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Evaluation of *Homarus gammarus* (Crustacea: Decapoda: Nephropidae) catches and potential in a Mediterranean small-scale fishery

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Summary: The aim of this study was to obtain a better understanding of the exploitation pattern of the European lobster population in a fully representative small-scale fishery of the Mediterranean (Corsica, France) and to collect initial biological information on this species. Data were collected by scientific observers on board net fishing vessels for eight consecutive years from 2006 until 2013. Average annual catches were estimated at 6.7 t. Length frequencies indicated that exploitation focused on large individuals. Catch per unit of effort varied significantly as a function of month, fishing area and depth. Our approach to catch distribution revealed spatial heterogeneity with large catches in the south area. A fishery-independent survey was performed in 2013 and 2014 in west Cap Corse using 540 lobster traps; it showed an extremely low catch rate, confirming the low abundance for this area. This study provided new biological knowledge of a little-studied species in the Mediterranean.

Keywords: European lobster; artisanal fisheries; catch rates; ecology; fisheries management; Corsica.

Evaluación de capturas de *Homarus gammarus* (Crustacea: Decapoda: Nephropidae) y potencial en pesquerías mediterráneas artesanales

Resumen: El objetivo de este estudio fue el de obtener una mejor comprensión del patrón de explotación y colectar datos iniciales de las poblaciones de bogavante europeo en una pesquera artesanal representativa del Mediterráneo (Córcega, Francia). Los datos fueron colectados por observadores científicos a bordo de embarcaciones de pesca durante 8 años consecutivos, de 2006 a 2013. Las capturas anuales fueron estimadas a 6,7 toneladas. La frecuencia de las tallas indica que la explotación se concentra en los individuos de gran tamaño. La CPUE varía de manera significativa en función del mes, la zona de pesca y la profundidad. La distribución de las capturas revela que hay una heterogeneidad espacial, con capturas de gran tamaño en la zona sur. Un monitoreo pesquero independiente fue llevado a cabo durante 2013 y 2014 en Cap Corse occidental empleando 540 trampas; éste mostró una tasa de captura extremadamente baja, lo que confirma la escasez de bogavante europeo en esta área. Este estudio aportó nuevos conocimientos a la biología de esta especie poco estudiada en el Mediterráneo.

Palabras clave: bogavante europeo; pesca artesanal; taza de captura; ecología; manejo de pesqueras; Córcega.

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INTRODUCTION

The European lobster, *Homarus gammarus* (Linnaeus), is a decapod crustacean species of great ecological and economic importance found in the northeastern Atlantic. Its distribution ranges from northern Norway to Morocco, but it is not present in the Baltic Sea (Holthuis 1991). It also inhabits the Mediterranean and the western Black Sea, including the Istanbul Strait (Gönülal 2015).

The species is listed in the Mediterranean in Appendix 3 (Protected fauna species) of the Berne convention on the Conservation of European Wildlife and Natural Habitats (e.g. Lloret and Riera 2008). This benthic animal is a nocturnal and territorial species found mainly on rocky substrates which feeds on a wide range of prey such as blue mussels, hermit crabs and Polychaeta (Bertran and Le Calvez 1988, Prodöhl et al. 2006). Individuals can weigh more than 7 kg and the largest males and females may live up to 42 and 72 years, respectively (Sheehy et al. 1999). *H. gammarus* and the American lobster *H. americanus* (Milne Edwards), found on the northwest coast of the Atlantic, are the only two species representing their genus within the family Nephropidae, and are anatomically very similar (Wahle et al. 2013).

With 5194 t of total landings in 2014 (FAO 2017), the European lobster is a significant fishery resource throughout its range. It is an important source of income and employment for artisanal and coastal fisheries considering its high commercial value. It is targeted by trap fisheries in northern Europe, mainly in the United Kingdom, Ireland, and northern France (Bennett and Lovewell 1977, Bennet et al. 1993, Browne et al. 2001). The traps have various designs, shapes, and sizes, and they can capture singly (one buoy for one trap) or in a gang (several buoys for several tens of traps) (Cobb and Castro 2006). Trap fishing is primarily performed inshore, often less than 5 km from the coast.

