
**E-ISSN: 2347-5129**
**P-ISSN: 2394-0506**
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2018; 6(4): 186-191

www.fisheriesjournal.com
Received: 14-05-2018
Accepted: 17-06-2018

**Jawad Kassila**
CSZIAM, Department of Aquaculture, National Institute of Fisheries Research, INRH, M'diq, Morocco

**Mohamed Ellilouchi**
Department of Fisheries, INRH, Casablanca, Morocco

**Mohamed Idhalla**
Department of Aquaculture, INRH, Casablanca, Morocco

**Correspondence**
**Jawad Kassila**
CSZIAM, Department of Aquaculture, National Institute of Fisheries Research, INRH, M'diq, Morocco

# Temporal variability in abundance and population structure of the edible sea urchin *Paracentrotus lividus* in relation to harvesting: A case study in the intertidal zone of Aoufist (SW Morocco, Atlantic Ocean)

**Jawad Kassila, Mohamed Ellilouchi and Mohamed Idhalla**

**Abstract**
The sea urchin (*Paracentrotus lividus)* fishery was investigated in the shallow rocky shore of Aoufist (SW Morocco, Atlantic Sea), heavily impacted by the harvesting activities. Test diameter, biomass and size-frequencies were assessed from January 2012 to December 2014. The results highlight suggestive evidence that intense fishing may cause reduction in the average size and biomass because of the selective harvesting of largest specimens ($p < 0.05$). Moreover, the individuals larger than 5 cm in size as the threshold size for commercialization were rare and accounted for less than 10% of the populations surveyed. The present study also highlights that the reproductive performance of sea urchin was reached early at 2-3 cm in size. This may be due to an adaptation to the disturbing conditions generated by the harvesting activities. A new management strategy is needed to guarantee the sustainability of the fishery of Aoufist. In lack of useful information on the commercial biomasses, the managers continued to set fixed quota per fishing season.

**Keywords:** *Paracentrotus lividus*, fishery, overexploitation, size, dynamic, size-frequency

## 1. Introduction
Several sea urchin species are intensively harvested for the delicacy of their gonads [1]. Therefore, a number of edible species are commercially harvested around the world [2], which led, in some cases, to strong reductions of their wild populations [3-6]. The consequent overfishing of commercial sea urchins led to the enforcement of specific management policies through catch quotas, rotational fishery and aquaculture, to allow stock restoration. A number of studies have examined effects of harvest restrictions on the edible sea urchin (*Paracentrotus lividus*) populations from the Mediterranean Sea [7-11]. Studies specifically addressing similar issues on Atlantic populations of the edible sea urchin are, however, scarce. The reproductive cycle of *P. lividus* has been investigated in a wide range of regions, determining parameters such as the spawning period and size at first maturity [12-15]. However, little is known about the variability in the reproductive cycle of this species on a small scale. The habitat characteristics can lead to intra-population variation in the spawning period or in the period of maximum gonad production. Furthermore, this information needs to be taken into account when appropriate management and exploitation strategies are determined for the local population.
In Morocco, *P. lividus* is exploited in the shallow rocky shores along the Atlantic coast, accessible at or near low tide. However, the influence of harvesting on condition of sea urchin populations is poorly investigated, and new management strategy is needed to guarantee the sustainability of these fisheries. Particularly, sea urchins were intensively exploited in the intertidal zone of Aoufist (SW Morocco, Atlantic Ocean), and their abundance decreased drastically in absence of a sustainable management strategy. No comparative study of the abundance patterns and distribution of urchins was previously carried out in this fishery, in spite of their potential importance for economically and ecologically relevant issues. The present study, therefore, is aimed at providing information the effects of harvesting on density, size and biomass and population structure of this target species in the fishery of Aoufist. The main objective was to provide information of interest for the managers. This paper also reports some results concerning recruitment and spawning periods of the sea urchin in the fished location.

## 2. Materials and methods

### 2.1 Sampling site

The present study was carried out in the Aoufist area (25°43'35.04"N, 14°38'52.08"W) (SW Morocco, Atlantic Ocean). This area is formed by large flat rocks and exposed to waves. The populations of sea urchins (*Paracentrotus lividus*) are often distributed in patches. Since 2007, the Marine Fisheries Department (DPM) implemented minimum size limits, restricted access and seasons in the urchin fisheries. Commercial exploitation of urchins occurs mostly from late autumn to late winter (December - March period), when the gonads get the most valuable size and texture for the market. The professional harvesters used hand tools to collect urchins only during daytime and at low tide, while the use of scuba diving equipment is forbidden.

