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Enhancing onboard post-catch vitality of discard Norway lobster (*Nephrops norvegicus*) for more sustainable Mediterranean trawl fishery

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Summary: The current European Union fisheries policy encourages improving handling practices to increase the survival of discards. Trawling on the Mediterranean upper slope often generates over 30% of discards of the total catch. Among other species, *Nephrops norvegicus* juveniles are abundantly returned to the sea, sometimes exceeding 40% of discarded biomass. *N. norvegicus* discard survival probability has been recently shown to be related to vitality on board and to vary seasonally, being especially low during the summer (0.06). Environmental characteristics (especially, high on-deck temperature in summer) make it necessary to improve vitality on board in order to increase discard survival. We therefore tested new discard handling methodologies for a Mediterranean mixed trawl fishery, with *N. norvegicus* as the target species. The results showed a survival rate on board higher than 0.8 resulting from vitality status improvements achieved by immersing *N. norvegicus* in cooled seawater on board during the catch selection and discard time. The implementation of this method would make an important contribution to more sustainable Mediterranean trawl fisheries.

Keywords: *Nephrops norvegicus*; discards; vitality; Mediterranean trawl fishery.

Mejorando la vitalidad a bordo posterior a la captura de la cigala descartada (*Nephrops norvegicus*) para una pesca de arrastre más sostenible en el Mediterráneo

Resumen: La política pesquera actual de la Unión Europea fomenta la mejora de las prácticas de manipulación de los descartes para aumentar su supervivencia. La pesca de arrastre en el talud superior del Mediterráneo, suele generar más del 30 % de los descartes de la captura total. Entre otras especies, los juveniles de *Nephrops norvegicus* son devueltos en gran abundancia al mar, a veces llegando a superar el 40% de la biomasa descartada. Recientemente se ha demostrado que la probabilidad de supervivencia al descarte de *N. norvegicus* está relacionada con la vitalidad a bordo y varía estacionalmente, siendo especialmente baja durante el verano (0,06). En este contexto, probamos y proponemos nuevas metodologías de manipulación de los descartes para una pesquería de arrastre mixta en el Mediterráneo, con *N. norvegicus* como especie objetivo, ya que las características ambientales (especialmente, la alta temperatura en cubierta en verano) hacen necesario mejorar la vitalidad a bordo de los descartes, para aumentar su supervivencia. Los resultados mostraron una tasa de supervivencia a bordo superior a 0,8 debido a las mejoras en el estado de vitalidad al sumergir *N. norvegicus* en agua de mar enfriada, durante la selección de capturas y el tiempo de descarte. La implementación de esta metodología, que mejora la vitalidad a bordo, es relevante para conseguir pesquerías de arrastre más sostenibles en el Mediterráneo.

Palabras clave: *Nephrops norvegicus*; descartes; vitalidad; pesca de arrastre mediterránea.

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INTRODUCTION

Discarding from commercial fisheries is one of the biggest sustainability problems at a global level, because it involves a waste of living resources, causes biodiversity loss and affects food chains, thus possibly contributing to stock decline in species of fisheries interest (Bozzano and Sardá 2002, Bellido et al. 2011, García-de-Vinuesa et al. 2021). Trawling is the type of fishing that produces the highest amounts of discards because of its multi-specificity and low levels of selectivity (Thrush and Dayton 2002, Kaiser et al. 2006, Damalas et al. 2015). A clear example is the Mediterranean trawl fleet targeting Norway lobster (*Nephrops norvegicus,* Linnaeus 1758), in which the discard fraction often exceeds 30% of the catch (García-de-Vinuesa et al. 2018). Discards of *N. norvegicus* are mainly juvenile individuals below the mean size at maturity, which is estimated to range from 30 to 36 mm in the Mediterranean (Relini et al. 1998, Tsagarakis et al. 2014, García-de-Vinuesa et al. 2018).

