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# Effects of reallocating fishing effort from trawling to creels in a Norway lobster fishery

Moritz Eichert[a,*], Aida Campos[b,c], Paulo Fonseca[b,c], Pedro Lopes[b,c], Lino Marques[a], Margarida Castro[a,c]

[a] FCT, Universidade do Algarve, Gambelas, 8005-139 Faro, Portugal
[b] IPMA, Rua Alfredo Magalhães Ramalho, 6, 1495-006 Lisboa, Portugal
[c] CCMAR, Universidade do Algarve, Gambelas, 8005-139 Faro, Portugal

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ABSTRACT

The consequences of reallocating fishing effort from trawling to creels in an area off the West coast of Portugal for the operation of the trawl fleet, as well as on the population dynamics and the global catch value for a high-valued species, the Norway lobster (*Nephrops norvegicus*) are evaluated. The results suggest that only small portions of the area of interest are used by the trawl fleet, opening the possibility for a trawl ban without major disruption of the trawling activity. Economic benefits are expected, since predictions two scenarios tested, heavy and moderate exploitation, indicate no loss of catch value with much lower operational costs. Social benefits to local communities can also be expected since a much lower investment is needed for creel fishing, making this fishery attractive to small local companies already operating in the region. The proposed ban is consistent with the ecosystem approach to fisheries management and the Common Fisheries Policy (CFP) where the transition towards more responsible fishing practices is encouraged.

## 1. Introduction

Fishing is a competitive activity where space and resources are strongly limited. Demersal trawling generally dominates over passive gears that lose competitiveness where trawling is active [1] and may even be prevented from operating if no spatial gear allocation is enforced [2]. The predominance of trawling over passive gears occurs despite evidence that in many cases, the latter are advantageous in terms of environmental impact, selectivity and socio-economics [3,4] and are often associated to successful local management systems [5]. In this study, the consequences of a trawl ban in an area off the West coast of Portugal, where a conflict exists between trawl and multi-gear fisheries harvesting the same resources, are evaluated for a high-value species, the Norway lobster (*Nephrops norvegicus*). This area is of interest to the multi-gear coastal fleet that targets Nephrops with creels in its vicinity.

### 1.1. Portuguese crustacean fisheries

Crustaceans are among the marine resources with highest unit value in Portuguese fisheries and Norway lobster is one such species, due to its marketing as a luxury product. Off the Portuguese coast, Norway lobster is captured as a target species by 24 trawlers holding a license specifically for crustaceans out of a total of 81 coastal trawlers (data at 31 Dec 2014). The crustacean trawlers use diamond mesh cod-ends with a minimum mesh size of 55–59 mm or > 70 mm, the latter being used when targeting Norway lobster, while the smaller mesh codend is used for catching a variety of deep-water shrimps, mainly rose shrimp (*Parapenaeus longirostris*) and occasionally other species such as red shrimp (*Aristeus antennatus*), giant red shrimp (*Aristaeomorpha foliacea*) and the scarlet shrimp (*Aristaeopsis edwardsiana*). The remaining trawlers target fish and cephalopod species and are allowed to land up to 30% of crustacean by-catch, including Nephrops.

Nephrops fishing grounds are situated off the Southwest (Alentejo) and South (Algarve) coasts, in soft sand and muddy bottoms of the continental slope at depths between 300 and 800 m [6]. Due to the narrow continental shelf of the Portuguese coast, trawling grounds are relatively close to shore, particularly off the West coast. The bottom morphology in those areas is patchy and crossed by steep canyons, with many areas inaccessible to trawling that are exploited by a number of vessels belonging to the multi-gear coastal fleet using gill-nets, longlines and creels for fish, crustaceans and cephalopods. This is the segment that can benefit most from a trawl ban.

* Corresponding author.
*E-mail address:* meichert@ualg.pt (M. Eichert).

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### 1.2. Case study

The creel fishery targeting Nephrops developed as a niche fishery along the canyon borders (Nazaré, Lisboa, Setúbal and Sesimbra), in the northern region of the fishing grounds on the West coast [Fig. 1], in areas that are not accessible to the trawl fleet due to steep seafloor and scattered rocky areas or to a lesser extent because the fishing grounds fall inside the 6 n.m. limit [7], where trawling is not allowed. Comparison between the fishing pressure exerted by the two gears used to target this species, creels and trawls, is used to illustrate the existing gear conflict and explore the possible consequences of the introduction of restrictions to trawling in an area of interest for both fleets.