### 2.2 Sampling methods

Samples were collected monthly between January 2012 and December 2014 in the intertidal zone of Aoufist at low tide periods. Using a 50 ×50 cm metal frame, we collected sea urchins located in the central part of five patches through handling. All urchins in the samples were counted and measured (diameter without spines, ± 0.1 mm) to estimate the population density. All sea urchin length measurements were pooled so that size frequency distributions of populations could be assessed visually.

### 2.3 Laboratory methods

For the study of the gonadal somatic index (GSI), a mean of 50 sea urchins per month were analysed following Quin and Kojis (1987) [30]. The specimens were wet-weighed (± 0.01 g), and through the visual analysis of the gonads, the sex was determined. The gonads and the contents of the digestive tract were wet-weighed (± 0.001 g) and set aside for calculation of gonadal and feeding indices. The remainder body was dried (48 h at 60°c) and weighed (DW, ±0.001 g).
The five gonads were dry-weighted (DW) and used to calculate a gonadal somatic index (GSI) of the form:

$$GSI = \frac{\text{DW of 5 gonads}}{\text{DW of body}} \times 100$$

For the estimation of a feeding index, we used a more direct measure of the consumption rate, and the gut contents of specimens were dry-weighed (DW) and used to calculate a repletion index (RI) following Guillou *et al*. (2010) [31]:

$$RI = \frac{\text{DW of gut contents}}{\text{DW of body}} \times 100$$

### 2.4 Estimated landings and total biomass assessments

The estimated landings were assessed through the analysis of the fishery-dependent data. These data were derived from harvest logbooks and validation logs. Three quantitative surveys were conducted in April of each year from 2012 to 2014 (just after the fishing season) in order to assess the biomass of sea urchins. We counted and measured urchins occurring within 0.25 $m^2$ quadrat that was flipped over the substrate every 5 m along the transect lines, following a lead line. In total, we sampled 60 quadrats along ten transects lines, perpendicular to the shoreline from the low to the high intertidal zones. These surveys had been conducted at or near low tide. The samples were weighed to the nearest gram and the lengths were recorded to the nearest millimetre using Vernier callipers.

### 2.5 Statistical analyses

Statistical analyses were performed mainly by one-way ANOVA for unbalanced designs and Tukey tests. Prior to performing parametric tests, the assumptions of normality and homoscedasticity were tested by Kolmogorov Smirnov and Bartlett tests, respectively. No transformation of the data was necessary. The XLSTAT was used for the analyses. All tests were declared significant for $p < 0.05$.

## 3. Results

### 3.1 Temporal variability in sea urchin populations

The mean densities of sea urchins between 2012 and 2014 are shown in Fig. 1. Pooled density decreased significantly from 2012 to 2013 ($p < 0.008$). Thereafter, there has been an increase in density at 2014, not significantly different from that recorded in 2012 ($p = 0.661$). Average test diameter of *P. lividus* decreased significantly from 2012 to 2014 ($p < 0.0001$) (Fig. 1). Mean biomass and density followed the same pattern with a significant decrease from 2012 to 2013 ($p < 0.001$) (Fig. 1). Mean biomass was greater at 2014 but not significantly different from that reported at 2012 ($p = 0.172$).

