The European Zoological Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tizo21

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To cite this article: R. Sousa, A. R. Pinto, J. Vasconcelos & R. Riera (2020) Does harvesting affect the relative growth in *Patella aspera* Röding, 1798?, The European Zoological Journal, 87:1, 395-401, DOI: 10.1080/24750263.2020.1791266

To link to this article: https://doi.org/10.1080/24750263.2020.1791266

Published online: 17 Jul 2020.

The European Zoological Journal, 2020, 395–401
Vol. 87, No. 1, https://doi.org/10.1080/24750263.2020.1791266

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Does harvesting affect the relative growth in *Patella aspera* Röding, 1798?

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(Received 5 April 2020; accepted 30 June 2020)

Abstract
Length–weight relationships (LWRs) provide valuable information about growth and individual fitness on the population. LWRs are commonly used in studies on life history, population dynamics, ecosystem modelling and stock assessment. A comparative study on the effect of harvesting in the relative growth of *Patella aspera* between Marine Protected Areas (MPAs) and exploited areas was conducted in the archipelago of Madeira (NE Atlantic Ocean). The results showed that populations from the exploited areas exhibited a negative allometric growth whilst the populations from the MPAs showed predominantly isometric and positive allometric growth. The effects of protection from MPAs on the populations of *P. aspera* were not only restricted to an increase in mean size but also in a more balanced growth. This study highlight the importance of MPAs in the preservation of *P. aspera* populations in Madeira archipelago. Hence, these results should be used to corroborate the positive effects of MPAs in safeguarding the exploited resources, especially in oceanic islands were species are more prone to over-exploitation.

Keywords: *Relative growth, limpets, MPAs, north-eastern Atlantic Ocean*

Introduction

Rocky shores are extremely productive ecosystems supporting a high diverse range of biological assemblages (Raffaelli & Hawkins 1999; Gamfeldt & Bracken 2009). The easy accessibility of intertidal makes them susceptible to human-induced perturbations such as, harvesting (Nakin & McQuaid 2014; Riera et al. 2016), pollution (Walsh et al. 1995) and habitat modification (Cole et al. 2012).

Human exploitation of intertidal organisms on the rocky shores is a significant cause of disturbance since prehistoric times (Bustamante & Castilla 1990; Boer & Prins 2002; Martins et al. 2008). The exploitation of these resources is greatly influenced by human demography, tradition, and economy (Rius & Cabral 2004). Harvesting frequently leads to local extinctions (Kido & Murray 2003; Martins et al. 2008), a reduction in abundances and shifts in size composition (Núñez et al. 2003; Riera et al. 2016). The effects of harvesting are not limited to alterations in targeted species, but they extend through cascading trophic effects to the whole ecosystem (Scheffer et al. 2005; Martins et al. 2017).

Intertidal grazers such as, *Patella aspera* Röding, 1798, are considered keystone species because of their pivotal role in the ecological balance of the rocky shores (Hawkins & Hartnoll 1983; Jenkins

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et al. 2005; Coleman et al. 2006). They have often been used as biological indicators to evaluate the consequences of anthropogenic impacts on rocky shores (Lima et al. 2007; Sousa et al. 2020). These grazers are essential in the structuring and regulating the ecological balance of intertidal communities, directly through the key process of grazing on algae, and indirectly by influencing the establishment of other organisms (Hawkins & Hartnoll 1983; Jenkins et al. 2005; Coleman et al. 2006).

The implementation of MPAs (Marine Protected Areas) is considered a key tool for the conservation of coastal biodiversity (Ballantine 1991; Edgar et al. 2014) due to its ecosystem-level approach for exploited species (Henriques et al. 2017). MPAs defined as no take zones, are an alternative to traditional management measures of marine resources (Halpern & Warner 2002), since the exploited organisms, usually attain higher density, biomass, and size in these zones (Hockey & Bosman 1986; Keough et al. 1993; Halpern 2003). The effect of harvesting ban of limpets such as *Patella* spp. in MPAs underpinned an increase of their abundances (Ceccherelli et al. 2006; Shears et al. 2012; Sousa et al. 2020), shell size and size at first maturity (Sousa et al. 2020). MPAs re-establish and protect marine resources within their boundaries, mainly the reproductive component, and also act as a source of larvae that may contribute to the settlement and recruitment outside of the reserves (Rakitin & Kramer 1996; Pelc et al. 2009). This process is due to larval connectivity between MPAs and full access areas (Christie et al. 2010).