The fishery is managed by number of licenses and a maximum number of creels per vessel (500–1000 depending on vessel length) and it shares a common annual TAC (total allowable catch) with the trawl fleet. Nephrops management is based on ICES advice for population functional units (FU); the Portuguese stock includes FU27 to FU29 but the main fishing grounds are in FU28 and FU29 [Fig. 1]. Although the population in FU27, north of FU28, is considered by ICES to be at a very low level of abundance and producing non-significant catches [8], there is fishing activity targeting Nephrops in in this area [9,10]. In fact, the area of interest defined in this work was chosen based on information obtained from fishermen operating in FU27, some of them using creels to catch Nephrops.

The maximum annual catch by the Portuguese fleet, for all FUs, was recorded in 1987, with 1438 t, and since then the landings have declined gradually to TAC levels, ranging from 133 (2011) – 291 t (2007) per year.[1] Populations of Nephrops were considered to be close to collapse and below biological safe limits and were subject to a recovery plan for Nephrops and the European hake *Merluccius merluccius* starting in January 2006 [11]. The management measures include the enforcement of minimum codend mesh size of 70 mm when targeting Nephrops and the establishment of closed areas (boxes) during part of the year one of them in FU28 [Fig. 1]. In addition, multiple short term temporal closures were implemented by local legislation since the introduction of the recovery plan [12].

The economic viability of trawlers and multi-gear vessels differs [7] due to the low operational costs and higher value of Nephrops caught with creels. These are predominantly large males that are marketed live, contrary to the trawl caught Nephrops that include a large proportion of smaller individuals that are sold refrigerated in ice with sulphites added to preserve the fresh appearance. The perceived difference in quality translates in very different prices per Kg that are key to compensating for the relative small catches in creels (5 t in 2014 [13]). The average first sale price of Nephrops caught by multi-gear vessels was 41.8 €/kg compared to 16.26 €/kg for the trawled Nephrops in 2014 [13].

Nephrops population structure, catch structure and fishing effort exerted differ between FU28 and FU29. In southern fishing grounds the crustacean trawl fleet targets the rose shrimp, the Norway lobster and the deepwater red shrimp. The Southwest area is not fished as heavily due to the geomorphological features mentioned above, and the target species are mostly Norway lobster and the red shrimp. In 2004, 83% of the fishing effort targeting Norway lobster was allocated to FU29 [14].

Despite being very distinct in terms of biomass and size distribution of Norway lobster, FU28 and FU29 are assessed as a single stock in part because the separation of the catches by FU cannot be deduced from the port landings. It is common that catch from vessels fishing on the west coast is transported by land and sold and registered at the port of Vila Real de Santo António (VRSA), on the southern border with Spain, where crustaceans reach higher prices.

This work aims to evaluate the consequences of a trawl ban in the area of interest on three aspects: (1) the population dynamics of Nephrops and (2) the impact on the operation of the trawl fleet and (3) the global catch value for this species.

The proposed ban is consistent with the ecosystem approach to fisheries management and the Common Fisheries Policy (CFP), where the transition towards more responsible fishing practices is encouraged (article 7, [15]).

## 2. Material and methods

The impacts of the trawl ban were assessed on: (1) the dynamics of Nephrops, based on simulations of the population structure (length and age classes and respective biomass) and egg production, catch structure and value, by combining the expected population structure with the selectivity of each gear; (2) the operability of the trawl fleet by estimating the importance of the loss of fishing grounds and (3) the overall catch value, taking into consideration the expected catch structure and the predicted ex-vessel values for the different size ranges.

Two scenarios were considered: present and future, where the future scenario corresponds to the stabilization of the new regime, after reallocation of the fishing effort from trawling to creels. The present scenario refers to 2014, the year in which Nephrops samples were collected simultaneously on board a trawler and a creel vessel operating in the same fishing grounds in the area of interest.

### 2.1. Area of interest

The area for which the trawl ban is proposed (area of interest) is identified in Fig. 1. It is situated along the central region of Portugal between Peniche and Sines (North and South limits at latitudes between 39°45'N and 37°45'N), and the lines coincident with the 6 and the 12 n.m. (East and West). This area covers the south of FU27 and the north of FU28 and includes traditional fishing grounds for fish trawlers in the north and crustacean trawlers in the south.

### 2.2. Importance of the area of interest for the trawl fleet

The fishing effort exerted by crustacean and fish trawl fleets inside and outside the area of interest was evaluated using data from the Automatic Identification System (AIS) for the year 2014. AIS data have the major advantage over Vessel Monitoring System (VMS) data of being received at a rate which can be as high as a point each minute (or even higher), while VMS is available at a 2-hour rate. On the other hand, AIS data reception is often irregular. Furthermore, the acquisition devices can be shut off, turning the vessels 'invisible'. In fact, of the entire trawl fleet constituted by 24 crustacean and 57 fish vessels, only 15 and 34 vessels, respectively, were identified in the available AIS dataset, representing about 60% of the total.

