at H1, H2, U1 and U2 respectively (Fig. 8). Mean densities of *M. galloprovincialis* varied from 141, 54, 410 and 836 mussels m^{-2} to 73, 8, 556 and 1134 mussels m^{-2} at H1, H2, U1 and U2 respectively. ANOVA tests showed that the interaction "Location × Time" had a significant effect only for *M. galloprovincialis* ($p < 0.01$; Table 1).

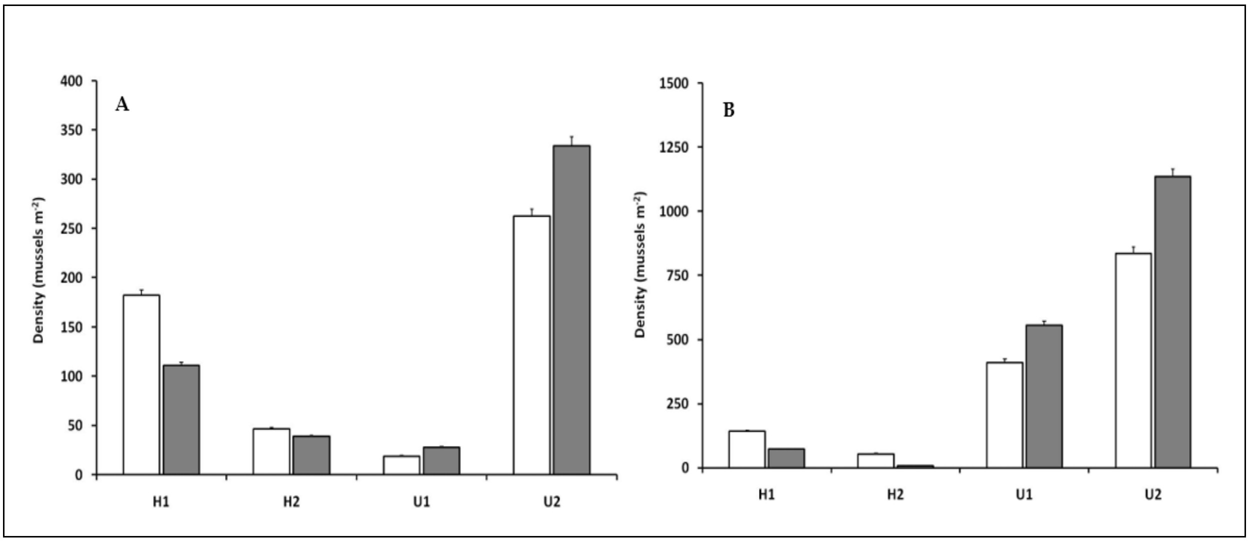


Fig 8: Density of *P. perna* (A) and *M. galloprovincialis* (B) (Mean + SD) at the fished (H1 and H2) and unexploited shores (U1 and U2) before (white) and after (black) the fishing season

Table 1: Results of two-way ANOVA tests of harvesting on density, size, and biomass of *P. perna* and *M. galloprovincialis* within the fished and unexploited locations before and after the fishing season

Source	*P. perna*									*M. galloprovincialis*								
	Density			**Size**			**Biomass**			**Density**			**Size**			**Biomass**		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Location = L	1	5,407.9	7.42^{1}	1	41.7	1.35	1	168.2	0.006	1	551,319.2	239.36^{2}	1	888.37	43.40^{1}	1	1086,595.6	170.24^{2}
Time = T	1	1.6	0.01	1	96.4	3.13	1	116,739.2	4.43^{3}	1	9,133.5	3.96	1	0.017	0.01	1	2,826.2	0.44
L × T	1	1,803.4	2.48	1	995.4	32.38^{2}	1	250,880.0	9.53^{1}	1	25,675.8	11.14^{1}	1	353.34	17.26^{2}	1	60,472.5	9.47^{1}
Residual	236	728.5		1,996	30.7		236	26,302.4		236	2,303.29		1,996	20.46		236	6,382.4	
Transformation		$\sqrt{x+1}$			none			none			$\sqrt{x+1}$			none			none	

$^{1} = p < 0.01$. $^{2} = p < 0.001$. $^{3} = p < 0.05$.

Student-Newman-Keuls (SNK) test evidenced that density of *M. galloprovincialis* was always higher at the reference shores both before and after the fishing season (Table 2). The test also demonstrated that density of *M. galloprovincialis* was higher after the fishing season only at the control shores. However, density of *P. perna* was higher at the unharvested shores only after the fishing season (Table 2).