In order to mitigate the problem of discards, through the current Common Fishery Policy the European Union has established a landing obligation (LO) for all animals with a minimum conservation reference size (MCRS). Under the provisions of the LO, species with an MCRS cannot be discarded and must be landed, at the fishermen's expense and without the possibility of generating economic returns from the sale. The current regulation should encourage member states to adopt measures to enhance discard survival (EU Reg. 1380/2013; (EC) No 850/1998, Reid et al. 2019). *N. norvegicus* is affected by the LO, because it has an MCRS of 20 mm CL (carapace length) in the Mediterranean Sea (Council Regulation (EC) No. 1967/2006). However, the regulation allows member states to implement an LO exemption for species whose high survival of discarding can be demonstrated under experimental conditions (Art. 15 of EU Reg. 1380 /2013). This exemption could be especially useful to increase the biomass of future stocks of target species whose discarded juveniles show high survival.

In the Atlantic Ocean, high survival (0.51) has been demonstrated for discarded *N. norvegicus* (Méhault et al. 2016). Survival varies seasonally (Castro et al. 2003, Albalat et al. 2010, Mérillet et al. 2018) and can be affected by sorting and handling practices on board, injuries induced by the trawl (Bergmann et al. 2001, Macbeth et al. 2006), duration of exposure to air, and temperature changes (Davis and Olla 2002, Broadhurst et al. 2006, Benoît et al. 2012). In recent years, the survival probability for unwanted fractions of Atlantic *N. norvegicus* catch has been improved through implementation of new rapid discard techniques, such as the "discard chute system" in trawlers, that allow for a shorter time exposure of *N. norvegicus* to stressors (Mérillet et al. 2018). A vitality study carried out in aquariums (captivity methods) (García-de-Vinuesa et al. 2020) showed that discard survival of *N. norvegicus* from the Mediterranean Sea has a large component of seasonal dependence and is directly related to their vitality on board. The survival was high during the winter months (0.74) and low or almost null during the warm months in spring (0.36) and summer (0.06); that is, survival is strongly linked to seasonal changes in air and water temperature. Therefore, it could now be possible to improve the discard survival of *N. norvegicus*, especially during the warm months, by enhancing vitality on board. The implementation of new techniques or methodologies on board, in the same way as in the Atlantic Ocean but adapted to the Mediterranean environmental conditions, could be especially useful for improving vitality on board of *N. norvegicus*, thus increasing their survival probabilities when they are discarded.

The goal of this study was to examine technical solutions for improving the sustainability of the *N. norvegicus* Mediterranean trawl fishery by improving the vitality on board of *N. norvegicus* juveniles through the implementation of new methods for handling discards.

MATERIAL AND METHODS

Study area and fishing characteristics

The study area was located in the northwestern Mediterranean, near to Blanes port, on an upper slope fishing ground with a mean depth of 298 m (García-de-Vinuesa et al. 2018) where the local bottom trawl fleet practises a mixed demersal fishery whose main target species is *N. norvegicus* (Fig.1).

The vessel used to carry out the experiments was a 20.6 m length overall commercial bottom trawler with 294 kW main engine. Field sampling was carried out in July 2019, trawling at 3 knots between 355 and 425 m depth for a duration of 2 h effective fishing time of each haul. The average total catch was 69 kg per tow , including the target species, commercial by-catch and discards.

