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REDUCTION AND MITIGATION OF THE CATCH OF ELASMOBRANCHS, SEA TURTLES, AND ANY OTHER VULNERABLE SPECIES (E.G. MARINE MAMMALS), INCIDENTALLY CAPTURED BY TRAWLERS ALONG TURKISH COAST

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Final Report

For

Reduction and mitigation of the catch of elasmobranchs, sea turtles, and any other vulnerable species (e.g. marine mammals), incidentally captured by trawlers along Turkish coast (GSA 24 – Northern Levant Sea)

Adana, April 2025

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List of Acronyms

ACCOBAMS	Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area
BRD	Bycatch Reduction Device
CPUE	Catch Per Unit Effort
DWRS	Deep-Water Red Shrimp
FAO	Food and Agriculture Organization of the United Nations
GFCM	General Fisheries Commission for the Mediterranean
GSA	Geographical Sub-Area (used in the GFCM area management system)
IUCN	International Union for Conservation of Nature
MLS	Minimum Landing Size
MCRS	Minimum conservation reference size
PA	Polyamide
PP	Polypropylene
TED	Turtle Excluder Device

Report compiled by:

Assoc. Prof. Dr. Çağatayhan Bekir Ersü

Assoc. Prof. Dr. Hacer Yeldan

Dr. Volkan Barış Kiyağı

Suheyla Saygıcak

Murat Çınar

Yaşar İşitmez

Murat Uzun

Şavaş Çapkan

Ali Dölek

Fahri Çağlar

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Abstract

This project aimed to assess the effectiveness of gear-based mitigation strategies to reduce bycatch of vulnerable species, particularly elasmobranchs and sea turtles, in Mediterranean trawl fisheries. The study, conducted in GSA 24 (Northern Levant Sea, Türkiye), combined sea trials, post-capture survival experiments, stakeholder engagement, and onboard observation programs to provide a comprehensive analysis of bycatch mitigation and its socioeconomic implications.

To investigate the potential of excluder grids in mitigating bycatch, extensive sea trials were carried out using commercial trawlers operating in both deep and shallow waters. A total of 40 trawl tows (20 control and 20 grid gear) were conducted in two separate trials. The tested gear configurations included two different excluder devices: a flexible grid with 50 mm bar spacing and a rigid grid with 95 mm spacing, both mounted within the trawl extension. During these trials, 517 individuals of vulnerable species were recorded, with a total biomass of 2,581.4 kg and an overall Catch-Per-Unit-Effort (CPUE) of 0,34 individuals per hour. These results confirm the regular presence of vulnerable species in trawl catches and emphasize the critical role of gear modifications in mitigating their impact. Statistical comparisons conducted using the Wilcoxon Signed-Rank Test indicated a significant reduction in bycatch rates for several elasmobranch species, including *Etmopterus spinax* and *Galeus melastomus*, in the test hauls compared to the control hauls. These findings underscore the species-specific effectiveness of the excluder devices, with the most notable reductions observed in small-bodied deep-sea sharks.

The test gear demonstrated a clear reduction in the bycatch of elasmobranchs and sea turtles compared to traditional codends. Two Chelonia mydas individuals were caught in the control gear during mitigation trials. However, the catch performance of target species (*Aristaeomorpha foliacea* and *Aristeus antennatus*) was lower in the grid gear, resulting in an estimated profit loss of €2.307,50 over 20 hauls. When extrapolated to a typical 100-day fishing season, this corresponds to a projected loss of approximately €23.075,00. Despite the losses in target species revenue and the resulting challenge this presents for the acceptance of the mitigation tool by fishermen, the results demonstrate that grid-based mitigation tools show promising potential as a trade-off between conservation and fishery sustainability.

In parallel, onboard monitoring activities and structured interviews were conducted to assess bycatch occurrence and stakeholder perspectives on mitigation measures. A total of 75 onboard commercial trawl observations and 120 structured interviews were completed across Mersin and Adana. Data collection followed GFCM protocols, covering biological data, discard practices, marine mammal interactions, and gear characteristics. No dolphin, whale, seabird, or turtle bycatch was recorded during general onboard monitoring. However, 65% of fishers perceived an increase in marine mammal interactions over the past five years, and 48% reported gear damage caused by non-mammal species, including rays, sea turtles, sharks, and puffer fish. Notably, 100% of respondents supported the idea of a dolphin observer program, reflecting strong community interest in sustainable practices. Workshops and stakeholder meetings helped reinforce awareness and acceptability of bycatch reduction technologies within the fleet.

Finally, the project evaluated short- and long-term post-capture survival rates of vulnerable species through experimental trials. Short-term survival assessments using a 1-ton tank system revealed that survival rates exceeded 99% for species such as *Gymnura altavela*, *Rhinobatos rhinobatos*, and *Rhinoptera marginata*. In contrast, long-term survival monitoring in submerged sea cages over 24 hours revealed delayed mortality, particularly in *Rhinoptera marginata*, suggesting that short-term vitality assessments may overestimate true survival potential. The findings support the feasibility of releasing live elasmobranchs post-capture, provided handling practices are optimized. Cage design also played a critical role, with knotted netting reducing entanglement in ray species.

Overall, the project provided strong field-based evidence on the effectiveness and limitations of bycatch reduction devices (BRDs) in reducing bycatch in Mediterranean trawl fisheries. The high short-term survival rates observed in elasmobranch species caught in shallow waters indicate the potential to enhance survival through best practices and gear modifications. However, experiments conducted in deep waters showed that vulnerable species have poor survival following capture, emphasizing the importance of physical exclusion using BRDs in deep-water fisheries. Although BRDs may result in some revenue loss, they offer a viable solution for balancing ecological conservation with commercial sustainability. When long-term ecological benefits—such as reduced mortality of threatened species and healthier ecosystems—are taken into account, the economic losses, although initially not well accepted by fishers, can still be considered justifiable. The results strongly support further refinement of BRDs and the integration of post-release survival data into fisheries management policies.

Introduction

The Mediterranean Sea is a globally recognized hotspot of marine biodiversity, particularly for long-living and slow-growing species such as elasmobranchs (Cavanagh and Gibson, 2007). Despite its ecological significance, the region has experienced a marked decline in shark and ray populations over the past century (Ferretti et al., 2008; Fernandes et al., 2017; Bradai et al., 2018; Dulvy et al., 2021). Overexploitation and incidental capture of non-target species (bycatch), primarily in non-selective fishing gears, are the leading causes of mortality (Bonanomi et al., 2017).

More than 50% of the 86 elasmobranch species recorded in the Mediterranean are listed as threatened in the IUCN Red List, with several species showing increasing risks of local extinction (Leonetti et al., 2020; Serena et al., 2020; Walls and Dulvy, 2021). Their life-history traits — including slow growth, late maturity, low fecundity, and large size at birth — render them particularly vulnerable to fishing pressure (Frisk et al., 2001; Jennings et al., 1998; Hutchings et al., 2012). Furthermore, the absence of mandatory catch reporting, particularly for discards and illegal landings, has resulted in significant data deficiencies (Colloca et al., 2017).

Elasmobranchs are frequently caught as bycatch in fisheries targeting high-value species such as tuna and swordfish (ICCAT, 2019), yet they often lack targeted management or technical mitigation measures. While the EU Landing Obligation (Regulation EU No. 1380/2013) requires all species under catch limits to be landed, most Mediterranean elasmobranchs are not subject to Total Allowable Catches (TACs) and remain unregulated (STECF, 2013, 2019). Consequently, these species are often captured in multi-species bottom trawl fisheries, which exert continuous and intense pressure on demersal communities (Colloca et al., 2017).

One fishery of concern targets deep-water red shrimp in the Levantine Basin of the Mediterranean Sea, hereafter referred to as the Deep-Water Red Shrimp (DWRS) fishery, operates between depths of 250 and 600 meters in the northeastern Mediterranean, particularly off the Turkish coast (Fiorentino et al., 2024), targeting two main species: giant red shrimp (*Aristaeomorpha foliacea*) and blue and red shrimp (*Aristeus antennatus*), both with a Minimum

Landing Size (MLS) of 25 mm carapace length (Official Gazette, 2024). This fishery typically uses commercial bottom trawl gear with 44 mm diamond mesh codends.

Although the fishery does not target elasmobranchs directly, incidental captures of vulnerable shark species are frequent (Carbonell et al., 2003; Brčić et al., 2015). Notably, the velvet belly shark (*Etmopterus spinax*)—listed as Vulnerable on the IUCN Red List—and the blackmouth catshark (*Galeus melastomus*)—listed as Least Concern—are commonly caught and discarded (Bayhan et al., 2018; Finucci et al., 2021). However, the lack of obligatory bycatch reporting in the DWRS fishery means the actual scale of these interactions remains unknown, highlighting the urgent need for focused investigation.

Efforts to improve gear selectivity in Mediterranean bottom trawl fisheries have focused primarily on modifications to codend mesh size and geometry (Sala and Lucchetti, 2011; Lucchetti et al., 2021; Petetta et al., 2020), as well as changes to the extension piece (Brčić et al., 2016, 2018; Bonanomi et al., 2020; Petetta et al., 2022), mainly to reduce the capture of undersized finfish. However, few studies have evaluated the selectivity of such gear for elasmobranchs. Moreover, proposals for larger mesh sizes (e.g., >50 mm) often encounter resistance from fishers due to concerns over loss of marketable catch (Ragonese et al., 2013; Bonanomi et al., 2020).

BRDs, such as Turtle Excluder Devices (TEDs), represent a promising technical solution. These consist of rigid or flexible grids installed ahead of the codend, allowing large organisms to escape (Epperly, 2003). TEDs have been successfully applied in the Mediterranean to reduce sea turtle bycatch (Atabey and Taskavak, 2001; Sala and Lucchetti, 2011; Lucchetti et al., 2016, 2019; Vasapollo et al., 2019), and have shown potential in excluding elasmobranchs as well (Brčić et al., 2015; Vasapollo et al., 2019), while also preserving commercial catch quality by reducing debris and facilitating sorting (Lucchetti et al., 2019).

In many trawl fisheries targeting shrimp, including those in the North Atlantic and Barents Sea, excluder grids—especially the Nordmøre grid—have been adopted to reduce fish bycatch (Isakson et al., 1992; Larsen et al., 2018, 2022). These grids work by directing shrimp and small fish through a grid into the codend while guiding larger bycatch species to an escape outlet. Grid bar spacing typically ranges from 19 to 22 mm in northern shrimp fisheries, but wider spacings (50–90 mm) are used to exclude larger species such as sharks and sea turtles in other contexts (Brčić et al., 2015).

While codend modifications have been tested in the DWRS fishery (Ragonese et al., 2002; Gorelli et al., 2017), excluder grids have not yet been systematically evaluated for reducing elasmobranch bycatch in Strait of Sicily and North-western Mediterranean. Accordingly, their effectiveness in the DWRS context warrants further investigation.

The present study was conducted in collaboration with the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS), with the aim of evaluating the effectiveness of a flexible excluder grid in reducing the bycatch of shark species in two distinct bottom trawl fisheries in the northeastern Mediterranean Sea: the shallow-water finfish fishery, and the DWRS fishery.

As part of the project, and in coordination with four additional FAO-GFCM-funded projects addressing similar topics, ACCOBAMS also organized the 1st Workshop on Commercial Fisheries Interaction with Vulnerable Species, held online on January 28, 2025. This workshop facilitated broader regional coordination and provided a platform for presenting early findings and sharing mitigation strategies among project partners.

The primary focus is on assessing the performance of a 50 mm bar spacing excluder grid mounted within the trawl extension section. Specifically, the study seeks to address the following research questions: Can a flexible excluder grid with 50 mm bar spacing effectively reduce the bycatch of shark species in both shallow and deep-water trawl fisheries? Can this mitigation measure be implemented without compromising the catch efficiency of key commercial target species in each fishery? The outcomes of this study are intended to support evidence-based recommendations for the adoption of practical and effective bycatch mitigation strategies in Mediterranean bottom trawl fisheries.

The activities carried out within the project were overseen and supported by a Steering Committee composed of representatives from the project partners and the FAO-General

Fisheries Commission for the Mediterranean (FAO-GFCM). The Committee was established with the support of ACCOBAMS and met three times a year to ensure the effective implementation of the project and the achievement of its objectives.

This report is organized into three main chapters, each corresponding to a core project task: Task 1, Mitigation trials; Task 2, Monitoring and stakeholder engagement; and Task 3, Post-capture survival experiments. Together, they provide a comprehensive assessment of the technical, ecological, and socioeconomic dimensions of bycatch mitigation in Eastern Mediterranean (GSA24) trawl fisheries.

