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# Artisanal Harvest of Shellfish in the Northeastern Atlantic: The Example of Limpet and Topshell Fisheries in the Archipelago of Madeira

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## Abstract

The harvesting of littoral benthic shellfish in the archipelago of Madeira dates back to the fifteenth century when the Portuguese discovered and colonized the archipelago. The consumption of littoral shellfish is part of the gastronomic cultural heritage of this region, appreciated by the local population and tourists, and has a high social and economic importance. Therefore, harvesting pressure on these resources is one of the greatest concerns, and as such, a sustainable exploitation based on proper regulation, considering the biological and ecological specificities of these species in their particular habitat, is crucial to promote the preservation of species and habitats at medium and long terms. This study presents the current harvesting management regime for gastropods in the archipelago of Madeira and characterizes the artisanal harvest through a period of 27 years (1990–2017) providing new insights for future research in these topics. This artisanal harvesting operates mostly by small vessels (<10 m), with low tonnage and capacity, in nearby areas preferentially in the North coast of Madeira and around Desertas Islands. During the studied period, management actions resulted in the reduction of 50% of the vessels operating in the harvesting of limpets and in slight recovery of the stocks of limpets. The economic impact of limpets gradually increased over the years, representing in 2017 96% of the economic value landed for molluscs and 2% of the total landings in this region. The present characterization provides a comprehensive outlook of the evolution of the marine gastropod harvest in the archipelago of Madeira and allows future comparisons with other regions where gastropods are commercially exploited.

**Keywords:** harvesting, management, sustainable exploitation, limpets, topshells, archipelago of Madeira

## 1. Introduction

The artisanal fisheries of marine invertebrates in the archipelago of Madeira (NE Atlantic) target mainly gastropods and cephalopods. The main gastropod

species harvested are the limpets *Patella aspera* Röding, 1798, and *Patella candei* d'Orbigny, 1840, the topshell *Phorcus sauciatus*, and the whelk or redmouthed rocksnail *Stramonita haemastoma*. Regarding cephalopods, the common octopus *Octopus vulgaris* Cuvier, 1797; the squid European *Loligo vulgaris* Lamarck, 1798; and the orangeback squid *Sthenoteuthis pteropus* (Steenstrup, 1855) are the main target species of this fishery. Additionally, the cuttlefish *Sepia officinalis* Linnaeus, 175, and the European flying squid *Todarodes sagittatus* (Lamarck, 1798) are sporadically captured.

The artisanal harvest of gastropods in the archipelago of Madeira is a low-cost activity, usually carried out by the owner of the vessel accompanied by professional snorkelers. This activity is one of the most important small-scale fisheries in this region, due to the economic and social benefits it provides directly to the coastal communities and indirectly to the whole community. This fishery dates back to the fifteenth century when the Portuguese colonized the archipelago. The good accessibility to the rocky shores prompted the exploitation of marine shellfish resources along the coast. The harvest activity becomes progressively more intensive with the demographic increase of human settlement around the islands' coasts and with the technological progresses that simplify the access to the coast at previously inaccessible areas [1, 2]. This long-term exploitation has changed the population dynamics, due to shifts on the abundance and/or size structure and density of the exploited marine gastropods over the years [3].

In the past, four species of the genus *Patella* were reported for the archipelago of Madeira, namely *Patella aspera* as the most abundant species, *Patella caerulea*, *Patella lusitanica*, and *Patella vulgata* (known locally as “concharéu” due to its large size, sharp edges, and helmet shape). The distribution of *P. candei* (formerly identified as *P. vulgata*), which once occurred in all the islands of the archipelago, became restricted, in the beginning of the twentieth century, to the Selvagens Islands [1]. Presently, *P. aspera* and *P. piperata* (formerly identified as *P. lusitanica*) are common species in all islands from the archipelago of Madeira, *P. candei* (formerly identified as *P. caerulea*) is present in Madeira Island, Porto Santo, and Desertas, while the real *P. candei* is restricted to the Selvagens Islands. Recently new molecular tools developed with novel microsatellite markers using next-generation sequencing suggest the use of *P. candei* for the species from the Selvagens and *Patella ordinaria* for the species of Madeira, Desertas, and Porto Santo islands [4].

Concerning topshell exploitation, two species of the genus *Phorcus* have been harvested in Madeira archipelago since early colonization times. *Phorcus sauciatus* (formerly identified as *Trochus colubrinus* Gould, 1849), the most common species and with a wider geographical distribution, occurring in all islands of the Madeira archipelago, and *Phorcus atratus* are restricted to the Selvagens Islands as the endemic subspecies *Phorcus atratus selvagensis* [5]. Nowadays, *P. sauciatus* continues to be exploited in Madeira, Porto Santo, and Desertas, except in the marine protected areas (MPAs), and *P. atratus selvagensis* is not commercially exploited since its distribution is restricted to the MPA of the Selvagens where harvesting is not allowed.

Both limpet consumption and topshell consumption in Madeira archipelago are part of the gastronomic cultural heritage of this region, appreciated by the local population and tourists alike, and have a high socioeconomic importance. Therefore, harvesting pressure on these resources is one of the greatest concerns. As such, a sustainable exploitation, based on suitable regulation considering the biological and ecological specificities of these species in their particular habitat, is crucial to promote the preservation of species and habitats at medium and long terms.

The aim of present work is to compile and characterize the harvest of limpets and topshells in the archipelago of Madeira, considering and discussing the

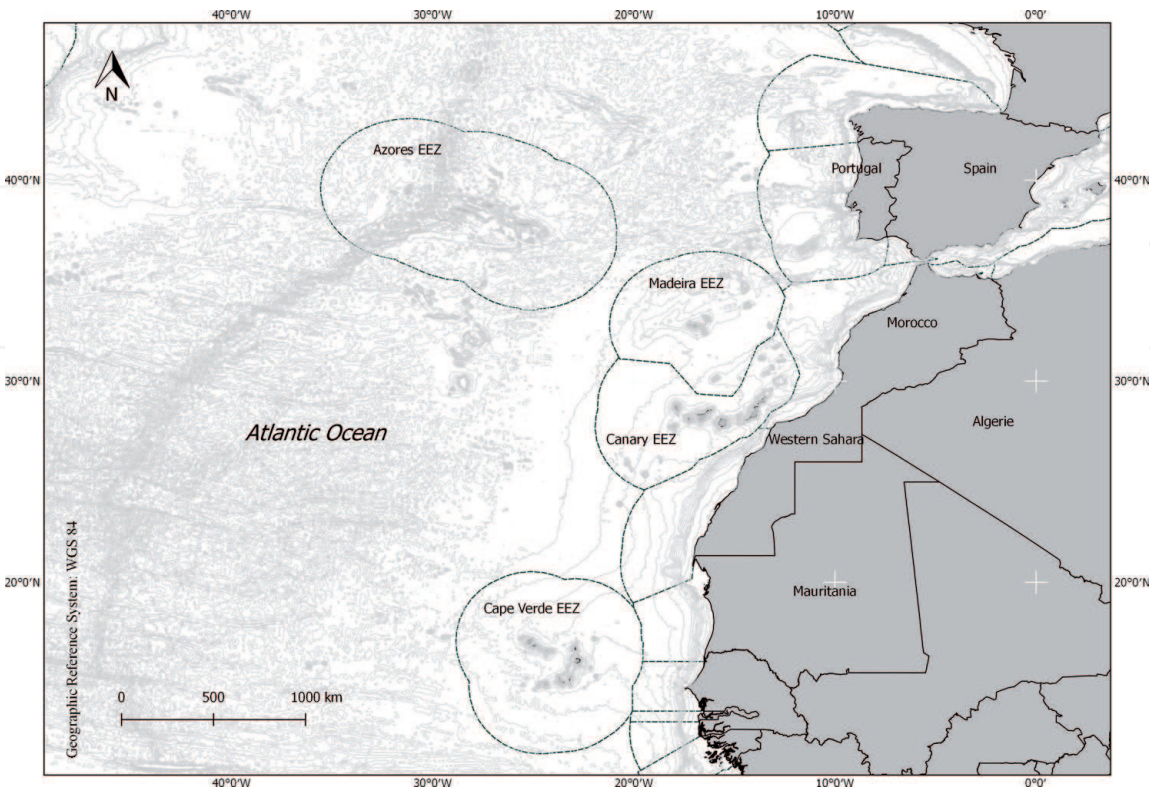
evolution of the landings and economic values and describing the activity, fishing fleets, exploited species, and yields for a period of 27 years (1990–2017). Additionally, the impact of this activity on selected aspects of limpet and topshell population dynamics is analyzed and discussed.