Taking the above into consideration, no absolute quantification of the fishing effort was possible. However, for the purpose of the present study it is sufficient to obtain a relative estimate of the effort both inside and outside the area of interest, subject to two reasonable baseline assumptions. First, it is assumed that the 60% vessel coverage by the AIS data is representative of both crustacean and fish trawl fleet segments. Secondly, it is assumed that possible gaps in the identification of fishing tows, due to data constraints, take place with the same probability inside and outside the area of interest.

Commercial tows were identified assuming that fishing corresponds to speeds between 3.5 and 5 knots, for fish trawlers, and between 2.5 and 3.5 knots for crustacean trawlers. Considering the irregularity in data reception, if a point distanced more than one hour from the previous one it was removed. This limit was considered optimal for the elimination of outliers, while still allowing 99% of the records of crustacean trawlers and 88% of the records for fish trawlers to be considered in the analysis. Towing time (effort) was calculated by adding the time intervals between each two adjacent points for each

[1] https://www.dgrm.mm.gov.pt/xportal/xmain?xpid=dgrm&xpgid=detPublicacao_v2&detPublicacao_v2_qry=boui=224736.

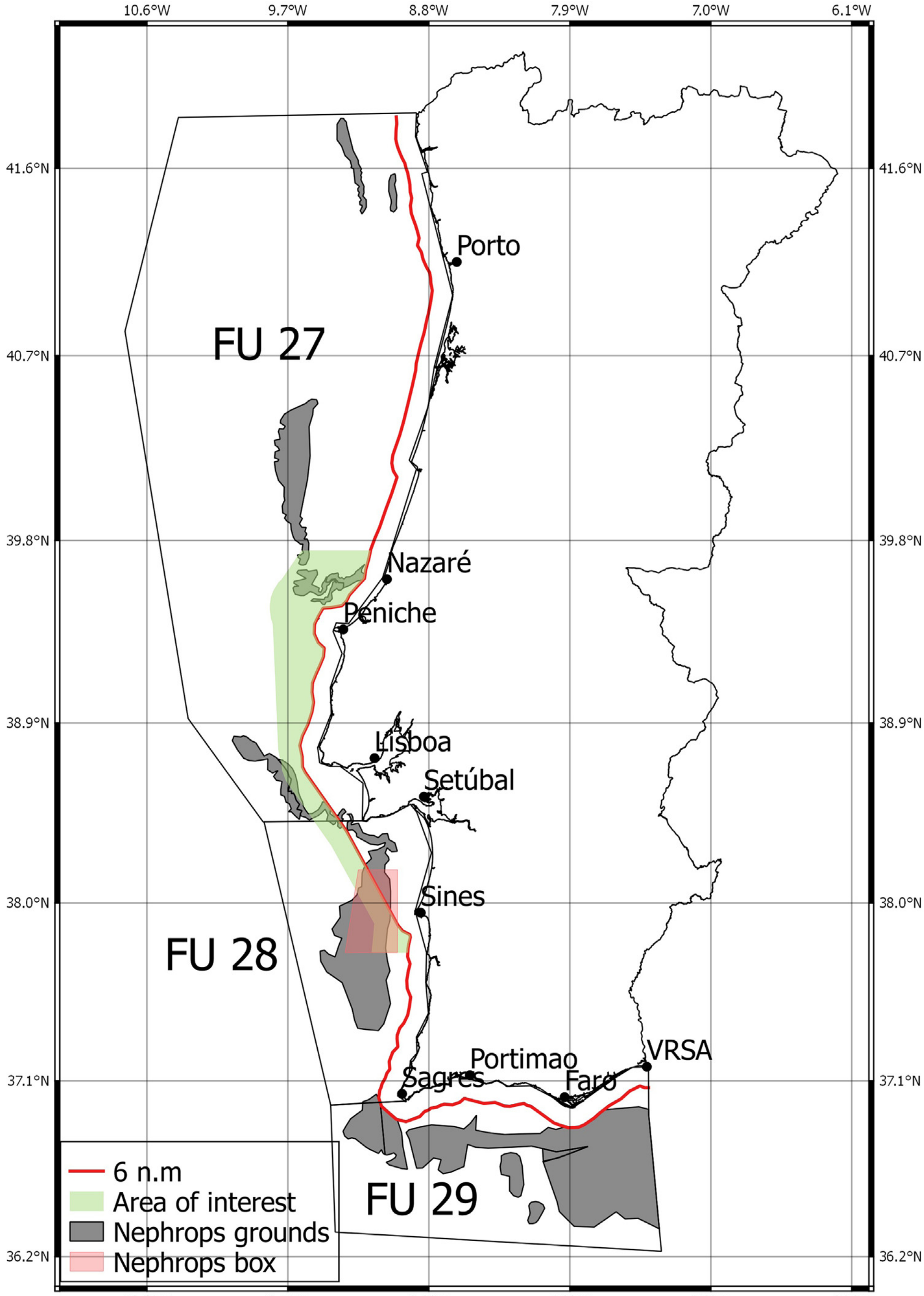


**Fig. 1.** Map with identification of the Nephrops Functional Units considered by the ICES (FU27 to FU29) and the main Nephrops fishing grounds [8]. Trawling is banned between the coast and the red line (roughly 6 n.m. from the base line). The proposed closed area is indicated in green and the box where capture Nephrops is interdicted during part of the year, off Sines, is indicated in red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