Study Area

This study was conducted in Geographical Sub-Area 24 (GSA 24), located in the Northern Levant Sea of the eastern Mediterranean, encompassing the Mersin Bay and İskenderun Bay along the southern coast of Türkiye (Figure 1). These bays represent key fishing grounds for both shallow-water demersal finfish and deep-water red shrimp fisheries. The area is characterized by a diverse range of bathymetric and ecological conditions, supporting high biodiversity, including several vulnerable species such as elasmobranchs. GSA 24 falls under the management framework of the General Fisheries Commission for the Mediterranean (GFCM) and is a critical region for ongoing research and implementation of bycatch mitigation measures in bottom trawl fisheries.

Figure 1. Mediterranean Geographical Sub Areas (GSA) as established by the General Fisheries Commission for the Mediterranean (GFCM) and study area GSA24 (showed with red arrow)

The mitigation project within the context of bottom trawl fishery is comprised of three key tasks, each serving a distinct purpose. These encompass:

Mitigation Measures

This phase involves the formulation and implementation of strategic measures aimed at minimizing the unintended catch of vulnerable species during bottom trawl fishing operations.

Monitoring Activities

Through rigorous monitoring and data collection, this work package aims to gather valuable insights into the occurrences of vulnerable species bycatch. It will entail identifying specific geographical areas, target species, and months when such instances are most prevalent within the study area.

Post-release Survival Trials

This phase will focus on conducting comprehensive post-release survival trials. These trials are designed to investigate the post-release survival of discarded cartilaginous fish caught in bottom trawls. The results of these trials will guide the conservation of these species.

The initiation of the study will be marked by the commencement of the second work package. The primary objectives at this stage include:

Facilitating Face-to-Face Engagement: Establishing direct communication channels with bottom trawl fishermen and fishing community to apprise them of the project's scope, objectives, and strategies.

Area, Species, and Temporal Analysis: Conducting thorough analyses to pinpoint the geographical zones, target species, and specific months where the incidence of vulnerable species bycatch is most pronounced.

Introduction of Mitigation Tools: Introducing the range of mitigation tools that will undergo testing during the project. This step will facilitate familiarity with these tools among the fishing community.

Collaborative Tool Development: Actively soliciting input and opinions from fishermen to foster a collaborative approach to the development and refinement of effective mitigation tools. This engagement will ensure that the proposed measures align with practical fishing practices.

Through the systematic execution of these work packages, the project aims not only to reduce unintended impacts on vulnerable species, but also to increase the sustainability of bottom trawl fishing practices.

Chapter 1: Mitigation Measures (Task 1)

This work package aimed to evaluate the effectiveness of mitigation measures—specifically gear modifications—in reducing the incidental bycatch of sea turtles, sharks, and rays in bottom trawl fisheries. The study involved testing and refining Bycatch Reduction Devices (BRDs) to minimize unintentional capture of vulnerable species while maintaining catch efficiency for commercial targets.

Material and Method

Experimental Design

Three surveys are planned in total, including one pre-test phase and four two experimental trials. Trials will be distributed in commercial fishing periods to account for seasonal variability (Table 1). Experiments will be stratified by gear type and fishing target (fish vs shrimp), with mitigation configurations tested under standard commercial operations.

Table 1. Experimental design of the mitigation trials

Trial Type	Areas	Period	No. of surveys	No. of hauls	No. of days
Pre-test	Mersin/İskenderun Bay (GSA24)	Spring 2024	1	5	3
Grid A	Mersin/İskenderun Bay (GSA24)	Spring 2024	1	10 (test) + 10 (control)	10
Grid B			1	10 (test) + 10 (control)	10

Stakeholder Engagement and Mitigation Selection

Stakeholder consultations were held with local fishers, researchers, and marine conservation experts between January 2024 at the Karataş (Adana) fishing ports. These meetings aimed to ensure that the selected mitigation strategies were practical, acceptable, and adapted to the operational realities of the local fleet. Additionally, a follow-up round of consultations was conducted in December 2024 at the fishing ports of Erdemli and Taşucu (Mersin) to present and discuss the results of the project with stakeholders, fostering transparency and reinforcing collaborative engagement in future management decisions.

Gear Configuration and Design

To facilitate the experimental trials, two custom-fabricated polyamide (PA) grids were integrated into a specially designed trawl extension section. This section was inserted between the codend and the standard extension piece of a conventional demersal trawl (Figure 2). The aim was to evaluate the selective performance of two Bycatch Reduction Device (BRD) configurations under commercial fishing conditions.

The grids were elliptical in shape, with overall dimensions of 1414 mm in height and widths of 960 mm and 900 mm, respectively. Each grid was constructed using vertical bars with a uniform thickness of 20 mm, mounted within a robust PA frame. The first grid design (Grid A) featured closely spaced bars at 40 mm intervals, while the second design (Grid B) utilized wider 95 mm spacing between bars (Figure 3). These two spacing configurations were selected to assess the trade-off between size selectivity and escapement efficiency for large-bodied bycatch species, such as elasmobranchs, without compromising the retention of commercial target species.

Both grids were installed in the extension section of the trawl, which included a guiding panel rigged into the net to direct the entire catch toward an escape vent positioned above the grid. (Figure 2). This configuration ensured that individuals too large to pass through the bars could exit the gear through the escape opening, thereby reducing incidental capture and associated mortality.

These structural adaptations are designed to enhance gear selectivity, especially for vulnerable species, and to support the development of practical technical solutions for bycatch mitigation in eastern Mediterranean bottom trawl fisheries.

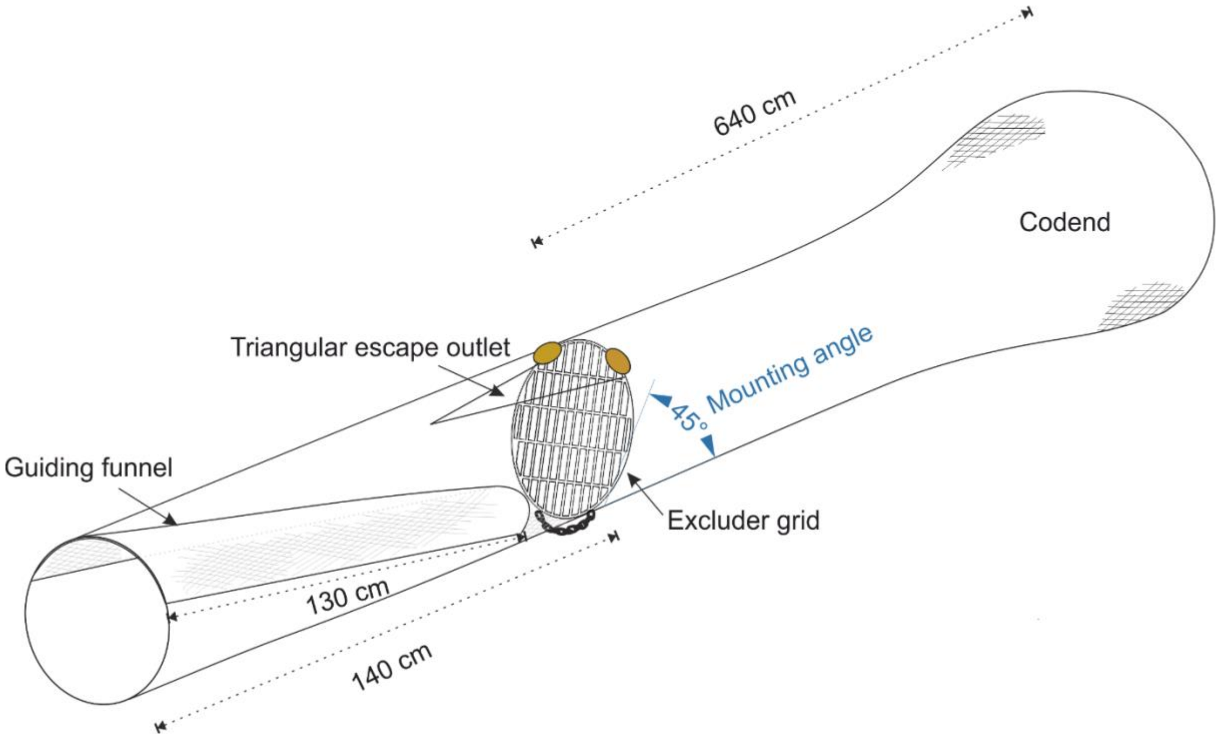

Figure 2. Illustration of the rigged gird (Brewer etal., 1998).

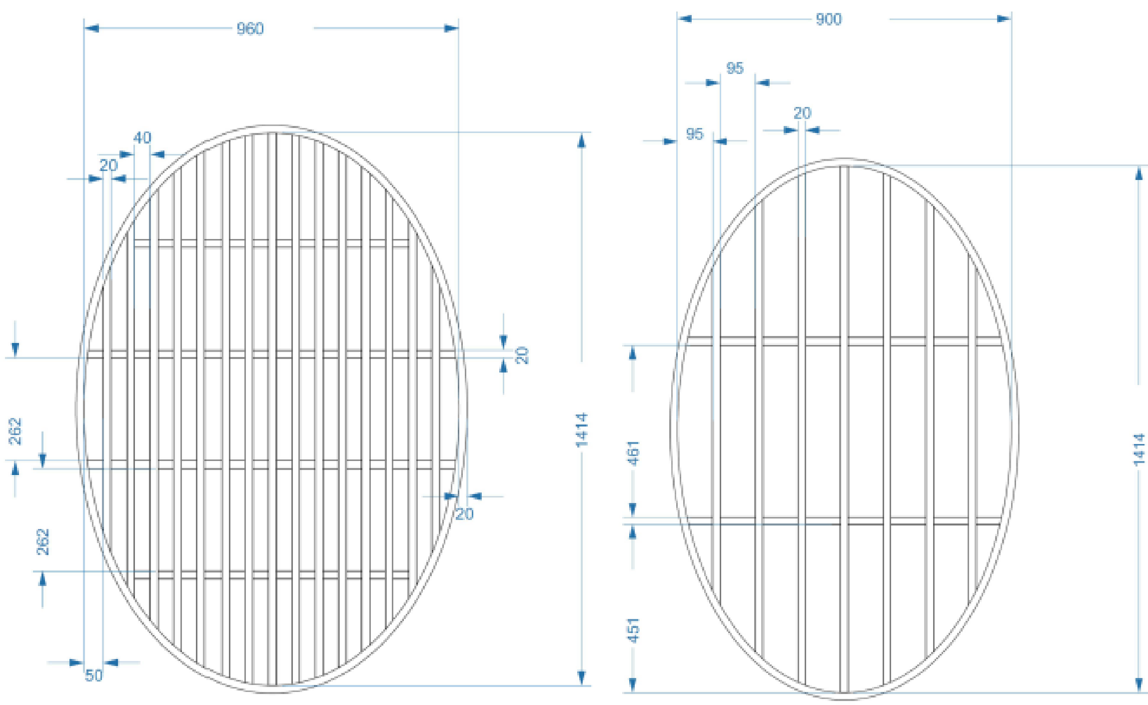

Figure 3. Technical drawings of the grids. Left drawing: 40mm Right drawing: 95mm bar distance

Data Collection and Analysis

During each haul (both test and control), data will be collected following the GFCM methodology outlined in "Monitoring the Incidental Catch of Vulnerable Species in Mediterranean and Black Sea Fisheries: Methodology for Data Collection". The following data will be recorded:

- Total catch weight and species composition
- Number and weight of elasmobranchs, sea turtles, and other vulnerable species
- Biological parameters (e.g., total length, individual weight, and sex)

Catch comparison data will be statistically analyzed to assess the performance of each BRD configuration. Differences in catch efficiency, discard composition, and species-specific bycatch mitigation will be evaluated using appropriate statistical methods to determine significance and practical applicability of the gear modifications.

Sea Trials and Trawl Gear Description

Sea trials were conducted aboard the commercial trawler *Çınar Bey* (26 m LOA, 390 kW) during two experimental periods in 2024: from 21 to 30 June using a 50 mm bar spacing grid, and from 10 to 15 December using a 95 mm grid. Trials were carried out in the waters off Taşucu, Mersin, located in the North-Eastern Mediterranean (GSA 24), and followed standard commercial fishing practices. The operations targeted two key fisheries: DWRS in offshore areas and demersal finfish species in shallower coastal zones. For the DWRS fishery, two hauls were performed daily, alternating between control and test gear by replacing the extension section of the trawl with or without the excluder grid. The average towing speed ranged from 2.6 to 2.8 knots, with haul durations between 4.8 and 6.0 hours (mean: 5.1 h). In the finfish fishery, the vessel conducted four to five hauls per day under a similar alternating design. These trials aimed to evaluate the performance of two excluder grid configurations in reducing elasmobranch bycatch while maintaining the catch efficiency of commercially targeted shrimp and finfish species (see Figure 4 for trawling area). The long yellow lines indicate trawl tracks from the deep-water red shrimp (DWRS) fishery, conducted offshore at greater depths, while the shorter yellow lines near the coast represent hauls performed in the shallow-water demersal finfish fishery. These trials were conducted to assess the effectiveness of excluder grids in reducing elasmobranch bycatch across two distinct fishing environments.

