

RESEARCH ARTICLE

Characterization and evolution of spearfishing in Madeira archipelago, Eastern Atlantic

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Abstract – Data obtained from licenses of spearfishers and surveys conducted in 2004 and 2017 allowed for the analysis, for the first time, of the practice of spearfishing in the Madeira archipelago. Only a small percentage of the population practices spearfishing, mostly local young men. Most of them practice the activity with a partner throughout most of the year and along most of the island's coastal areas, although preferentially along the North and Southeast coast. Results show how, in recent years, despite the population of spearfishers decreasing, the abundance in the annual catch potentially increased, probably due to the higher investment of time in this activity. It has been observed that many fishers complement their catches with manual collecting of invertebrates. Overall, 40 teleost fishes and also 4 crustaceans and 8 molluscs were identified. The most frequently captured fish species were parrotfish and white seabream, while limpets were the most collected invertebrates in both selected periods.

Keywords: Recreational fishing / surveys / spearfishing / Madeira (Portugal) / species catch composition

1 Introduction

Recreational fishing is a popular leisure activity that covers a wide variety of methods, involving a large number of people (FAO, 2016; Hyder et al., 2018). The different varieties of recreational fishing modes are practised in many points, mainly along the coast, causing strong fishing pressure on many species (Coleman et al., 2004). In recent years, this problem has come to the attention of fisheries scientists and legislation was introduced to try to reduce the negative impact of these activities on ecosystems (Richardson et al., 2005) and fish assemblages that inhabit shallow coral reefs and rocky bottoms (Dulvy and Polunin, 2004; Lloret et al., 2008; Meyer, 2007).

Spearfishing is one of the modalities of the different recreational fishing methods used worldwide. This activity can be a valuable tool to investigate the coastal environment, since spearfishers are able to reach areas of difficult access (Barreiros, 2009). Some authors consider this type of fishing

not very harmful, due to its limitation to shallow waters, so the proportion of target fish available is less than that available for other fishing modalities; also, because it is a high selectivity fishery in terms of individuals caught (Coll et al., 2004; Barreiros, 2009; Frisch et al., 2012; Fenner, 2012). Moreover, it has been shown that spearfishing captures a small proportion of fishes, <1% compared to other forms of recreational and commercial fishing (Smith and Nakaya, 2002).

However, spearfishing targets species inhabit rocky and reef habitats, which make them particularly vulnerable to exploitation (Jennings et al., 1999; Hawkins et al., 2000; Dulvy and Polunin, 2004; FAO, 2016; Meyer, 2007). Some target species can be slow growing, such as limpets (Sousa et al., 2017) or groupers (Jiménez-Alvarado et al., 2019), which exhibit low resilience under intense fishing pressure. Spearfishing can thus produce severe impacts on certain populations (Grau, 2008), affecting their abundance and reproductive potential (García-Rubies and Zabala, 1990; Francour, 1991; Harmelin et al., 1995; Jovenel and Pollard, 2001; Coll et al., 2004; Birkeland and Dayton, 2005; FAO, 2016; Rius, 2007). In some areas it has become a problem, due

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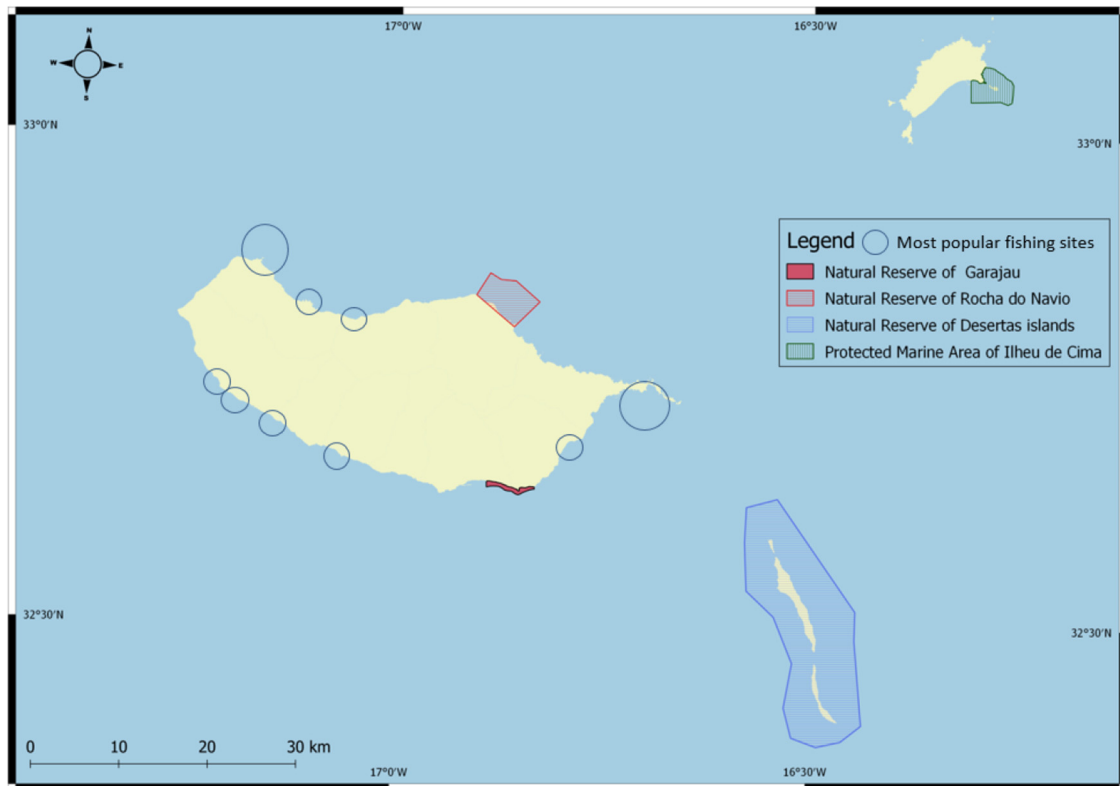


Fig. 1. Map of Madeira with most popular fishing sites (circle size reflects spearfishers preference) and areas where spearfishing is banned (Marine Protected Areas “Rocha do Navio”, “Ponta do Garajau”, Marine Protected Areas in Porto Santo Island (Ilheu de Cima), and Desertas islands classified as a special protection area since 1990 and as a reserve since 1992 (Quintal, 2004).

to the increasing fishing effort. In some cases, spearfishing surpassed other recreational fishing activities in terms of biomass of catches, which may cause significant fluctuations in populations (Meyer, 2007).