Genetic analyses using different molecular markers (mitochondrial DNA and allozymes) were conducted to look for genetic differentiation across the entire range of *H. gammarus* (Jørstad et al. 2005, Triantafyllidis et al. 2005). They indicated the presence of genetic subpopulations, broadly defined as Mediterranean, Atlantic, northern Norway, and the Netherlands (Triantafyllidis et al. 2005). This information, coupled with studies showing limited movement of adult lobsters (Moland et al. 2011), a short larval stage (Bennet et al. 1993), and possibly small-scale larval dispersal (Schmalenbach and Buchholz 2010), suggests that the Mediterranean subpopulation of the European lobster population should be considered separately.

Artisanal fisheries or small-scale coastal fisheries are particularly important in the Mediterranean (Farrugio et al. 1993, Guyader et al. 2013), where they constitute about 80% of the fishing fleet (European Commission 2004). Fishermen operate with small boats near the coast (0-200 m depth) and adapt their practices to resource availability: a wide variety of gear is used, targeting a diversity of species that change in space and time (Colloca et al. 2004, Leleu et al. 2014). Along the Mediterranean coast, the European lobster is not a target species and is more often a by-catch that occurs in trammel nets targeting the common spiny lobster *Palinurus elephas* (Fabricius) (Marin 1987, Quetglas et al. 2004) or in gillnets targeting fish (Gönülal 2015). Spiny lobster fishing in the Mediterranean accounts for a large part of the income generated during the fishing season, but it is showing increasing signs of overexploitation (Goñi and Latrouite 2005, Pere 2012). Given the equivalent high commercial value of *H. gammarus*, this species is of potential interest for fishermen wishing to diversify crustacean-fishing activities in the Mediterranean. In Corsica (NW Mediterranean), the overall fleet can be described as artisanal, which makes it fully representative of Mediterranean small-scale fisheries (Marengo et al. 2016).

While the literature on the ecology and fishing of *H. gammarus* in the Atlantic is abundant, no single study provides comprehensive information regarding its exploitation in the Mediterranean Sea and its potential for the development of specific fisheries. The aim of this study was therefore to obtain a better understanding of the exploitation pattern and to collect initial biological information on the European lobster population around Corsica. More specifically, we analysed (1) the catch per unit of effort (CPUE), including the dynamics of the catches in space, time, and water depth; (2) the total annual production of the island; (3) the distribution; and (4) the potential abundance of the species.

MATERIALS AND METHODS

Study area

The study was conducted in Corsica, France (northwestern Mediterranean, geographical sub-area 8, 42°N and 9°E, Fig. 1). It covers 1047 km of coastline and is characterized by high environmental heterogeneity with the occurrence of the seagrass *Posidonia oceanica* (Linnaeus) Delile, meadows, rocky bottoms and sandy shores. Geomorphology and bathymetric range are highly heterogeneous, with a narrow continental shelf, submarine canyons and deep water along the western coast, as well as wide expanses of shallow waters on the eastern coast, along the Tyrrhenian Sea (Pluquet 2006).

Fishery data

Data were collected by scientific observers on board fishing vessels for eight consecutive years (2006 to 2013) during the main fishing period (April to September). Around the island, fishing boats are widely dispersed over 34 harbours and smaller sheltered areas where boats can be anchored during the fishing season. In the first step, the fishermen of the "active" boats were identified, and the data were updated each year (Pere 2012). "Active" boats are those which have a real activity among all the boats having a fishing licence.

A total of 922 fishing trips were performed during the eight-year sampling period (Table 1). Fishing ac-