Figure 4. Study Area Map Showing Trawling Tracks in Mersin and İskenderun Bays (GSA 24, Northeastern Mediterranean) [long yellow lines for DWRD hauls and short and close to coast lines for finfish hauls]

Trawl Configuration

Fishing operations were conducted using a traditional commercial bottom trawl, commonly employed in the northeastern Mediterranean. The trawl featured a fishing circle composed of 1200 meshes and was equipped with a hand-woven codend constructed from multi-monofilament polyethylene (PE) twine (Ø 0.35 mm × 15). The codend had a nominal diamond mesh size of 44 mm, a stretched length of 630 cm, and a circumference of 300 meshes. A protective cover, made from 2.5 mm diameter polypropylene (PP) twine with an 88 mm nominal mesh size and 200 meshes in circumference, was installed to minimize damage to the codend.

The trawl sweeps measured 270 meters in length and were constructed from a composite material including polypropylene, lead, and steel, with an overall diameter of 32 mm. The footrope, measuring 72 meters in length and 28 mm in diameter, was attached directly to the lower wings and bosom. The ground gear, reinforced with additional chains, had an estimated weight of 4 kg per meter. The trawl was towed using rectangular wooden doors reinforced with an iron frame, each with a surface area of 1.85 m^2 and an approximate weight of 125 kg.

Assessment of Grid Effects on Size-Dependent Catch Efficiency

The study used a paired-haul design, with alternate hauls using control (no grid) and test (grid-mounted) configurations. Size-dependent catch comparison (CC) analysis was conducted following Herrmann et al. (2017) and Olsen et al. (2019), to evaluate differential size-selective efficiency between the two gears.

For each species and size class *l*, the catch comparison rate (CC_l) was calculated as:

$$CC_l = \frac{\sum_{j=1}^{h}\left\{\frac{nT_{lj}}{qT1_j}\right\}}{\sum_{j=1}^{h}\left\{\frac{nT_{lj}}{qT1_j}+\frac{nC_{lj}}{qC_j}\right\}}$$

Where:

• nT_{lj}, nC_{lj}: number of individuals of size *l* caught in test and control hauls, respectively

• qT_j, qC_j: subsampling factors accounting for the fraction of measured individuals and normalized tow length

The CC curve was fitted using maximum likelihood estimation (MLE), by minimizing:

$$-\sum_{l}\left\{\sum_{j=1}^{h}\left\{\frac{nT_{lj}}{qT_j}\times ln\big(CC(l,v)\big)+\frac{nC_{lj}}{qC_j}\times ln\big(1.0-CC(l,v)\big)\right\}\right\}$$

where *CC(l, v)* is modeled as a logistic function:

$$CC(l,v) = \frac{exp\big(f(w, v_0, \ldots, v_s)\big)}{1 + exp\big(f(w, v_0, \ldots, v_s)\big)}$$

with *f* defined as a polynomial function of order *s*. Up to 31 alternative models (with parameters v_0–v_4) were considered via multi-model inference (Burnham & Anderson, 2002).

Catch Ratio and Confidence Intervals

The catch ratio (CR) was estimated from the CC curve as:

$$CR(l,v) = \frac{CC(l,v)}{\big(1 - CC(l,v)\big)}$$

A CR of 1.0 indicates equal catch efficiency; CR < 1.0 indicates lower efficiency of the test gear for size class *l*. Double bootstrap procedures (Herrmann et al., 2017) were used to generate 95% confidence intervals, accounting for both haul variability and subsampling uncertainty.

Size-Integrated Indicators

For shrimp species, size-integrated catch ratios were calculated relative to the Minimum Landing Size (MLS):

$$CR_{average-} = 100 \times \frac{\sum_{l<MLS} \sum_{j=1}^{h} \left\{\frac{nT_{lj}}{qT_j}\right\}}{\sum_{l<MLS} \sum_{j=1}^{h} \left\{\frac{nC_{lj}}{qC_j}\right\}}$$

$$CR_{average+} = 100 \times \frac{\sum_{l\geq MLS} \sum_{j=1}^{h} \left\{\frac{nT_{lj}}{qT_j}\right\}}{\sum_{l\geq MLS} \sum_{j=1}^{h} \left\{\frac{nC_{lj}}{qC_j}\right\}}$$

Statistical Comparison of Elasmobranch

To evaluate the effectiveness of the grid gear in reducing elasmobranch bycatch compared to traditional control gear, a statistical analysis was conducted using the Wilcoxon Signed-Rank Test, a non-parametric method suitable for paired sample comparisons. Catch data were collected for each species across a set of control and grid gears during the trawl operations. The Wilcoxon Signed-Rank Test was applied separately for each species where catch data were available in both gear types. Species with zero observations in one gear type were excluded from the test. Statistical significance was set at $p < 0.05$, with results further categorized as follows: *$p < 0.001$, $p < 0.01$, *$p < 0.05$*, and *ns* (not significant).

Software and Statistical Tools

All analyses were performed using the SELNET software (Herrmann et al., 2012; 2017; 2022), which provides integrated tools for modeling size-dependent catch efficiency, performing multi-model inference, and estimating statistical indicators with bootstrap uncertainty estimates. The statistical analysis was performed using Python 3.11 with the scipy.stats.wilcoxon function for statistical computation.

Results

A total of 20 paired trawl hauls were completed during the sea trials, with ten pairs conducted for each configuration: one using the BRD (test gear) and the other using the standard trawl setup without the grid (control gear). Each pair of hauls was carried out consecutively under similar environmental and operational conditions to ensure comparability. This paired design enabled direct evaluation of the excluder grid’s effectiveness in reducing bycatch, particularly of elasmobranch species, while assessing its impact on the retention of commercial target species in both the deep-water red shrimp and demersal finfish fisheries.

Deep Water Red Shrimp Fishery Trials

Aristeus antennatus

The catch comparison analysis for *Aristeus antennatus* revealed a size-dependent effect of the 50 mm excluder grid on catch efficiency (Figure 5). The catch comparison curve (black line) shows that for shrimp below approximately 25 mm carapace length, marked by the dashed purple line indicating the minimum conservation reference size (MCRS), the BRD retained a higher proportion of individuals compared to the control. This is reflected in catch comparison probabilities exceeding 0.5. However, for individuals larger than the MCRS, the curve drops below 0.5, indicating that the control gear retained more of the larger individuals.

The catch distribution (red line) indicates that the majority of *A. antennatus* captured during the trials ranged from 24 to 30 mm in carapace length, with peak catches occurring just above the MCRS. Notably, the 50 mm grid did not substantially reduce the capture of undersized shrimp, and the total catch efficiency of the test gear was 28.8% lower than the control, as indicated in the plot.

The wide confidence interval band (grey shading) highlights variability in catch efficiency across length classes, especially below the MCRS, though the general trend suggests reduced retention of market-sized individuals when the grid was used. This outcome suggests that while the 50 mm grid may have limited effectiveness in excluding undersized shrimp, it may also result in some loss of commercial catch, highlighting the need for further optimization of grid design for this species.

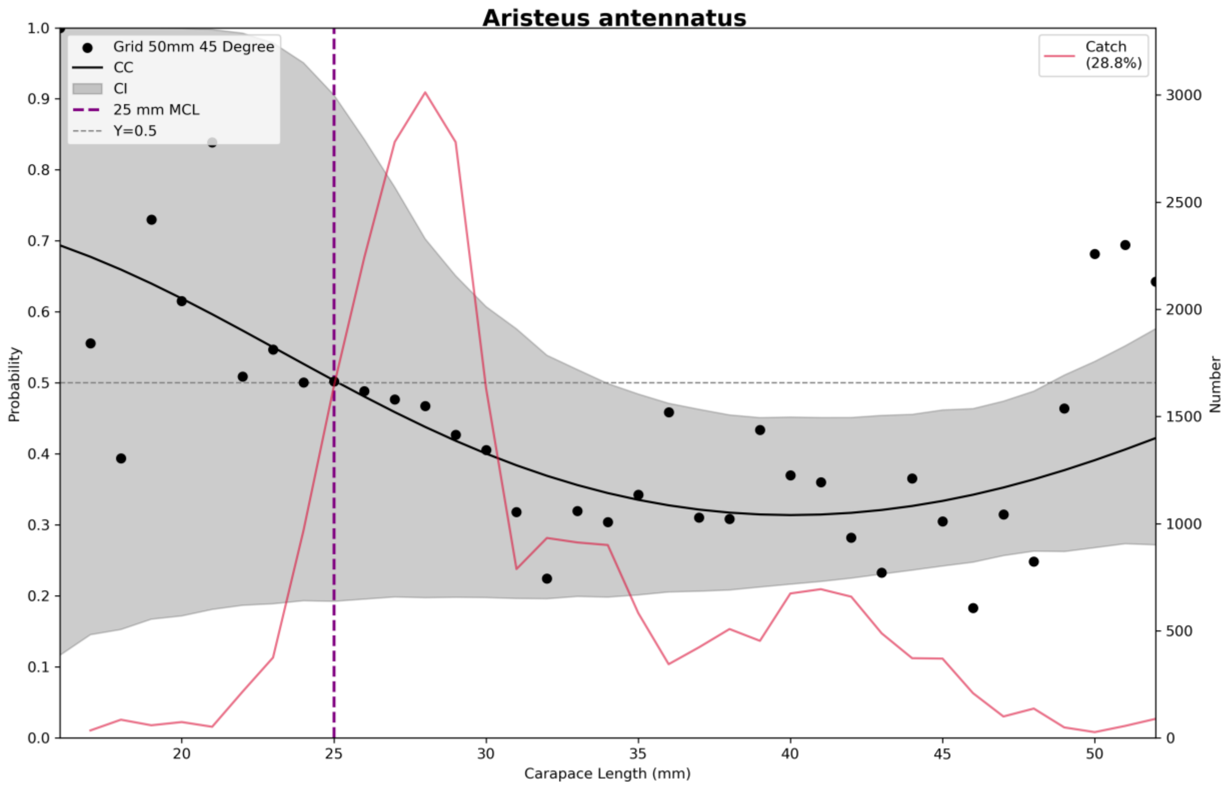

Figure 5. Catch comparison analysis for *Aristeus antennatus* using a 50 mm bar spacing excluder grid mounted at a 45° angle.

Aristaeomorpha foliacea

The catch comparison plot for *Aristaeomorpha foliacea* illustrates the impact of the 50 mm bar spacing excluder grid (mounted at a 45° angle) on the size-dependent retention of individuals (Figure 6). The catch comparison curve (black line) indicates that the grid gear generally retained fewer individuals compared to the control gear, as evidenced by the majority of the curve falling below the 0.5 probability line across most carapace length classes.

In particular, the probability of capture using the grid was consistently lower for individuals larger than the MCRS of 25 mm (indicated by the dashed purple line), suggesting a measurable reduction in the retention of market-sized shrimp. The red curve representing the catch distribution shows that most individuals were concentrated between 22 mm and 40 mm in carapace length, aligning with the range where the catch comparison probability is below 0.5.

The total catch efficiency of the gear fitted with the excluder grid was 15.4% lower than the control gear, highlighting a substantial loss in commercial catch. Despite a wide confidence interval (grey shaded area), especially across the 25–45 mm size range, the trend suggests that the excluder grid may reduce the retention of both undersized and legally sized individuals, thereby affecting overall fishing efficiency.

These results imply that, while the grid may contribute to some bycatch mitigation, further refinement of grid design and configuration is needed to balance conservation objectives with commercial viability in the fishery targeting *A. foliacea*.