Madeira is an oceanic archipelago composed by 4 groups of islands (Madeira, Porto Santo, Desertas and Selvagens) located in a subtropical region of the Atlantic Ocean, between 30–34° N latitude and 15–18° W longitude (Fig. 1). It comprises a total land area of about 817 km² and 288 km of coastline, and is relatively isolated by oceanic depths reaching 4000 m (Menezes, 2003).

The Madeiran coast and its environmental conditions can be considered optimal for spearfishing throughout the whole year. Average temperatures are 22 °C in summer and 16 °C in winter (Araújo et al., 2008), and seawater temperature is relatively high, varying between 17 °C and 23 °C (Quintal, 2004). The seabed is usually rocky and irregular near the coast, dropping almost abruptly along the slope, reaching depths of about 1800 m at around 5 nm from the coast (Morato, 2012). The absence of a continental shelf reduces the amount of available habitat for coastal species compared to mainland coasts (Hermida and Delgado, 2016). The geographical location of Madeira makes it possible to find a mixture of species with distinct biogeographical affinities, including the Mediterranean Sea, North Atlantic and tropical waters (Menezes, 2003).

In general, spearfishers access the fishing areas directly from the coast (see Supplementary Information, Fig. S1), but

sometimes the fishing journey is made by boat, which allows access to more complicated areas and transport of additional material and storage of the fish caught (Domingues, 2010). However, this fishing activity is practised in the coastal area and partially overlaps with the traditional fishing area of the professional artisanal fleet, creating a conflict between the two parties. This situation constitutes an important management issue worldwide (West and Gordon, 1994; Pomeroy et al., 2007) including in Portugal (Veiga et al., 2010; Assis et al., 2018). This conflict led the Department of Fisheries establishing some rules. Specific policies to control possible negative effects of spearfishing have been in place in Madeira since 1995 (Regional Legislative Decree 11/95/M of 21 June 1995), but previous national legislation specific to this activity already existed in Portugal since 1963 (Decree 45116 of 6 July 1963). Recently, conditions were reviewed and a new regulation of recreational fishing has been adopted (Decree 484/2016).

This regulation aims at creating the best conditions for the practice of this type of fishing, ensuring the sustainability of marine resources. Some of the most relevant points were the requirement of license acquisition (even for those who already have a license issued in mainland Portugal) and the ban of artificial respiration. Additional measures to conserve marine ecosystems were also implemented, such as minimum conservation reference sizes (MCRS), banning of the capture of vulnerable species, limitations on the number of daily catches, and prohibition of the practise of spearfishing in marine protected areas (Fig. 1).

A specific regulation for recreational fishing in the region was introduced at the end of 2016 (Decree 484/2016), and from that moment the Regional Fisheries Directorate replaced the Marine Captaincy as the competent authority to issue licenses. Currently, the bag limit is of 10 specimens per fisher per day (no more than five of the same species) and minimum legal sizes were also established for the most common species. In addition, considering that some spearfishers complement their catches by harvesting invertebrates, limits to the capture of these were also included in this legislation.

Although spearfishing has been practised in the region for a long time (at least since 1963, the year of its first legislation), to date no study has been carried out on this fishing method. Recently, a study has been carried out comparing the profile and habits of spearfishers throughout Portugal, including only 14 people from Madeira (Assis et al., 2018). The aim of the present study is to characterize this activity and obtain an overview of its impact, comparing the results of surveys carried out in two different historical moments (2004 and 2017) and to identify trends in the licenses issued in recent years.

The results of this study will allow us to better understand the socioeconomic characteristics of spearfishers, temporal and seasonal patterns, abundance and variety of species caught. This work constitutes the first study about spearfishing in Madeira archipelago.

2 Methods

2.1 Licenses

Registers of licenses issued from 2007 to 2019 were obtained from the Maritime Captaincy and Regional Fisheries Department, in order to assess the trend in the number of recreational spearfishers over the years.

2.2 Spearfishers survey 2004

In 2004, a collaboration began between the University of Madeira and the Maritime Captaincy of Funchal, according to which the spearfishers had to apply for a license to practice the activity. Several questionnaires were placed in the Maritime Captaincy offices and made available to be filled in voluntarily by fishers while they were waiting to receive the license. The survey was carried out from the 1 January to 15 September 2004, and during this period 509 questionnaires were completed by spearfishers. Questions included demographic characteristics like nationality, age, gender, marital status, education and place of residence; and some fishing related data (fishing areas, fishing frequency in days per year, species and quantity of catches, and fisher preferences in terms of species). Motivations for practicing this type of fishing were also investigated. A list of possible motivations was provided, and respondents were instructed to select up to four answers.

Survey data were also used to estimate annual effort and catch per unit of effort (CPUE) in number per hours fished. In 2004, the total catch in number was estimated for the surveyed spearfishers, using the number of registered licenses, the last year average number of fishing days per fisher and the average number of fish caught in each fishing trip in the previous year. Thanks to the replies to question 6.2 in the survey

(see Supplementary Information, Fig. S2), it was possible to estimate the number of spearfishers without a license, which was used to perform a correction of the total data and thus estimate the total population of fishers. However, the number of fishing days per year was given as a range, so an average value had to be used.