Post-catch vitality on board experiment

We examined the discard fraction of the *N. norvegicus* catch from five hauls (replicates) obtained under commercial conditions. With the help of fishermen, within 5 minutes of hauling the catch on board from

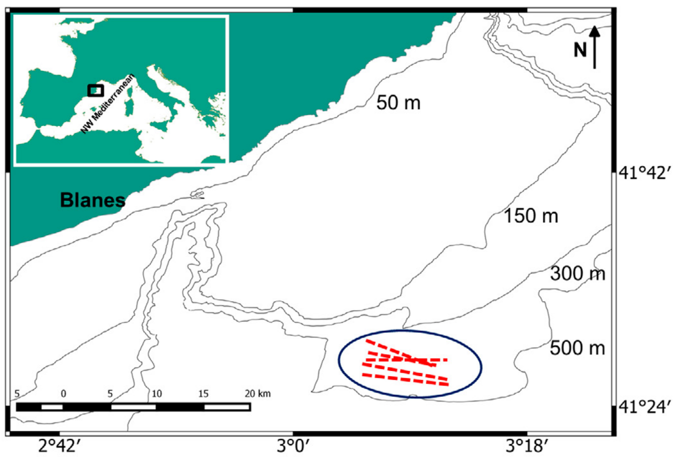

Fig. 1. – Study area. Red lines show the tracks of the hauls carried out in this study.

each replicate we selected randomly 75 discardable juvenile *N. norvegicus* with a size between 17 and 27 mm CL, 25 individuals for the control, 25 for treatment 1 and 25 for treatment 2. The control set tried to simulate the standard conditions that *N. norvegicus* encounter from their arrival on deck until their return to sea. To this end, the animals were placed on a non-slip black plastic surface used as a regular rule by the fishermen and were individually separated by means of a perforated white plastic grid to avoid mixing or confusion in the animal's vitality evaluation during the experimental time (Fig. 2A). Treatment 1 tried to simulate a technique used by fishermen during the warm months to maintain the quality of the commercial fraction, in which fishermen protect the catch with a white cloth that is wetted approximately every 5 minutes with surface seawater. The same kind of white cloth (Fig. 2B) was placed on an identical setup as the control design and wetted with abundant seawater every 5 min until the experimentation time ended. Treatment 2 tested a new method in which the animals were placed in divided containers filled with seawater placed on ice flakes to achieve a water temperature similar to that of the *N. norvegicus* habitat, which is stable year round at 13°C to 14°C (Hopkins 1985) (Fig. 2C). Temperature measurements of the water for treatment 2 and of the air for control and treatment 1 were taken with a mercury thermometer three times during the experimental process at 10 min intervals.

Post-catch vitality assessment

Vitality on board was tested within 5 min after the arrival of the catch on board for 30 min (total experiment time) using a categorical vitality assessment (CVA) method (ICES-WKMEDS 2014, ICES CRR 2020) similar to the one implemented by García-de-Vinuesa et al. (2020) (Table 1). This assessment method used