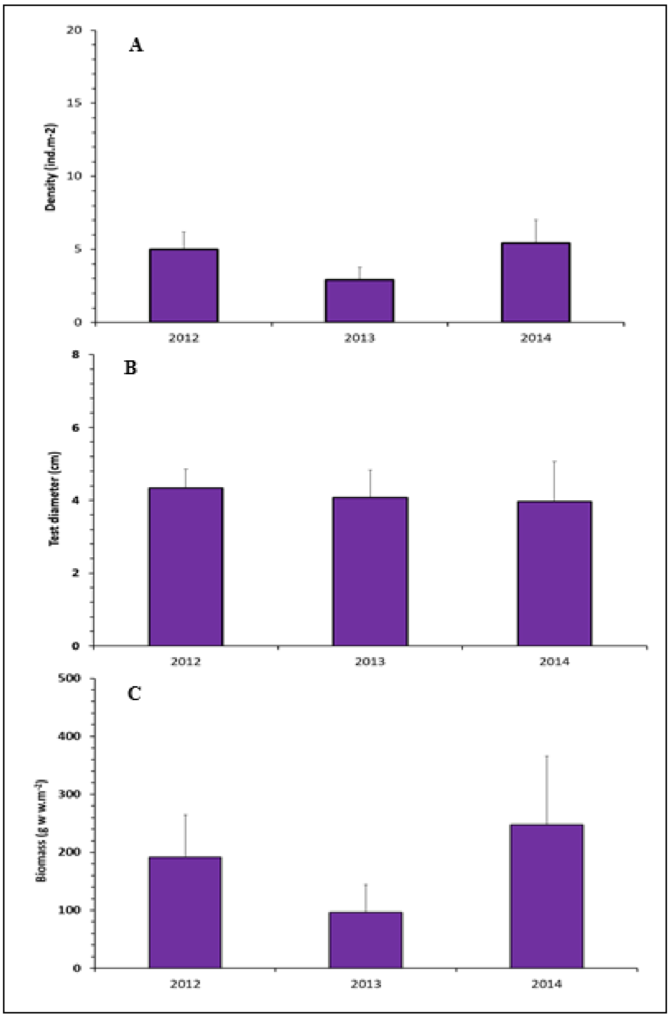


**Fig 1:** Density (A), test-diameter (B) and biomass (C) (Mean values ± S.D) of the edible sea urchin between 2012 and 2014

The size frequency distributions showed a tight range of sizes and fitted a unimodal curve both in 2012 and 2013 (Fig. 2). A single mode was formed by urchins from 3 to 5 cm, representing 86 % of the urchin population. The dominance of these classes suggested that the recruitment was very low or absent both in 2011 and 2012. Small urchins (< 2 cm in diameter) were less conspicuous. In 2014, the urchins from 3 to 5 cm represented 60% of the population, and the size distribution was skewed towards small size classes: 2-2.9 cm, 3-3.9 cm and 4-4.9 cm. This abundance of small urchins in 2014 was due to the recruitment and a significant rise of the recruits (1-1.9 cm) was then reported. Overall, the individuals larger than 5 cm (threshold size for commercialisation) accounted for less 10% between 2012 and 2014.

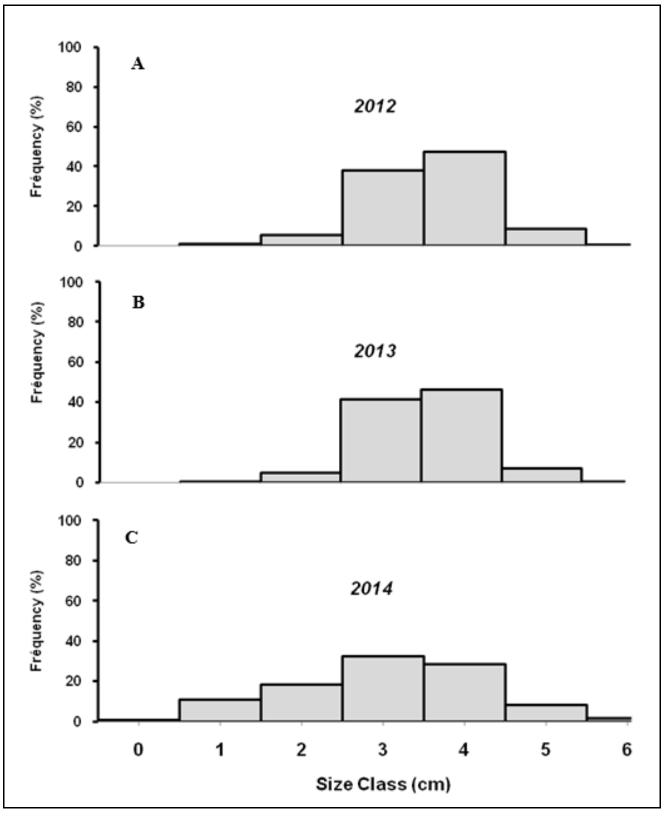


**Fig 2:** Mean size frequency distribution of the edible sea urchin in 2012 (A), 2013 (B) and 2014 (C). Size classes: 0 = 0-0.9 cm, 1 = 1-1.9 cm, 2 = 2-2.9 cm, 3 = 3-3.9 cm, 4 = 4-4.9 cm, 5 = 5-5.9 cm, 6 = 6-6.9 cm

### 3.2 Reproductive parameters

From 2012 to 2014, the sex-ratio of *P. lividus* did not deviate significantly from 1:1 in the Aoufist area ($p = 0.313$) (Fig. 3), and the females (50.1%) seemed to be present in equal proportion with males (49.9%).