2.3 Spearfishers survey 2017

A second voluntary survey was conducted by a researcher from November 2016 until the end of 2017, interviewing 190 spearfishers in person during this period. Of these, 132 were interviewed while they were acquiring their licenses at the Regional Fisheries offices, and 58 before or after the fishing activity at different points of the island (including usually frequented areas as well as more remote spots). From this second group, the percentage of spearfishers who fish without a license was estimated.

The participation rate of the population was calculated based on the number of licenses issued in 2017 divided by the total Madeiran population, with a correction for the percentage of people who practise spearfishing without a license.

For the socioeconomic characterization, the following variables were studied: gender, age, marital status, nationality, area of residence, educational level and monthly net income. For the description of the fishery, years of experience, expense, schedule, frequency, dive time and depth, fishing area and an average of the hours for each fishing trip were analysed, as well as the species most captured, also an average estimate in kg and the number of specimens from the previous year's catches and their final destination. Also, opinions of spearfishers about legislation and suggestions for improvements were registered (see Supplementary Information, Fig. S3).

In 2017, for the analysis of catches, the value of catches per unit of effort (CPUE) was determined, and measured in: Number of individuals caught/hour/fisher; and Weight of individuals caught in kg/hour/fisher. These formulations were used because they were considered to characterize efficiently the effort applied to recreational fisheries in the region under analysis. The amounts of fish captured by fishers who have an annual license, a monthly license, or were unlicensed, were calculated separately, and an estimate of the total number and weight of catches by spearfishing in 2017 was calculated by escalating these amounts to the total spearfisher population, known from the number of licenses issued for this year.

$$C_T = (CPUE_y \times Days_y \times Hours_y \times N^{\circ}licenses_y) + (CPUE_M \times Days_M \times Hours_M \times N^{\circ}license_M) + (CPUE_N \times Days_N \times Hours_N \times N^{\circ}licenses_N)$$

C_T = total capture (in number or in kg depending de CPUE); CPUE = average catches per unit of effort; Days = average days fished; Hours = average hours per exit trip; Y = annual licenses; M = monthly licenses; N = unlicensed.

3 Results

3.1 Licenses

A total of 1778 spearfishers obtained licenses in 2017 (1685 annual and 123 monthly), including 2.3% by women, 1.7% by tourists, and 10.4% by Porto Santo residents. For

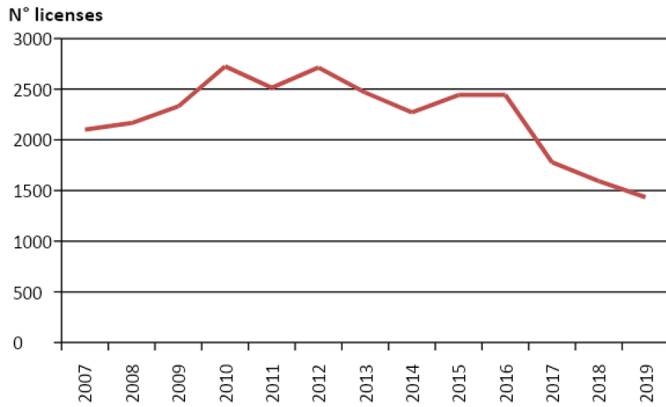


Fig. 2. Trend in the number of spearfishing licenses from 2007 to 2019.

monthly licenses, about one third (33.58%) were obtained by foreigners. A low proportion of the Madeiran population practices spearfishing; participation rate in the region is 0.7%, although participation in Porto Santo is much higher, 3.8% (including people without licenses).

The trend of licenses issued over the years was also analysed (Fig. 2). Results show that with the new licensing system there was a decrease in the number of spearfishers that obtain the license. In 2018 the decline was more marked, with only 1593 licenses issued (1387 annual and 206 monthly), and in the following year only 1434 licenses were issued (1284 annually and 150 monthly).

Results from surveys show a low percentage of spearfishers without licenses: 4.1% in 2004 ($n = 590$, licensed fisher but who admitted to having practised the activity without being in possession of the license) and 5.1% in 2017 ($n = 58$, only fishers interviewed while fishing).

3.2 Survey results

The participation ratio for the surveys carried out in 2004 was very high. In fact, considering that in 2004 were requested 2000–2050 licenses, about 29% of the practitioners participated to the survey. In 2017, only 190 fishers on a total of 1778, filled in the questionnaire, reaching a participation rate of 10.6%.

3.2.1 Spearfishers profile (Tab. 1)

Most of the spearfishers interviewed were male (97.8% in 2004 and 98.9% in 2017), confirming the low number of women participating in the activity. The great majority were Madeiran residents, with almost half living in the capital, Funchal.

Spearfishing is an activity generally practised by young people, with some fishers starting this activity as children, aged between six and seven (respectively in 2004 and 2017). In addition, they are usually experienced, with fishers surveyed in 2017 generally reporting having more experience than those surveyed in 2004 (Tab. 1).

In 2017 the average expenditure per fisher per year was 465.40 ± 798.80 euros ($n = 174$). If we calculate the expense generated by the activity for this year, taking into account the average expense incurred by those fishers with annual,

Table 1. Comparison of spearfishers’ demographic characteristics between 2004 and 2017.

