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Shrimp trap selectivity in a Mediterranean small-scale-fishery

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Abstract

Small-scale shrimp trap fisheries, which have received very little attention in areas with limited potential for economic diversification, could offer a sustainable and socially beneficial option for profitable businesses in these regions. This study explores the effect of mesh size on selectivity of the commercially important narwal shrimp, *Plesionika narval*, in the Mediterranean Sea. Three different mesh sizes (8x8, 12x12 and 12x25 mm) were tested in fishing trials, with a theoretical Minimum Landing Size (MLS) using a defined maturity size of 12 mm to support interpretation of the results. Using the retention rates and the estimations on population fractions above and below MLS, we show that the use of the smallest- and largest-sized meshes would not support sustainable or efficient fishery. The results demonstrate a significant decrease in capture probability of undersized narwal shrimps with increased mesh size. The medium-sized mesh traps prove to be the best compromise for the fishery with high catch efficiency of commercial size shrimp and a low capture probability of undersized individuals. The results outlined in this article could be used to develop management plans for small-scale trap fisheries as a basis for developing viable enterprises in remote coastal communities.

Keywords: selectivity, traps, minimum landing size (MLS), retention, Plesionika, small-scale-fisheries

Introduction

Crustacean fisheries comprise an important part of marine commercial catches, recently representing approximately 7.5 % of world total catches (approx. 6 million tons) and the same percentage for Mediterranean catches (FAO, 2018). Crustacean catches are mostly comprised of shrimp, caught with trawls and to a lesser extent with traps. Traps are well known for their high species selection and size selection of the target species, catches are generally retained in good condition and often live, discards are minimal and can be returned unharmed, gears need not be attended, are robust and relatively inexpensive and platform requirements are modest (Miller, 1990). As passive gears with a small footprint, traps have a low environmental impact and are a highly prioritized option by some stakeholders in government and civil society (Soma et al., 2018). This has been reflected by comparative trawl/trap studies (Morello et al., 2009; Leocádio et al., 2012) and in some cases a shift from areas away from trawling to more selective trapping (Hornborg et al., 2017). A fishery policy encouraging shifting gears from the higher to lower impact categories has been suggested in the USA whenever alternatives exist (Chuenpagdee et al., 2003) and in the EU such shifts have potential benefits, for example, in the current EU landings obligation (European Union, 2013), where discards are increasingly banned (Veiga et al., 2016).

Work has been undertaken over many decades to improve these already selective trap fisheries, both in target species attraction, but also in size selection (Sala et al., 2011). Selectivity has been investigated taking into account the likelihood of an individual encountering a trap, entering trap, escape through the entrance, or escape through another part of the trap. As such, selectivity of these traps are dependent on a number of factors, including time and area of trap deployment, shape and design of the trap, type of entrance, type of bait, presence of escape panels and quite importantly, the shape and size of the mesh (Brown, 1982; Salthaug and Furevik, 2004; Tallack, 2007; Jirapunpipat et al., 2008; Favaro et al., 2010; Winger and Walsh, 2011; Broadhurst et al., 2014; Sousa et al., 2017). Because of their low operational demands, trap fisheries are often small-scale and local fisheries targets various species of crab, lobster, Norway lobster and shrimps depending on the local area and markets.

The narwal shrimp (*Plesionika narval*) (Fabricius, 1787) is a nektobenthic cosmopolitan species occurring from the surface down to 910 m depth in a large variety of habitats including muddy, sand-muddy, rocky bottoms and submarine caves (Holthuis, 1987; Thessalou-Legaki et al., 1989; Biscoito, 1993). In both the North-Eastern Atlantic and the Central Mediterranean Sea, ovigerous individuals have been found to occur all year round indicating a prolonged spawning period (Arculeo and Lo Brutto, 2011; Sousa et al., 2014; Anastasopoulou et al., 2017; Triay-Portella et al., 2017). In the Aegean Sea, catches of the narwal shrimp have been shown to vary both with depth and season, together with a vertical migration of females to shallower waters during the period of thermal stratification (Kalogirou et al., 2017). Fisheries depths reported from the eastern central Atlantic were from 200 to 500 m, on cliffs off the continental shelf, or close to the deep zones associated with the coral *Dendrophyllia* sp. (González et al., 1997).

The small-scale-fishery for narwal shrimp is one of the most profitable small-scale fisheries in the Aegean Sea (Eastern Mediterranean). The fishery is prosecuted by small-scale trap fishery vessels (5 to 15 m length overall, LOA), from dusk to dawn with baited shrimp traps at depths ranging from 5 m to 200 m, deployed close to the bottom (Kalogirou et al., 2017). The vast majority of vessels are smaller than 12 m. and square or round traps with a mesh size of 8 to 12 mm are used (Vasilakopoulos et al., 2018). Depending on vessel size and trap capacity, number of traps can vary from 15 to 250 traps (Kalogirou et al., 2015; Vasilakopoulos et al., 2015). This relatively abundant species represents approximately 85% of the total catch; the remaining percentage mainly consists of bycatch *Plesionika edwardsii* and *Octopus vulgaris* and discards (Kalogirou et al., 2015). Size selection is carried out by trap design on the seabed and during hauling (by winnowing) with further manual sorting on-board. Catches for this species are neither regulated by weight (no TAC) or minimum landing size (or minimum conservation reference size under the new EC Reg. (European Union, 2013).

Despite the importance of narwal shrimp fisheries for fishing communities around the Aegean Sea, scientific knowledge about this species selectivity in commercial traps remains scarce (Kalogirou et al., 2017). A strong scientific knowledge base is crucial in order to develop a sustainable management strategy for the narwal shrimp fishery in the Aegean Sea. An important aspect of worldwide selectivity experiments with traps is that they have been undertaken almost exclusively through the use of comparative fishing between traps with different modifications or against non-modified traps. Comparisons have been taking into account only the retained part of the catch between different designs/modifications, with no information concerning the escaped part of the catch and therefore the percentage of the population retained. This would be analogous in trawl experiments comparing design modifications by alternative haul experiments or using a twin trawl (trouser trawl). A more precise method is carried out with the use of a covered cod end that more accurately allows the estimation of the non-retained a part of the population that has encountered the gear. To our knowledge selectivity trials have not been carried out with traps using a ‘covered’ method to retain the escaping proportion of the population. The novel experimental design with covered traps used in this study have compared to with the traditional experimental design applied for investigating size selectivity in trap fishery where small-meshed control traps are fished in parallel with the test traps the benefit by requiring a much smaller dataset to be collected to obtain the same precision for the estimated size selectivity curve. Specifically, Herrmann et al. (2016) found that it can be expected that the covered experimental design applied here only requires approximately 10% in terms of number of individuals caught and length measured as compared with the traditional paired experimental design with test and control gear to obtain the same uncertainty level of the estimated size selectivity curve.

The present experimental study aimed to estimate the size selectivity of narwal shrimp using three different mesh sizes in commercial traps, towards the maximization of commercial size selection efficiency and sustainable fishery. This is the first study to experimentally investigate size fractions of the narwal shrimp population, retained or released using a covered-trap approach.

Materials and Methods

Experimental Survey

The experimental fishery survey was carried out in the Dodecanese archipelago of the south-eastern Aegean Sea (Figure 1). The work was carried out using a commercial fishing vessel following common fishing practice for this type of fishery. The studied area is a commonly exploited fishing ground for the narwal shrimp (36° 04′ 06.97″; 28° 05′ 28.89″). Selectivity trials were performed over rocky bottoms at an average depth of 80±10 m. Fishing was undertaken during the hours of darkness (20:30-06:00 hours) due to the nocturnal activity of the narwal shrimp, with three replicate trials carried out between 20-22 June 2015, during the main fishery period (May to July).

Figure 1.

Square-base traps (length 60 cm, width 60 cm and height 20 cm) of galvanized metal mesh were used with two square mesh and one rectangular mesh configuration of sizes 8x8, 12x12 and 12x25 mm, respectively (Figure 2). Traps were covered with a square base cover (length 100 cm, width 100 cm, height 60 cm) of 6x6 mm mesh size. Each trap was positioned inside the cover in such a way that all the sides of the trap were at equal distance of 20 cm from the corresponding side of the cover and to minimise masking of the main mesh (Wileman et al., 1996).

In common with the typical configuration of commercial traps, a cylinder of 13 cm diameter was used for the entrance of specimens, through the cover and into the trap. A closable side entry allowed access to catches in the trap and the cover. The bait used consisted of a dough mixed from fermented oily fish (e.g. *Sardina pilchardus* and *Scomber scomber*), and stabilized with flour and water.

Figure 2.

Traps were deployed on a bottom main-line, with all rigging components of the gear identical with those commonly adopted in the commercial fishery. The total length of the main-line was adjusted to fishing depth and traps were attached with a 2 m bridle at a distance of 35 m between the traps along the bottom (Figure 3).