The implemented management measures regulating the harvest of marine molluscs in the archipelago of Madeira are characterized in detail and their impact on the exploited stocks critically discussed through a comparative analysis of any relevant available data on these species from this region. Finally, the economic and social contextualization of this fishery is made in the overall fisheries sector in the region.

## 2. Study area

The archipelago of Madeira is located in the northeastern Atlantic Ocean and is included in the Macaronesian biogeographical region together with the Azores, Canary, and Cape Verde (Figure 1). The islands of these archipelagos are of volcanic origin, resulting from the activity of several geological hotspots and sharing the oceanic nature, the geographic location, and the climatic regime. However, with specific characteristics according to the proximity of the islands to the mainland regions [6].

The archipelago of Madeira comprises the islands of Madeira (741 km<sup>2</sup> of area), Porto Santo (42 km<sup>2</sup>), Desertas (14 km<sup>2</sup>), and the Selvagens islands (3 km<sup>2</sup>). The island of Madeira is located approximately at 635 km from Morocco and at 900 km from the Portuguese mainland. The Selvagens islands are the southernmost territory of Portugal at 239 km from the island of Madeira and at 375 km from the coast of Morocco. This subtropical archipelago is influenced by the Azores anticyclone, the Gulf and the Canary currents, the continental anticyclonic center of Northwest Africa and Western Europe, and the frontal systems associated with the lower pressure center of the polar front [7].



**Figure 1.**  
*Representation of the southern part of the Northeastern Atlantic showing the study area, the archipelago of Madeira, included in the Macaronesian biogeographical region.*



The islands of Madeira and Desertas represent the most recent islands of the archipelago of Madeira with 4.6 and 3.6 million years, respectively. Porto Santo has an estimated age of 14.3 million years and the Selvages islands an estimated age between 24 and 29 million years [8, 9].

The population living in the archipelago of Madeira in 2017 was *ca.* 254 thousand inhabitants, and the fishing activity employed 618 registered fishermen (DRP-RAM). The annual landings increased 38.6% in relation to 2016 with 6.739 tonnes of fish and molluscs corresponding to 21,636 thousand €.

## **2.1 Data collection**

Data on the landings (i.e., species, day, weight, and economic value) and on the artisanal fleet (i.e., length of the fishing vessel, tonnage, capacity, métier, fishery license) were obtained from the Regional Fisheries Department of Autonomous Region of Madeira (DRP-RAM) for both limpets and topshells.

Logbook data analyses were only available to characterize the limpet harvesting activity (i.e., harvesting area, typology of bottom, depth of harvesting, number of divers, number of snorkelers per vessel, and landing place and time), since it is mandatory to fill the logbooks according to the regulation of the limpet harvest in the archipelago of Madeira. For topshells these data are not available due to this activity not being regulated.

Landings data were compiled and analyzed covering the period from 1990 to 2017 and the logbook data from 2008 to 2017, concerning the period after the regulation of the harvesting of limpets that required the filling of all the harvesting information in logbooks.

## **3. Harvesting regulation in the archipelago of Madeira: a driver to sustainable exploitation**

The fisheries sector should protect fish resources and environment through an effective legal regulation and an appropriate compliance and enforcement to ensure the sustainable resource exploitation [10]. Based on this principle, the regulation of limpet harvesting in the archipelago of Madeira sets the basis for a sustainable and responsible exploitation of these resources.

The rules of governing the harvesting of limpets in Madeira were initially set by the necessity to establish proper measures to the regional specificities, with regard to the practice of underwater hunting. These measures were implemented through the article 6 of the Regional Government under the Regional Legislative Decree No 11/1995/M on 21 June 1995 and setting a maximum allowable catch of 3 kg/day per person for limpets. This was the first management action regarding the harvesting of gastropods in the archipelago of Madeira.

The legal regulation of the limpets' harvesting method was decreed by the Legislative order No 1102-B/2000, 22 November 2000, which established the tools and instruments to be used in limpet harvesting.

The current limpets' management in Madeira was based in technical measures implemented by the Regional Government under the Regional Legislative Decree No 11/2006/M, 18 April 2006, which establishes the legal regime for the harvesting of these gastropods in this region [3]. The management measures were implemented in 2006 based on the knowledge obtained from studies on the biology, population dynamics, and assessment of the stocks and intended to advise a precautionary approach capable of harmonizing the need to protect stocks with the preservation of the economic activities associated with their capture and gastronomic use [11].

For this purpose, regulators established several management measures for the traditional and commercial exploitation of the species *P. aspera* and *P. candei*. For the commercial exploitation, a minimum catch size of 40 mm, the obligation of harvesting licenses, logbook provision, the landings and first auction sale, and catch limits were implemented, enforcing the maximum allowable commercial catch of 15 kg/person/day or 200 kg/boat/day, being exempted of any license the traditional harvest that does not exceed 3 kg/day per person.

Additionally, the Legislative Orders No 80/2006 and No 81/2006, 17 June 2006, set the establishment of a closed season between November 1 and January 31 to avoid limpet harvest during the reproductive season and the rules concerning the harvesting card.

In 2009, based on continuous population monitoring, the closed season was changed to become effective between December 1 and February 28 (Legislative Order No 5/2009, 4 July 2009). In 2016, the closed season was extended through the Legislative Order No 40/2016, 17 February 2016, in result of the data obtained from the continuous monitoring of the stocks, in order to more efficiently provide protection to these heavily exploited species, now lasting from December 1 to March 31. The extension of the closed season is intended to result in biological benefits, allowing greater protection of spawning, larvae development, and settlement and to increase the success of annual recruitment and subsequent development of limpets. Additionally, the competent authorities implemented a reduction in the number of harvesting licenses aiming to diminishing the pressure on the resource [3, 12].