Length–weight relationships (LWRs) allow the estimation of the average weight at a given length of a species in a given geographic area (Ferreira et al. 2008) and could vary between regions and habitats (Vaz-Dos-Santos & Gris 2016). These relationships are pivotal for the comparison of life history, population dynamics, ecology ecosystem modelling, stock assessment and estimation of the production and biomass of a population among regions (Anderson & Gutreuter 1983; Erzini 1994; King 1995; Santos et al. 2002; Vaz-Dos-Santos & Gris 2016). For instance, exploited populations of limpets are known to have reduced reproductive potential due to the decrease in abundance and size (Oliva & Castilla 1986), which contributes to the reduction of reproductive output. Data on reproduction is of utmost importance for the conservation and management of heavily exploited limpet populations (Espinosa et al. 2006), since size-selective harvesting negatively affects their reproductive output (Fenberg & Roy 2008).

The effect of more balanced and natural conditions of the MPAs on the relative growth of *P. aspera* were analysed through a comparative analysis in the Madeira archipelago. It was hypothesized that populations in MPAs will have a more balanced growth than in exploited areas.

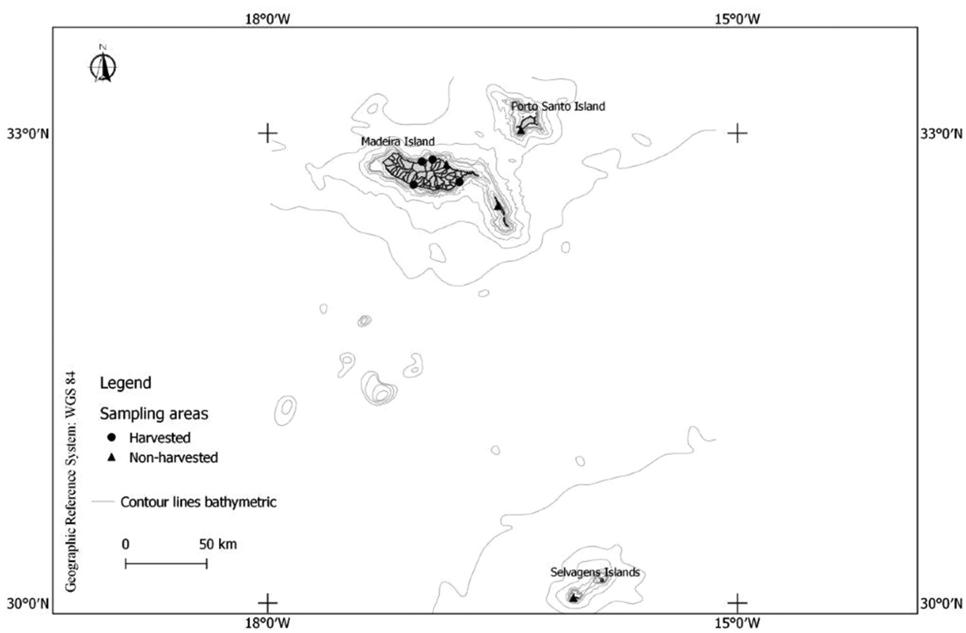

Figure 1. Sampling locations of *Patella aspera* populations in Madeira archipelago (• exploited Areas, Δ Marine protected areas).

Material and methods

The study was conducted on fresh specimens of *P. aspera* randomly collected from the intertidal and subtidal zones of the rocky shores of the Madeira archipelago (NE Atlantic). Each harvesting set was performed by snorkelling for a standard period of 30 minutes by the same experienced harvesters, without selecting for size and all observed individuals were censused.

The locations were as similar as possible to each other and selected considering the coastal settlements with analogous conditions (e.g. type of substrate, slope of the coast, rugosity, hydrodynamics).

All specimens were measured to the nearest 0.01 mm (total shell length, TL) using a Vernier calliper and weighed (total weight, TW) on a digital balance (0.01 g accuracy).

The comparative study was conducted considering the LWRs of *P. aspera* according to the exploitation level, non-harvested (MPAs) and harvested (exploited areas). Sampling was performed at four MPAs (Desertas, Garajau, Rocha do Navio and Selvagens) and four exploited coastal areas (Santa Cruz, Ribeira Brava, São Vicente and Porto Moniz) from April to August 2018 (Figure 1).