For each of the three sampling days, a total of 30 traps were deployed, 10 for each configuration randomly ordered. After a soak time of 9.5 hour, traps were hauled on board and the catch was immediately separated into the retained (trap) and released (cover) fractions. All traps hauled on board had a catch and all shrimps captured were measured. Shrimp carapace length (mm) and wet weight (g) was measured in each fraction.

A total of 38 experimental traps were lost during the sampling campaign, possibly due to the height of the experimental trap making it more prone to get stuck along the bottom (S. Kalogirou, pers. comm.). Day 1: 2 with 8x8 mesh size, 2 with 12x12 mesh size and 9 with 12x25 mesh size; Day 2: 6 with 8x8 mesh size, 5 with 12x12 mesh size and 5 with 12x25 mesh size; Day 3: none of the 8x8 mesh size, 3 with 12x12 mesh size and 6 with 12x25 mesh size.

Figure 3.

Size selectivity analysis

Size selection was modelled using a logistic curve with parameters L50 and Selection Range (Wileman et al., 1996):

$$r(l, L50, SR) = \frac{e^{\frac{\ln(9)}{SR}\times(l-L50)}}{1+e^{\frac{\ln(9)}{SR}\times(l-L50)}} \qquad (1)$$

L50 and SR are the trap selection parameters considered. L50 is the length of shrimps that have a 50 % probability of being retained by the trap after entering it. SR is the difference in length of individuals having, respectively, 75 % and 25 % probability of being retained by the trap after entering it.

To include the effect of between-trap deployment variations in size selectivity into a single selection curve a *"fishery selection curve"* was used (Millar, 1993). Data were pooled over trap deployments for each trap type separately before fitting the logistic curve to the data. The analysis was conducted based on the capture (retained in the trap) and release (released to the cover) data from the deployments with the specific trap type. Thus, expression (2) was minimized, which is equivalent to maximizing the likelihood for the observed data in the form of the length-dependent number of individuals measured as retained in the trap (nT_l), versus the number collected in the cover (nC_l).

$$-\sum_{j=1}^{m}\sum_{l}\left\{nT_{jl}\times ln\left(r\left(l, L50, SR\right)\right)+nC_{jl}\times ln\left(1.0-r\left(l, L50, SR\right)\right)\right\} \qquad (2)$$

In (2), the outer summation is over trap deployments conducted with the specific trap mesh size and the inner summation is over length classes in the data.

The ability of the model (1) to describe the data was based on calculating the corresponding p-value. A p-value greater than 0.05 implies that the model fits the data sufficiently well and that the difference between the data and the model could well be a coincidence (Wileman et al., 1996).

Efron 95 % percentile confidence bands (Efron, 1982) for the size selectivity curve (model (1)), and the parameters in it (L50, SR), were obtained using a double bootstrap method implemented using the software tool SELNET (Sistiaga et al., 2010; Herrmann et al., 2012; Sala et al., 2015). Specifically, between trap deployment variation in size selectivity, which corresponds to between haul-variation in trawl selectivity studies, was accounted for in the outer bootstrap loop by selecting with replacement among the pool of trap deployments with the specific trap type. The number of selected trap deployments equalled the total number of deployments for that trap type during the fishing trials (outer summation in equation 2). Within each resampled trap deployment, the data for each length class were resampled in the inner bootstrap repetition (index *l* in equation 2) to account for uncertainty in the size selection for that deployment due to the number of shrimps caught in it. For each trap configuration analyzed, 1000 bootstrap repetitions were conducted to estimate the 95 % confidence limits (Efron percentile).

To infer the effect of mesh size, the difference in the length-dependent retention probability $\Delta r(l)$ was estimated:

$$\Delta r(l) = r_{12x12}(l) - r_{8x8}(l) \qquad \Delta r(l) = r_{12x25}(l) - r_{12x12}(l) \tag{3}$$

where the $r(l)$ is the retention probability in each mesh size (e.g. 8x8 mm, 12x12 and 12x25). The 95 % confidence intervals for the two $\Delta r(l)$ were obtained based on the two bootstrap population results (1000 bootstrap repetitions in each mesh size). As they are obtained independently from each other, according to Larsen et al. (2018) two new bootstrap population of results for $\Delta r(l)$ were created.

A Minimum Landing Size (MLS) is usually used as a reference point for comparison of L50 values, where for sustainable purposes the L50 should be above MLS. Previous studies have estimated that the size at which 50 % of narwal shrimp individuals reach maturity was 11.7 mm (Anastasopoulou et al., 2017). Therefore in this study, a theoretical MLS of 12 mm has been used.

To estimate the average length-integrated percentages of fractions retained (in number of individuals) below (nP_{-}), above (nP_{+}) and the ratio between below and above ($nRatio = nP_{-}/nP_{+}$) the MLS has been calculated for each trap. This was done by summing the number of individuals retained that were below and above MLS for each trap. This sum was then divided by the total number of individuals in this size fraction for each specific trap to obtain the average fraction. Thus, the fractions were estimated using the following formulae:

$$nP_{-} = 100 \times \frac{\sum_j \sum_{l<MLS} nT_{jl}}{\sum_j \sum_{l<MLS} \{nT_{jl} + nC_{jl}\}} \quad (4)$$

$$nP_{+} = 100 \times \frac{\sum_j \sum_{l\geq MLS} nT_{jl}}{\sum_j \sum_{l\geq MLS} \{nT_{jl} + nC_{jl}\}} \quad (5)$$

$$nRatio = \frac{\sum_j \sum_{l<MLS} nT_{jl}}{\sum_j \sum_{l\geq MLS} nT_{jl}} \quad (6)$$

The two-compartments data format meant that, for each haul (*j*), counted numbers of narwal shrimp at each length class *l* in compartment cover *C* (nC_{jl}) and in compartment trap *T* (nT_{jl}) were available. nP_{-} gives an estimate of how large the fraction is, in number of individuals below MLS for each trap catch. It thus gives an indication if fishing is problematic in terms of removing undersized individuals from the population size structure. nP_{-} should preferably be low. The opposite factor nP_{+} gives an indication of the retention efficiency of the population above MLS for the specific trap while considering the size structure of the population fished. In our case, where the species is the target species, nP_+ should preferably be high (close to 100). The *nRatio* gives the number of individuals retained below and above MLS. Thus, for the size selectivity of the trap to be well adjusted for the MLS and considering the population fished, the *nRatio* should be low (close to zero).

The above indicators were based on number of individuals but since the value of catch is more related to weight, similar indicators based on weight were also estimated:

$$wP_- = 100 \times \frac{\sum_j \sum_{l<MLS}\{w_l \times nT_{jl}\}}{\sum_j \sum_{l<MLS}\{w_l \times nT_{jl} + w_l \times nC_{jl}\}} \quad (7)$$

$$wP_+ = 100 \times \frac{\sum_j \sum_{l\geq MLS}\{w_l \times nT_{jl}\}}{\sum_j \sum_{l\geq MLS}\{w_l \times nT_{jl} + w_l \times nC_{jl}\}} \quad (8)$$

$$wRatio = \frac{\sum_j \sum_{l<MLS}\{w_l \times nT_{jl}\}}{\sum_j \sum_{l\geq MLS}\{w_l \times nT_{jl}\}} \quad (9)$$

Where the weight w_l, for individual belonging to length class *cl (carapace length)*, have been estimated by:

$$w_l = a \times l^b \quad (10)$$

Length-weight relationships for all samples showed a good fit to the exponential curve, with R-squared greater than 0.920. The value of β was 2.86342 and for α was 0.00109.

To estimate the uncertainty in nP_- , nP_+ , *nRatio*, wP_- , wP_+ and *wRatio*, considering both the effect of between-trap variation and the uncertainty related to within-trap variation, the double bootstrapping method, implemented in the software tool SELNET and described in Sala et al. (2015) has been used to estimate the *bca "Efron percentile" 95 confidence limits*.

