Estimates of biomass and potential yield for the deep-water red crab, *Chaceon affinis* and the toothed rock crab, *Cancer bellianus* (Decapoda: Brachyura) off the Azores (Mid-North Atlantic)

MÁRIO PINHO, RÉGIS SANTOS, OCTÁVIO MELO, EDUARDO ISIDRO, ANA NOVOA-PABON, WENDELL SILVA AND JOÃO GONÇALVES

Pinho, M., R. Santos, O. Melo, E. Isidro, A. Novoa-Pabon, W. Silva and João Gonçalves 2020. Estimates of biomass and potential yield for the deep-water red crab, *Chaceon affinis* and the toothed rock crab, *Cancer bellianus* (Decapoda: Brachyura) off the Azores (Mid-North Atlantic). *Arquipelago*. Life and Marine Sciences 37: 21 – 36.

Available information on the deep-water red crab, *Chaceon affinis* and the toothed rock crab, *Cancer bellianus*, resulting from exploratory research surveys and commercial fishing experiments carried out in the Azorean Exclusive Economic Zone (EEZ), were summarized to estimate the biomass and potential yield (Maximum Sustainable Yield – MSY) for both fishery resources. The fishery potential was estimated through empirical methods usually applied when available information is scarce in line with the precautionary approach principle. Results suggest modest MSY values (considered as precautionary Total Allowable Catch – TAC), around 2,205 t for the deep-water red crab (2,159 t year^{-1} at seamounts and 46 t year^{-1} at coastal areas), and 471 t for the toothed rock crab (281 t year^{-1} at offshore seamounts and 189 t year^{-1} at coastal areas). Considering the limited available data and high uncertainty associated with these estimations, it is suggested that only a reduced number of vessels should be allowed to fish in the aggregated areas, namely coastal and seamount areas. The exploitation of these resources should be started in a very limited way followed by an ad hoc observer programme, aiming to collect reliable data that will allow, if it is the case, to raise in the future the exploitation level in a gradual and sustainable way.

Key words: *Chaceon affinis*; *Cancer bellianus*; abundance; fishery potential; deep-sea; Azores.

Mário Pinho[1,2,3], Régis Santos[1,2] (email:regisvinicius@gmail.com), Octávio Melo[1,2], Eduardo Isidro[1,2,3], Ana Novoa-Pabon[2,3], Wendell Silva[1,2], João Gonçalves[1,2,3]. 1IMAR Institute of Marine Research, University of the Azores, 9901-862, Horta, Portugal. 2Okeanos R&D Centre, University of the Azores, 9901-862, Horta, Portugal. 3Faculty of Science and Technology, Department of Oceanography and Fisheries, University of the Azores, 9901-862, Horta, Portugal.

Corresponding author: Régis Santos (email:regisvinicius@gmail.com)

INTRODUCTION

The deep-sea crustaceans from the Azores archipelago (Mid-North Atlantic) can be considered as virgin or poorly exploited resources. In fact, only the toothed rock crab, *Cancer bellianus* J. Y. Johnson, 1861, has been sporadically exploited for local consumption in three of the nine islands that form the archipelago, i.e. Terceira (65% of reported landings), São Miguel (16%) and Pico (14%) islands, reaching annual average values of eight tons between 1997 and 2018 (Lotaçor S.A., commercial landings database).

Studies on Azorean deep-sea crabs, *C. bellianus* and *Chaceon affinis* A. Milne-Edwards and Bouvier, 1894, began in 1994 with sporadic cruises and "opportunistic" actions (i.e. fishing and sampling on cruises not directed to crustaceans) (Gonçalves 1994; Gonçalves & Pinho 1994; Gonçalves et al. 1995). More detailed knowledge about the biology and fishing aspects of these species were obtained from the European project "Biology of some Macaronesian deep-sea commercial species" (González et al. 1998) and the regional project "CRUSTAÇO" (Pinho et al. 2001a; Santos et al. 2019).

As the results obtained in the preliminary studies (above referenced) suggested that these resources had the potential to develop a small fishery, commercial fishing experiments were carried out using two coastal closed-deck vessels of around 14 m length (Pinho et al. 2001a). These vessels operated primarily in coastal areas of Terceira, Graciosa, São Jorge, Pico and Faial islands (central group of the Azores archipelago) and the results showed that there was indeed potential for both species to be exploited and that this potential was greater for the toothed rock crab than for the deep-water red crab (Pinho et al. 2001 a, b, c).

At this stage, some limiting factors for exploitation were also identified, namely: (a) Lack of established local or external markets at stimulating prices; (b) Aggregate distribution or "patches" of the resource (not uniform and very dependent on specific habitat available) introducing great variability of abundance from site to site; and (c) Technological difficulties related to the operation of the artisanal fleet, namely those related to the power of the hauler and the necessary space to work with ropes and traps.

There is nowadays a growing interest in the exploitation of crab resources as an alternative or a complement to the traditional demersal resources intensely exploited. However, there is a requirement for scientific studies reporting the potentially sustainable levels for the exploitation of these resources to guide management. In fisheries terms, populations need to be maintained within safe biological limits, i.e. the maximum sustainable yield (MSY) that is the highest theoretical equilibrium yield that can be continuously taken (on average) from a stock under existing (average) environmental conditions without affecting significantly the reproduction process (FAO 1997; ICES 2018a).

This work aims to review and summarize all the available information for *C. affinis* and *C. bellianus* in the Azorean region (Mid-North Atlantic) to estimate the biomass and potential yield as MSY proxies to guide management advices.

MATERIALS AND METHODS

Azores archipelago

The Azores archipelago is placed in the Mid-North Atlantic Ocean between 33.5° – 43° N, and 21° – 35.5° W, and its Exclusive Economic Zone (EEZ) has approximately 1,000,000 km^2. The Azores archipelago is constituted of nine islands (western group: Flores and Corvo; central group: Terceira, Graciosa, São Jorge, Pico and Faial; eastern group: São Miguel and Santa Maria), several islets and many seamounts and banks of volcanic origin (Figure 1).

Muddy sediments are the most extensive substrate types in the Azores (ICES 2019). Continental shelves are quite narrow (*ca* 1,500 km^2) and the average depth in the Azorean EEZ is about 3,000 m, 0.8% of the total EEZ area has depths < 600 m and 6.8% is between 600 and 1,500 m (ICES 2018b). The North Atlantic Central Water (NACW) at depths shallower than 600-700 m, the North Atlantic Deep Water (NADW) below 2000 m depth, and the Subarctic Intermediate Water (SAIW), Labrador Sea Water (LSW) and Antarctic Intermediate Water (AAIW) at intermediate depths are the main water masses in the Azorean region (Bashmachnikov & Martins 2007). Mediterranean Water can also occur approximately between 650-1,200 m depth (Bashmachnikov & Martins 2007).