Since the implementation of limpet harvest regulation, the non-compliance of the imposed management measures is punishable with administrative offenses and penalties. The sanctions include monetary fines (between 49.88 € and 44,891.81 €), harvesting prohibition, and suspension of harvesting licenses. Nevertheless, poaching continues to occur during the closed season, without abiding the minimum catch size of 40 mm of shell length [3].

The regulation of limpets in the archipelago of Madeira allowed safeguarding the peak of reproduction, the immature specimens, and the catches of both *P. aspera* and *P. candei*. Although the management measures on these resources have been implemented for several years, only a slight recovery on the limpet populations has been observed, maybe due the peculiar life trait characteristics of this species, as slow growth and longevity. Hence, it is of paramount importance to keep up with the enforcement of the implemented measures in order to achieve higher recovery rates of the exploited limpet stocks.

Currently, topshell harvest in the archipelago of Madeira is not regulated, with the exception of harvest ban on MPAs [2]. As such, the effort exerted and the shifts on the populations' dynamics of the harvested populations, exploited for more than 500 years, are unknown. However, management measures based on recent studies [2] are in progress and shall enter into force during the year 2019, aiming to promote both profitable and sustainable harvest. The establishment of a maximum catch of 2 kg per day for noncommercial use and 20 kg per day for commercial use, the implementation of landing obligations and first sale at auction, the establishment of a minimum catch size of 15 mm shell length, and the establishment of a closed season between February and May are recommended [2].

Further European legislation through the European Community Council Regulation No 199/2008, 25 February 2008, prompted an increase in the knowledge regarding the fisheries sector in the European Union, including smaller sections such as limpet harvest, meeting the demands generated by the necessity to evolve toward a sustainable fisheries sector, with its management based on the fleet and fishing areas rather than based on fish stocks. As such, the collection of data and their availability by region will provide the basis for the better scientific advice.

4. Harvesting

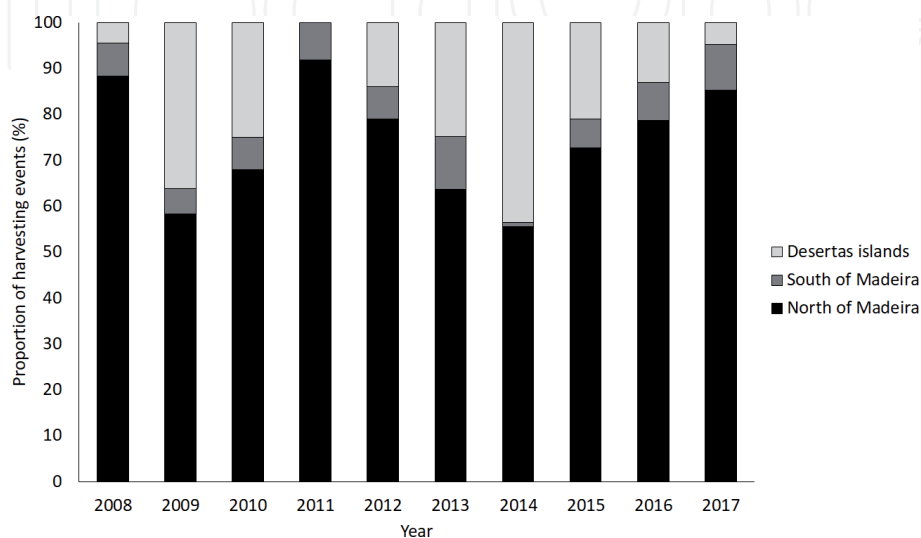
Limpets and topshells are collected by hand, in the intertidal zone by the local population (traditional harvesting) and in the subtidal zone by snorkelers executing several dives per day (commercial harvesting), from 1 to 6 m deep ( $\bar{x} = 1.74 \pm 1.31$ ). The harvesting fleet operates preferentially on the northern coast of Madeira and Desertas Islands (**Figure 2**), the least accessible zones, while traditional harvesters collect limpets from all around the island preferably in areas with easy access and milder sea conditions.

The harvest of limpets in the archipelago of Madeira is operated from April to November for limpets and all year round for topshells mostly by small vessels (<10 m). Between 1990 and 2017, the number of vessels operating on the harvesting of gastropods was reduced from 17 (1990) to 9 (2017) (**Figure 3**). The observed reduction in the number of vessels and licenses results from the implementation of regulation, which among other management measures included the gradual reduction in the number of fishing licenses and vessels in order to reduce the harvesting pressure on limpet stocks.

The majority of the fishing vessels have less than 10 m length (78%), and the remaining ranges between 10 and 12 m (11%) and between 12 and 18 m (11%). This artisanal fleet includes vessels of low tonnage (0.74–17.28 gross tonnage) and capacity between 11 and 136 KW, usually operating in nearby areas reachable in a short time.

Limpet harvest is deeply rooted in the local community and particularly on coastal fishing communities representing an additional revenue source for many families, thus contributing to the local economy. The number of snorkelers per fishing vessel, between 2008 and 2017, varied between two and eight depending on the vessel size ( $\bar{x} = 4.9 \pm 1.29$ ). The number of professional harvesters registered per vessel and nonprofessional harvesters (15 kg/person/day) decreased over the study period following the management measures implemented (**Figure 4**).

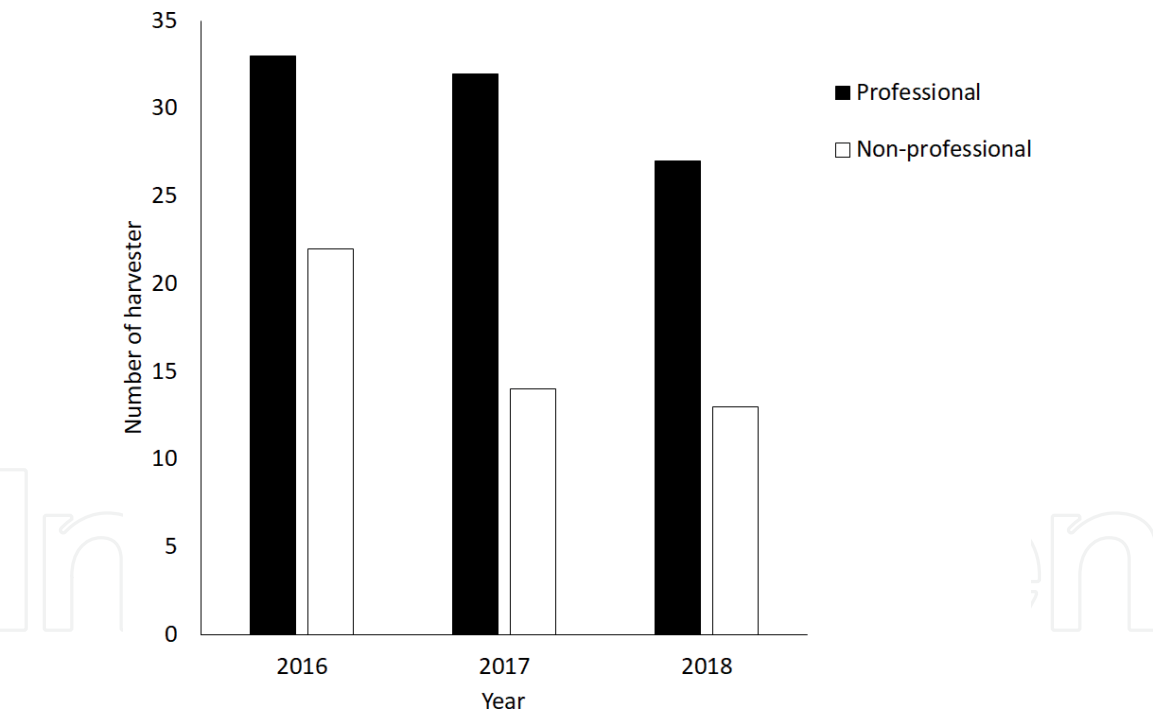
A remarkable proportion of the Madeiran fishing fleet focuses solely on the harvesting of gastropods; nevertheless due to the implementation of a closed season, some fishing fleets operate with two or three métiers. In 2017, 56% of the fishing fleet operated exclusively in the harvesting of gastropods; 33% operated with 3 métiers and 11% with 2 métiers (**Figure 5**). The complementary métiers were essentially directed to the capture of tuna fish and demersal fish.