Check for potential bias in estimation of trap size selectivity by the covered trap method

A potential risk with the covered trap design used in this study is that shrimps that once have escaped through the meshes of the test traps and are retained in the small-meshed cover surrounding the test traps will re-enter the test traps through the meshes maybe attracted by the bait. If this type of re-entrance occurs, it potentially could lead to that some small shrimps that had escaped first would be found retained in the test traps which would bias the estimated size selectivity. Therefore, before trusting trap size selectivity results obtained by method described in the previous section it is necessary first to check if there is any indication for that trap re-entry have biased the estimated size selection curve. In case of such bias should be present a proportion of the small shrimps that normally all should be found in the trap cover would be found retained in test trap. This would lead to a size selection pattern well-known from active fishing gears where only a fraction of fish is able to contact the selection device to escape. This is for example the situation for escape through square mesh panels and sorting grids in trawls and in such cases, it has been found that the traditional logistic size selection model (1) would not be able to describe the collected experimental size selection data well. Contrary, would require a size selection model that explicit accounts for that only a fraction *C* of those that could have escaped did. Several studies have found that in such cases, the traditional size selection model should be replaced by the *CLogit* model (Zuur et al., 2001; O'Neill et al., 2006; Sistiaga et al., 2010; Herrmann et al., 2013; Larsen et al., 2016):

$$r(l, C, L50, SR) = 1 - \frac{C}{1 + e^{\frac{ln(9)}{SR} \times (l - L50)}} \quad (11)$$

In (11) *C* is a size-independent number between 0.0 and 1.0 and quantify the fraction fish or shrimp that utilize the escape possibility (make selectivity contact) through the selection device. In case *C* is 1.0 all make selectivity contact and (11) would simply to the traditional logistic size selection model (1). In case *C* is less than 1.0 a fraction 1.0-*C* of the sizes that could have escaped would be found retained as would be the case with the traps if re-entry had biased the size selection data for the trap.

Based on the above considerations it was checked if model (11) would be better at describing the collected size selection data than the traditional logistic model (1) by using each in (2). In case both models provide acceptable p-values (>0.05) implying that they both could describe the experimental data sufficiently well AIC-values was compared and the model with the lowest value should be selected (Akaike, 1974). In case the traditional logistic model (1) is found to be the model of choice for all three test trap types (8x8, 12x12, 12x25) we conclude that there would be no indication on that potential shrimp re-entry would have biased the estimated trap size selectivity and then the results obtained with the covered trap experimental design by the method described in the previous section can safely be trusted to be unbiased.

Results

In total, size-selectivity data were collected from 22, 20 and 10 deployments of the 8x8, 12x12 and 12x25 mm trap types respectively during the experimental fishing (Table 1). These numbers were considered to be sufficiently high to account reliable for between-deployment variation in the estimated size selectivity for all three trap types.

Table 1

In total 1222 narwal shrimp were caught and measured with the 8x8 mm trap with 1095 retained in the trap and the remaining collected in the cover. For the 12x12 mm trap the total number of narwal shrimp was 2038 with 1101 being retained. Finally, for the 12x25 mm trap the total number of narwal shrimp was 302 with 63 being retained. No bycatch or discards were found in the experimental traps.

The *p*-value and deviance versus degrees of freedom showed that there were no problems in using the logistic curve to describe the retention data relating to each trap type (Table 2; Figure 4) by using the traditional logistic size selection model (1). However, to check for potential bias in estimated size selection by trap re-entry it was checked for each trap type whether the *CLogit* size selection model would describe the collected experimental data better. In all three cases found that the *CLogit* model resulted in an AIC-value that was exactly 2.0 higher than for the model (1) with respectively 81.57 versus 79.57, 635.24 versus 633.24 and 130.00 versus 128.00. Therefore, in all three cases the logistic size selection model (1) were the clear choice meaning that there was no indication of bias in the estimated trap size selection by this model and the results obtained based on this can therefore be trusted. This is further supported by that in all cases for the *CLogit* model the parameter *C* was estimated to be 1.0 implying 100% selectivity contract and thereby no re-entry bias.

The mean length of an individual with a 50 % probability to be retained in the trap (L50) was estimated at 8.25 (CI: 8.01-8.47), 11.68 (CI: 11.39-11.99) and 14.56 (CI: 13.47-15.18) mm for the mesh sizes of 8x8, 12x12 and 12x25 mm, respectively (Table 2), proving that L50 increased with increasing mesh size and that the smallest mesh size (8x8) had a L50 well below MLS, the medium mesh size close to the MLS and the larger mesh size well above the indicative MLS. The mean selection range (SR) was estimated at 0.52 (CI: 13.47-15.18), 1.18 (CI: 0.99-1.42) and 1.20 (CI: 0.76-1.65) mm for the mesh sizes of 8x8, 12x12 and 12x25 mm, respectively (2). This demonstrates an increase with increase in trap mesh size at least between the first two.

Figure 5 compares the length dependent retention probability between the different designs. It is particularly evident that an increase in trap mesh size decreases retention probability for smaller narwal shrimps. The difference in retention probability between the mesh size pairs: 12x12 and 8x8, 12x25 and 12x12 (Delta plot, Figure 5) demonstrate that the mesh size significantly affects the trap retention and therefore the probability of shrimp escape. Since confidence intervals for the curves in the Delta plots did not contain 0.0 (Figure 5), significant effects were detected by increasing mesh size. Retention comparison between 12x12 and 8x8 shows that at least 90% more shrimps between 9-10.5 mm pass through the mesh size 12x12 than 8x8 mm. This difference gradually decreases with length, reaching 35% at the MLS of 12 mm, for retention of the 12x12 trap, as the trap used as baseline (8x8) has 100 % of retention (Figure 5).

Notably, in comparing between the 12x25 and 12x12 mesh-sizes, with the latter used as baseline, above the MLS of 12 mm, the difference in retention probability is significant until 14.5 mm with a decrease in the retention between 64-87 % (Figure 5). This result implies that, for commercially viable shrimp sizes, the 12x25 trap is less efficient compared to the 12x12 trap.

Table 2.

Figure 4.

Figure 5.

A significantly lower retention of shrimp individuals below the MLS was found when using larger mesh size, resulting in a decreasing fraction of retained undersized shrimp, both in number ($nP-$) and in weight ($wP-$), with increasing mesh size (Table 2). It should be noted that besides the trap selection properties, retained fractions are also affected by the size distribution of the shrimp population coming into contact with the traps (Figure 4).

The estimated number of individuals below MLS (*nP*-), retained in the 8x8 mesh size, was 67.35 % of the total catch. Retention of individuals below MLS (*nP*-) for mesh size 12x12 was 7.62 % and 0 % for the tested trap with mesh size of 12x25. The corresponding retention of shrimps in terms of weight below MLS (*wP*-) was 85.68 %, 14% and 0 % for the three tested mesh sizes of 8x8, 12x12 and 12x25, respectively (Table 2).

The estimated number of individuals above MLS (*nP+*) retained in the 8x8 mesh size was 100 % of the total catch. Retention of individuals above MLS (*nP+*) for mesh size 12x12 mm was 94.14 %, and 38.18 % for the tested trap with mesh size of 12x25 mm. The corresponding retention of shrimps in terms of weight above MLS (*wP+*) was 100 %, 96.46 % and 47.55 % for the three tested mesh sizes of 8x8, 12x12 and 12x25 mm, respectively (Table 2).

The relationship between the fraction of individuals retained below and above MLS (*nRatio*), in the 8x8 mm mesh size, was 0.31 (CI: 0.21-0.47) (Table 2). The *nRatio* for the mesh sizes with 12x12 and 12x25 were 0.07 (CI: 0.05-0.10) and 0.0 (CI: 0.00-0.00), respectively.

The corresponding relationship between the fraction retained below and above MLS based on weight (*wRatio*), in the 8x8 mm mesh size, was 0.13 (CI: 0.08-0.19) (Table 2). The *wRatio* for the mesh sizes with 12x12 and 12x25 were 0.03 (CI: 0.02-0.04) and 0.0 (CI: 0.00-0.00), respectively.

Discussion

This study presents novel results for trap size selectivity and selection range of the narwal shrimp from a small-scale fishery in the Mediterranean Sea. This is the first time a) decapod selectivity has been estimated using the covered trap methodology, b) a statistical approach has been used to estimate population fractions retained above and below a theoretical MLS, and c) selectivity has been studied in small-scale fisheries targeting small-sized shrimps.

The covered trap method allows for a much more accurate assessment of selectivity than the normally used modification comparisons giving more detail on the target-gear interaction through the escaped part of the population. Further, according to Herrmann et al. (Herrmann et al., 2016) it enables obtaining size selectivity estimates with a specific precision with a much smaller experimental effort than with the traditional method using both test and none selective control traps. However, using the covered trap method leads to the potential risk that escaped individuals could re-enter the test traps from their covers and thereby potentially bias the estimated test trap size selectivity. Therefore, when using this method, it should include a formal check whether results indicate such bias. To do this it was in this study demonstrated how such check can be formally performed. Luckily, the results of this check did not indicate any problems regarding estimating the size selection of the narwal shrimp based on the covered trap method and the results obtained in this study is therefore considered to be reliable.

Potentially this new covered trap method could equally be applied to other more economically important decapod crustacean fisheries where there is a potential gear shift, for example, the partial shift from trawls to traps in the Kattegat/Skagerrak targeting *Nephrops norvegicus* (Hornborg et al., 2017), or in Scotland where it has been reported that a decrease trawling activity in inshore waters could lead to more trapping and larger benefits (Williams and Carpenter, 2016). Using this approach, estimating selectivity parameters with respect to a reference value such as MLS, allows a better assessment of gear performance. The ideal gear will have minimal fraction of target species catch below the reference value, a maximal fraction of target species catch above the reference value and consequently close to zero ratio for the two fractions.