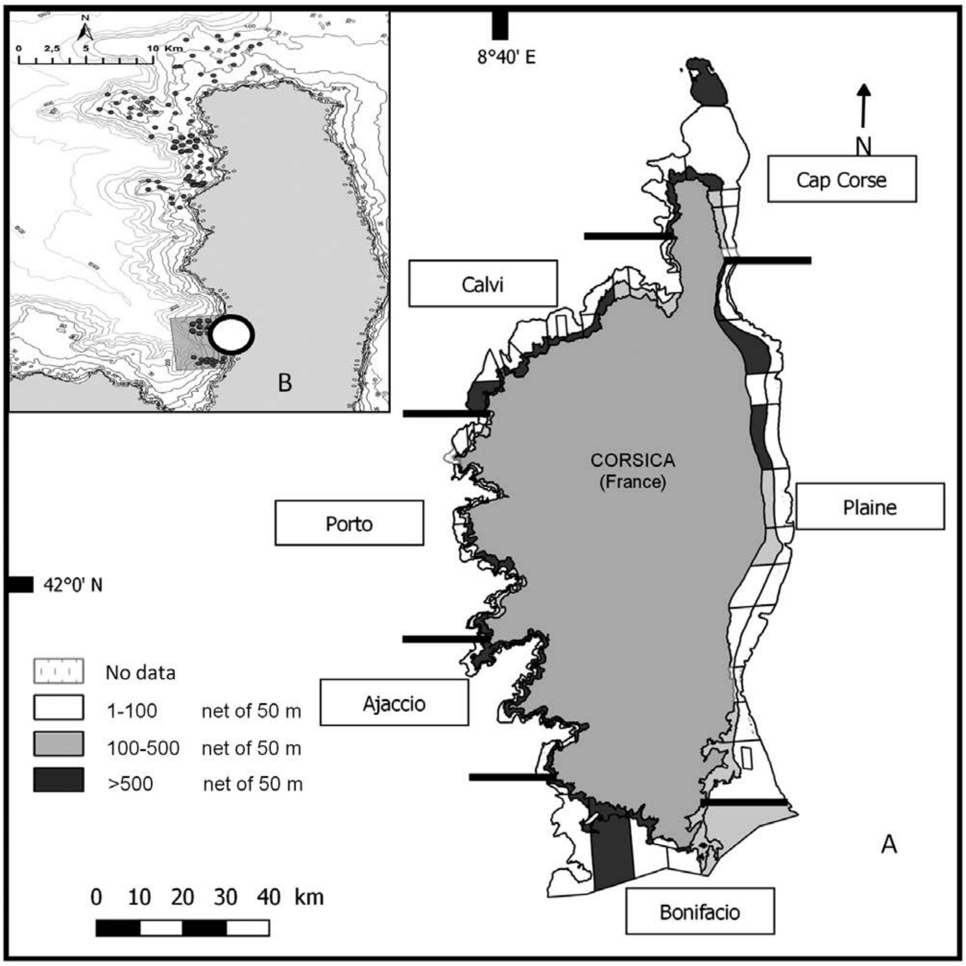

Fig. 1. – Map of Corsica (NW Mediterranean, France), showing the six fishing areas delimited by the black horizontal lines, fishing grounds and spatial distribution of fishing effort (number of nets) over the sampling period (2009-2013) (A). Map of the fishery-independent survey of *H. gammarus*: grey circles show the position of traps lines sampled; the white circle and the grey rectangle represent the location of the lobster catches in the Cantonnement de Nonza (B).

Table 1. – Summary of sampling data.

Fishing areas	Number of fishing trips	Number of trammel nets	Number of gillnets	Number of combined nets	Net length (km)
Ajaccio	203	794	54	1	467
Bonifacio	175	961	32	1	464
Calvi	210	1086	118	51	629
Cap Corse	129	540	51	0	348
Plaine	100	362	40	3	231
Porto	105	342	72	15	240
Total	922	4085	367	71	2379

tivity is practised near the coast and average time at sea is 6-7 hours (Pere et al. 2008). Each year, the daily observed fishing trips were chosen at random by a network of four to five scientific observers spread all over the island. During the monitoring period, 30% of the active fleet was sampled at least once every year and 75% of the active fleet was sampled during the whole study period. A total of 4523 hauls were sampled during the study, corresponding to 2379 km of net. All the nets were observed during a sampled fishing trip. Data related to technical characteristics (length, mesh size, type of net and mesh composition) and utilization (location, depth, soak time) were collected. After capture, each European lobster was measured (carapace length, CL) to the nearest mm, and sex was recorded. As it was impossible to precisely weigh individuals on board commercial vessels, weight was estimated from available length-weight relationships (Latrouite 2001) for males and females.

Scientific survey data

The independent fishery survey was performed in 2013 and 2014 in the west of the Cap Corse area with a 12-m professional fishing boat using selective inkwell pot, "Conquetois" type European lobster traps (height 43 cm; length 65 cm; width 50 cm; 20 cm diameter opening on the top). The survey area included a fishing

Table 2. – Total number of *H. gammarus* sampled.