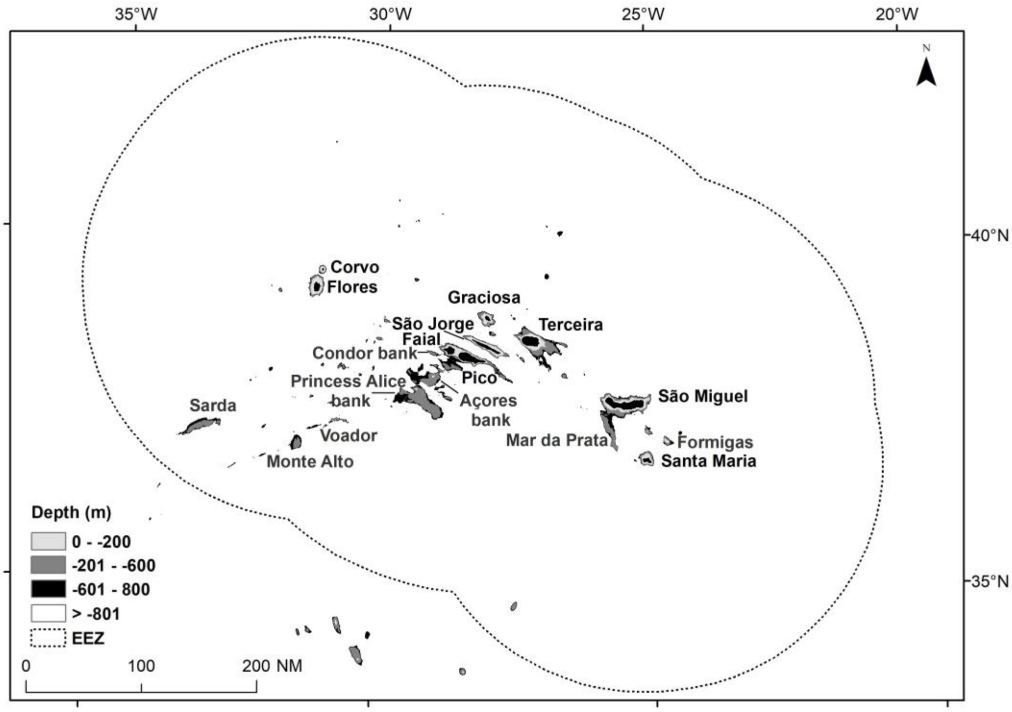

Fig. 1. The Azores archipelago (mid-North Atlantic Ocean) with depth contours layers and location of the nine islands (in bold), major seamounts, and the limit of the Exclusive Economic Zone (EEZ).

Data collection

The primary data used in this study were obtained in:

(a) commercial experimental trap fishing operations targeting the deep-water red crab during 2003. These data were collected by observers on board of an Azorean industrial vessel, with enough autonomy and power to operate in the offshore banks and seamounts.

(b) exploratory research surveys using traps targeting the deep-water red crab and the toothed rock crab from 1994 to 2000 (Pinho et al. 2001a, b, c).

In each set carried out by the aforementioned commercial vessels (items "a"), information on start and retrieval dates, time, geographical position, depth, number of dropped and lost traps, as well as the capture per trap in number of individuals were obtained. In addition, information on the vessel and gear characteristics was recorded. For crustaceans (the deep-water red crab and the toothed rock crab), sex and carapace length were also recorded whenever possible. The landing by weight was subsequently registered for each trip.

Survey data (item "b") were obtained mainly in coastal areas of the central group (Faial, Pico and São Jorge). Of the banks, only the Princess Alice Bank was sampled. This study area was stratified into depth strata with 100 m intervals (i.e. the first stratum represented 0-100 m, the second 100-200 m and so on) down to 1,200 m. Within each stratum, random sets were allocated, guaranteeing a minimum of two sets per stratum. For each set, information was collected on fishing (start and retrieval dates, time, geographical position, depth, number of dropped and lost traps, catch in number of individuals per trap, etc.) and biology (length and carapace width, weight, sex, etc.). The bait was *ca* 1 kg of salted Atlantic chub mackerel *Scomber colias*. For details of the sampling methodology see Pinho et al. (2001b, c). For this study, we selected data corresponding only to sets made with benthic bottom traps. Although different types of bottom traps (Fathom

Plus® and the homemade crab trap "Josué"; see Melo (2009) for technical specifications) were used, abundance was considered to be independent of the trap type because no significant differences ($\alpha = 0.05$) were found in abundance between traps (t-test, $t = 1.24$, $p = 0.22$).

Assuming that depths of greatest abundance correspond to the preferential habitat of the species, the depths of 500-900 m for the deep-water red crab and 200-600 m for the toothed rock crab were adopted based on the survey available information. It was considered that the species distribution in the Azorean EEZ along the respective bathymetric is identical to that of the sampled areas. For coastal zones of the islands, the average catch per unit of effort (CPUE - estimated number of individuals per trap) estimated for each species based on the survey data was used as abundance index (Pinho et al. 2001b, c). For bank area and the deep-water red crab, the average CPUE was estimated from the data collected by the observers throughout the experimental commercial fishing operation. For the toothed rock crab, the average CPUE value estimated for the Princess Alice Bank using survey data was extrapolated for all bank areas. Only the complete records, i.e. those containing catch, fishing effort and georeferenced information, were used in the analysis. The data corresponding to a group of strata, due to the displacement of the fishing gear, were eliminated from the analysis. The CPUE in number was converted to weight, using the average weight for each species estimated by Pinho et al. (2001b, c).

Areas of occurrence

Areas of probable occurrence of these resources in the Azorean EEZ were estimated from Smith and Sandwell (1997) (http//topex.ucsd.edu/sandwell/sandwell.html) bathymetric mapping and assuming an amplitude of bathymetric distribution of 200 to 600 m for the toothed rock crab and 500 to 900 m for the deep-water red crab.

The bathymetric mapping was first constructed through the kriging method for data interpolation using the Surfer© 7.05 software (Surface Mapping System Golden Software, Inc.). The areas were then estimated using the Map Viewer© 4.0 software (Thematic Mapping System, Golden Software, Inc.). For mapping details of banks and seamounts of the Azores, see Machete et al. (2005).

Estimates of biomass and potential yield

The biomass (abundance) of each species was estimated according to the methodology of the theoretical attraction (influence) area for traps (Eggers et al. 1982). This methodology, similar to the swept area procedure used in the case of bottom trawls, has been proposed and largely employed to evaluate other trapped crab resources (Miller 1975; McElman & Elner 1982; Melville-Smith 1986; Defeo et al. 1991; Arana 2000; Cores et al. 2019).

For the approximate biomass estimation, the follow expression was used:

$$N = A*D*q$$

where: N – biomass (abundance) of the resource in number; A – total area of distribution of the resource in the Azorean EEZ; D – average density of the resource (number of individuals per km^2); and q – catchability coefficient (proportion of individuals that are trapped in the catchment area and actually captured).