**Figure 2.**  
*Proportion of harvesting events of limpets per zone based on data from logbooks.*



**Figure 3.**  
Number of fishing vessels operating in the harvesting of limpets from 1990 to 2017 in the archipelago of Madeira.

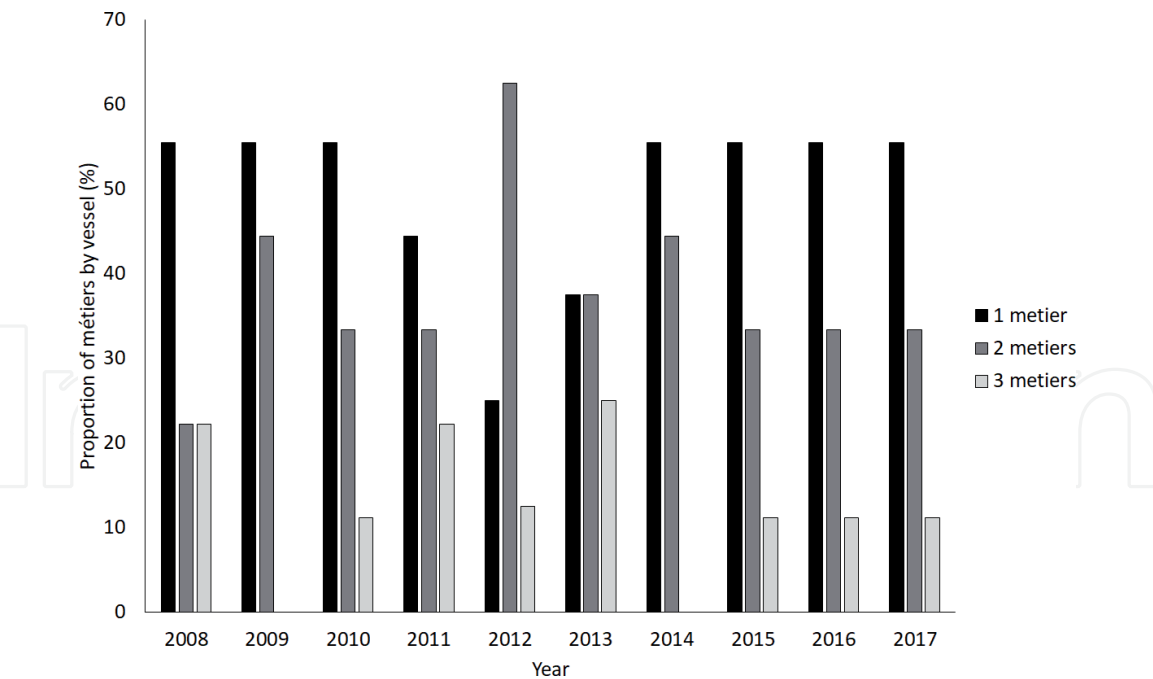


**Figure 4.**  
Number of professional and nonprofessional harvesters registered in the archipelago of Madeira between 2016 and 2018.

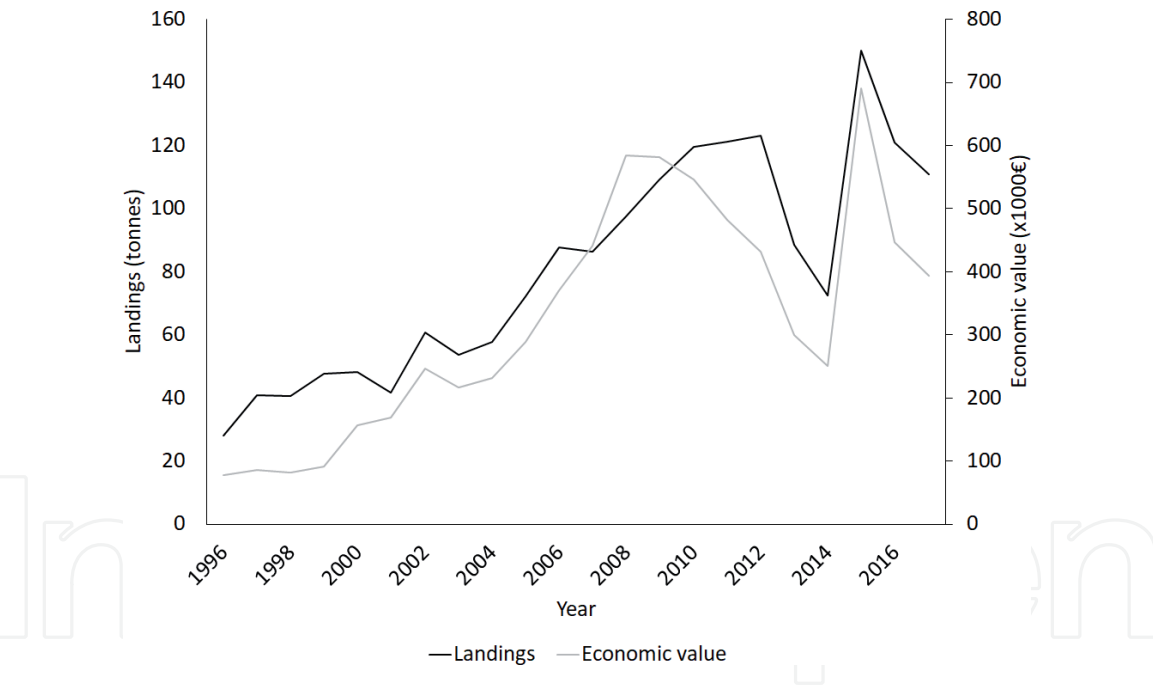
#### 4.1 Species and yields

In the archipelago of Madeira, limpets are mostly harvested by scuba diving in a mixed exploitation of *P. aspera* and *P. candei* with relevant commercial importance [13, 14] for the involved population. This activity represented approximately 1.5% of the total of the fisheries and 2% of the total of the economic value (€) in 2017, reaching an average value of 4 € per Kg [3]. In 2011, this activity represented *ca.* 5% of the total economic value (€) of the fisheries which landed in the archipelago of Madeira.