fishing operation, and then summing up to get the total effort inside and outside the area of interest.

### 2.3. Cohort simulation

A simple cohort model, considering exponential decay of numbers in a cohort along time (function of natural and fishing mortality rates) was built, to evaluate long term changes in population structure, assuming stable biological parameters and constant recruitment. The theoretical cohorts were based on one million recruits (50% each sex). Under the assumption of population stability (constant recruitment, growth and mortality rates), the cohort structure can be considered equivalent to the population structure at any point in time.

Changes in population structure and fishing yields and revenue, expected if trawling is replaced by creeling, were considered to be the result of differences between the two gears in selectivity, sex ratio of the catch and size and sex specific mortality rates. Males and females were modelled separately.

Biological parameters [Table 1] were obtained from the literature and values for the SW coast (FU27 or FU28) were used whenever possible:

**Table 1**
Biological parameters used in the cohort simulation.

| Description | Parameter | Value | Sex | Source |
|---|---|---|---|---|
| **Growth** – von Bertalanffy growth model. Parameters K and $L_{inf}$ estimated from two independent sets of parameters; $t_o$ chosen so length at age zero equals 4 mm carapace length | $L_{inf}$ (CL in mm) | 59.6 | F | This work, based on [10,17–19] |
| | K | 0.381 | | |
| | $t_o$ | −0.183 | | |
| | $L_{inf}$ (CL in mm) | 81.6 | M | |
| | K | 0.314 | | |
| | $t_o$ | −0.160 | | |
| **Weight-Length** - Power function for weight (W) as a function of carapace length (CL): $W = a\ CL^b$ | a | 0.0005648 | F | [25] |
| | b | 3.024 | | |
| | a | 0.0004335 | M | |
| | b | 3.115 | | |
| **Natural mortality** – instantaneous annual natural mortality rate. | M | 0.2 | F + M | [21,22] |
| **Fecundity** – Power function for number of eggs (E) as a function of carapace length CL): $E = a\ CL^b$ | a | 0.0647 | F | [23] |
| | b | 2.6215 | | |
| **Female maturation** – Logistic model. Proportion of mature individuals by size class = 1/[1 + exp(-a-b CL)] | a | −15.997 | F | [10] |
| | b | 0.341 | | |

a) Growth was considered to follow a von Bertalanffy model. Two distinct sets of growth parameters for each sex are available for the area of interest [9,16]. Size-at-age was estimated using both sets of parameters and average size-at-age was obtained (females and males were treated separately). A von Bertalanffy curve was then fit to these average values using a non-linear fitting technique (SOLVER, EXCEL add-in). The parameter $t_0$ was chosen to force length at age zero to equal 4 mm carapace length, the size at hatching [17,18];
b) The weight-length relationship was considered to follow a power function [19];
c) Natural mortality was assumed to be 0.2 for both sexes [20,21];
d) Fecundity expressed as number of eggs was considered to increase exponentially with carapace length [22], using information for late stage egg development only;
e) The proportion of mature females was expressed as a function of carapace length and assumed to follow a logistic distribution [9];
f) Maximum age considered was 15 years [23], corresponding to 59 mm carapace for females and 81 mm for the males.
The assumptions for gear selectivity, necessary to build the catch structure [Table 2], were the following:
g) The selectivity of the commercial 70 mm diamond mesh codend in use was based on published data for the fleet of interest, [6] [Table 2] and is assumed to follow a logistic curve. In the simulations, knife-edge selection was considered at $L_{50\%}$.
h) Size at first capture for creels was considered to be 46 mm carapace (males only). This value was obtained by comparing the length distributions of the trawl and creel catches [10]. It was assumed that trawl catches corrected for selectivity are the best available representation of the population structure (males only). Creel catch size distributions were compared with the population and 46 mm carapace length is the midpoint between (1) size of smallest Nephrops caught in creels and (2) the point where the shape of the creel length distribution matches the population.
i) Creel catches were considered to be males only, although one female (1 out of 807 Nephrops sampled) was found in the creels [10] and fishermen reported that females are occasionally caught. This assumption was considered acceptable to simplify the simulations.
j) A simple economic indicator, the global value of the catch, was used to compare present and future scenarios.
k) The mean value of the catch by commercial size category was available for 2011 [7]. The values were updated to 2014 [Table 2] by applying a coefficient equal to the ratio of average price per kg in 2014 and 2011 [13,24].