The mean density of the resource was estimated as follows:

$$D = C/a_1$$

Where: C – average number of individuals caught per trap; and a_1 – theoretical area of attraction of a trap (km^2).

The theoretical attraction area of the trap was considered to have a circular shape, assuming a null or minimal underwater current. Thus, according to Eggers et al. (1982), the effective theoretical mean attraction area of a trap in an overlapping configuration of successive traps in line was calculated as:

$$a_t = a_1 - \frac{n_a - 1}{n_a} * L$$

Where: a_t – effective mean theoretical attraction area of a trap in overlapping configuration; a_1 – theoretical attraction area of a trap; n_a – total number of traps per fishing gear (line); and L – overlapping area of influence (attraction) of two adjacent traps, calculated as:

$$L = 2 * \left[\cos^{-1}\left(\frac{s}{2R}\right) * R^2 - \frac{s}{2} * \left(R^2 - \frac{s^2}{4}\right)^{\frac{1}{2}} \right]$$

Where: s – distance between adjacent traps along a line of traps; and R – radius of the attraction area of a trap.

Biomass was estimated for combined sexes and by species, for radius of attraction of a trap varying between 25 and 45 m (intervals of five metres). In the case of data from the research surveys, the first radius (25 m) corresponds to a non-interaction configuration between adjacent traps while the following ones correspond to an interaction configuration. The distance between adjacent traps along a line was approximately 50 m in the research surveys and 45 m in commercial fishing experience. The commercial fishing vessel used on average 60 traps per line, while approximately 10 traps per line were used in the research survey (Pinho et al. 2001 b, c).

The potential yield for each species was estimated using Gulland's empirical formula for estimating the maximum sustainable yield (MSY) of unexploited (virgin) populations (Gulland 1971, 1983):

$$P = x*M*B_0$$

Where: P – potential yield; M – natural mortality; B_0 – virgin biomass; and x – constant (related to growth and mortality characteristics).

Gulland (1971) proposed the value of 0.5 for "x", while Garcia & Le Reste (1981), Beddington & Cooke (1983), and Garcia et al. (1989) suggested using more conservative values (x < 0.5). Thus, in this study, potential yields were estimated with values of "x" varying between 0.1 and 0.5. For the natural mortality was adopted the value M = 0.15, which corresponds to the mean value of mortality for the species estimated by empirical methods, such as Tanaka (1960) (assuming that of 5% of the population reaches the maximum age 20 years if only natural mortality acts), and Rikhter & Efanov (1976) (assuming that the length of first maturation estimated for these species in the Azores, between 80 and 85 mm of carapace length, corresponds to 10 years of age; Pinho et al. 2001b,c). This value also corresponds to the estimated value used by other authors for deep-water crab species (Cayre et al. 1979; Melville-Smith 1988; Defeo et al. 1991; Arana 2000). The virgin biomass (B_0) corresponded to the biomass estimated since the resources are pristine.

RESULTS

Distribution and catches

Cancer bellianus was found distributed in the Azores between 100 and 800 m depth, with higher catches at coastal areas, approximately 5 individuals (ca 2.73 kg) $trap^{-1}$ between 200 and 600 m (Table 1). The results showed a great variability in abundance in all depth strata (catches at coastal zones and in the 200-600 m stratum vary from ca 1 to 10 individuals $trap^{-1}$), meaning that the distribution of the species was not uniform. The estimated CPUE for the Princess Alice Bank for this species was very low and had a great variability (Table 1).

Chaceon affinis was found distributed in the Azores between 400 and 1,100 m depth with higher catches between 600 and 900 m depth (Pinho et al. 2001c) (Table 2). The catch variability was very significant particularly in the survey data, evidencing the distribution characteristics of the species by "patches". The CPUE value at coastal zones estimated from the research surveys and commercial fishing were very similar, revealing that the occurrence of the species at coastal zones was relatively scarce (Table 2). The estimated CPUE from the commercial fishing experience during the year 2003 was very high, meaning that only areas of high concentration of the species were probably covered.

Table 1. Estimated average catches for the toothed rock crab Cancer bellianus per trap and per depth stratum, for the Azorean coastal zones and Princess Alice Bank. The mean values for the 200-600 m stratum adopted for the fishery potential estimation are also presented in the table. CPUE - Catch per Effort Unit (number of ind. per trap); SD - Standard deviation; n - number of sets; na - not sampled.

Depth strata (m)	Coastal zones			Princess Alice Bank		
	CPUE	SD	n	CPUE	SD	n
100	0.50	0.00	3	0.00	0.00	6
200	5.89	4.92	22	1.52	1.75	5
300	4.91	3.36	24	1.97	2.57	22
400	8.41	5.18	17	2.45	3.61	11
500	4.71	3.13	17	1.66	1.18	4
600	3.08	2.02	17	0.75	0.12	2
700	1.01	0.98	12	0.48	0.26	3
800	0.79	0.70	6	na	na	na
200-600	5.39	4.19	97	1.95	2.61	44

Table 2. Estimated average catches for the deep-water red crab *Chaceon affinis* per trap and per depth stratum, for the Azorean coastal zones and seamounts. The mean values for the 500-900 m stratum are also presented, with the values adopted for the fishery potential estimation in bold. CPUE - Catch per Effort Unit (number of ind. per trap); SD - Standard deviation; n - number of sets; na - not sampled.

Depth strata (m)	Commercial fishery						Research surveys		
	Seamounts			Coastal zones			Coastal zones		
	CPUE	SD	n	CPUE	SD	n	CPUE	SD	n
400	5.43		1	na	na	na	0.01	0.03	14
500	5.07	1.57	4	0.80		1	0.27	0.63	14
600	5.30	3.32	10	0.83	0.21	2	0.33	0.46	22
700	5.45	2.28	15	1.37	0.59	6	0.42	0.44	18
800	5.81	2.12	13	1.01	0.37	4	1.06	1.22	19
900	0.43	-	1	na	na	na	0.80	1.24	17
1,000	na	na	na	na	na	na	0.78	0.83	13
1,100	na	na	na	na	na	na	0.25	0.35	2
500-900	**5.37**	**2.49**	**43**	1.13	0.49	13	**0.79**	**1.30**	**90**

Areas of occurrence

The total areas available in the Azorean EEZ for depths considered optimal for the distribution of the species were summarized in Table 3. These areas represented approximately 1.4% of the Azorean EEZ in the case of *Cancer bellianus* and 3.4% in the case of *Chaceon affinis*. Coastal habitat areas available for both species were scarce(representing approximately 24% of the total habitat available in the Azorean EEZ for the toothed rock crab and 13% for the deep-water red crab). Offshore (banks and seamounts) habitat areas available for these species in the Azorean EEZ were also very scarce, especially for the toothed rock crab, meaning that the number of banks and seamounts with depth strata between 200-600 m was relatively small.