The results from this study revealed significant differences in size selectivity between the different trap mesh sizes. It is to be mentioned that the narwal shrimp forms schools and thus the between trap variation is considered natural. From very early studies, it is known that increasing mesh size in shrimp fisheries would cause a decrease in target catch (Lindner, 1966). In more detailed mesh-size shrimp selectivity studies, the L50 estimates and selection ranges have shown significant increases with increased mesh size and a decrease in the proportion of undersized individuals retained (Ragonese and Bianchini, 2006; Yamaguchi et al., 2006). The traps with smallest mesh size (8x8 mm) revealed poor selectivity in all parameters and although this mesh retained all individuals over the reference size, it had the highest retention of small-sized individuals, which may promote discarding of visibly moribund individuals (pers com. S. Kalogirou). The traps with the largest mesh size (12x25 mm) revealed lowest retention in both small size and large-size fractions, exhibiting the highest selection range, approximately similar with the intermediate sized traps (12x12 mm), but >2 times higher than the smallest mesh. The optimal exploitation pattern was obtained for the 12x12 mm mesh size, as was demonstrated by a low catch of undersized shrimps and a high proportion of shrimps retained above MLS. Mesh shape also has impacts on the selectivity of the gear (Sala et al., 2008; Sala and Lucchetti, 2010; Sala and Lucchetti, 2011; Winger and Walsh, 2011; Butcher et al., 2012; Broadhurst et al., 2014) and part of the more significant differences between the larger mesh and the other two may have been due to its shape. There are very few other studies of trap selectivity of narwal shrimp, but Sousa et al. (2017) in a catch comparison of two trap types with circular plastic mesh in Madeira in the Atlantic reported L50 values of 12.26 mm from a bottom trap (mix of 5 mm and 15 mm diameter mesh) and

14.73 mm in a floating trap (15 mm diameter mesh), not dissimilar in a mesh range to this study with similar population sizes from their bottom traps. The study by Sousa et al. (2017), showing vertical mobility of shrimps, indicate that the longer cylindrical entrance used may have a minor effect on shrimp entry. The authors recommended a larger mesh size (15 mm) in the fishery to reduce the capture of smaller individuals, protecting recruits and juveniles also in relation to a first maturity estimated at 14.61 mm (Sousa et al., 2014).
The narwal shrimp is a relatively small shrimp compared to other commercial Mediterranean shrimp, particularly the main Mediterranean target, deep water rose shrimp *Parapenaeus longirostris* (Sobrino et al., 2005). Because of the nature of the narwal shrimp fishery, fishermen may not spend time removing small individuals with limited grading (pers. comm. S. Kalogirou). For important catch and larger commercial decapods there is often a legal MLS (*P. longirostris*, *Nephrops norvegicus*, crabs, lobster) and for trap target species a specific mesh is prescribed or escape panels are necessary (Miller, 1990; Broadhurst et al., 2014).

In addition, the narwal shrimp is a short-lived species, thus making it more vulnerable to various fishing pressures. Exemptions to the landing obligation due to high survivability are not suggested in this fishery, since clogging in the traps during hauling and on-board handling is assumed to significantly minimize survivability. Due to the recent enforcement of the landing obligation, an introduction of a minimum mesh size of 12x12 mm and thus a MLS of 12 mm carapace length (taking into account size of maturity - (Anastasopoulou et al., 2017), would have a positive impact on this important stock in the area under study. The methodology and results presented in this study could support the sustainability of the Greek narwal fishery but also give insights for fisheries management in other areas targeting small-sized shrimps and small-scale fisheries. Limitations of our study included the cover influence flow through the trap, the diffusion of the bait and the selectivity of the trap. More replicates at different depths and locations would increase our understanding on spatial (depth and location) variations in selectivity and minimize the effect of high proportion of lost traps.

The work presented in this study can be used as a typical paradigm of this new governance era for Mediterranean fisheries and, as equally importantly, to similar fisheries worldwide (Maravelias et al., 2018). It provides basic information required to develop new comprehensive governance involving all stakeholders and empowering fishermen, especially within small scale fleets, to take direct responsibility in the participative management of fisheries, building on the Mediterranean self-regulatory tradition. It can also serve to promote and establish a culture of compliance and trust based on transparency as well as on efficient prevention, detection and action to ensure a rule-based management of fisheries. Further it may ensure adequate data collection and exchange on all types of fleets including small-scale and recreational fisheries and reinforce scientific knowledge on fish and shrimp stocks.

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S.K. conceived the idea, S.K. and L.P. designed the sampling, S.K., A.S. and B.H. analysed the data and interpreted the results. All authors carried out the writing and approved the final version of the manuscript. The work was carried out entirely during the period of the project (Apr 2014 – Dec 2015). The contribution of Christos D. Maravelias to this work was exclusively completed while at the Hellenic Centre for Marine Research. This article in no way expresses his current employer position (European Commission) nor anticipates its future policy in the area.

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Table 1

Table 1. Details of the field experiment. Mesh size of traps used (Trap type), time during setting and hauling (Set, Haul), coordinates of setting (latitude and longitude), depth at setting traps, number of shrimps retained (nT) and escaped (nC), minimum and maximum carapace length (min and max Length) in mm.

			Time		Coordinate						
ID_Depl	Trap type	Date	Set	Haul	Latitude	Longitude	Depth	nT	nC	Min. Length	Max. Length
1	8x8	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	62	10	7.0	16.5
2	8x8	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	26	3	7.0	16.5
3	8x8	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	22	0	7.5	14.5
4	8x8	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	49	10	7.0	17.0
5	8x8	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	22	3	7.5	16.5
6	8x8	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	29	5	7.0	17.0
7	8x8	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	23	4	7.0	16.5
8	8x8	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	55	11	6.5	17.5
9	8x8	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	93	5	7.0	18.0
10	8x8	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	69	14	6.5	20.0
11	8x8	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	51	10	7.0	17.0
12	8x8	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	82	0	10.0	18.0
13	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	82	6	6.0	18.5
14	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	54	16	6.0	18.5
15	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	29	0	10.0	18.5
16	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	52	3	6.5	17.0
17	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	56	0	7.5	17.0
18	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	54	0	8.5	17.0
19	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	58	10	6.5	17.0
20	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	54	0	8.5	17.0
21	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	55	9	6.5	17.0
22	8x8	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	18	8	6.5	17.0
23	12x12	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	34	71	6.5	15.5
24	12x12	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	31	21	6.5	18.5
25	12x12	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	82	61	6.5	18.0
26	12x12	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	34	21	6.5	18.5
27	12x12	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	59	20	6.0	18.0
28	12x12	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	8	20	6.5	16.0
29	12x12	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	72	65	6.5	17.5
30	12x12	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	69	26	6.0	18.0
31	12x12	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	47	71	6.5	18.5
32	12x12	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	49	72	6.5	18.0
33	12x12	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	48	21	6.5	18.0
34	12x12	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	83	24	6.5	17.0
35	12x12	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	84	76	6.5	19.0
36	12x12	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	70	81	6.5	19.0
37	12x12	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	53	78	6.0	17.5
38	12x12	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	54	79	6.0	17.5
39	12x12	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	53	23	6.5	18.0
40	12x12	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	58	30	6.5	18.0
41	12x12	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	82	25	6.5	18.0

42	12x12	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	31	52	6.5	19.0
43	12x25	20/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	4	40	7.0	16.5
44	12x25	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	16	112	7.5	18.0
45	12x25	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	24	16	6.5	17.0
46	12x25	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	7	14	6.5	15.0
47	12x25	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	5	27	6.0	16.5
48	12x25	21/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	2	23	7.5	15.5
49	12x25	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	0	3	10.0	11.5
50	12x25	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	0	3	10.0	11.0
51	12x25	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	1	9	8.5	15.0
52	12x25	22/06/2015	20:30	06:00	36° 04′ 06.97″	28° 05′ 28.89″	70	4	5	10.0	15.5

Table 2

Table 2. Direct estimate of the selectivity parameters for narwal shrimp (*Plesionika narval*) in the three traps (8x8, 12x12, and 12x25 mm) tested during the field experiment. The acronyms of trap names provide the nominal trap mesh size. Mean values (in bold) and Efron percentile 95 confidence limits (*in italics*) of the retention length at 50 % (L50), Selection Range (SR) and the length-integrated percentage of fractions below and above MLS in number of individuals and the ratio between number below and above (nP− , nP+, nRatio) retained in each trap. Since the value of catch is more related to weight similar indicators based on weight (wP− , wP+, wRatio) have been also estimated. L50 and SR are in mm.