**Figure 5.** Proportion of métiers operated by the fishing vessels involved in the harvesting of gastropods in the archipelago of Madeira.



**Figure 6.** Representation of landings (tonnes) and economic value (1000 euros) of limpets from 1990 to 2017 in the archipelago of Madeira.

The commercial landings in weight of limpets harvest varied from *ca.* 5 tonnes in 1990 to *ca.* 111 tonnes in 2017 (**Figure 6**). The maximum value landed was 150 tonnes in 2015 yielding a first auction sale value of 0.7 M€. The decrease in landings in 2016 and 2017 is related to the increase of the closed season from 3 to 4 months, reducing the harvesting activity in 1 month which was reflected in the annual landing values. Data from 1990 to 2006 needs to be analyzed carefully since limpet harvesting was not regulated and landing obligation was not mandatory.

The limpets landed in Madeira are for internal consumption and, to a minor extent, for exportation, mainly to the archipelago of Azores. However, data on the exportations of limpets are not available and as such are not possible to determine accurately.

The average annual value of limpets per kg landed in the archipelago of Madeira fluctuated considerably, from 1990 to 2017, increasing from 1.80 € in 1990 to 3.65 € in 2017 ( $\bar{x}=3.33 \pm 1.25$  €). For this period the average annual price varied from 1.21 € in 1990 to 5.90 € in 2008 (**Figure 7**). Since 2008, the value per kg decreased due to the increase in landings and the demand for this resource. Even so, the value per kg is still very attractive for the professionals involved in this activity.

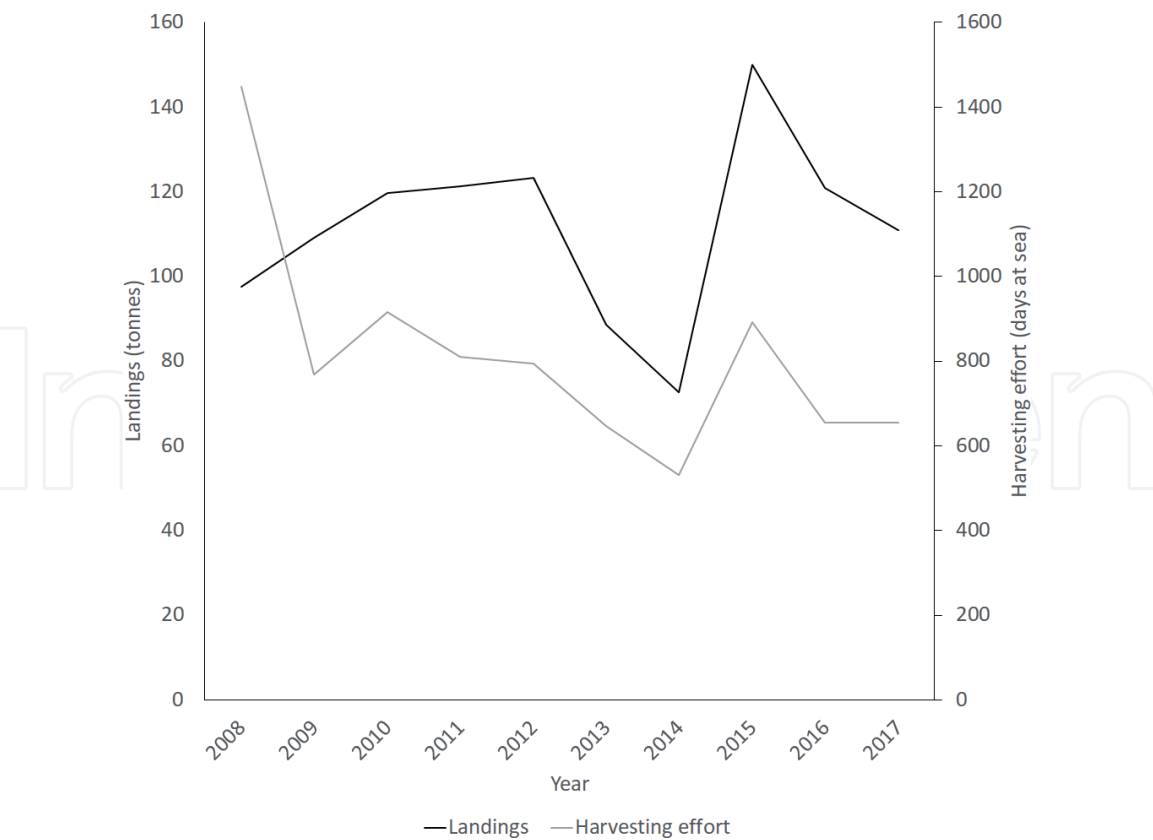
The harvesting effort, represented by the number of days employed in the harvest of limpets, decreased from 1448 days in 2008 to 655 days in 2017. However, in general the reduction in fishing effort contrary to what would be expected led to an increase in the landings (*ca.* 98 tonnes in 2008 to *ca.* 111 tonnes in 2017). From 2013 to 2017, the oscillations on the landings were related to different sea conditions among years, e.g., in 2015 the milder sea conditions resulted in more 361 days at the sea. The increase verified in the landings seems to result from the management measures implemented in 2006 (**Figure 8**). In fact, if the management measures implemented were successful, then it is expected that the exploited stocks have greater biomass, not only in density but also larger individuals are supposedly more abundant which in return means that lower effort returns similar or superior yields.

The highest proportion of landings of limpets, for the considered time period, occurred from May to August, corresponding to the months with better sea conditions in the archipelago of Madeira (**Figure 9**). The comparison between monthly landings before and after the implementation of the closed season showed that the highest proportion of landings remained identical between the two periods, except for the months of the closed season, when limpet harvesting is not allowed.

In the archipelago of Madeira, landings of limpet commercially harvested, between 1990 and 2017, occurred in 10 ports, namely, Funchal, Câmara de Lobos, Calheta, Madalena do Mar, Paúl do Mar, Porto Moniz, Santa Cruz, Machico, Caniçal, and Porto Santo. The total landings per port in tonnes are represented in **Figure 10**. During this period, Porto Moniz, Funchal, Caniçal, and Paúl do Mar were the most important ports representing approximately 96% of the limpets landed in 1990 and 100% of the limpets landed in 2017.