Table 3. Coastal zone and bank and seamount areas identified in the Azorean EEZ as potential habitats for the toothed rock crab *Cancer bellianus* (200-600 m) and the deep-water red crab *Chaceon affinis* (500-900 m).

Habitat	Depth (m)	Area (km^2)
Coastal zones	200-600	2,694
	500-900	4,247
Banks and seamounts	200-600	11,106
	500-900	32,775

Estimates of biomass and potential yield
Cancer bellianus

The estimated average biomass for banks/seamounts ranged from approximately 2,912 to 9,392 t, depending on the value of the radius of attraction adopted for a trap. These values corresponded to a mean density between 0.5 and 2 individuals per 1000 m^2. At coastal zones, estimated average biomass values varied between 1,952 and 6,296 t, corresponding to mean densities between 2 and 6 individuals per 1,000 m^2 (Table 4).

The potential yield (MSY) varied considerably according to the combination of each radius of attraction area (R) and exploitation rate (constant of empirical equation, x) (Tables 5 and 6). In the most pessimistic scenario, it was estimated a MSY (considered as precautionary TAC) of 44 t of the toothed rock crab at banks and seamounts, and 704 t in the most optimistic scenario (Table 5). On coastal zones, values of 29 t in a pessimistic scenario and 472 t in an optimistic one was estimated (Table 6).

Table 4. Average biomass of the toothed rock crab *Cancer bellianus* estimated at banks/seamounts and coastal zones of the Azorean EEZ. The table shows the lower (LCI) and upper (UCI) limits of the estimates for a 95% confidence interval. R - radius of attraction area of a trap; a_t - effective theoretical mean area of attraction of a trap in overlapping configuration; Area - total area of the 200-600 m stratum available in the Azorean EEZ; CPUE - Catch per Effort Unit (number of ind. per trap); $\overline{W}$ - average weight in the catch.

Habitat	R (m)		25*	30	35	40	45
	a_t (m^2)		1,963	1,164	2,032	2,880	3,755
	Area (km^2)	CPUE	Biomass (t)				
LCI		1.18	3,367	5,678	3,253	2,295	1,760
Banks and seamounts	11,106	1.95	5,570	9,392	5,381	3,797	2,912
UCI		2.72	7,773	13,106	7,509	5,299	4,064
LCI		4.56	3,156	5,322	3,049	2,152	1,650
Coastal zones	2,694	5.39	3,734	6,296	3,607	2,545	1,952
UCI		6.22	4,312	7,270	4,166	2,939	2,254

* Non-interaction condition between traps. $\overline{W}$ = 0.505 kg

Table 5. Maximum sustainable yield (MSY) of the toothed rock crab *Cancer bellianus* estimated for the aggregated bank and seamount areas of the Azorean EEZ. The table shows the lower (LCI) and upper (UCI) limits of the estimates for a 95% confidence interval. R – radius of attraction area of a trap; x – constant. Bold values correspond to the base option.

R (m)	Biomass (t)		x				
			0.1	0.2	0.3	0.4	0.5
25*	LCI	3,367	51	101	152	202	253
	Mean	5,570	84	167	251	334	418
	UCI	7,773	117	233	350	466	583
30	LCI	5,678	85	**170**	255	341	426
	Mean	9,392	141	**282**	423	564	704
	UCI	13,106	197	**393**	590	786	983
35	LCI	3,253	49	98	146	195	244
	Mean	5,381	81	161	242	323	404
	UCI	7,509	113	225	338	451	563
40	LCI	2,295	34	69	103	138	172
	Mean	3,797	57	114	171	228	285
	UCI	5,299	79	159	238	318	397
45	LCI	1,760	26	53	79	106	132
	Mean	2,912	44	87	131	175	218
	UCI	4,064	61	122	183	244	305

* Non-interaction condition between traps.

Table 6. Maximum sustainable yield (MSY) of the toothed rock crab *Cancer bellianus* estimated for the aggregated coastal areas of the Azorean EEZ. The table shows the lower (LCI) and upper (UCI) limits of the estimates for a 95% confidence interval. R – radius of attraction area of a trap; x – constant. Bold values correspond to the base option.

R (m)	Biomass (t)		x				
			0.1	0.2	0.3	0.4	0.5
25*	LCI	3,156	47	95	142	189	237
	Mean	3,734	56	112	168	224	280
	UCI	4,312	65	129	194	259	323
30	LCI	5,322	80	**160**	239	319	399
	Mean	6,296	94	**189**	283	378	472
	UCI	7,270	109	**218**	327	436	545
35	LCI	3,049	46	91	137	183	229
	Mean	3,607	54	108	162	216	271
	UCI	4,166	62	125	187	250	312
40	LCI	2,152	32	65	97	129	161
	Mean	2,545	38	76	115	153	191
	UCI	2,939	44	88	132	176	220
45	LCI	1,650	25	50	74	99	124
	Mean	1,952	29	59	88	117	146
	UCI	2,254	34	68	101	135	169

* Non-interaction condition between traps.

Table 7. Average biomass of the deep-water red crab *Chaceon affinis* estimated at banks/seamounts and coastal zones of the Azorean EEZ. The table shows the lower (LCI) and upper (UCI) limits of the estimates for a 95% confidence interval. R - radius of attraction area of a trap; a_t - effective theoretical mean area of attraction of a trap in overlapping configuration; Area - total area of the 500-900 m stratum available in the Azorean EEZ; CPUE - Catch per Effort Unit (number of ind. per trap); $\overline{W}$ - average weight in the catch.

Habitat	R (m)		25	30	35	40	45
	a_t (m^2) – Commercial fishery		468	1,286	2,025	2,770	3,548
	a_t (m^2) – Research surveys		1,963*	1,164	2,032	2,880	3,755
	Area (km^2)	CPUE	Biomass (t)				
LCI		4.63	170,324	62,004	39,394	28,794	22,480
Banks and seamounts	32,775	5.37	197,721	71,978	45,731	33,425	26,096
UCI		6.12	225,119	81,951	52,067	38,057	29,712
LCI		0.52	596	1,006	576	407	312
Coastal zones	4,247	0.79	902	1,521	871	615	472
UCI		1.06	1,207	2,036	1,167	823	631

* Non-interaction condition between traps. $\overline{W} = 0.526$ kg

Table 8. Maximum sustainable yield (MSY) of the deep-water red crab *Chaceon affinis* estimated for the aggregated bank and seamount areas of the Azorean EEZ. The table shows the lower (LCI) and upper (UCI) limits of the estimates for a 95% confidence interval. R – radius of attraction area of a trap; x – constant. Bold values correspond to the base option.