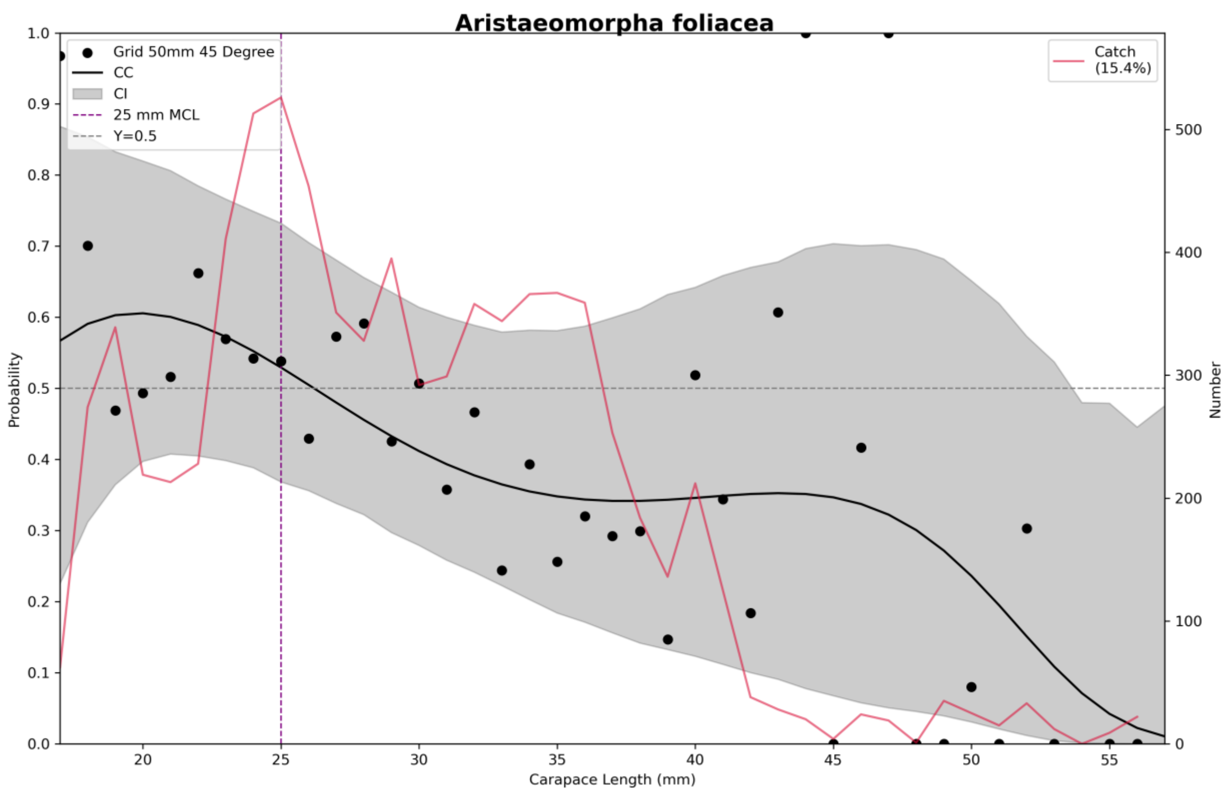

Figure 6. Catch comparison analysis for *Aristaeomorpha folicea* using a 50 mm bar spacing excluder grid mounted at a 45° angle.

Etmopterus spinax

The catch comparison plot for *Etmopterus spinax* illustrates the effect of the 50 mm bar spacing excluder grid (mounted at a 45° angle) on the gear's ability to reduce bycatch of this small demersal shark species (Figure 7). The catch comparison curve (black line) remains consistently below 0.5 across the full range of total lengths (approximately 9–27 cm), indicating that the gear with the excluder grid consistently retained fewer individuals than the control gear.

The red line representing the size frequency distribution shows that *E. spinax* were captured across a relatively broad range of lengths, with the majority of individuals falling between 12 and 22 cm. The estimated total catch using the grid was 45.3% lower than the control configuration, suggesting a substantial reduction in bycatch for this species.

Although the confidence interval (shaded grey area) is relatively wide—reflecting natural variability in haul-specific catches and limited sample size—the catch comparison trend clearly supports the conclusion that the excluder grid is effective at reducing the capture probability of *E. spinax* across all observed length classes.

These results suggest that the 50 mm grid may be a promising mitigation tool for reducing the incidental capture of velvet belly shark in bottom trawl fisheries targeting deep-water shrimp, without requiring major operational changes.

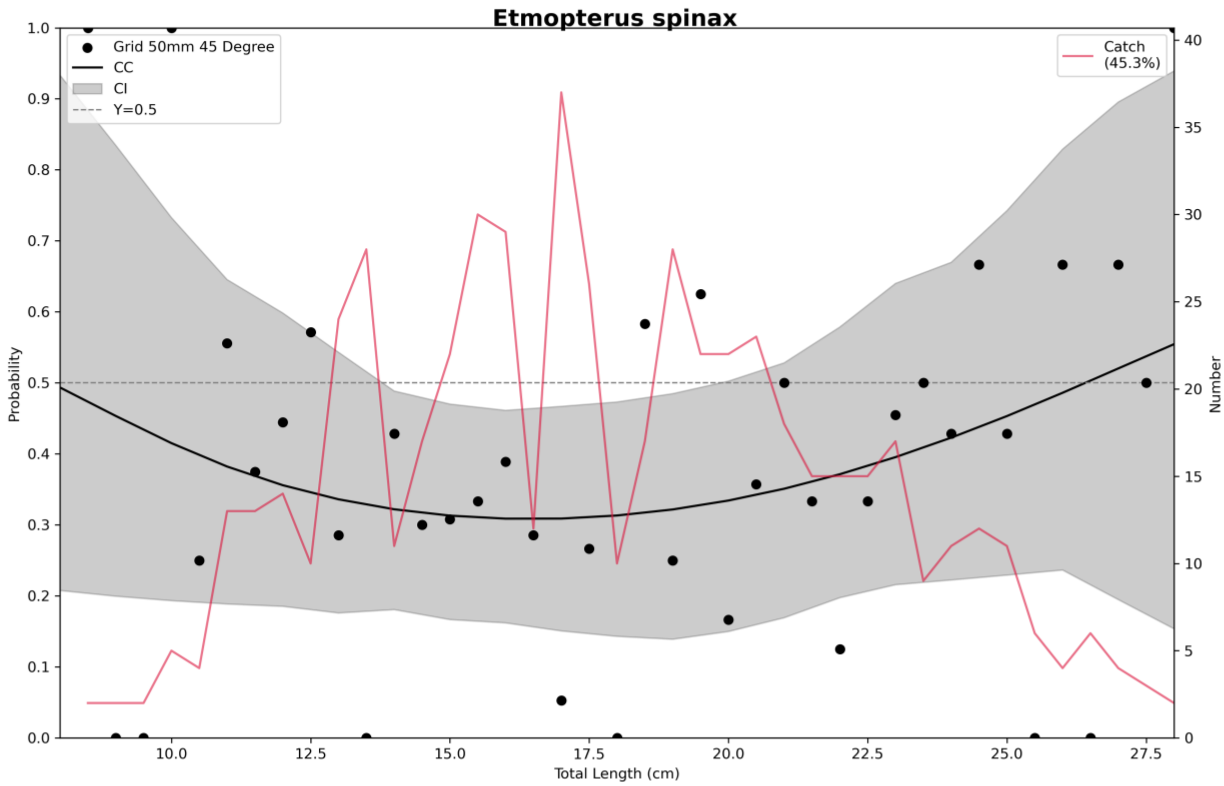

Figure 7. Catch comparison analysis for *Etmopterus spinax* using a 50 mm bar spacing excluder grid mounted at a 45° angle.

Galeus melastomus

The catch comparison plot for *Galeus melastomus* demonstrates a significant reduction in catch probability when using the 50 mm excluder grid compared to the standard gear (Figure 8). The catch comparison curve (black line) lies well below the 0.5 reference line across all observed length classes (15–30 cm), indicating that the test gear with the excluder grid consistently caught fewer individuals than the control.

This effect is most pronounced between 16 and 23 cm, where the majority of individuals were captured, as shown by the peak in the catch distribution (red line). The use of the grid resulted in a 68.8% reduction in total catch for *G. melastomus*, one of the highest observed among all species assessed during the trials.

The shaded confidence interval around the catch comparison curve, although relatively broad, does not cross the 0.5 threshold for most of the length range, reinforcing the conclusion that the excluder grid is effective in reducing the bycatch of this species. These findings highlight the potential of the 50 mm grid to serve as a viable mitigation measure for demersal elasmobranchs such as *G. melastomus* in bottom trawl fisheries targeting deep-water shrimp.

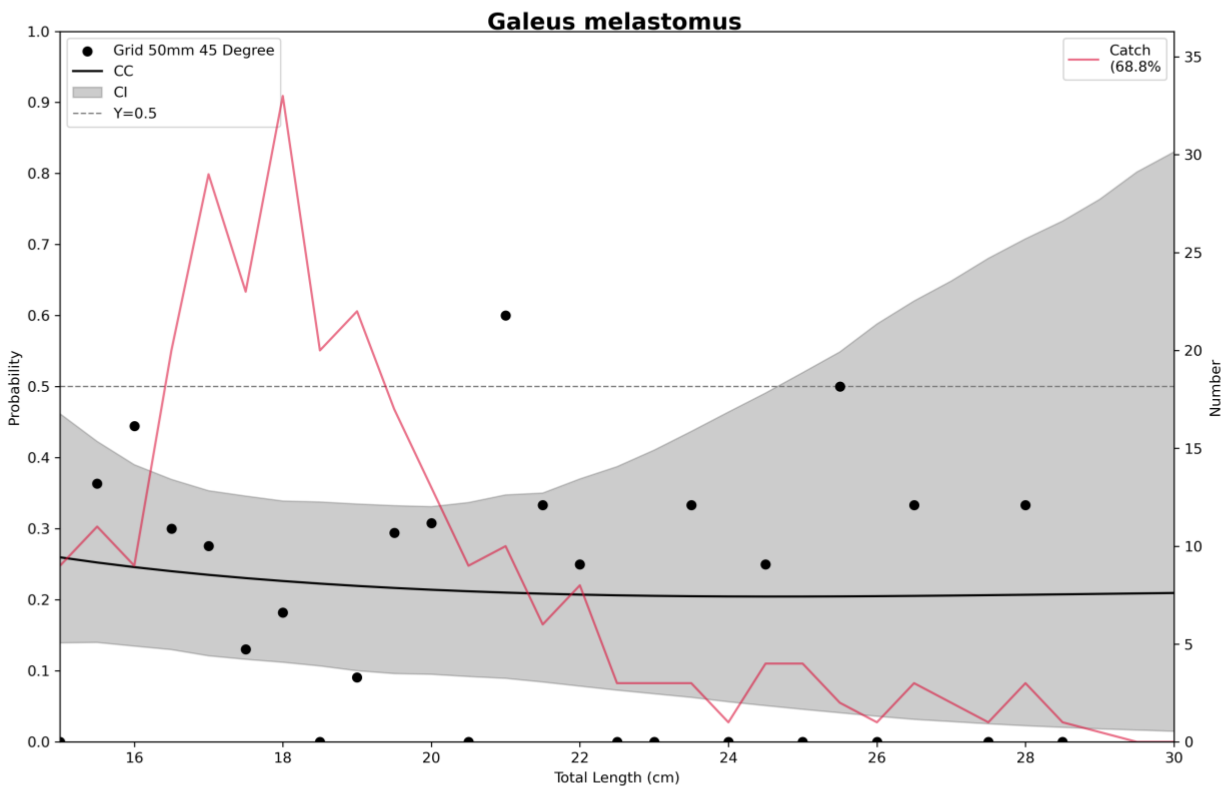

Figure 8. Catch comparison analysis for *Galeus melastomus* using a 50 mm bar spacing excluder grid mounted at a 45° angle.

Finfish Trawl Trials

Saurida lessepsianus

The catch comparison plot for *Saurida lessepsianus* evaluates the effect of the 95 mm bar spacing excluder grid, mounted at a 135° angle, on size-selective catch performance (Figure 9). The fitted catch comparison curve (black line) remains mostly below the 0.5 probability line across smaller length classes (15–23 cm), indicating that the test gear retained fewer small individuals compared to the control. However, beyond approximately 24 cm in total length, the probability of retention by the test gear increases significantly, surpassing 0.5 and approaching 1.0 for the largest individuals.

This size-dependent trend suggests that the grid effectively excluded smaller *S. lessepsianus*, while allowing larger, more commercially desirable individuals to pass through. The red curve representing catch distribution shows that most individuals were concentrated between 18 and 24 cm, where the catch probability of the test gear was still lower than the control.

Overall, the use of the excluder grid resulted in a total catch reduction of 86.1%, indicating strong selectivity pressure against smaller individuals. Despite this high overall reduction, the curve's upward slope in larger size classes suggests that the grid has potential to improve catch quality by preferentially retaining larger individuals while reducing bycatch of undersized fish.