Years	Ajaccio	Bonifacio	Calvi	Cap Corse	Plaine	Porto	Total
2006	2	15	4	1	0	3	25
2007	2	12	2	2	1	4	23
2008	7	15	8	0	0	9	39
2009	9	20	13	1	0	0	43
2010	2	22	8	0	0	1	33
2011	2	23	2	3	1	1	32
2012	6	21	3	1	0	1	32
2013	8	3	4	0	0	2	17
Total	38	131	44	8	2	21	244

no-take area (Cantonnement de Nonza, Fig. 1). Traps were arranged in lines of three spaced 20 m apart. Salted sardine was used as a bait in a specific pocket inside the trap. The spatial sampling scheme was randomly stratified, covering various substrata and a bathymetry ranging between 30 and 120 m depth. For each trip 20 lines were deployed, totalling 180 lines and 540 traps over the survey period. The sampling area covered fishing grounds located northwest of the Island used by fishermen from Centuri harbour, and the Nonza no-take area was sampled at its northern and southern parts for operational reasons. Soak time was fixed to four days in order to maximize the catch rate (Smith and Tremblay 2003). Captured lobsters were measured for CL and total length to the nearest mm, weighed (g), sexed, then tagged using T-bar tags and released at the capture point.

Data analysis

Catches (CPUE) were expressed in density (number) and biomass (weight) of European lobsters per 50 m of net. All nets were taken into account (trammel nets, gillnets and combined nets), and CPUE included commercial lobsters, small lobsters that returned alive to the sea, and dead lobsters (Table 2). For the spatial analyses, the island was divided into six fishing areas (Fig. 1), designated as Ajaccio, Calvi, Cap Corse, Plaine, Porto, and Bonifacio (Pere et al. 2008). These fishing areas were determined based on geomorphologic criteria (e.g. differences in depth and habitat type).

The combination of continuous and categorical variables in generalized linear models (GLM) allows the relative influence of variables affecting catch rates to be evaluated (Maynou et al. 2003). The CPUE data were log transformed [log(CPUE + 1)] prior to all the analyses to meet the normality requirements of the test, and a Gaussian distribution was used (Santos et al. 2014). Adjusted sums of squares (Type III) were used to calculate the F-value and p-values. The main factor effects and interactions were determined using the GLM (Minitab 2000). The explanatory variables considered and tested with the GLM were years (2009-2013, 8 levels), months (April–September, 6 levels), depths (0 to >100 m depth, 6 levels) and fishing areas (Ajaccio, Bonifacio, Calvi, Cap Corse, Plaine, Porto, 6 levels). Within the GLM, all possible pairs of interactions were tested. For example, the two-way and three-way interactions between these factors were investigated using a "forward selection" procedure.

Specific comparisons between the factors were performed using post hoc Tukey honest significance difference (HSD) tests. Finally, catch and effort spatial distributions were mapped using a geographical information system (QGIS 2.6.1). Fishing effort was estimated as the annual number of fishing trips and mean length of net hauled per fishing trip. The annual total yield estimate was derived from the catch data and the fishing effort calculated above (for more details, see Pere 2012). The positionS of the trap lines and lobster catches were represented on the map of Corsica and bathymetry was added using ArcGIS 10.2 (Fig. 1B).

RESULTS

Catch variation

According to the variance analysis produced by the GLM, fishing areas, depths and months were the factors that had a significant effect on the catch rates of *H. gammarus* (Table 3), but CPUE values were not significantly related to the factor years. Interactions between months and depths as well as between years, months and depths were significant. Statistically significant interactions ($p<0.01$) between months and fishing areas were also detected. Tukey's HSD test revealed that CPUE differed significantly across fishing areas, being much higher at Bonifacio than at Ajaccio, Calvi, Cap Corse and Plaine (Fig. 2A).

Catches of this species showed a seasonal peak in April and July (Fig. 2B) and a wide range of bathymetric distribution with values ranging from 10 (minimum) to 164 m depth (maximum). The maximum exploitation depth was between 40 and 60 m (Fig. 2C). CPUE differed significantly among depths ($p<0.05$), and was smaller at 0-20 m, 20-40 m and >100 than at 40-60 m (Fig. 2C).