R (m)	Biomass (t)		x				
			0.1	0.2	0.3	0.4	0.5
25*	LCI	170,324	2,555	5,110	7,665	10,219	12,774
	Mean	197,721	2,966	5,932	8,897	11,863	14,829
	UCI	225,119	3,377	6,754	10,130	13,507	16,884
30	LCI	62,004	930	**1,860**	2,790	3,720	4,650
	Mean	71,978	1,080	**2,159**	3,239	4,319	5,398
	UCI	81,951	1,229	**2,459**	3,688	4,917	6,146
35	LCI	39,394	591	1,182	1,773	2,364	2,955
	Mean	45,731	686	1,372	2,058	2,744	3,430
	UCI	52,067	781	1,562	2,343	3,124	3,905
40	LCI	28,794	432	864	1,296	1,728	2,160
	Mean	33,425	501	1,003	1,504	2,006	2,507
	UCI	38,057	571	1,142	1,713	2,283	2,854
45	LCI	22,480	337	674	1,012	1,349	1,686
	Mean	26,096	391	783	1,174	1,566	1,957
	UCI	29,712	446	891	1,337	1,783	2,228

* Non-interaction condition between traps.

Table 9. Maximum sustainable yield (MSY) of the deep-water red crab *Chaceon affinis* estimated for the aggregated coastal areas of the Azorean EEZ. The table shows the lower (LCI) and upper (UCI) limits of the estimates for a 95% confidence interval. R – radius of attraction area of a trap; x – constant. Bold values correspond to the base option.

R (m)	Biomass (t)		x				
			0.1	0.2	0.3	0.4	0.5
25*	LCI	596	9	18	27	36	45
	Mean	902	14	27	41	54	68
	UCI	1,207	18	36	54	72	91
30	LCI	1,006	15	**30**	45	60	75
	Mean	1,521	23	**46**	68	91	114
	UCI	2,036	31	**61**	92	122	153
35	LCI	576	9	17	26	35	43
	Mean	871	13	26	39	52	65
	UCI	1,167	17	35	52	70	87
40	LCI	407	6	12	18	24	30
	Mean	615	9	18	28	37	46
	UCI	823	12	25	37	49	62
45	LCI	312	5	9	14	19	23
	Mean	472	7	14	21	28	35
	UCI	631	9	19	28	38	47

* Non-interaction condition between traps.

Chaceon affinis

The estimated average biomass at banks/seamounts ranged from approximately 26,096 to 197,721 t, depending on the value of the radius of attraction adopted for a trap. These values corresponded to a mean density between 2 and 12 individuals per 1,000 m^2. at coastal zones, estimated average biomass values varied between 472 and 521 t, corresponding to mean densities between 0.2 and 0.7 individuals per 1,000 m^2 (Table 7). The potential yield varied considerably according to the combination of each radius of attraction area (R) and exploitation rate (constant of empirical equation, x) (Tables 8 and 9). In the most pessimistic scenario, MSY was estimated to 391 t of the deep-water red crab on banks and seamounts, and 14,829 t in the most optimistic one (Table 8). In coastal zones, values of 7 t in a pessimistic scenario and 114 t in an optimistic one, were estimated (Table 9).

DISCUSSION

Distribution and catches

The results showed two important facts: a) the abundance of the studied resources seems to vary considerably in their spatial distribution, although the depth range of the species can be well defined; and b) there seems to be areas/strata of dominance for each species with *Cancer bellianus* being more abundant in coastal zones and *Chaceon affinis* on banks/seamounts (Tables 1 and 2).

The variability of abundance for the two species within each area can be explained by several factors. However, it is likely that different bottom types from site to site or at the same site from stratum to stratum is the main factor (Pinho et al. 2001b, c; Biscoito et al. 2015; Triay-Portella et al. 2017; Santos et al. 2019). This appears to be more evident for *Chaceon affinis* that showed a clear aggregate distribution ("patches"), possibly reflecting the preference for specific habitats, e.g. muddy bottom with some rocks. Variable abundance may also be explained by sampling bias due to seasonal changes, for instance in migration movements and spawning.

The differences in density observed between coastal areas and banks/seamounts are more difficult to explain. A possible ecological significance of the dominance of each species in particular habitats should be explored. The lower abundance of *Cancer bellianus* on banks/seamounts appears to be due to the depths available, which makes the habitat area for this species considerably smaller (Pinho et al. 2001c). It should be noted that in coastal areas, where all depth strata are present the habitat can be defined continuously, although in some areas the strata may be wider or narrower than in others. For banks/seamounts, on the contrary, the discontinuity predominates due to diversity of sizes, shapes, elevations and inclinations between these structures, or even within the same structure (see Machete et al. 2005). Another explanation may be that the catches used for this analysis do not reflect indices of abundance in these offshore areas because the sampling coverage may not be representative of the total area. In this study, 83 banks/seamounts were identified in the Azorean EEZ. Among them, only 35% were considered to have *C. bellianus*, although only 7% of the cases detected the occurrence of the entire habitat (areas with depths between 200 and 700 m). The abundance index used for *C. bellianus* came only from an area partially covered by research surveys, the Princess Alice Bank. However, it must be asked if the result of sampling of a bank/seamount should be extrapolated to other areas of identical characteristics or not. The abundance index used for *Chaceon affinis* came from samples taken from four banks/seamounts, but 70% of the samples were taken from Princess Alice bank. The representativeness of these samples is an issue that future studies should confirm.

Further studies are needed to clarify the essential habitat for these species and to understand how habitat limits population size, structure, and abundance. However, to identify the essential habitat can be a difficult task since the same species can use different habitat types for different purposes related to their life cycle or life history (e.g. spawning in one area and foraging in another).

The reason why the abundance of *Chaceon affinis* is considerably lower in coastal areas than in banks/seamounts is unclear, but the difference may have been magnified by bias sampling. Samples from bank areas were obtained from a commercial fishing vessel that concentrated its fishing activity in areas of greater abundance, while data from coastal areas resulted from a stratified random sampling (research surveys).

The total areas available in the Azorean EEZ for depths considered optimal for species distribution are relatively scarce (Figure 1). These areas, defined as habitats, also have the peculiarity of being spatially discontinuous (islands and banks/seamounts). For the purposes of estimating the fishery potential, areas were aggregated at local (coastal) and offshore (banks/seamounts) zones due to the importance they have for management purposes related to fishing technology and vessel characteristics necessary for the exploitation at each area. The interactions among different areas related to the dynamics of each population are unknown and therefore, it is not yet known if each of these areas should be managed as a management unit. A research programme with implementation priorities to better understand the approach to be followed in the management of these fisheries, would be necessary. However, considering that they are fragile habitats, any development of a fishery must take these uncertainties into consideration to avoid local depletion or even overexploitation because of connectivity mechanisms between areas and subpopulations.