Demographic characteristics	2004		2017	
	%	<i>n</i>	%	<i>n</i>
Gender				
Male	97.8	590	98.9	190
Female	2.2		1.1	
Residence				
Madeira	98.4	521	89	200
Funchal	41.9		41	
Porto Santo	0.3		2.5	
Education level				
No education	1.6	64	0.5	188
Basic	34.4		30.9	
Secondary	32.8		35.6	
Professional course	9.4		17.5	
University	21.9		15.4	
Civil status				
Single	45.3	64	41.2	188
Married	50		50.4	
Divorced	4.7		6.8	
Widowed			1.6	
Employment				
Retired		190	2.6	
Self-employed			11.1	
Unemployed			23.2	
Contract			45.3	
Student			4.1	
Disabled			1.1	
Public service			11.6	
Monthly income				
0		174	29.9	
0–500 €			13.2	
500–1000 €			33.3	
1000–1500 €			8.6	
>1500 €			4.6	
Variable			10.3	
Age (Average ± s.d.)				
Age	32.8 ± 10	590	38.3 ± 12.1	190
Experience	12.4 ± 10.4	565	18.1 ± 13.6	190
Started at age	20.2 ± 7.2	565	20.1 ± 9.1	190

monthly licenses, or unlicensed, the amount is 881 745.00 euros. The expenses considered included the cost of fishing material as well as general expenses for the fishing day, such as food or fuel.

3.2.2 Fishery characteristics (Tab. 2)

Results from the 2017 survey show that around half (51.1%, $n = 190$) of the people who practise spearfishing also employ other recreational fishing methods (shore angling or boat angling). In addition, it was observed that a large majority of interviewees (81.4%) practised spearfishing almost all year round; 12.7% start fishing in April and only 3.7% fish only during the summer season ($n = 189$). Fishers that prefer to go fishing on weekends are 44.7%, while 51.1% have no preference ($n = 202$). Half of the interviewees (50.5%) do not have an established schedule to go fishing, 28.4% prefer to

Table 2. Fishing characteristics.

Fishing characteristics	2004		2017	
	%	<i>n</i>	%	<i>n</i>
Practice				
Alone	65.6		66.4	
Accompanied	10.9	64	1.1	188
Both	20.3		22.3	
Starting Point				
Coast	77.6		68.2	
Boat		588	5.8	173
Both	22.4		26	
License				
Spearfishing			48.9	
Spear + Shore angling			27.3	
Spear + Boat			15.2	190
Spear + Shore + Boat			8.4	
Season				
All the year			81.4	
Spring, summer and autumn			12.7	189
Summer			3.7	
Day time				
No schedule			50.5	
Morning			28.4	
Afternoon			11	190
Tides			10	
Week time				
Weekend			44.7	
No preference				190
Location				
North coast of Madeira	55.1		22.8	
South West coast of Madeira	44.7		19.6	
Funchal	6.3	539	5.3	189
Porto Santo	6.5		2.6	
No preference	4.6		38.6	

go in the morning, 11% in the afternoon and 10% depending on the tide ($n=190$).

The preferred fishing areas are the North coast (22.8%–55.1%) and Southwest part of the island (19.6%–44.7%); many fishers fish all along the Madeira island coast (38.6%). It is interesting to highlight that not many fishers travel from Madeira to Porto Santo to practise spearfishing (2.6%), and that only 5.3% fish in the capital, Funchal ($n=189$). Most frequented spots where spearfishing is practiced were marked in [Figure 1](#).

When asked if they practise the activity alone or accompanied, in 2004, 65.6% replied that they usually go fishing with somebody else, 10.9% go alone, and 20.3% both ($n=64$). In 2017, 66.5% claimed to go fishing with someone else, and only 1.1% prefer to go alone, while 22.3% chose both options ($n=188$).

Most of the spearfishers do not use a boat. In 2004, 22.4% of the spearfishers said that sometimes they use a boat ($n=588$); in 2017, 68.2% stated that they always access the fishing areas directly from the coast, 5.8% always use a boat, and 26.0% can use either option ($n=173$).

3.2.3 Fishing effort and catches

Information obtained from both surveys included the dive time and depth reached. In 2004, results show an average dive time of 83.4 ± 44.1 seconds ($n=510$). In 2017 the average dive time was 72 ± 35.1 seconds ($n=180$). With respect to the depth, in 2004 the average depth was 11.9 ± 6.6 m ($n=555$). In 2017 results were very similar, with the average depth 13.9 ± 7.7 m ($n=184$).

In terms of fishing effort, the average number of fishing days from the 2004 survey was 31.2 ($n=569$), whereas in 2017 it was more than double, with an average of 69.4 ± 67.9 days/year ($n=184$). For the 2017 survey, daily effort in hours was also calculated, with an average of 3.9 ± 1.5 (minimum 1 h – maximum 8.5 h) hours per fishing trip ($n=182$).

Based on the 2017 survey, the average weight caught by each fisher per day was 3.7 ± 2.1 kg ($n=175$) and the number of fishes captured is 5.4 ± 1.9 per fishing trip (in comparison, the estimated number from the 2004 survey was 4.9 fishes, $n=513$). CPUE calculated in number in 2017 was 1.5 ± 0.6 fishes per hour ($n=125$), and in weight it was 1.1 ± 0.6 kg/hour ($n=170$).

These results allow us to estimate the overall yearly catches. Considering that in the year 2017 there were 1685 spearfishers with annual licenses and 123 with monthly licenses, and including a correction for the percentage of active spearfishers without a license, the estimated amount of fish caught is 732 341 in number and 517.7 t in weight. In 2004, 2025 fishers were registered; with the addition of 4.1% unlicensed, we therefore consider 2108 spearfishers for that year, who fish an average of 4.9 fishes each fishing trip and made an average 31.2 trips per year. The estimated total catch for 2004 is 321 906 fishes.

With regard to the destination of the catch, in 2017 most spearfishers (97.3%) said that mainly they use it for their own consumption, sometimes (23.9%) they offer it to friends or relatives and 6.9% admit to selling it ($n=188$) more than the 3.1% of interviewees in 2004 ($n=64$).

Species caught by spearfishing are mainly teleost fishes, but in many cases the catch is complemented with invertebrates that are also collected during the dives. In fact, it is interesting to note that limpets and octopuses are among the species most often caught by these fishers. The relative abundance of each species in the catch is presented in [Table 3](#).