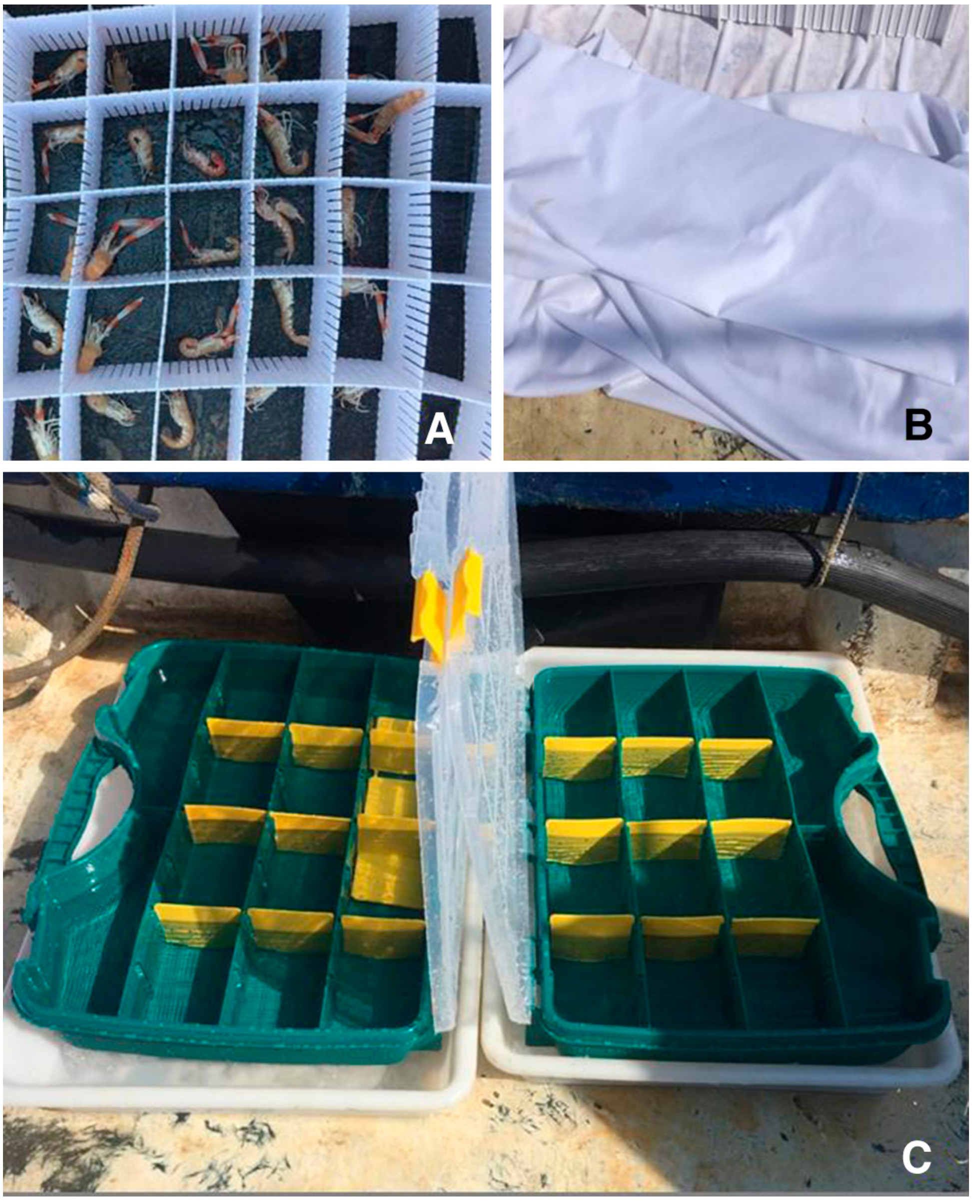

Fig. 2. – Control and treatment configuration; A, control; B, white cloth used in treatment 1; C, treatment 2.

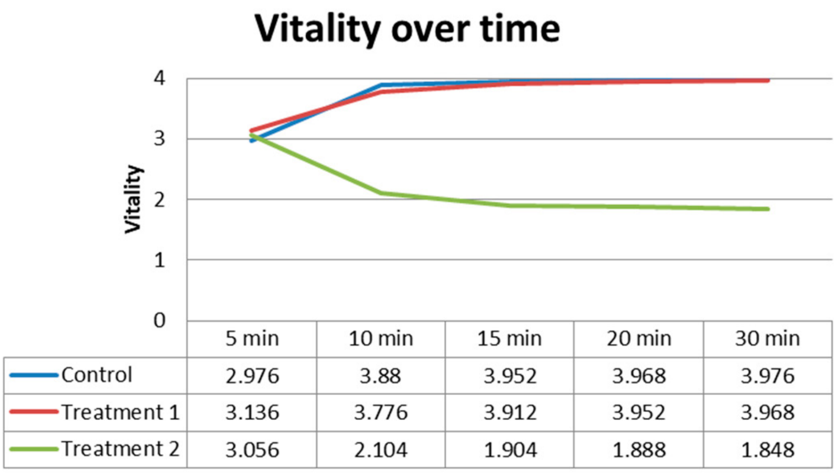

Fig. 3. – Average vitality over time under the control, treatment 1 (white cloth) and treatment 2 (cold water). Vitality status values were 1 (excellent), 2 (good), 3 (poor) and 4 (dying or dead).