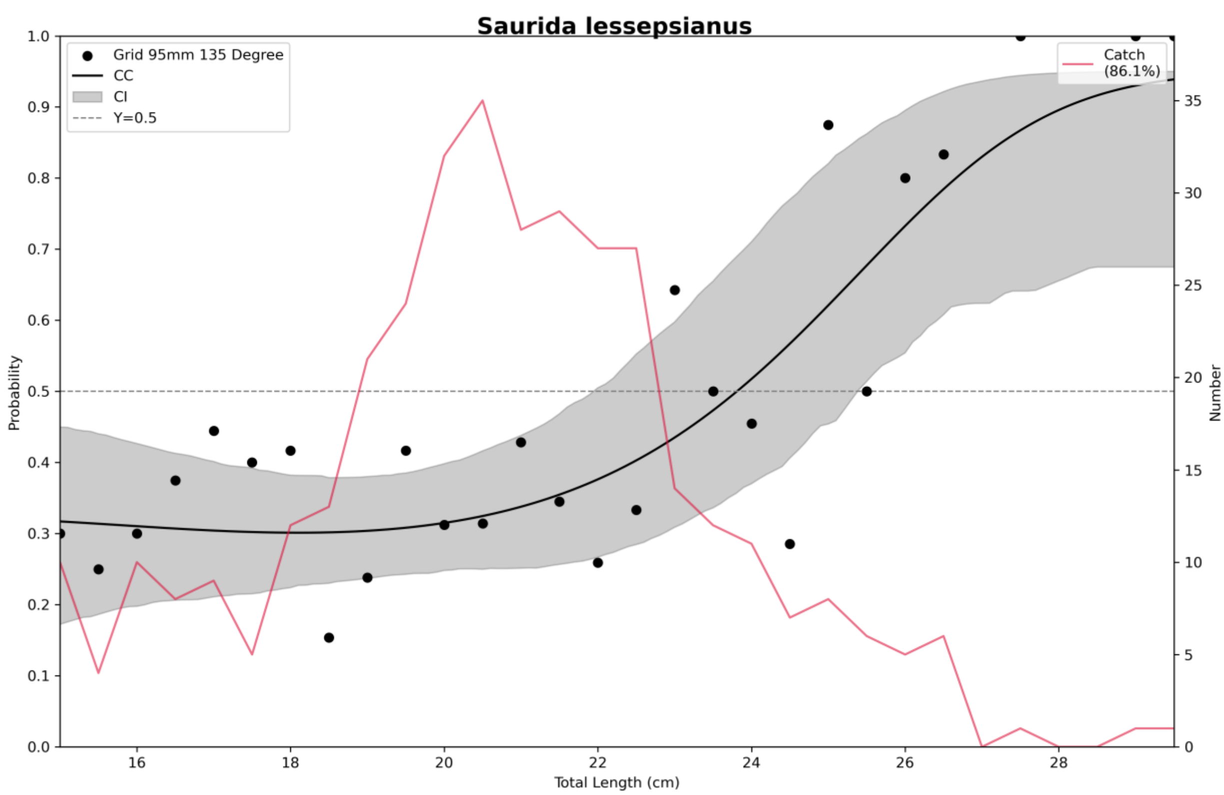

Figure 9. Catch comparison analysis for *Saurida lessepsianus* using a 95 mm bar spacing excluder

grid mounted at a 135° angle.

Upeneus moluccensis

The catch comparison plot for *Upeneus moluccensis* demonstrates the selectivity pattern of the 95 mm excluder grid mounted at a 135° angle (Figure 10). The catch comparison curve (black line) shows a U-shaped pattern, with a lower catch probability for individuals around 10–11 cm in total length and increased probability for both smaller and larger individuals. This indicates that the grid had reduced efficiency in retaining mid-sized individuals, but allowed smaller and larger fish to pass through the grid and enter the codend.

The red line representing the catch distribution indicates that the majority of individuals caught were between 10 and 13 cm, with peak abundance near 11–12 cm. In this size range, the test gear (with the grid) consistently retained fewer individuals than the control, as the curve dips below the 0.5 threshold.

Overall, the excluder grid resulted in a 28.4% reduction in total catch for *U. moluccensis*. The moderately wide confidence interval (grey band) around the curve reflects variability across hauls but supports the general trend of lower retention in the mid-size classes. These results suggest that the grid can partially reduce bycatch of *U. moluccensis* in trawl fisheries, particularly around the most abundant size classes, although further refinement may be needed to enhance overall selectivity.

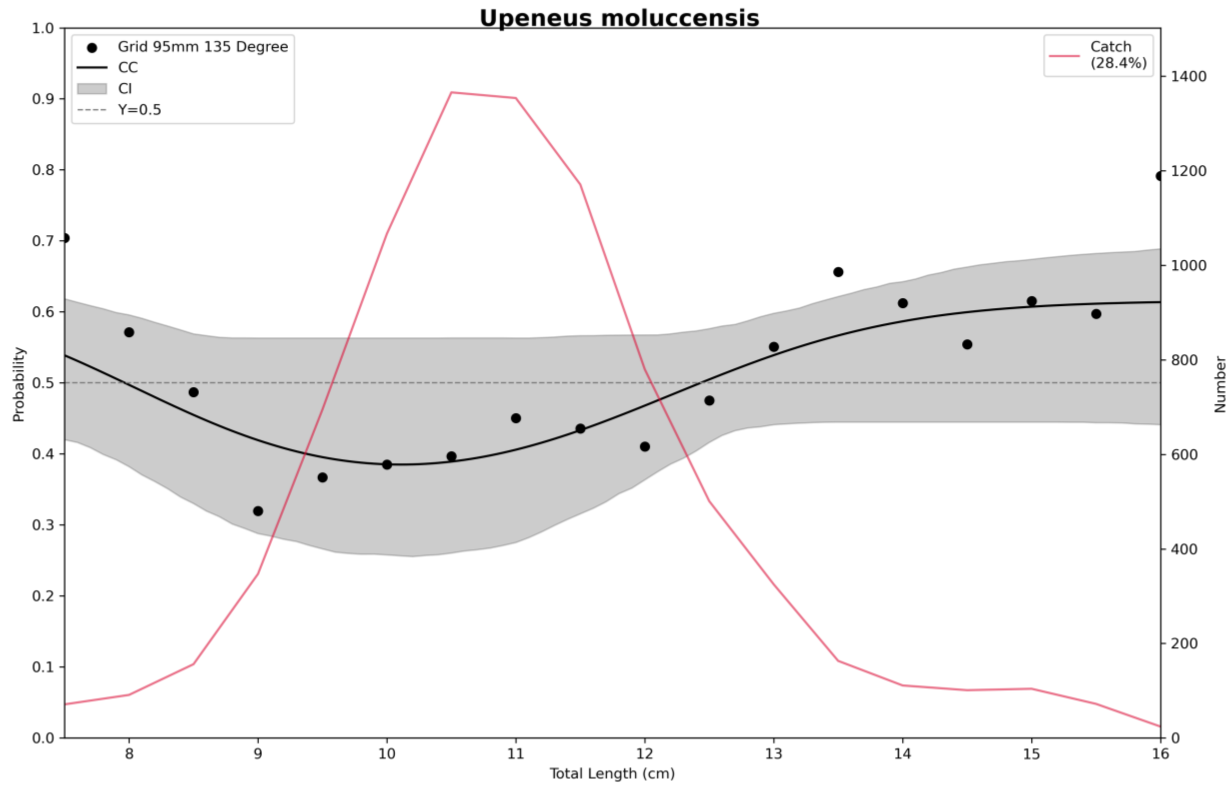

Figure 10. Catch comparison analysis for *Upeneus moluccensis* using a 95 mm bar spacing excluder grid mounted at a 135° angle.

Statistical Comparison of Elasmobranch Bycatch Between Control and Grid Gear

A non-parametric Wilcoxon Signed-Rank Test was performed to assess differences in species-specific bycatch between control and grid gear as part of a mitigation study targeting elasmobranch species in the northeastern Mediterranean.

The analysis was conducted for seven species, with counts distributed between gear types and normalized across sampling stations to allow for paired comparisons. Due to the nature of the Wilcoxon test, species that were absent in one of the gear types (*Dasyatis pastinaca*, *Rhinobatos rhinobatos*) were excluded from statistical testing (Table 2).

Table 2. Species-wise Wilcoxon Signed-Rank Test Results Comparing Bycatch Between Control and Grid Gear in the Northeastern Mediterranean

Species	**Control**	**Grid**	**Wilcoxon Statistic**	**p-value**
Dasyatis pastinaca	4	0		
Gymnura altavela	48	5	0.0	**p<0.01
Raja miraletus	16	3	0.0	**p<0.01
Rhinoptera marginata	282	14	0.0	**p<0.01
Rhinobatos rhinobatos	14	0		
Aetomylaeus bovinus	1	0		
Myliobatis aquila	4	0		

The results revealed statistically significant differences (p = 0.0078) between control and grid gear for the following species: *Gymnura altavela*, *Raja miraletus*, *Rhinoptera marginata*

In each case, the use of the grid gear resulted in a significant reduction in catch compared to the control gear, indicating the potential effectiveness of this mitigation measure in reducing bycatch of these species.

The Wilcoxon Signed-Rank Test results support the hypothesis that grid gear configurations can significantly reduce the bycatch of certain elasmobranch species, particularly *Gymnura altavela*, *Raja miraletus*, and *Rhinoptera marginata*. Additionally, the absence of *Dasyatis pastinaca*, *Rhinobatos rhinobatos, Myliobatis aquila and Aetomylaeus bovinus* in grid gear further emphasizes the potential of this mitigation method. These findings contribute to the growing body of evidence supporting gear modifications as effective tools for improving selectivity and reducing the impacts of bottom trawl fisheries on vulnerable species.

Catch Composition and Profit Analysis Between Control and Grid Gear

During the mitigation trials, comparisons between control and grid trawl gear configurations revealed measurable differences in the retention of the two primary commercial target species: *Aristaeomorpha foliacea* (giant red shrimp) and *Aristeus antennatus* (blue and red shrimp).

The control gear yielded 650 kg of *A. foliacea* and 216 kg of *A. antennatus*, whereas the grid gear resulted in 546 kg of *A. foliacea* and 158 kg of *A. antennatus*. This corresponds to a 16.0% reduction in *A. foliacea* and 26.9% reduction in *A. antennatus* catch when using the grid gear relative to the control.

Assuming a gate sale (ex-vessel) price of 650 TL (€16.25) per kilogram for both species, the estimated revenues were as follows:

- **Control Gear Revenue:**

$$(650\text{ kg of } \textit{A. foliacea} + 216\text{ kg of } \textit{A. antennatus}) \times 650\text{ TL} = 866\text{ kg} \times 650\text{ TL}$$
$$= 562{,}900TL(€14{,}072.50)$$

- **Grid Gear Revenue:**

$$(546\text{ kg of } \textit{A. foliacea} + 158\text{ kg of } \textit{A. antennatus}) \times 650\text{ TL} = 704\text{ kg} \times 650\text{ TL}$$
$$= 457{,}600TL(€11{,}765.00)$$

This results in a total profit loss of 105,300 TL (€2,307.50) with the use of the grid gear.

Profit loss by species:

***Aristaeomorpha foliacea*:**

$$(650 - 546)\text{ kg} \times 650\text{ TL} = 67{,}600TL(€1{,}690.00)$$

***Aristeus antennatus*:**

$$(216 - 158)\text{ kg} \times 650\text{ TL} = 37{,}700TL(€942.50)$$

These estimates, based on ex-vessel prices, provide a realistic representation of economic trade-offs associated with gear modification. While the grid gear has demonstrated potential for reducing the bycatch of vulnerable species, such as elasmobranchs and sea turtles, the observed reduction in marketable catch and associated revenue underscores the importance of further refinement to balance economic viability with ecological sustainability in Mediterranean bottom trawl fisheries.

Calculation: Extrapolated Profit Loss for DWRS Fishing Season

The economic loss estimates presented in this study are based on data collected from 20 paired tows, corresponding to approximately 10 fishing days, under the assumption that each fishing day includes an average of two trawl operations. In the DWRS fishery, vessels typically operate for 25 days per month over a span of 4 months, resulting in an estimated 100 fishing days per season. Therefore, the experimental trials represent roughly 10% of the seasonal fishing effort. The observed profit loss of €2,307.50, attributable to the reduced catch of *Aristaeomorpha foliacea* and *Aristeus antennatus* when using the grid gear, provides a representative snapshot of the economic trade-off associated with this mitigation technology.

Extrapolating this loss over the entire fishing season yields a projected seasonal profit reduction of approximately €23,075.00 if grid gear were adopted across all operations.

One of the key findings of this study is the inherent trade-off between the immediate economic interests of fishers and conservation measures aimed at protecting vulnerable species such as elasmobranchs and sea turtles. Hilborn (2007) highlights that fisheries management often involves balancing conflicting objectives ecological sustainability, economic profitability, and social equity. Implementing bycatch mitigation strategies, such as BRDs, clearly illustrates this trade-off, as they significantly reduce vulnerable species bycatch but concurrently lower immediate commercial catch volumes, thus impacting fishers' revenue.

This estimate reflects the cumulative decrease in the retained biomass of high-value shrimp species, valued at ex-vessel (gate sale) prices. While this represents a tangible economic cost to fishers, it must be weighed against the ecological benefits offered by BRD, particularly the reduction of bycatch involving vulnerable species, such as elasmobranchs and sea turtles. Consequently, further optimization of gear design and selectivity, along with appropriate management incentives or market-based support, may be necessary to facilitate the widespread and sustainable adoption of such mitigation measures within the DWRS trawl fleet.