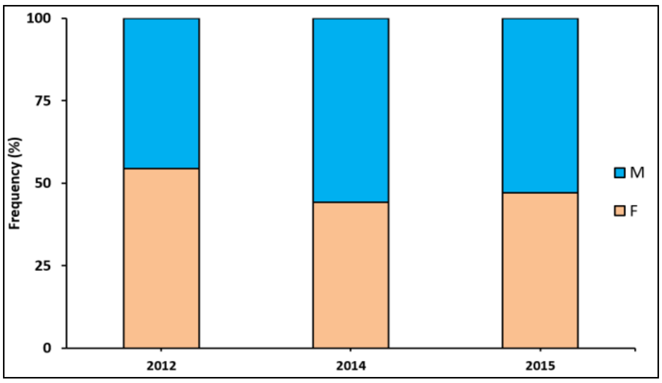


**Fig 3**: Frequency (%) of sex ratio in the edible sea urchin between 2012 and 2014. M: Males and F: Females

The monthly changes in Gonadal Somatic Index (GSI) are shown in Fig. 4. The mean values were 6.1, 8.4 and 7.0 in 2012, 2013 and 2014 respectively. The statistical test showed no significant difference in GSI from 2012 to 2014 ($p = 0.131$). The temporal trend of GSI from 2012 to 2014 showed generally two peaks, in February and in July. The monthly changes in GSI were monitored in order to highlight the spawning periods. A decrease in GSI was visible annually during two different periods, from March to April and from August to September. They probably corresponded to the spawning periods as a complementary histological study was missing.

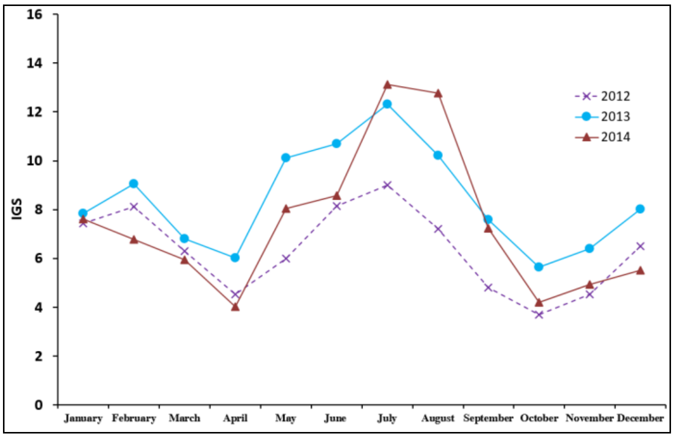


**Fig 4:** Monthly trend of the gonadal somatic index (GSI) in the edible sea urchin (Mean values ± S.D) between 2012 and 2014

The relationship between GSI and size (all years pooled) is presented in Fig. 5. There was a sharp rise in GSI for urchins having 10-30 mm in diameter, and then the GSI course reached a plateau. The values of the repletion index varied markedly with size and the curve levelled off from sizes ≥ 30 mm. The trend of RI and GSI indices were almost parallel in these populations, indicating a coincidence between the life stages at which there was an increase in feeding activity and in gonadal development.

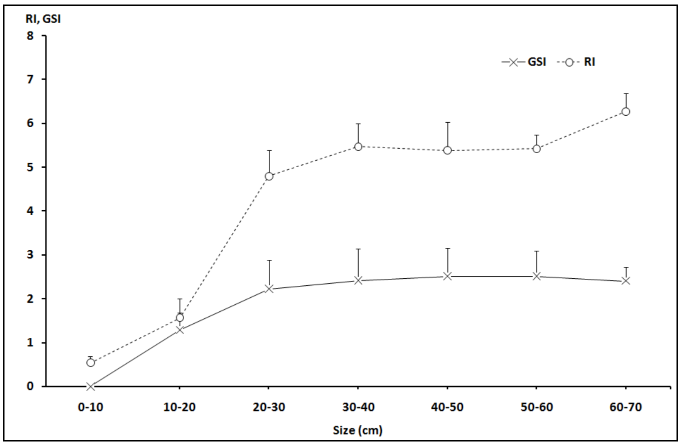


**Fig 5:** Variations of the repletion index (RI) and the gonadal somatic index (GSI) as a function of size in the edible sea urchin (bars are standard deviations)

### 3.3 Estimated landings and total biomass assessments

The sea urchin landings estimated from the harvest logbooks were close to achieving the quotas fixed in 2010-2011 and 2014-2015 fishing seasons (Fig. 6). The lowest landings were, however, observed for 2011-2012 and 2013-2014 fishing seasons. Indeed, only 10-50% of the quota has been landed.