Table 1. – Criteria of the Categorical Vitality Assessment (CVA) for *N. norvegicus*, following García-de-Vinuesa et al. (2020).

Vitality status	Score	Behavioural
Excellent	1	Spasmodic body movements, aggressive posture.
Good	2	Continuous body movements, responds to contact.
Poor	3	Weak body movements, can move antennas, pereiopods or maxillipeds.
Dying or dead	4	No movement, does not respond to repeated contact.

Table 2. – Wilcoxon rank-sum test for comparison of control with treatment 1 (T1) and treatment 2 (T2) through the time of experimentation. In bold font are the p-values that showed significant differences and their W statistic.

Comparison	Time	W statistic	p-value
Control Vs T1	5 min	215.5	0.056
	10 min	398.5	0.076
	15 min	356	0.298
	20 min	327	0.683
	30 min	325	0.698
Control Vs T2	5 min	265.5	0.352
	10 min	625	p<0.0001
	15 min	625	p<0.0001
	20 min	625	p<0.0001
	30 min	625	p<0.0001

behavioural indicators to determine the vitality status of each animal with respect to one of four categories, each of which was assigned a score: 1 (excellent), 2 (good), 3 (poor) and 4 (dying or dead). The CVA was carried out five times during the approximate time involved in the sorting and selection of discard on board by the crew (30 min), at 5, 10, 15, 20 and 30 min for

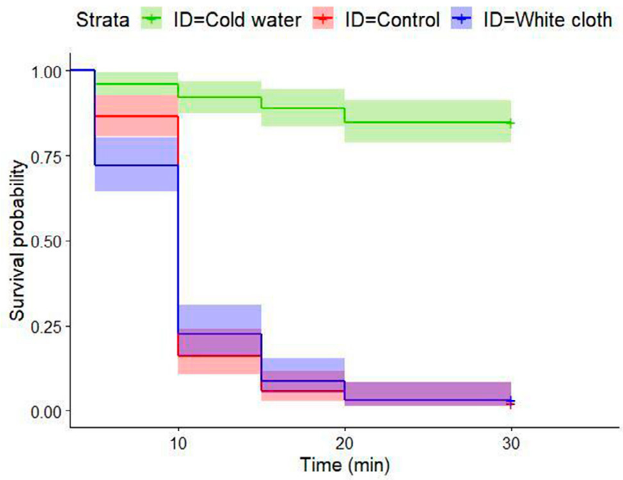

Fig. 4. – Kaplan-Meier survival on board curves (with 95% confidence intervals) for *N. norvegicus* over time exposed to treatment 2-cold water (green), the control (red) and treatment 1-white cloth (purple); data were pooled across replicates. Values near to 1 represent a high survival rate while values near to 0 represent a low survival rate.

each of the 75 *N. norvegicus* individuals examined in the experimental set, with the assistance of crew members and a recorder.

Data analysis

For the vitality study, the scores obtained were added, giving mean scores of between 1 (for individuals in an excellent state) and 4 (for animals dead or dying) to control and both treatments. Then, a graphical representation of these vitality scores through experimentation timewas carried out (Fig. 3) and, in order to search for significant differences between the control and the two treatments, a Wilcoxon rank-sum test was carried out for the five times that the CVA was carried out (Table 2).

Table 3. – Survival rates and confidence intervals at 95% for the five replicates (Rep ID) of the control (Surv.C and CI.C), treatment 1 (Surv.T1 and CI.T1) and treatment 2 (Surv.T2 and CI.T2) at the end of the experiment (30 min).