Table 3. – Analysis of variance table for GLM fitted to *H. gammarus* catch rates. p-values: ***, p<0.001; **, p<0.01; *, p<0.05; NS, not significant.

Model (source of variation)	d.f.	F-value	p-value	Statistical significance
Main effects				
Months	5	2.77	0.017	*
Fishing areas	5	7.81	0.000	***
Depths	5	3.77	0.002	**
Years	7	0.30	0.952	NS
Interactions				
Months × fishing areas	25	1.97	0.003	**
Months × depths	25	1.57	0.035	*
Years × months × depths	175	1.22	0.028	*

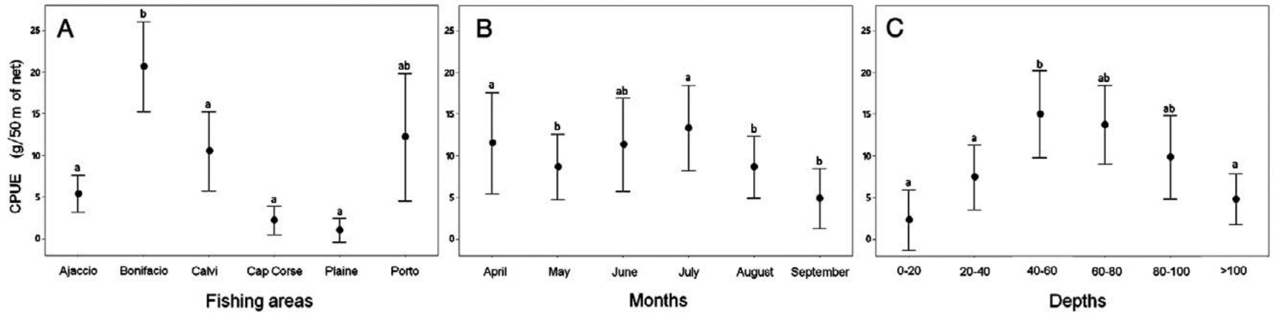

Fig. 2. – Variations of mean CPUE of biomass (g/50 m of net; ±SE) between fishing areas (A), month (B) and depth (C) in Corsica (2006-13) for *H. gammarus*. The values sharing no letter are significantly different (post hoc Tukey test performed on log-transformed data [log(CPUE+1)] ; *p<0.05).

Spatial distribution of catches

A heterogeneous distribution of catches of the European lobster was observed around Corsica. The highest CPUEs were mainly located in the south of Corsica (Bonifacio) (Fig. 3), while the lowest were found in the east of Corsica (Plaine) and Cap Corse.

Total catches

An annual fluctuation of catches was observed. During the study period, the estimated mean annual total production was 6.7 t (±1.6 t se). Over time, the time-series analysis highlighted several trends. Recent years have been marked by strong intra- and inter-annual fluctuations in catches and two main trends were observed: (i) a relatively stable yield from 2006 to 2009 and (ii) an increase in 2011, with maximum production that reached 9.8 t/year (Fig. 4). The peak was mainly due to catches in a favourable fishing area (Bonifacio). After 2011, fluctuations occurred and catches dropped to 5 to 7 t per year (2012-2013).

Size distribution

Between 2006 and 2013, a total of 244 specimens were sampled. The size of *H. gammarus* ranged from 61 to 200 mm CL (Fig. 5). Three predominant size classes were detected: 100-120, 120-140 and 140-160 (Fig. 5).