The most captured species in both years was the parrotfish *Sparisoma cretense* (Linnaeus, 1758), followed by limpets (*Patella* spp.). The next most caught species were the white seabream *Diplodus sargus* (Linnaeus, 1758) and the common octopus *Octopus vulgaris* Cuvier, 1797. Amberjacks were the third most caught taxon in 2004, whereas mullets were more frequent in catches in 2017, but similar to amberjacks. It can therefore be considered that the main species caught have not varied much in recent years. Considering both sources of information, a total of 40 fish taxa caught by spearfishers were identified, as well as 12 invertebrate taxa (4 crustaceans and 8 molluscs).

We must also highlight the capture of dusky groupers (*Epinephelus marginatus* Lowe, 1834), despite their capture being prohibited, and the presence of species that did not occur in the region some years ago, especially gilthead sea bream

Table 3. Relative abundance of the species captured. Results obtained from surveys made in 2004 (captured and preferred) and 2017 survey.

Species	2004 captured (N = 2961)	2004 preferred (N = 2479)	2017 captured (N = 877)	Invertebrates	2004 captured (N = 2961)	2004 preferred (N = 2479)	2017 captured (N = 877)
Osteichthyes							
<i>Abudefduf luridus</i>	0.54	1.17	0.11	Arthropoda: Decapoda			
<i>Acanthocybium solandri</i>	0.07	0.12	1.03	<i>Grapsus adsepcionis</i>	0.37	2.26	1.03
<i>Balistes caprisicus</i>	2.77	3.47	2.17	<i>Maja brachydactyla</i>	0.00	0.08	0.00
<i>Bodianus scrofa</i>	0.03	0.04	0.91	<i>Palinurus elephas</i>	0.00	0.65	0.11
<i>Boops boops</i>	0.24	0.32	0.46	<i>Scyllarides latus</i>	0.07	0.93	1.37
<i>Bothus podas</i>	0.07	0.00	0.00	Mollusca: Cephalopoda			
Mugilidae	1.89	3.95	4.68	<i>Loligo vulgaris</i>	0.03	0.00	0.34
<i>Conger conger</i>	0.07	0.00	0.11	<i>Octopus vulgaris</i>	6.52	10.69	11.19
<i>Coryphaena hippurus</i>	0.00	0.00	0.11	Ommastrephidae	0.00	0.00	0.34
<i>Dentex gibbosus</i>	0.00	0.00	0.11	<i>Sepia officinalis</i>	0.98	5.08	2.51
<i>Dicentrarchus labrax</i>	0.27	0.04	0.11	Mollusca: Gastropoda			
<i>Diplodus cervinus</i>	0.07	0.00	1.03	<i>Haliotis</i> sp.	0.03	0.00	0.00
<i>Diplodus sargus</i>	14.35	7.14	9.48	<i>Phorcus sauciatus</i>	2.23	0.28	3.77
<i>Diplodus vulgaris</i>	0.34	0.73	0.80	<i>Patella</i> spp.	17.63	4.28	13.81
<i>Epinephelus marginatus</i>	0.03	0.20	0.11	<i>Stramonita haemastoma</i>	0.07	0.00	1.14
<i>Heteropriacanthus cruentatus</i>	0.00	0.00	0.23				
<i>Katsuwonus pelamis</i>	0.00	0.32	0.00				
<i>Kyphosus sectatrix</i>	0.07	0.08	0.46				
<i>Lithognathus mormyrus</i>	0.00	1.25	0.11				
<i>Mullus surmuletus</i>	0.44	1.21	1.03				
<i>Muraena</i> spp.	0.54	0.20	0.68				
<i>Mycteroperca fusca</i>	1.42	1.13	2.28				
<i>Oblada melanura</i>	0.00	0.44	0.80				
<i>Pagellus acarne</i>	0.00	0.00	0.23				
<i>Pagellus erythrinus</i>	0.00	0.16	0.34				
<i>Pagrus pagrus</i>	1.55	1.33	3.88				
<i>Phycis phycis</i>	0.00	0.00	0.46				
<i>Polyprion americanus</i>	0.00	0.00	0.11				
<i>Pomatomus saltatrix</i>	0.14	0.44	1.14				
<i>Pseudocaranx dentex</i>	0.54	3.19	1.03				
<i>Sarda sarda</i>	0.03	0.00	0.00				
<i>Sarpa salpa</i>	1.93	2.18	2.97				
<i>Scorpaena scrofa</i>	0.07	0.00	0.00				
<i>Seriola</i> spp.	3.31	2.10	4.00				
<i>Serranus atricauda</i>	3.11	9.00	2.97				
<i>Sparisoma cretense</i>	37.39	35.50	16.89				
<i>Sparus aurata</i>	0.20	0.04	0.23				
<i>Sphyaena</i> spp.	0.44	0.00	2.85				
<i>Thunnus alalunga</i>	0.03	0.00	0.00				
<i>Trachinotus ovatus</i>	0.17	0.00	0.46				

Sparus aurata Linnaeus, 1758, and sea bass *Dicentrarchus labrax* (Linnaeus, 1758).

In 2004 fishers were asked which species they preferred to catch; they highlighted the parrotfish, the blacktail comber (*Serranus atricauda* Günther, 1874) and the white seabream. Two cephalopods were indicated as desired species, the octopus and the cuttlefish (*Sepia officinalis* Linnaeus, 1758).

3.2.4 Opinions on regulations and motivations for fishing

In 2004, 13.1% ($n=590$) of the fishers interviewed stated that they were unfamiliar with the legislation for spearfishing. A quarter of the interviewees (25.3%) disagreed with the legislation and 94.6% confirmed that they were aware of the species' size limits.

In the 2017 survey, there were additional questions about the opinions of spearfishers regarding the evolution of this activity over time. One of the most relevant questions was about the evolution of fish abundance in recent years; 58% say that the number of fish has decreased and 35.6% that it has remained constant ($n=176$). In addition, 66.6% of the respondents considered that the size of the fishes has remained stable and 30.4% that the size of the individuals has decreased ($n=138$). In relation to the number of active spearfishers, a high percentage of the interviewees (74.7%) consider that there are currently more people involved in the activity than in previous years ($n=166$).