In the latest ICES assessments total mortality (Z) estimates are based on catch curve methodologies where the length distribution of the catch is converted into age distributions by applying a von Bertalanffy growth model [25]. The ICES growth parameters used produce mean values at age 15 (assumed to be close to the longevity of this species [23]) of 43 mm for females and 57 mm for males, far below the maximum sizes observed in the samples caught off the west coast (60 mm for females and 76 mm for males [10]). This may be the result of considering FU28 and FU29 together [21], and using data predominantly from FU29, where most Nephrops catches are obtained, leading to parameters and outputs that are more appropriate for FU29.

Since the focus of this work was the west coast, estimates of present values for Z were obtained by applying a simple catch curve methodology [26] to the samples obtained on board vessels operating close to the area of interest [10] using length and natural mortality parameters from Table 1. The Z values obtained were 0.57 for females and 0.63 for males. There was no significant difference between the slopes of the descending part of the age converted catch curve for the two sexes, and therefore an average value of Z = 0.6 was considered, split between 0.2 for natural mortality (M) and 0.4 for fishing mortality (F). The F values were applied to fully recruited classes (knife-edge selection, Table 2).

For the future scenario, corresponding to a stable situation after the effort reallocation from trawls to creels, the same F value was applied to fully recruited male classes but for females F was considered zero.

The fishing mortality rate F = 0.4 used here is considerably higher than the values presently used in ICES assessments, 0.09 and 0.14 for females and males respectively [27]. The natural mortality rate (M = 0.2) was the same as the value used in ICES assessments for females, but lower than the natural mortality rate considered for males (M = 0.3). Given the importance of mortality rates and growth parameters in the simulations, in particular to estimate biological indicators such as biomass, maturation, fecundity and egg production, the simulations for present and future scenarios were also run with growth and mortality

**Table 2**
Fishing activity related parameters used in the cohort simulation.

| Description | Parameter | Value | Sex | Source |
|---|---|---|---|---|
| **Trawl selectivity** - knife-edge, for codend diamond mesh 70 mm = $L_{50\%}$ | trawling (CL in mm) | 27 | M + F | [6] |
| **Creel selectivity** - knife-edge, estimated from observed creel catches | creels (CL in mm) | 46 | M + F | This work, based on [11] |
| **Average value of the catch** - per fleet segment | €/kg - trawl | 13,47 | M + F | [14] |
| | €/kg - creels | 40,45 | M + F | |
| **Average prices** (€/kg) - per size category for 2011 multiplied by the ratio: $\frac{€ / kg\ in\ 2014}{€ / kg\ in\ 2011}$. | Size category 4 ($25 \le CL < 44$ mm) | 6,00 | M + F | [7,14,26] |
| Individuals with CL < 25 mm considered discards | Size category 3 ($44 \le CL < 52$ mm) | 15,50 | M + F | |
| | Size category 2 ($52 \le CL < 60$ mm) | 45,00 | M + F | |
| | Size category 1 ($CL \ge 60$) | 88,50 | M + F | |

**Table 3**
Growth and mortality parameters used in ICES assessment [29].

| Description | Parameter | Value | Sex |
|---|---|---|---|
| **Growth** - K and $L_{inf}$ from ICES, $t_0$ chosen so length at age zero equals 4 mm carapace length. | $L_{inf}$ (CL in mm) | 65 | F |
| | K | 0.065 | |
| | $t_o$ | −0.977 | |
| | $L_{inf}$ (CL in mm) | 70 | M |
| | K | 0.3 | |
| | $t_o$ | −0.294 | |
| **Weight-Length** | a | 0.00056 | F |
| Power function for weight (W) as a function of carapace length (CL): | b | 3.024 | |
| | a | 0.00028 | M |
| $W = a\ CL^b$ | b | 3.0288 | |
| **Natural mortality** | M | 0.2 | F |
| Instantaneous annual natural mortality rate | | 0.3 | M |
| **Fishing mortality** – instantaneous annual fishing mortality rate (applied to fully recruited classes) | F | 0.09 | F |
| | | 0.14 | M |

rates used in ICES assessments [Table 3].

The two sets of parameters, both based on the available published data, presented in Table 1 (for the west coast FU27 and FU28) and in Table 3 (used in ICES assessments and dominated by characteristics of FU29 stocks) correspond to scenarios A and B respectively. The most important difference between these two scenarios is related with the exploitation rate E = F/Z, respectively 0.67 in A and 0.23 (females) and 0.41 (males) in B.