Time	Rep ID	Surv.C	CI.C.	Surv.T1	CI.T1	Surv.T2	CI.T2
30 min	Rep1	0.04	0-0.28	0	-	0.84	0.71-0.99
	Rep2	0	-	0	-	0.88	0.76-1
	Rep3	0	-	0.04	0-0.28	0.80	0.66-0.97
	Rep4	0.04	0-0.28	0.08	0.02-0.3	0.88	0.76-1
	Rep5	0.04	0-0.28	0.04	0-0.28	0.84	0.71-1

From the data obtained on the vitality on board, a Kaplan-Meier analysis (Kaplan and Meier 1958) was carried out to study the survival on board (with a 95 % confidence interval) for each trawl haul replicate at the final time of experimentation (30 min) (Table 3) and over the whole experimentation time to control, treatment 1 and treatment 2 pool data (Fig. 4). Animals assessed with vitality scores of 1, 2 and 3 were considered alive and those assessed with a score of 4 were considered dead, except for the individuals assessed in state 4 that improved their vitality at the end of the experiment to categories 1, 2 or 3. To study the possible significant differences of survival over time, a log-rank test on pooled data was conducted to compare the control versus treatment 1 and the control vs treatment 2. These analyses were conducted using the "survival" (Therneau and Grambsch 2000) and "car" packages in R 3.3.1 (R Development Core Team 2016).

RESULTS

A total of 1875 CVAs were carried out on 375 *N. norvegicus*. The environment temperature varied between 31°C and 34°C (average 32.3°C) for the control, between 22°C and 25°C (average 24.2°C) for treatment 1 and between 14°C and 16°C (average 15.3°C) for treatment 2.

Post-catch vitality on board

Average of *N. norvegicus* vitality was near 3 (poor) in control and treatments at the beginning of the experiment (Fig. 3). A very similar behaviour was observed over time for the control and treatment 1 animals, which showed a worsening of their vitality state from the beginning of the experiment (3), becoming dead or dying (4) already at the second observation step (10 min). In treatment 2, an improvement was observed over time, reaching a score below 2 at the end of experiment, which corresponds to "good vitality" of the animals.

The Wilcoxon rank-sum test found no significant differences during the experimentation time between the vitality status of the control and treatment 1 (Table 2). However, except for the vitality status at beginning of the experiment (5 min), the Wilcoxon rank-sum test found significant differences for all the *N. norvegicus* vitality assessments compared with the control in treatment 2.

Survival on board

The application of the Kaplan-Meier replicate analysis to the control and the two treatments showed a low survival rate, very close to 0, for the control and treatment 1 at the end of the experiment and high survival rates for treatment 2, with values at 30 minutes greater than or equal to 0.8 in all its replicates (Table 3).

Kaplan-Meier analysis for the pooled data (Fig. 4), showed high survival on board for the control and the two treatments at the beginning of the experiment (5 min). However, there was an abrupt drop in survival, reaching values close to 0.2 of the control and treatment 1 at 10 min, approaching 0 from this moment until the end of the experiment. Treatment 2 maintained a low drop in survival over time, with its survival rate at the end of the experiment greater than 0.8. Changes in the vitality score of the individuals considered dead or dying (4) to vitality of individuals considered alive (1, 2, 3) were only found in treatment 2 during the experimentation time. The log-rank test found significant differences during the experimentation time between the control and treatment 2 ($p<0.001$).

DISCUSSION

The results of this study show that relatively simple modifications to the current discard-handling methods used by trawl fishermen in the Mediterranean can significantly increase the onboard vitality status of *N. norvegicus* juveniles, which could increase their discard survival, because there is a direct relationship between onboard vitality and discard survival (García-de-Vinuesa et al. 2020). This relatively simple solution would contribute significantly to the efficiency and sustainability of the fishery, because *N. norvegicus* stocks are currently exploited excessively (Quetglas et al. 2017, García-de-Vinuesa et al. 2018).