Spearfishers were also asked to comment on the new legislation ($n=91$). Regarding the license, 9.9% think that it should be cheaper, 4.4% believe that there should not be a license, and 2.2% consider that it should be free. A majority of respondents, therefore, agree that there should be a fishing license, and with the respective charge.

It was asked what modifications they considered should be included in the regulations. Of those who responded ($n=91$), 10.9% propose that information meetings should take place or at least that regulations should be clearer and more accessible. 14.2% believe that it should be possible to capture a greater number of fish, 21.9% that there should be more control by the authorities (with 8.8% considering that it would be necessary to control fish sizes). They also offered some suggestions for improving the practise of this activity, such as improving accesses to coastal areas (7.7%), establishment of MPAs (4.4%) with restrictions for all kinds of fisheries and not only for spearfishing (which is what happens in the majority of the MPAs in Maderia), or restocking of the most captured species (3.3%). Some fisher (4.4%) did not understand why the capture of certain species is forbidden, for example amberjack (*Seriola* spp. Cuvier, 1816) or dusky groupers.

Some fishers also provided some insights about the influence of environmental features on fishing success, emphasizing that with high tide, bigger fish approach the coast, and that in summer the water is warmer, so there is an increased abundance of fish.

In the 2004 survey, there was a question regarding the motivations for practising spearfishing. Pleasure and physical activity were the main motivations (Fig. 3).

4 Discussion

First of all, the participation rate of fishers that answered the survey in 2004 was higher than in 2017, reaching about

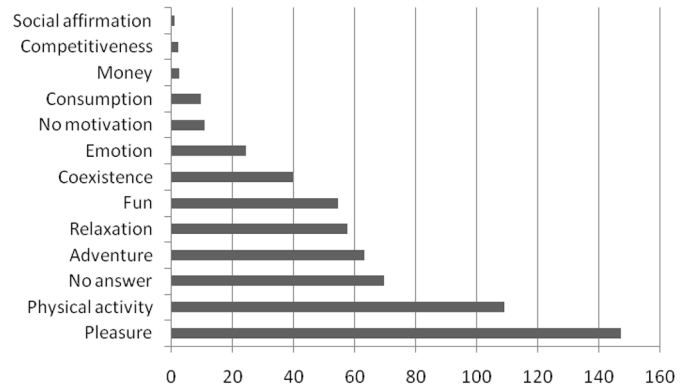


Fig. 3. Spearfisher's motivations. More than 140 spearfishers indicated that "pleasure" was their main motivation (2004 survey, $n=590$).

29% of participation rate versus the 10.6% in 2017. This could be explained by the different methods of data collection. In fact, in 2004 the questionnaires were available to the entire population of spearfishers that requested licenses that year. In 2017, the number of spearfishers reached was probably lower because the surveys were conducted by a researcher who interviewed the spearfishers personally, and it was therefore not possible to reach the entire target group.

Also, it should be noted that the questionnaires used in each year were different. The one carried out in 2004 was not aimed at analysing the activity per se, rather it was specifically focused on obtaining knowledge about the population engaged in spearfishing, and the possibility of offering related training to improve the skills and knowledge of practitioners. Despite this, part of the information collected is interesting and complementary to that obtained in the 2017 survey, allowing for a comparison of the activity in two different historical moments and to analyse how it has evolved. Furthermore, it should be noted that both surveys are potentially affected by various biases. Most of the surveys were carried out when the fisher were not practising the activity, since they were obtained when fishers were acquiring the fishing license; therefore, these were conducted as an off-site method (Zarauz et al., 2015). This type of questionnaire is considered more practical and accessible, but has a major drawback, since it is associated with several biases, of which coverage and non-response biases are worth noting (despite the high number of people who participated in the 2004 survey, it is possible to observe how on many occasions, the response rate is very low). Both of these are considered representation errors, which prevent the sample from representing the population accurately (Zarauz et al., 2015). Another error that can lead to biases in the responses is refusal to participate, since it is considered that more avid fishers are more likely to respond than those with zero catches (Tarrant and Manfredi, 1993).

Measurement errors, which introduce a difference between the value provided by the respondent and the true value, should also be highlighted. The main error of this type is recall bias, which is related to the fisher's difficulty in remembering past events. This deviation is associated with and is influenced by the length of the recall period and the frequency of participation. The more time has elapsed since the fishing event, the greater the bias; as well as the avidity of the fisher, that is, if the interviewee is a person with a high level of

activity, it is easier for them to confuse fishing trips and therefore generate more bias (Zarauz et al., 2015). In general, the authors found that as recall periods increased, estimates of the trip characteristics became larger. This effect has already been studied by Fisher et al. (1991) when they observed that the number of fishing days increased 44% when a 3-month recall period was used and the average travel expenses increased 39%; and they increased again with respect to these results, 34% and 42% respectively, when compared to an annual recall period. Both questionnaires included questions about the previous year, which might be difficult to remember accurately.

Other factors that contribute to the results being erroneous are the simple exaggeration of the activity and the 'telescope phenomenon', which implies the inclusion of activities that occurred outside the study period (ICES, 2010). Clear examples of exaggeration can be found in the answers obtained when asking what was the maximum apnea time reached by the participants, where surprisingly in 2004 up to 29 fisher reported being able to hold their breath for over three minutes, with one fisher claiming to have reached 420 seconds of uninterrupted immersion, which is highly improbable. Therefore, in other results such as the number of individuals caught, the average weight of the catch, the fishing time or the average expenditure per year, errors due to exaggeration might also be found.