## 3. Results

### 3.1. Importance of the area of interest for the trawl fleet

In 2014, the area of interest was of relatively small importance for the trawl fleet [Table 4 and Fig. 2]. The number of fishing hours was estimated inside and outside this area for crustacean and fish trawlers for which AIS data was available [Table 4], indicating that they spent only 2% and 6% of their fishing time in this area, respectively. Fig. 2 also suggests little overlap between this area and the fishing grounds exploited by these two fleet segments. This is particularly evident for crustacean trawlers [Fig. 2 -B].

In spite of the above, for 10 out of the 34 fish trawlers analyzed this was a preferential area. Nine of them were active there between 25% and 50% of their fishing time and one vessel 75% of the time. With respect to crustacean trawlers, only four of the 15 in the analysis were found to be active in the area of interest, two of them during a small percentage of their fishing time (2% or less), one during 10% and one during 20% of the fishing time.

### 3.2. Simulation outputs

The outputs of the simulations, relevant for evaluating the consequences of gear change from trawling to creeling in the Norway lobster fishery, are presented in Table 5.

The effects of the gear change on the Nephrops population are very positive, with considerable increases in biomass and egg production, due to the protection of females.

The economic return of the fishing activity does not change significantly since the absence of females in the catch is compensated by an increase in males of larger size and age due to selectivity differences between both gears; the average age corresponding to knife-edge selection is 2.5 years for creeling (46 mm carapace length) and 1.1 years for trawling (27 mm carapace length). Higher value of larger Norway lobsters is related to higher overall economic return from creeling.

**Table 4**
Proportion of fishing effort inside the area of interest for the trawling fleet in 2014.

| Fishing license | All the coast (outside the 6 n.m. limit) | | Area of interest | | % of fishing effort inside the area of interest |
|---|---|---|---|---|---|
| | Number of vessels | No. hours trawled ($\times 10^3$) | No. vessels | No. hours trawled ($x10^3$) | |
| Crustacean | 15 | 48.3 | 4 | 1.0 | 2.1% |
| Fish | 34 | 12.2 | 19 | 0.7 | 5.9% |

## 4. Discussion

The results of this analysis are in agreement with previous work dealing with the effects of gear change from trawling to creeling in Nephrops fishery. A previous study carried out in the area of interest comparing the viability of the two gears [7] demonstrated the robustness of the economic viability of creel fishing. Other authors in the Adriatic [28], Scotland [29] and in Swedish waters [30] reached similar conclusions.

### 4.1. Benefits for the multi-gear fleet

Additional social benefits from the trawl ban can be expected since much lower investment and time at sea are needed for creel fishing, making this fishery attractive to small local companies already operating in the region and bringing benefits to local communities. A likely higher number of vessels belonging to the multi-gear fleet could benefit from adding a license for deep-water crustacean creel fishing, opening the possibility to up-scale the creeling operations. Other benefits would result from the expansion of passive gears such as creels and longlines in this area, to exploit a variety of bottom fish species with lower environmental effects, including higher selectivity, reduced footprint on the sea bed and lower impact on benthic communities.

If these licenses are issued within the context of global management of the fishery in territorial waters, they could be used as a tradeoff to stop the use of trammel nets, at present the most popular fixed gears used, that also have considerable negative impacts. The fixed net *métiers* in Southern Europe are characterized by high bycatch ratios [31], and the trammel nets in the central region of the west coast of Portugal are not an exception, with bycatch rates estimated to be 22% of the catch [32] due to a wider spectrum of sizes caught when compared with gillnets, longlines or creels [33].

The restriction of towed gears represents a step towards compliance with environmental, social and economic objectives of EU policies, such as the reformed CFP [15], and the Marine Strategy Framework Directive (MSFD) [34] by (1) incentivizing the change from demersal trawling to more selective and low-impact fishing on fish and invertebrate populations, contributing to MSFD Descriptor 3; (2) allowing the recovery of a significant area from the chronic disturbance by bottom trawling to fulfill descriptor 6 and (3) redistributing fishing rights more equally over the fishers community by allowing a number of multi-gear fishermen to participate in the fishing for Norway lobster and other deep-water resources.