Table 2: Results of Student-Newman-Keuls (SNK) test on the interaction term "Location × Time"

Source	*P. perna*			*M. galloprovincialis*		
	Density	Size	Biomass	Density	Size	Biomass
Location						
H	B = A[1]	B > A	B > A	B = A	B > A	B > A
U	B = A	B < A	B = A	B < A	B < A	B = A
Time						
B	H = U[2]	H > U	H > U	H < U	H > U	H < U
A	H < U	H < U	H < U	H < U	H > U	H < U

[1] B = Before and A = After. [2] H = Harvested, U =

4.3 Size

Before the fishing season, average size of *P. perna* were 35.4, 48.3, 39.8 and 33.9 mm at H1, H2, U1 and U2 respectively (Fig. 9). After the harvesting period, the results showed a marked reduction of size to 31.4 and 33.4 mm at H1 and H2 respectively. Conversely, average size of *P. perna* increased to reach 45.0 and 37.0 mm at U1 and U2 respectively. Mean size of *M. galloprovincialis* shifted from 31.6 to 22.7 mm in H2, and remained unchanged around 34.4 mm at H1. Conversely, average size increased to reach 29.5 and 22.6 mm at U1 and U2 respectively**.**

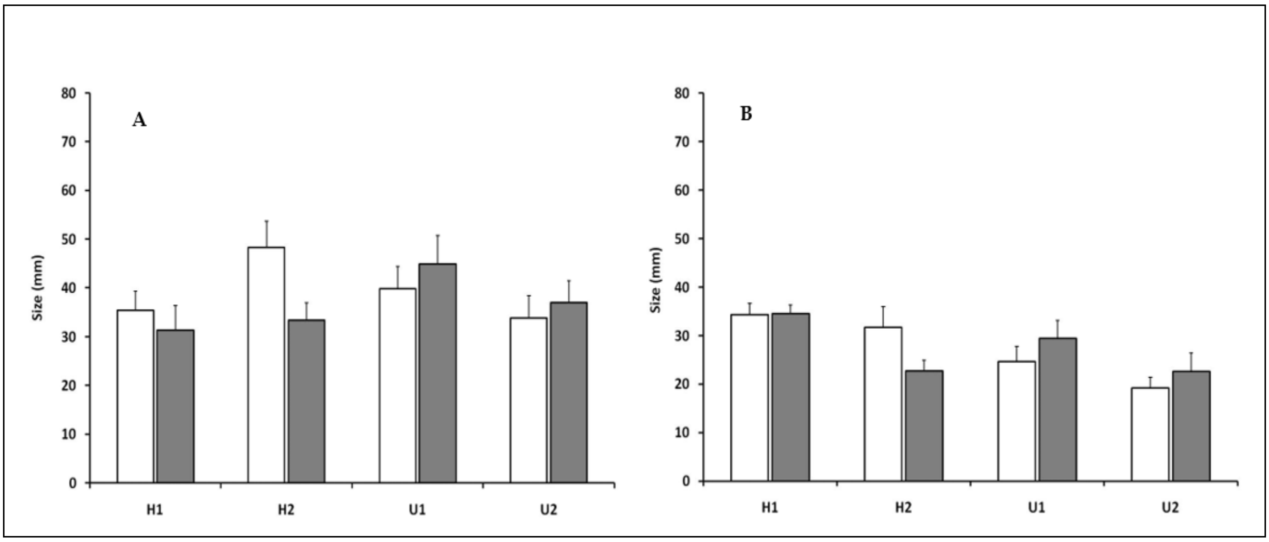
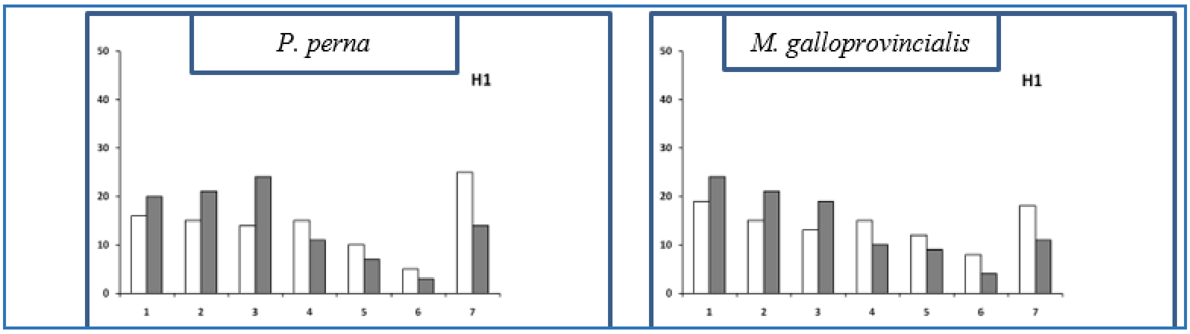