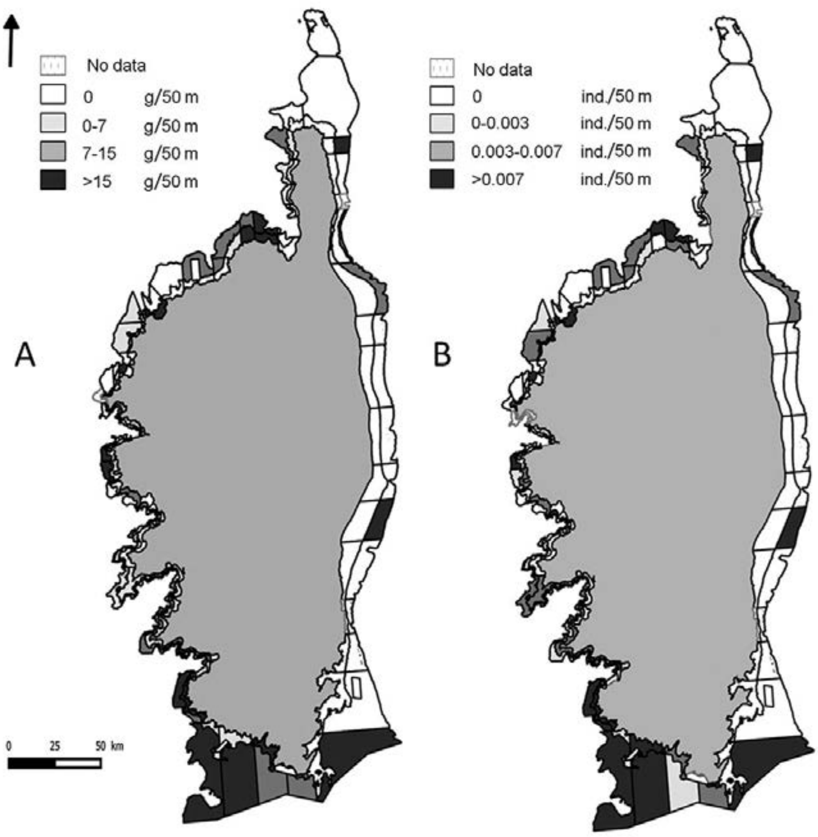

Fig. 3. – Map of fishing grounds around Corsica showing CPUE of biomass (g/50 m of net; A) and CPUE of individuals (ind./50 m of net; B) (2006-13) for *H. gammarus* caught by artisanal fisheries.

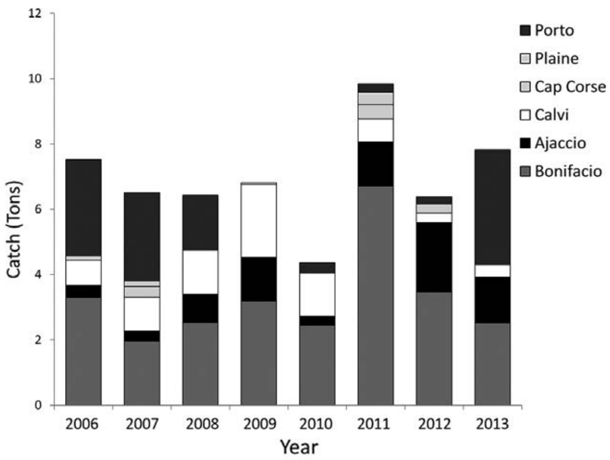

Fig. 4. – Estimated annual production (t/year) of *H. gammarus* for artisanal fishing around the six fishing areas of Corsica during the period 2006-2013.

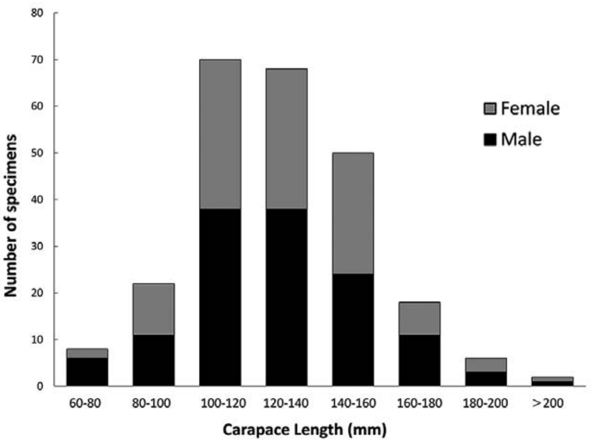

Fig. 5. – Length-frequency distribution for *H. gammarus* (n=244) by artisanal fisheries.

Fishery independent survey

The fishery independent survey showed an extremely low catch rate over the study period, with only one lobster caught out of the 540 deployed traps, resulting in a mean catch rate of 0.002±0.043 lobsters per trap. This individual was caught in May 2013 at 35 m depth (Fig 1B). It was a male of 150 mm CL, 383 mm total length and 2.5 kg.