Trap / Parameter	**8x8**	**12x12**	**12x25**
L50	**8.25**	**11.68**	**14.56**
	8.01-8.47	*11.39-11.99*	*13.47-15.18*
SR	**0.52**	**1.18**	**1.20**
	0.31-0.70	*0.99-1.42*	*0.76-1.65*
p-Value	1.000	0.994	1.000
DOF	26	25	23
Deviance	3.77	10.86	5.11
nP-	**67.35**	**7.62**	**0.00**
	55.33-78.31	*4.85-11.53*	*0.00-0.00*
nP+	**100.00**	**94.14**	**38.18**
	100.00-100.00	*90.42-96.75*	*21.28-80.49*
nRatio	**0.31**	**0.07**	**0.00**
	0.21-0.47	*0.05-0.10*	*0.00-0.00*
wP-	**85.68**	**14.00**	**0.00**
	78.46-91.01	*9.15-21.04*	*0.00-0.00*
wP+	**100.00**	**96.46**	**47.55**
	100.00-100.00	*94.14-98.06*	*30.66-86.12*
wRatio	**0.13**	**0.03**	**0.00**
	0.08-0.19	*0.02-0.04*	*0.00-0.00*

Figures with captions

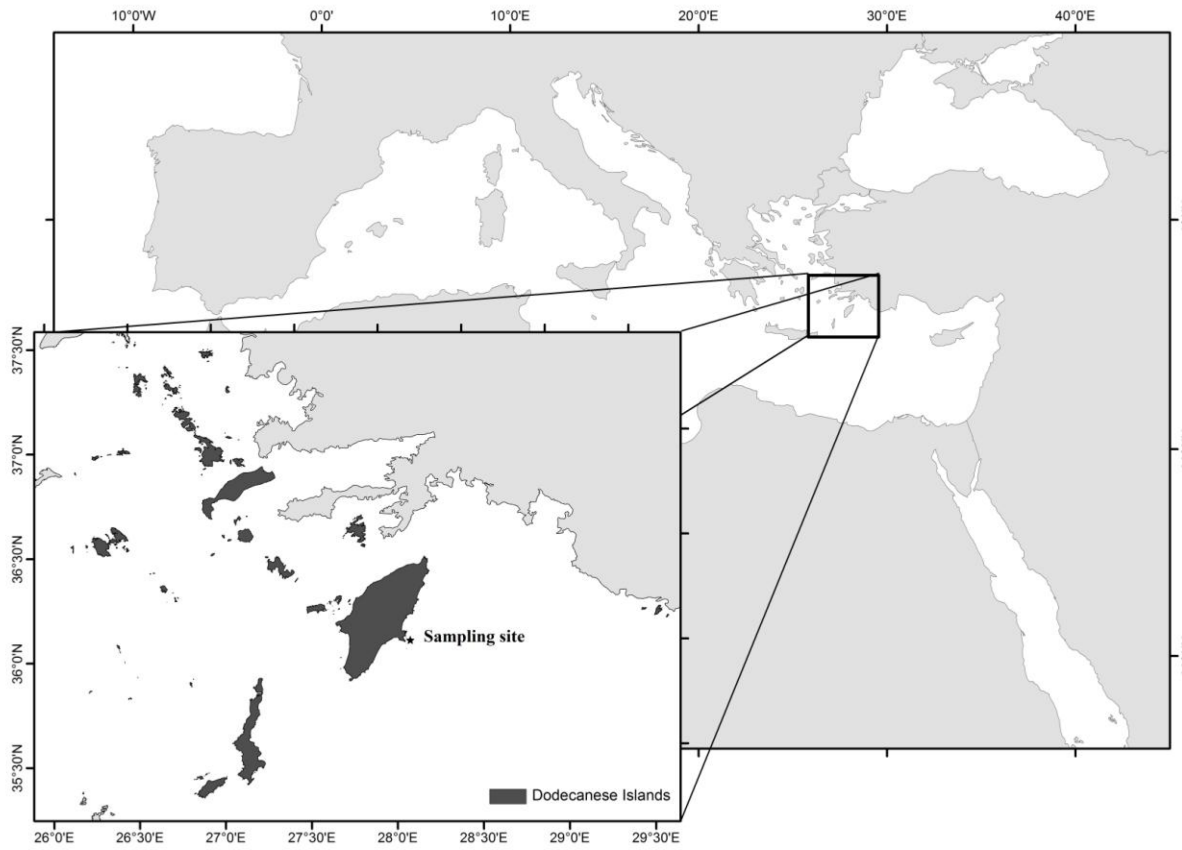

Figure 1. Study area and location of sampling (marked with an ★, at Rhodes – larger island) within the Dodecanese islands (shaded islands) in the South-Eastern Aegean Sea (Eastern Mediterranean Sea).

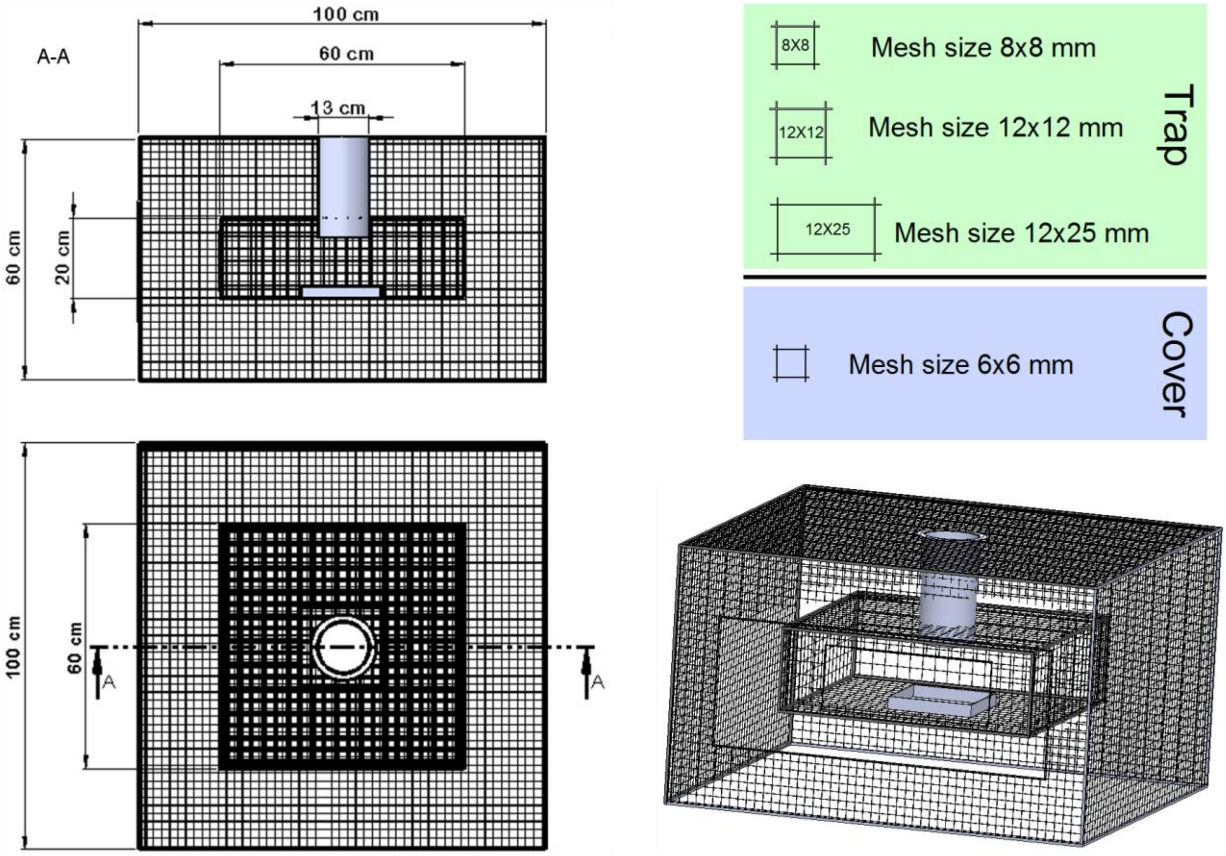

Figure 2. Schematic illustration of the traps and cover. The traps (60x60x20 cm) were constructed from galvanized metal mesh in three different mesh sizes: 8x8 mm, 12x12 mm and 12x25 mm. Each trap was surrounded by a cover, made of galvanized metal mesh of size 6x6 mm. A solid open cylinder (13 cm diameter) allows for the entrance of specimens through the top of the cover into the trap; bait plate is opposite to the entrance. Side doors for emptying the trap and cover on the right hand side. Not shown are 6 vertical structural metal spacer bars around the trap holding the trap within the cover.