These short-term economic impacts must be assessed within the broader context of long-term ecological and economic sustainability. According to Rice (2011), successful fisheries management under an ecosystem approach requires aligning conservation objectives with fisheries' socio-economic realities. Van Putten et al. (2016) also emphasize that clearly defined objectives reflecting both ecological and community values can increase acceptance and compliance among fishers, particularly when they are actively involved in the decision-making process.

Furthermore, Gutiérrez et al. (2011) advocate for co-management practices, noting that fisheries managed collaboratively with strong leadership, social capital, and clear incentives tend to achieve superior sustainability outcomes. This approach helps fishers perceive conservation strategies not merely as short-term economic sacrifices but as integral to long-term profitability and resilience of their fisheries.

Hence, integrating economic incentives (such as subsidies, eco-labeling, or compensation schemes) and fostering active stakeholder participation from the outset can help mitigate economic burdens and enhance fisher acceptance of conservation measures. Achieving this balance is crucial to sustainable fisheries management and maintaining healthy marine ecosystems.

Chapter 2: Monitoring, Promotion, and Information Activities (Task 2)

Monitoring and Stakeholder Engagement Activities

The objective of the monitoring methodology was to improve the collection of data on the incidental capture of vulnerable species, such as elasmobranchs, sea turtles, and marine mammals, during bottom trawl fishing operations. It also included monitoring depredation events involving marine mammals, following FAO technical guidance and GFCM protocols.

To achieve this, a total of 75 on-board bottom trawl observations and 120 structured interviews (106 small scale fishery, 12 trawlers, 3 purse seiners) were conducted, with flexibility to adjust according to seasonal patterns, fishing behavior, and local participation. Data collection methods included direct on-board monitoring, structured questionnaires, and telephone surveys, all aligned with GFCM standards. In addition, two stakeholder meetings were organized—in Karataş, Adana and Erdemli and Taşucu, Mersin. The first meeting, held prior to the sea trials, aimed to identify and agree upon suitable mitigation tools. The second meeting, conducted after the trials, served to share project results and gather feedback from the stakeholders to inform future recommendations.

To further promote the exchange of experiences and views on the activities carried out and the results achieved, as well as to foster collaboration by creating a network of experts and entities working on fisheries interactions, ACCOBAMS also organized the 1st Workshop on Commercial Fisheries Interaction with Vulnerable Species, held online on January 28, 2025. The workshop served as a platform for sharing knowledge about monitoring and mitigation of incidental catches, and depredation involving vulnerable marine species. It featured contributions from a broad network of experts and organizations operating across the ACCOBAMS and GFCM areas, and beyond (the final report of the workshop is available in Annex 1).

Activities and results of the project were also disseminated through press releases and social media posts.

Fleet Characteristics and Fishing Activities

To assess the structure and operation of key fishing segments in the region, a questionnaire survey was conducted targeting fishers using different gear types: purse seines, trawls, set nets, and longlines. The survey provided insights into fleet demographics, average crew size, seasonal activity, and primary target species.

Stakeholder meeting

As part of the participatory approach to ensure practicality and acceptance of mitigation strategies, two stakeholder meetings were organized during the course of the project—one prior to the sea trials and one after the completion of field activities.

First Stakeholder Meeting – Karataş, Adana

On January 31, 2024, a stakeholder meeting was held at the fishing port of Karataş, Adana, with the participation of 35 representatives from various fishing métiers, including gillnetters, longliners, bottom trawlers, and purse seiners. In addition to fishers, officials from the Ministry of Agriculture and Forestry, the Coast Guard, and cooperative managers attended the session (Figure 11).

The primary objective of this meeting was to present the scope and objectives of the ongoing project on mitigating the impacts of fishing on vulnerable species and to introduce the mitigation tools under consideration. Detailed presentations were delivered on the design, operation, and intended outcomes of proposed tools, such as selective fishing gears, bycatch reduction devices, spatial and temporal fishing restrictions, and best practice guidelines.

Participants provided valuable feedback based on their operational experience. Fishers highlighted the practicality of the mitigation tools, potential operational constraints, and concerns over economic impacts, such as potential reductions in catch and increased costs. They emphasized the importance of training programs, continued technical support, and the need for stakeholder-oriented monitoring and incentive mechanisms to support the adoption of sustainable practices. The meeting reinforced the project's collaborative approach and was instrumental in refining mitigation tools in line with the needs of the fishing community.

Figure 11 Participants at the stakeholder meeting held in Karataş, Adana

Second Stakeholder Meeting – Erdemli and Taşucu, Mersin (December 2024)

The second stakeholder meeting was held in December 2024 in Erdemli and Taşucu, Mersin, with the participation of 20 fishery stakeholders from gillnet and bottom trawl fleets, as well as representatives from the Ministry of Agriculture and Forestry, the Coast Guard, and cooperative managers (Figure 12). This meeting focused on presenting and discussing the results of the field trials, including data on the reduction of vulnerable species bycatch and associated commercial catch losses.

For the finfish grid trials, fishers expressed concern over significant reductions in the catch of marketable fish and considered the gear unsuitable for this segment of the fishery. However, for the deep-water red shrimp (DWRS) fishery, after reviewing survival results of captured deep-water shark species, stakeholders acknowledged the ecological importance of excluding these vulnerable species. This shift in perception reinforced support for the use of grid devices in deep-water trawling as a conservation tool.

Nonetheless, economic considerations remained a key factor. Fishers emphasized that while they are open to adopting mitigation gear, it must not result in a catch loss exceeding 5%. This consensus reflects a growing recognition among fishers of the need to protect vulnerable species, provided that sustainability measures do not compromise their economic viability.

These two stakeholder consultations were critical in aligning the technical aspects of the project with the operational realities of the fishing sector and ensuring that the proposed mitigation strategies are both effective and acceptable to those directly impacted by their implementation.

Figure 12 Participants at the stakeholder meeting held in Erdemli, Mersin

Results of Questionnaire

Demographic and Operational Characteristics

The average age of respondents differed slightly across fishing gear types. Fishers engaged in purse seine operations reported the highest average age (52.5 years), followed by trawl fishers (47.4 years) and those using set nets or longlines (46.3 years). Overall, the average age across all respondents was 47.5 years, suggesting that the sector is composed largely of experienced operators.

Crew size varied significantly by gear type. Purse seine vessels employed the largest crews, with an average of 16 crew members, reflecting the labor-intensive nature of this method. In contrast, trawl vessels operated with an average of 3.2 crew, and set nets/longline vessels were typically manned by just 1.3 persons, indicating the prevalence of small-scale or artisanal operations. The overall average personnel per vessel across all gear types was 3.8.

Target Species by Gear Type

The main target species varied according to gear configuration: Purse Seine: Focused on pelagic species such as bonito (*Sarda sarda*) and sardine (*Sardinella aurita*). Trawl: Targeted a diverse assemblage of demersal and benthic species, including lizardfish (Saurida spp.), shrimp (both coastal and deep-water species), red mullet (*Mullus barbatus*), and silverfish. In offshore operations, deep-water red shrimp (*Aristaeomorpha foliacea* and *Aristeus antennatus*) was a major target. Set Nets: Used primarily for Panaeid shrimps, common sole (*Solea solea*), and red mullet. Longlines: Targeted high-value demersal species such as groupers (*Epinephelus aeneus*).

Fishing Activity by Season

Seasonal patterns were clearly defined by gear type and regulatory frameworks: Purse Seine and Trawl Fisheries: Both operated legally from September to April, with additional activity allowed under special permits in international waters targeting large pelagics (for purse seiners) and deep-water red shrimp (for trawlers). Set Nets and Longlines: Used year-round, with peak activity occurring in January–February (particularly for sole) and between May and September for grouper and shrimp. This reflects both the biological seasonality of the target species and the flexibility of smaller-scale gears to operate outside of industrial fishing constraints. This survey-based assessment provides a valuable overview of operational patterns and species dependence across gear types. These insights are critical for developing targeted management strategies and evaluating the socioeconomic and ecological implications of bycatch mitigation and effort regulation measures.

Fishing Gear Characteristics, Usage, and Interactions with Marine Fauna

Survey results provided a detailed comparison of the physical characteristics, usage intensity, and interactions with marine mammals across four primary fishing gears: longlines, purse seines, set nets, and trawls.

Gear configuration and usage varied widely among fishing types. Longlines had the greatest operational length (average: 6,000 m) and the highest number of hooks (12,600 hooks), while purse seines averaged 700 m in length, set nets 6,375 m, and trawl nets were considerably shorter (50 m), reflecting their different operational modes. In terms of annual usage, set nets were employed most frequently (164.4 days/year), followed by trawls (150.0 days), purse seines (120.0 days), and longlines (43.3 days).

Interactions with marine mammals were reported with varying frequency. Longline fishers reported the highest rate of interaction—positive or negative—occurring in 93.3 out of 100 operations, while trawlers reported 68.0, set netters 45.0, and purse seiners 30.0. Encounters where marine mammals were sighted without contact occurred most frequently in trawl operations (27.5/100 operations), and least in longlining (6.7/100 operations). When considering only negative interactions, such as gear damage or catch loss, longlines again ranked highest with 86.7% of trips affected, followed by trawls (42.0%), set nets (32.8%), and purse seines (20.0%).

Seasonal trends in fishing activity also varied by gear type: Purse seines were predominantly operated between September and April, aligning with the legal pelagic fishing season. Trawl fisheries operated mainly from October through April, with peak effort reported in January, February, and March. Set nets were used year-round but with peak activity during January, February, March, May, June, November, and December. This broader temporal spread underscores the importance of set nets in multi-seasonal and multi-species fisheries.

A detailed breakdown of evidence of depredation (e.g., bite marks, fish heads remaining in gear, bait theft) revealed that longline fisheries were impacted most severely by both dolphins and sea turtles. In these cases, 50% of the damage was attributed to bite marks and 50% to bait removal. In set nets, damage was more variable, with 37.5% of interactions showing bite marks and other signs, 25% indicating scattered catch. Trawl gear also showed signs of dolphin depredation, equally split between bite marks, head-only remains, and dispersed catch (each 33.3%). Purse seines were mainly impacted by dispersed catch (100%), indicative of group foraging or chase behavior.

Finally, analysis of hole sizes in damaged gear indicated that purse seines and trawls experienced larger holes (≥81 cm), while set nets suffered more variable damage: 23.4% large, 38.3% medium (31–80 cm), and 38.3% small (≤30 cm). These patterns suggest gear-specific vulnerabilities to different forms of marine mammal interaction, with longlines facing the highest rates of direct depredation, and purse seines and trawls affected more by behavioral disruptions.

Further analysis of the questionnaire responses revealed the extent of gear damage attributed to marine mammal interactions. According to fishers' self-reported estimates, the average percentage of damaged gear was highest in set nets and trawls, each with an average of 84.0% of operations experiencing some degree of damage. Longline fishers also reported substantial gear damage, with an average of 75.0% of their gear affected. No damage was reported for purse seine operations, consistent with their lower frequency of direct interaction and different operational dynamics. These findings highlight the economic burden and operational challenges posed by depredation, especially in static and demersal gear types more prone to prolonged exposure and contact with marine mammals.

Bycatch Gear Use, Seasonality, and Stakeholder Perspectives

Survey responses revealed key patterns in the use of fishing gears associated with bycatch. On average, trawl nets were used 2.57 times per day over 131.4 days per year, reflecting the high intensity and frequency of this fishing method. In contrast, set nets and longlines were each used once per day, over 150 and 30 days per year, respectively. These data suggest that although trawl nets are more intensively operated per day, set nets exhibit the highest annual usage, making them a critical gear type in the assessment of cumulative bycatch risk.

Stakeholder perspectives on management priorities revealed diverse views: Among trawl fishers 60% identified the development of gear-based deterrent methods (e.g., pingers, exclusion devices) as the most important management need, followed by 20% prioritizing enforcement (lack of control) and another 20% emphasizing control of overfishing. Among set net users 80% identified overfishing and unsustainable practices as their top concern, while 20% prioritized the development of deterrent technologies. No responses were recorded for purse seine operators in this question set.

Regarding the potential implementation of a dolphin observer programme, all respondents expressed a supportive stance. Specifically, 100% of fishers using trawls and set nets, as well as the sole purse seine respondent, indicated that they believed such an initiative would be beneficial ("Positive"). This unanimous support reflects strong community openness to integrating dolphin observation efforts into fisheries operations, particularly in regions where interactions with marine mammals are frequent. The findings suggest that fishers recognize the value of monitoring and potentially mitigating these interactions through structured observation programmes.