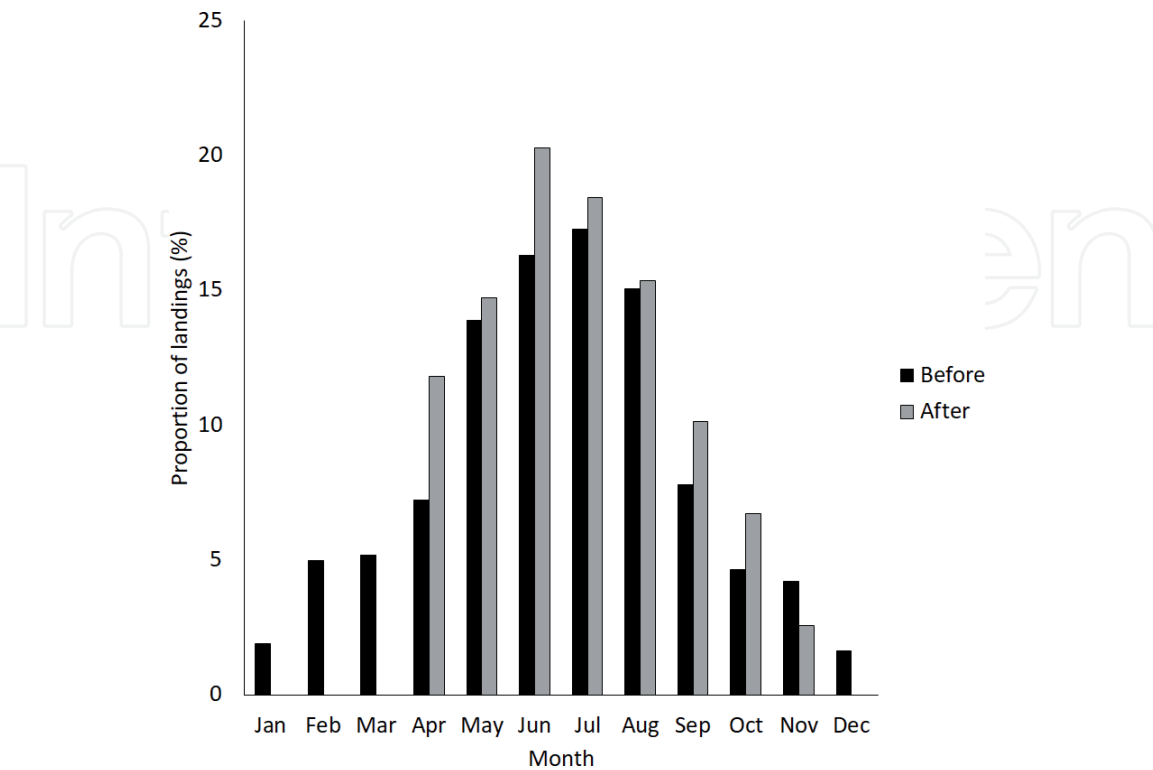


**Figure 7.**  
Average annual price of the limpets landed in the archipelago of Madeira from 1990 to 2017.

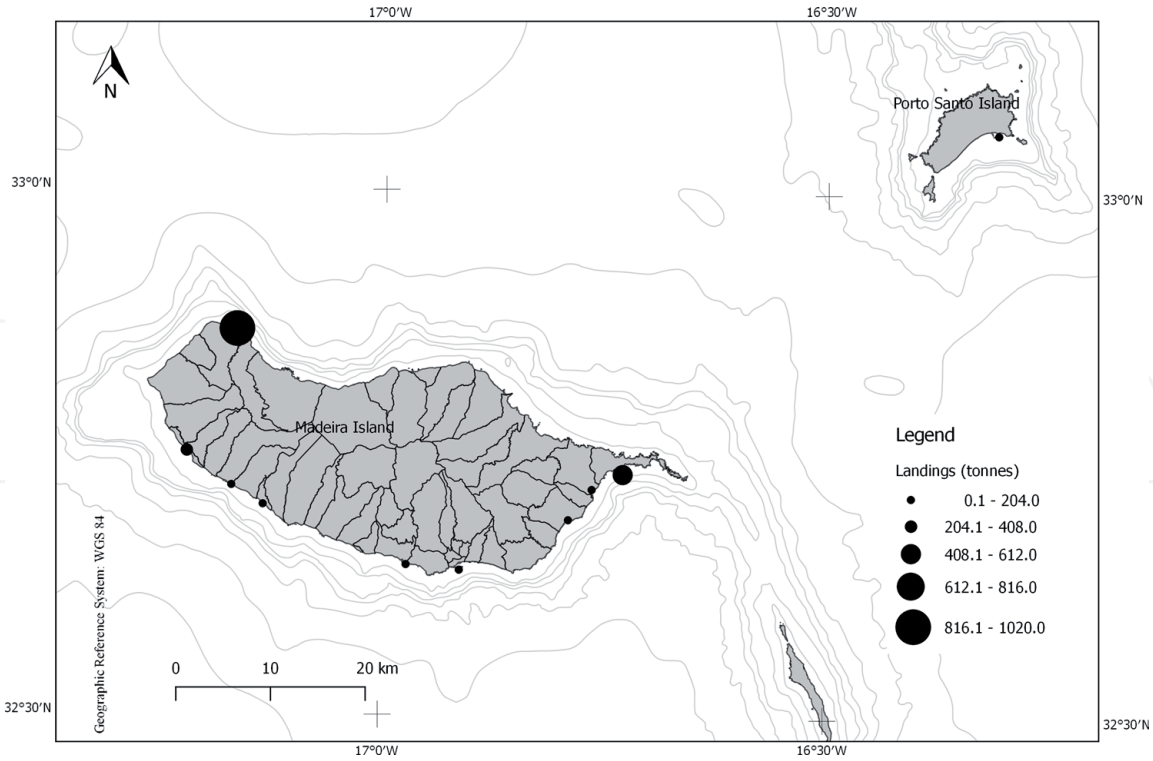


**Figure 8.**  
*Landings and harvesting effort from 2008 to 2017 in the harvesting of limpets in the archipelago of Madeira.*

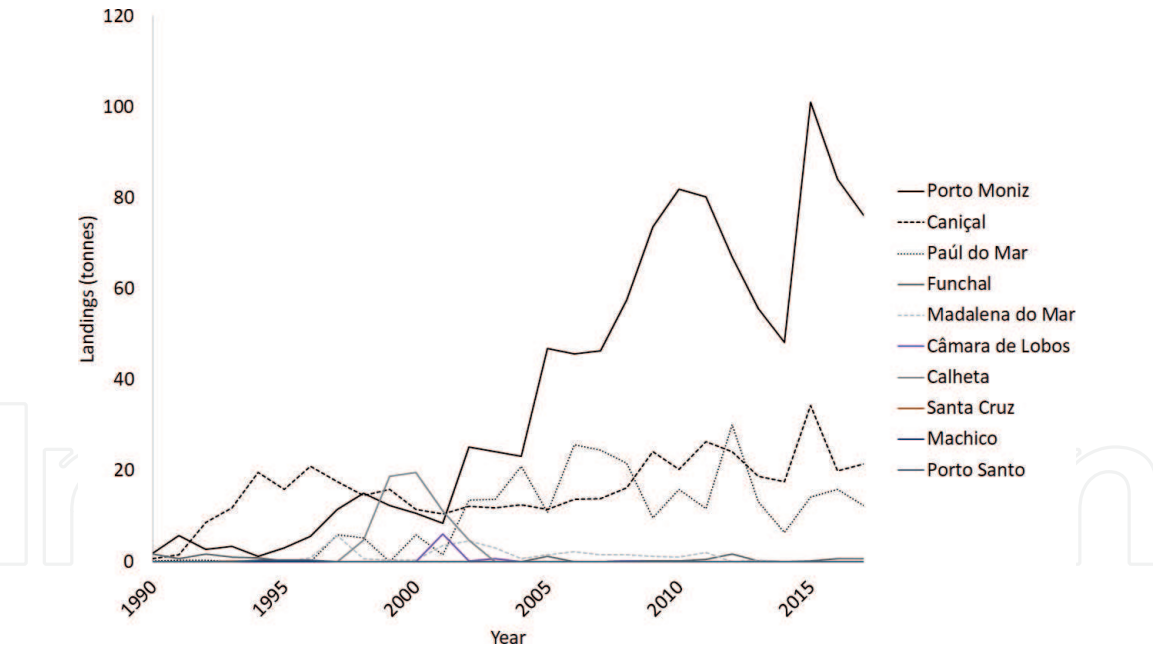
Porto Moniz showed the highest annual limpet landings with 1.9 tonnes in 1990 and 76 tonnes in 2017, representing approximately 69% of the total landings of limpets in 2017 (**Figure 11**). Six fishing vessels landed *ca.* 96 tonnes representing