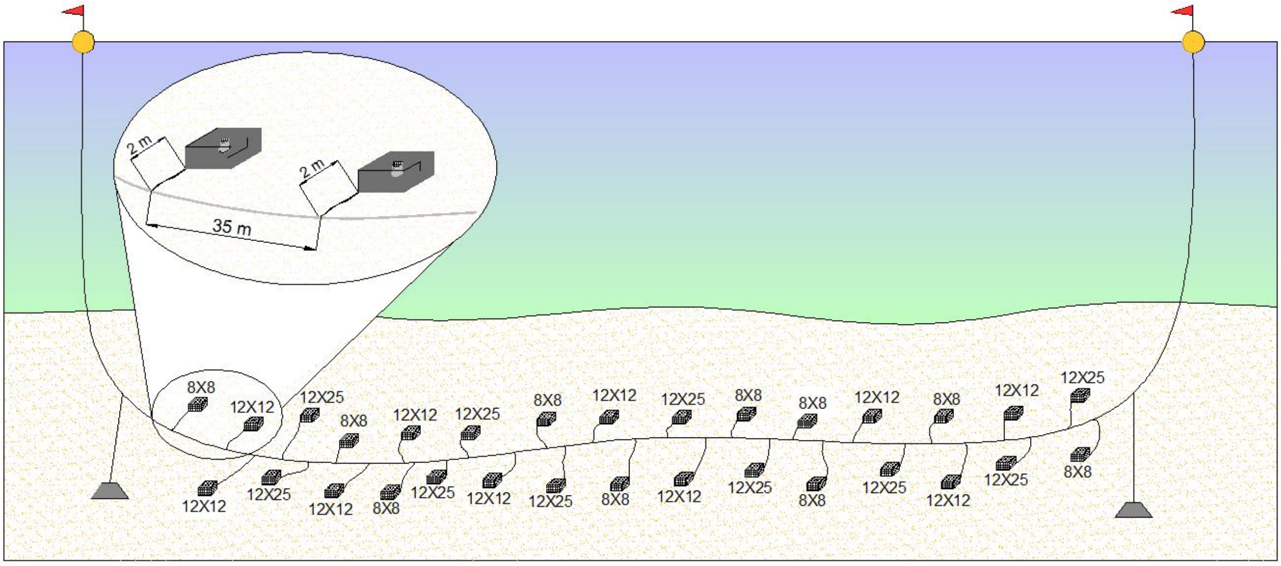

Figure 3. Deployment of traps. Along the main-line the traps were fixed every 35 m with bridles of 2 m. The length of the main-line was depth-adjusted. Three types of traps (8x8, 12x12, 12x25, see Figure 2 for details) were deployed randomly along the main-line. Two dead weights are used to immobilise the traps on the bottom, with buoys, at the beginning and the end of the main-line, for location and recovery.

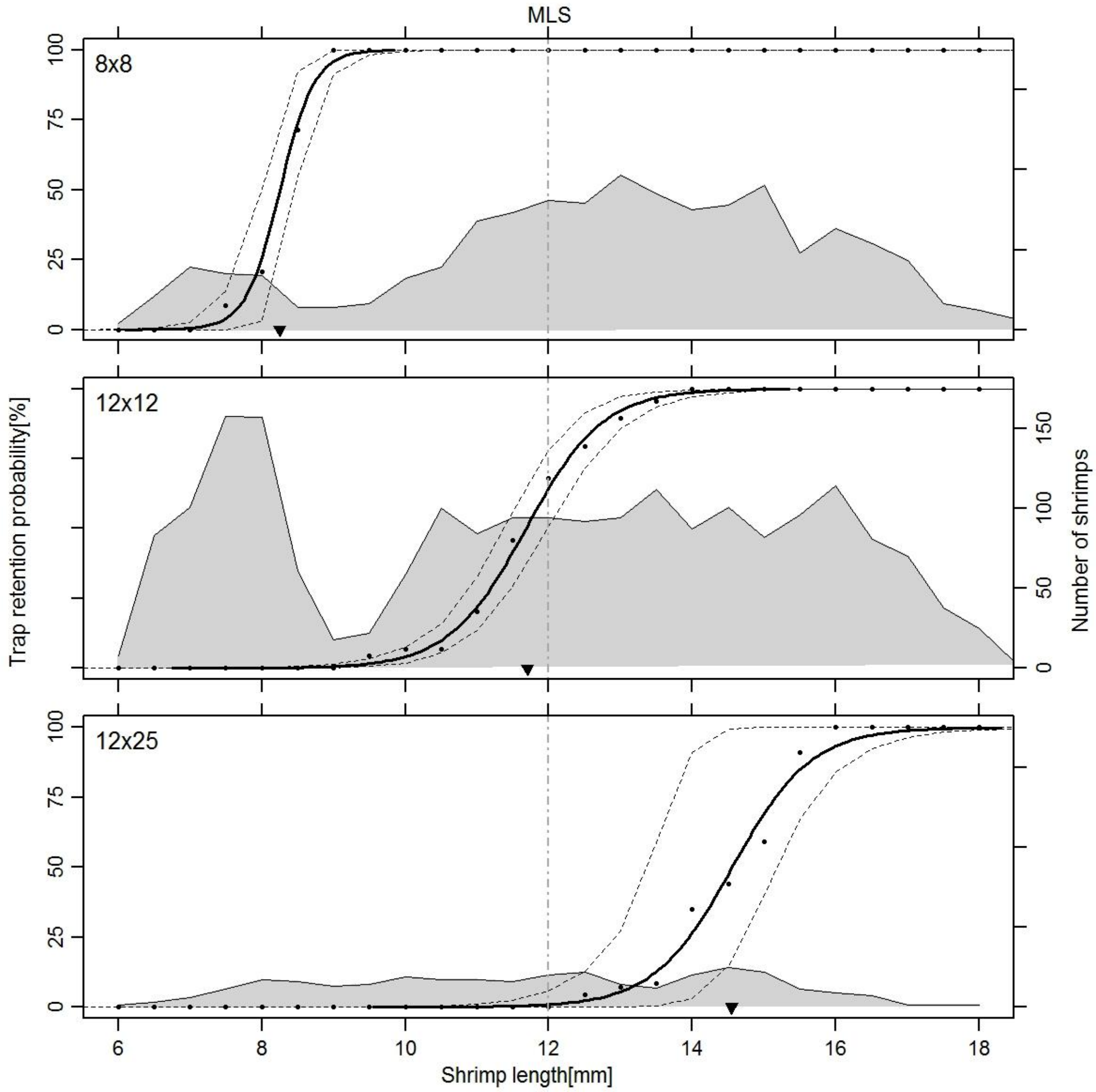

Figure 4. Mean size selectivity curves modelled for narwal shrimp (*Plesionika narval*) in the three traps tested during the sea trials. The three traps differ in rectangular-mesh size (8x8 mm, 12x12 mm and 12x25 mm). Circles represent the experimental data; thick solid curves and dotted curves indicate the mean and the 95 % confidence limits for the fitted size selection curves, respectively; vertical grey dashed-dotted line represents the Minimum Landing Size (MLS); grey shaded areas represent the whole population of narwal shrimp entering the traps.