The shell length–weight relationship was estimated by the equation $W = aL^b$ (Bagenal & Tesch 1978), where W is the total weight in grams, L the shell length in millimetres, *a* is the intercept (condition factor) and *b* is the slope (relative growth rate). The parameters *a* and *b* were determined by linear regression analysis fitted by the least-squares method over log-transformed data ($logW = loga + blogL$) subsequently the use of log-log plots to detect and exclude outliers (Froese 2006).

The coefficient of determination r^2 was used as an indicator of the quality of the linear regression (King 1995) and a Student's t-test was applied to test the hypothesis of an isometric relationship (H_0: $b = 3$; H_1: $b \neq 3$, at the 5% significance level). A significant difference of the *b* parameter from 3 implies an allometric growth either negative ($b < 3$; $P < 0.05$) or positive ($b > 3$; $P < 0.05$) and an isometric growth is assigned when b is not significantly different from 3 ($P > 0.05$) (Zar 1996). All statistical analyses were performed using SPSS v.24.0 (IBM Corp 2016). For all tests, $P < 0.05$ was used as the cut-off for significance.

Results

A total of 1,739 limpets from 8 locations (4 MPAs and 4 exploited areas) of the rocky shores of Madeira were sampled. The mean shell length of the 1,052 specimens of *P. aspera* from the MPAs was higher (55.78 ± 9.33 mm TL) than for the 687 specimens from the exploited areas (38.15 ± 6.07 mm TL). In terms of body weight, the same pattern was observed in MPAs (22.58 ± 12.02 g TW) relative to exploited areas (5.34 ± 2.77 g TW).

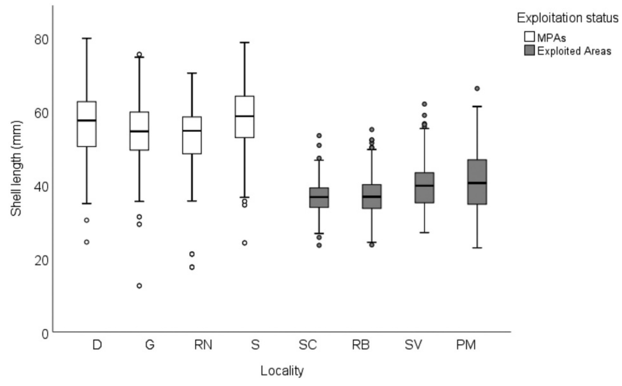

Figure 2. Shell length for *Patella aspera* populations from D (Desertas), G (Garajau), RN (Rocha do Navio), S (Selvagens), SC (Santa Cruz), RB (Ribeira Brava), SV (São Vicente) and PM (Porto Moniz). Box plot showing median (black line) and upper and lower quartiles of the data.

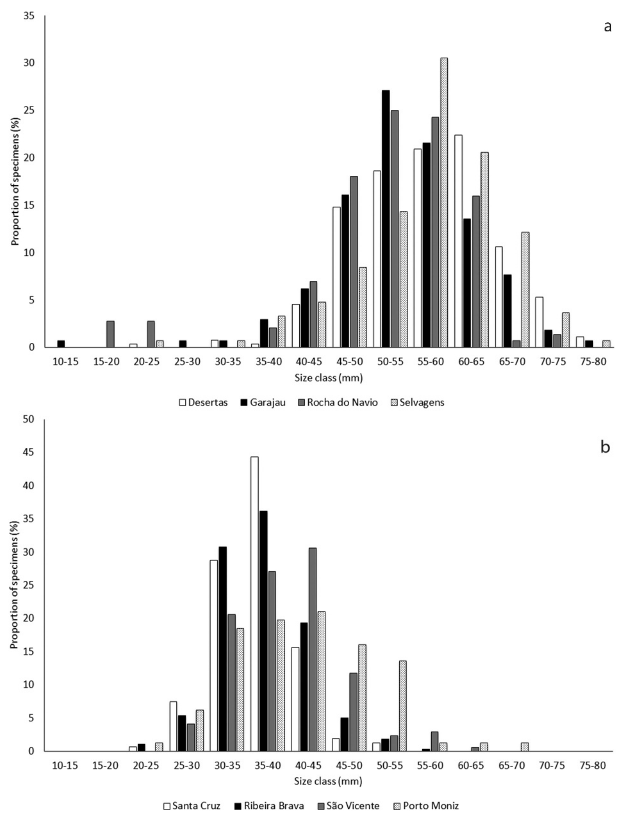

Figure 3. Size distribution of *Patella aspera* sampled in (a) Marine Protected Areas and (b) exploited coastal areas.