Although enhanced vitality on board of *N. norvegicus* has been directly related to discard survival in the Mediterranean Sea (García-de-Vinuesa et al. 2020), the onboard survival rate obtained in this study could be higher than discard survival, because *N. norvegicus* can suffer additional mortality in the longer time required by discard survival studies (ICES 2014, 2020). Improvements in onboard vitality in *N. norvegicus* treated with cool water may be due to a reduction in stress that is accompanied by a recovery in plasma values and muscle metabolites such as lactate found in non-stressful conditions, although the only study carried out in this regard had a longer duration (Barragán-Mendez et al. 2020). For the implementation of this new discard-handling method, it should be taken into account that trawlers in the Mediterranean usually carry out several hauls during the fishing day (Demestre et al. 2018, García-de-Vinuesa et al. 2020). For this reason, after their arrival on board, the catch remains on the deck waiting for the crew members to finish carrying out the manoeuvre of shooting the trawl net to start the next haul, which usually takes at least 20 minutes. Therefore, quick separation and introduction of juvenile *N. norvegicus* in cool water seems unfeasible, so the whole catch should be introduced in a container with seawater previously cooled to between 14°C and 16°C. This refrigeration can be carried out by simple means such as contact with the ice in the container (all trawlers carry ice compulsorily to keep the commercial catch cool for sale) well in advance until the manoeuvres are finished. This practice would improve the post-release survival of trawling of *N. norvegicus,* especially during the warm months, when their mortality has been shown to be higher both in the Mediterranean and in the Atlantic (Méhault et al. 2016, García-de-Vinuesa et al. 2020, Fox et al. 2020). In this trawl fishery, the amount of catches under the MCRS is very low (*ca*. 1%) with the current regulatory trawl net, but juvenile *N. norvegicus* of legal size in the range 20 to 30 mm CL are routinely and legally discarded for market reasons, sometimes exceeding 40% of the discarded biomass (García-de-Vinuesa et al. 2018). Increasing the post-release survival likelihood of the discarded individuals would mean a better use of resources and economic benefits for fishermen, because surviving *N. norvegicus* could be added to the stocks of adult animals for this fishery. In addition, if this method were extrapolated to the rest of the Mediterranean trawl fleet, it could increase the chances of survival of other invertebrates belonging to trawl discards that have already been shown to have a high survival probability (Giomi et al. 2008, Tsagarakis et al. 2018, Demestre et al. 2018), by protecting them from thermal shock. The increased survival of the invertebrates discarded could lead to better conservation of the habitat of *N. norvegicus* (and other Mediterranean habitats affected by trawling), which would have a positive effect on the health of the stocks of commercial species that inhabit them by reducing mortality based on a better functioning of the benthonic and demersal food web (Demestre et al. 2018, García-de-Vinuesa et al. 2020).

The additional implementation of other technical measures, such as the "discard chute system" (Mérillet et al. 2018), would considerably reduce the discard time once the individuals have been dumped from the container with water, exposing the animals to stress for the shortest possible time and thus increasing their chances of survival (Davis and Olla 2002, Broadhurst et al. 2006, Benoît et al. 2012). In addition, in the Mediterranean it has been shown that short-duration hauls also have a positive effect on invertebrates' survival probabilities when they are discarded from trawling (Demestre et al. 2018). Therefore, carrying out three or four hauls of short duration rather than one or two of long duration could also improve survival of discarding of *N. norvegicus* and other animals.

CONCLUSION

The implementation of technical and methodological improvements such as the introduction of the catch in cold water during the warm months prior to discarding improves the onboard vitality of *N. norvegicus* juveniles. This result can improve the sustainability and efficiency of the trawl fishery, with positive consequences for the economy of fishermen in the medium to long term and progress in the conservation of management-based habitats and ecosystems. The implementation of this methodological enhancement should be encouraged by the European Union, including through direct financial aid to fishermen (Veiga-Malta et al. 2019). However, as this new method can be implemented relatively easily, it can be transferred to fishermen sooner, because it can increase stocks of commercial species and the fishermen's economy in the short to medium term, while at the same time helping to recover and conserve Mediterranean marine habitats.

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