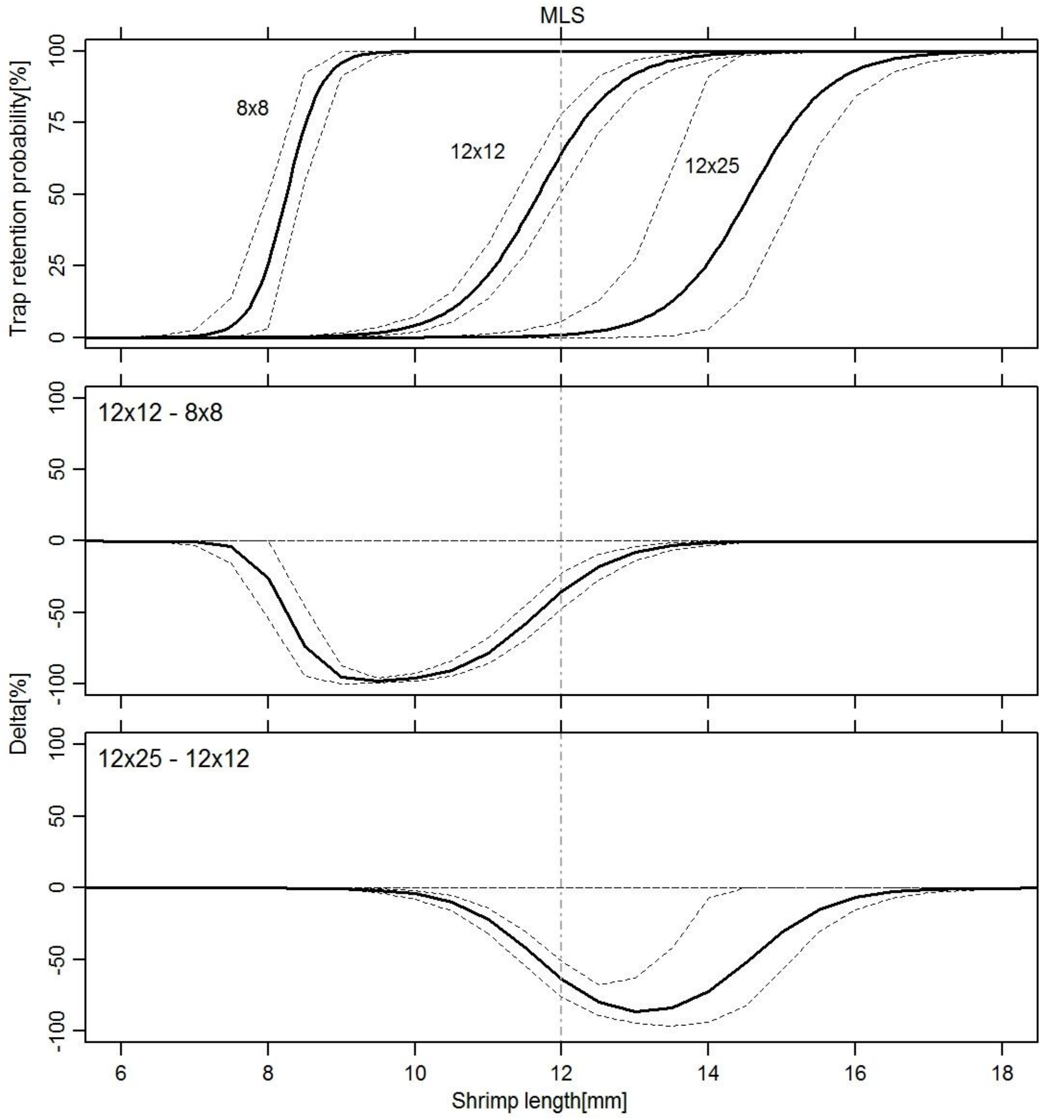

Figure 5. Comparison of the mean size selectivity curves modelled for narwal shrimp (*Plesionika narval*) of the three traps tested (8x8 mm, 12x12 mm and 12x25 mm) and difference in the trap retention probability (Delta) between the 12x12 and 8x8 and between the 12x25 and 12x12 traps.

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Figure 1

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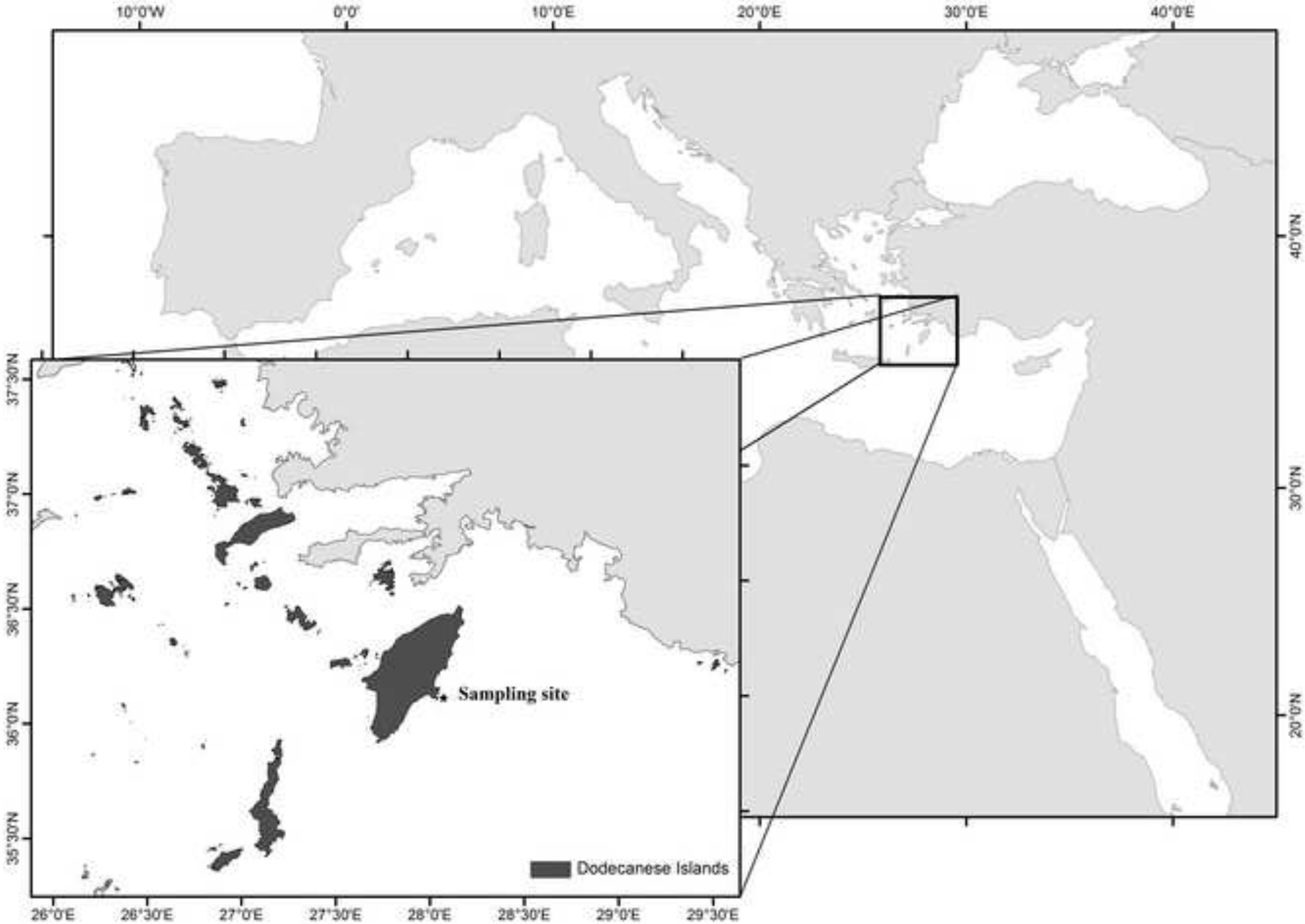

Figure 2

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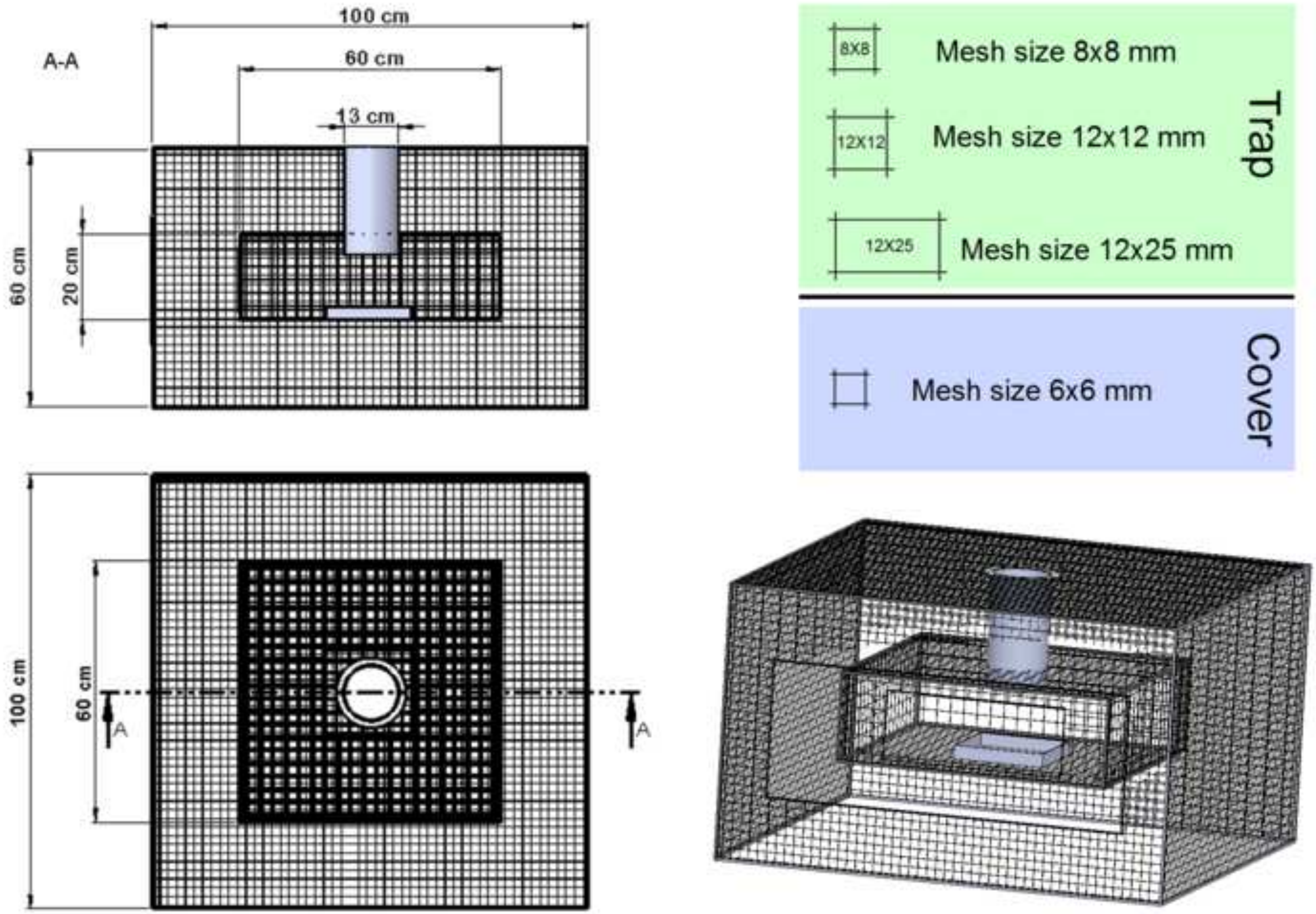