Fig 9: Size of *P. perna* (A) and *M. galloprovincialis* (B) (Mean + SD) at the fished (H1 and H2) and unexploited shores (U1 and U2) before (white) and after (black) the fishing season

After the fishing season, the size-frequency distribution of *P. perna* showed a remarkable decrease of the size class larger than 60 mm at H1 and H2 (Fig. 10). Conversely, mean size of both species was greater at U1 and U2, and size-frequency distribution showed larger modal size classes from 5 to 7 cm (Fig. 10). Analysis of variance detected significant differences for the interaction "Location × Time" for both species (p<0.001; Table 1).



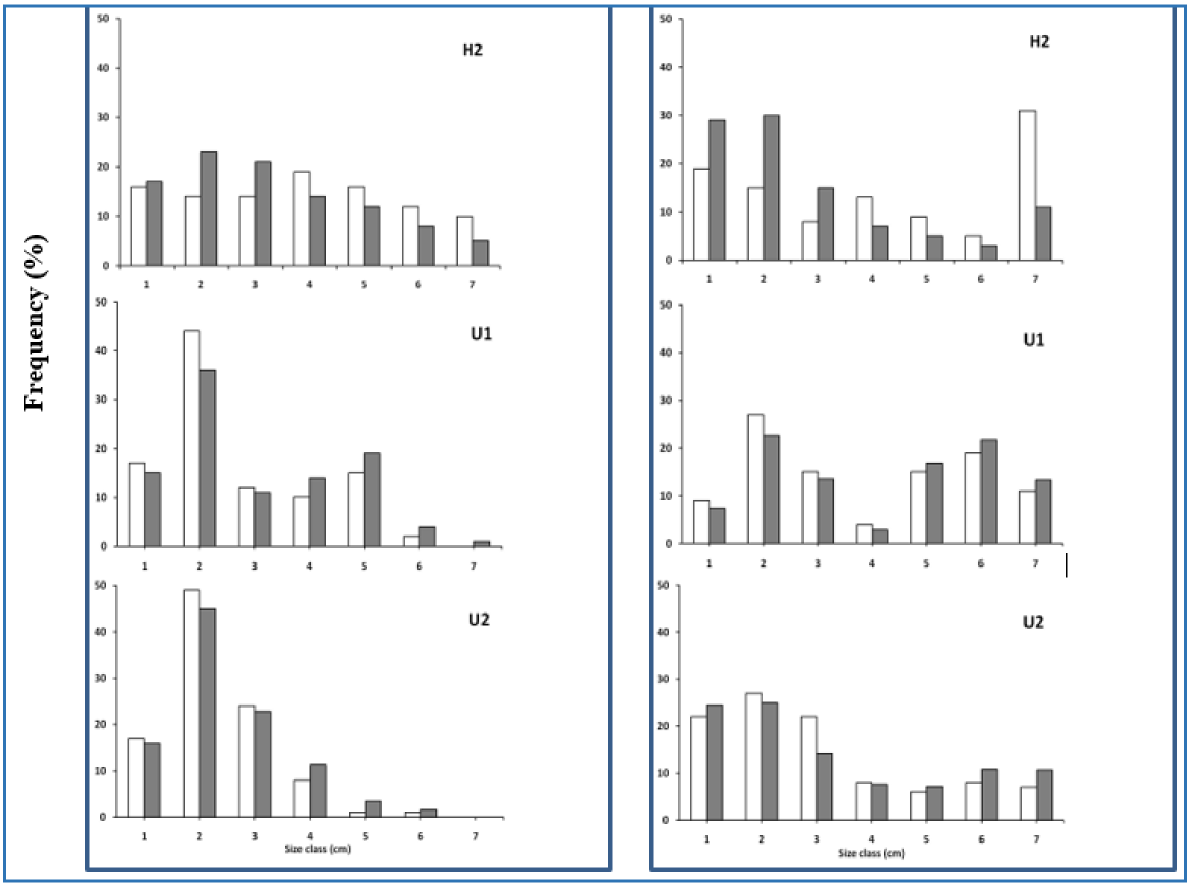


Fig 10: Test size frequency distribution of *P. perna* and *M galloprovincialis* at the fished (H1 and H2) and unexploited locations (U1 and U2) before (white) and after (black) the fishing season (N = 500 at each location for each sampling time)

SNK test showed that mean size of both species decreased significantly after the fishing season at the fished shores, while an increase occurred at the controls (Table 2). Also, mean size of both species was higher before the fishing season at the fished locations, and it was greater only for *P. perna* after the fishing season at the reference shores.