Table I. Descriptive statistics for *Patella aspera* from Marine Protected Areas (MPAs) and exploited zones in the northeastern Atlantic. (*n*: sample size; S.D.: standard deviation; Min: minimum; Max: maximum; and CV: coefficient of variation).

			Shell length (mm)				
Exploitation status	Locality	*n*	Mean	S.D.	Min	Max	CV (%)
MPAs	Desertas	263	57.11	8.72	24.44	79.90	15.26
	Garajau	273	54.35	9.03	12.56	75.53	16.61
	Rocha do Navio	244	52.18	10.39	17.63	70.45	19.92
	Selvagens	272	57.83	8.86	24.22	78.87	15.32
Exploited	Santa Cruz	160	36.72	4.56	23.58	53.41	12.42
	Ribeira Brava	178	37.02	5.24	23.67	55.07	14.14
	São Vicente	179	39.85	6.41	27.03	62.00	16.08
	Porto Moniz	170	41.33	6.68	22.88	66.26	20.16

Table II. LWR parameters for *Patella aspera* from Marine Protected Areas and exploited zones in the northeastern Atlantic. (*n*: sample size, a and b = parameters of equation $W = aL^b$; S.E.: standard error; CL 95%: confidence limits; r^2: coefficient of determination, type of allometry; and *t*: test values).

			WLR parameters and statistics								
Exploitation status	Locality	*n*	a	SE(a)	95% SL(a)	b	SE(b)	95% SL(b)	r^2	allometry	*t*
MPAs	Desertas	263	0.021	0.143	0.016–0.028	2.962	0.038	2.802–3.122	0.86	Isometry	0.463
	Garajau	273	0.021	0.104	0.017–0.026	2.931	0.060	2.812–3.050	0.90	Isometry	1.140
	Rocha do Navio	244	0.009	0.107	0.008–0.012	3.386	0.063	3.262–3.511	0.95	Positive	6.146
	Selvagens	272	0.008	0.140	0.006–0.011	3.523	0.080	3.366–3.679	0.88	Positive	6.563
Exploited	Santa Cruz	160	0.035	0.162	0.025–0.048	2.570	0.103	2.366–2.775	0.89	Negative	4.154
	Ribeira Brava	178	0.031	0.140	0.024–0.041	2.627	0.089	2.451–2.802	0.88	Negative	4.183
	São Vicente	179	0.034	0.046	0.031–0.037	2.894	0.042	2.811–2.977	0.85	Negative	1.969
	Porto Moniz	170	0.025	0.197	0.017–0.037	2.766	0.122	2.523–3.010	0.89	Negative	1.910

The shell length in MPAs ranged from 12.56 mm in Garajau to 79.90 mm in Desertas while in exploited areas varied between 23.56 mm in Santa Cruz and 66.26 mm in Porto Moniz (Figure 2). The smallest mean shell length occurred in Santa Cruz with 36.72 ± 4.56 mm TL (exploited area) and the largest in Selvagens with 57.83 ± 8.86 mm TL (MPA) (Figure 3; Table I).

The WLRs, related statistics and nature of growth for *P. aspera* specimens by exploitation status in the archipelago of Madeira are shown in Table II. The estimated relative growth rate ranged between 2.962 (Desertas) and 3.523 (Selvagens) in the MPAs and from 2.570 (Santa Cruz) and 2.894 (São Vicente) in exploited areas.

The relative growth pattern was negative allometric for all the exploited areas and isometric (Desertas and Garajau) and positive allometric (Rocha do Navio and Selvagens) for MPAs.

Discussion

Oceanic islands harbour less diverse marine ecosystems than those observed in the corresponding continental habitats (Paulay 1994; Hawkins et al. 2000), and thus they are more susceptible to over-exploitation (Martins et al. 2008). Harvesting activities can lead to irreversible impacts by affecting not only the target species but also the entire ecosystem through a trophic cascading effect (Castilla 1999).

Limpets harvesting is a traditional activity in Madeira archipelago, dating back to 15th century (Silva & Menezes 1921) and represents one of the most profitable economic activities of small-scale fisheries (Sousa et al. 2020). *P. aspera* is being exploited near its maximum sustainable yield, however, a slight recovery of the exploited populations was observed after the harvesting regulation of this species in 2006 (Sousa et al. 2017, 2020).

We herein show the LWRs for *P. aspera* in the NE Atlantic Ocean. The LWRs are considered a practical condition index that could vary temporally according to factors such as food availability, feeding rate and reproduction, however, the b parameter usually does not vary significantly throughout the year (Bagenal & Tesch 1978).