Figure 3
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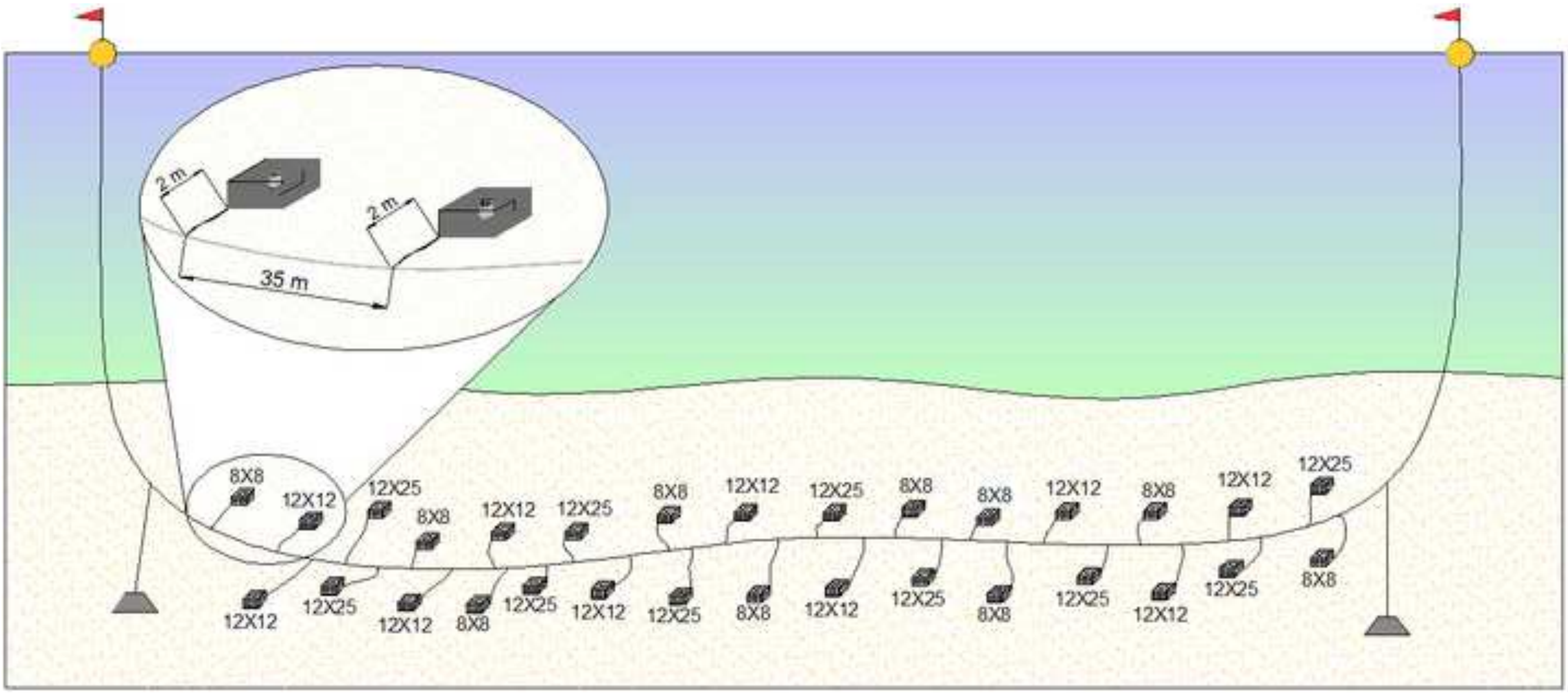

Figure 4
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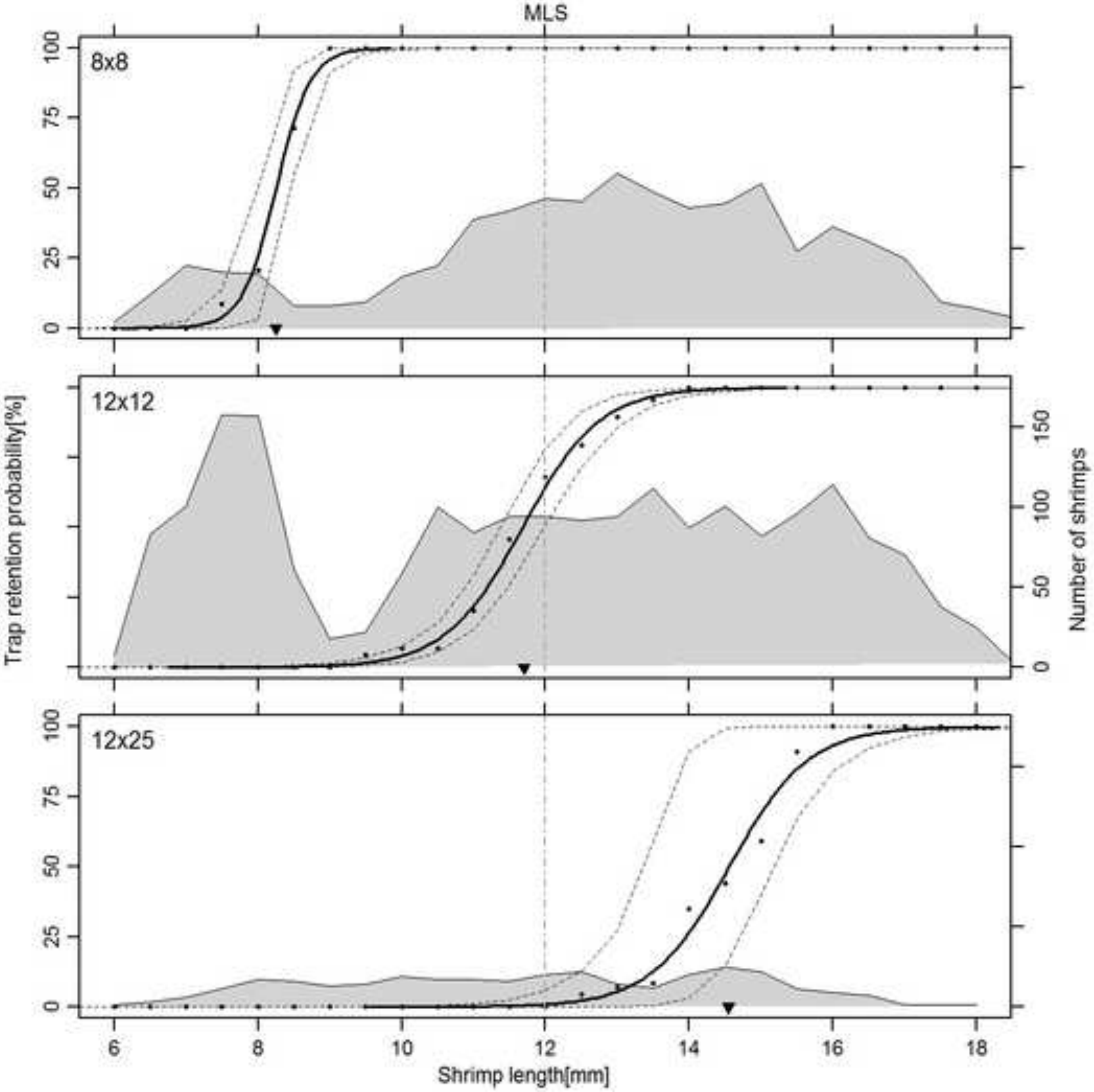

Figure 5
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