Catches approximately equal to 5 individuals per trap for each species in dominance areas (coastal areas for *Cancer bellianus* and banks/seamounts for *Chaceon affinis*) can be considered reasonable. In the case of *Chaceon affinis*, catches in the Azores (global average of 3 kg trap^{-1}) agreed with the minimum and maximum catch values found in other world areas for similar species (see Arana 2000).

Estimates of biomass and potential yield

Biomass and potential yield results showed a considerable variability depending on the values adopted for the trap radius of attraction (R) and the exploitation rate (x) (Table 4-9). Similar results are expected for a range of different catchability values that may be adopted.

It should be noted that the estimated values correspond to estimates in data-poor situations (in this case, virgin, i.e. not exploited resources). Thus, the results are valid as short-term indicators, for example for a fishery implementation, and should not be confused as indicators of MSY for a long-term fishery, which should be estimated after the start of exploration.

Cancer bellianus

The total average biomass of *C. bellianus* estimated as most likely for the Azorean EEZ, considering an optimal average R of 30 m, was 15,688 t, corresponding to a total mean density of approximately 2.3 individuals per km^2 (Table 4). However, this density varied spatially, being much more abundant in coastal areas, approximately 5 individuals per km^2, than in bank/seamount zones, approximately two individuals per km^2. Although estimates of abundance for these species are not reported in the literature, these values can be considered quite reasonable and particularly high in coastal areas.

Considering the base values of x = 0.2, as suggested by Beddington & Cooke (1983), and R = 30 m, it was estimated as the average annual MSY for the Azorean EEZ approximately 471 t $year^{-1}$ (282 t $year^{-1}$ at banks/seamounts and 189 t $year^{-1}$ at coastal areas). Assuming an average CPUE for coastal areas of 2.7 kg $trap^{-1}$ (computed as the average kg $trap^{-1}$ for the combined trap sets for coastal depth strata range of 200-600 m), a total of 200 traps to fish per day (three lines with approximately 66 traps each) and 200 annual fishing days per year, the average catch per vessel would be approximately 109 t $year^{-1}$. Considering the fishery potential of the resource in these areas (189 t $year^{-1}$), it would be sustainable to develop an initial fishery with approximately two vessels. For bank/seamount areas, assuming a CPUE of 0.98 kg $trap^{-1}$ (computed as the average kg $trap^{-1}$ for the combined trap sets for bank/seamount depth strata range of 200-600 m), a total of 500 traps per day and 200 annual fishing days, the average catch per vessel would be approximately 98 t $year^{-1}$. In these areas, it would be sustainable to develop an initial fishery with approximately three vessels.

Chaceon affinis

The total average biomass of *C. affinis* estimated for the Azorean EEZ, considering an optimum average R of 30 m, was 73,499 t (Table 7). However, this density varied considerably with the habitat, approximately 4 individuals per km^2 at banks/seamounts and approximately 0.7 individuals per km^2 in coastal areas. These densities are within the limits of mean densities estimated for deep-water crab species in other world areas (see Arana 2000).

Considering the base values of x = 0.2 and R = 30 m, the average annual MSY for the Azorean EEZ was estimated to approximately 2,205 t $year^{-1}$ (2159 t $year^{-1}$ at banks/seamounts and 46 t $year^{-1}$ in coastal areas). Assuming an average CPUE of 0.7 kg $trap^{-1}$ (computed as the average kg $trap^{-1}$ for the combined trap sets for coastal depth strata range of 500-900 m), a total of 200 traps to fish per day (three lines with approximately 66 traps each) and 200 annual fishing days per year, the average catch per vessel would be approximately 32 t $year^{-1}$ in coastal areas. Considering the fishery potential of the resource in these areas (46 t $year^{-1}$), it would be sustainable to develop an initial fishery with approximately one vessel. For bank/seamount areas, assuming a CPUE of 2.8 kg $trap^{-1}$ (computed as the average kg $trap^{-1}$ for the combined trap sets for bank/seamount depth strata range of 500-900 m), a total of 500 traps per day and 200 annual fishing days, the average catch per vessel would be approximately 283 t $year^{-1}$. In these areas, it would be sustainable to develop an initial fishery with approximately seven vessels.

Methodology

The effective trapping area method (Miller 1975; Eggers et al. 1981) is only an approximation whose quality depends on several basic assumptions of the model indirectly related to the fixed gear capture process (Fernö & Olsen 1994) and more directly with the degree of reliability of the values of some variables used, such as average CPUE, radius of attraction of a trap, total size of the estimated area, etc.

Soak time and gear saturation, for example, are considered the variables of the fixed gear capture process that most affect the abundance estimation (Murphy 1960; Rothschild 1967; Sigler 2000; Bacheler et al. 2013). The operational regime of data used in the analyses of the abundance estimates is more or less standardized (24 h immersion, similar standard gears with approximately the same space between them and with the same average branch line; Pinho et al. 2001b, c). However, the soak time and gear saturation effects were not analysed in the present study.

The optimal radius of attraction of a trap is another factor affecting the abundance estimation. For example, the use of a radius smaller than the optimum, can considerably underestimate the biomass. The method assumes that each trap has a fixed catch field with a circular shape centred in the trap. Optimum values for radius of attraction have been reported as between 27 and 33 m (Miller 1975; Cayre et al. 1979; McElman & Elner 1982; Defeo 1991). However, Sigler (2000) considered that the radius of attraction of a trap is not fixed, and it is not valid to estimate its value from experiments with variable spaces between traps, since the field of attraction increases considerably with the concentration of traps. For this reason, different values of radius of attraction varying between 25 and 45 m were used in this study, in order to analyse the sensitivity of abundance variability with this parameter. However, the value of 30 m was considered as optimal for purposes of comparison with other studies.

The abundance index (CPUE) used to calculate biomasses may not be representative of the actual abundance of the stocks, since it was estimated from non-standardized exploratory research surveys with samples taken at different times of the year in a reduced area of distribution of the resource or from commercial fishing experiences probably carried out only in areas of high concentration of resources. For example, the CPUE of *Cancer bellianus* estimated from the Princess Alice Bank survey data (Table 1) may not be representative of species abundance on all banks and seamounts because the sampling area may not be representative of the abundance in banks/seamounts of different characteristics (e.g. depths available, bottom type). However, results from commercial fishery directed to *C. affinis* during 2003 also showed low abundances of *C. bellianus* in bank/seamount areas, estimating for the 200-800 m stratum a CPUE of 0.31 ± 0.47 individuals trap^{-1}. It should be noted, however, that the industrial vessel that operated in 2003 during this fishing experience made the sets primarily at banks and at depths usually below 600 m, which is considered to be the limiting depth of *C. bellianus*. Also, the population structure can vary seasonally with depth, as suggested by Pinho et al. (2001c).