Due to the low demand, no quota has been granted for 2012-2013 fishing season.

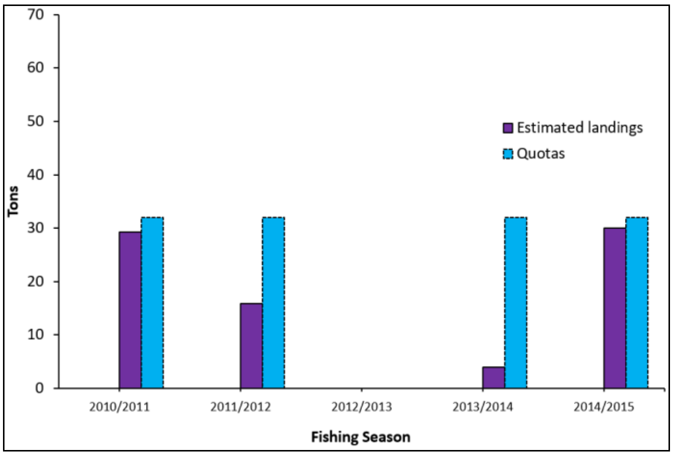


**Fig 6:** Estimated landing and quota in metric tons of the edible sea urchin by commercial fishing season

The total biomass of *P. lividus* in the Aoufist area was assessed annually through the analysis of fishery–independent data. These data were obtained from one survey per year, done after the fishing season. The minimum legal size is 50 mm, which corresponds to 2 year olds in the Atlantic coast of Morocco. The results showed that the total biomass of the legal-sized urchins (≥ 5 cm) remained between 2012 and 2014 less than 1.3 tons in the Aoufist location (Fig. 7).

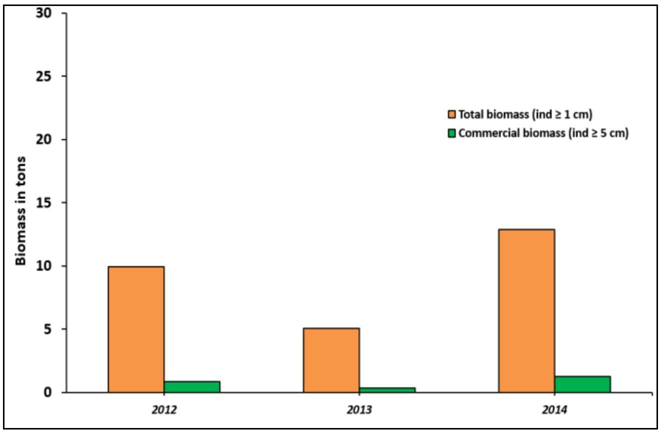


**Fig 7:** Total (ind ≥ 1 cm) and commercial (ind ≥ 5 cm) biomasses of the edible sea urchin from 2012 to 2014

## 4. Discussion

### 4.1 Temporal variability in sea urchin populations

The decreases in density and biomass observed both in 2012 and 2013 were mainly attributed to the fishing pressure. About 15 and 29 tons of sea urchins were harvested in 2012 and 2013 respectively. However, no severe rarefaction of the large-sized was recorded in 2013 and remained about 10 % of the total population. Thereafter the density and biomass increased significantly in 2014 as no fishing quota was granted in 2013. Similarly, the results emphasized the effect of human exploitation on the test diameter of the edible sea urchin [5]. In absence of age information, the size frequency distributions were plotted to investigate the population structure. Since the fishing was highly selective in size, the abundance of the largest sea urchins (usually ≥ 5 cm) decreased drastically after the fishing seasons. This fundamentally distinguishes humans from other predators as chiefly fish, usually feeding intermediate size, around 2-4 cm [16]. The size distribution of urchins in presence of intense fish predation is often bimodal, as juveniles (< 2 cm) remain sheltered [17]. The dominance of 3-5 cm individuals both in 2012 and 2013 suggested that the recruitment was very low or absent in 2011 and 2012. The recruitment was here defined as the set of smaller individuals (< 2 cm). Individuals belonging to the size class (1-1.9 cm) are assumed to be recruits of the previous year like suggested by Lopez *et al.* 1998 [18] and Sala *et al.* (1998) [19]. The shape of the size distribution did not evolve normally from 2012 to 2013 due to the inconsistent recruitment during the previous years; they did not give sufficient rise to successive classes. Several factors may determine the size structure of sea urchin populations as recruitment [20,21], disease [20], physical [22]and predation [23,24]. This lack of recruits should be considered by the managers to establish a new suitable strategy. Moreover, this area not experienced any severe storm or other phenomena that delayed the recovery of sea urchins during the experimental period. The recruitment depending on the climatic conditions involved in the settlement of post-larvae did not show the inter-annual variability between 2012 and 2013. The presence of small classes in 2014 could indicate that the recruitment and/or immigration were successful, especially after the unharvested season (2012-2013).