### 4.2. Impact on the Nephrops population

The results in terms of the population structure obtained here should be taken as a preliminary approach to understanding the effect of the gear change. The simulations do not consider positive feedbacks of increased egg production on recruitment, a factor that could further increase the biomass and the catches even if at some point the environmental carrying capacity would impose a limit on recruitment success. Other feedback mechanisms could occur that would alter the predicted outcomes of a trawl ban, such as: (1) slowdown in growth

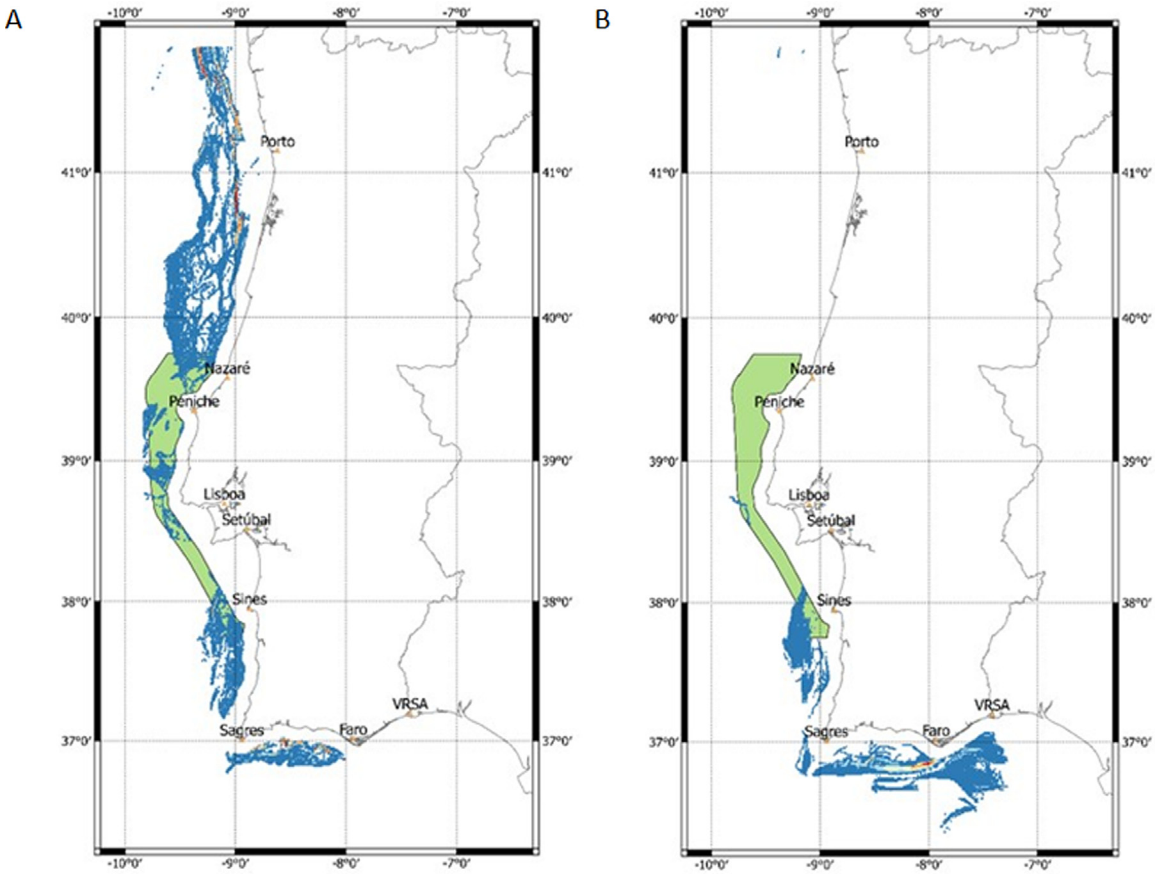


**Fig. 2.** Fishing grounds for sampled fish trawlers (blue low intensity and red high intensity fishing activity, area of interest in green): A – fish trawlers and B - crustacean trawlers, using available AIS data for 2014. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

**Table 5**
Outputs of the simulations considering the present scenario (trawl fishing) and a future scenario (creel fishing) for Norway lobster, on the west coast of Portugal. A - growth and mortality rates as described in; B - Growth and mortality parameters used in ICES assessments [29].

A

| | **Present = trawl** | | **Present = traps** | | **Total** | **Total** | |
|---|---|---|---|---|---|---|---|
| | **Females** | **Males** | **Females** | **Males** | **Present** | **Future** | **% Change** |
| Numbers at Sea (M) | 1.16 | 1.16 | 2.41 | 1.40 | 2.32 | 3.81 | 64% |
| Biomass (tones) | 26.8 | 56.7 | 138.0 | 81.8 | 83.5 | 219.8 | 163% |
| Egg Production (M) | 257 | | 2379 | | 257 | 2379 | 826% |
| Yield (tones) | 10.15 | 16.80 | | 28.00 | 26.95 | 28.00 | 4% |
| Revenue (M€) | 0.19 | 0.90 | | 1.70 | 1.09 | 1.70 | 56% |
| Average size CL (mm) | 37 | 45 | | 55 | 40 | 55 | 38% |
| Unit value (Euro/kg) | 19.08 | 53.51 | | 60.82 | 40.54 | 60.82 | 50% |