The more controlled conditions and the reduction of the human impacts on the populations of *P. aspera* in the MPAs were not only restricted to an increase in mean size but also in a more balanced growth. The isometric

(Desertas and Garajau) and positive allometric growth (Rocha do Navio and Selvagens) indicates an improvement of the ecosystem and populations health in the MPAs. Desertas and Garajau were the more balanced areas with an increase in length and weight at approximately the same rate, thus allocating the same amount of energy to reproduction and growth. Contrarily, the exploited areas showed populations with negative allometric growth indicating differential growth between length and weight. It occurs a higher investment in individual shell growth in relation to the increase in total weight. Thus, generally, these species assigns more energy to growth than to reproduction in the exploited areas. The negative allometric growth was only obtained for the exploited areas, this may be explained by the high level of harvesting pressure that leads to lower densities and alterations on populations dynamics and size structure (Riera et al. 2016; Sousa et al. 2019). This is in accordance with Sousa et al. (2019) that found a similar pattern of growth, smaller mean size populations and a lower proportion of reproductive individuals in the exploited limpet populations of this region.

In the archipelago of Madeira, the coastal areas with reduced anthropogenic impact, e.g. MPAs, where harvesting has been banned for over 20 years, limpet populations showed higher abundances and more balanced size composition (Sousa et al. 2020). The results confirmed that MPAs are one of the most important tools in the conservation of coastal resources (Micheli et al. 2008; Pérez-Ruzafa et al. 2008; Edgar et al. 2014). The more controlled environmental and natural conditions in MPAs contribute to a more balance growth. Also, MPAs promote the recovery of age and length structure, to enhance yield and maintain balanced sex ratios (Alonzo & Mangel 2004; Hamilton et al. 2007).

The present results also showed that a more balance growth in MPAs would prevent shifts to early maturation, since MPAs are supposed to preserve age structure, enhance yield, preserve balanced sex ratios, prevent sperm limitation, and restrict evolutionary as shifts to early maturation (Alonzo & Mangel 2004; Hamilton et al. 2007). The high coefficient of determination obtained in the estimation of WRLs indicates a good quality of the prediction of the linear regression for the analysed limpets populations and could be applied in other geographical areas considering this significant size range.

The value of the b parameter estimated for *P. aspera* is within the usual range of 2.5–3.5 (Bagenal & Tesch 1978; Froese 2006), indicating normal growth dimensions and/or the well-being of the studied populations (Carlander 1969; Bagenal & Tesch 1978; King 1995).

The results obtained highlight the importance of MPAs in the conservation of *P. aspera* populations in Madeira archipelago. The present data should be used to corroborate the positive effects of MPAs in the protection of the exploited resources especially in distant oceanic archipelagos, with low-connectivity with other regions. Hence, these populations are more prone to overexploitation.

Acknowledgements

We are grateful to the Fisheries Research Service (DSI) of the Regional Directorate of Fisheries of the Autonomous Region of Madeira. We acknowledge Dr.[a] Antonieta Amorim for providing the map. We also thank Filipe Andrade and Jorge Lucas for their help in biological sampling and harvesting surveys. Our appreciation to the IFCN (Instituto das Florestas e Conservação da Natureza da RAM) for allowing and collaborating in the collection of limpets in the natural reserve zones. The first author (RS) was supported by a grant from ARDITI OOM/2016/010 (M1420-01-0145-FEDER-000001-Observatório Oceânico da Madeira-OOM) and the fourth (RR) partially funded by UCSC (FAA 01/2019). The present study was also supported by the UE European Regional Development Fund in the framework of the Projects MARISCOM AC (MAC/2.3d/097) and MACAROFOOD (MAC/2.3d/015), and the Regional Government of Madeira and by the strategic project UID/MAR/04292/2019 granted to MARE by FCT.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Agência Regional para o Desenvolvimento da Investigação, Tecnologia e Investigação / Observatório Oceânico da Madeira [ARDITI OOM/2016/010 M1420-01-0145-FEDER-000001-OOM]; MARE - Centro de Ciências do Mar e do Ambiente [UID/MAR/04292/2019 (FCT)]; UE European Regional Development Fund / Regional Government of Madeira [MARISCO MAC(MAC/2.3d/097) MACAROFOOD(MAC/2.3d/015)]; Universidad Católica de la Santísima Concepción [FAA 01/2019].

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