### 4.2 Reproductive parameters

The sex ratios in sea urchins balanced 1:1 in the study area, may change depending on the characteristics of the environment and the sexual maturity condition. The monitoring of the gonadal somatic index (GSI) in the edible sea urchin showed a clear annual pattern with gonad development in February and May-July period. Furthermore, the first spawning period was probably modulated by the phytoplankton abundance [25, 26]. Moreover, the gonadal somatic index (GSI) remained easy to measure but less reliable due to the fact that is greatly affected by the nutritive tissue of the gonad [27]. Indeed, the histological observation of the gonads will provide the most reliable methods for assessing the reproductive cycle of sea urchins. When the gonads were studied histologically, a single annual gametogenic cycle with one spawning season was found [28, 29, 30, 21]. However, little is known about the size at first maturity in the edible sea urchin. Our results highlighted that the trend of GSI with size was tied and the reproductive performance of sea urchin was reached early at 2-3 cm in size. This may be due to an adaptation to the disturbing conditions generated by the harvesting activities. Generally, the increase in GSI as a function of size occurred less abruptly in stable community as in TOSSA (Barcelona, Spain) [21]. This study also showed that the nutritive index (RI) and GSI followed the same pattern. Accordingly, this timing indicated that the allocation to gonadal development explained a good deal of the variability in feeding activities.

### 4.3 Estimated landings and biomass assessments

In the assessments of landings, a source of uncertainly could be due to the fishery-dependent data which were completed by the fishermen. The low landings estimated during 2011-2012 and 2013-2014 fishing periods were attributed to the weak demand of consumers and were not indicative of the abundance of urchins. However, the analysis of the fishery–independent data showed that the total biomass exhibited striking fluctuations from one year to another with a clear drop in 2013. The total biomass of the legal-sized urchins (≥ 5 cm) remained less than 1.3 tons between 2012 and 2014. The laws regulating *P. lividus* fisheries are rarely enforced, so that authorized fishermen and occasional collectors, freely exploit local populations [32]. In lack of useful information on the commercial biomasses, the managers continued to set 28-32 tons as a regular quota per fishing season. Effect of harvest restrictions on populations of *P. lividus* have been investigated only in recent years, providing shifting findings [7, 9, 10]. The unique use of the fishery-dependent data could be problematic because they often exhibit hyper-stability [33]. The catch and effort data between 2007 and 2013 were considered uncertain. The difference between the estimated landings and the total biomasses showed clearly the illegal activity of the fishermen. To complete the quotas allocated to them, the fishermen harvested large quantities of urchins from the unauthorized areas. This fact should be considered by the managers who will have to request useful information on the ranges of sustainable harvest quotas and the recent trends of the population structure of sea urchins.

**5. Conclusion and recommendations**

The negative effect of harvesting activities on density, size and biomass of *P. lividus* evidenced in this study leads us to conclude that fishing pressure on edible sea urchin has a heavy impact in the fishery of Aoufist. Since the fishing was selective in size, the abundance of individuals ≥ 5 cm decreased drastically after the fishing seasons. The dominance of 3-5 cm individuals suggested that the recruitment was very low or absent. Therefore, the shape of the size distribution did not evolve normally due to the inconsistent recruitment. The present study also highlights that the reproductive performance of sea urchin was reached early at 2-3 cm in size. This may be due to an adaptation to the disturbing conditions generated by the harvesting activities.