DISCUSSION

Marin (1987) estimated European lobster and European spider crab *Maja squinado* (Herbst) production at 5 to 10 t per year in Corsica. This result is consistent with average annual catches estimated at 6.7 t in this study. Based on FAO data for the period (2006-2013), production in France was estimated at 550 t per year (Atlantic and Mediterranean coasts, FAO 2017), so Corsica represents about 1.2% of total captures of this species at the national level. The European lobster is an accessory catch in Corsica, but it can constitute a significant part of landings, especially in the south of the island. Production on the French Mediterranean coast is estimated at 5.5 t, confirming the general underestimates of FAO data in the Mediterranean in general and also in Corsica (Le Manach et al. 2011).

Historical records of the Mediterranean show catastrophic declines in the landings of clawed lobster in the 20th century (Dow et al. 1980). According to Cobb and Castro (2006), this trend persists today. Statistics of this type should be considered with caution, since it is difficult to evaluate the landings of artisanal small-scale fisheries and they are often underestimated. However, it has been clearly demonstrated that specific lobster stocks in the Mediterranean have suffered from overexploitation, with significant declines in catches, e.g. in Spain (Lloret and Riera 2008) and in the Adriatic (Lotze et al. 2011).

In addition to overexploitation, a pattern of low abundance is evident throughout the Mediterranean compared with Atlantic fisheries. Temperature changes might play a major role for the *H. gammarus* population in its southern distribution, with excessively high temperatures leading to reduced population abundance (Triantafyllidis et al. 2005). High temperature could especially affect fragile, newly settled European lobsters. Although specific observation of the early benthic phase of the European lobster in the wild is still lacking (Linnane et al. 2001), *H. gammarus* post larvae are assumed to settle and remain cryptic in shelter-providing rocky substrata and to emerge from their shelters only once they have reached between 25 and 40 mm CL (Linnane et al. 2000a,b, Ball et al. 2001). Hence, high temperatures in shallow coastal waters during the summer period in the Mediterranean could play a major role in juvenile survival and recruitment success. Moreover, the European lobster may be sensitive to climate change, as rising temperature is the most important factor driving shifts in its range of distribution, and increased abundance is found at higher latitudes and decreased abundance at lower latitudes (Caputi et al. 2013, Green et al. 2014).

Catchability of the European lobster is affected by numerous factors, including feeding behaviour and moulting status (Wahle et al. 2013). Thus, high catches in April could be the consequence of an increase in lobster feeding activity with increasing temperature (Bennett and Lovewell 1977, Lizárraga-Cubedo et al. 2015). The decline in catch rates from May to June may be attributable to moulting activity (Miller 1990, Sheehy et al. 1999), and the following peak in CPUE in July is consistent with the increased feeding activity observed during the post-moult period.

The size structures of Corsican catches (range 61-200 mm CL; mean size 127 mm CL) seem to shift towards larger individuals compared with those coming from east Britain (range 78-115 mm CL; mean size 94 mm CL), South Wales (range 90-146 mm CL; mean size 109 mm CL), Scotland (range 62-140 mm CL; modal size 95 mm CL), and Brittany (range 60-160 mm CL) (Howard 1987, Lizárraga-Cubedo et al. 2003, Laurans et al. 2009). The minimum conservation reference size (MCRS), which is usually broadly equivalent to the mean size at first maturity, was imposed under EU fisheries legislation at 87 mm CL for the Atlantic

(EC Reg., 850/98) and 105 mm CL for the Mediterranean (EC Reg., 1967/2006). In this study, 80% of the lobsters sampled were above the MCRS, indicating that the individuals were mostly mature.

No individual smaller than 60 mm CL was caught, and similar observations were made by Latrouite (2001) and Prodöhl et al. (2006) in the Atlantic. This result could be linked to gear selectivity, because many European lobsters in the Mediterranean are caught in trammel nets with a large-mesh size (62-83 mm) for the inner panel (Campillo and Amadei 1978). Finally, the cryptic behaviour and limited movement of juveniles could better explain the absence of small and young European lobsters.

In the Atlantic, *H. gammarus* primarily occurs from low intertidal zones to depths usually no greater than 50 m (Holthuis 1991). For example, the mean water depth of the lobster catches was 37.5 m on the Basque continental shelf (Galparsoro et al. 2009). In Corsica, bathymetric analysis revealed that the highest abundance was between 40 and 80 m. This deeper distribution is potentially due to the high surface temperature in the Mediterranean Sea, which can affect this cold-water species.