Perceived Trends in Marine Mammal Interactions

According to the questionnaire results, the majority of fishers perceived an increase in interactions with marine mammals and other sensitive species over the past five years. Overall, 65% of respondents indicated that such interactions had increased, 23% believed the frequency remained the same, and 12% reported a decrease. Gear-specific trends showed that trawl fishers most frequently reported an increase, while set net fishers were more evenly split between reporting no change and an increase. Responses from purse seine fishers were balanced across the three categories, and longline fishers consistently perceived an increase in interactions.

Other Species Causing Gear or Catch Damage

In addition to marine mammals, fishers reported that other animal groups also caused damage to fishing gear and catch. Nearly 48% of all respondents acknowledged the presence of non-mammal species causing such damage. Among gear types, set net and longline users most frequently reported these issues, while trawl fishers reported them much less frequently, and purse seine fishers did not report any damage from non-mammal species.

Identified Species Groups Responsible for Gear Damage

When asked to identify which species caused damage other than marine mammals, fishers most commonly mentioned rays, sea turtles, sharks, and puffer fish. Rays and sea turtles were particularly common in set net fisheries, while sharks were associated with both set nets and trawls, and puffer fish were linked to longlines and set nets. These findings highlight the diverse range of interactions affecting different gear types, with passive gears such as set nets and longlines being more vulnerable due to longer soak times and stationary operation. The results underline the importance of designing broader mitigation measures that address not only marine mammals but also other sensitive species that contribute to gear loss, damage, and reduced catch quality.

Onboard Observation

Catch-Per-Unit-Effort (CPUE) Analysis for Vulnerable Species

To evaluate the relative catch rates of elasmobranch species in bottom trawl fisheries, catch-per-unit-effort (CPUE) was calculated using two standardized metrics: (i) the number of individuals per hour and (ii) total weight (kg) per hour. The analysis was based on 75 fishing trips observed under commercial conditions, using tow durations calculated from haul start and end times.

The dataset includes observations from a total of 75 fishing trips, conducted during commercial trawl operations. Across these trips, a total of 517 elasmobranch individuals, comprising sharks, rays, and skates, were recorded, with a cumulative biomass of 2,581.40 kg. Each trip is uniquely identified by the ID fishing trip field. For each species, CPUE was calculated as follows:

CPUE by individual count:

$$\text{CPUE}_{\text{ind}} = \frac{\sum N_i}{\sum T_i}$$

Where:

$\sum N_i$ = total number of individuals of species *i* caught across all trips

$\sum T_i$ = total trawling time (in hours) across all trips where species *i* was present

CPUE by weight:

$$\text{CPUE}_{\text{kg}} = \frac{\sum W_i}{\sum T_i}$$

Where:

$\sum W_i$ = total weight (kg) of species *i* caught across all trips

$\sum T_i$ = total trawling time (in hours)

These formulas provide standardized indices of relative abundance and biomass contribution per hour of effort for each species.

The total CPUE for each species was calculated by summing the total number of individuals caught across all trips and dividing by the cumulative tow time for that species.

The results indicate that *Dasyatis pastinaca* exhibited the highest CPUE by individual number (0,407 ind/h), while *Aetomylaeus bovinus* and *Dipturus oxyrinchus* showed the highest CPUE by weight (2,258 kg/h and 1,947 kg/h, respectively), despite low capture frequencies (Table 3). These results underscore the importance of evaluating both count- and biomass-based CPUE to understand species dominance and bycatch significance.

Across the 75 fishing trips monitored, no incidental captures of dolphins, whales, sea birds, or other marine mammals were recorded. This suggests limited interaction between these protected taxa and the observed bottom trawl fisheries. However, two individuals of the endangered sea turtle species *Chelonia mydas* were captured during the mitigation trials using the control net (i.e., without the excluder grid). No sea turtles were captured during trials using grid-modified gear, suggesting that excluder grids may effectively reduce turtle bycatch in this fishery.

These results provide critical insights for improving trawl selectivity and underscore the potential of gear modifications to mitigate bycatch of vulnerable and protected marine species in the northeastern Mediterranean.

Table 3. Overall Catch-Per-Unit-Effort (CPUE) per Species Based on Fishing Trip Records

Species	Catch		Tow Duration (hour)	CPUE (per hour)	
	Count	Weight (kg)		Count	kg
Aetomylaeus bovinus	1	7,00	3,10	0,32	2,26
Dasyatis pastinaca	37	126,23	90,93	0,41	1,39
Dipturus batis	9	29,70	39,47	0,23	0,75
Dipturus oxyrinchus	5	28,10	14,43	0,35	1,95
Etmopterus spinax	10	3,15	30,43	0,33	0,10
Galeorhinus galeus	1	2,40	4,15	0,24	0,58
Galeus melastomus	9	0,86	30,43	0,30	0,03
Glaucostegus cemiculus	1	2,00	3,70	0,27	0,54
Gymnura altavela	8	52,30	22,31	0,36	2,34
Heptranchias perlo	2	24,00	10,10	0,20	2,38
Mustelus mustelus	44	252,83	86,82	0,51	2,91
Myliobatis aquila	2	3,02	8,01	0,25	0,38
Oxynotus centrina	4	16,30	15,85	0,25	1,03
Prionace glauca	6	16,74	6,00	1,00	2,79
Raja sp.	10	55,62	24,69	0,41	2,25
Raja asterias	23	20,10	43,68	0,53	0,46
Raja brachyura	29	89,68	57,20	0,51	1,57
Raja clavata	32	180,54	58,86	0,54	3,07
Raja miraletus	21	21,52	37,44	0,56	0,58
Raja montagui	12	56,80	32,51	0,37	1,75
Raja polystigma	5	8,71	11,95	0,42	0,73
Raja radula	5	20,07	14,38	0,35	1,40
Rhinobatos rhinobatos	6	42,34	15,10	0,40	2,80
Rhinoptera marginata	12	102,45	34,00	0,35	3,01
Rostroraja alba	3	1,80	11,96	0,25	0,15
Scyliorhinus canicula	166	1231,25	94,95	1,75	12,97
Squalus blainville	11	37,40	34,50	0,32	1,08
Tetronarce nobiliana	5	3,91	14,50	0,35	0,27
Torpedo sp.	13	131,00	21,00	0,62	6,24
Torpedo marmorata	25	13,60	51,16	0,49	0,27

Chapter 3: Post-Release Survival Experiments (Task 3)

Experimental Setup

A controlled environment was prepared for post-release survival experiments. This could involve large holding tanks (onboard) and/or cages placed in proximity to the fishing operation area. Ensure proper water circulation and environmental conditions to mimic natural habitats. After capturing process vitality assessment will be done immediately based on the categorical vitality assessment (CVA). Categorical vitality assessments (CVA) aim to produce observations that can be obtained rapidly (within 5–10 s) for individual organism by trained observers during commercial fishing operations. CVA frameworks have been applied to various species and fisheries and all are based on a notion of quantifying vitality (e.g. Hoag, 1975; van Beek et al., 1990; Kaimmer and Trumble, 1998; Laptikhovsky, 2004; Hueter et al., 2006; Benoît et al., 2010). Most of these frameworks are based on ordinal categories (classes) that encompass injury severity, fish activity, or a rough evaluation of reflex impairment (Table 4)

Table 4. Example of the codes used by on-board observers to score the pre-discarding vitality of individual fish (*adapted* from Benoît *et al*., 2010).

Condition	Catagory	Code	Description
Vitality	Excellent	1	Vigorous body movement; no or only minor[1] external injuries
	Good/fair	2	Weak body movement; responds to touching/prodding; minor[a] external injuries
	Poor	3	No body movement, but fish can move operculum; minor[1] or major[2] external injuries
	Moribund	4	No body or opercular movements (no response to touching or prodding)
Injury	None	1	No bleeding or injuries apparent
	Minor	2	Minor bleeding; some damage to mouth parts (e.g. in longline fisheries)
	Major	3	Major bleeding; extensive damage to mouth parts

Captive observation is a common technique, where discarded animals are transferred into

[1] Minor injuries are defined as "minor bleeding or minor tear of mouthparts or operculum (≤ 10% of the diameter) or moderate loss of scales (i.e. bare patch)".
[2] Major injuries are defined as "major bleeding or major tearing of the mouthparts or operculum or everted stomach or bloated swimbladder".

containment facilities (e.g. tanks or underwater cages) after experiencing in situ representative fishing conditions (i.e. capture, handling, and release). However, the experimental subjects are not actually discarded, but are retained in captivity for a period of time to monitor their vitality and survival.

This approach facilitates the monitoring of the experimental subjects, and allows both dead and surviving animals to be sampled and assessed for injuries, physiological status, and vitality. However, it also introduces some potential limitations with respect to the applicability of the survival estimates. Firstly, holding wild animals, unaccustomed to captivity, can induce stress (Snyder, 1975; Portz et al., 2006), and thereby can potentially induce captivity-related mortality in addition to the treatment effect. Also, most examples of this technique will isolate the captive population from their natural predators, so it will not account for any predation on discard survival (e.g. Raby et al., 2013).

Post-Release Survival Experiments

Short-Term Survival Assessment

To evaluate the immediate post-capture survival potential of vulnerable elasmobranch species, short-term holding experiments were conducted using a 1-ton capacity on-board survival tank. The tank measured 147 × 117 × 88 cm, with a total volume of 930 liters (Figure 13), and was continuously supplied with fresh ambient seawater throughout the experiment to maintain optimal oxygenation and temperature conditions.

Figure 13. Short term survival experiment tank images

At the end of each trawl haul, selected individuals were carefully transferred into the survival tank to minimize handling stress. Each individual was held for one hour to assess their short-term vitality following capture. The monitored species included both shallow-water and deep-water taxa:

- Shallow-water species: *Rhinobatos rhinobatos, Gymnura altavela, Rhinoptera marginata, Aetomylaeus bovinus*, and *Dasyatis pastinaca*

- Deep-water species: *Heptranchias perlo, Dalatias licha, Hexanchus griseus*, and *Dipturus oxyrinchus*

During the holding period, each individual was examined and scored based on external injury levels and vitality condition, following established criteria (e.g., responsive movement, gill ventilation, and swimming capability). After the observation period, all individuals assessed as alive were released back into the sea at the capture location to ensure ethical handling and ecological relevance.

Long-Term Survival Assessment

To assess delayed mortality and recovery dynamics, long-term survival experiments were conducted using submerged sea cages deployed at the fishing site. The trials were designed to simulate post-release conditions and evaluate species-specific tolerance to trawl-induced stress. Individuals were observed over a 24-hour period, with evaluations carried out every 3 hours to monitor vitality and behavior.

Initial Cage Design and Modification

The initial experiment utilized a square HDPE frame cage with dimensions of 1.3 × 1.3 m, fitted with a 1.2 × 1.2 × 1.5 m enclosure made from knotless 20 mm diamond polyamide (PA) mesh for the side panels and a 10 mm mesh base layer (Figure 14 Left). However, during preliminary trials, entanglement issues were observed, particularly in ray species whose stingers became lodged in the fine knotless mesh. This resulted in increased stress and potential injury.

To address this issue, the design was modified for subsequent trials. The new configuration employed knotted 150 mm diamond PP mesh (Figure 14 in the middle) for both the side walls and base, maintaining the same overall cage dimensions (1.2 × 1.2 × 1.5 m). The larger mesh size and knotted structure significantly reduced the risk of entanglement, particularly for species with protruding anatomical features such as tails or stingers.

Figure 14. Experimental cages used for long-term survival trials (Left: Cage constructed with knotless polyamide (PA) netting (20 mm mesh). Middle: Cage constructed with knotted polypropylene (PP) netting (150 mm mesh). Right: Cages deployed at sea during the experiment.)

Monitoring and Data Collection

After each trawl haul, selected individuals were gently transferred into the experimental cages to minimize handling stress. Target species included vulnerable demersal elasmobranchs, including rays and small deep-water sharks. Throughout the 24-hour holding period, individuals were assessed at 3-hour intervals for:

- General behavior (active, sluggish, motionless)
- Swimming ability
- Response to external stimuli
- Gill ventilation rate
- Posture and buoyancy

Mortality was recorded, and any deceased individuals were promptly removed to avoid potential stress on co-housed individuals. All surviving specimens were released back into the sea at the conclusion of the experiment.

This experimental design enabled the evaluation of species-specific delayed mortality, and informed the need for gear design considerations when handling live elasmobranchs. The shift to a knotted large-mesh configuration highlights the importance of cage design in ensuring accurate and ethical survival assessments in post-capture research.

Calculation of Survival Rates

Short-Term Survival Calculations

Short-term survival was evaluated using a controlled on-board seawater tank experiment. After each trawl operation, individuals from selected elasmobranch species were transferred into a 1-ton (930 L) capacity survival tank and monitored for 1 hour under continuous flow of fresh ambient seawater.