A new management strategy is needed to guarantee the sustainability of the fishery of Aoufist. In lack of useful information on the commercial biomasses, the managers continued to set fixed quota per fishing season. The managers must apply rigorous measures to prevent irreversible damage of the sea urchin stocks. The assessment results using the most recently available commercial catch and survey information will need to be updated regularly.

**6. Acknowledgements**

The authors thank Dr. Karim Hilmi, Dr. Malainine Malainine and Dr. Hassan Nhhala for their encouragement and their support to conduct this study. We also would like to acknowledge the anonymous reviewers for their comments and suggestion that improve the manuscript.

**7. References**


1. Lawrence JM. Edible sea urchins: biology and ecology. Elsevier, Amsterdam, 2001.
2. Andrew N, Agatsuma Y, Ballesteros E, Bazhin AG, Creaser EP, Barnes DKA *et al*. Status and management of world sea urchin fisheries. Oceanography Marine Biology Annual Review. 2002; 40:343-425.
3. Smith AH, Berkes F. Solutions to the ‘tragedy of the commons’: sea-urchin management in St. Lucia, West Indies. Environmental Conservation. 1991; 18:131-136.
4. Agatsuma Y. Ecology of *Strongylocentrotus intermedius*. In: Lawrence, J.M. (Ed.), Edible Sea Urchins: Biology and Ecology. Elsevier, Amsterdam, 2001, 333-346.
5. Carter SK, VanBlaricom GR. Effects of experimental harvest on red sea urchins (*Strongylocentrotus franciscanus*) in northern Washington. *Fishery Bulletin*. 2002; 100:662-673.
6. Chen Y, Hunter M. Assessing the green sea urchin (*Strongylocentrotus droebachiensis*) stock in Maine. USA. Fisheries Research. 2003; 60:527-537.
7. Guidetti P, Bussotti S, Boero F. Evaluating the effects of protection on fish predators and sea urchins in shallow artificial rocky habitats: a case study in the northern Adriatic Sea. Marine Environmental Research. 2005; 59:333-348.
8. Gianguzza P, Chiantore M, Bonaviri C, Cattaneo-Vietti R, Vielmini I, Riggio S. The effects of recreational *Paracentrotus lividus* fishing on distribution patterns of sea urchins at Ustica Island MPA (Western Mediterranean Italy). Fisheries Research. 2006*;* 81:37-44.
9. Ceccherelli G, Pinna S, Sechi N. Evaluating the effects of protection on *Paracentrotus lividus* distribution in two contrasting habitats. Estuarine Coastal Shelf Science. 2009; 81:59-64.
10. Pais A, Chessa LA, Serra S, Ruiu A, Meloni G, Donno Y. The impact of commercial and recreational harvesting for *Paracentrotus lividus* on shallow rocky reef sea urchin communities in North-western Sardinia. Italy Estuarine Coastal Shelf Science. 2007; 73:589-597.
11. Pais A, Serra S, Meloni G, Saba S, Ceccherelli G. Harvesting effects on *Paracentrotus lividus* population structure: a case study from northwestern Sardinia, Italy, before and after the fishing season. Journal of Coastal Research. 2012; 28:570-575
12. Haya de la Sierra D. Biología y ecología de *Paracentrotus lividus* en la zona intermareal. Dissertation. Universidad de Oviedo, Spain, 1990.
13. Spirlet C, Grosjean P, Jangoux M. Reproductive cycle of the echinoid P*aracentrotus lividus*: analysis by means of the maturity index. Invertebrate Reproduction & Development. 1998; 34(1):69-81
14. Sánchez-Espana AI, Martínez-Pita I, García JF. Gonadal growth and reproduction in the commercial sea urchin *Paracentrotus lividus* (Lamarck, 1816) (Echinodermata: Echinoidea) from southern Spain. Hydrobiologia. 2004; 519:61-72
15. El Jouhari S, Rharbi N, Id halla M, Belhsen OK. Reproductive cycle of the edible sea urchin *Paracentrotus lividus* (Lamarck, 1816) (Echinodermata: Echinoidea) in the coastal region El Jadida-Safi (Atlantic Ocean, Morocco). Journal of Marine Biology & Oceanography 2014; 3:4
16. Sala E, Zabala M. Fish predation and the structure of the sea urchin *Paracentrotus lividus* populations in the NW Mediterranean. Marine Ecology Progress Series. 1996; 140:71-81.
17. Sheibling ER. The role of predation in regulating sea urchin populations in eastern Canada. Oceanologica Acta. 1996; 19:421-430.
18. Lopez S, Turon X, Montero E, Palacin C, Duarte C, Tarjuelo I. Larval abundance, recruitment and early mortality in *Paracentrotus lividus* (Echinoidea). Interannual variability and plankton-benthos coupling. Marine Ecology Progress Series. 1998; 172:239-251.
19. Sala E, Ribes M, Hereu B, Zabala M, Alva V, Coma R, Garrabou J. Temporal variability in abundance of the sea-