In this study, 65% of the animals were encountered in "spiny lobster nets", which are gears defined by the target species *P. elephas* and by their use (soak time ≥2 d and depth ≥50 m) (Pere 2012). Other Mediterranean small-scale fisheries display the same trend. In Languedoc-Roussillon (northwestern Mediterranean, France), *H. gammarus* is mainly found in gillnets for various finfish and in trammel nets for crustaceans (Guillou et al. 2002). Around the Tabarca Marine Reserve (southwestern Mediterranean, Spain), *H. gammarus* and *Scorpaena scrofa* Linnaeus are accessory species caught in trammel nets for *Palinurus* (mean water depth=64 m; mean soak time=46 h) (Forcada et al. 2009).

The bathymetric distribution of European lobsters and the nature of the fishing net in which it is caught provide information on adult habitats, which essentially consist of rocky and coralligenous substrates where natural protective structures (micro-caves, holes and crevices) are numerous. It has been reported that the most suitable habitats for the European lobster are locations at the boundary between sedimentary and rocky bottoms (Galparsoro et al. 2009). In Corsica, these kinds of substrates are widely distributed around the island (except on the east side, Martin et al. 2014) and are particularly common in the Strait of Bonifacio, where the continental shelf has the particularity of being very large (Buron et al. 2012).

The spatial approach identified an area of high abundance in the south, precisely in the Strait of Bonifacio. In the south of the island, potentially suitable habitats for adults coupled with (i) a considerable larval pool from the Bonifacio Strait Natural Reserve (Santoni et al. 2008), (ii) favourable early life history traits such as short pelagic larval duration (Bennet et al. 1993, Goñi and Latrouite 2005, Øresland and Ulmestrand 2013) and (iii) advantageous hydrological features such as eddies (Gérigny et al. 2015) could explain the high abundance of the European lobster. For *H. gammarus*, larval self-recruitment mechanisms have already been discussed (Schmalenbach and Buchholz 2010, Øresland and Ulmestrand 2013). Elsewhere, several spots around the island also show high European lobster abundance. Despite the lack of favourable habitats on the eastern coast, several wrecks known by fishermen provide shelters for lobsters (Reveche 1979). The north of the island is marked by low yields. This result is somewhat surprising because the northern grounds are potentially suitable for the European lobster, with the occurrence of rocky bottoms and coralligenous assemblages (Pluquet 2006, Bonacorsi 2012). However, this low European lobster catch rate is corroborated by the fishery-independent data from the scientific survey performed in west Cap Corse. By contrast, spiny lobsters are abundant in these areas, which is consistent with their preference for such grounds (Marin 1987, Pere 2012).

Various habitats and depths were covered seasonally by the spatially randomly stratified sampling scheme, but only one lobster was caught out of 540 traps. It is generally expected for experimental fishing to achieve lower catch rates that follow a randomly stratified sampling scheme than fishery-dependent data obtained by fishing effort concentrated on specific areas. Experimental Atlantic fishing surveys had a mean catch rate of between 0.8 and 3 lobsters per trap in Norway (Moland et al. 2013) and between 0.29 and 1.32 lobster per trap in England (Addison 1995). A relatively low abundance of 0.09 lobsters per trap was observed in the south of the Bay of Biscay (Galparsoro et al. 2009). The low abundance in west Cap Corse corroborates the low catch rates obtained with fishery-dependent data for the same area. Unfortunately, to our knowledge no single survey using specific lobster traps has been performed in the Mediterranean, thus making it impossible to make such a comparison.

Onboard monitoring of small-scale fisheries is an important tool that contributes to the suitable exploitation of various key species from the perspective of the island's fishery management (Le Manach et al. 2011, Marengo et al. 2016). Despite the reporting of greater landings in Fishstat statistics since 2006, the abundance of *H. gammarus* seems to remain low and stable (Wahle et al. 2013). In Corsica, the lack of historical landing datasets prevents us from concluding on the evolution of the stock and on the current population's health status. However, the occurrence of this non-target species in selective (trap) and non-selective (trammel net) fishing gear around the island is low. In this context, we cannot reasonably expect that the targeting of European lobster would be an efficient solution for diversification of the artisanal fishery at the scale of the whole island.

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