**Figure 9.**  
*Proportion of landings of limpets per month before (1990–2007) and after (2008–2017) the implementation of management measures in the archipelago of Madeira.*



**Figure 10.**  
*Total landings of limpets per port between 1990 and 2017.*



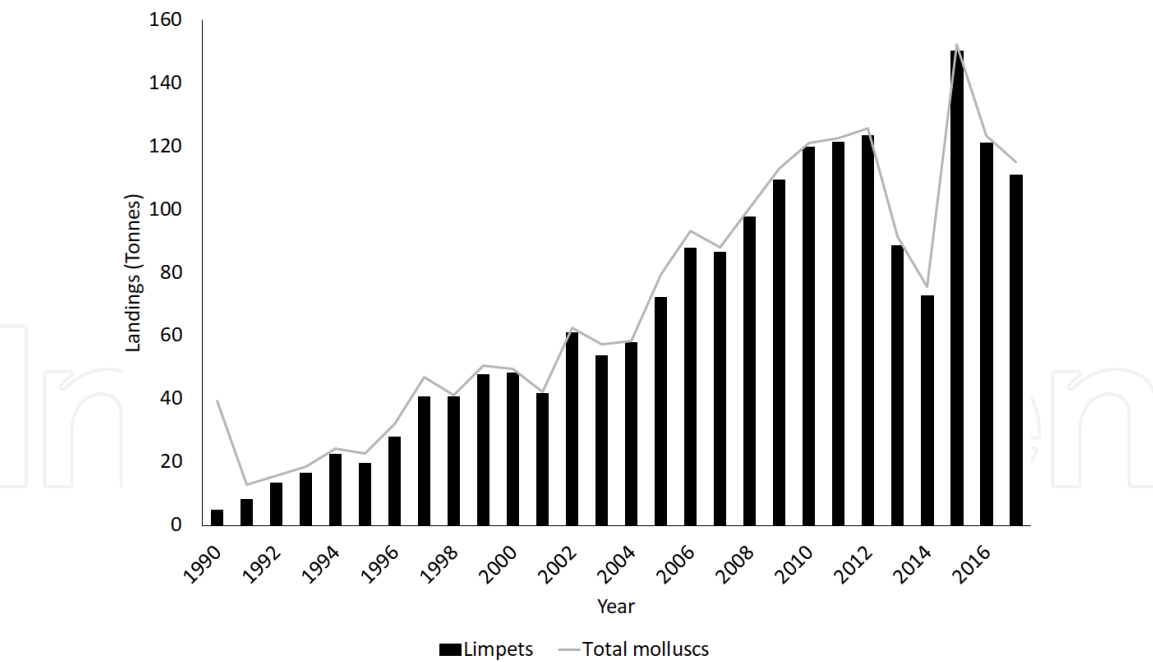
**Figure 11.**  
*Landings of limpets per year considering the landing port.*

86% of the total of limpets landed in 2017. Since 2014, landings of commercially harvested limpets occur only in four ports (Porto Moniz, Caniçal, Paúl do Mar, and Funchal), mainly due to the proximity of the ports to the harvesting zones.

The commercial landings of limpets (in weight) in the archipelago of Madeira increased from 12% in 1990 to 96% of the total of molluscs landed in this region (**Figure 12**). Since 1998, limpets represent >90% of the landed molluscs in weight, increasing in importance over the years.

The economic importance of limpets in the fisheries sector of the archipelago of Madeira gradually increased over the years. In 1990, limpets represented





**Figure 12.**  
*Landings of limpets and the landings of the total molluscs per year, between 1990 and 2017 in the archipelago of Madeira.*

approximately 26% of the total economic value landed for molluscs and in 2017 approximately 96%. Since 1991, limpets represent the majority of the landed value for molluscs. From 1998 to 2017, this resource represents over 90% of the landings of molluscs (**Figure 13**).

The traditional harvesting of limpets carried out by the local populations is not represented in the landings since current harvesting regulation does not require first auction sale for this activity (<3 kg/day/person), thus making it difficult to quantify the real impact of the traditional harvest on the exploited populations. Also, illegal harvest is not considered on the total of landings. Nonetheless, it is



**Figure 13.**  
*Economic value of the landings of limpets and the economic value of the landings of the other molluscs per year, between 1990 and 2017 in the archipelago of Madeira.*

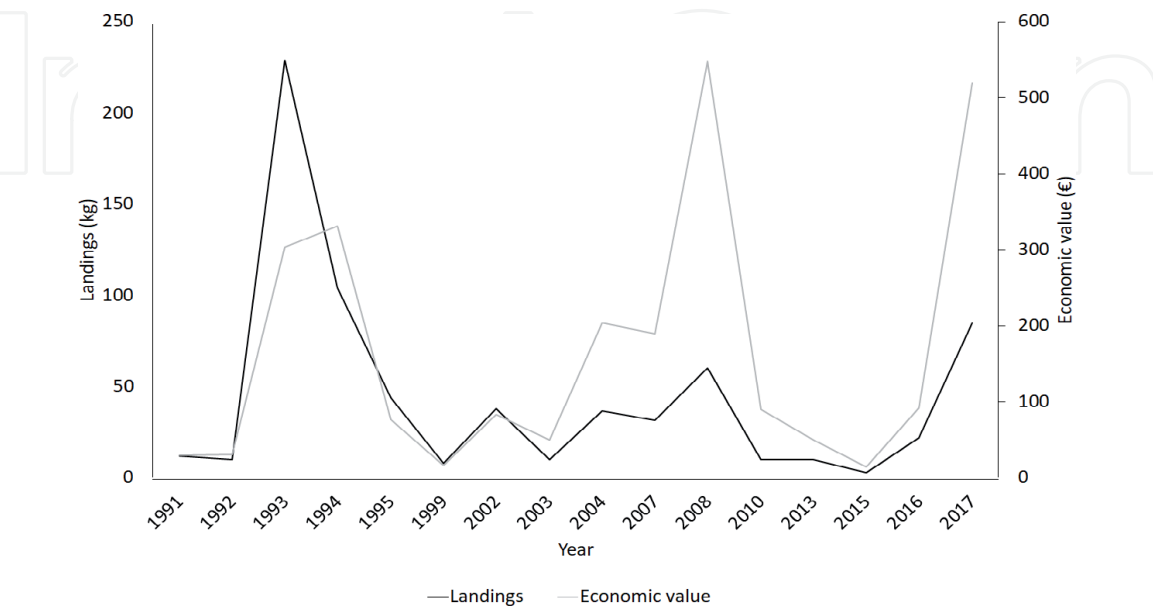
known that commercial harvest occurs preferentially on certain locations (north coast of Madeira Island and around the Desertas), and, for these regions at least there is a better understanding of the harvesting effort on the exploited stocks.