urchin *Paracentrotus lividus* and *Arbacia lixula* in the northwestern Mediterranean: Comparison between a marine reserve and an unprotected area. Marine Ecology Progress Series. 1998; 168:135-145.

20. Azzolina JF. Contribution à l'étude de la dynamique des populations de l'oursin comestible *Paracentrotus lividus* (Lmck). Croissance, recrutement, mortalité, migrations. Thèse doctorat. Université Aix-Marseille II, 1988.
21. Lozano J, Galera J, Lopez S, Turon K, Palacin C, Morea G. Biological cycles and recruitment of *Paracentrotus lividus* (Lamarck) (Echinodermata: Echinoidea] in two contrasting habitats. Marine Ecology Progress Series. 1995; 122:179-191.
22. Turon X, Giribet G, Lopez S, Palacin C. Growth and population structure of *Paracentrotus lividus* (Lamarck) (Echinodermata: Echinoidea) in two contrasting habitats. Marine Ecology Progress Series. 1995; 122:193-204.
23. Boudouresque CF, Caltagirone A, Lefevre JR, Rico V, Semroud R. Macrozoobenthos de la reserve naturelle de Scandola (Gorse, Mediterranee nord-occidentale). Analyse pluriannuelle de l'effet réserve. In Impact économique des espaces côtiers protégés de Méditerranée (Olivier J., Gerardin, N. & Jeudy de Grissac, A., eds) Impact économique des espaces côtiers protégés de Méditerranée. Secrétariat du MEDPXN publication. Ajaccio, 1992, 15-20.
24. Savy S. Les predateurs de Paracentrotus lividus (Echinodermata).In: Boudouresque CF (ed) Colloque International sur *Paracentrotus lividus* et les oursins comestibles. GIS Posidonie, Marseille, 1987, 413-423.
25. Starr M, Himmelman JH, Therriault JC. Environmental control of green sea urchin, *Strongylocentrotus droebachiensis*, spawning in the St. Lawrence Estuary. Canadian Journal of Fisheries and Aquatic Sciences. 1993; 50:894-901.
26. Himmelman JH. Phytoplankton as a stimulus for spawning in three marine invertebrates. Journal of Experimental Marine Biology and Ecology. 1975; 20:199-214.
27. Gonor J. Reproductive cycles in Oregon populations of the echinoid, *Strogylocentrotus purpuratus* (Stimpson). I. Annual gonad growth and ovarian gametogenic cycles. Journal of Experimental Marine Biology and Ecology. 1993; 12:45-64.
28. Pearse JB, Cameron RA. Echinodermata: Echinoidea, Giese AC (Ed.), Echinodermata and Lophophorates. 1991. Boxwood Press, Pacific Grove CA 513-662.
29. Byrne M. Annual reproductive cycles of the commercial sea urchin *Paracentrotus lividus* from an exposed intertidal and a sheltered subtidal habitat on the west coast of Ireland. Marine Biology. 1990; 104:275-289.
30. Quinn NJ, Kojis BL. Reproductive Biology of *Scylla spp*. (Crustacea: Portunidae) from the Labu Estuary in Papua New Guinea. Bulletin of marine science. 1987; 41(2):234-241.
31. Guillou M, Lumingas LJL, Michel C. The effect of feeding or starvation on resource allocation to body components during the reproductive cycle of the sea urchin *Sphaerechinus granularis* (Lamarck). Journal of Experimental Marine Biology and Ecology. 2000; 245:183-196.
32. Guidetti P, Terlizzi A, Boero F. Effects of the edible sea urchin, *Paracentrotus lividus*, fishery along the Apulian rocky coast (SE Italy, Mediterranean Sea). Fisheries Research. 2004; 66:287-297.
33. Squires D, Vestergaard N. Productivity growth, catchability, stock assessments, and optimum renewable resource use. Marine Policy. 2015; 62:309-317.