The results from this study indicate that spearfishing is not practised by a large percentage of people in Madeira. Spearfishing is the only fishing method in which the fisher specifically chooses the target individual that will be captured, focusing mainly on valuable species and large individuals (Dalzell, 1996; Coll et al., 2004, Pita and Freire, 2016); in addition, as it is practiced while free diving, it is limited to relatively shallow areas, so the percentage of target species available to this fishery is lower than that available for people who practice other modalities (Santos, 2015). Nevertheless, this activity might still have a negative impact on marine fish populations, because even though it is very selective, it targets particular species and preferentially removes large specimens (Frish et al., 2012), which may cause significant changes in the abundance and structure of fish populations and communities (Meyer, 2007; Lloret et al., 2008).

It is generally thought that there are few spearfishers who can fish below 15 m depth; therefore, these areas are considered refuge zones from this kind of fishery, where there is a greater species richness and abundance (Tyler et al., 2009), and they are of great importance for fish populations, allowing them to recolonize areas subject to greater fishing pressure. However, in this study we found that there are some spearfishers who report reaching greater depths (21.1% of spearfishers in 2004 and 28.8% in 2017).

The analysis of the number of licenses issued throughout the year indicates a decrease in the number of spearfishers. This decreasing trend has become more evident since the most recent regulations (Decree 484/2016) came into effect, probably because the price of the license increased, a fact that seems to have produced a filter in these fishers. In 2018 and 2019, the total number of licenses continued to decrease, but the number of monthly licenses increased in comparison to the previous year, so it seems that some spearfishers decided to concentrate the practice in certain months. In addition, it

should be noted that these licenses were issued mainly in the summer months (July and August), usually holiday season, where fishers have more time to enjoy the activity. One-third of the monthly licenses were requested by foreigners (33.58%), corresponding to only 41 people, including residents and tourists.

On the other hand, the perception of the fishers was that in recent years there were more people practising the activity. This could mean that there was an increase in the number of unlicensed spearfishers, or it could mean that active spearfishers went fishing more frequently (the results of the current study in terms of fishing days/fisher/year, comparing 2017 versus 2004, support this statement). Moreover, usually spearfishers share the same areas, in part probably due to the limited good access points in the Island, and in part because the best spots with more abundance of target species were preferred.

It has been estimated that at least 5.1% of people who practise spearfishing do so without a license. The result is very close to that obtained for the Canary Islands (5.06%) by Gordoia et al. (2019). Even so, the percentage is probably higher as, since it is an illegal act, some fisher might be reluctant to admit it.

Results show that in 2004 most of the interviewed spearfishers were Madeiran residents, while in 2017 there was an increase in the number of foreigners practising spearfishing, which could be related to the increase in the number of tourists in the region. The registration of guests in hotel establishments increased by 45.2% from 2004 to 2017 (Instituto Nacional de Estatística).

Usually, only a small percentage of the population practices spearfishing. Although the participation rate in Madeira is low, it is higher than that recorded in different regions of Spain, and more than double that found in the Canary Islands (Gordoia et al., 2019).

Although spearfishing is an activity practiced mostly by men, it is interesting to note the participation of some women in this activity in the region of Madeira, something that is rare in other places, like the Azores (Diogo and Pereira, 2013) or Catalonia (Lloret et al., 2008). The average age is higher in 2017 than in 2004, but in the range of the different regions in Portugal (Assis et al., 2018).

A large percentage of spearfishers go fishing all year round, reaching an average of 70 fishing days per year, possibly due to the good weather conditions in the region. Results are very similar to the 65 days per year recorded for Galicia and Canary Islands, where it is also an activity practised throughout the year (Pita and Freire, 2016; Gordoia et al., 2019). In contrast, in the Azores an average of only 22 fishing trips per year were registered, mainly carried out in the summer months, due to the severe winter weather that characterises that region (Diogo and Pereira, 2013). The average time of a fishing event is 3.9 hours, close to the effort shown in Galicia, where fishing trips lasted an average of 3.0 hours (Pita and Freire, 2016), and higher than in the Azores, where spearfishers spent 1.7 hours per fishing day (Diogo and Pereira, 2014).

As mentioned above, off-site survey methods are subject to biases; while they are very useful for obtaining results on the human dimensions of the fishery, estimated catches and effort based on these methods should be approached with caution. Nevertheless, results indicate that the total annual catch

Table 4. Comparison of CPUE (kg/fisher/hour) values for spearfishing in Madeira and other regions of the world.

Place	CPUE	References
Madeira	1.1	Present study
Azores	0.7	Sousa (2014)
Portugal	1.3	Diogo and Pereira (2013)
Galicia	1.6	Pita and Freire (2016)
Cape Creus (NW Mediterranean)	1.3	Lloret et al. (2008)
Hawaiian Reefs	1.1	Meyer (2007)

obtained by spearfishing in 2017 is remarkably high (517.7 t estimated to have been captured by 1778 spearfishers), and the average catch per fisher is similar when both years are compared, with slightly better efficiency in 2017, probably due to the improved fishing gear and skills of spearfishers over the years. CPUE values obtained in the present work for 2017 are similar to those obtained in other areas (Tab. 4).

Analysis of catch composition revealed 52 different taxa (40 fishes and 12 invertebrates), which is similar to the diversity found in the Azores (42 fishes and 12 invertebrates) (Diogo and Pereira, 2013) and higher than the fish diversity generally reported from spearfishing studies in the Mediterranean (Morales-Nin et al., 2005; Lloret et al., 2008) or in Galicia (Pita and Freire, 2014).