B

| | **Present = trawl** | | **Present = traps** | | **Total** | **Total** | |
|---|---|---|---|---|---|---|---|
| | **Females** | **Males** | **Females** | **Males** | **Present** | **Future** | **% Change** |
| Numbers at Sea (M) | 1.63 | 1.39 | 1.67 | 1.56 | 3.02 | 3.23 | 7% |
| Biomass (tones) | 6.1 | 33.0 | 7.2 | 45.6 | 39.1 | 52.8 | 35% |
| Egg Production (M) | 2.18 | | 3.76 | | 2.18 | 3.76 | 72% |
| Yield (tones) | 0.28 | 3.60 | | 3.80 | 3.88 | 3.80 | −2% |
| Revenue (M€) | 0.00 | 0.11 | | 0.18 | 0.11 | 0.18 | 64% |
| Average size CL (mm) | 31.5 | 39.9 | | 53.3 | 39.0 | 53.3 | 37% |
| Unit value (Euro/kg) | 6.00 | 31.40 | | 49.24 | 29.56 | 49.24 | 67% |

rates due to higher densities of juveniles and females, (2) higher natural mortality due to the increase in predators not targeted by fixed gears, (3) lower food availability due to reduced discards and (4) negative effects for the fitness of the population resulting from the removal of large males.

Several authors have reported that Nephrops growth rates and density are inversely related [35]. Several mechanisms may explain this such as a direct response to density dependence by delaying the molt (a mechanism found in the closely related species *Homarus americanus* [36]), by chemically controlled responses that result in less foraging activity [37] (verified in *H. americanus*) or by increase in competition for food [38]. All these factors can contribute to produce a density dependent growth response resulting in slower growth rates as the fishing pressure decreases.

Fishing, in particular trawling, modifies the ecosystem in multiple ways including chemical, physical and biological modification of the environment. Trawling alters the biogeochemistry of the sediments, in particular of muddy sediments [39], either by directly mixing the top layer and homogenizing the habitat [40,41], or by inducing resuspension and resettling of fine sediments [39,42]. Observed consequences include destruction of microhabitats [40,43], decrease in organic matter and organic matter turnover [42] and perturbation of organic matter remineralization and nutrient cycling [39]. Continued sediment perturbation leads to infauna diversity and biomass loss [41,42,44], with filter feeders being the most affected [45]. Changes in infauna lead to alterations in the epifauna, benefiting species such as small scavengers [44,45] and depleting others such as larger top predators [46]. In addition, in deep-water fisheries, large quantities of discards provide food subsidies to bottom scavengers, including Nephrops [47,48].

If moving from trawling to creels, a reversal of the processes described above should be expected, namely an evolution towards stable restructuring of the sediments and infauna, an increase in the general biodiversity at all levels (from meiofauna to macrofauna including large predators) and a decrease of high densities of small scavengers. Such changes can have positive and negative impacts on Nephrops populations. While a healthier, more diverse and less perturbed environment should bring benefits, the decrease of small macrofauna (small scavengers) and the increase in larger animals, may result in more competition for food and higher predation rates.

Lastly, the use of creels may have an unintended impact on population fitness through sperm limitation and reduced fertilization success. This has been observed in creel fisheries for decapod species where males reach larger sizes and suffer higher fishing mortality rates [49,50].

## 5. Conclusions

The predictions arising from both scenarios, heavy and moderate exploitation, suggest that a closure of the proposed area of interest would benefit the multi-gear creel without major overall impacts on the activity of crustacean trawlers. This may not be true for a number of fish trawlers that spend a considerable amount of time in crustacean grounds. The latter vessels often overcome the current legislation, which limits the catch of crustaceans by fish trawlers to a maximum of 30% of total catches, by complementing their catches with low value species.

Multi-gear fisheries have much lower operational costs and are thus less capital-demanding, entailing lower risks from an economic point of view, and potentially providing more opportunities for the local coastal communities. Both the overall societal benefits and the reduced environmental impact of creeling compared to trawling are in agreement with EU policies.

Nevertheless, it is recognized that prior to the formal implementation of the trawl ban in the area of interest, an updated and comprehensive investigation of the trawling activity inside the area should take place. Another issue that needs investigation is the possible feed-back effects of a decrease in the fishing pressure for females and the concentration of effort on the male population.

Following these questions, a critical aspect for the success of Nephrops management off the coast of Portugal would be the separation of FU28 and FU29. While these areas are markedly different in terms of Nephrops biology and fishing pressure, they nevertheless continue to be managed as a single unit.


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## Declarations of interest

None.


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