4.5 Biomass

Before the fishing season, mean biomass of *P. perna* were 1947, 606, 172 and 1507 g m^{-2} at H1, H2, U1 and U2 respectively (Fig. 9). After the fishing period, the results showed a marked reduction in biomass of 59 and 57 % at H1 and H2 respectively. Conversely, biomass of *P. perna* increased by 34 and 16 % at U1 and U2 respectively. Mean biomass of *M. galloprovincialis* decreased by 44 and 93 % in H1 and H2 resepctively, and inversely increased by 11 and 18% at U1 and U2 respectively**.**

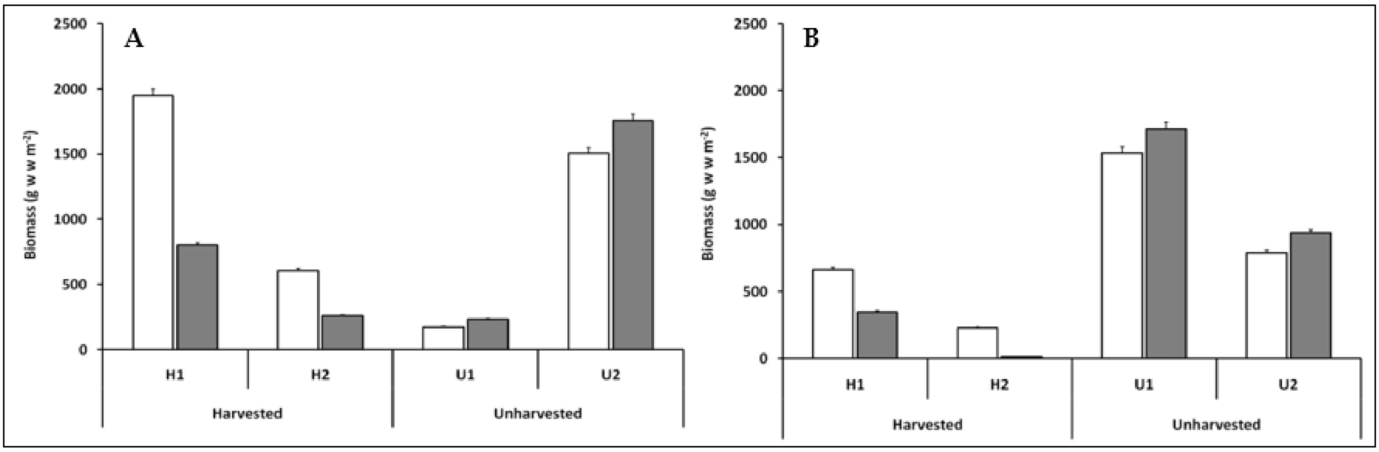


Fig 11: Biomass of *P. perna* (A) and *M. galloprovincialis* (B) (Mean + SD) at the harvested (H1 and H2) and unharvested locations (U1 and U2) before (white) and after (black) the fishing season

ANOVA tests showed significant differences in both species for the interaction “Location × Time” ($p < 0.01$; Table 1). After the fishing season, mean biomass of both species was lower at the fished shores, while it did not differ at the controls (SNK tests, Table 2). However, average biomass of *M. galloprovincialis* was always higher both before and after the fishing season at the reference shores.

4.5 Discussion

This paper is the first to report on human exploitation of mussel populations in Morocco. The results highlighted the impact of fishing at sites H1 and H2 while the references shores (U1 and U2) exhibited healthier mussel populations. At the fished shores, reduced cover and low abundance of large mussels were encountered. Both species were adversely affected by the human collectors. The positive effect on cover, density, and biomass of both species at the reference shores leads us to deduce that fishing pressure at the fished locations has a heavy impact on these resources.