The topshell (*P. sauciatus*) harvest in the archipelago of Madeira is carried out unregulated and without auction obligation, and as such, the landings of this species are residual, being impossible to estimate the real harvesting effort exerted on this species [2]. The landings varied from *ca.* 3 kg (2015) to *ca.* 230 kg (1993) between 1991 and 2017, yielding annual landed values between 14 and 520 € (Figure 14). Usually this species is sold directly to the markets at very high prices, reaching prices, i.e., between 15 and 20 € per kg.

#### 4.2 Stock status

Specific stock assessments for limpets in the archipelago of Madeira begun in the mid-2000s and were the basis for regulation of shellfish harvest in the region [11]. Nevertheless, due to the increasing interest in these molluscs, preliminary monitoring of limpet populations began in 1996. More recently, studies on the biology and stock assessment of *P. candei* and *P. aspera* were accomplished by Henriques et al. [13] and Sousa et al. [14].

The stocks of *P. candei* and *P. aspera* were found to be underexploited but with exploitation occurring near their maximum sustainable yield in the archipelago of Madeira. However, limpets' specific life traits, like slow growth rates and long life-span, make these molluscs extremely vulnerable to overexploitation, and as such continuous monitoring of the stocks and the enforcement of the existing harvest regulations must be accomplished if future overexploitation is to be avoided [13, 14]. Surveillance and enforcement of the closed season are also particularly important to avoid poaching and safeguard the reproduction of these species. Specifically, for *P. aspera* since this species is a protandrous hermaphrodite, and thus especially vulnerable to size selective harvest, since after reaching sexual maturation a percentage of males shifts to females, thus the removal of larger individuals will target primarily females leading to a decreased reproductive success.



**Figure 14.**  
*Landings and economic value of topshells from 1990 to 2017 in the archipelago of Madeira.*

Presently, some concerns persist regarding the management of the commercial exploitation of these two species in the region, namely, the lack of knowledge on the genetic connectivity between populations. In this sense, studies in this field are ongoing to establish proper conservation strategies considering connectivity or isolation of the populations. Another important concern relates to illegal poaching in the closed season and in MPAs and new conservation policies raising public awareness using innovative approaches involving not only decisionmakers but also the local communities which will be pivotal for the conservation of these species [12].

The first approach to assess the status of the stock of the topshell *P. sauciatus* in the archipelago of Madeira was held in 2018 although this species has been exploited since the fifteenth century. The stock of *P. sauciatus* seems to be moderately exploited in the region but vulnerable to the harvest of small specimens. Conservation measures on harvesting regulation, considering the biological and ecological specificities of this species in this region, are required to preserve the stock in the medium and long terms, and efforts in implementing it are currently underway.

## 5. Effects of management measures in limpet populations

The implementation of limpet harvest management measures in the archipelago of Madeira was of paramount importance due to the life history traits of these species allied to their economic importance that results in a high harvesting pressure on these resources.

The continuous monitoring of the limpet populations over time allowed the regulators to readjust harvesting regulation in Madeira, namely, the closed season period that initially lasted from November to January and presently ranges from December to March, to protect more effectively the breeding period of limpet species. This continuous monitoring clearly maximizes the returns that can be achieved through the regulation of this activity; since the responses of exploited stocks to harvest are continually changing, regulation has to adapt to these changes in order to promote its sustainability. The reduction of the number of harvesting licenses, the prohibition to capture immature individuals (<40 mm shell length), and the catch limits have also contributed to the increase of the mean size of the specimens, to the recovery of the size composition and to the increase of the abundance of the limpets' populations, in the archipelago of Madeira [3].

Conservation measures prompted an overall improvement of the exploited stocks on both exploited limpet species in Madeira. Comparative studies on the effectiveness of the implemented management measures demonstrated that the stocks of *P. aspera* and *P. candei* are slightly recovering since regulatory measures entered into force. The harvesting regulation was conducted to an increase in limpets mean shell length and to a more balanced size structure of the populations and a dominance of reproductive individuals. This effect was more noticeable in *P. aspera* populations due to the greater exploitation pressure exerted on this species [3].

The implemented management measures and the current levels of enforcement in the archipelago of Madeira showed positive results contrarily to those in the archipelago of Azores and the Canaries where management and enforcement were insufficient to protect the exploited limpet populations [15, 16].

The management measures led to an increase of 14% in proportion of reproductive individuals and to an increase in the size and age of first maturity for both species. A shift from a biased sex ratio before harvesting regulation to a balanced sex ratio after regulation occurred for *P. aspera* (R.S., pers. obs.).

Marine protected areas also contributed to the protection of limpet populations in the archipelago of Madeira. The increase of size-at-first maturity, shell size,

balanced size composition, and capture per unit effort (CPUE) is evident in MPAs when compared to exploited populations. Also in the oldest and well-enforced MPAs, a high representation of large adults and more balanced populations for both limpet species (R.S., per. Obs.) was found. In fact, MPAs play a pivotal role in the recovery of the exploited stocks of limpets in the archipelago of Madeira, considering their potential to promote replenishment and recruitment in nearby coastal areas where limpets are or have been heavily exploited. However, further studies are required to confirm this possible positive effect of MPAs on limpet stocks.

## 6. Conclusions

The harvesting of limpets in the archipelago of Madeira is protected by legislation that provides the basis for a sustainable exploitation. However, it is still very common for violations to the current management policies and regulations which are punishable with the application of penalties when detected by the local authorities to occur. The two major weaknesses in this regard are the lack of compliance by the fishermen, which is mostly due to the lack of knowledge about the importance of the implemented management measures, and the poor enforcement by the regional authorities. A greater effort in the enforcement of regulations is required to ensure compliance of the fishing communities and an increase of the surveillance by the authorities to discourage illegal harvesting of these molluscs. Concerning topshells it is crucial to establish management measures on the harvesting of this resource to promote a sustainable exploitation in a medium and long term.

The ecological role that these key resources play in the coastal ecosystem and the importance of their survival not only from a conservational perspective but also economical needs to be clearly transmitted to the fishermen and the general public, stakeholders, and authorities. This can be achieved through a proximity approach promoting training and involvement of all interested parties in the management and protection of these species. Promoting the awareness and advice to consumers in order to reduce illegal harvesting. Also, by instilling entrepreneurial spirit in fishermen by complementing their fishing activity with tourism through vessel trips and dives, adding value to these resources and increasing the fishermen income.

The implementation of obligatory species-specific landings for limpets is urgent to more accurately quantify the landings of each species and monitor the exploited stocks, since they are landed together as a mixed exploitation.

The encouragement of aquaculture investments and post-harvest facilities will reduce fishing pressure on exploited gastropods in the archipelago of Madeira and open the possibility of stock replenishment by reintroduction of cultured individuals to their natural habitat. This would also positively contribute to the socioeconomic development of the region, not only through production but also through job creation.

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