In both surveys, parrotfish (*S. cretense*) was the most frequently caught species. This species, due to its characteristics (subtropical, fast-growing and resilient), is considered not vulnerable (Martín-Sosa, 2019), and has a classification of “Least Concern” in IUCN. Some other frequent catches are white seabream, amberjacks and blacktail comber. This does not match the results of Assis et al. (2018), who reported that jacks (*Seriola* spp.) were the main target species in Madeira, but this discrepancy could be due to the limited number of Madeiran participants in that study. In fact, Hermida and Costa (2020), who carried out a study on fish consumption in the region, observed high positive correlations between subsistence fishing activity and the consumption of many coastal species, where some of the highlighted species were precisely the parrotfish and the blacktail comber. In other archipelagos, such as the Canary Islands and the Azores, parrotfish was also the most captured target species by spearfishers (Martín-Sosa, 2019), including in terms of weight (Diogo and Pereira, 2013).

The 2004 survey shows that preferred species are similar to the actual catch, with the exception of limpets, since they are often collected, but not particularly desired. In Madeira, the harvesting of limpets (*Patella aspera* Röding, 1798 and *P. candei* d’Orbigny, 1840) represents one of the most profitable commercial activities in small-scale fisheries (Sousa et al., 2017), but also is a very important resource for recreational fishers. Overexploitation of the stocks due to their high economic value, together with their biological characteristics, could lead to the decline of populations, therefore specific legislation for their collection was implemented, both for commercial (Decree 11/2006) and recreational (Decree 484/2016) harvesting.

Catches observed in both survey results indicate the presence of species which did not occur in Madeira some years ago, in particular gilthead seabream, sea bass and pink dentex.

Gilthead seabream is the main aquaculture product in Madeira, and is cultured in sea cages, from which occasionally there have been escapes, especially due to weather damage. This species seems to have become naturalized in the region in recent years. Sea bass has only recently been observed in Madeira (Abreu, 2019) and previously captured in 2016 by one of the authors. Probably they have reached the area from nearby regions, like the African coast or the Canary Islands. Pink dentex was first recorded in Madeira in 1986, when a specimen was fished by hand line in the Bay of Funchal; it had never been seen before in the local fish market (Wirtz et al., 2008). At present it is a species that can be frequently found.

Special attention should also be directed to the populations of some protandrous species, like *Diplodus* spp. High catch rates of individuals of the same sex could reduce their long-term reproductive rates (Birkeland and Dayton, 2005). It would also be important to explain the prohibition of the capture of some species, such as the dusky grouper, included in the IUCN Red List of Threatened Species (Pollard et al., 2018), or amberjacks, since, an outbreak of ciguatera was reported in Madeira in 2008 (Costa et al., 2017). As a precautionary measure, it is forbidden to catch individuals exceeding 10 kg, due to the fact that the consumption of this species is potentially the cause of food poisoning due to ciguatine toxin (Decree 484/2016). A higher control by authorities seems to be necessary, since the capture of some specimens has been verified.

Based on the 2004 survey results, most spearfishers mention pleasure and physical activity as the main motivations to practise this activity. Actual motivations may have changed slightly, since many years have passed since the survey was carried out. Young et al. (2016) found that for 96% of recreational fishers, connection with nature is considered a key motivation. Also, a minority recognize that spearfishing can be a source of food and sometimes money. The historical tradition of being able to obtain food from the ocean requires that one look at the activity from a social and cultural perspective. Fish caught is mainly for personal and family consumption, but some spearfishers admit to occasionally selling the catch. This practice goes outside the definition of recreational fishery, but is widely recognized that illegal, unreported and unregulated fishing is a common practice in spearfishing (Ramdeen et al., 2013). The illegal sale of fish by recreational fishers has also been reported by Pawson et al. (2008) or Young et al. (2016) and in Portugal by Veiga (2012) for shore angling. More recently, Hermida and Costa (2020) suggest a high participation in the informal acquisition of fish in the region, outside the commercial circuit, with values ranging between 25% and 65% of the population, depending on the area, that acquire fish in this way.

5 Conclusion

This study obtained unique knowledge about spearfishing in Madeira and compared the characteristics of this activity in two historical moments (2004 and 2017). Our data revealed that even though the number of spearfishers decreased over time, the number of catches did not follow the same trend and increased by double. A possible explanation could be related to the higher fishing time effort recorded in the 2017 survey.

In addition, it should be noted that many practitioners complement their captures with the collection of invertebrates, comprising a total of 52 taxa (40 osteichthyes, 4 crustaceans and 8 molluscs). The most frequent species captured in both analysed periods were parrotfish, white seabream and limpets.

In a future study, collaboration with a group of spearfishers who collect information on their fishing trips is recommended. It would be interesting to conduct new surveys using enough random samples (days, areas) to ensure that the target population has more probability of being sampled, and use on-site surveys to estimate catch and effort. Additionally, the use of record sheets, logbooks, or mobile applications, which are being used in other regions with interesting results (Morales-Nin et al., 2005, Tracey et al., 2011, Papenfuss et al., 2015, Venturelli et al., 2017), could provide a valuable source of information. Moreover, involving spearfishers and taking their opinions into account should be considered when implementing new legislation. Communication among all the stakeholders should be improved to know spearfishers' opinions and to inform them about the problems and conflicts that may arise from this activity, as well as to explain and inform them about the requirements and the objectives of the licensing system.

Finally, it should be noted that although the number of spearfishers in Madeira archipelago is not very high, and despite the bias associated with survey sampling, the collective annual catch may be significant, making spearfishing an activity with a potential negative impact on coastal species. Spearfishing should be taken into account in fisheries management, and adequate monitoring of this activity should be carried out in order to assess the evolution of exploited marine resources over time.

Supplementary Material

Supplementary Figure S1 to S3.

The Supplementary Material is available at <https://doi.org/10.1051/alr/2020015>.

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Author contribution statement

Roi Martínez-Escauriaza: design, data acquisition, analysis and interpretation, methodology, and writing original draft. Claudio Vieira: data acquisition. Lídia Gouveia: supervision, funding acquisition, and resources. Nuno Gouveia: conceptualization, supervision, funding acquisition, and resources.

Margarida Hermida: supervision and writing review. All authors read and approved the final manuscript.

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