The estimation of the total area available for each species was based on a planar estimation using available bathymetric information. However, imprecision of these bathymetric data can introduce great errors in the strata size estimation, especially on bank/seamount zones which are still insufficiently mapped. Additionally, some areas, such as the Menez Gwen hydrothermal vent, have not been considered in this study. However, hydrothermal vents have been identified as areas with the highest catches of *C. affinis* when compared to other seamounts and coastal regions, being possible areas to be protected although their ecological role in the distribution of this resource remains unknown (Pinho et al. 2001b; Santos et al. 2019).

The methodology used to estimate the MSY for virgin resources suggested by Gulland (1971) is empirical, and there is no explicit scientific justification for that mathematical expression. However, it is considered reasonable in the assumptions that the natural growth of biomass follows the production model of Schaefer (1954) and that fishing mortality corresponding to MSY is equal to the natural mortality (for details, see Gulland 1971; Die & Caddy 1997). In the present study, different values for exploitation rate (x) were used in order to analyse the sensitivity of the MSY variability with this parameter.

In view of these inaccuracies, our results should be considered preliminary and interpreted as guides on the species abundances and for management and development of possible fisheries (precautionary approach principle). We consider that more important than the precision of the estimates is the order of potential catches values estimated, which suggests that the exploitation of these resources, if desired, should always be on a very small scale and highly controlled. This is the most important contribution of this study and it may be extrapolated to other remote insular areas.

Management

The implementation and management of a spatial exploitation scheme for these resources should be considered, despite the current limitations of knowledge, especially on the mobility of individuals and connectivity between adjacent areas.

Although it is convenient to manage these resources by island and bank/seamount, the difficulties of implementing, managing and supervising a complex exploration design, suggest that it may be more appropriate to implement species-based fisheries with licensing by aggregated areas, such as coastal and bank/seamounts.

Measures for statistical collection on fisheries and biological information should be promoted by introducing for example the fishing logbook and to condition the license renewal to its proper completion and delivery, and the on-board observers or landings control under a sampling programme.

Ovigerous females of *Cancer bellianus* are not generally captured (Pinho et al. 2001c) which in itself can function as a conservation measure. However, the introduction of a minimum landing size (MLS) of 13 cm carapace width (8.5 cm carapace length), corresponding to the size of first maturation, is recommended in order to preserve the juveniles. Ovigerous females of *Chaceon affinis* occur approximately between October and March (Pinho et al. 2001b; Biscoito et al. 2015). These months correspond to the period of reduced fleet activity in the Azorean EEZ due to the meteorological conditions, and a design of seasonal exploitation with a fishing stop during this period should be considered. The aim would be to control fishing effort and avoid local depletion effects, especially at bank/seamount areas. It is also suggested that an MLS of 8.5 cm carapace length should be introduced to protect juveniles.

Final considerations

The scientific knowledge of these resources in the Azorean EEZ until the present moment went through three initial phases: 1) preliminary observation of the species occurrence; 2) preliminary collection of biological information and fisheries technology; and 3) hypotheses formulation about the distribution and abundance of resources and prediction of potential yields (MSY) from these hypotheses. The next step should be to identify key variables to evaluate and to test these predictions. This objective involves several studies that integrate the abundance estimation by areas and analysis of the population structure according to the environmental characteristics (resource-environment analysis); growth and reproduction studies, including early life-history stages characterization; and theoretical modelling of the impacts of the implementation of different commercial exploration strategies on population dynamics, including multispecies and multiarea spatiotemporal dynamics. In this perspective, it is recommended that all results obtained be presented, discussed and validated in working groups within international scientific forums.

ACKNOWLEDGMENTS

We are grateful to Gui Menezes, Helen Martins, Nagib Souza and Ricardo Medeiros for their support. We thank all the crew members of R/V “Arquipélago”, and “Três Rosas”, “Alexa Marie”, “Garcia Miguel” and “Pescatum” commercial vessels, for all assistance during the data collection. Régis Santos was supported by the IMAR Institute of Marine Research, through a post-doc fellowship (ref. IMAR/DEMERSAIS/001-2018). Wendell Silva was funded by the IMAR Instituto do Mar, through a scholarship (ref. IMAR/UNI/MAR/04292/2013 MARE/001-2018). Ana Novoa-Pabon was funded by an FCT Ph.D. fellowship (ref. SFRH/BD/124720/2016).

REFERENCES

Arana, P.M. 2000. Estimación de abundancia y biomasa del cangrejo dorado (*Chaceon chilensis*), en el archipiélago de Juan Fernández, Chile. *Investigaciones Marinas* 28: 53-68.

Bacheler, N.M., Z.H. Schobernd, D.J. Berrane, C.M. Schobernd, W.A. Mitchell and N.R. Geraldi 2013. When a trap is not a trap: converging entry and exit rates and their effect on trap saturation of black sea bass (*Centropristis striata*). *ICES Journal of Marine Science* 70: 873-882.

Bashmachnikov, I. and A. Martins 2007. Water masses, circulation patterns and oceanographic data density of the subtropical NE Atlantic, Presentation, 1st DEECON meeting, Horta, Azores, 29-31 Oct. 2007.

Beddington, J.R. and J.G. Cooke 1983. The potential yield of fish stocks. *FAO Fisheries Technical Paper* 242: 1-47.

Biscoito, M., M. Freitas, J.G. Pajuelo, R. Triay-Portella, J.I. Santana, A.L. Costa, J. Delgado and J.A. González 2015. Sex-structure, depth distribution, intermoult period and reproductive pattern of the deep-sea red crab *Chaceon affinis* (Brachyura, Geryonidae) in two populations in the north-eastern Atlantic. *Deep-Sea Research Part I: Oceanographic Research Papers* 95: 99-114. https://doi.org/10.1016/j.dsr.2014.10.010.

Cayré, P., P. Le Loeuff and A. Intès 1979. *Geryon quinquedens*, le crab rouge profond : biologie, pêche, conditionnement, potentialities d`exploitation. *La Pêche Maritime* 1210: 1-8.

Cores, C., M. Gaspar and K. Erzini 2019. Estimating the density of Pennant's swimming crab, *Portumnus latipes* (Pennant, 1777) in the swash zone using baited stakes and area of attraction. *Journal of the Marine Biological Association of the United Kingdom* 99(4): 887-890. doi:10.1017/S002531541800067X

Defeo, O., V. Little and L. Barea 1991. Stock assessment of the deep-sea red crab *Chaceon notialis* in the Argentinian-Uruguayan Common Fishing Zone. *Fisheries Research* 11: 25-39.

Die, D.J. and J.F. Caddy 1997. Sustainable yield indicators from biomass: are there appropriate reference points for use in tropical fisheries? *Fisheries Research* 32: 69-79.

Eggers, D.M., N.A. Rickard, D.G. Chapman and R.R. Whitney 1982. A methodology for estimating area fished for baited hooks and traps along a ground line. *Canadian Journal of Fisheries and Aquatic Sciences* 39: 448-453.