The high reproductive potentials of *P. perna* and *M. galloprovincialis* [30, 31] could explain why the average density did not change significantly after the fishing period at the fished locations. Several studies reported the existence of density-dependent processes that affect growth, recruitment and natural mortality in bivalve species. High adult densities can result in extremely low rates of recruitment, while moderate densities of spawning stock can maximise recruitment [32]. This is due to competition for food and habitat [33, 34] and settling larvae that can be filtered passively by adult individuals, inhibiting the settlement and subsequent recruitment [33, 35]. Based on the trends of biomass of both species, it is evident that human exploitation has been intensive at the fished shores. This equates to losses of 44-93 % and 57-59 % of the initial biomass of *M. galloprovincialis* and *P. perna* respectively, due to uncontrolled fishing effort. To our knowledge, no natural processes such as storms, disease, or predation, could be responsible for such a decline after a short period of 8 months. Although the turnover rate of both species is high, this study suggests that mussel populations at the fished locations are at risk and are poorly suited will to withstand human harvesting pressure. Decline of adult biomass due to controlled fishing effort can even be determinant factor for the success of next year's catches [36]. The largest individuals of both species were removed at the fished shores, and these were also the main contributors to spawning. Exploitation of molluscs is often selective, affecting the largest and most fecund individuals [37-40]. However, the comparison of the size-frequency distribution before and after the fishing period, reported not only a reduced abundance of individuals of commercially valuable size (≥ 60 mm), but also individuals of the smaller illegal sizes (30-59 mm for *M. galloprovincialis* and 40-59 mm for *P. perna*). Shifts in the size structure of a population towards smaller and younger individuals may also result in a disproportionate decrease in the reproductive ability of the population because the reproductive potential increases exponentially with size [41]. Furthermore, restrictions must be enforced in Aoufist area to prevent the harvest of undersized individuals allowing mussels to grow a more marketable size and reproduce at least once before capture. At the reference shores, the number of large mussels in 5-7 cm size classes increased after the fishing period. Non-exploited sections of the coast such as U1 and U2 areas may act as important buffer zones or sources areas from which species can recolonize, providing recruitment to adjacent shorelines where collecting takes place [42]. The presence of inaccessible areas near to the fished locations can seed recruits to adjacent exploited areas and help to achieve resilience to overexploitation.

One indicator of mussel depletion is the size of mussels at sexual maturity and the preferred collection size for harvesters [43]. If the size at sexual maturity is less than the collected size, the exploited animals normally include reproducing individuals. If, however, the size at maturity is greater than the collected size, there is a serious risk that removal of large numbers of reproductively active individuals that will drastically reduce the reproductive output of the population [39]. The size of first sexual maturity of *P. perna* is 25–30 mm [39], while *M. galloprovincialis* is mature after 1 year of settlement with a shell length 28-46 mm [7, 27, 44]. Thus, the exploited sizes of *M. galloprovincialis* include the size at first sexual maturity, suggesting that harvesting pressure is severe enough to cause reproductive failure, but the presence of smaller sizes (class 1, 2) at the harvested shores showed little to no evidence of recruitment failure.

Marine protected areas (MPA´s) are used as management tools in order to allow previously over-fished populations to recover [45]. However, the presence of fish predators in MPA´s did not contribute to the enhancement of mussel populations, as mussel beds are subjected to trophic cascade effects through fish predation [46]. The development of techniques which allows the successful transplanting of juveniles may provide the basis for a management strategy [47] and maybe rotational cropping elsewhere [48, 13]. However, rotational cropping is not a viable management strategy for fisheries in which harvesting can transform community structure [49]. Evidence suggests that such changes may take long time periods (if ever) to be reversed. A more viable management strategy is to use zonation to protect representative sections of the coast in the long term and to institute controlled harvesting at predetermined levels at other sites and conduct *in situ* monitoring of stocks and community structure to allow an adequate evaluation of optimal harvesting [49].

5. Conclusion

The present study evidenced that human exploitation dramatically affected the condition of the mussels at the fished shores in Aoufist area. These results should be considered as a starting point to define which measures can best prevent irreversible damage of mussels, and provide a database for further monitoring studies. Because the mussel resources have been degraded in the Aoufist area, it is possible that the increasing pressure of fishing will move in the coming years to the unharvested shores further south. These data underline the urgent need not only to protect the mussel beds at the fished shores in Aoufist area, but also to prevent their decline in several areas along the Atlantic coast of Morocco. Appropriate management strategies (e.g., the observation of the minimum fishable size, catch quotas, and rotational fishery) could be sufficient to manage the resource, avoiding overfishing and decline of this fishery.

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