At the end of the holding period, each individual was assessed for survival status using behavioral criteria such as spontaneous movement, gill ventilation, and righting response. Survival was recorded as a binary outcome (alive or dead).

The short-term survival rate (S_1h) was calculated as:

$$S_{1h} = \left(\frac{N_{\text{alive}}}{N_{\text{total}}}\right) \times 100$$

Where:

• N_{alive}= number of individuals alive at the end of the 1-hour period

• N_{total} = total number of individuals placed in the tank

Long-Term Survival Calculations

Long-term survival was assessed over 24 hours using submerged sea cages. Individuals were placed in the cages immediately after trawl capture and monitored at 3-hour intervals. At each interval, survival status was determined through visual inspection, with dead individuals removed and recorded.

Survival probabilities over time were estimated using Kaplan–Meier (K–M) survival analysis, which accounts for time-to-death data and right-censored observations (i.e., individuals surviving to the end of the 24-hour period). The survival probability function S(t) was defined as:

$$S(t) = \prod_{t_i \leq t} \left(1 - \frac{d_i}{n_i}\right)$$

Where:

- t_i= time of each observed death
- d_i = number of deaths at time t_i
- n_i = number of individuals at risk just prior to time t_i

Survival curves were constructed for each species separately. Log-rank tests were used to evaluate statistical differences in survival distributions among species, with significance set at α= 0.05.

Short-Term Survival Results-Shallow water

A total of 648 individuals belonging to five ray species were captured and evaluated during short-term post-capture survival trials (Table 5). Of these, 425 individuals were used in controlled survival assessments conducted in a 1-ton capacity seawater tank and observed for a 1-hour period. The survival rate was exceptionally high across all species, with most exhibiting no external signs of injury and strong vitality.

Table 5. Summary of short-term survival for shallow water species

Species	Total Catch	Experiment Subjects	Survival Rate (%)
Gymnura altavela	40	40	100.00
Rhinobatos rhinobatos	234	230	99.13
Rhinoptera marginata	366	146	100.00
Aetomylaeus bovinus	5	5	100.00
Dasyatis pastinaca	4	4	100.00
Total	648	425	–

Vitality and injury assessments were performed on all individuals placed in the survival tank. Injury levels were scored on a scale of 1 (no visible injury) to 3 (severe injury), based on external damage and behavioral signs (Table 6). The majority of individuals (90.4%) were categorized as level 1, indicating a strong physiological tolerance to trawl capture and handling.

Table 6. Injury level distribution of experimental subjects for shallow water species

Species	Injury Level 1	Injury Level 2	Injury Level 3
Gymnura altavela	34	–	6
Rhinobatos rhinobatos	228	2	–
Rhinoptera marginata	113	–	33
Aetomylaeus bovinus	5	–	–
Dasyatis pastinaca	4	–	–
Total	384	1	39

These findings confirm the high short-term survival potential of benthic ray species when carefully handled and released promptly after capture. However, observed injuries—particularly in *R. marginata*—highlight the importance of minimizing handling stress and improving on-board practices.

Short-Term Survival Results – Deep-Water Species

A total of 20 individuals from four deep-water elasmobranch species were captured and evaluated in short-term survival trials using the on-board seawater tank setup (Table 7). All 20 individuals were selected as experimental subjects and were monitored for one hour post-capture. The short-term survival rate for all deep-water species was 100%. No visible injuries or abnormal behavior were recorded during the observation period (Table 8).

Table 7. Summary of short-term survival for deep-water species

Species	Total Catch	Experiment Subjects	Survival Rate (%)
Heptranchias perlo	10	10	100.00
Dalatias licha	2	2	100.00
Hexanchus griseus	1	1	100.00
Dipturus oxyrinchus	7	7	100.00
Total	20	20	100.00

Table 8. Injury level distribution for deep-water species

Species	Injury Level 1	Injury Level 2	Injury Level 3
Heptranchias perlo	10	–	–
Dalatias licha	2	–	–
Hexanchus griseus	1	–	–
Dipturus oxyrinchus	7	–	–
Total	20	–	–

Long-Term Survival Results

Long-term post-capture survival was assessed over a 24-hour period for three ray species (*Gymnura altavela, Raja miraletus,* and *Rhinoptera marginata*) using submerged experimental sea cages. A total of 30 individuals were monitored, with survival recorded at 3-hour intervals.

The Kaplan–Meier survival curves (Figure 15) illustrate the time-dependent survival probabilities for each species. *Rhinoptera marginata* (n = 21) exhibited the highest decline in survival, with cumulative mortality beginning at approximately 15 hours post-capture and decreasing to around 40% survival by hour 24. *Raja miraletus* (n = 3) also experienced mortality beginning after 15 hours, ultimately reaching 0% survival by the end of the observation period. In contrast, *Gymnura altavela* (n = 6) demonstrated strong resilience, maintaining a relatively stable survival curve throughout the 24 hours, with 67% survival at the final time point.

Statistical comparison using the log-rank test showed no significant difference in survival probabilities among species (p = 0.22), although visual inspection of the survival curves suggests species-specific trends in post-capture tolerance. Shaded regions surrounding each survival curve represent 95% confidence intervals, which were widest in R. marginata due to greater sample size variability over time.

These results underscore the species-specific nature of delayed mortality responses following trawl capture, highlighting the importance of tailored post-release handling and gear adaptations for improving survival outcomes in vulnerable elasmobranchs.

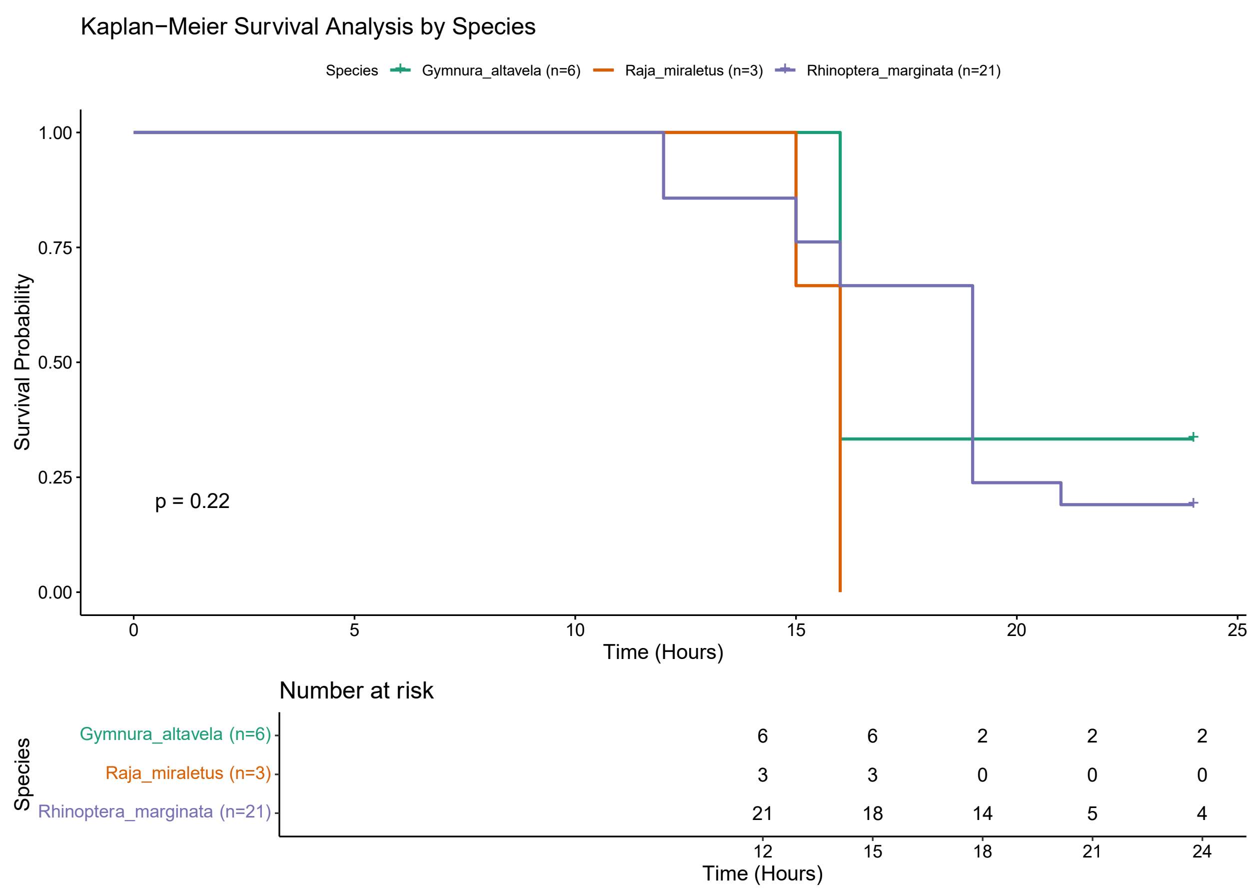

Figure 15. Kaplan–Meier survival analysis over 24 hours for three ray species: *Gymnura altavela* (n = 6), *Raja miraletus* (n = 3), and *Rhinoptera marginata* (n = 21).

Survival probability was assessed at 3-hour intervals following trawl capture and placement in experimental sea cages. Shaded areas represent the 95% confidence intervals for each species. The log-rank test yielded no significant difference in survival among species (p = 0.22). The table below the plot shows the number of individuals at risk at each time point.

The short- and long-term survival trials conducted in this study provided valuable insight into the resilience of both shallow and deep-water elasmobranchs captured by trawl fisheries in the northeastern Mediterranean. The high short-term survival rates observed across multiple ray and shark species indicate that many individuals are capable of withstanding the immediate physical stress of capture and handling when promptly released under controlled conditions. Particularly notable were the robust responses of species such as *Gymnura altavela*, *Rhinobatos rhinobatos*, and *Aetomylaeus bovinus*, which exhibited minimal injury and strong vitality scores during tank-based assessments.

Despite these encouraging short-term results, the long-term survival experiments highlight more nuanced challenges. While several individuals initially survived the 24-hour holding period, particularly *Gymnura altavela*, others such as *Rhinoptera marginata* showed considerable delayed mortality. These differences may reflect species-specific physiological tolerances, stress responses, or susceptibility to capture-related trauma not immediately visible during short-term observations. Moreover, the entanglement of rays in the initial cage design underscores the importance of refining holding protocols for accurate post-release mortality studies. The switch to larger mesh knotted nets successfully mitigated this issue and should be considered a best practice in future studies.

The findings also emphasize the complexity of interpreting survival based solely on immediate post-capture assessments. Long-term monitoring is crucial to accurately estimate the effectiveness of bycatch mitigation measures and inform evidence-based conservation and management strategies. Variability in survival across species and timeframes suggests that gear modifications—such as excluder grids—should be tailored to minimize interaction with the most vulnerable species while maintaining the viability of target catch.

This study demonstrated the effectiveness of grid-based bycatch reduction devices and survival assessment methodologies in mitigating the incidental capture of vulnerable species—particularly elasmobranchs and sea turtles—in bottom trawl fisheries of the Northern Levant Sea

(GSA 24). Field trials with flexible (50 mm) and rigid (95 mm) grids significantly reduced the catch of large non-target species while maintaining operational compatibility with commercial trawling practices.

Short-term survival experiments conducted using onboard seawater tanks indicated high survivability for several ray and shark species in shallow-water fisheries, whereas deep-water species exhibited poor survival rates. Long-term cage-based trials further confirmed that traditional confinement methods are not suitable for these species. These findings underscore the need for more robust survival monitoring techniques, such as capture–recapture tagging.

Importantly, the implementation of mitigation gear resulted in a measurable reduction in the retained biomass of high-value shrimp species. While this represents a real economic cost to fishers—estimated at €2,307.50 over 20 paired tows—the benefits of reduced bycatch and improved ecological outcomes offer significant long-term value. Balancing these trade-offs is essential. Therefore, the integration of technical refinements, management incentives, and market-based support mechanisms will be critical for widespread adoption.

BRD configurations can be effectively adapted in other trawl fisheries to reduce vulnerable species bycatch. Onboard short-term survival assessments are practical and informative. Co-management and stakeholder engagement can enhance the understanding of mitigation measures while increasing the likelihood of their acceptance by the industry. Economic tools (e.g., subsidies, eco-labeling) may enhance adoption of sustainable gear.

Further BRD trials should be conducted to refine technical parameters such as bar spacing and diameter, grid angle, and material type, particularly within the DWRS fishery. Additionally, advanced long-term survival studies using tagging-based methodologies are strongly recommended to accurately evaluate post-release outcomes. These efforts should be complemented by expanded economic impact analyses and long-term ecological monitoring programs to guide adaptive fisheries management.

In conclusion, this project contributes practical solutions and tested methodologies for mitigating bycatch in Mediterranean trawl fisheries. It provides a foundation for replication, scalability, and policy development aligned with regional conservation and sustainability objectives.

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