FAO, 1997. *FAO Technical Guidelines for Responsible Fisheries* No. 4: Fisheries Management. Rome, FAO, 82 pp.

Fernö, A. and S. Olsen 1994. *Marine fish behaviour in capture and abundance estimation*. Oxford, Fishing New Books, 221 pp.

Garcia, S. and L. Le Reste 1981. Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks. *FAO Fisheries Technical Paper* 203: 1-215.

Garcia, S., P. Sparre and J. Csirke 1989. Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. *Fisheries Research* 8: 13-23.

Gonçalves, J.M. 1994. “Lucky Strike”, outras fontes hidrotermais, escorrências frias e relatório de participação na 2ª parte da campanha “Diva-2”. Arquivos do DOP, Série Estudos 3/94, 26 pp.

Gonçalves, J.M., H.R Martins and M.R. Pinho 1995. Deep water crabs, *Chaceon affinis*, a new fisheries resource in the Azores? *ICES CM* 1995/K:43.

Gonçalves, J.M. and M.R. Pinho 1994. Relatório da campanha nº17/94 do N/I Arquipélago (ensaio de pesca de crustáceos de profundidade com covos, manutenção do DCP da Graciosa e arrastos de bongo). *Arquivos do DOP*, Série Cruzeiros, 1/94, 7 pp.

González, J.A., I.J. Lozano, J.M. Lorenzo, L.J. López-Abellán, J.M. Bautista, D.M. Carvalho, M.J. Biscoito and G. Menezes 1998. Biology of some Macaronesian deep-sea commercial species. Final report of the UE-DG XIV Study contract 95/032. Telde, Las Palmas, Instituto Canario de Ciencias Marinas, 356 pp.

Gulland, J.A. 1971. The fish resources of the ocean. West By-fleet, Surrey, Fishing News (Books), Ltd., for FAO, 255 pp. rev. ed. of *FAO Fisheries Technical Paper* 97: 1-425.

Gulland, J.A. 1983. *Fish stock assessment: a manual of basic methods*. New York, Wiley, 223 pp.

ICES 2018a. Advice basis. In Report of the ICES Advisory Committee, 2018. *ICES Advice* 2018, Book 1, Section 1.2. https://doi.org/10.17895/ices.pub.4503

ICES 2018b. Report of the Working Group on the Biology and Assessment of Deep-sea Fisheries Resources (WGDEEP), 11–18 April 2018, ICES HQ, Copenhagen, Denmark. *ICES CM* 2018/ACOM:14, 771 pp.

ICES 2019. Azores ecoregion – Ecosystem overview. In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, Section 3.1. https://doi.org/10.17895/ices.advice.5753.

Machete, M., T. Morato and G. Menezes 2005. Modeling the distribution of two fish species in seamounts of the Azores. *FAO Fisheries Proceedings* 3/1: 182-195.

McElman, J.F. and R.W. Elner 1982. Red crab (*Geryon quinquedens*) trap survey along the edge of the Scotian shelf, September 1980. *Canadian Technical Report of Fisheries and Aquatic Sciences* 1084: 1-12.

Melo, O.E.B.M. 2009. Biologia e abundância do camarão *Plesionika edwardsii* (Brandt, 1851) nos Açores. (Dissertação de Mestrado em Estudos Integrados dos Oceanos). Horta: Universidade dos Açores, 67 pp.

Melville-Smith, R. 1986. Red crab (*Geryon maritae*) density in 1985 by the technique of effective area fished per trap on the northern fishing grounds of South West Africa. *South African Journal of Marine Science* 4: 257-263.

Melville-Smith, R. 1988. The commercial fishery and population dynamics of red crab *Geryon maritae* off South West Africa, 1976-1986. *South African Journal of Marine Science* 6: 79-95.

Miller, R.J. 1975. Density of the commercial spider crab, *Chionoecetes opilio*, and calibration of effective area fished per trap using bottom photography. *Journal of the Fisheries Research Board of Canada* 32: 761-768.

Murphy, G.I. 1960. Estimating abundance from longline catches. *Journal of the Fisheries Research Board of Canada* 17: 33-40.

Pinho, M.R. 2000. Pesca experimental de crustáceos de profundidade nos Açores (CRUSTAÇO). Relatório de progresso. *Arquivos do DOP,* Série Relatórios internos, nº4/2000, 31 pp.

Pinho, M.R., J.M. Gonçalves, H.R. Martins and G.M. Menezes 2001b. Some aspects of the biology of the deep-water crab, *Chaceon affinis* (Milne-Edwards and Bouvier, 1984) off the Azores. *Fisheries Research* 51: 283-295.

Pinho, M.R., J. Gonçalves and H. Martins 2001c. Biology and abundance of *Cancer bellianus* (Decapoda, Brachyura) around the Azores. *ICES Journal of Marine Science* 58: 896-903.

Pinho, M.R., O. Melo, J. Gonçalves and H. Martins 2001a. Pesca experimental de crustáceos de profundidade dos Açores (CRUSTAÇO). *Arquivos do DOP*, Série Relatórios internos, Nº2/2001.

Rikhter, V.A. and V.N. Efanov 1976. On one of the approaches to estimation of natural mortality of fish populations. *ICNAF Research Documents* 76/VI/8: 12 pp.

Rothschild, B.J. 1967. Competition for gear in a multiple-species fishery. *ICES Journal of Marine Science* 31: 102-110.

Santos, R., M. Pinho, O. Melo, J. Golçalves, A. Leocádio, A. Aranha, G. Menezes and E. Isidro 2019. Biological and ecological aspects of the deep-water red crab populations inhabiting isolated seamounts to the west of the Azores (Mid-Atlantic Ridge). *Fisheries Oceanography,* https ://doi.org/10.1111/fog.12454.

Schaefer, M. 1954. Some aspects of the dynamics of the populations important to the management of the commercial marine fisheries. *Inter-American Tropical Tuna Commission Bulletin* 1(2): 23-56.

Sigler, M.F. 2000. Abundance estimation and capture of sablefish (*Anoplopoma fimbria*) by longline gear. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 1270-1283.

Smith, W.H.F. and D.T. Sandwell 1997. Global seaflor topography from satellite altimetry and ship depth soundings. *Science* 277: 1957-1962.

Tanaka, S. 1960. Studies on the dynamics and management of fish populations. *Bulletin of Tokai Regional Fisheries Research Laboratory* 28: 1-200. [in Japanese].

Triay-Portella, R., J.G. Pajuelo and J.A. González 2017. Spatio-temporal variation in biomass of the deep-sea red crab *Chaceon affinis* in Gran Canaria Island (Canary Islands, Eastern-Central Atlantic). *Marine Ecology* 38(5): 1-14. https://doi.org/10.1111/maec.12462

Submitted 6 Dec 2019. Accepted 7 Apr 2020. Published online 30 Jun 2020.